Published by

World Scientific Publishing Co. Pte. Ltd.
5 Toh Tuck Link, Singapore 596224
USA office: 27 Warren Street, Suite 401-402, Hackensack, NJ 07601
UK office: 57 Shelton Street, Covent Garden, London WC2H 9HE

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

ENDOPHYSICS, TIME, QUANTUM AND THE SUBJECTIVE
(With CD-Rom)
Proceedings of the ZiF Interdisciplinary Research Workshop

ISBN 981-256-509-4

Printed in Singapore.

CONTENTS

CHAPTER III: QUANTUM

CHAPTER IV: THE SUBJECTIVE

PREFACE

The workshop "Endophysics, Time, Quantum and the Subjective" was the third in a series started by "Studies on the Structure of Time: From Physics to Psycho(patho)logy" (1999, Palermo/Italy) and followed by the NATO ARW "The Nature of Time: Geometry, Physics and Perception" (2002, Tatranská Lomnica/Slovak Republic). The workshop focused on the possible role of the endo-physical paradigm in the future development of physics and in our understanding of Nature as a whole. General topics discussed were the nature of time, quantum theory and the concept of subjectivity; more specific topics included the puzzling discrepancy between the physical and psychological aspects of time, psychopathology of time, quantum entanglement, separability and non-locality, the status of first-person perspective and the prospect of naturalizing subjectivity.

Modern physical theories are based on reductionist and *exo*-physical perspectives. The reductionist point of view rests on the assumption that a few simple fundamental laws are able to account for all the observed and predictable phenomena. Per the exo-physical point of view, each human is able to achieve a complete description of the external world independently of other humans and irrespectively of their interaction with the world itself. These paradigms led, on the one hand, to the remarkable progress in sciences and technology. Yet, on the other hand, they gave rise to an ever-increasing discrepancy between our immediate experience of reality and the physical formalism.

One of the most striking and pronounced facets of this duality concerns the nature of *time*. Time, as we perceive it, exhibits a non-trivial internal structure, consisting of past and future, the two domains being separated from each other by a unique moment, the present. This time seems to "flow," to proceed from the past into the future — thus apparently manifesting an arrow of time. Physics, however, tells us a completely different story. For not only are its fundamental equations time reversible, i.e. they do not distinguish between past and future, but the very concept of the present, the "now," is absent. A host of fundamental questions naturally emerge: Why does there exist such a puzzling discrepancy between the two aspects of time? What does that imply? Can the two concepts be reconciled?...

Another example of where the exo-physical paradigms seem to be seriously at odds with the nature of scientific inquiry is furnished by *quantum* mechanics, whose interpretation has been a subject of serious debate for decades, triggered by the famous paradoxes of Einstein, Schrödinger and others. Here, the crucial role of the subject/observer manifests itself at a minimum of three levels: 1) the properties of a phenomenon depend on the modality of its observation; 2) the prediction of an outcome can only be made in probabilistic terms, and 3) the description of a phenomenon can only be obtained after the process of measurement.

The third issue, where the exo- vs. endo- controversy is perhaps most pronounced, is the concept of *subjectivity* and what can be considered its three fundamental dimensions, viz. intentionality, self-awareness and inter-subjectivity. Here the most pressing questions are: Can subjectivity and consciousness be naturalized? Is it ultimately possible to account adequately for the puzzling discrepancy between the first-person perspective and third-person observable behaviour? What is the role of "anomalous/peculiar" experience in our understanding of Nature? A few prominent scholars (e.g., Wigner, Eccles, Penrose and Davies) suspect these three questions are intimately connected via the concept of time — the most basic element of any process. Hence, since time is poorly understood, difficulties in understanding the problem of measurement in quantum mechanics, as well as the age-old hiatus between brain mechanisms and conscious experience, may be overcome when studied per this triplet of questions.

In fact, the current stalemate in physics may result from the neglect of the *endo*-physical, *first*-person perspective in the development of physics. We believe that this perspective is crucial in obtaining deeper insight into the nature of time, quantum theory and the scientific appropriation of the subjective. Our workshop provided, for the first time in many years, an in-depth interdisciplinary dialogue/debate between these closely interconnected issues. It is therefore our hope that this volume will be of great relevance to anyone interested in the conceptual issues related to both contemporary physics and cognitive sciences.

Finally, we express our deepest gratitude to the Directorate and all the personnel of the Center for Interdisciplinary Research (ZiF), Bielefeld University, for providing the event with both financial and logistic support and a highly interactive and stimulating setting. We also acknowledge the partial sponsorship of SkyEurope Airlines, thank all the manuscript reviewers for their hard work and are grateful to Dr. Richard Komžík for his technical/software assistance.

Tatranská Lomnica, June 2005

Rosolino Buccheri
Avshalom Elitzur
Metod Saniga

LIST OF INVITED SPEAKERS

Shahar Arzy, Dr., (Mr.)
Functional Brain Mapping Laboratory, Neurology Department,
University Hospital of Geneva, 24 Rue Micheli-du-Crest, CH-1211 Geneva,
SWITZERLAND
Phone: ++41-22-3728334
Fax: ++41-22-3728300
E-mail: Shahar.Arzy@hcuge.ch
URL: http://www.hug-ge.ch

Harald Atmanspacher, Dr., (Mr.)
IGPP, Department of Theory and Data Analysis, Wilhelmstr. 3a,
D-79098 Freiburg, GERMANY
Phone: ++49-761-207-21-17 or -18
Fax: ++49-761-207-21-91
E-mail: haa@igpp.de
URL: http://www.igpp.de/english/tda/info.htm

Guido Bacciagaluppi, Prof., (Mr.)
Institut d'Histoire et de Philosophie des Sciences et des Techniques,
13 Rue du Four, F-75006 Paris, FRANCE
Phone: ++33-1-43546036
Fax: ++33-1-44071649
E-mail: guido.bacciagaluppi@univ-paris1.fr
URL: http://socrates.berkeley.edu/%Ebacciaga/

Igor Balaž, Postgraduate Student, (Mr.)
Faculty of Natural Sciences & Mathematics, Dept. of Biology and Ecology,
Trg Dositeja Obradovica 2, University of Novi Sad, 21000 Novi Sad,
SERBIA AND MONTENEGRO
Phone: ++381-21-350-122
Fax: ++381-21-450-620
E-mail: igor_balaz@yahoo.com
URL: not available

Vasileios Basios, Dr., (Mr.)
Center for Nonlinear Phenomena and Complex Systems, Université Libre de Bruxelles, Campus Plaine, CP231, B-1050 Brussels, BELGIUM
Phone: ++32-2-650-55-39
Fax: ++32-2-650-57-67
E-mail: vbasios@ulb.ac.be
URL: http://www.ulb.ac.be/cenoliw3/

Laxmidhar Behera, Dr., (Mr.)
Department of Electrical Engineering, Indian Institute of Technology, 208 016 Kanpur, INDIA
Phone: ++91-512-2597198
Fax: ++91-512-2590063
E-mail: lbehera@iitk.ac.in
URL: http://home.iitk.ac.in/~lbehera/

Rosolino Buccheri, Dr., (Mr.)
Istituto per le Tecnologie Didattiche, CNR, Via Ugo La Malfa 153, I-90146 Palermo, ITALY
Phone: ++39-091-6809-602
Fax: ++39-091-6809-616
E-mail: rosolino.buccheri@itd.cnr.it
URL: http://www.pa.itd.cnr.it/web/personale/buccheri/

Mauro Dorato, Prof., (Mr.)
University of Rome 3, Department of Philosophy, Via Ostiense 234, I-00146 Rome, ITALY
Phone: ++39-06-54577-523
Fax: ++39-06-54577-340
E-mail: dorato@uniroma3.it
URL: http://host.uniroma3.it/dipartimenti/filosofia/personale/cving.htm

Avshalom Elitzur, Dr., (Mr.)
Unit of Interdisciplinary Studies, Bar-Ilan University, 52900 Ramat-Gan, ISRAEL
Phone: ++972-8-9316-777
Fax: ++972-3-5354-389
E-mail: avshalom.elitzur@weizmann.ac.il
URL: http://faculty.biu.ac.il/~elitzua/

Lucien Hardy, Prof., (Mr.)
Perimeter Institute for Theoretical Physics, 35 King Street North,
Waterloo, Ontario N2J 2W9, CANADA
Phone: ++1-519-569-7600 (Ext. 321)
Fax: ++1-519-569-7611
E-mail: lhardy@perimeterinstitute.ca
URL: http://www.qubit.org/people/lucien_hardy/

Ivan M. Havel, Prof., (Mr.)
Center for Theoretical Study, Jilská 1, CZ-11000 Prague 1,
CZECH REPUBLIC
Phone: ++420-2-2222-0671
Fax: ++420-2-2222-0653
E-mail: havel@cts.cuni.cz
URL: http://www.cts.cuni.cz/~havel/

Robert G. Jahn, Prof., (Mr.)
Dept. of Mechanical and Aerospace Engineering, Princeton University,
Princeton, NJ 08544-5263, U.S.A.
Phone: ++1-609-258-4550
Fax: ++1-609-258-1993
E-mail: rgjahn@Princeton.EDU
URL: http://www.princeton.edu/~pear/jahn.html

George Jaroszkiewicz, Dr., (Mr.)
School of Mathematical Sciences, University of Nottingham,
University Park, Nottingham, NG7 2RD, U.K.
Phone: ++44-115-951-4958
Fax: ++44-115-951-4951
E-mail: george.jaroszkiewicz@nottingham.ac.uk
URL: http://www.maths.nottingham.ac.uk/htbin-local/staff.info?gaj

Andrei Yu. Khrennikov, Prof., (Mr.)
School of Mathematics and Systems Engineering, University of Växjö,
S-35195 Växjö, SWEDEN
Phone: ++46-470-708790
Fax: ++46-470-84004
E-mail: Andrei.Khrennikov@msi.vxu.se
URL: http://www.masda.vxu.se/Personer/akhmasda/home.html

Olav Arnfinn Laudal, Prof., (Mr.)
Matematisk Institutt, Universitetet i Oslo, Boks 1053, Blindern,
N-0316 Oslo, NORWAY
Phone: ++47-22-85-58-97
Fax: ++47-22-85-43-49
E-mail: arnfinnl@math.uio.no
URL: http://www.math.uio.no/~arnfinnl/

Pete Mandik, Prof., (Mr.)
Department of Philosophy, William Paterson University of New Jersey,
Wayne, NJ 07470, U.S.A.
Phone: ++1-973-720-2173
Fax: ++1-973-720-2827
E-mail: mandikp@wpunj.edu
URL: http://www.wpunj.edu/cohss/philosophy/faculty/mandik/

Hans J. Markowitsch, Prof. Dr., (Mr.)
Universität Bielefeld, Abteilung für Psychologie, Postfach 10 01 31,
D-33501 Bielefeld, GERMANY
Phone: ++49-521-106-44-87
Fax: ++49-521-106-60-49
E-mail: Hans.Markowitsch@uni-bielefeld.de
URL: http://www.uni-bielefeld.de/psychologie/personen/ae14

Josef Parnas, Prof., (Mr.)
Center for Subjectivity Research, University of Copenhagen, Købmagergade
46, DK-1150 Copenhagen, DENMARK
Phone: ++45-3532-3703
Fax: ++45-3532-3751
E-mail: parnas@cfs.ku.dk
URL: http://www.cfs.ku.dk/cv_jp.htm

Michel Planat, Dr., (Mr.)
Institut FEMTO-ST, CNRS, Département LPMO, 32 Avenue de l'Observatoire,
F-25044 Besançon, FRANCE
Phone: ++33-3-81853-957
Fax: ++33-3-81853-998
E-mail: planat@lpmo.edu
URL: http://www.lpmo.edu/

Bjørn Torgrim Ramberg, Prof., (Mr.)
Department of Philosophy, University of Oslo, Box 1024, Blindern,
N-0315 Oslo, NORWAY
Phone: ++47-228-569-56
Fax: ++47-228-569-63
E-mail: b.t.ramberg@filosofi.uio.no
URL: http://www.uio.no/~bjoerntr/

John J. Sanfey, Dr., (Mr.)
Alvaston Medical Centre, 39 London Rd., Shardlow, Derby, DE72 2GR, U.K.
Phone: ++44-1332-792207
Fax: ++44-1332-758403
E-mail: John.Sanfey@btinternet.com
URL: not available

Metod Saniga, Dr., (Mr.)
Astronomical Institute of the Slovak Academy of Sciences,
SK-05960 Tatranská Lomnica, SLOVAK REPUBLIC
Phone: ++421-52-4467-866
Fax: ++421-52-4467-656
E-mail: msaniga@astro.sk
URL: http://www.astro.sk/~msaniga/

W. Mark Stuckey, Prof., (Mr.)
Dept. of Physics and Engineering, Elizabethtown College, Elizabethtown, PA 17022, U.S.A.
Phone: ++1-717-361-1436
Fax: ++1-717-361-1176
E-mail: stuckeym@etown.edu
URL: http://www.etown.edu/physics&engineering/faculty/stuckey

Jiří Wackermann, Dr., (Mr.)
IGPP, Dept. of Empirical & Analytical Psychophysics, Wilhelmstr. 1b,
D-79098 Freiburg, GERMANY
Phone: ++49-761-207-21-71
Fax: ++49-761-207-21-99
E-mail: jw@igpp.de
URL: http://www.igpp.de/english/ppl/cv/cv_jw.htm#publist

LIST OF OTHER PARTICIPANTS

Alexey Alyushin, Dr., (Mr.)
Philosophical Faculty, 1st Humanities Building, Room 1136, M.V. Lomonosov Moscow State University, 1 Vorobyovy Gory, 119899 Moscow,
RUSSIA
Phone: ++7-095-939-2008
Fax: ++7-095-939-1925
E-mail: aturo@mail.ru
URL: http://www.ied.msu.ru/faculties/philos.html

Paul Bernstein, Dr., (Mr.)
Vital Signs Editor, International Association for Near-Death Studies,
East Windsor Hill, CT 06028-0502, U.S.A.
Phone: ++1-617-889-4971
Fax: ++1-617-889-4971
E-mail: pbernste@earthlink.net
URL: http://www.iands.org

Emilios Bouratinos, Dr., (Mr.)
Petaloudas Street 2, Ekali, GR-145 65 Athens,
GREECE
Phone: ++30-210-813-12-00
Fax: ++30-210-622-92-59
E-mail: ebouratinos@hol.gr
URL: (not available)

Michel Cermolacce, Dr., (Mr.) – Postdoctoral Student
Center for Subjectivity Research, University of Copenhagen, Købmagergade 46, DK-1150 Copenhagen, DENMARK
Phone: ++45-4051-0972
Fax: ++45-3532-3751
E-mail: michel.cermolacce@wanadoo.fr
URL: (not available)

Bart D'Hooghe, Dr., (Mr.)
Center Leo Apostel (CLEA), Vrije Universiteit Brussel, Krijgskundestraat 33, B-1160 Brussels, BELGIUM
Phone: ++32-2-6442-677
Fax: ++32-2-6440-744
E-mail: bdhooghe@vub.ac.be
URL: http://www.vub.ac.be/CLEA

Detlef D. Dietrich, Dr., (Mr.)
Medizinische Hochschule Hannover, Abteilung für Klinische Psychiatrie und Psychotherapie, Carl-Neuberg-Str. 1, D-30623 Hannover, GERMANY
Phone: ++49-511-532-6749
Fax: ++49-511-532-2415
E-mail: dietrich.detlef@mh-hannover.de
URL: (not available)

Brenda J. Dunne, Dr., (Mrs.)
Dept. of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ 08544-5263, U.S.A.
Phone: ++1-609-258-5950
Fax: ++1-609-258-1993
E-mail: bjd@Princeton.EDU
URL: http://mae.princeton.edu/people/e57/dunne/profile.html

Dieter Gernert, Prof., (Mr.)
Hardenbergstr. 24, D-80992 Munich
GERMANY
Phone: ++49-89-140-19-10
Fax: (not available)
E-mail: t4141ax@mail.lrz-muenchen.de
URL: http://www-gernert.bwl.ws.tum.de/

Antonio Giuditta, Prof., (Mr.)
Dip. di Fisiologia Generale, Via Mezzocannone 8, Università di Napoli "Federico II", I-80134 Naples, ITALY
Phone: ++ 39-081-2535089
Fax: ++ 39-081-5424848
E-mail: giuditta@cds.unina.it
URL: (not available)

Yukio-Pegio Gunji, Prof., (Mr.)
Department of Earth & Planetary Sciences, Faculty of Science,
Kobe University, Kobe Nada 657-8501, JAPAN
Phone: ++81-78-803-5759
Fax: ++81-78-803-5757
E-mail: yukio@kobe-u.ac.jp
URL: http://www.kobe-u.ac.jp/~nlinear/gunji/

Martin Jankovič, Dr., (Mr.) – Ph.D. Student
Central European University, Philosophy Department, Nador u. 9,
H-1051 Budapest, HUNGARY
Phone: ++36-1-327-3806
Fax: ++36-1-327-3072
E-mail: FPHJAM01@phd.ceu.hu
URL: http://www.ceu.hu/phil

Shmuel Marcovitch, M.Sc., (Mr.) – Graduate Student
School of Physics and Astronomy, Tel Aviv University, 69978 Tel Aviv,
ISRAEL
Phone: ++972-3-6200540
Fax: ++972-3-6067564
E-mail: lemna@hotmail.com
URL: (not available)

Thomas Marlow, M.Sc., (Mr.) – Ph.D. Student
School of Mathematical Sciences, University of Nottingham,
University Park, Nottingham, NG7 2RD, U.K.
Phone: ++44-115-951-4949
Fax: ++44-115-951-4951
E-mail: pmxtm@nottingham.ac.uk
URL: (not available)

John D. Pettigrew, Prof., (Mr.)
Vision Touch and Hearing Research Centre, School of Biomedical Sciences,
University of Queensland, 4072 Brisbane, AUSTRALIA
Phone: ++61-7-3365-4484
Fax: ++61-7-3365-4522
E-mail: j.pettigrew@vthrc.uq.edu.au
URL: http://www.uq.edu.au/nuq/jack/jack.html

Petr Pracna, Dr., (Mr.)
J. Heyrovský Institute of Physical Chemistry, Dept. of Chemical Physics,
Dolejškova 3, CZ-18223 Prague, CZECH REPUBLIC
Phone: ++420-2-6605-3426
Fax: ++420-2-8658-2307
E-mail: petr.pracna@jh-inst.cas.cz
URL: http://www.jh-inst.cas.cz/science/dept1-t.html

Jean Schneider, Prof., (Mr.)
Laboratoire de l'Univers et ses Théories, Observatoire de Paris-Meudon,
Bat. 18, Pl. J. Janssen, 92195 Paris-Meudon, FRANCE
Phone: ++33-1-4507-7510
Fax: ++33-1-4507-7971
E-mail: Jean.Schneider@obspm.fr
URL: http://luth2.obspm.fr/~luthier/schneider/

Jan Tilden, Dr., (Mrs.) – Science Communicator
Coastal CRC, 80 Meiers Road, Indooroopilly QLD 4068,
AUSTRALIA
Phone: ++61-7-3896-9205
Fax: ++61-7-3362-9372
E-mail: jan.tilden@nrm.qld.gov.au
URL: http://www.coastal.crc.org.au/

Beatrice Vivoli, Dr., (Miss) – Ph.D. Student
Department of Philosophy, University of Florence, Via Bolognese 52,
I-50139 Florence, ITALY
Phone: ++39-055-4622415
Fax: ++39-055-475640
E-mail: beatricevivoli@tiscali.it
URL: (not available)

GROUP PHOTO

CHAPTER I:

∼ENDOPHYSICS∼

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 3–21

EVOLUTION OF HUMAN KNOWLEDGE AND THE ENDOPHYSICAL PERSPECTIVE

ROSOLINO BUCCHERI
[a]*Istituto per le Tecnologie Didattiche del CNR, Sez. di Palermo*
Via Ugo La Malfa 153, 90146 Palermo, Italy
Centro Interdipartimentale di Tecnologie della Conoscenza, Universitá di Palermo
Via Archirafi 34, 90134 Palermo, Italy
(rosolino.buccheri@itd.cnr.it)

MAURO BUCCHERI
Via Flora 28, 90151 Palermo, Italy
(pantareimab@yahoo.it)

Abstract: We aim at replacing the currently adopted exophysical perspective with the humbler, but more realistic, approach offered by endophysics that goes beyond the boundaries of the former. Our arguments are based on three well established circumstances. First, our unavoidable mutual interaction with nature allows us to bypass any unproved *ad hoc* assumptions like the Cartesian cut. Second, the historical evolution of human knowledge compels us to recognize a substantial similarity between the notions of "subjective" and "objective" as referred to a single individual, or to a group of individuals. This emphasizes the role of subjectivity in the formulation of theories for the representation of the world. Third, the lack of satisfying progress in the numberless attempts at the unification of physical theories, in spite of the fundamental changes produced by quantum mechanics in the interpretation of nature, seems to indicate that the exophysical approach has already reached its limits.

Keywords: Endophysics – Self-Organization – Knowledge – Subjectivity – Evolution

1 Views of "External" World: A Brief Historical Introduction

Parmenides — the father of ontology — considered "being" (and therefore "true") as equivalent to incorruptible, stable and indivisible. Variable phenomena were considered illusive, "false." Accordingly, there could be no relationship between ideas and experience: truth — "being" — cannot be inferred via our senses, but can only be revealed by our thoughts. He therefore remarked the ontological dichotomy between the apparent reality —

[a]Permanent address.

imperfect and changeable — communicated by senses, and the true reality of ideas [1].

Plato accepted a relationship between ideas and data communicated by senses, with the latter being only imperfect copies of the former, thus subordinating the observed reality to that of the ideas. According to Plato, we can get closer to truth only in so far as we are able to get free from our senses, notably at the time of our death, when our soul will finally be able to ascend to the *Iperuranium*, the world of ideas [2].

At variance with the idealism of Parmenides and Plato, Aristotle considered unnecessary to look for the essence of the external world out of itself, thus opening the road to realism. He actually wrote "It seems impossible that the substance exists independently from the objects of which it is substance; then, how can Ideas, if they are substances of things, exist independently of things?" [3]. As a dialectician with an excellent common sense, he was both an empiricist and a rationalist and his open mind allowed him to see that each of the two aspects had to be appropriately considered. According to Aristotle, truth is neither an absolute entity accessible only by ideas nor the private property of single human beings, but a collective achievement of the mankind as a whole [4].

The debate between Plato's idealism and Aristotle's realism strongly affected thinkers of following centuries and, during the Middle Ages, it was the basis for the development of the famous discussion about the *Universals*, i.e. those general concepts that can be referred to more than one object, thereby constituting their essence. The problem of medieval doctors regarded the question of whether *Universals* were only mental concepts or also ontological realities existing in each object (solution of Aristotelian inspiration) or outside it (solution of Platonic inspiration)[5,6].

We can reasonably attribute the birth of modern realism to Sir Francis Bacon for whom there is an intrinsic — "objective" — reality governed by fixed rules, well knowable and controllable by man. In Bacon's view, all theories are full of prejudices leading man to error. The only way to achieve the "truth" (the intrinsic properties of "objective" reality), and then fully know and control nature, is a "pure" observation, free from prejudices [7].

Bacon's realism found its highest expression in the work of his great contemporary, Galileo Galilei. For Galileo, the "truth" is given by observed facts confirmed by reproducible experiments; accordingly, mathematics is the language of nature and deterministic science is the only means to interpret and describe objective reality. This gave new strength to the mechanistic determinism — known since Epicurus and the old atomistic conceptions

— and reopened the need of reconciling it with the trust on humans' free will.

René Déscartés reconciled free will and determinism by assuming a substantial difference between inert matter — *res extensa* — constrained to rigidly obey the laws of physics, and living matter — *res cogitans* — capable of violating the laws of physics [8]. The Cartesian cut was not always accepted and, two centuries later, the mechanistic determinism was emblematically represented in its extreme rigour by Pierre-Simon de Laplace who thought that even our free will is illusive [9].

In the second edition of his "Critics of the Pure Reason," Immanuel Kant made a distinction between *phenomenon* — the reality as it appears to us — and *noumenon* — the reality as it is intrinsically. According to him, there is an "objective" reality governed by precise laws. The concept was clearly expressed through his famous four propositions:

- in mundo non datur hiatus (no spatial gaps),
- in mundo non datur saltus (no temporal leaps),
- in mundo non datur casus (no blind chance),
- in mundo non datur fatum (no blind necessity).

Kant, however, recognized in senses and in ideas two different but equally important sources of knowledge. The former because of the inherent characteristics of intuition and receptivity, the latter because of the spontaneity with which the data offered by intuition are synthesized.

It should be stressed that Kant's concept of "objectivity" is connected to the presence in all humans of the same mental structures (the so called "*a priori* forms") by which the experiential data are filtered. The "truth" that for Plato is accessible only by thoughts, for Kant is inaccessible to our comprehension because man deals only with the *phenomenon*, not with the *noumenon*.

The Galileian determinism, confirmed by Newton's laws of mechanics and gravitation, led physics to become completely autonomous from philosophy and religion. With or without the Cartesian cut and the contribution of idealism, it became a firm common view of the western society throughout the Enlightenment until the beginning of the 20th century.

The Galileo/Bacon realism was formalized in the famous 1935 article by Albert Einstein, Boris Podolsky and Nathan Rosen by explicitly considering two well-defined requisites, "correctness" and "completeness," needed for a theory to be considered a good representation of the (independently existing) reality [10]. In the EPR paper, correctness and completeness were explicitly connected by the need to identify (qualitatively and quantitatively) all the elements of the "objective" reality via observations and experiments. The subsequent debate stimulated, among physicists, a search for "hidden variables," unknown elements of reality, whose knowledge and measurement could completely explain all aspects of nature.

During the 5th Solvay Congress, Niels Bohr succeeded in imposing the so-called "Copenhagen interpretation" of quantum mechanics, where probabilism and unpredictability became the accepted way to look at the world by physicists. According to this interpretation, the indeterminateness described by the Heisenberg principle is not epistemic and cannot be solved by whatever precise method of measurement, because it is inherent to the intimate essence of physical nature, as perceived by man. According to Bohr, when we interview nature with the aim of unveiling its properties, nature answers in different ways, according to the means we use. It is our belief in classical realism that makes us (unwarily) attribute to nature "objective" (i.e. independent from us) properties [11].

David Bohm tried to mediate between Einstein's realism and Bohr's probabilism. He proposed the distinction between an *implicate order* (the deep level of nature, impossible to unveil due to man's limitations in terms of senses, instruments and language) and an *explicate order* (the observable manifestations of implicate order). According to Bohm, the probabilistic interpretation is epistemic but unavoidable due to our limitations and to the language already developed on the basis of classical concepts [12].

2 The Exophysical Attitude

As outlined above, most of classical representations of the world by western countries — both the idealistic and the realistic view, enriched or not with the Cartesian cut — have been historically characterized by an exo-physical attitude. Basically, they claim that man can explore the world by looking at it from the outside, on the implicit assumption that he is able to avoid his interactions with nature and so violate the cause-effect relationship inert matter rigidly obeys. In other words, the exophysical attitude implicitly attributes to man a potential capacity to achieve a-temporality, that is a simultaneous perception of all events in both past and future of the universe, together with all their connections.

Within both classical Newtonian physics and Einstein's relativity, the mathematical equations describing elementary phenomena are reversible in time, thereby implying a world where its past and future cannot be distinguished. This circumstance has favoured the physicists' belief of the illusiveness of the flow of time and has supported the exophysical attitude. The latter, powered by the Cartesian cut, acted as a paradigm, implicitly accepted all over the centuries, even within the "Copenhagen interpretation" of quantum mechanics, where the presence of a semi-classical observer is needed, independent of the observed world.

As a consequence of the adopted exophysical attitude and the assumed illusiveness of the psychological arrow of Time, the image of a static and all-embracing universe, visible from the outside in its spatial and temporal totality is implied. This has given rise to the notion of *Block Universe* and to the search for a *Theory of Everything* which, according to Stephen Hawking, should be able to decode God's mind [13]. It is worth noting that the exophysical attitude is strengthened by the claim that all the mathematics we know could be part of an absolute entity existing independently of us, whose hidden aspects are little by little discovered by the curiosity of man.

3 Self-Organization of Open Systems of Inert Matter

Boltzmann's re-elaboration of the second principle of thermodynamics and the observation of the continuous formation of large structures like stars and galaxies, gave rise to a long-lasting debate and to a great amount of observations and studies [14]. These have pointed out the appearance in nature of a large variety of open systems in which inert matter organizes itself in ordered configurations exchanging energy, matter and information with the environment. Among the simplest examples, chemical clocks appear to be most spectacular [15]. They are offered by some chemical reactions characterized by catalytic feedback in which the products of the reaction contribute to accelerate its rate. Typical of this class is the Belousov-Zhabotinsky reaction, discovered by Boris Belousov around 1950 and published only after a long debate in 1964 due to the efforts of Anatol Zhabotinsky. Other interesting examples, in fields other than chemistry, are very common Bénard's cells, occurring in a liquid heated from below, and the more complex Lotka-Volterra model describing the oscillating behaviour of biological species competing for food [16].

In 1967, Ilya Prigogine established the notion of *dissipative structure*, valid for physical systems far from thermodynamical equilibrium and able to produce order and information [17]. Such ability is due to non linear processes, working in feedback with the environment and capable of compensating the energy and entropy acquired in input with that dissipated in output. During the self-organization process, dissipative structures increase in complexity and display new behaviour, not always easily explained by the known fundamental laws. In addition, the rate of the process is progressively reduced until the balance due to feedback stabilizes the system in both shape and behaviour.

Dissipative structures are characterized by the presence of bifurcations in their temporal trajectories due to the non-linearity of the evolution process. At these points, the system may follow two different evolution paths, the choice being casually determined by (even very low) statistical fluctuations. This feature implies the irreversibility of the process, especially in the case of very complex systems where the evolution diagram may show a very high number of bifurcations [18].

Following Prigogine's studies, a vast class of physical, chemical and biological phenomena started to be studied from this point of view. Self-organization in biochemical processes is nowadays intensely investigated within single cells and between different cells with regard to the synthesis of enzymes and proteins, at the metabolic level, in the process of stabilization of the cardiac rhythm and so on. The phenomenon of the circadian rhythm is a well-known example that stems from the necessity of our vital processes to adapt to the external conditions and results from the coupling of various biochemical oscillators with periods less than one day.

Special mention should be made of the discovery of deterministic chaos as it has given rise to extremely relevant results, all concurring to reveal, in spite of the rigour of mathematics, the unpredictable behaviour of complex systems described by non-linear equations. In many of these systems, information increases with time, thus making them suddenly unstable and prone to self-disruption. This situation is well-illustrated by the hypothetic butterfly effect described by Edward Lorenz in 1972. Some of the catastrophically unstable structures are included in René Thom's Theory of Catastrophes [19].

The study of deterministic chaos has produced many useful ideas to better study the processes of self-organization. One of the most interesting concepts concerns the "cellular automaton," first proposed by John Von Neumann and then revisited by Stephen Wolfram who conceived a self-evolving machine, on the hypothesis that vital processes can be simulated by computational models. The cellular automaton devised by John Horton Conway and called "Game of life" is a very well-known example [20].

Several authors — Christopher Langton among others — have proposed that the quantity of information exchanged in the self-organization process is essential for the evolution of complex systems, in particular that their stability critically depends on it. In other words, the stability of self-organizing systems is connected with a well-defined degree of complexity: too simple systems are unable to get sufficient information to evolve but an excess of information may cause disruption of the system.

Living systems are open systems far from the thermodynamical equilibrium which evolve in competition with the environment and taking advantage of the cooperation with other systems. As in many dissipative structures, the quantity of information exchanged by living systems with the environment keeps the structure at a level of complexity sufficient for temporary stabilization. It is reasonable to consider the origin and evolution of life as derived from the tendency of inert matter to organize itself toward the formation of stable, complex structures.

Studies by Humberto Maturana and Francisco Varela have described the complex operations of a living system as a self-organizing web where all nodes continuously exchange information between each other, starting from the input given by external stimuli. In these *autopoietic* systems, the feedback relations between the nodes are able to modify (in some cases even create or delete) the functions of the nodes themselves in order to stabilize the whole system [21].

All these studies lead us to think that evolution through formation and chaotic development of self-organization processes might be a general principle nature obeys in all its manifestations. This topic was amply discussed about 30 years ago by Ilya Prigogine who proposed a unified study of all natural phenomena, that is in science but also in humanistic, economic, social and political fields [22]. The history of mankind and the process of human civilization may also be considered parts of the evolution of the universe and characterized by the same self-organizing tendency. As a matter of fact, human societies are open, many-body systems interacting with the environment from which they receive resources and information. They are characterized by complex interactions between their members. These interactions create coherences which generate and maintain complex collective patterns. Very likely, human societies might be described by high order non-linear equations and therefore by chaotic, irreversible and unpredictable evolution.

4 The Evolving Human Knowledge

A very interesting example of process with seemingly chaotic characteristics is offered in the realm of social sciences. It concerns the formation and evolution, on a very long time scale, of a representation of the world in the mind of single human beings living within a social group. Throughout this evolution process, we start to distinguish ourselves from the external environment, with such distinction becoming progressively more pronounced with our expanding space of consciousness. The information accumulated by the so-formed "subject," coming from the interacting external world — the "object" — slowly increases, allowing our mental constructs to reach always higher levels of stability, characterized by a well-defined view, or "theory," of the external world.

In this view, the world is seen as a collection of many separate structures or "objects," incessantly moving or changing in their physical and morphologic properties. They seem to have a definite space localization and their unceasing and irreversible changes seem to be subject to laws governing their behaviour. A good global representation of the these laws in our mind has always been essential both for survival, within the continuous struggle for life — prevailing in prehistoric times — as well as for purely intellectual reasons — more typical nowadays. Following Kenneth Craik, let us refer to Mental Model of Reality (MMoR) for this integrated mental construct [23].

Our mind builds its own MMoR through very complex neurocomputational processes which take into account both the external stimuli and our ontogenetic characteristics. Our MMoR's include data and connections directly observed in the course of our life but also many additional data and connections not directly observed but assumed to be true (by unconscious intuition or even by ideological, political or religious beliefs) and considered as necessary to connect separate opinions of single aspects of reality. This mental construction allows us to have as complete and self-consistent a global view as possible.

In the course of our continuous interaction with the environment, we systematically update our MMoR's as a result of new observations and experiments. The strategy used to fill in the gaps in our knowledge depends on our personal needs. It changes from one individual to the next and is different even in the same individual according to his/her physical and mental conditions. Therefore, the way we observe and what we include into our MMoR depends on many factors, including our previous knowledge and beliefs. Due to this large number of variables, all MMoR's exhibit both individual instabilities and large differences between each other [24].

With the emergence and development of human societies, individual MMoR's have been influenced by mutual confrontations. This induced their modification by adding more and more new knowledge coming from other individuals and encompassing relevant aspects of social co-existence, such as laws, traditions, common ways of communicating, *etc.*, together with always new relations discovered between observed events. The common understanding, known today as *intersubjectivity*, thus acquires an always higher level of stability, creating a basis for the development of a consensus view of the world within each social group. Due to intersubjectivity, all individual MMoR's evolve toward a model of reality that has a common part accepted by a majority of members of the involved society. This common part, in turn, affects individual MMoR's in a loop of increasing knowledge, whereby the "objective" model of reality becomes always more precise in collectively representing the world's behaviour within a single social group. This collective model — let's call it a *Social Model of Reality* (SMoR) — entails all aspects of a society's picture of the world, including politics, morality, aesthetics, religion, communication language and, within science, an agreed investigation methodology [24].

The schematisations implicit in our means of communication limit the number and the quality of details that can be transferred from one MMoR to another. This implies the need by any individual to "interpret" the communicated messages with a consequent lack of precision. This lack of precision adds to the individual instabilities and inter-individual differences discussed above, thus requiring the continuous updating of the intercommunication process by addition of new, commonly accepted rules.

The evolution path of an SMoR is signposted by new and appealing ideas elaborated by individuals with great communication skills and firm beliefs. These new ideas drive new common views, new elements for a more precise language of communication and updated ways of performing new experiments and observations. However, the updated SMoR does not hold forever due to various factors: strong reactions of the society, newly coming more appealing ideas, conflicts arisen with the previous view. Readjustments will then occur and a new SMoR is established for some more time. This process is not linear and shows important analogies with chaotic processes because of the numerous bifurcation points encountered along its evolution path. The direction taken by each single social group in correspondence of the bifurcation points may vary in an unpredictable way due to the fluctuations connected with the unforeseen birth of new appealing ideas. History provides us with innumerable examples in all fields: science, economy, religion, *etc.*

In science we usually refer to our theories as "objective" descriptions of the observed world. But, due mainly to the pervasive exophysical attitude, the term "objective" has often been given a superior meaning and raised to the rank of "intrinsically true." However, as derived from the above discussion, the term "objective" only expresses the achieved consensus within the society. The starting point of the process toward increasing knowledge is the individual subjective view which, after interaction with others' individual views within a society, is integrated into a more general view, featuring the culture of that society. It follows that the two terms, "subjective" and "objective," do not represent a real dichotomy: the latter means no more than the former when referred to a human society instead that to a single individual of that society [25].

Due to the chaotic structure of SMoR's within social groups; their "objective" nature in a social sense; the limitations intrinsic in the intercommunication process nourishing the differences among individual MMoR's, a unique universal SMoR can only be achieved on extremely long time scales and is the only possible kind of Theory of Everything.

5 Criticism of the Exophysical Approach. Role of Subjectivity

Ludwig Boltzmann, after a long and hard confrontation with several scientists, wrote that the arrow of time exists only in regions of the universe far from thermodynamical equilibrium. In these regions, human beings may exist and perceive a time direction determined from the tendency of the entropy to increase. For Boltzmann, the increase of disorder predicted by the second principle of thermodynamics was not "objective" in the classical sense but depended on the human ability to classify observed systems in terms of their recognizable configurations. As a result, Boltzmann's long search for objectivity in science was definitely frustrating, which led him to commit suicide, at least according to Karl Popper [26]. In view of the general trust on realism and on the exophysical attitude, Popper's guess does not seem too much off beam.

Along the history of human thought, Boltzmann's vicissitude is just an example of the numerous, never succeeding attempts, to eliminate subjectivity from science. From Aristotle, who referred to the human soul as the element able to establish the before and the after of an event, until our times with the frequent reference to the anthropic principle, the discussion about the intrinsic essence of the external reality is still open. This tells us that the solution of the problem needs a careful study on the way human beings interact with the world. The studies undertaken by many research groups in the world, with the aim of founding a science of consciousness, based on the concurrent endeavours of different disciplines like neurosciences, experimental psychology and quantum physics, go along this direction. In his

"Essai Sur les Donnés Immédiates de la Conscience," (1888) Henri Bergson wrote:

> Consciousness, tortured by an unappeasable desire of distinguishing, replaces the symbol to the reality or detects the latter only through the former. And, since the fundamental "I", thus refracted and therefore subdivided, fits much better to the requirements of social life in general, and of language in particular, it (the consciousness) prefers (the symbol) and, little by little, forgets the fundamental "I".

However, a sharp distinction between subject and object is strictly inherent to our own existence and therefore looks quite reasonable: it is "I" (the subject) that investigates the world and, according to the way we have developed our logic and our language, "I" is distinct and alternative to "not-I" (the object). The development of classical physics between the XVII and the beginning of the XX century, markedly contributed to assign an absolute value to such distinction. In addition, the Déscartés assumption, well-acknowledged in view of the established religious beliefs, have acted as a definite enclosure, giving man — the subject — the rank of a founder (for idealists), or of a discoverer (for realists), of the external world.

Kant expressed scepticism on the possibility for man to unveil the *noumenon* because he thought that the world we see is filtered by our mental structures from which we can never get free and that preclude us from reaching a fully neutral point of view. Accordingly, he suggested that the world had to be understood starting from man's physical and perceptive characteristics (*sub specie hominis*) rather than from the presumptuous and impossible cosmic point of view (*sub specie aeternitatis*) from which, free from any interaction with the environment, we claim to reach any level of knowledge.

With Friedrich Nietzsche, a contemporary of Boltzmann, a long debate started about the question of the "subject," seen as an unavoidable condition of every experience, a unique criterion of judgement and truth. Nietzsche denied any "objective" truth whatever and any stable and definite "subject" *à la Déscartés* — absolute, stable and detached from his environment. He considered man as an animal, first naturally bound to the environment and eventually caged by society — especially after the diffusion of Christianity — that repressed his instinct through the imposition of social and moral rules [27].

According to Martin Heidegger, presocratics had already conceived reality as never completely unveilable (*aletheia*), but with Protagora and Plato, western thought started to decline, especially under the influence of modern science, due to the belief in man as having full power over the laws governing nature. For Heidegger, the Cartesian *cogito* would actually be a process aimed to take possess of something and western thought would be tending to dominate nature rather than to listen to it [28].

He stated that an "objective" knowledge is impossible because every knowledge is the result of an "interpretation" on the basis of our predispositions, our pre-visions and our pre-cognitions. As interpretation is never the neutral knowledge of something "objective" but the representation of the interpreting subject, external reality is never precisely measurable and may be unveiled by man only partially [29].

This concept was taken up by Hans George Gadamer — considered the founder of the philosophycal hermeneutics — who thought that the process of increasing knowledge is a sort of "hermeneutic circle," i.e. we have always partial knowledge of what we are going to learn. Actually, in our search for knowledge, we are always conditioned by our pre-cognitions, that Bacon, naively, tried to eliminate as negative elements. Comprehension, according to Gadamer, cannot be reduced to a pure reproductive act as it always has a poietic, productive, component [30].

Bacon's empiricism was also criticized by Karl Popper, particularly the belief that theories can lead to error because they are full of prejudices. In fact, he thought that pure observations do not exist and man always interprets nature in terms of his theories. Hence, we can never get free from prejudices and Bacon's truth (*veracitas naturae*) can never be fully known. Popper also criticized Déscartés' certainty that truth (*veracitas Dei*) is there out, ready to be known by man. According to Popper, Bacon and Déscartés were not able to get rid of authority, but only succeeded in substituting one authority (Aristotle/the Bible) with another one (the senses/the mind) thereby remaining prisoners of the exophysical view of reality [31]. According to Popper, instead, our knowledge has no authority: both experience and reason are important but both can lead us to errors. From this belief he derived the notion of a *falsifiable* theory, the only theory that can be properly defined scientific. With this notion, the myth of induction, born with modern science, crashes with the claim that science can derive general laws starting from a number, however large, of individual cases. Our theories, being only SMoR's, are not certainties: they can only be considered working hypotheses which, as stated by Friedrich Dürenmatt, "conform to human beings, at variance with enacted truths to which any human being must conform" [32].

Quantum physics has been the most important element of disruption of the realistic view of nature. Its achievements — the wave-corpuscle duality, the indivisibility observer-observed, the Heisenberg uncertainty principle, the non-epistemic randomness, the non-local features of the theory — while splendidly explaining a multitude of phenomena, show a "reality" very different from the classical view. Richard Feynmann was fully aware of this tricky situation and gave up asking unanswerable questions, limiting himself to the practical aspects of quantum theory as given by its extraordinary results.

The so-called "problem of measurement" is particularly significant for the description of the difficulties of interpretation arisen by quantum mechanics. The collapse of the wave function describes a clearly irreversible event not foreseen by the Schrödinger equation, because the latter is linear and time symmetric and, as such, strictly deterministic. The predictions of the Schrödinger equation, however, hold only for closed systems — i.e. systems not interacting with their environment — in particular for the entire universe. As any measurement implies an exchange of energy and information between the observer and the object of the observation, neither the former nor the latter are closed systems. The collapse of the wave function and its implied irreversibility is therefore relative to the point of view of the observer, an open system interacting with the rest of the universe. From the observer's point of view, then, the evolution of the external environment is neither deterministic nor reversible. The very fact that the probabilistic interpretation of quantum mechanics requires the presence of a semi-classical observer, considered external to the unitary evolution of the universe described by the Schrödinger equation, shows the rootedness of the exophysical attitude.

6 Toward an Endo-Physical Viewpoint?

It is a matter of fact that the exophysical attitude has worked very well for centuries, bringing science and technology to the present great successes. Also, the major contributions to such successes are due to the exceptional ability of great thinkers to reach high levels of abstraction from the environment. However, our discussion shows that we cannot avoid the constraint that we — the "subjects" — exist and investigate nature from within and, therefore, that subjectivity cannot be eliminated because it is inherent to our status of investigators of nature.

Whatever his skill in detaching himself from the world, man can never succeed completely, and therefore cannot pretend to have an absolute degree of neutrality which actually appears strictly dependent on the dynamics of the society which he belongs to. Also, we cannot exclude that the limitations imposed by the investigation of the micro-world, where the interaction man-nature is particularly strong, are at the origin of the stalemate in which theoretical physics finds itself for so many decades. Possibly, the intrinsic limits of applicability of the exophysical approach have already been reached. If this is the case, it will be necessary that both the interaction of man with nature and the role of subjectivity find a proper place in science, to be framed in a perspective other than the exophysical attitude (in neither idealistic nor realistic sense).

In 1982 Karl Popper came back to the concept of determinism by ironically inviting scientists to invent a new Laplace demon, capable of predicting the future of the world starting from the inside. Since nobody can predict the results of his own predictions, first of all in view of the finite speed of light, Popper warned that men cannot be considered pure spirits, external to the universe [33]. His point of view seems very close to the one we nowadays call the endophysical perspective where the capacity of humans to achieve a complete detachment from their interacting environment is excluded. We recall that *endophysics* is the term coined to convey the concept of an investigation of the world from the inside, according to the actual place of man in nature. The concept has been largely discussed in the 1980's but soon left out in view of the practical difficulties arisen [34,35].

We want to stress that the process of increasing knowledge in terms of a subjective-objective-subjective loop, closely connected with the features of our individual subjectivity, is a main characteristic of the endophysical viewpoint. Our MMoR's are always the result of this subjective-objective-subjective loop and our theories reflect our continuous interaction with the other individuals and with nature. This being the case, the claim to find a *Theory of Everything* (strictly speaking), is inconsistent, because it involves the subject of the prediction itself and ignores his interaction with the rest of the universe. Due, instead, to the unavoidable man-matter interaction, we cannot find — from the inside — a unique theory encompassing everything in the universe — now and forever — but many single theories valid within specified limits, and defined by our interaction.

As for the cosmological aspect, an endophysical theory has to consider the whole universe as an evolving, self-referential system, that must include interactive "subjects" — the human beings investigating the laws of nature. A description of the evolution of the universe consistent with the endophysical point of view has been proposed by Jon Eakins and George Jaroszkiewicz. Their universe is a self-contained and self-referential quantum automaton which organizes its own evolution without a semi-classical observer standing outside it. Its laws can change from one stage to the next on the basis of a super-law (*a rule of the rules*), intrinsic to the deeper reality of the automaton [36,37]. This theory complies with the unity of evolution described by the Schrödinger equation and, at the same time, it explicitly contains the collapse of the wave function. This eliminates the contradiction implicit in the "Copenhagen interpretation."

We believe that a theory like this may be an important first step toward the construction of a general theoretical scenario consistent with the endophysical perspective, that may include all existing theories with their limits and may also explain the psychological arrow of time [38,39,40]. Further steps in this direction should include future theories that deal with other aspects of nature, emerging from more detailed observations, paying special care to the definition of their application limits, and connected with the intrinsic, unavoidable subject/object interaction.

7 Summary

Since ancient times, man has tried to get a representation of the external reality ranging from extreme idealistic to extreme realistic scenarios, which included different "mixtures" of ideas and experience.

Classically, these representations have generally been based on the exophysical attitude, i.e. on the belief that man can exclude, even if in principle, mutual interaction with his environment and therefore achieve complete abstraction from the observed nature. Such belief has implicitly led to the concept of the Block Universe and illusiveness of the flow of time and has given rise to a stubborn search for the Theory of Everything.

These concepts, however, are in contradiction with the generally accepted belief of the free will, a contradiction that was overcome by Déscartés with his *ad hoc* assumption of a distinction between living and inert matter. We know, however, that inert matter in situations far from the thermodynamical equilibrium is able to organize itself and to give rise to stable and ordered physical systems exchanging energy, matter and information with the environment.

Looking at the evolution of man as recorded by history, we think it reasonable to assume that human societies, single human beings and even their world views, be the possible results of specific self-organization processes.

At a certain stage of evolution of a living organism, the system may start to distinguish between itself (the "subject") and the rest of the environment (the "objects") and, at its highest level, may even become conscious of this distinction. By acquiring knowledge via its competition and/or cooperation with the rest of nature within the struggle for life, the organism forms mental constructs, "Mental Models of Reality" (MMoR), integrating its ideas about the various aspects of the external world, ideas that change and evolve together with the changing interaction of the "subject" with its environment.

Once human groups and societies are formed, they strongly interact with single individuals by means of an intercommunication language. The feedback society-individuals gives rise to the *Intersubjectivity*, and single MMoRs evolve towards collective SMoRs (*Social Models of Reality*). A high level example is provided by scientific theories. Moreover, the feedback produces agreed instruments and methods for investigating nature of which scientific methodologies are important examples. In view of this, the equation "objective" $\equiv$ "true essence" does not seem to hold and the notion of "objective" seems nothing but a social evolution of the notion of "subjective." This is in contrast with the exophysical tendency to attribute the absolute truth to "objectivity."

It is a fact that, in spite of centuries of attempts, man has never succeeded in getting rid of subjectivity in science. From one side, thermodynamics tells us that the increase of entropy (and disorder), predicted by the second principle, depends on the human point of view, i.e. man's classification of "objects" in terms of increasing order. In addition, at the beginning of the XX century, quantum mechanics showed that the view of the "external" world depends on the observer's choices and on his modalities of observation, a circumstance that led to the quantum probabilism and to the holographic realism *à la Bohm*.

These arguments rise doubts on the *tout-court* validity of the exophysical attitude which, by the way, has had strong opponents along history. Notable examples are, among others, Kant's scepticism on the capability of man to reach a complete abstraction, Nietzsche's perspectivism, Popper's epistemology in sharp disagreement with both Bacon's empiricism and Déscartés' rationalism, Heidegger's criticism of the dominant subjectivism of western tradition, and the hermeneutics of Gadamer who — following Nietzsche and Heidegger — prefers to talk of interpretation rather than truth. The point to keep in mind is that we cannot escape the constraint of being inside the nature we investigate and in strict, unavoidable, interaction with it.

Such awareness implies that the stubborn search for a unique Theory of Everything is hopeless: being part of the nature, all what we can achieve is a complete set of theories separately describing all aspects of nature. To this aim, in spite of serious technical and psychological difficulties, we should endeavour toward the development of new methodologies of investigation within an endophysical approach.

Acknowledgements

It is with great pleasure that we thank the Zentrum für interdisziplinäre Forschung (ZiF), Bielefeld University, for having supported and funded this workshop. We are indebted to Prof. Antonio Giuditta for his fruitful suggestions.

References

1. Lami, A. (a cura di) (2000) *I Presocratici: Testimonianze e Frammenti da Talete ad Empedocle*, Biblioteca Universale Rizzoli, Milano, pp. 273–295.
2. Valgimigli, M. (Transl.) (2000) *Platone: Fedone*, Laterza, Bari.
3. Reale, G. (a cura di) (2000) *Aristotele: Metafisica*, Bompiani, Milano, p. 57.
4. Evangeliou, C.C. (1997) *The Hellenic Philosophy: Between Europe, Asia and Africa*, Global Publications, IGSC, Binghamton University, New York.
5. Spade, P.V. (Transl.) (1994) *Five Texts on the Medieval Problem of Universals: Porphyry, Boethius, Abelard, Duns Scotus, Ockham*, Hackett, Indianapolis.
6. Padellaro De Angelis, R. (1970), *Nominalismo e Realismo nell'XI e XII Secolo*, Elia, Roma.
7. Thomas, S. (2003) *Valerius Terminus: Of the Interpretation of Nature by Francis Bacon*, The University of Adelaide, Library Electronic Texts Collection.
8. Landucci, S. (Transl.) (1997) *Déscartés: Meditazioni Metafisiche*, Laterza, Bari.
9. Pierre-Simon de Laplace (1921) Essai philosophique sur les probabilités, *Ouvres (1886), Vol. II*, Gauthier-Villars, Paris.
10. Einstein, A., Podolsky, B., and Rosen, N. (1935) Can quantum mechanical description of physical reality be considered complete?, *Physical Review* **47**, 777–780.
11. Bohr, N. (1958) *Atomic Physics and Human Knowledge*, John Wiley, New York.
12. Hiley, B.J., and Peat, F.D. (1997) *Quantum Implications — Essays in Honour of David Bohm*, Routledge, London.
13. Hawking, S. (1998) *A Brief History of Time*, Bantham Books, New York.
14. Pereira, A., Jr.(1997) *Irreversibilidade Física e Ordem Temporal na Tradição Boltzmanniana*, Editora UNESP, Sao Paulo.

15. Epstein, I.R. (1987) Patterns in time and space generated by chemistry, *Chemical and Engineering News* **65**, 24–36.
16. Lotka, A.J. (1925) *Elements of Physical Biology*, Williams and Wilkins Co., Baltimore.
17. Prigogine, I., and Nicolis, G. (1977) *Self-Organization in Non-Equilibrium Systems: From Dissipative Structures to Order Through Fluctuations*, John Wiley, New York.
18. Prigogine, I., and Stengers, I. (1983) *Order Out of Chaos*, Bantham Books, New York.
19. Thom, R. (1994) *Structural Stability and Morphogenesis*, Westview Press, Boulder.
20. Gardner, M. (1985) *Wheels, Life, and Other Mathematical Amusements*, W.H. Freeman, New York.
21. Maturana, H.R., and Varela, F.J. (1980) *Autopoiesis and Cognition. The Realization of the Living*, D. Reidel Publishing Co., Dordrecht.
22. Prigogine, I., and Stengers, I. (1981) *La Nuova Alleanza. Metamorfosi della Scienza (La Nouvelle Alliance. Métamorphose de la Science)*, Einaudi, Torino.
23. Craik, K. (1943) *The Nature of Explanation*, Cambridge University Press, Cambridge.
24. Buccheri, R. (2003) The intelligibility of nature, the endophysical paradigm and the relationship between physical and psychological time, in R. Buccheri, M. Saniga and W. M. Stuckey (eds.), *The Nature of Time: Geometry, Physics and Perception (NATO ARW)*, NATO Science Series, Kluwer Academic Publishers, Dordrecht–Boston–London, pp. 403–416.
25. Buccheri, R. (2002) Time and the dichotomy subjective/objective. An endo-physical point of view, *Russian Temporology Seminar*, http://www.chronos.msu.ru/EREPORTS/buccheri-time.htm.
26. Fischer, E.P. (1995) *Aristotle, Einstein and Co.*, R. Piper and Co., München.
27. Masini, F. (Transl.) (1999) *Nietzsche: Genealogia della Morale (Zur Genealogie der Moral)*, Adelphi, Milano, pp. 33–35 and 73–77.
28. Chiodi, P. (Transl.) (1969) *Heidegger: Essere e Tempo (Sein und Zeit)*, UTET, Torino, pp. 247–250.
29. Volpi, F. (a cura di) (2000) *Heidegger: Nietzsche*, Adelphi, Milano, pp. 642–670.
30. Vattimo, G. (Transl.) (2001) *Gadamer: Veritá e Metodo (Wahrheit und Methode: Grundzuge einer philosophischen Hermeneutik)*, Bompiani, Milano, pp. 342–357.
31. Trinchero, M. (1998) *Popper: Scienza e Filosofia*, CDE, Milano, pp. 69–120.
32. Idra, D. (Transl.) (2003) *Dürenmatt: Nachgedanken (Nel Cuore del Pianeta)*, Marcos y Marcos, Milano.
33. Popper, K. (1982) *The Open Universe: An Argument for Indeterminism*, Hutchinson, London.
34. Rössler, O.-E. (1992) *Endophysik, Die Welt des Inneren Beobachters*, Merwe Verlag, Berlin.
35. Kampis, G. (1996) Explicit epistemology, in K. Matsuno (ed.), *Review de la Pensée d'Aujourd'hui* **24**, pp. 264–275.

36. Eakins, J. (2004) Classical and quantum causality in quantum field theory, or "The Quantum Universe", *Ph.D. Thesis*, The University of Nottingham.
37. Jaroszkiewicz, G. (2001) The running of the universe and the quantum structure of time, preprint `quant-ph/0105013, v2`.
38. Saniga, M. (1998) Pencils of conics: A means towards a deeper understanding of the arrow of time?, *Chaos, Solitons* & *Fractals* **9**(7), 1071–1086.
39. Buccheri, R., Jaroszkiewicz, G., and Saniga, M. (2003) Endophysics, the fabric of time and the self-evolving universe, in S. G. Pandalai (ed.), *Recent Research Development in Astronomy* & *Astrophysics, Volume 1 – Part II*, Research Signpost, Trivandrum (India), pp. 609–623.
40. Saniga, M. (2005) A geometrical chart of altered temporality (and spatiality), *this volume.*

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 23–42

THE ENTROPY OF THE FUTURE

GEORGE JAROSZKIEWICZ
School of Mathematical Sciences, University of Nottingham, University Park, Nottingham, NG7 2RD, U.K.
(jag@maths.nott.ac.uk)

Abstract: We apply Shannon's entropy of information to a quantum computational model of the universe to discuss how big the future could be relative to a given present. We discuss how such a model could provide a basis for an endophysical description of the universe.

Keywords: Shannon Entropy – Quantum Mechanics – Process Time – Information – Contextuality

1 Introduction

There are a number of conflicts running throughout science which have arisen because conventional thinking about time, information and contextuality deal with these issues inadequately. Science starts with the study of objects but ends with the undue objectification of processes. Once we objectify complex phenomena such as life, consciousness and time by regarding them as context-free, then we come to think of them as absolute. This is a natural error caused by the normally reasonable tendency of humans to create simple models of a vastly complex and ever-changing universe.

In addition to the exo-endophysics debate, there is the frequentist versus Bayesian interpretations of probability, unitary (Schrödinger) evolution versus state reduction in quantum mechanics, classical versus quantum counterfactuality as exemplified by the Bohr-Einstein debate about the interpretation of quantum mechanics, manifold time (block universe) versus process time, absolute truth values versus relative (contextual) truth values, absolute space and time versus relative space and time, and even Hilbert's axiomatization programme for mathematics versus Gödel's incompleteness theorems [1].

In probability theory, Jaynes stands out as a strong advocate of the Bayesian approach, as opposed to Fisher, a leading frequentist. A remarkable and timely recent book by Jaynes [1] presents powerful arguments for the extension of Bayesian methods beyond purely statistical applications. These and the recent work of Khrennikov on contextual quantum mechanics, reported in these proceedings, supports the view that we have come to, viz., that prior information and contextuality are not only related, if not indeed synonymous, but are essential in any careful discussion in science and philosophy.

What lies at the heart of the frequentist-Bayesian debate is the objectification by the frequentists of probability. For them, a fair coin *has* an intrinsic fifty-fifty chance of landing heads. Bayesians point out, however, that tossing a coin is a *process*, involving the observer who throws the coin and makes the observations. For Bayesians, the *context* of the throw cannot be removed from the discussion. We agree with that.

A similar error of objectification occurs when quantum theorists insist on strict unitary evolution of quantum wavefunctions. Schrödinger evolution without observation is a physically meaningless concept. When information is extracted in a quantum experiment, the prepared state must change. Otherwise we could go on and perform a measurement incompatible with the first and thereby circumvent the uncertainty principle. Most importantly, the context, or choice of experiment, cannot be excluded from this discussion.

The conflict between classical and quantum notions of counterfactuality, so well exemplified by the famous Einstein-Bohr debate [2], is another example of misplaced objectification. For followers of Einstein, such as hidden-variables theorists, prepared states of systems have intrinsic classical attributes, regardless of whether they are measured or not. Followers of Bohr, however, believe that the choice of experiment dictates the range of possible outcomes. In other words, the context of an experiment determines the range of possible futures.

This brings us to the crux of this paper, which is the assertion that, contrary to standard quantum mechanics principles, this context cannot be a completely free choice of the observer. In a paper on the simulation of physics with computers, Feynman wrote [3]

> "...we have an illusion that we can do any experiment that we want. We all, however, come from the same universe, have evolved with it, and don't really have any real freedom. For we obey certain laws and have come from a certain past."

There are two important points about this quotation. First, it occurs in a paper attempting to describe the laws of physics in terms of computation. That is a remarkable concept which has stimulated our own ideas about the quantum universe. Second, this quotation shows that, despite his recorded disdain for philosophy, Feynman realized that something was missing in the standard exophysical approach to quantum mechanics that he had so successfully contributed to. If indeed, experimentalists have no real freedom of choice of experiment, then the standard approach to quantum mechanics, which takes no account of why particular experiments are being done, must be incomplete. This seems to be a call for the study of endophysics.

This has motivated us to start thinking of the measuring apparatus as part of the system under observation. We call our particular approach the "stages paradigm", because the universe is assumed to evolve in a series of stages, or jumps in information content. Our ultimate objective is a consistent formulation of quantum cosmology. This may well be an inconsistent or impossible ambition, but until we try, we can have no hope of understanding the problems.

2 Opposing Views of Time

Philosophers of the manifold believe that time is geometrical and can be parametrized by real numbers. Examples are Newtonian absolute time [4] and coordinate time in relativity, which is integrated with space to form a four-dimensional manifold known as spacetime. In this approach, past, present and future exist in a four-dimensional manifold, giving rise to the so-called "block-universe" [5], in which the notion of a point particle is replaced by that of a line threading through spacetime.

In contrast, process time philosophers believe that time is synonymous with physical processes. For them, the notorious "moment of the now", so derided by modern relativistic physics, is the only meaningful reality, but it is constantly changing. Like water in a stream, it is there, but when we try to grasp it, it slips through our fingers.

The mistake made by manifold time theorists is to objectify time regardless of context. In process time, past and future can only be discussed relative to a given present, in the context of the information currently available to the observer at that moment of the present. This is the way we look at time in the stages paradigm, discussed below.

Although manifold time is too naive a view of time, physicists generally use it and avoid discussing process time for a number of reasons: the manifold picture seems to work extremely well, it seems impossible to model "passing time" using conventional mathematics, and process time seems incompatible with relativity.

Despite its successes, there are a number of deep conceptual problems with manifold time and block universe. The block universe model is like a map showing all the places we have seen and wish to see. But a map cannot say where we are right now unless we mark the map in some way, such as an arrow pointing to a place on the map with the caption "*you are here*". However, this works only because an observer using such a map adds information available to them which is not on the map. For instance, an observer has to look around at their environment carefully and compare it with what is on the map before they can be sure that they are actually at the place indicated by the arrow. In other words, just having a map is inadequate. It requires the observer and the context of the place where they actually are actually at in order for any map to be useful. The block universe model is inadequate because it takes systems into account, but not the observers of those systems.

Other problems with manifold time arise because it does not naturally take irreversibility into account. Block universe models of physics invariably need to introduce various kinds of clocks, or arrows of time, particularly if they want to discuss thermodynamics and cosmology. A clock is just any device with a memory, i.e., a device which registers irreversibility in time in some way. But irreversibility corresponds to the acquisition and loss of information, and so we come to the conclusion that time is synonymous with information exchange,which implies sources and sinks of information.

Whenever little or no attention is paid to the necessity of having both of these concepts, we should expect to run into conceptual difficulties. For this reason, Einstein's geometrization of physics programme is doomed to failure in the long run. It does not adequately deal with observers and this is why general relativity and quantum mechanics have not been reconciled. The fact is, special and general relativity do not discuss information exchange between systems and observers in any way. Their relativity concerns the relativity of different observers' accounts of an assumed classical reality, which by definition is context free. Cartan's development of a coordinate-free, differential geometric description of physics has to be severely criticized, because it trained theorists to decontextualize observation in relativity, with the consequences that we see today. Quantum mechanics on the other hand is really all about information exchange between system and observer, not about the absolute properties of systems *per se*.

3 Opposing Views of Probability

Quantum physics shows that randomness is a fundamental attribute of the universe, so a proper understanding of probability is crucial for any interpretation of time. Indeed, a moment's thought suffices to convince us that probability is all about the relationship between time and information.

As we have already mentioned, there are two contrasting interpretations of probability: the frequentist and the Bayesian. Frequentists believe that probability is a fundamental attribute of systems associated with random events, i.e., is not contextual. For them, probabilities are identified as well-defined ratios of frequencies of observed outcomes to total outcomes, when considered in the limit of very many observations. Because all the predictions of quantum mechanics have been fully confirmed via statistics collected from spatial and temporal ensembles, the frequentist approach to probability has gained a firm foothold in the camp of the quantum theorists. This has contributed greatly to the persistence of conceptual problems associated with quantum theory. Such problems occur in quantum cosmology and decoherence theory, which do not have satisfactory accounts of the Born probability rule.

The frequentist approach makes sense only if large numbers of repetitions or runs of a basic experiment can be performed, from which averages can be worked out and then related to quantum theoretic expectation values. But if all observers are endophysical and for them, the universe runs only once in process time, then it cannot be considered in terms of an ensemble of universes in any meaningful way. We would have to introduce the notion of a superobserver, or exo-observer, standing outside of an ensemble of universes before we could meaningfully talk about a probability of a Big Bang occurring, for example.

Bayesian probabilists, on the other hand, believe that probability concerns both subject and observer. The prior knowledge of the observer is a fundamental ingredient without which no meaningful inferences can be made. The Bayesian observer uses prior information to draw conclusions about hypotheses from data obtained by observations on a system. A typical scenario [1] is the following. If X represents the observer's prior information, D represents data obtained from observation and H represents some hypothesis to be tested, then

$$P(H|DX) \equiv P(H|X)\frac{P(D|HX)}{P(D|X)}, \quad P(D|X) \neq 0, \qquad (1)$$

is the *posterior probability* that the hypothesis (or *proposition*) H is true, given the prior information and the data. In principle we can calculate the conditional probabilities on the right hand side and draw our inferences. By using this process to update prior information, the Bayesian approach gives a "dynamical" framework for information exchange between system and observer. This closely matches the stage paradigm we shall discuss below.

4 Context is Information

The Bayesian approach to probability is very similar to the standard approach to quantum mechanics, in that in each case, we are dealing with prior information which is used to make probability assignments to future outcomes of an experiment or observation. Also, in each case, once we have acquired new information because of some new data, our prior information has to be updated, along with our probability assignments, and this looks very much like an "informational collapse". In quantum mechanics this very reasonable point of view, known as state reduction or wave-function collapse, has been demonized as unphysical and inconsistent with unitary evolution. However, this argument ignores the role of the observer and as an objection is certainly very strange, considering that the whole point of quantum theory is to calculate probabilities, which are necessarily associated with the concept of informational collapse.

5 The Entropy of the Future

If the universe ran on completely classical, deterministic lines, then according to Laplace [6], knowing everything about the present would allow us in principle to predict the future with absolute certainty. Even if we could not compute the future, we would still believe that the future was determined. Quantum mechanics however, tells us that the universe does not run on classical lines and this means that the future we face is not determined. The question is, can we make any estimate about how large is the set of possible futures that we face? Our answer involves probability and entropy.

The concept of entropy has been subject to the same degree of confusion as the concept of probability and the other problems mentioned at the beginning of this paper. Physics books often refer to *the* entropy of a system, as if it was some objective property of a system, with no reference to the role of the observer in the discussion. In an influential book on quantum mechanics [7], Peres explained clearly the role of the observer's state of knowledge about the system under observation in the formulation of the Shannon entropy of information concept [8].

Suppose we have an experiment with a set $X = \{x_1, x_2, \ldots, x_n\}$ of n possible outcomes, each of which occurs with probability $P_i \equiv P\{X = x_i\}, 1 \leq i \leq n$. These probabilities sum to certainty, i.e., $\sum_{i=1}^{n} P_i = 1$. The self-information, or surprise, $I_i \equiv I(X = x_i)$ of outcome x_i is defined to be $I_i \equiv -\ln(P_i)$. This nomenclature is consistent with the way we think about likely and unlikely events occurring in the real world: if an event is absolutely certain to occur, then we are not surprised when it occurs, whereas we are very surprised when a low-probability event happens.

The average, or expectation value, of the self-information is known as the (Shannon) entropy of information $S(X|\mathbf{P})$, and is defined by

$$S(X|\mathbf{P}) \equiv \sum_{i=1}^{n} P_i I_i = -\sum_{i=1}^{n} P_i \ln(P_i), \tag{2}$$

where $\mathbf{P} \equiv (P_1, P_2, \ldots, P_n)$. Here, the "prior information" we have about the system is the set $\mathbf{P}$ of probabilities that we have assumed about the outcomes. These probabilities set the context of the experiment. In this sense, information and context are synonymous. Clearly, the concept of an entropy "for a system" with no reference to any observer is a meaningless one.

Shannon's formula for entropy has a number of important properties, two of which are *i*) entropy is always either zero or positive, with equality only when one of the probabilities is unity, which corresponds to absolute certainty, and then all the other events have probability zero and *ii*) suppose that what we call the n^{th} event x_n is in fact one of a set of alternatives $Y = \{y_1, y_2, \ldots, y_m\}$, associated with probabilities $\mathbf{q} \equiv \{q_1, q_2, \ldots, q_m\}$ such that $P_n = q_1 + q_2 + \ldots + q_m$. Assuming P_n is non-zero, then the total entropy satisfies the rule

$$\begin{aligned} S(Z|P_1, P_2, ..., P_{n-1}, q_1, q_2, ..., q_m) &= S(X|\mathbf{P}) \\ &\quad + P_n S(Y|\frac{q_1}{P_n}, \frac{q_2}{P_n}, ..., \frac{q_m}{P_n}), \end{aligned} \tag{3}$$

where $Z \equiv \{x_1, x_2, \ldots, x_{n-1}, y_1, y_2, \ldots, y_m\}$. From this we deduce that

$$S(Z|P_1, P_2, \ldots, P_{n-1}, q_1, q_2, \ldots, q_m) \geq S(X|\mathbf{P}). \tag{4}$$

This result will be used to represent the idea that the further we try to look into the future, the "fuzzier" it should get.

6 The Quantum Future

The conventional objectivist view of a quantum experiment is that it extracts information about a system. There is a lot wrong with this notion. It objectifies the notion of a "system" by leading us to think that the context in which we look at a system is irrelevant. It suggests that a system has properties independent of the rest of the universe.

We take a different view. For us, both the preparation of a state of a system *and* the experiment subsequently performed on it are regarded as part of the same context which conditions the possible future. In other words, a quantum experiment is a portal into many different potential futures, rather than a look at what happened in the past. If the objectivist view of Einstein were valid, we would indeed be looking at just the past, i.e., seeing the consequences of how the state was prepared. However, the Heisenberg uncertainty principle tells us that Bohr's contextual view is the right one; how we decide to look at the system dictates what we can find out about it. Therefore, we are looking not only at the past when we do an experiment. Decisions that we make in the present are equally important, which means that quantum mechanics is inherently endophysical.

Of course, if we could arrange to perform many repetitions of many different experiments on an ensemble of identically prepared systems, then we would begin to build up a picture of a quantum state which transcended the information we could obtain in any one run, or even in a large number of runs with a given choice of experiment. This ensemble approach is often used by some quantum theorists to argue that the concept of a quantum state has no ontological meaning but is merely a statistical concept. We cannot agree with this; quantum interference supports the view that the universe does not run on classical statistical mechanical principles.

Our approach is consistent with the standard scenario discussed by von Neumann [9]. Such an experiment involves the following temporal sequence of events. First, using a preparation apparatus Σ_0, the observer prepares a system in an initial state Ψ_0. Next, the observer passes the prepared state through an apparatus Σ_1. At the end of each *run* (or repetition) of the experiment, one and only one out a finite number n of possible outcomes is observed. Which one occurs cannot be predicted in advance, unless the probability of one of the outcomes happens to be unity.

The mathematical representation of the above sequence of events uses the formalism of Hilbert space, which involves operators and vectors. The initial state Ψ_0 of the prepared system is represented by a normalized vector $|\Psi_0\rangle$ in some n-dimensional Hilbert space $\mathcal{H}$. The dimension n of $\mathcal{H}$ is the number of possible outcomes of the detecting apparatus Σ_1, which is represented by a Hermitian operator $\hat{\Sigma}_1$ called an *observable.* We note that generally, quantum theorists do not concern themselves with the details of the preparation apparatus Σ_0. The reason for this has to do with the way quantum mechanics is thought about. It is a standard assumption that the choice of initial state is entirely free, within the parameters of allowed physics. For example, if we were calculating the cross-section of a scattering experiment involving electrons and protons, we would normally assume that electrons of any incident momentum could be used in the initial state, and being theorists, we would rarely ask how such electrons could be prepared. This introduces an element of fiction into the theory. In the real world, we could not create electron states with momenta beyond a certain range, on account of our finite resources and, more to the point, because the physics of the universe would introduce its own cutoffs in energy and momentum.

Problems arise because the context in which initial states are created is usually ignored in conventional quantum theory. Our approach focuses on that context. We take the view that the preparation of an initial state is as much part of the dynamics of an experiment as the detection of the final state. In the stages paradigm, which we discuss below, state preparation and state detection are regarded as opposite sides of the same coin.

Each of the n possible outcomes $\Psi_1^\alpha,\ \alpha = 1, 2, \ldots, n$, of the test is represented by a distinct normalized eigenvector $|\Psi_1^\alpha\rangle$ of the operator $\hat{\Sigma}_1$. This operator is assumed Hermitian and non-degenerate, and so the potential outcomes are disjoint, i.e., $\langle\Psi_1^\alpha|\Psi_1^\beta\rangle = \delta_{\alpha\beta}$. The probability $P(\Psi_1^\alpha|\Psi_0)$ of outcome Ψ_1^α, conditional on initial state being Ψ_0, is given by the Born rule

$$P(\Psi_1^\alpha|\Psi_0) = |\langle\Psi_1^\alpha|\Psi_0\rangle|^2. \tag{5}$$

All predictions based on the Born rule have been fully vindicated countless times in many experiments.

The notation in (5) is too limited for our purposes. Most importantly, there is no reference in the notation to the actual experiment Σ_1. The notation as it stands suggests that *any* choice of final state is permitted. This is not consistent with process time. There comes a point when it is too late to change an experiment once it is under way. We shall replace the left-hand side $P(\Psi_1^\alpha|\Psi_0)$ with $P(\Psi_1^\alpha|\Psi_0, \Sigma_1)$, which stresses the fact that quantum outcome probabilities are conditioned not only on the initial state but by the choice Σ_1 of experiment or test. This underlines Bohr' position that quantum mechanical probabilities are not attributes of prepared quantum states alone but have a meaning only within an experimental context.

Using Born's rule, for a given initial state Ψ_0, each choice Σ_1 of experiment is associated with an outcome entropy $S(\Psi_0, \Sigma_1)$ given by

$$S(\Psi_0, \Sigma_1) \equiv -\sum_{\alpha=1}^{N} P(\Psi_1^\alpha|\Psi_0, \Sigma_1) \ln \{P(\Psi_1^\alpha|\Psi_0, \Sigma_1)\}, \qquad (6)$$

provided of course that we can actually do experiment Σ_1.

An interesting alternative way of viewing the above is to interchange the roles of state and test. Instead of saying that (6) measures the entropy of the initial state Ψ_0 relative to choice of test Σ_1, we could just as well say that it gives the entropy of Σ_1 relative to Ψ_0. Perhaps the most reasonable point of view would be that (6) is the entropy of the future relative to both subject and observer, i.e., relative to the initial state Ψ_0 and test Σ_1.

If we were allowed to change the test Σ_1, then the entropy (6) would almost certainly change. In other words, *if we can make free will choices of experiment* Σ_1, *then the potential future will depend on our choice.* However, if we take seriously the quote from Feynman given earlier, this is not possible. We then come to the conclusion that humans do not understand at least half of physics; given a choice of quantum experiment on a prepared system, we can use the rules of quantum mechanics to work out outcome probabilities by the Born rule, and these are generally completely successful. However we know next to nothing about why we made that choice in the first place.

It seems contrary to the spirit of science to reply to this with the assertion that quantum physics, as it is currently constituted, is in its final formulation. Certainly Feynman seems not to have been convinced of this.

7 Null Tests

There is a very interesting and useful aspect of the von Neumann scenario which gives rise to the idea that physical time is actually "multi-fingered". In the following, we work in a modified version of the Heisenberg picture, in which time evolution is located with operators rather than states (the modification arises in that we allow otherwise frozen states to jump to outcomes states when tests have been completed).

Suppose we chose the test Σ_1 to be the same as the preparation apparatus, i.e., $\Sigma_1 = \Sigma_0$. By this we mean that Σ_1 is not precisely the same as Σ_0 in time (it has to occur later), but otherwise, is an experiment with essentially all the same features. For example, if Σ_0 involves the passage of an electron through a Stern-Gerlach apparatus with quantization axis along vector **a**, then Σ_1 is another Stern-Gerlach experiment, also with quantization axis along vector **a**. According to the von Neumann scenario, the prepared state Ψ_0 is ray equivalent to one of the eigenstates of the test Σ_1, so that the outcome probability $P(\Psi_0|\Psi_0, \Sigma_1)$ is one (i.e., certainty) and all the other outcome probabilities are zero (i.e., cannot occur).

In such a case, the entropy $S(\Psi_0, \Sigma_1)$ is zero, because the future is absolutely determined and we can be absolutely sure (modulo any experimental uncertainty that Σ_1 is a duplicate of Σ_0) of the outcome of test Σ_1, even before it has been completed. This is the quantum version of Laplacian determinism. Such a situation corresponds to no information exchange between subject system and observer: no new information about Ψ_0 or Σ_1 is extracted from the system and whatever knowledge we had before the experiment remains unchanged after the experiment has finished.

A profoundly important side-effect of this scenario is that the initial state goes through Σ_1 without change, so that in effect, *time has effectively stopped* for that state. From this we deduce that, in this modified Heisenberg picture, the passage of physical time is synonymous with information exchange between system and observer.

8 The Stages Paradigm

We now review the stages paradigm, which we shall use to discuss the possibility of observers and systems emerging from a quantum computational model of the universe [10]. This framework is necessarily based on a lot of guesswork, with no understanding currently about how tests are selected.

First and foremost, the stages paradigm is a mathematical framework for the description of a fully quantized, self-contained and self-referential universe. By this is meant the extension of the standard principles of quantum mechanics to encompass the entire universe. Whether or not this is reasonable is still a matter for debate, but we shall assume the position of quantum cosmologists, for whom the concept of “state of the universe” is a valid one. For us, the universe is regarded as an enormous quantum automaton, that is, a generalized quantum computation in a vast Hilbert space composed of many quantum bits.

An important assumption is that the universe we think we see is not the universe that is really there. The spacetime of the block universe does not exist *per se*, and therefore neither do the concepts of metric, reference frames, observers, Hamiltonians, and so on. All of these are regarded as convenient objectifications of vastly more subtle quantum processes, only emerging under certain conditions contingent on the fact that the universe consists of a vast number of quantum degrees of freedom.

Pre-emergent time, or "exo-time", is regarded as synonymous with the quantum process of change of one stage of the universe to the next, and is therefore discrete and integrable. This time is not the physical time associated with observers however. When used with quantum registers, discussed below, the stages paradigm is consistent with the concept of a "many-fingered", local and non-integrable endo- time, related to the notion of proper time in relativistic physics. This arises because of the possibility of null tests acting on various factors in the state of the universe.

The origin of temporal discreteness is state reduction, which is regarded here as synonymous with information exchange between various factors in the state of the universe. Successive stages therefore may be labelled by an integer, n. At any given exo-time n, the universe is postulated to be in a unique stage $\Omega_n \equiv \Omega(\Psi_n, I_n, \mathcal{R}_n)$. A stage always has three essential components: *i*) the current state of the universe Ψ_n is an element in a Hilbert space $\mathcal{H}$ which must be of enormous dimension $N \gg 1$, *ii*) the current information content, I_n, is information over and above that contained in Ψ_n, and *iii*) the current rules, $\mathcal{R}_n$, which govern the dynamical development of the universe.

For any given stage Ω_n, all other stages such as Ω_{n+1} and Ω_{n-1} can only be discussed in terms of conditional probabilities, relative to the condition that the universe is in stage Ω_n. This is our mathematical representation of the concept of process time.

The dynamics in the paradigm follows all of the standard principles of quantum mechanics, except for the non-existence of semi-classical observers with free will. The current state of the universe (referred to as the *present*) Ψ_n is the unique outcome (modulo inessential phase) of some unique test Σ_n, represented by a non-degenerate Hermitian operator $\hat{\Sigma}_n$. Ψ_n acts as the initial state for the next test $\hat{\Sigma}_{n+1}$, which is also non-degenerate.

The next test of the universe $\hat{\Sigma}_{n+1}$ is associated with a unique preferred basis, B_{n+1}, consisting of the eigenstates of $\hat{\Sigma}_{n+1}$. These form a complete orthonormal set and the next state of the universe Ψ_{n+1} is one of these possible eigenstates.

The factors which determine $\hat{\Sigma}_{n+1}$ are postulated to depend only on $\Omega_n \equiv \Omega(\Psi_n, I_n, \mathcal{R}_n)$ and are currently not understood (recall Feynman's comment). An important assumption in the stages paradigm is that these factors do not involve any external observer making any sort of free choice.

Given $\hat{\Sigma}_{n+1}$, the one-jump conditional probability $P_1(\Psi^{\alpha}_{n+1}|\Psi_n, \hat{\Sigma}_{n+1})$ that the next state of the universe Ψ_{n+1} is the particular eigenstate Ψ^{α}_{n+1}

of $\hat{\Sigma}_{n+1}$ is given by the Born rule

$$P_1(\Psi_{n+1}^{\alpha}|\Psi_n, \hat{\Sigma}_{n+1}) = |\langle\Psi_{n+1}^{\alpha}|\Psi_n\rangle|^2, \tag{7}$$

assuming the vectors Ψ_n, Ψ_{n+1}^{α} are normalized to unity. We should ask who has this information and who makes this probability estimate. This is the central question in endophysics. Our answer is that humans are inside the universe, but that has not prevented them from making probability estimates about their own futures or that of the universe. We note that possible objections to the above, involving concepts of computability and the Gödel theorems, are probably incorrect, because human thought is not perfectly rigorous, or always logical or strictly computational.

More generally, if $\hat{\Sigma}_{n+1}$ is not determined uniquely by Ω_n, we should use the full one-jump stage-stage probability

$$P_1(\Omega_{n+1}^{A\alpha}|\Omega_n) = |\langle\Psi_{n+1}^{A\alpha}|\Psi_n\rangle|^2 P(\Sigma_{n+1}^{A}|\Omega_n), \tag{8}$$

where $P(\Sigma_{n+1}^{A}|\Omega_n)$ is the conditional probability that Σ_{n+1}^{A} is the next test of the universe, given Ω_n, and where $\Psi_{n+1}^{A\alpha}$ is one of the eigenstates of Σ_{n+1}^{A}. The index A in the above ranges over all possible tests, which involves vastly more complex possibilities than the set of all outcomes of a given test.

These probabilities are meaningful only from the point of view of endophysical observers such as physicists who are attempting to understand what the future of the universe may be like. Feynman's comment can now be understood as a recognition that we have no idea how to calculate $P(\Sigma_{n+1}^{A}|\Omega_n)$. If we could, we would understand time much better.

After each jump $\Psi_n \rightarrow \Psi_{n+1}$, the information content I_n and the rules $\mathcal{R}_n$ are updated to I_{n+1} and $\mathcal{R}_{n+1}$ respectively and the whole process is repeated. It has been noted by R. Buccheri that how the rules might change must somehow be encoded into the rules themselves, i.e., they are also "The Rules of the Rules".

9 The Entropy of the Future in the Stages Paradigm

Given the one jump stage-stage probability $P_1(\Omega_{n+1}^{A\alpha}|\Omega_n)$, the one-jump entropy of the future $S_1(\Omega_n)$ is defined by

$$S_1(\Omega_n) \equiv -\sum_{A}\sum_{\alpha=1}^{N} P_1(\Omega_{n+1}^{A\alpha}|\Omega_n) \ln P_1(\Omega_{n+1}^{A\alpha}|\Omega_n), \tag{9}$$

where the first summation is over all possible tests. Using (8) this reduces to

$$S_1(\Omega_n) = S_\Sigma(\Omega_n) + \sum_A P(\Sigma^A_{n+1}|\Omega_n) S(\Psi_{n+1}, \Sigma^A_{n+1}), \tag{10}$$

where

$$S_\Sigma(\Omega_n) \equiv -\sum_A P(\Sigma^A_{n+1}|\Omega_n) \ln P(\Sigma^A_{n+1}|\Omega_n) \tag{11}$$

represents the *entropy of test formation*, or entropy associated with the choice of the next test of the universe, and

$$S(\Psi_{n+1}, \Sigma^A_{n+1}) \equiv -\sum_{\alpha=1}^{N} |\langle \Psi^{A\alpha}_{n+1}|\Psi_n\rangle|^2 \ln |\langle \Psi^{A\alpha}_{n+1}|\Psi_n\rangle|^2 \tag{12}$$

is the entropy associated with test Σ^A_{n+1}.

We have no idea how variable the size of the potential future is over very short time scales, because the entropy of test formation is completely not understood and because we expect individual test entropies for the universe to be enormous. If there is genuine free will and we could in principle choose any test (locally), then the entropy of test formation for the universe could conceivably be infinite. If on the other hand there is no free will in the universe, then the entropy of test formation would be zero. There remains the possibility, however, that the choice of test is not determined fully by the present but is subject to laws of chance analogous to those associated with the outcomes of quantum tests. This raises the possibility that a "quantum theory" of test selection might one day be developed. There are reasons for suspecting that, if such a thing were possible, it would be much more complicated than the quantum mechanics associated with test outcome probabilities, because the "size" of the basis set of operators associated with an n-dimensional Hilbert space is n^2 [7].

10 The Two-Jump Entropy of the Future

Now consider following a given "present" stage Ω_n along a branch into its future involving two jumps. First we have the jump

$$\Omega_n \equiv \Omega(\Psi_n, I_n, \mathcal{R}_n) \to \Omega(\Psi^{A\alpha}_{n+1}, I^{A\alpha}_{n+1}, \mathcal{R}^{A\alpha}_{n+1}) \equiv \Omega^{A\alpha}_{n+1}, \tag{13}$$

where $\Psi^{A\alpha}_{n+1}$ is an outcome of Σ^A_{n+1}, followed by the jump

$$\Omega^{A\alpha}_{n+1} \to \Omega(\Psi^{AB\alpha\beta}_{n+2}, I^{AB\alpha\beta}_{n+2}, \mathcal{R}^{AB\alpha\beta}_{n+2}) \equiv \Omega^{AB\alpha\beta}_{n+2}, \tag{14}$$

where $\Psi_{n+2}^{AB\alpha\beta}$ is an outcome of $\Sigma_{n+2}^{AB\alpha}$. The two-jump probability $P_2(\Omega_{n+2}^{AB\alpha\beta}|\Omega_n)$ is given by

$$P_2(\Omega_{n+2}^{AB\alpha\beta}|\Omega_n) = P_1(\Omega_{n+2}^{AB\alpha\beta}|\Omega_{n+1}^{A\alpha})P_1(\Omega_{n+1}^{A\alpha}|\Omega_n). \tag{15}$$

The two-jump entropy $S_2(\Omega_n)$ is defined by

$$S_2(\Omega_n) \equiv -\sum_{AB}\sum_{\alpha\beta} P_2(\Omega_{n+2}^{AB\alpha\beta}|\Omega_n) \ln P_2(\Omega_{n+2}^{AB\alpha\beta}|\Omega_n). \tag{16}$$

Using (15), this reduces to

$$S_2(\Omega_n) = S_1(\Omega_n) + \sum_{A\alpha} P_1(\Omega_{n+1}^{A\alpha}|\Omega_n)S_1(\Omega_{n+1}^{A\alpha}). \tag{17}$$

This readily generalizes to the expression

$$\boxed{S_{k+1}(\Omega_n) = S_1(\Omega_n) + \sum_{A\alpha} P_1(\Omega_{n+1}^{A\alpha}|\Omega_n)S_k(\Omega_{n+1}^{A\alpha})} \tag{18}$$

for $k = 1, 2, \ldots$. From this we deduce $S_k(\Omega_n) \geq S_{k-1}(\Omega_n) \geq \ldots \geq S_1(\Omega_n)$, in accordance with the intuitive notion that the further we try to look into the future, the more uncertain it becomes. If at any point equality held, then the non-negativity of both entropy and probability would make it look as if time had stopped there to all intents and purposes. However, this would only be valid if the information content and rules remained unchanged. In the real world, physicists can do a null test *and* accumulate the information that they have done so.

11 The Emergence of Endophysics

To begin to get a handle on endophysics, we extend the stages paradigm by specifying the Hilbert space $\mathcal{H}$ to be a quantum register. A quantum register $\mathcal{H}^n$ of rank n is the tensor product $\mathcal{H}^n \equiv \mathcal{H}_1 \otimes \mathcal{H}_2 \otimes \ldots \otimes \mathcal{H}_n$ of n elementary Hilbert spaces $\mathcal{H}_1, \mathcal{H}_2, \ldots, \mathcal{H}_n$. We shall choose each subregister $\mathcal{H}_i$ to be a quantum bit, or qubit. A qubit is an elementary two-dimensional Hilbert space $\mathcal{Q}$ which is the quantum analogue of the classical bit (which has only two states: "yes" or "no"). A suitable basis for a qubit is the set $\{|0\rangle, |1\rangle\}$ of orthonormal vectors representing these classical truth values, i.e., $|0\rangle \equiv$ "no" and $|1\rangle \equiv$ "yes". In contrast to classical bit states, we can superpose these quantum "truth values" and have states of the form $|\psi\rangle \equiv \alpha|0\rangle + \beta|1\rangle \in \mathcal{Q}$, where α and β are complex numbers.

Quantum bit registers have a number of distinct properties. First and foremost, a rank n quantum bit register is a Hilbert space of dimension

2^n. This simple fact endows large rank quantum registers with a mathematical complexity which far outstrips their classical analogues. Another fundamental property possessed by quantum registers which classical registers do not have is that quantum registers contain both separable states, i.e., those which can be written as a tensor product of lower rank states, and entangled states, which cannot be so written.

The important point about quantum registers is that the separable states give us a way of modelling the classical concepts of distinct subsystems and observers, whilst the entangled states model the quantum entanglement which has been observed experimentally. No other approach provides such a natural description of the basic physical concepts required to discuss quantum endophysics.

12 The Planck-Hubble Estimate

The stages paradigm based on quantum registers models the universe as a vast quantum automaton running on quantum computational principles [10]. The idea behind the quantum computational universe is to associate one qubit for every elementary informational degree of freedom in the universe. Just looking around us is enough to convince us that we will need a very large rank quantum register. How many qubits might we need if we wanted to model the entire visible universe?

This question is very hard to answer with any great accuracy or meaningful certainty. However, we can make a very crude estimate as follows, just to give us an idea of the scale of the systems we are dealing with. First, we recognize that if we modelled our universe by putting one qubit at every point of continuous space, we would end up with an infinite rank quantum register. In such a case we could not label our quantum bits with the integers; continuous space simply has too many points. This approach has recently been considered by Deutsch [11] and we reject it for the reason given by Feynman. According to Minsky, Feynman said that he could not believe that a finite volume of space could contain an infinite number of degrees of freedom. Our estimate is based on finding the number of elementary Planck scale cubes which would fill the visible universe and then associating at least one qubit with each.

The Planck length L_P is defined via the known fundamental constants by the expression, $L_P \equiv \sqrt{G\hbar/c}$ and is approximately 1.6×10^{-35} metres, which is far below any current scales of resolution, being about a thousand times less than the Grand Unification scale inferred from data. We should expect at least one qubit per elementary Planck cube. We will not be particularly bothered if we are out by many factors of ten, because we are after an order of magnitude estimate.

It is important to keep in mind that we are not really thinking here in terms of one qubit actually sitting inside each Planck-scale cube in physical space. The relationship between our qubits and physical space is undoubtedly quite different and subtle. What matters is the information content associated with Planck scale cubes, which will be related in some way to the information content of the quantum register, in much the same way that information about a function $f(t)$ of a real variable t can be transformed into information about its Fourier transform $\tilde{f}(\omega)$, and back again. Another analogy is with the information content of a DVD disc, which can be transformed via a DVD player into a film with sound and vision.

To make our estimate, we simply work out the number of elementary Planck scale cubes which could fill the currently visible universe. To find the size of the visible universe, we imagine that it has been expanding at the speed of light since the Big Bang. The age T of the universe is currently believed to be of the order $T \simeq 12 \times 10^9$ years $\simeq 4 \times 10^{17}$ seconds. Given the speed of light $c \simeq 3 \times 10^8$ metres per second, we estimate the radius R of the visible universe to be of the order $R \simeq cT \simeq 10^{26}$ metres. Hence the number N_{PH} of Planck cubes within a sphere of this radius is approximately $N_{PH} \simeq 10^{183}$.

This number, N_{PH}, which we refer to as the *Planck-Hubble number*, is large by most ordinary standards. It represents a lower bound to the number of qubits we expect is needed to model the visible universe in reasonable detail. It includes spatial degrees of freedom but if as we expect we should include degrees of freedom associated with quantum fields, we may need to increase this estimate substantially. Whatever the final result, the important point is that we should expect our quantum register to be extremely large under any circumstance where we want to model the universe in this way.

The dimension of the associated Hilbert space for the universe is at least $2^{10^{183}}$, which is a truly enormous number. Clearly, the scope for entanglement and separation of quantum states is staggering. It should be appreciated that currently, much work is being done on the entanglement and separation properties of low rank quantum registers, and it is clear that systems as small as rank two and three have many interesting and novel properties still waiting to be explored physically and mathematically.

Recently, there has emerged from studies of quantum gravity and string theory the notion of the *holographic principle*, which suggests that the information content of the universe should be identified not with the volume of physical space but with its defining area. If this is valid, then the rank of our quantum register for the universe has to be replaced by something like $(N_{PH})^{2/3} \simeq 10^{120}$, a figure recently quoted as the maximum number of physical informational degrees of freedom possible. This is still extremely large.

13 Endophysical Observers

The numbers involved in quantum registers large enough to describe the universe have some fascinating properties. Suppose we imagine using qubits to model the information content of a laboratory with everything in it, including the apparatus and all the human observers. Consider a laboratory one hundred meters cubed. The number of qubits needed, using Planck-scale estimates, is approximately $N_{lab} \simeq 10^{110}$. Now consider a state of the universe which has separated into two factors, $\Psi_n = \Phi_n \otimes \Theta_n$, where Θ_n represents the current state of the laboratory and Φ_n represents the current state of everything else. Θ_n is a state in a subregister $\mathcal{H}_{lab}$ consisting of $N_{lab} \simeq 10^{110}$ qubits whilst Φ_n is a state in a subregister $\mathcal{H}_{outside}$ consisting of all the other qubits in the universe. The quantum register $\mathcal{H}_{Universe}$ for the universe is given by the split form $\mathcal{H}_{Universe} = \mathcal{H}_{lab} \otimes \mathcal{H}_{outside}$, with a rank $R_{Universe} > N_{PH}$ given by the sum of the two ranks, viz $rank\{\mathcal{H}_{Universe}\} = rank\{\mathcal{H}_{lab}\} + rank\{\mathcal{H}_{outside}\}$. The somewhat surprising conclusion is that $rank\{\mathcal{H}_{outside}\} = rank\{\mathcal{H}_{Universe}\} - rank\{\mathcal{H}_{lab}\} > 10^{183} - 10^{110} \simeq 10^{183}$. In other words, the universe is so large that we can use vast numbers of qubits to represent observer factor states without making much difference in the numbers estimates. This is analogous to what we are doing when we are talking about test particles in general relativity. Such a particle is affected by gravity but does not itself affect gravity. Likewise, a physicist exists in the universe and is properly a part of it, but in practical terms can be isolated from the rest without altering substantially its properties.

The study of quantum cosmology seems reasonable from this basis, if by that we understand the isolation of enough qubits to represent observers, but not enough to seriously alter the dynamics of the rest of the universe.

14 The Emergence of Classicality

The stages paradigm used with quantum register physics allows some simple yet powerful statements to be made. Suppose we have a rank-N quantum register $\mathcal{H}^N$ stages paradigm model with current state of the universe Ψ_n

which is completely entangled. Suppose further that the dynamics (as exemplified by the rules $\mathcal{R}_n$) forces the next test of the universe $\hat{\Sigma}_{n+1}$ to be factorizable itself, i.e., $\hat{\Sigma}_{n+1} = \hat{A}_{n+1} \otimes \hat{B}_{n+1}$, where $\hat{A}_{n+1}$is a non-degenerate operator acting on a rank-p subregister $\mathcal{H}^p$ and $\hat{B}_{n+1}$ is a non-degenerate operator acting on a rank-q subregister $\mathcal{H}^q$, with $p+q=N$ and $\mathcal{H}^N = \mathcal{H}^p \otimes \mathcal{H}^q$. Since $\hat{A}_{n+1}$ is non-degenerate, it has 2^p distinct eigenstates $\{|\alpha\rangle_A : \alpha = 1, 2, \ldots, 2^p\}$ forming a preferred basis for $\mathcal{H}^p$ and likewise, the 2^q eigenstates of $\hat{B}_{n+1}$ form a preferred basis $\{|\beta\rangle_B : \beta = 1, 2, \ldots, 2^q\}$ for $\mathcal{H}^q$. The 2^{p+q} tensor products $\{|\alpha\rangle_A \otimes |\beta\rangle_B\}$ are then eigenstates of $\hat{\Sigma}_{n+1}$. Moreover, they are all distinct and orthogonal.

However, according to the stages paradigm, the 2^N eigenstates $\hat{\Sigma}_{n+1}$ are non-degenerate and form an orthonormal set. By comparing the numbers involved, we deduce that *all the eigenstates of* $\hat{\Sigma}_{n+1}$ are separable. In the stages paradigm, therefore, we have the theorem that *factorizability of test implies factorizability of outcome.* This theorem is not true the other way around; "entangled" tests can have separable outcomes.

Two points emerge from this analysis. First, if the stages dynamics increases the factorizability of successive tests with increasing exo-time, then the state of the universe necessarily has to factorize accordingly. This would be equivalent to reducing entanglement and hence increasing classicality in the universe. This process would give a dynamical mechanism for the expansion of the universe, if we regarded space as a manifestation of separability (an eminently reasonable idea). Second, the observed persistence of semi-classical observers over extended time-scales could be accounted for if there were persistence of separability of successive tests. Unfortunately, because we currently do not understand the dynamics of tests, we have no current understanding of how these things could come about.

15 Concluding Remarks

The stages paradigm is like a house of cards built on a tabletop. We have some confidence in its foundations but nevertheless, the edifice remains shaky. The most serious objection, that the very notion of a quantum state for the universe is invalid, is offset by the use of the quantum register concept, which has tremendous potential to describe the universe as it really is. In particular, we believe that the correct use of quantum contextuality, in the form discussed by Khrennikov [12] and applied to the quantum register stages paradigm, has the potential to describe endophysics properly.

References

1. Jaynes, E.T. (2003) *Probability Theory: The Logic of Science*, Cambridge University Press, Cambridge.
2. Wheeler, J.A., and Zurek, W.H. (eds.) (1983) *Quantum Theory and Measurement*, Princeton University Press, Princeton (NJ).
3. Feynman, R.P. (1982) Simulating physics with computers, *Int. J. Theor. Phys.* **21**, 467–488.
4. Newton, I. (1686) *The Principia (Philosophiae Naturalis Principia Mathematica)*.
5. Price, H. (1997) *Time's Arrow*, Oxford University Press, Oxford.
6. Laplace, P.S. de (1812) *Essai Philosophique sur les Probabilites*, Veuve Courcier, Paris.
7. Peres, A. (1993) *Quantum Theory: Concepts and Methods*, Kluwer Academic Publishers, Dordrecht.
8. Shannon, C.E. (1948) A mathematical theory of communication, *The Bell System Technical Journal* **27**, 379–423.
9. Neumann, J. von (1955) *The Mathematical Foundations of Quantum Mechanics*, Princeton University Press, Princeton (NJ).
10. Eakins, J., and Jaroszkiewicz, G. (2005) New developments in quantum cosmology research, in A. Reimer (ed.), *Horizons in World Physics – Volume 247*, Nova Science Publishers, Hauppauge (NY), in press.
11. Deutsch, D. (2004) Qubit field theory, preprint `quant-ph/0401024`
12. Khrennikov, A.Yu. (2005) To quantum mechanics through projection of classical statistical mechanics on prespace, *this volume*.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 43–55

CONSTRUCTION OF ENDO-TIME AND ITS MANIPULATION IN AUTOPOIETIC SYSTEMS

IGOR BALAŽ
Dept. of Biology and Ecology, Fac. of Natural Sciences, University of Novi Sad, Trg Dositeja Obradovica 2, 21000 Novi Sad, Serbia and Montenegro
(balazi@neobee.net)

Abstract: Two main factors determine construction of internal temporal architecture in autopoietic systems: external pressure and network of internal interdependences. External influences are given for systems and they are only able to incorporate them into its own functional and temporal blueprint, with very small space for further manipulations. But, internal processes, or more precisely, irreversible reductions toward determined states are enclosed into mobile and alterative network of re-productive cycles. On that basis autopoietic systems are able to construct and manipulate with different temporal strategies as reversibility, delaying, circularity, spiral flows, different distribution of times and so on. Special case is construction of transient time fields, called here intersubjective times, that arise as fusions of two or more specific temporal architectures during their interactions. This paper describes construction of internal proliferation of time patterns and analyze their functional usefulness.

Keywords: Time – Autopoietic Systems – Functionality – Living Systems

1 Introduction

The observation of time as an objective flow from the past through the present and into the future turned out to be a constant source of absurdity. Through such a perspective we are unsuccesfully trying to locate now which transforms itself into the uncatchable region between was and will be (the past and the present) thus defying all limitations. "But if the present were always present, and did not pass into past time, it obviously would not be time but eternity. If, then, time present — if it be time — comes into existence only because it passes into time past, how can we say that even this is, since the cause of its being is that it will cease to be?" These thoughts of St. Augustine [1] still present a paradigmatic illustration of the difficulties connected with the problem of time flow. Although apory of this magnitude is an innate consequence of the presentation of time as a structureless and objective flow, the metaphor is preserved as something common and intuitive. Since Einstein it has become clear that time is dependent on a referential system, but unfortunately this great opportunity to delve deeper into the structure of time has been missed. The common thought was focused on the time plurality issue which restricted itself only on the matter of clarification of difference between movement and time, while the problem of structure of time flow wasn't even considered in science. But it was accepted and further developed in philosophy. Due to a lack of time I will not review works of Husserl, Merleau-Ponty, Bergson or Deleuze and I will ask you to take as granted that time is not an independent flow, inert to change in itself. It is not a simple line of successive infinitesimal quantities but a duration filtered through perceptive schematism. Chronology (time flow) is a construct of an observer and can't be equated with duration or changes in duration. Following that reasoning, this paper is divided into two parts: "duration and construction of time" and "time and its manipulations." Since duration, excluded from any kind of perception, leads into metaphysical speculations, where the only criteria is someone's choice to believe, in the first part I'll restrict myself only to the problem of construction of time from duration.The second part will be more concrete and more detailed, and will focus on the versitility of intra-systemic time flows and possibilities of their manipulation.

2 Duration and Construction of Time

As it is mentioned, time is a perceptive construction generated from duration. On the cognitive level, what is called intuition of time and time flow is far from structureless or given intuition. As Piaget infered [2], human perception of time is built from intuitions of movement and speed as a result of the outer world schematisation. At the very beginning of the cognitive development, space and time are inseparable unity. Separation of these two dimensions is possible only after the construction of functional processes. Therefore, the construction of time does not start with a simple extraction of objective changes from the environment, but, according to Piaget, is built on the capability to register changes of arrangement inside a functional system. Without such a systemic encapsulation it is impossible to construct the appearance of global time which consists of partial time fields of discrete events. Perception itself is incapable of that until it is integrated into systemic network where comparison becomes possible, and only then can we talk about shorter or longer periods between events instead of simple succession of states. For a perceptive entity (although inside the system) time remains in form of partial successions. If there is no signal, there is no time. For these entities there is no difference between state, time and space. Only through system of relations can this unity be divided into changes of state and changes of time flow. Given that building the objective time metrics is possible exclusively in cognitive systems, other autopoietic systems are only able to construct discrete relations where norms are not formalized and universal, but they are highly contextually dependent. Before I move on to the analysis of the systemic time, it is necessary to shed some light on a still open question of the structure of time flow. Do time intervals exist as objective, or are they in constant reconstruction through the horizons of retention and protention?

In the preceding section, it was emphasised several times, without further explanation, that the construciton of time flow can only take place as a consequence of perceptivity. Therefore, I will briefly emphasize some inherent outcomes of perceptivity. Perception is always absolutistic. It destructs the environmental continuum into absolute, operational domains. In other words, it simultaneously wipes out all variations inside one defined field and highly emphasises the boundary intervals. The values included in these intervals are no longer in ordinary linear succession of states, but are associated with the formalized schemes of identification and processing. Therefore we cannot talk about indifferent neighboring states but a succession, which, filtered through perceptive-functional schematism, can generate diametrically opposite functional rearrangments. In that way the outer world (environment) is transformed into an assembly of operational absolutes where every absolute is connected to purposeful, (by system) predefined reaction. Therefore, it is not possible to analyse time flow as some kind of given countdown which is independent of everyting, but on the contrary, changes in duration are basics upon which we (and every perceptive entity) construct time flow. When we realize those fundamental stages in formation of time (from duration), then it becomes clear that time flow cannot be a structureless line, that time moments do not exist in succession but differentiate from each other. Or, as it is emphasized by Merleau-Ponty [3]: "at every moment system of retentions converge in itself that, which moments ago was system of protentions." There is not one, uncatchable and absolute now which flows through (given) time, but in every succeeding moment, the former is altered. Retentional modifications are not limited only to the periods connected with now, but there is a constant sequence of retentional alterations; every retention is followed by another. Retention is not a modification of states, retention is modification.Therefore, retentions are not linear lineups in a way of successive changes which diverge from one point, but the point is modified by retentions [4]. We cannot say that "before" was constitutive; "before" is constitutive. Every succeeding moment can change the validity of the preceding moment(s) and through advanced retreat into the past, the same continuous complexity is modified until it disappears (because modifications are always connected with attenuation).

Along with retentional alterations, a similar process is happening in the opposite direction. In retention the new moments constantly change the validity of the previous ones, in the same way as the previous happenings influence the way of perception of the forthcoming events. They form a horizon of protention which cuts into the future and in connection with the structure of perceptive entity, constitutes a scope of functional possibilities.

Here, we should always keep in mind one thing: perception is only an interpretation and a single interpretation is only a part, no matter how important, but only a part of total possibilities of readings. An interpretation is a systemic insertion between the wholeness of environment and tendency for controlling it. It is only a model of the environment through which the environment is refracted into normative space of functionally useful norms. It deforms environment through schematization and is certainly not able to engulf it. Since time is constructed as a result of interpretations it is generated as and through a simulation of the environment. Simulation is a construction of resemblances, imitations which in some aspects can correspond to the original. At the same time, order can be established only as a result of the reduction of environment (or more precisely as a result of simulation of its dynamics — see Sect. 3.2.2). This reduction extends only in one direction — from an observer towards his environment, and exists only for the observer. Therefore, as Delez [5] said; "observer can't see duration; he can see duration only through external distinctions, making discontinuity cuts." And seriation of these cuts generates, what we call, time flow.

3 Time and Its Manipulations

Representation of time flow through specific functional wholes merged into gauges, seems to be a universal trend. In different human cultures and for different purposes most frequent gauges are periods of similar or monotonous activities, as, for example, seasons or periods of days [6]. Non-cognitive autopoietic systems certainly do not have a possibility to form any kind of abstract chronology, but are able to perform rudimentary operations of comparison and, based on that, to use (in a similar manner) specific functional wholes as time gauges which are further used in control and regulation of proceses. Before I proceed with the analysis of time manipulations in systems I'd like to briefly introduce a few important facts about the processes in general.

In spite of their representations in classical mathematics and physics as idealized equations, functional processes are always irreversible and dispersed into fields of possibilities. However, in isolated processes, outside a system, those fields have narrowly defined temporal seriation where transformation of the preceding into the subsequent event has only a few degrees of freedom. Therefore a field of possible variations of final states is existable but greatly suppressed. If that is so without many problems, we can qualify isolated fragments of processes as irreversible reductions towards a determined state (in an ideal case) or a group of very similar states. However, in systems, that kind of almost indispensable flow enclosed into rigid structure is no longer a primary way of achieving functionality. It is here possible to perform different arrangements of irreversible sequences which lead to gradual relativisation of processual indispensability with every superposed level of construction of functionality. This gradualism is possible because on each superposed level, relativities of the previous steps are taken as a basis for further construction. Therefore, individual events are no longer necessary premises needed to continue the line of transformations (which is the case with isolated processes), but they decline on a hierarchical level and become "one of" possible ways in realization of functionality. In this way, temporal architecture, where the presently actual is transformed into the indispensable future, is no longer valid within systems, which means freeing the intra-systemic time from its monotonous, one-way flow.

3.1 Formation of intra-systemic time flow

On the grounds of relativisation of necessities, the system can construct anticipatory structures (they can also be called functional structures, but the term "anticipatory" is, at the moment, more appropriate because here we talk about temporality and not about some eternal, pure formal structures) which in one available now (or more precisely — in perceptively constructed present) choose indicators that are in correlation with changes in the future, associate them with adequate systems of transformations and in that way prepare themselves for the following events. But, in a dynamical structure, it is not only important to accomplish some function; equally important is temporal compatibility with other, parallel processes. And only a combination of these two factors (possibility of anticipation and regulation by anticipation) can create a basis for the construction of autonomous, systemic time flow, which is partially independent of environment and is liable to systemic manipulations. A prerequisite for that is to relieve systemic time from: (i) external causations, (ii) direct pressure of outer time, and (iii) necessity of unilateral flow.

Relieving systemic time from external causations does not mean its independence of environment. It means that inter-systemic time responds to outer changes, regardless of their cause. Therefore, a system does not need to process anything beyond the available signals, thus economizing with time, organization and material resources. On a level of systemic complexity, schematic responses are created to encircle a wide spectrum of environmental constellations, thus reducing the number of necessary functional units to construction of limited amount of external receptors. At the same time, the lack of processing of background causations results in a certain amount of free time which is rerouted to internal construction of anticipatory systems.

If a system reacted to environmental events at the time of their occurrence, it would be incapable of developing functional processes, and would be reduced to a collection of physical and chemical causations. Only prediction and delay of response provide room for development of its own strategies [7]. The insertion of such time periods is realized in its full length only within a framework of constructed anticipative structures. Here, the increased functional complexity and insertion of inter-processes breaks down direct input-output connection and inserts a waiting period within which is possible to further develop functional strategies. As a side effect, distribution of time in systems became unequal, since in some operations waiting period cannot be long, while others are relieved of time pressure and therefore more susceptible to systemic manipulations.

The third specified prerequisite (relieving a system of unilateral flow necessity) can be acquired only through separation of systemic time from the totality of outer changes which impose unilateral time flow perspective. When such isolation occurs (not only to a system as a whole, but to subsystemic interrelations as well) certain irreversible processual segments can be placed into different contexts, where rearrangements are not burdened with necessities of irreversible reductions. In such a situation during interactions, a field of temporary mutually assigned times (intersubjective time) is formed and all further coordination is based on that. Subsystems mutually detect only certain intervals of changes which lead to a condition where (i) what is beyond the scope of perception does not exist and (ii) when there is no signal, there is no time. The construction of intersubjective time is a final step which enables time manipulations because processual time is realized through partial absolutisms of mutual assignment of time with space of free activity (which is invisible for "other") among them. As an illustration we can imagine a hypothetic interaction of only two elements A and B. A is capable of registering changes in B only through changes of a certain parameter Xb with 50UC (unit of change) range, while "actual" changes of Xb have range of 1UC. At the same time changes of Xb are the result of intra-systemic interactions between processes Yb, Zb, Wb. These processes can also have their own structure (Yb2, Zb2, Wb2), which can ideally continue ad infinitum, but will be disregarded for the sake of simplicity. We can assume similar situation in A (Xa, Ya, Za, Wa). Let B follow Xa in intervals of 100UC; and, at the same time Xa is changed simultaneously with registered changes of Xb in a function with basis 2 (it activates after every 2nd registered change). When Xa is activated, it affects changes in some other parameter of B, let's say Qb. We could continue to complicate the model, but let's stop here. Apparently, both A and B in certain aspects have their own independent time flows. Even so, a field of intersubjective time is formed, where every element interprets another through its own perception which leads to formation of new temporal field which cannot be reduced to any of the participants. In other words, during the interaction, participants attribute time to each other and a pattern of mutual influence rises as a consequence of that attribution. Therefore during interactions there is a constant process of changing each other's time, according to "own" times. However, in order to accomplish functionality, that game of mutual attributions cannot be arbitrary, beyond any constraints. On the contrary, it is necessary that all interacting elements share the same normative rules because simultaneity of interactions cannot be materialized in the case where we have two distinct times without any connections.The construction of intersubjective time field can make illusion of penetration into others, but this is only a localized phenomenon, valid only for the interacting elements or, expressed in terms of modal logic: valid only in the world constructed by these elements.

3.2 Systemic manipulations with time

As we have seen in the previous paragraphs, time is a perceptive construction, where only some aspects of reality are perceived and transformed into chronology. Therefore it should be clear that that construct is readily available for further manipulations. There are two fundamentally different classes of time manipulations in autopoietic systems: (i) regulation of duration and (ii) direct functional manipulations of time. In the first class the system deals with cycles of decomposition and re-construction of elements. The second class involves manipulations based on intrinsic consequences of perceptivity.

3.2.1 The temporalization of elements

The fact that in autopoietic systems almost every element is subject to decomposition and re-construction can look like a simple, notorious fact. But until recently it was almost completely omitted in issues regarding systemic functionality. As a result, in models of different systems and their internal regulations, functional elements have been considered as some eternal, meta-temporal entities. Only recently, in theory of autopoiesis [8] has that problem been brought into focus. Since in autopoietic theory it became clear that identification of elements is crucially dependent on contextual interactions, it becomes obvious that systemic elements should be in constant self-reproduction in order to achieve adequate (and necessary) level of functionality. However, this is not a tautological circle of meaningless and therefore timeless reproductions, but here we face the cycles of reflexive re-productions.

For the sake of clarity, let me go, for a moment, to the problem of production and re-production. According to Waldenfels [9] neither production nor reproduction can be considered as a pair of absolutely polarized concepts. Reproductive operations can be realized only through available dispositions. However, there is no pure reproductive operation and vice versa; there is no absolutely productive operation. Pure reproduction can only be seen in ideal models (or with some aproximations in mechanical processes) and pure production should imply production of its own prerequisites which would be punctual creation from nothing. Inovations are processes of remaking and distorting existing formations. The main point here is the appearance of variations whose source is in given formations but (additionally) they also should deviate it. Here, we should bear in mind that a deviation is not only a change toward greater or lesser efficiency, but deviation can also lead to transformation into some other framework. "Changes within system are not simple changes of horizon, but they are also initiators of systemic conflicts where boundaries are relocated, focuses are displaced and solid forms are eroded" [9]. Therefore, temporalized reproduction does not mean mere iteration, but it is reflexive production; production based on one's own needs, which are constantly surveyed, and constantly changed. Re-productive changes arise as a constant process of multi-dimensional self-modulation of instructions.

After this short survey, we can go back to analysis of the temporality of elements. The first obvious problem which the system should surpass, when dealing with ephemerality of its elements, is preservation of functionality. In order to achieve this, systemic cycles of re-production must not perturb the permanence of metabolical processes (in organisms, or in any other functional processes when speaking about autopoietic systems in general). Therefore, is it reasonable to stipulate the existence of some elementary functional units which cannot be further divided. If we focus our attention on analyzing the wholeness of internal systemic transformations and its functional subsystems, it will be impossible to find such functional atoms, since its importance (and possibility of regarding them as essential) is always contextually dependent. However, if we leave behind space of formalized relations and go down to the level of concrete, material transformations, then we can clearly see emergence of such functional atoms. In organisms, every single step in the processes of metabolic transformations is performed by enzymes. Therefore it is not possible to cut or divide them into independent phases; single enzymatic transformation is an inherently irreversible process — atom of functionality. Only through that enclosure of single occurrences into a web of functionally meaningful events, it becomes possible for systems to base their functionality on recursive, reflexive re-production of elements. This is possible because raising of elementary events up from the level of discrete, meaningless occurrences on to the level of finished processes, makes grounds for a situation where any kind of interruption or rearrangement cannot violate fundamentality of irreversible functional atoms. Without that kind of organization, introducing temporalization of constitutive elements into systems would be destructive for them. Even after this brief introduction we can make a clear distinction between the presented concept and the classical theory of complex, dynamical systems. That theory deals with permanent and independently definable elements (and that assumption is not taken as an auxiliary tool for analysis of some functional aspects of organisms, but it is granted as paradigm of their organization) which only as an oversimplified analogy can have some connections with real situation. It is reasonable to use cybernetic models as a background for the analysis of processual fragments. In that case the analysis deals with elements whose duration exceeds the duration of the whole process. However, this is only a naive sketch of living systems. In order to take a further step forward, we should change the paradigm and establish a continuous instability of mere elements (since in contemporary systemic analysis only processes are considered instable and changeable) where manipulations with elements' duration constitute three fundamentally new types for achieving functionality: (i) decomposition of processual segments, (ii) destruction of causal chains, and (iii) enforcement on constant self-adaptation.

The constitutive elements of living systems are quite flexible; they are complex and contextually transformable enough to incorporate flexible variations into functional architecture. However, that level of organizational flexibility alone is not enough to provide survival in highly variable environments (such as any ecological niche). Without temporalization of elements, establishing higher levels of organizational structure would be gradually and rapidly hindered with every next level of structural superposition because interactions and, even more important, contextual interdependence of identities would take place between persistent elements which would form encircled and ultimately tautological structure. In that case, functional superpositions (which are inherently based on previous levels, and the first level is always material) would deal with insurmountable constraints such as: the number of elements, rigidity of their functional arrangements, and rigidity of their causal networks, which altogether form rigorous network of functional processes. Now it should be clear why the temporalization of elements is so important. It breaks down gradual accumulation of obstacles by physical elimination of processual segments, hence compelling them to constant re-construction and in organizational structure making available space for different insertions, divergences and reroutings. Without that, for every modification of existent functional processes (in form of insertion of additional phases or rerouting of inter-phases into other subsystems) additional specific regulators should be introduced as reorganizers which would demand enormous additional resources.

Besides alleviation of functional superpositions, cyclical re-composition of elements also destructs causal chains and it is another important difference with regard to a classical cybernetic paradigm where eternal elements constitute processes which are entirely causally enclosed. Here we have a completely different situation; through the temporalization, the system purposefully eliminates groups of elements concordantly eliminating them from the possibility of direct re-actions (regarding other elements, subsystems, *etc.*). Thus, the primacy of successive stepwise regulation is greatly diminished and the structure itself becomes a major determinant in the regulation of re-productive periodicity. Also, it should be greatly emphasized that through its ability to cut causal chains into momentarily adequate segments, the system distances itself from causal pressure of environment, and uses its own past as its own causal basis [7]. In that manner the internal structure of a system perpetually re-constitutes a causal basis for its own processes and the past is not a mere, fixed set of preceding events which linearly vanished, but it is dynamic (fluid) accumulation where, according to its relevancy to the current state (and that relevancy is constantly updated with causal reconstitution), some elements and structures can be summoned while others disappear without any further functional influences.

Finally, the temporalization forces a system to be constantly self-adapted. Every subsystem has different dynamics of degradation and accordingly, with each cycle of re-constitution, the structure and organization of certain subsystems have been adapted to (internal) environment. Here, we do not deal with some specifically constructed process of self-adaptation; on the contrary, it is an innate consequence of the fact that the construction of elements itself (in autopoietic systems) is not some kind of ideal, serial manufacturing indifferent to external variations but it constantly "listens" to external changes, and makes slight, but sometimes very important differences in outputs. In other words, through temporalization the system is forced to be not self-adapted but in self-adaptation, because material realizations based on previous informational context are constantly decomposed and in order to maintain functionality it has to incessantly deal with informational flow.

3.2.2 Manipulation through simulation

As it was already mentioned, perceptivity is inherently segmented and therefore there is always something "outer" — invisible and nonexistent for a perceptive entity. Consequently, a vast amount of intra-systemic activities remain unregistered by "other" (functional) subsystems and stay enclosed in their own "world" with their own rules and dynamics undisturbed by external supervisions. That state of affairs is an excellent basis for the construction of a wide spectrum of simulation based manipulations (defined here as a simulacrum): "world" of interactions is limited only to a narrow space of boundary zones and their actualization is ultimately dependent on a reciprocial representations of subsystems. What is excluded from a simulation is simply non-existent for other subsystems. They can register only momentary, discrete regions of interactions. Within them, subsystems simulate regularities for each other: identities, cyclicity, reversibility,. . . ; and on that basis they create an interlaced structure of mutual illusions (the simulacrum) with enormous functional importance. Essential parts of the simulacrum are time manipulations. It should be emphasized that the internal structure of any functional simulation is composed as a fusion of several "elementary" parts; for example time manipulations are based on three pillars: perceptive simulation of identity, contextual simulation of conditions and temporal simulation of alterations. Formation of perceptive absolutes (which is a basis for simulations of identities and conditions) has been briefly introduced at the beginning of this paper. The third category — simulated flow of alterations — instantaneously emerges when we pass from the analysis of frozen, timeless systems to real, dynamic ones. Here, "simulations" do not mean that there are no alterations at all. However, unbroken, objective flow is materialized as continuous preservation of self-identity of elements, irrespective of the extent of alterations. Only after a disruption of that continuity (as an inherent consequence of perceptivity), alteration of precedent is not only and exclusively a variation of the same, but it can appear as a new, qualitatively new entity. Based on this the system generates different distribution of times in itself. Registering changes as faster or slower is the least connected with objective iterations in duration. What really generates the character of time flow are perceptive patterns, i.e. a pattern of distribution of boundaries among different perceptive absolutes. That distribution can be homogenous — which generates an illusion of total deceleration or acceleration of external changes (time); on the other hand, boundaries can be in-homogeneously arranged, thus generating acceleration/deceleration of time, depending on functional context. Thereby, distribution of time is performed in accordance with systemic needs, as well as with external pressures which are not submissive to systemic manipulations.

This is only valid when alterations exceed perceptive thresholds — if it is not the case, entities are registered as an unchanged unity. However if that unity appears in different intervals, separated by periods of some other action, then all the prerequisites for simulations of reversibility and cyclicity are acquired. On effective level, these two phenomena (reversibility and cyclicity) are very close to each other and their difference comes only through a pattern of perception. If the separation of intervals is performed by "other" subsystem, an observer perceives them only as an iteration of input. We should not forget that iteration is a result of a real or spurious reversion to an initial condition — in that way, iterations insert loops into an observer's structure of time. However, for "other" subsystem itself, these actions are certainly not mere iterations. They are processes which capture its time flow into self-enclosed structure. Since they are not able to perform self-reflection, and accordingly that limits of any formal system cannot be seen from within the system (but only from the perspective of an observer), that enclosedness of time for a subsystem practically means its involvement into infinite, purposeless time flow. On this example it can be clearly seen that diversity of time and manipulations with it are strictly systemic categories, which can be realized only through the existence of fundamentally different perspectives enclosed into structure of mutual ascriptions and impositions. From a perspective of every subsystem, its own time is infinite, linear and purposeless; for intrasystemic, functionally incorporated observers, time of the others is in a form of loops, which presents one of determinants for its own dynamics; and finally, cyclicity occurs only on a semi-material organizational level. But on that level we cannot talk about the perception of cyclicity, since there is no material perception of cycles as such. It is rather a functional result of coordination of different dynamics of processual segments.

Acknowledgements

I warmly thank Marija Bukurov for her valuable linguistic comments on the manuscript and Branislava Šušić for illuminating discussions.

References

1. St. Augustine, *Confessions & Enchiridion*, a digitized electronic edition, translated and edited by A.C. Outler (1993), http://www.ccel.org/a/augustine/confessions/confessions.html.
2. Piaget, J. (1973) *Introduction a l'Epistemologie Genetique. 2) La Pense Physique*, Serbian translation by D. Janjic, Izdavacka Knjizarnica Zorana Stojanovica, Novi Sad.
3. Merleau-Ponty, M. (1945) *Phenomenologie de la Perception*, Serbian translation by A. Habazin, Veselin Maslesa, Sarajevo.
4. Husserl, E. (1928) *Vorlesungen zur Phanomenologie des inneren Zeitbewußtseins*, Serbian translation by C.D. Koprivica, Izdavacka Knjizarnica Zorana Stojanovica, Novi Sad.
5. Deleuze, G. (1991)*Bergsonism*, Zone Books, New York.
6. Whitrow, G.J. (1988) *Time in History: The Evolution of Our General Awareness of Time and Temporal Perspective*, Oxford University Press, New York.
7. Luhmann, N. (1999) *Soziale Systeme. Grundrißeiner allgemeinen Theorie*, Serbian translation by L. Topic, Izdavacka Knjizarnica Zorana Stojanovica, Novi Sad.
8. Zeleny, M. (ed.) (1981) *Autopoiesis: A Theory of Living Organization*, Elsevier North-Holland, New York.
9. Waldenfels, B. (1985) *In den Netzen der Lebenswert*, Serbian translation by J. Vlaisavljevic, Veselin Maslesa, Sarajevo.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 57–72

OPEN LIMIT: A WHOLENESS WITH VAGUENESS DRIVING VER-HANDLUNG

YUKIO-PEGIO GUNJI[a]
Department of Earth & Planetary Sciences, Faculty of Science, Kobe University
Nada, Kobe 657-8501, Japan
(yukio@kobe-u.ac.jp)

TAICHI HARUNA, TOMOHIRO SHIRAKAWA and KOHEI SONODA
Graduate School of Science & Technology, Kobe University
Nada, Kobe 657-8501, Japan
(e-mail)

Abstract: Measurement, cognition and understanding can be regarded as gluing parts by using of the notion of wholeness, and forgetting a limit called de-measurement leads to dissolution. Although measurement and de-measurement is convertible if the wholeness is expressed as a limit, they give rise to negotiation between parts and whole in a real world since wholeness has vagueness. We introduce a particular limit that has vagueness, call it open limit, and show that an open limit plays an essential role in making intrinsic development, by illustrating physarum mold pattern formation.

Keywords: Endo-physics – Lattice – Ver-handlung

1 Introduction

Any concept is expressed as a pair of intent and extent [1,2]. If we generalize such a notion, an object is expressed as a pair of generalized intent and extent. The next question arises what is the relationship between intent and extent. If there is neither possibility of translation nor transformation, one has to accept both two perspectives as basic ones to reveal an object. That is nothing but a dualism illustrated by mind and body. If there is a translation or transformation, intent and extent can be converged into a monism. Whether one admits a dualism or monism, it is assumed that an object is described as the self-consistent one in terms of a pair of intent and extent.

[a]Also at Graduate School of Science & Technology, Kobe University.

Self-consistency of an object reveals that the object is separated from the world, since it does not matter the rest of the world. By contrast, if one thinks an object within the world [3,4], he has to pay attention to the relationship between a pair of intent and extent and the rest of the world. How is the interface between the pair and the rest of world described? We think that inconsistency inherited in the pair or between intent and extent is one of the most hopeful candidates. Inconsistency can be conventionally expressed as self-reference logically entailing to a contradiction. We, therefore, think that logical self-reference is too strong to describe inconsistency, and that the notion of self-reference conventionally arises from too metaphysical self-consistent description. In a real world, the premise of self-reference is invalidated, and it provides dynamical inconsistency [5–8]. In this sense, we propose a model for being within a world as a pair of intent and extent featuring inconsistency in the form of invalidated self-reference.

Especially, a pair of intent and extent is taken as a pair of the perspectives; the one called Interpretation-A, consists of separated parts, and the other called Interpretation-B consists of integrated parts via a limit. From Int-A to B, there is an operation of adding a limit by which parts are glued, and from Int-B to A, a limit is forgotten. In this paper, we first formalize such a scheme without inconsistency, and then modify it by replacing a limit with open-limit. Introduction of an open limit can provide inconsistency and openness in the model, and we show that it can provide a model for an object within a world.

2 Consciousness, Self-Reference and Weak Adjunction

If one focuses on the notion of consciousness, autonomy and/or self-organization, one has to pay attention to the form of self-reference. Conventionally self-reference is destined to reveal a contradiction, and Lawvere showed that self-contradiction including Gödel's theorem of incompleteness results from the self-referential property in terms of category theory [9]. Although researchers concerning about self-organization and/or autonomy often attempts to resolve a contradiction resulting from self-referential property, we think that logical self-reference is too metaphysical and that the contradiction does not matter to real self-organization. Intuitively, self-reference contains dual indication for a part and whole, and that entails to a contradiction. Definite indicating a whole is, however impossible, and that is entitled by the frame problem. In this sense, the frame problem in a real world can invalidate the premise of self-reference [10]. Such an invalidated self-reference can be used for the model of self-organization. So as to invalidate the premise of self-reference we first investigate the self-referential property.

Let us consider Cantor's diagonal argument. The question whether an infinite set X is smaller than its power set is considered. Since the power set is a collection of all subsets, it is expressed as a set $2^X = \{f : X \to 2\}$ where $2 = \{0, 1\}$. Given a subset A of X, if x in X is an element of A $f(x) = 1$; otherwise $f(x) = 0$, and then 2^X is isomorphic to the power set. One can define $\mathrm{ev} : X \times 2^X \to 2$ such that $\mathrm{ev}(x, f) = f(x)$. If there is $g : X \to 2^X$, $\mathrm{id} \times g : X \times X \to X \times 2^X$ is also defined such that $\mathrm{id} \times g(x, y) = (x, g(y))$, where id is an identity map. Given a map $w : X \times X \to 2$, there uniquely exists $w^{"} : X \to 2^X$ such that $w = \mathrm{ev}(\mathrm{id} \times w^{"})$. Choose a one map corresponding to a subset, $f^{'}$ in 2^X. One can obtain $f : X \times X \to 2$ satisfying $f(x, x) = f^{'}(x)$. It results in that for all x in X, $f(x, x) = \mathrm{ev}(\mathrm{id} \times f^{"})(x, x) = f^{"}(x)(x) = f^{'}(x)$, since $f^{"} : X \to 2^X$ satisfies that $f = \mathrm{ev}(\mathrm{id} \times f^{"})$. So as to verify that an infinite set X is smaller than its power set, assume that the power set is equal to X with respect to cardinality. It leads that $f^{"} : X \to 2^X$ is surjective, and that is called self-referential property. Then, there exists z in X such that $f^{'}(z) = hf^{'}$ even for $h : 2 \to 2$ with $h(0) = 1, h(1) = 0$. One obtains that $f^{"}(z)(x) = hf^{'}(x) = hf(x, x) = hf^{"}(x)(x)$. In Substituting z for x, one obtains a fixed point with respect to h, such that $f^{"}(z)(z) = h(f^{"}(z)(z))$, and that is a contradiction.

In this proof sequence, essential premise of contradiction due to the self-referential property is unique correspondence between $f^{"} : X \to 2^X$ and $f : X \times X \to 2$, and that is expressed by

$$\mathrm{Hom}(X \times X, 2) \simeq \mathrm{Hom}(X, 2^X), \tag{1}$$

called adjunction in terms of category theory, where $\mathrm{Hom}(S, P)$ represents a set of maps from S to P [11, 12]. Adjunction consists of a pair of functors such as $(-)^X$ and $X \times (-)$, that maps both sets and maps. For any set Y, each functor assigns Y^X and $X \times Y$, respectively. For any map $p : Y \to Y^{'}$ $X \times (-)$ assigns $\mathrm{id} \times p : X \times Y \to X \times Y^{'}$, and $(-)^X$ assigns $p^X : Y^X \to {Y^{'}}^X$ that maps $s : X \to Y$ to a map $ps : X \to Y^{'}$. It is easy to verify that these functors preserve identity and composition of maps. If those operations do not preserve composition (i.e., not satisfying the condition of a functor), one cannot designate a map since for any p, $p^X \neq \mathrm{id}p^X$, and $w \neq \mathrm{ev}(\mathrm{id} \times w^{"})$. It never leads to a fixed point [6].

The premise for a fixed point is an adjunction consisting of functors. If a functor is replaced by a "pre-functor" that do not preserve the composition, even self-reference never leads to a contradiction. Such an idea can be extended to a general framework. Generalize $(-)^X$ and $X\times(-)$ by functors, G and F, and sets X and 2 by mathematical structures, S and $S^{'}$, and the adjunction is expressed as $\mathrm{Hom}(FS, S^{'}) \simeq \mathrm{Hom}(S, GS^{'})$. The left-hand and right-hand sets represent the perspective with respect to generalized extent and intent, respectively. Imagine a pair of extent and intent in a set theory. For even numbers, extent is a collection of $0, 2, 4, \cdots$ and intent is $2n$, and they are uniquely correspondent to each other. A pair of perspectives, intent and extent constitutes one consistent concept, and that is what adjunction implies. If adjunction holds, two distinct perspectives called categories are isomorphic to each other in the form of (1). Therefore one can address the one of a pair of perspectives and can ignore the other (e.g., in logic syntax or axiomatic structure is mainly addressed and semantics is not). In this sense we call the one of Hom-sets generalized intent and the other generalized extent. By contrast, two categories are not isomorphic to each other in a real world, as if two categories are interconnected by pre-functors [6,7]. Under that framework, self-reference never entails to a contradiction, but leads to negotiation between two categories.[a] It is the perpetual negotiation resulting from invalidated self-reference that is a formal expression for an object within a world.

3 Measurement and De-Measurement in a Formal World and Beyond

In starting from $\mathrm{Hom}(FS, S^{'}) \simeq \mathrm{Hom}(S, GS^{'})$, replace a pair of functors by one of pre-functors, and construct an invalidated self-reference [6,7]. In this paper, we starts from a particular adjunction,

$$\mathcal{P}ar(P, UL) \simeq \mathcal{L}at(TP, L), \tag{2}$$

where P called an object of $\mathcal{P}ar$ is a finite partially ordered set, L called an object of $\mathcal{L}at$ is a finite lattice, $\mathcal{P}ar(P, P^{'})$ is a set of order-preserving maps, $\mathcal{L}at(L, L^{'})$ is a set of lattice morphisms, and a pair of T and U is a pair of adjunctive functors. We think that such an adjunction is one of abstract expressions to reveal ideal measurement process. In the one perspective $\mathcal{P}ar$, a mathematical structure is a partially ordered set that only implies local ordering. A set consists of some parts of ordered sets while there

[a]Concerning negotiation of this kind, we discussed with Dr. Hans Dibner. He kindly suggested that in adopting Heidegger's way of using the German language, we may translate our notion of negotiation to "Ver-handlung". This emphasizes acting between complementary poles.

cannot be any limit (or co-limit) that is lower (or greater, respectively) than any element of parts. By contrast, in the other perspective $\mathcal{L}at(L, L^{'})$, mathematical structure is a lattice that is a special partially ordered set closed with respect to the least upper bound and the greatest lower bound, and that implies that there exist limit and co-limit for any pair of elements. In other words, L has wholeness, and P does not.

A vanishing point in a perspective drawing can provide an adequate example for the role of limit and two categories. Imagine tall and small figures in a perspective drawing. If one forgets a vanishing point, the difference on a size is regarded as the difference on a body size. There is no global property in a whole drawing, and a part (a figure) is independently separated from each other. By contrast, if one pays attention to a vanishing point, one can understand two figures under the law of perspective. There are two interpretations in that illustration. In the one interpretation, we call it Int-A, a drawing is divided into some independent parts, and in the other one, we call it Int-B, parts are glued by a vanishing point that is a limit. Adding a limit makes Int-A to be transformed into Int-B, and forgetting limit makes Int-B to be Int-A. Since measurement, recognition and/or understanding are grasping some parts as a whole, adding limit is a process of measurement in an abstract sense. Similarly we call the process of forgetting a limit is de-measurement process. Int-A and Int-B can correspond to a partially ordered set in $\mathcal{P}ar(P, P^{'})$, and to a lattice in $\mathcal{L}at(L, L^{'})$, respectively. Therefore, in adjunction $\mathcal{P}ar(P, UL) \simeq \mathcal{L}at(TP, L)$, a functor T represents a process of adding a limit (measurement) and U represents one of forgetting a limit (de-measurement), respectively.

We here consider the adjunction $\mathcal{P}ar(P, UL) \simeq \mathcal{L}at(TP, L)$ in detail. A partially ordered set P is defined by a set with binary relation such that reflective law ($a \geq a$), anti-symmetric law ($a \geq b, b \geq a \Rightarrow a = b$) and transitive law ($c \geq b, b \geq a \Rightarrow c \geq a$) holds for all a, b, c in P. Given $S \subset P$, upper bound, $S^u = \{z \in L | z \geq x, \forall x \in S\}$, lower bound, $S^l = \{z \in P | x \geq z, \forall x \in S\}$. Given $S = \{x, y\}$, $x \wedge y$ is defined by the least upper bound, and $x \vee y$ is defined by the greatest lower bound for S. A lattice L is defined by a partially ordered set closed with respect to binary operation $\wedge$ and $\vee$. It means that for all x, y in a partially ordered set L, $x \wedge y$ and $x \vee y$ are also in L [13]. Especially, we here consider a subset of the power set of X, $\mathfrak{P}(X)$, given a finite set X, and denote the subset of $\mathfrak{P}(X)$ by P, that is a partial ordered set with respect to inclusion relation. So as to define a pair of functors, T and U, we introduce the notion of upset. Given $P \subset \mathfrak{P}(X)$, we define $\mathcal{O}(P) = \{\bigcup_{p \in S} \uparrow p | S \subset P\}$, where an upset is defined such that $\uparrow p = \{q \in P | p \subset q\}$. A functor T from $\mathcal{P}ar$ to $\mathcal{L}at$ is defined as a transformation for each object of $\mathcal{P}ar$ and for each order-preserving map. For an object, P,

$$T(P) = \mathrm{Im}(C_P), \tag{3}$$

that is an image of C_P, where $C_P : \mathfrak{P}(X) \to \mathfrak{P}(X)$ is defined by; for $p \subset X$, $C_P(p) = \bigcap \uparrow p = \bigcap\{q \in P | p \subset q\}$. Since C_P satisfies that for all $p, r \subset X$, (i) $p \subset C_P(p)$, (ii) $p \subset r \Rightarrow C_P(p) \subset C_P(r)$, and (iii) $C_P(C_P(p)) \subset C_P(p)$, it is called a closure operator [13]. We here define $g : \mathcal{O}(P) \to \mathrm{Im}(C_P)$ by; for $\bigcup \uparrow p \in \mathcal{O}(P)$, $g(\bigcup \uparrow p) = \bigcap(\bigcup \uparrow p)$, and it is easy to verify that $\mathrm{Im}(C_P) = g(\mathcal{O}(P))$. For each order-preserving map, $\varphi : Q \to P$, we define $\varphi^{-1} : \mathcal{O}(P) \to \mathcal{O}(Q)$ by; for $x = \bigcup \uparrow p \in \mathcal{O}(P)$, $\varphi^{-1}(x) = \{y \in \mathcal{O}(Q) | \varphi(y) = x\}$, and it is easy to see that φ^{-1} is a lattice homomorphism such that $\varphi^{-1}(x_1 * x_2) = \varphi^{-1}(x_1) * \varphi^{-1}(x_2)$ with $* = \bigcup$ and $\bigcap$. Finally we define $T(\varphi) : \mathrm{Im}(C_P) \to \mathrm{Im}(C_Q)$ such that for each $a \in \mathrm{Im}(C_P)$,

$$T(\varphi)(a) = g\varphi^{-1}(\uparrow a). \tag{4}$$

As a result, $T(\varphi)$ is also a lattice homomorphism preserve composition and identity, and then T is a functor. By contrast, we define $U : \mathcal{L}at \to \mathcal{P}ar$ as a forgetful functor such that for $L, U(L) = L$, and for $f \in \mathcal{L}at(TP, L), U(f) = f$. Since a lattice is a partially ordered set and a lattice homomorphism is an order-preserving map, U maps them into an underlying set and map. Finally, it can be verified that adjunction $\mathcal{P}ar(P, UL) \simeq \mathcal{L}at(TP, L)$.

As mentioned before, adjunction is too metaphysical and too ideal. In an object of $\mathcal{P}ar$, parts are separated and ordering holds only locally. If one applies T to a partially ordered set, one obtains a lattice, and in a lattice $T(P)$ local ordering parts are glued as a whole. If one forgets the notion of wholeness and applies T again, one obtains that $TUT(P) = TT(P) = T(P)$. It means that $T(P)$ is a fixed point with respect to T, and that never reveals dynamical motion, development or evolution. If a fixed point such that $TT(P) = T(P)$ holds, self-referential property entails to a contradiction. Therefore in the case of the relationship between $\mathcal{P}ar(P, UL)$ and $\mathcal{L}at(TP, L)$, invalidating self-reference can be replaced by no fixed point with respect to the transformation from $\mathcal{P}ar$ to $\mathcal{L}at$. The next question arises why in a real world, recognition and measurement are not stable but robust in keeping structural change and can be developed. Our answer is that a real-world wholeness is not an ideal perfect limit but an imperfect open limit, and that yields to perpetual negotiation between $\mathcal{P}ar$ and $\mathcal{L}at$.

Imagine a partitioned image of Mt. Fuji that corresponds to Int-A (Fig. 1 top left). Gluing them makes a reconstruction of Mt. Fuji corresponding to Int-B, where gluing is finding a continuous curve revealing the edge of Mt. Fuji, and such a curve reveals a wholeness (Fig. 1 top right). A curve revealing wholeness is assumed to be an ideal one and has no thickness, whereas a curve that we can recognize results from the integration of ideal thing and material, and has finite thickness. It sounds as if an ideal curve was illustrated by a real curve with finite thickness on a paper. If one pays attention to the origin of an ideal curve, the question arises why one can imagine an ideal curve at first. What one already recognized a real curve in a real world partly yields an answer, whereas the origin of recognition of a curve also contains imagining an ideal curve. It results in the notion of a curve contains both ideal thing and material coexisting, and that ambiguity provides the vagueness of wholeness we call open limit. Therefore, in a real world, incomplete parts corresponding to Int-A can be glued by a curve with finite thickness that provides an adequate example of the vagueness carrying ambiguity of ideal thing and material. Since a curve has finite thickness or area, one can make a fine drawing on a thick curve, and that can make the image of a particular volcano corresponding to Int-B (Fig. 1 below). The emergent image appeared in Int-B can be also articulated into imperfect parts, since in a thick curve discontinuity can be also drawn. It implies that even an emergent image of volcano can be collapsed and be articulated into imperfect parts. It results in perpetual negotiation between Int-A and Int-B, and that dynamical motion, Ver-handlung, provides being resulting from inconsistent measurement and de-measurement.

A thick curve is a metaphor of an imperfect open limit, and is employed both as wholeness and as the trigger entailing to the imperfect parts. In recalling $\mathcal{P}ar$ and $\mathcal{L}at$, the former corresponds to the imperfect parts and the latter corresponds to the image with wholeness. In such an analogy, the operations T and U have to be abandoned since they are so strong that they can constitute the adjunction. Then our purpose is to construct weaken pre-functor instead of T and U, so as to invalidate the adjunction and to reveal dynamical negotiation or Ver-handlung between Int-A and Int-B.

4 Proto-Closure and Over-Forgetful Operation

As a model for a pair of Int-A and Int-B, a pair of $\mathcal{P}ar$ and $\mathcal{L}at$ is taken also in this section, whereas it is to be modified. In the adjunction, $\mathcal{P}ar(P, UL) \simeq \mathcal{L}at(TP, L)$, $T(P)$ is defined by using the closure operator, $C_P : \mathfrak{P}(X) \rightarrow$

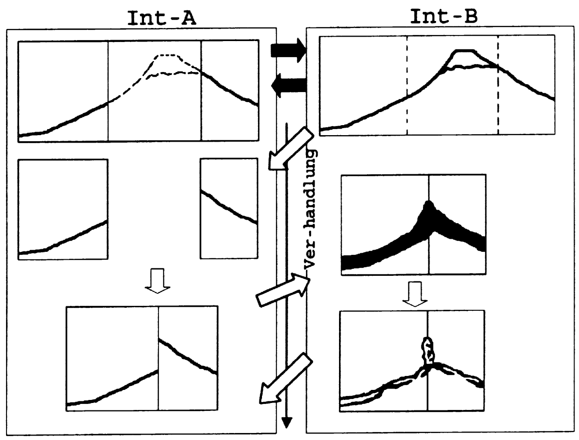


Figure 1. Ideal measurement from Int A to B and ideal de-measurement from Int-B to A are represented by solid thick arrows. By contrast, real measurement and de-measurement featuring a thick curve are represented by blank arrows.

$\mathfrak{P}(X)$, that reveals the process of adding a limit. So as to weaken the closure operator, we first investigate why closure operator glues some parts. Given $X = \{a, b\}$, imagine $P = \{\{a\}, \{b\}\}$ that is a partial ordered set. Since $\{a\} \cap \{b\}$ and $\{a\} \cup \{b\}$ are not in P, it is not a lattice. Here $C_P(\emptyset) = \bigcap\{\{a\}, \{b\}\} = \emptyset$, $C_P(\{a\}) = \{a\}$, $C_P(\{b\}) = \{b\}$, and $C_P(\{a, b\}) = \bigcap \emptyset = \{a, b\}$. As a result, $\mathrm{Im}(C_P)$ is obtained as a lattice, $\{\emptyset, \{a\}, \{b\}, \{a, b\}\}$. Why an element such as $\emptyset$ and $\{a, b\}$ employed for a limit can be added to P? Since $\bigcap$ in the closure operator is taken in the power set, $\mathfrak{P}(X)$, such elements can be obtained. In other words, the closure operator has a complete knowledge for a whole world $\mathfrak{P}(X)$.

Recall a thick curve as a metaphor of an imperfect open limit. In the ideal measurement process, it is assumed that an observer has complete knowledge of Mt. Fuji, and at that time he can compensate for the loss of some parts. By contrast, in real measurement process, he has no complete knowledge of Mt. Fuji, and then he has to introduce a thick curve. Analogously, in the transformation from $\mathcal{P}ar$ to $\mathcal{L}at$, instead of the closure operator based on the observer who has a complete knowledge on $\mathfrak{P}(X)$, we define a proto-closure based on the observer who has a limited knowledge with $K \subset \mathfrak{P}(X)$. A proto-closure $C_{P,K} : \mathfrak{P}(X) \to \mathfrak{P}(X)$ is defined by,

$$C_{P,K}(p) = \bigcap_K \{q \in P | p \subset q\}, \tag{5}$$

for all $p \subset X$, where $\bigcap_K$ is intersection in a K that is a subset of $\mathfrak{P}(X)$, and for $M \subset \mathfrak{P}(X)$,

$$\bigcap_K M = \bigcap M \quad \text{if } \bigcap M \text{ exists in } K;\ \downarrow \text{otherwise.} \tag{6}$$

It is also defined that $\bigcap \emptyset = \uparrow$. Note that $\downarrow$ is the virtual element that can be usually used as the least element. Actually, if $\bigcap_K M = \downarrow$, a real element corresponding to the virtual element is chosen from m in M^l such that there is no $m^{'}$ in M^l such that $m \subset m^{'}$. Analogously, $\bigcup_K M = \downarrow$, if $\bigcup M$ does not exist in K. In this definition, if an observer employed in proto-closure cannot find an adequate element, and i.e., the corresponding element is not contained in the knowledge of the observer, the virtual element is obtained. For most cases, $\downarrow$ can be regarded as the least element. For a particular case such that given $P = K = \{\{a\}, \{b\}, \{a, b, c\}, \{a, b, d\}\}$ with $X = \{a, b, c, d\}$, $C_{P,K}(\{a, b\}) = \bigcap_K \{\{a, b, c\}, \{a, b, d\}\} = \downarrow$, and we obtain that $\text{Im}(C_{P,K}) = \{\uparrow, \{a\}, \{b\}, \{a, b, c\}, \{a, b, d\}, \downarrow\}$. At that case, if $\downarrow = \emptyset$ and $\uparrow = X$, $\text{Im}(C_{P,K})$ is no longer a lattice. Since the virtual element $\uparrow$ has ambiguity, one can see that $\downarrow \subset \{a\}(\text{or}\{b\}) \subset \downarrow \subset \{a, b, c\}(\text{or}\{a, b, d\}) \subset \uparrow$. At that case, if one calculate the real element $\bigcap_K \{\{a, b, c\}, \{a, b, d\}\} = \downarrow$, it can be obtained either $\{a\}$ or $\{b\}$, and for $\bigcup_K \{\{a\}, \{b\}\} = \downarrow$, it can be obtained either $\{a, b, c\}$ or $\{a, b, d\}$. By contrast, $\uparrow$ is always used as the virtual greatest element. In a lattice theory, if there exists the greatest element, $\bigcap \emptyset$ coincides with the greatest element. We define the virtual greatest element whether the greatest element exists or not. Independent of confirmation of existence, the virtual greatest and least element are introduced. That is why it makes sense with respect to the notion of open limit. It is easy to see that $\text{Im}(C_{P,K})$ is a complete lattice. Finally, we define $T^{'}(P) = \text{Im}(C_{P,K})$ instead of a functor T. Both $\uparrow$ and $\downarrow$ are regarded as virtual elements, that can be calculated corresponding to the real element.

In the transformation $\mathcal{L}at$ to $\mathcal{P}ar$, we define over-forgetful operation, $U^{'}$, instead of U. Since both $\uparrow$ and $\downarrow$ are virtual elements, they can be arbitrary real element in $\mathcal{P}ar$ to some extent. Also in this case, we introduce an observer who has an incomplete knowledge. That process $m : \{\uparrow, \downarrow\} \rightarrow \mathfrak{P}(X)$ is defined by; $m(\uparrow) = q$ such that $\exists p \in L, p \subset q$, and $m(\downarrow) = r$ such that $\exists p \in L, r \subset p$. Due to that operation, we obtain that for an object of $\mathcal{L}at$, $U^{'}(L)$ is defined by

$$U^{'}(L) = (L - \{\uparrow, \downarrow\}) \cup \{m(\uparrow), m(\downarrow)\}. \tag{7}$$

Since $U^{'}(L)$ is not necessarily a lattice but a partially ordered set, it is called a over-forgetful operation.

For $\varphi : P \rightarrow P^{'}$ in $\mathcal{P}ar$ we define that $T^{'}(\varphi) = \varphi^{*}$ where $\varphi^{*}(x) = \varphi^{-1}(x)$ if $x \in \mathrm{Im}\varphi$ and otherwise, chosen randomly. $T^{'}(\varphi)$ is no longer a lattice homomorphism, however there exist x_1 and x_2 such that $T^{'}(\varphi)(x_1 * x_2) = T^{'}(\varphi)(x_1) * T^{'}(\varphi)(x_2)$ with $* = \bigcup$ and $\bigcap$, we call it partial lattice homomorphism. Similarly, we can define for a lattice homomorphism, f, a partial order-preserving map $U^{'}(f)$. From these definitions, adjunction no longer holds, and the premise of self-reference no longer holds. Especially, compared to a fixed point with respect to T, in $\mathcal{P}ar(P, UL) \simeq \mathcal{L}at(TP, L)$, there is no fixed point with respect to $T^{'}$. It leads to Ver-handlung, motion, development and evolution as being.

5 Physarum Mold Path Formation

So as to estimate the significance of open limit and proto-closure, we define a two-dimensional interactive system. We here investigate the physarum pattern formation and compared it with a simulated pattern. Slime mold physarum is a single celled giant amoeba, and feeds bacteria. In the biological experiment, physarum was cultivated on an agar medium, and the circular culture area was surrounded by plastic sheet to prevent slime's expanding. When three food sources and a physarum were located in the circular area, a physarum expanded and were distributed over the circular area and then it shrank into the final pattern such that food sources were connected through some tubes. Actually protoplasmic flows propagated between food sources through those tubes. The tube pattern looks as if it provided the minimum pattern with respect to the total length of tubes [14,15], while there are some varieties. The problem is how a physarum solves the problem that might require global information, through local interaction.

There can be several methods to construct a model to mimic a physarum tube pattern. If the tube is enforced by protoplasmic flow, the tube pattern can be developed through perpetual protoplasmic flow, and that mechanism is similar with that for the trail formation of ants, called active walker [16]. In the model of active walker, each ant secrets trail pheromone, and that constitutes temporal potential for walk. Although it is assumed that ants follow the potential in the model, real ants and/or bees perpetually make a decision whether it follows the potential or not [17,18]. It makes sense that the global information such as the potential or the distribution of pheromone is also vague and indefinite, and that can reveal the development of trail pattern. Analogously, we here concentrate on the vagueness of global property with respect to the physarum tube pattern by using a model based on proto-closure.

Global property of the physarum is here given by the distribution of possible tubes. It reveals the distribution of materials to form tubes. Possible tubes are locally computed, and that local computation is expressed by logical operation featured with proto-closure. Actual tubes are grown from the food source in choosing possible tubes, and can influence the distribution of possible tubes. Possible and actual tube generation can be compared to the context and the operational computation under the context, respectively. Two computations proceed in a parallel fashion and influences with each other.

Given a two dimensional space, at each site (i, j), we first explain the context computation or the computation of possible tubes. For an initial time step, and at each site (i, j), $P^0(i, j) \subset \mathfrak{P}(X) - \{\emptyset, X\}$ is given, where $X = \{a, b, c, d\}$, and each element of X corresponds to the direction, North (a), South (b), West (c) and East (d), respectively. The direction in which j decreases is North. At each step, $P^t(i, j)$ is compensated so as to construct a lattice due the local incomplete observer, $K^t(i, j)$ such that $K^t(i, j) = \bigcup_{i',j'} P^t(i', j')$, where i' is randomly chosen from $\{i-1, i+1\}$ and j' from $\{j-1, j+1\}$. As a result, the local knowledge to construct a lattice depends on the nearest neighbors, and the number of neighbors contributing to $K^t(i, j)$ is changed randomly from 1 to 4. The transition of $P^t(i, j)$ is expressed as $P^{t+1}(i, j) = (\mathrm{Im}C^t_{P,K}(i, j) - \{\uparrow, \downarrow\}) \cup \{m(\uparrow), m(\downarrow)\}$, where $\uparrow$ and $\downarrow$ are the virtual elements in $\mathrm{Im}C^t_{P,K}(i, j)$. Each proto-closure $C^t_{P,K}(i, j) : \mathfrak{P}(X) \to \mathfrak{P}(X)$ is expressed as; for p in $\mathfrak{P}(X)$, $C^t_{P,K}(i, j)(p) = \bigcap_K \{q \in P^t(i, j) | p \subset q\}$, where K is an abbreviation of $K^t(i, j)$. The possible tube between $P^t(i, j)$ and $P^t(i', j')$ with $i' \in \{i-1, i+1\}$ and $j' \in \{j-1, j+1\}$ is defined by the following. Since $X = \{a, b, c, d\}$, and these elements are regarded as the direction, if the direction from $P^t(i, j)$ to $P^t(i', j')$ is x (e.g., a corresponding to North), the directed bond $P^t(i, j) \to P^t(i', j')$ is defined by

$$P^t(i, j) \to P^t(i', j') :\Leftrightarrow \quad x, x^c \in P^t(i, j), \quad x^c, (x^c)^c \in P^t(i', j'), \tag{8}$$

where x^c is defined such that $x \wedge x^c = \downarrow_{P(i,j)}$, and $x \vee x^c = \uparrow_{P(i,j)}$, $(x^c)^c$ is defined such that $(x^c)^c \wedge x^c = \downarrow_{P(i',j')}$, and $(x^c)^c \vee x^c = \uparrow_{P(i',j')}$, where $\downarrow_{P(i,j)}$, and $\uparrow_{P(i,j)}$ are the least and greatest element of $\mathrm{Im}C^t_{P,K}(i, j)$. Note that $(x^c)^c$ is not necessarily x. The bond is defined by

$$P^t(i, j) - P^t(i', j') :\Leftrightarrow P^t(i, j) \to P^t(i', j') \text{ and } P^t(i', j') \to P^t(i, j). \tag{9}$$

That is a possible tube that can be employed as an actual tube.

A distribution reveals some clusters that are divided and aggregated step by step. It suggests that mesoscopic structure since smaller cluster than mesoscopic size changes faster and mesoscopic clusters are also changed slowly. Such a feature results from the property of open limit (Fig. 2A).

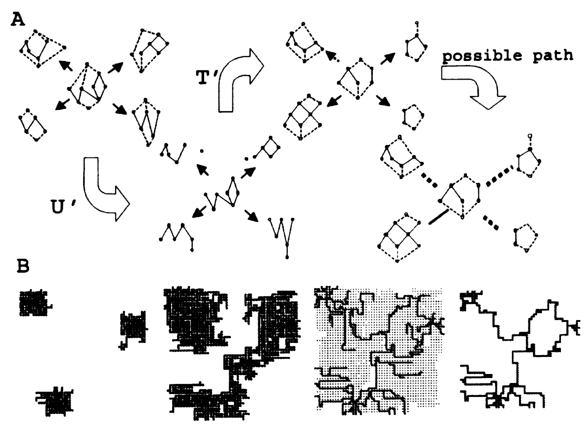


Figure 2. A. Interaction among nearest neighbors in two dimensional space, revealing context interaction. Given $\mathrm{Im}C^t_{P,K}(i,j)$, due to over-forgetful operation, $U^{'}$, partially ordered set are obtained at each site. Applying $T^{'}$ to each set makes a lattice. Through logical operation among lattices possible tubes can be computed. B. Development of actual tubes. In starting from three food sources, clusters of actual tubes are grown and then it shrinks to the final pattern.

Actual tubes are generated from a given food source. Given a food source at (i,j), actual tube such as $(i,j)-(i^*,j^*)$ is generated if $P^0(i,j)-P^0(i^*,j^*)$ holds, where $(i^*,j^*) = (i-1,j),(i+1,j),(i,j-1)$ or $(i,j+1)$. It is also assumed that actual tubes cannot be connected with the site at which already connected by actual tubes. It prohibits the generation of a loop structure with respect to actual tube cluster. The generation rule of actual tubes reveals the growth of a branching tree from a food source. Actual tube also influences possible tubes. If the tip of branch at (i,j) is opened toward x-direction in $\{a,b,c,d\}$, and i.e., in the x-direction actual tube can be newly generated, then $P^t(i,j)$ is replaced by $P^t(i,j)\cup\{x\}$. It makes possible tubes to be generated more easily. A cluster of actual tubes generated from a source is distinguished from each other until one encounters another. If one cluster encounters another for the first time, it is fused with each other, and a fused one behaves as one cluster henceforth. If actual tubes distribute over a whole space, all tip are shrunk till the branch encounters a T-junction, and that leads to the final pattern of actual tubes (Fig. 2B).

If possible tubes are given randomly, actual tubes are generated in a radial fashion from each source. If possible tubes are computed based on not a proto- but a closure, where a particular initial condition mentioned later is given, possible patterns are fixed, and then generated actual patterns are similar with the patterns with random possible patterns. It results in the shortest connection between sources as a final pattern of actual tubes. Given a probability of absence of possible tube at each connection, in the most range of parameter region, the shortest connection can be achieved. To estimate such a property, we measure the centripetal intensity (CI) of the final pattern of actual tubes. In simulating studies, given three food sources, CI is obtained as follows. If the region surrounded by the actual tube and the edge of the triangle consisting of three sources is squeezed out of the triangle, the area is positive; otherwise, it is negative. All areas are summed up, and it is normalized in a term of the area of the triangle. If $CI = 0$, the final active pattern mimics the triangle. If the probability increases, all sources cannot be connected, and that leads to low CI. It shows that there is a critical probability whether all sources are connected or not , and that as far as all sources are connected the pattern is similar with the triangle (Fig. 3).

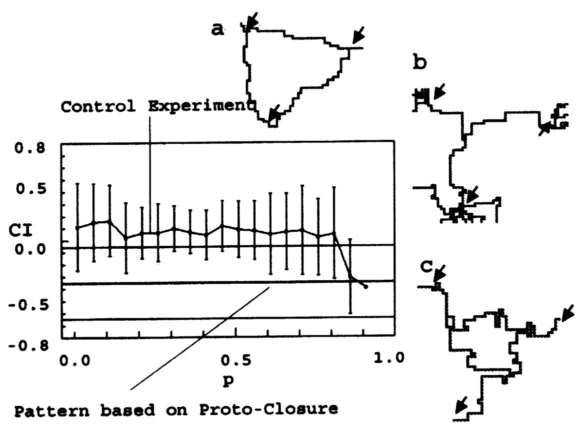


Figure 3. Centripetal Intensity (CI) is plotted against probability for the control experiment (i.e., context computation is given with probability), and for our model based on proto-closure. Generated patterns of actual tubes for control experiment (a) and ones for our model (b, c) are also shown.

When the possible tubes are computed through the context computation based on proto-closure, we prepare a particular initial condition for possible tubes such that short local tubes directed to other sources are locally distributed near the food source. It reveals that the incomplete information on the distribution of food source is acquired though protoplasmic flows. Fig. 2 shows the time development of actual tubes. Clusters are distributed inside the triangle consisting of food sources, and final pattern of actual tubes could mimic real physarum tube patterns. The centripetal intensity, CI of the generated pattern is negative, while it reveals diversity with respect to CI, as shown in Fig. 3.

Context computation based on proto-closure can yield incomplete information of whole distribution, since a local computation is incomplete due to proto-closure. In spite of partial information indexing the direction of other sources given initially, the tube patterns directly connecting food sources are not achieved. Final actual patterns are generated as a pattern consisting of concave tubes toward the center of the triangle. Since partial information for global distribution of sources is perpetually modified and yields dynamic distribution of possible tubes, actual tubes are finally generated in mimicking natural physarum patterns. It shows the openness in local computation in possible tubes plays an essential role in pattern formation.

6 Conclusion

We here proposed the model for an object within a world in the form of inconsistent pair of generalized intent and extent. Especially, generalized extent and intent are taken as the perspective consisting of imperfect parts and one consisting of parts glued by a limit, corresponding to a category of partially ordered sets and one of lattices. In that scheme a lattice can be constructed by adding a limit to a partially ordered set. On one hand, one can compute binary operation, the lowest upper bound and the greatest lower bound in a lattice, and on the other hand one cannot in a partially ordered set. In our physarum model, through those operations in a lattice, an agent at each local site in a two dimensional space can communicate with the nearest neighbors. Therefore a partially ordered set never provides a way to communicate with other agents, since it is ill defined due to the loss of a limit. By adding an open limit a partially ordered set is reconstructed as a lattice.

In engineering researchers sometimes confront an ill-defined problem of which some parameters are not given. At that time he determines parameter randomly while it is allowed in an adequate parameter range. Although the adequate parameter range is not explicitly shown, such a range concretely provides well-defined problem. As for our system of partially ordered set, if one adds some arbitrary elements to the set, one cannot obtain a lattice. Closure operation shows that one has to have a perfect knowledge of the world, although a real observer has at most imperfect knowledge. How can we work out the problem under imperfect knowledge? So as to prove the problem we introduce the notion of open limit. In an open limit indefiniteness still remains with respect to a value, whereas it can be used as the least or the greatest element that can glue parts. In a finite lattice, a limit is not only an ideal element but also a concrete entity. By contrast, in an open limit two roles, ideal one and concrete one are separated with each other although they are mixed with up. Another attempts for ill-defined problems are developed in [19]. In that model, a system contains a pool of dynamics and modules and the interaction between stimulus dynamics and the system gives rise to response. It also contains the idea of compensation for incompleteness in keeping interactability.

Through open limit, we can construct dynamic inconsistency between generalized intent and extent, and can access the second persons' perspective. Monod takes *Le Mythe Sisyphe*, and shows the origin of free will [20]. If a man who carries the boulder toward the top and fails repeatedly doubts a base of his act and finally finds that there is no reason, he can accept that the punishment is accepted by his own free will. Monod says that in this sense, a man carrying a boulder can be changed from being passive to being active. We think that the change can be regarded from the third persons' perspective (objectively that is a punishment) to the first persons' perspective (subjectively that is his own autonomous act). There is no room for the second persons' perspective, since in Monod's talk the world consists only of a man and god, that is dualism, and there is no inconsistency between them. The perfect world is regarded either as the first or the third persons' perspective dependent on interpretation. By contrast, if there is inconsistency between them we can see the first persons' perspective in the third persons' one, and that is the second persons' perspective bridging the first and third one. That is what we call subjectivity.

Acknowledgements

This work was supported by 21st century COE of "Origin & Evolution of Planetary Systems (Kobe University)".

References

1. Ganter, B. and Wille, R. (1999) *Formal Concept Analysis, Mathematical Foundations*, Springer, Berlin.

2. Barwise, J. and Seligman, J. (1997) *Information Flow, The Logic of Distributed Systems*, Cambridge University Press, Cambridge.
3. Matsuno, K. (1987) *Protobiology, Physical Basis of Biology*, CRC Press, Boca Raton (MI).
4. Rossler, O.-E. (1998) *Endophysics, The World as an Interface*, World Scientific, Singapore.
5. Gunji, Y.-P. and Higashi, H. (2001) The origin of universality: making and invalidating free category, *Physica D* **156**, 283–313.
6. Gunji, Y.-P., Takahashi, T., and Aono, M. (2004) Dynamical infomorphism: form of endo-perspective, *Chaos, Solitons & Fractals* **22**, 1077–1101.
7. Gunji, Y.-P. and Kamiura, M. (2004) Observational heterarchy enhancing active coupling, *Physica D* **198**, 74–105.
8. Gunji, Y.-P., Miyoshi, H., Takahashi, T., and Kamiura, M. (2005) Dynamical duality of type- and token-computation as an abstract brain, *Chaos, Solitons & Fractals*, in press.
9. Lawvere, W. (1969) Diagonal arguments and Cartesian closed categories, *Springer Lecture Notes in Mathematics* **92**, 134–145.
10. Gunji, Y.-P., Aono, M., Wakisaka, S., and Tsuda, S. (2005) Abstract heterarchy: Time/State-scale re-entrant system, *BioSystems*, in press.
11. Mac Lane, S. (1971) *Categories for the Working Mathematician*, Springer, New York.
12. Awody, S. (2002) *Category Theory*, preprint `http://www. andrew.cmu.edu/-course/80-317-713`.
13. Davey, B.A. and Priestley, H.A. (2002) *Introduction to Lattices and Order (2nd edition)*, Cambridge University Press, Cambridge.
14. Nakagaki, T., Yamada, H., and Toth, A. (2000) Intelligence: Maze-solving by an amoeboid organism, *Nature* **407**, 470.
15. Shirakawa, T. and Gunji, Y.-P. (2005) Homologous network formation of Physarum polycepharum driven by the local-global interaction in a cell, *BioSystems*, submitted.
16. Helbing, D., Schweitzer, F., Keltsch, J., and Molnar, P. (1997) Active walker model for the formation of human and animal trail systems, *Phys. Rev. E* **56**, 2527–2539.
17. Gould, J.L. and Gould, C.J. (1994) *The Animal Mind*, The Scientific American Library, New York.
18. Kitabayashi, N. and Gunji, Y.-P. (1997) Making decision in estimating pheromone by an ant itself, expressed as a cause-effect loop, *Rev. Biologia* **90**, 393–422.
19. Diebner, H.H. (2002) A simulating cognitive system with adaptive capability, *BioSystems* **64**, 141–147.
20. Monod, J. (1971) *Chance and Necessity: An Essay on the Natural Philosophy of Modern Biology*, Austryn Wainhouse, New York.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 73–93

ENDOPHYSICAL MODELS BASED ON EMPIRICAL DATA

ROBERT G. JAHN and BRENDA J. DUNNE
Princeton Engineering Anomalies Research, Princeton University, C–131 E–Quad
Princeton, New Jersey 08544–5263, U.S.A.
(rgjahn@princeton.edu; bjd@princeton.edu)

Abstract: Any proposed endophysical models need to acknowledge a number of subjective correlates that have been well established in such objectively quantifiable experimental contexts as anomalous human/machine interactions and remote perception information acquisition. Most notable of these factors are conscious and unconscious intention; gender disparities; serial position effects; intrinsic uncertainties; elusive replicability; and emotional resonance between the participants and the devices, process, and tasks. Perhaps even more pertinent are the insensitivities of the anomalous effects to spatial and temporal separations of the participants from the physical targets. Inclusion of subjective coordinates in the models, and exclusion of physical distance and time, raise formidable issues of specification, quantification, and dynamical formulation from both the physical and psychological perspectives. A few primitive examples of possible approaches are presented.

Keywords: Consciousness-Related Anomalies – Empirical Evidence – Subjective Correlates – Theoretical Models

1 Perspectives

Perusal of the relevant literature, and indeed of the abstracts and theme statement of this conference, suggests that the concept of "endophysical" has yet to be precisely defined, thereby entitling, or perhaps even obliging, each fresh author to specify his particular usage of this terminology. In our case, as developed in more detail in several earlier publications [1,2,3], we posit an unobservable, perhaps ineffable, possibly even inconceivable, understructure of experiential reality, wherein logic retreats to abstraction, and common distinctions of spatial/temporal, material/mental, external/internal, blur into a miasma of pre-information and pre-experience that is the ultimate source of all physical expression and mental impression, both objective and subjective. In its response to physical experiments, this source yields objectively specifiable phenomena that can be represented by exophysical models that in general have proven extraordinarily effective and self-consistent. But as encountered in personal subjective experience, this same source presents a number of endophysical deviations from the exophysical expectations, most notably concerning the passage of time, quantum entanglement, subjectivity itself, and the consciousness-related anomalous physical phenomena we shall describe herein.

It is our conviction that attempts to reconcile such disparities via a more expansive conceptual framework can benefit from careful assessment of those experiments in which both material and mental, objective and subjective parameters play demonstrable roles. In particular, we should study those situations wherein subjective properties attending the involvement of human consciousness are found to correlate with objectively definable and measurable alterations in physical behavior, especially when those correlations are inexplicable in terms of prevailing exophysical models. Much as Freud invoked dream evidence as his "royal road to the unconscious," consciousness-related physical anomalies may help us to circumscribe our conception of the ontic regime from which these, and all other epistemic material and mental events emerge, and thereby to reconcile the exophysical/endophysical dilemmas.

Before setting foot on this road, we also should specify that in our usage, the term "consciousness" is intended to subsume all manner of mental process, both conscious and unconscious; logical, emotional, and spiritual; local and collective; human and non-human; and is by no means restricted to biological brain function or even to the full neurophysiological response system. As we shall later contend more explicitly, the hierarchical span of the character and manifestations of consciousness is every bit as extensive and replete as that of the physical world in which it operates. In short, it encompasses all of the first half of the "self/not-self" dichotomy that underlies the endophysical/exophysical distinction.

From these perspectives, then, let us offer the following illustrative review of some potentially indicative experimental data. Given the breadth of scholarly backgrounds, familiarity with this class of research in general and with our PEAR program in particular, and the *a priori* personal convictions regarding the topic that prevail in this audience, no single style of brief presentation can hope to be uniformly effective. Rather, we must sacrifice depth for breadth, and rely on referenced publications to flesh out details as befits individual interests.

2 The PEAR Program [4,5]

The Princeton Engineering Anomalies Research program was established in 1979 in the School of Engineering and Applied Science at Princeton University, for the purpose of systematic study of a selection of consciousness-related anomalous physical phenomena that had for many years been reported in the scientific and anecdotal literature, and that seemed to be of growing potential pertinence to contemporary and future information-processing technologies. As its title implies, it is intended as an academically based, engineering oriented, rigorously scientific research enterprise, aspiring to increasing basic understanding of the fundamental processes contributing to the anomalous effects, their implications for various scholarly disciplines, and their potential practical applications. Over its more than a quarter century of activity, the program has involved a number of interdisciplinary professionals, interns, students, support staff, visitors, and hundreds of volunteer operators. Its results have been presented in some fifty archival publications, and in a comparable number of more detailed technical reports. Our website (www.princeton.edu/~pear/) presents a more comprehensive review of the history, style, and program of the laboratory, along with a full list of publications, many of which can be downloaded.

From its inception and throughout its subsequent history the research agenda has comprised three interrelated topics: a) anomalous human/machine interactions; b) remote perception; and c) theoretical models. Here we shall focus primarily on the first, with passing attention to the other two.

3 Human/Machine Interactions

Over the course of the program, scores of simple physical devices have been deployed as targets for interaction with our human operators. Most of these have been electronic in character, but others have been mechanical, optical, acoustical, or fluid mechanical in nature. All entail some form of random physical process which can be conditioned into an output string of binary digits, the expected combinatorial distributions of which are theoretically calculable and/or empirically calibratable. All are replete with a variety of failsafes and controls that guarantee their integrity against artifact or tampering, and only mature technologies are employed. Differential technical logic, protocols, and analyses are used throughout to protect the measurables from any spurious drifts or environmental contaminations.

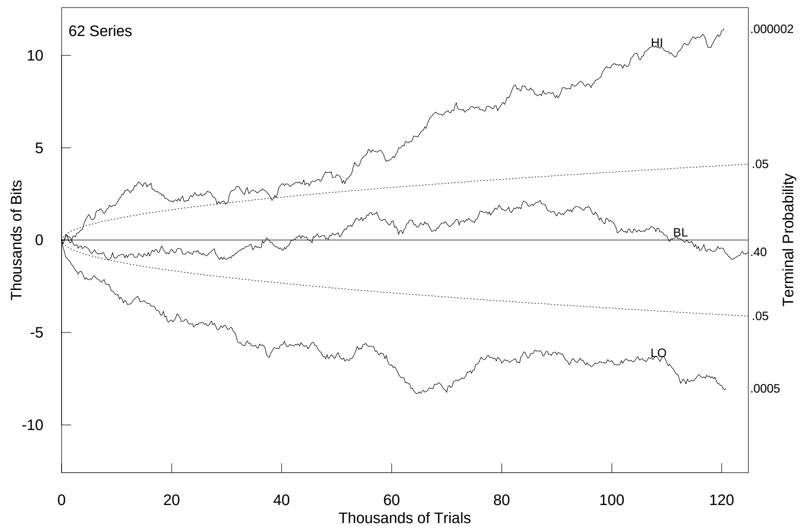


Figure 1. Cumulative deviations of REG mean shifts achieved by one operator over some 375,000 experimental trials.

3.1 Electronic random event generators

As a specific example of this class of experiment, consider our benchmark microelectronic random event generator (REG) whose primary noise source is a commercial unit utilizing a back-volted solid-state junction, *i.e.*, is based on electronic noise. Conditioning of this source into an output string of randomly alternating, regularly spaced positive and negative pulses suitable for prescribed counting, and their accumulation into essentially Gaussian frequency-of-count output distributions are detailed in several references [6,7,4].

The basic protocol calls for a human operator, seated in front of such a machine but in no physical contact with it, to attempt, via some mental strategy alone, to alter the output distributions in a pre-specified fashion. Usually this is simply to shift the mean from its chance expectation to a higher value (HI), to a lower value (LO), or to exercise no intention, *i.e.*, to generate a baseline (BL). For all of the data reviewed here, the REG devices were set to produce "trials," each comprising 200 binary samples (*i.e.*, bits), accumulated at a rate of 1000/sec, for which the chance expected mean $\mu = 100$ and standard deviation $\sigma = 7.071$.

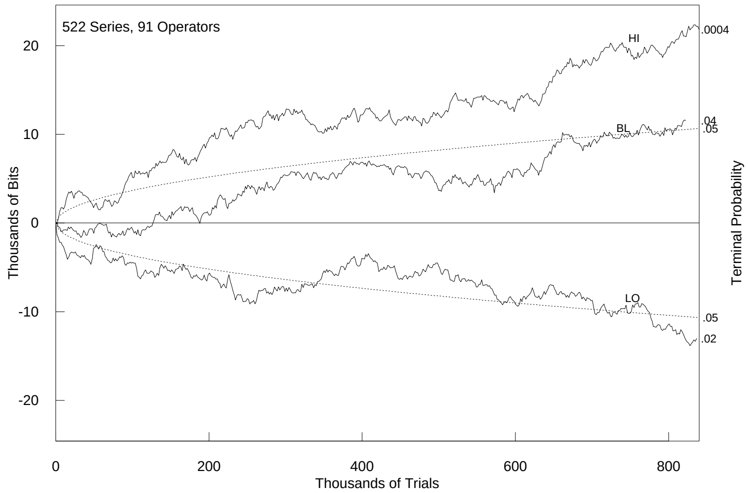


Figure 2. Cumulative deviations of REG mean shifts achieved by all 91 operators comprising a database of some 2.5 million trials.

Fig. 1 displays the collective results of some 125,000 trials per intention, achieved by one of our most productive operators over many years of such experimentation, arrayed as cumulative deviations of count distribution means from the chance expectation. For each of the pre-recorded directions of effort, we find a corresponding secular progression superimposed on the stochastic background noise intrinsic to the binary combinatorial process. The overall HI − LO separation is unlikely by chance to the order of 10^{-8}. (In this representation, the reference parabolas denote the loci of 0.05 chance probabilities for the cumulated data.)

Questions of the replicability and commonality of such anomalous effects, and the identification of their most salient correlates have been major foci of our experimental efforts for nearly three decades, and even now no unequivocal specifications can be made. On the one hand, we have had a few operators who have maintained consistently impressive performances like that illustrated in Fig. 1 over long periods of effort. Others have shown less consistent patterns of achievement. Many have not exceeded chance expectation, and a few have persisted in anti-correlations of their results with their stated intentions. Nevertheless, when the performances of all 91 operators who have participated in these benchmark experiments are concatenated into a composite cumulative deviation record, the overall HI

− LO separation is still unlikely by chance to the order of 10^{-4} (*cf.* Fig. 2). Unattended calibration data taken concurrently with these active experiments show no significant departures from chance expectation.

Since these collective data include a wide variety of individual operator database sizes, a more instructive display of the composite pattern of operator performance can be made by plotting the individual HI − LO differences in mean shifts achieved *vs.* the square root of the number of trials performed by that operator (*cf.* Fig. 3). In this format, the loci of statistical significance levels are nested hyperbolas like those shown, with respect to both the chance mean and the composite shifted mean. The deduction from such an array is that the overall effect is not attributable to any particular "superstar" operators, but rather to a subtler combination of incremental effects over the group as a whole, particularly those "prolific" operators who have provided us with very large datasets.

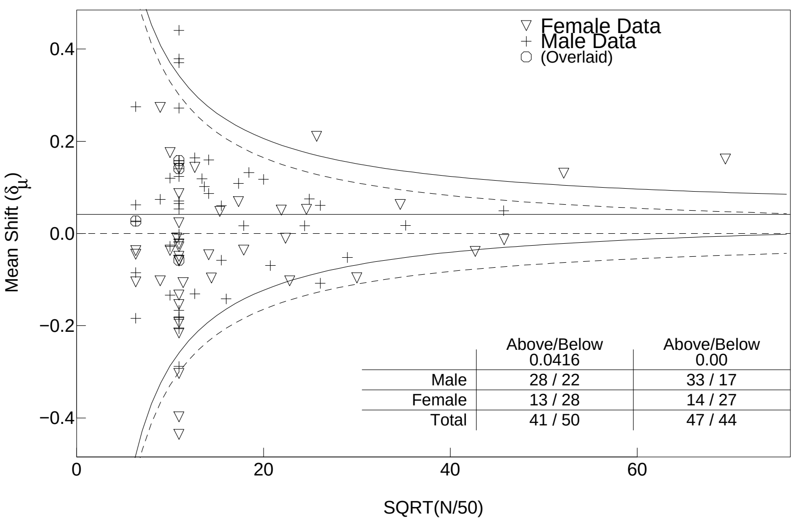


Figure 3. HI − LO mean shift separations achieved by 91 individual operators *vs.* their database sizes.

3.2 Gender effects

Major experimental attempts have been made to establish primary correlates of such anomalous effects, with some definitive, albeit surprising results. For example, beyond the evident statistical correlations with the pre-stated intentions of the operators, a strong gender disparity in their performances also emerges from the overall database. In Fig. 3, for example, male and female operators are designated by different symbols. Clearly these do not comprise the same distributions. Rather, the modestly significant male mean shift is achieved by a relatively symmetrical and smooth distribution; in contrast, the larger female mean shift is driven by a few prolific operator positive results, diluted by a host of smaller datasets, many of which are opposite to intention.

This stark "gender effect" can be statistically quantified by an elementary analysis as presented in Table 1, which breaks out the Z-scores of the HI − LO mean-shifts (Z_Δ), the operator performance scatter with respect to the chance mean (χ^2_Δ) and with respect to the shifted mean ($\hat{\chi}^2_\Delta$), for various permutations of All/Male/Female, prolific/non-prolific operator pools. The corresponding chance probabilities (p) are computed by comparisons of χ^2_Δ and $\hat{\chi}^2_\Delta$ with the number of operators (N_o), or with ($N_o - 1$), respectively. Clearly the anomalous mean shift of the "All" database is driven primarily by the prolific female operators, who also scatter their individual results, both with respect to the chance mean and with respect to the shifted mean, to an extraordinary degree. By these same criteria, the male performance, although milder, is much more consistent with intention.

Table 1. HI − LO REG Data, by Operator Groups.

	N_o	$Z_\Delta(p)$	$\chi^2_\Delta(p)$	$\hat{\chi}^2_\Delta(p)$
All	91	3.81 (7×10^{-5})	124.50 (.01)	109.99 (.07)
Males	50	1.87 (.03)	44.85 (.68)	41.33 (.77)
Females	41	3.38 (4×10^{-4})	79.66 (3×10^{-4})	68.22 (.0036)
Prolific	20	4.15 (2×10^{-5})	63.85 (2×10^{-6})	46.64 (4×10^{-4})
Non-prolific	71	0.57 (.28)	60.65 (.80)	60.32 (.79)
Prolific males	9	0.70 (.24)	7.36 (.60)	6.86 (.55)
Prolific females	11	4.54 (3×10^{-6})	56.49 (4×10^{-8})	35.87 (9×10^{-5})

Similar gender disparities appear in many of our other human/machine experiments. In general, we have repeatedly found that although the female operators tend to provide larger individual databases, the males display significantly stronger correlations of mean shifts with their prerecorded high and low intentions, relatively symmetrically displaced with respect to their baseline results. The female data, in contrast, feature larger effect sizes, albeit strongly asymmetrical and poorly correlated with intention, and larger score distribution variances. Since no such gender differences appear in experiments that yield null overall results, it appears that the successful experiments comprise both of these classes of response superimposed, *i.e.*, that the data have a substantial interior structure that reflects operator gender [8].

The relevance of the gender factor has also been reinforced by bodies of *ad hoc* experimental data produced by pairs of operators working in concert. In these "co-operator" studies, it has been found that two operators of the same sex tend to produce results indistinguishable from chance, or even slightly opposite to intention. In contrast, operators of opposite sex tend to produce positive effects significantly larger than chance, indeed substantially larger than those characterizing the same individual operators working alone. Yet more striking has been the observation that if the opposite-sex partners are emotionally involved ("bonded pairs"), their collective effect sizes are nearly an order of magnitude larger than those attained by the single-operator pools [9].

3.3 Serial position effects

Additional subjective correlates have also emerged from these and other databases. Particularly notable is the dependence of operator performance on the number of major encounters with the particular experiment, usually indexed in terms of completed "series" of trials (typically 1000–5000 trials in each direction of attention, depending on the particular experiment). A substantial retrospective analysis of prolific operator effect sizes over the larger datasets has revealed clear correlation with the ordinal positions of the experimental series, in both the collective and individual results. Specifically, there are statistically significant tendencies for operators to produce better scores in their first series, then to fall off in performance in their second and third, and eventually to recover to some intermediate levels during their fourth, fifth, or subsequent series. Such correlation appears in both local and remote experiments and is also indicated over a sequence of other experimental protocols, but no such effects appear in the baseline or calibration data [10]. Survey of standard psychological literature indicates that similar patterns have been identified in more conventional experiments on perception, cognition, and memory, suggesting that our anomalous serial position effects are primarily psychological in origin, and may subsume the rudimentary "decline," "primacy," "recency," and "terminal" effects propounded in the parapsychological and psychological literature.

3.4 Space and time dependence

Additional subjective correlates will be mentioned in a subsequent context, but here we should move on to address a number of objectively specifiable (*i.e.*, exophysical) correlates that are conspicuously absent. Most notable by far is the statistical independence of the anomalous effect sizes on physical distance and time [11]. A large body of REG data has been accumulated in a protocol variant wherein operators have attempted to influence the outputs at progressively larger separations from the machine, *e.g.*, from an adjacent room; from local sites up to a few miles away; or from global distances. The effect sizes achieved in these experiments show no statistical dependence on this physical separation; *i.e.*, the operators appear to be as successful in shifting the means of the output distributions from thousands of miles away as they are in the proximate experiments. Beyond this, individual prolific operators seem to produce similar patterns of performance in their local and remote efforts. Even more striking is the independence of the results on temporal separations of the operator efforts from the times of machine operation, up to plus or minus several days. In other words, the operators also appear to be able to achieve substantial shifts in the machine output distributions by exerting their intentions well before, or well after, the actual data generation. Although the smaller sizes of these "remote" and "off-time" databases somewhat restrains their statistical significance, the effect sizes are comparable with, in some cases even larger than, those established in the local experiments.

3.5 Source dependence: random mechanical cascade

A second reasonable exophysical parameter to explore for possible correlations with the anomalous effects is the character of the machine itself, or alternatively the nature of the random physical process embodied in that machine. As mentioned, our experiments have utilized a wide range of such sources: microscopic and macroscopic; electronic, mechanical, optical, acoustical, and fluid dynamical; physically random and pseudorandom; all entertaining a variety of protocols, feedback modalities, and bit processing rates. Here again, with the possible exception of some of the pseudorandom sources, we have found little sensitivity of the anomalous effect sizes to the specific character of the machines on which they are achieved, or to the particular protocol variants.

Perhaps the most extreme example of this ubiquitous nature of the effects has been demonstrated on a large mechanical facility known as a Random Mechanical Cascade (RMC)[12]. Based upon a common statistical demonstration device known as "Galton's Desk," this machine allows 9000 polystyrene balls to drop through a quincunx matrix of 330 pegs, scattering them into 19 collecting bins with a population distribution that is

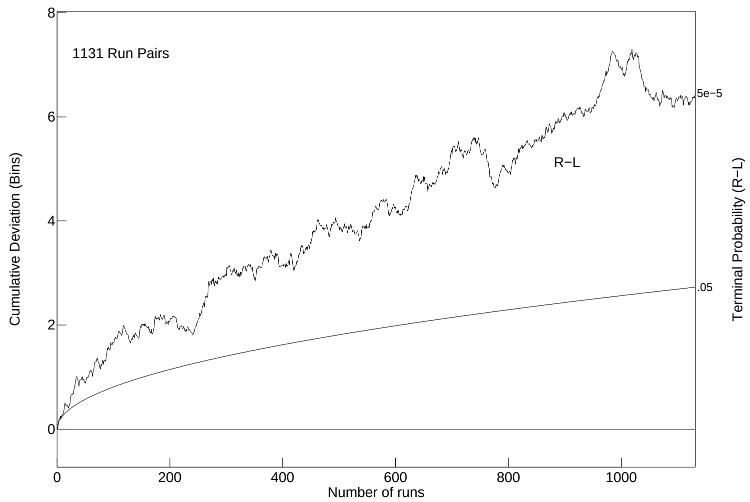


Figure 4. Cumulative right minus left mean shifts achieved on a Random Mechanical Cascade (RMC).

approximately Gaussian. As the balls enter the bins, progressive counts are accumulated photoelectrically, displayed as feedback for the operator, and recorded on-line. Operators attempt to shift the mean of the developing distributions to the right or left, relative to a proximately generated baseline distribution. As displayed in Fig. 4, the overall mean difference of right versus left efforts concatenated across a total database of 87 series (1131 runs per intention), has a probability against chance of $<10^{-4}$, with 15% of the individual series significant at $p < .05$, and 63% conforming to the intended directions. Prolific operator achievements tend to compound marginally but systematically in cumulative deviation patterns characteristic of the particular individuals and, in several cases, similar to those produced by the same operators in microelectronic Random Event Generator (REG) experiments. Again we find stark gender disparities between the female and male performances, which lead to an asymmetry in the overall patterns of the differential effects, virtually all of which is attributable to the female operators. Here too, the anomalous effects appear in comparable magnitude in remote and off-time variants of the experiment.

These and similar results acquired from other random processors thus suggest that whatever the fundamental nature of these anomalous effects may be, it functions not so much in the technical dynamics of the sources, *per se*, but in the statistical patterns of information they generate out of the otherwise random backgrounds, and therefore it is with these patterns that the minds of the operators, themselves functioning as information processors, must be interacting. That the former category of information can be specified objectively, whereas the latter clearly involves subjective aspects, must complicate any attempts to model the phenomena, but therein lies their essence.

3.6 Composite results

To summarize these, and many other laboratory-based human/machine experiments we have performed, the overall chance probability of the results compounded from more than 1000 separate experimental series is less than one part in 10^{-12} ($z > 7$), with an overall average effect size of the order of 10^{-4} bits deviation/bit processed [7]. The primary correlate of these effects is the pre-stated intention of the operators; secondary correlates include operator gender, serial position of the effort, and two other subjective factors to be discussed below: resonance and perceived uncertainty. Notably absent as correlates are physical distance, time, and specific characteristics of the target machines.

4 FieldREG Studies and the Role of Resonance

Beyond the explicitly demonstrated correlations of the anomalous REG data with operator intention, gender, and serial position, another subjective property has frequently projected itself anecdotally to equal importance, namely emotional resonance. Akin to the ineffable harmony one can enjoy with a friend or loved one, with an automobile or computer, with a musical instrument or delicate tool, it has been widely testified by our operators that a similar affection or involvement with the experimental devices and tasks can facilitate the desired effects. The superior results achieved by the bonded co-operators also suggest the efficacy of this quality in the experimental environment. In an effort to explore this correlate more systematically, we have implemented an adjacent experimental program to address the role of such subjective resonance in the anomalous creation of objective information. It is called "FieldREG"[13,14].

These studies utilize miniaturized versions of our conventional REGs ("microREGs") that are sufficiently compact to allow their deployment in a variety of group environments, such as ritual ceremonies, artistic performances, sporting events, business meetings, diagnostic and therapeutic counseling, *etc.* From such field applications, it appears that those venues that engender strong collective resonance among the participants show larger deviations of the REG output sequences from chance expectations than those generated in more pragmatic or mundane assemblies. In fact, as illustrated in Fig. 5, while FieldREG units deployed in the "resonant" venues display much noisier than chance displacements of their digital output strings, at a collective χ^2 level of chance probability of 3.2×10^{-10}, those immersed in the "mundane" environments actually yield quieter traces than expected by chance. While these experiments are still ongoing, we now have in hand a substantial database of several hundred such applications, large enough to assure that the observed results are not attributable to statistical artifact, and that much is to be learned by further systematic research.

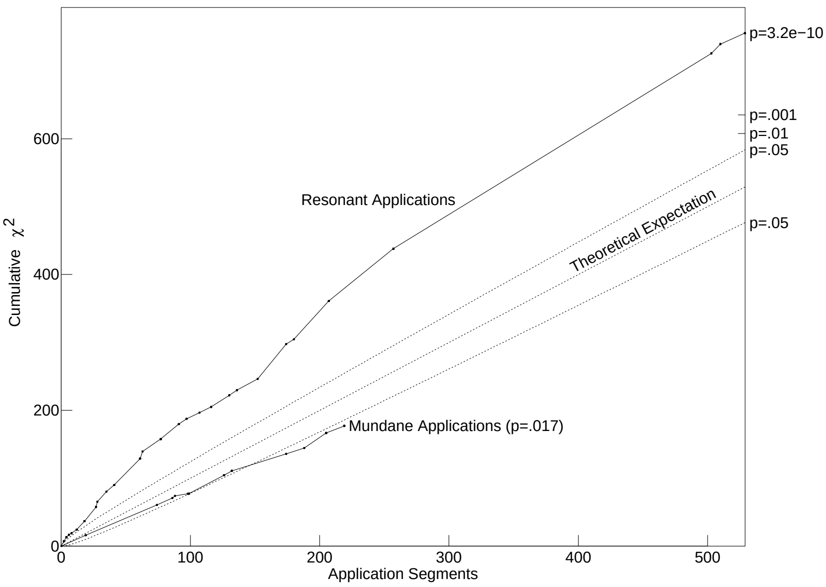


Figure 5. Cumulative χ^2 values for "resonant" and "mundane" FieldREG applications, compared to chance expectations.

The analytical and theoretical complexities posed by these FieldREG studies are quite severe. Although the importance of resonance as a complement to conscious intention in stimulating the anomalous effects seems well established, more detailed interpretation of the data records in terms of the various possible statistical indicators that might be applied to the direction and endurance of the anomalous excursions is not yet secure. Beyond that, the establishment of a database-management system that can effectively index and correlate all of the subjective and objective parameters that might conceivably bear on the form and magnitude of the anomalous responses is a major enterprise in itself. All of these interpretive challenges notwithstanding, the vision of a technology, however subtle and complex, that could reliably sense the degree of coherent purpose and productive resonance prevailing in such diverse arenas of human dynamics as business and industry, healthcare, education, athletics, artistic performance, and creative scholarship, among countless others, and lead to beneficial applications therein, seems to justify unlimited effort to bring to fruition.

The possible psychological implications of the intention/resonance complementarity may also be pertinent to ongoing attempts to model the phenomena. In the laboratory experiments, intention primarily implies mentation at a conscious level, although there are some indications even here of unconscious processing, *e.g.*, in the generation of aberrant baselines, or in the anti-correlations of certain operators' performance with their stated intentions. Resonance, on the other hand, especially in the FieldREG situations, would seem largely to be an unconscious or visceral process, stimulated by the emotional character of the prevalent environment. The dynamical relationship between these two qualities of consciousness may be pertinent to the emergence of the anomalous (exo)physical effects, and therefore to the conceptualization of models to represent them.

5 Remote Perception

Space will not permit any adequate review of the second major portion of the PEAR program that we term "Remote Perception" (elsewhere labeled "remote viewing," or more traditionally, "clairvoyance"), other than to note that our experimental efforts here have replicated the successful work of many others over recent decades [15,16,17,18], and that our particular contribution has been to develop and apply analytical methods to quantify the degree of extra-chance information acquired using such experimental techniques. Briefly, the basic protocol of these experiments involves one participant, termed the "percipient" who, without resort to any conventional sensory means, attempts to perceive and describe a randomly selected geographical site at which a second participant, the "agent," is stationed at a given time. Both participants then render their descriptions of the scene into free response transcripts, and subsequently into various descriptor specifications which then may be compared via an assortment of computerized scoring algorithms developed to quantify the degree of information acquisition [19]. The principle findings of this extensive experimental and analytical effort have been the following:

(i) For the database of 653 formal experimental trials performed over several phases and modalities of the program, the cumulative extra-chance information acquired reaches a statistical Z-score above 5.4 ($p < 3 \times 10^{-8}$).

(ii) The experimental success is not notably dependent on any of the secondary protocol parameters tested, *e.g.*, volitional *vs.* random target selection; target categories and characteristics; diurnal or seasonal aspects; single or multiple percipients; *etc.*

(iii) As with the human/machine experiments, the information yield also shows no statistical dependence on the physical separation of the percipient from the target, up to global distances, or on the time interval between target visitation by the agent and the perception effort, up to several days, plus or minus.

(iv) The amount of information acquired is strikingly anti-correlated with the degree of complexity of the analytical formats imposed on the percipients and agents in formulating their specifications of the target scenes [20].

It was the establishment of feature (iii) in these experiments that inspired the remote and off-time studies in the human/machine portion of our program, which yielded similar results of statistical independence of the effects on intervening distance and time. This in turn strengthened our suspicion that these two superficially different genres of anomalous effect actually were drawing from the same phenomenological well, with the only distinction that in one case information was being inserted into an otherwise random physical process; in the other, information was being extracted.

5.1 The role of uncertainty

Observation (iv) may have even more profound implications for conceptualization and representation of these phenomena, in the sense that here we may be encountering manifestation of an inescapable "consciousness uncertainty principle" that inherently constrains our ability to achieve such effects. This issue has been pursued in some detail in Ref. [20], and from somewhat different perspectives in Refs. [4] and [21]. The generic concept emerging from these empirical and theoretical considerations is that while the emergence of consciousness-related anomalous physical effects seems largely to be driven by a host of subjective factors, our efforts to demonstrate, record, and quantify them necessarily entail the imposition of objective criteria and measurements. Unfortunately, the former appears to be obstructed by the latter, and vice versa, and we are left with the challenge of finding a way to straddle the subjective/objective dichotomy with some optimized compromise. In this case, our efforts to establish defensible and quantitative remote perception data by successive refinements of the analytical techniques seem to have progressively suffocated emergence of the phenomenon. Whether this interference functions primarily in the psyches of the human participants, or whether it is more endemic in the physical character of the information itself, is unclear and possibly unresolvable. Notwithstanding, similar indications have emerged from a number of our other experiments, collectively suggesting that this uncertainty is not merely a limitation on the attainable empirical precision, but is evidence of the fundamental importance of informational "noise" as a raw material out of which the anomalous effects are constructed. Comparable examples could be cited from less controversial physical, technological, biological, and psychological venues wherein random processes also seem to play essential roles in the establishment of orderly effects. Such a counter-intuitive noise/signal dynamic, compounded with the other extraordinary characteristics of the phenomena, further challenges attempts to construct viable models, as addressed in the following section.

6 Models

As for any scientific enterprise, consequential scholarly understanding of these curious phenomena can advance only if the empirical results can enter into dialogue with astute theoretical models. The problem we face here, however, is that the experimental studies present such a bewildering array of irregularities, contradictions, and departures from canonical, indeed from rational and even intuitive, precedents and expectations that any classical modeling strategies are essentially denuded of any hope of effectiveness. Simply reprising our foregoing text, we are faced with the following daunting array of phenomenological characteristics that any proposed model is obliged to accommodate:

- Tiny informational increments riding on stochastic backgrounds;
- Primary correlations of objective physical evidence with subjective parameters, most notably intention, resonance, and uncertainty;
- Data distribution structures consistent with slight alterations in the elemental binary probabilities;
- Statistical independence of the magnitude of the effects on intervening distance and time;

- Complexly irregular replicability, including oscillatory sequential patterns of performance.

These inescapable empirical aspects force abandonment of any direct applications or extrapolations of extant physical, psychological, or informational models, and of necessity turn us toward more radical propositions, whereby consciousness can assume a proactive role in the establishment of physical reality, and deterministic causation is vastly generalized. The essential features of such unconventional modeling approaches have been proposed in the context of a "Science of the Subjective" [22], the challenge of which has been specified in the following terms:

"Any disciplined re-admission of subjective elements into rigorous scientific methodology will hinge on the precision with which they can be defined, measured, and represented, and on the resilience of established scientific techniques to their inclusion. For example, any neo-subjective science, while retaining the logical rigor, empirical/theoretical dialogue, and cultural purpose of its rigidly objective predecessor, would have the following requirements: acknowledgment of a proactive role for human consciousness; more explicit and profound use of interdisciplinary metaphors; more generous interpretations of measurability, replicability, and resonance; a reduction of ontological aspirations; and an overarching teleological causality. More importantly, the subjective and objective aspects of this holistic science would have to stand in mutually respectful and constructive complementarity to one another if the composite discipline were to fulfill itself and its role in society."

Within this generic attitude, our particular efforts have converged on three categories of model, each of which has been thoroughly described in a number of publications and presentations. Here we can only sketch their essence.

6.1 Quantum mechanics of consciousness

Quite early in the program we were struck by a number of similarities between the historical and conceptual evolution of quantum science and the ongoing unfolding of the experience and representation of consciousness-related physical anomalies. In both scenarios, classically respected conceptual and analytical models of reality have been challenged by the advent of diverse bodies of new empirical data, made possible via the development of more sensitive and reliable experimental equipment and techniques. In each case extensive attempts to rationalize the anomalous data within prevailing formalisms have been categorically and profoundly unsuccessful, forcing postulation and development of a number of counter-intuitive concepts. Some of those originally posed in the atomic-scale physical domain may offer potentially productive metaphorical associations with the mind/matter issue, as well. Among these one could list the quantization of energy and other physical observables; the wave/particle duality and the wave mechanics of atomic structure; the uncertainty, complementarity, exclusion, and indistinguishability principles; and the probabilistic character of quantum observations. The proposition is that all of these might be regarded as impositions by the experiencing consciousness, rather than as intrinsic characteristics of the physical events, *per se* [21].

In this spirit, the concepts and formalisms of elementary quantum mechanics have been appropriated via suitable metaphors to represent the characteristics of consciousness interacting with its environment. For example, if consciousness is represented by a quantum mechanical wave function, and its environment, including its own physical corpus, is represented by an appropriate potential profile, Schrödinger wave mechanics yields eigenfunctions and eigenvalues that can be associated with the cognitive and emotional experiences of that consciousness in that environment. To articulate this metaphor it is necessary to associate certain mathematical aspects of the formalism, such as the coordinate system, the quantum numbers, and even the metric itself, with various impressionistic descriptors of consciousness, such as its intensity, perspective, approach/avoidance attitude, balance between cognitive and emotional activity, and "yin/yang" or passive/active disposition. But with these in hand, certain computational applications display metaphoric relevance to individual and collective experience, and in particular to our experimental situations. Specifically, such traditional quantum theoretic exercises as the central force field and atomic structure, covalent molecular bonds, barrier penetration, and quantum statistical collective behavior become useful analogies for representation and correlation of certain consciousness experiences, both normal and anomalous, and for the design and interpretation of experiments to study these systematically. For example, our empirical resonance factor can be related to molecular bonding; our gender effects to electronic spin and its pairing; FieldREG results to collective particle behavior in potential wells; and the conditional replicability features to the intrinsic statistical uncertainties of all quantum phenomena. Intangible as these associations may be, they do allow conceptual representation of mind/matter interactions wherein the "anomalous" effects become quite normal expectations of quantum-bonded human/machine and human/human systems.

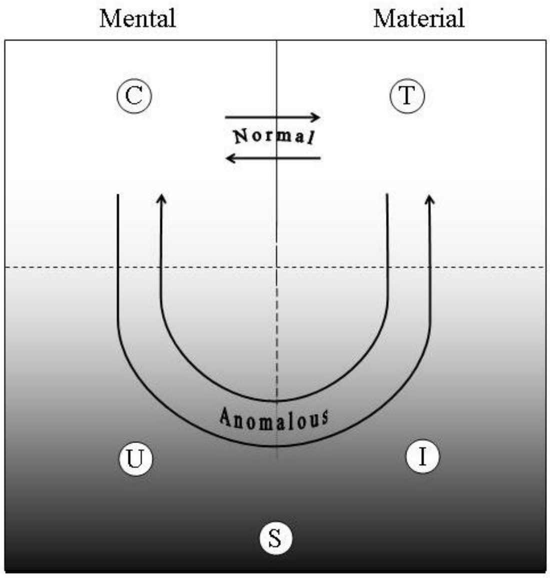


Figure 6. Modular taxonomy of anomalous information transfer.

6.2 Modular models

A second model, consonant with our introductory position statement, has been proposed under the title of "A Modular Model of Mind/Matter Manifestations (M^5)" [1], and extended as "M*: Vector Representation of Subliminal Seed Regime of M^5" [2]. With reference to Fig. 6, the M^5 and M* models postulate that anomalous effects such as those we observe in our experiments do not emerge from direct intercourse between the conscious mind Ⓒ and the tangible physical world Ⓣ, but have their origin in the depths of the unconscious mind Ⓤ and in an intangible substrate of physical reality Ⓘ wherein the Cartesian distinction between mind and matter blurs and loses its functional utility. Both of these are misty domains of uncertainty and potentiality, where space and time have yet to be defined, let alone distinguished, and where information waits to be born. When the conscious mind expresses a strong desire enhanced by a deep feeling of resonance, that resonant intention can stimulate some process in the unconscious mind that is reflected in the pre-physical potentiality, and subsequently expressed in subtle biasing of probabilistic physical events, such as the REG experimental outputs. This process also may work in reverse order, as in the remote perception experience, where physical information about the target scene diffuses into its underlying intangible composition, whence it may exert some formative influence upon the unconscious mind of the percipient, thence to emerge into a conscious experience and subsequent description of the scene. With the more explicitly bounded regimes of the conscious mind and manifest physical world thus indirectly linked via the less constrained modules of the unconscious and the intangible substrates, it should not be surprising to encounter apparently acausal correlations between objective and subjective aspects that current exophysics classifies as anomalous, but that a mature endophysics would regard as normal. This model also raises, but does not attempt to resolve, the possible role of a transcendental cosmic "Source" Ⓢ which may permeate, inform, and influence the entire modular configuration.

The implications of this taxonomy for experimental design and interpretation include subtler feedback schemes that facilitate submission of conscious intention to unconscious mental processing; physical target systems that provide a richness of intangible potentialities; operators who are amenable to such interactions; and an environmental ambience that supports the composite strategy. Requisites for theoretical extension of the model include better understanding of the information flow between conscious and unconscious aspects of mind; more pragmatic formulations of the relations between tangible and intangible physical processes; and most importantly, cogent representation of the merging of mental and material dimensions into indistinguishability at their deepest levels. Several of our ongoing experiments have been designed specifically to test these and other aspects of the predictions, but have not yet produced large enough databases to permit definitive conclusions.

6.3 Consciousness filters

The concept of a dynamical two-way exchange between a primordial Source and an organizing consciousness that was posed briefly in the M^5 context has been developed more thoroughly under the title of "Sensors, Filters, and the Source of Reality"[3]. This model proposes that the common but very limited local interactions of our personal consciousness with its proximate environment are relatively superficial aspects of a vaster creative process in which we could engage more proactively, whereby we might acquire more profound information and alter our individual experience to an extent dependent on the depth and breadth of the interpenetration of our consciousness and the Source. These interactions are both ordered and restricted by the intervention of an array of physiological, psychological, social, and cultural influences, or "filters," which condition our perceptions, and thereby our conscious experiences. Since most function on an unconscious level, however, we seldom invoke interpretations of our experiences other than those consistent with our filtered preconceptions. By bringing these influences to a conscious level it becomes possible to re-tune the filters of consciousness and thus to alter the experiential reality to a measurable degree. In particular, such attitudinal tactics as openness to alternative perspectives, utilization of transdisciplinary metaphors, ego-sacrificial resonance, tolerance of uncertainty, and balancing of analytical rigor with emotional involvement can enable experiential realities that draw more deeply from the Source and are more responsive to intention, desire, or need, to an extent consistent with our empirical laboratory evidence.

It should be evident that all three of these genres of conceptual model share some features with a host of mystical and religious practices. They also conform to some degree with the prevailing distinctions in contemporary theoretical physics and philosophy of science between epistemic and ontic domains or, in the parlance of this conference, between exophysics and endophysics, and their relationship to one another. Perhaps more to the point, they each acknowledge the role of pertinent experiential data, both objective and subjective, in their conception, construction, and verification. And that, of course, has been the purpose of this presentation.

References

1. Jahn, R.G. and Dunne, B.J. (2001) A modular model of mind/matter manifestations (M^5), *J. Scientific Exploration* **15**, 299–329.
2. Jahn, R.G. (2002) M*: Vector representation of the subliminal seed regime of M^5, *J. Scientific Exploration* **16**, 341–357.
3. Jahn, R.G. and Dunne, B.J. (2004) Sensors, filters, and the source of reality, *J. Scientific Exploration* **18**, 547–570.
4. Jahn, R.G. and Dunne, B.J. (1987) *Margins of Reality: The Role of Consciousness in the Physical World*, Harcourt Brace Jovanovich, San Diego–New York–London.
5. Jahn, R.G. and Dunne, B.J. (2005) The PEAR proposition, *J. Scientific Exploration* **19**, in press.
6. Jahn, R.G., Dunne, B.J., and Nelson, R.D. (1987) Engineering anomalies research, *J. Scientific Exploration* **1**, 21–50.
7. Jahn, R.G., Dunne, B.J., Nelson, R.D., Dobyns, Y.H., and Bradish, G.J. (1997) Correlations of random binary sequences with pre-stated operator intentions, *J. Scientific Exploration* **11**, 345–367.

8. Dunne, B.J. (1998) Gender differences in human/machine anomalies, *J. Scientific Exploration* **12**, 3–55.
9. Dunne, B.J. (1991) *Co-Operator Experiments with an REG Device*, Technical Note PEAR 91005, Princeton Engineering Anomalies Research, Princeton University, School of Engineering and Applied Science.
10. Dunne, B.J., Dobyns, Y.H., Jahn, R.G., and Nelson, R.D. (1994) Series position effects in random event generator experiments, with an Appendix by A. Thompson, "Serial position effects in the psychological literature," *J. Scientific Exploration* **8**, 197–215.
11. Dunne, B.J. and Jahn, R.G. (1992) Experiments in remote human/machine interaction, *J. Scientific Exploration* **6**, 311–332.
12. Dunne, B.J., Nelson, R.D., and Jahn, R.G. (1988) Operator-related anomalies in a random mechanical cascade, *J. Scientific Exploration* **2**, 155–179.
13. Nelson, R.D., Bradish, G.J., Dobyns, Y.H., Dunne, B.J., and Jahn, R.G. (1996) FieldREG anomalies in group situations, *J. Scientific Exploration* **10**, 111–141.
14. Nelson, R.D., Jahn, R.G., Dunne, B.J., Dobyns, Y.H., and Bradish, G.J. (1998) FieldREG II: Consciousness field effects: Replications and explorations, *J. Scientific Exploration* **12**, 425–454.
15. Dunne, B.J. and Bisaha, J.P. (1979) Precognitive remote viewing in the Chicago area: A replication of the Stanford experiment, *J. Parapsychology* **43**, 17–30.
16. Puthoff, H.E. and Targ, R. (1976) A perceptual channel for information transfer over kilometer distances: Historical perspective and recent research, *Proc. IEEE* **64**, 329–354.
17. *J. Scientific Exploration* **10**, 1–184.
18. Bisaha, J.P. and Dunne, B.J. (1977) Multiple subject and long distant precognitive remote viewing of geographical locations, in *Proc. Int'l. Conf. Cybernetics & Society, Washington, DC, September 19–21, 1977* (sponsored by IEEE Systems, Man and Cybernetics Society), pp. 512–516.
19. Jahn, R.G., Dunne, B.J., and Jahn, E.G. (1980) Analytical judging procedure for remote perception experiments, *J. Parapsychology* **44**, 207–231.
20. Dunne, B.J. and Jahn, R.G. (2003) Information and uncertainty in remote perception research, *J. Scientific Exploration* **17**, 207–241.
21. Jahn, R.G. and Dunne, B.J. (1986) On the quantum mechanics of consciousness with application to anomalous phenomena, *Foundations of Physics* **16**, 721–772.
22. Jahn, R.G. and Dunne, B.J. (1997) Science of the subjective, *J. Scientific Exploration* **11**, 201–224.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 95–110

A NEW CONCEPTUAL FRAMEWORK FOR PHYSICS: SOME THOUGHTS ON WHERE AND HOW TO BEGIN

EMILIOS BOURATINOS
Petaloudas 2, Ekali
Athens, GR–145 65, Greece
(ebouratinos@hol.gr)

Abstract: If 20th century physics have taught us one thing, it is that its findings point way beyond its conceptual framework. It doesn't mean we need a new epistemology or a new paradigm. What we need is a pre-epistemology and a non-paradigm. We must learn to think in terms of what we apprehend. We must stop apprehending in terms of what we think. The basic task is to become aware of how we objectify the world – and why we lock into our objectifications once we do. Pre-epistemology will help us understand nature in more subtle ways. A non-paradigm will help us avoid getting stuck on any conception whatever. Quality cannot be appreciated by a person obsessed with quantity; non-local connections don't reveal themselves to localising mindsets; dynamic processes are not accessible to a structure-mediated worldview. Nothing of this means we should discard the tools of modern science. It only means their use should become more discerning. Ultimately three things matter: (1) that we keep systems and minds open; (2) that in fragmenting and abstracting nature we never lose sight of its oneness; (3) that what we count doesn't dictate for us what counts.

Keywords: Pre-Epistemology – Objectification – Abstraction – Paradigm – Worldview

> *He who [likes to] think must turn himself into an object of his thoughts, in keeping with [the practice of] original nature.*
> Plato

> *Our notions of physical reality can never be final. We must always be ready to change these notions — that is to say, the axiomatic structure of physics — in order to do justice to perceived facts in the most logically perfect way.*
> Albert Einstein

> *Certain scientific anomalies are recognized only after they are given compelling explanations within a new conceptual framework.*
> Alan Lightman and Owen Gingerich

1 Introduction

If 20th century science has taught us one thing, it is that its breakthroughs point way beyond its conceptual framework. This has happened in a dual sense. The first touches on the capacity of researchers to translate their quantitative findings into a qualitative overview of the area under their investigation. For example, biologists discovered long ago that a sponge or hydra reassembles in water cell by cell after it has been crushed to pulp and passed through a sieve. Has this inspired any thoughts among them on what may explain the phenomenon — what ordering principle may be involved and how it gets the job done?

The second sense in which the breakthroughs of 20th century science point beyond its conceptual framework touches on the capacity of researchers to discern the theoretical implications of their findings for science as a whole. For example, ontogenesis occurs in organic matter on a much more complex level of organisation than it occurs in inorganic. Has this weakened the belief in reductionism as the royal road to explaining nature? Has it inspired any thoughts on the qualitative link between part and whole, or on how to reach the latter through (and in) the former?

In both cases it is clear that researchers find it increasingly difficult to translate *what* they find into *how* they think. They believe that facts are independent of mind and speak for themselves. Werner Heisenberg has described this tendency in relation to quantum mechanics:

> "When new groups of phenomena compel changes in the pattern of thought?" he wrote, "even the most eminent of physicists find immense difficulties." [1]

One wonders what he would have said had 'the new groups of phenomena' concerned not a mere scientific revolution, like quantum mechanics, but a revolution in the very way that science thinks of — and therefore goes about — its business.

One cannot know, of course, how Heisenberg would have reacted. But the fact remains that quantum mechanics has only an empirical base. The reality on the ground enlightens the researcher. The researcher enlightens the reality on the ground only if – and to the extant that – he perceives it through its own eyes. So it is probable that Heisenberg would have acknowledged the need for inviting nature to tell us more about herself than we presently allow her. In so doing he would have walked in the footsteps of Leonardo da Vinci who, through his insatiable curiosity for how things work, was able to develop an excellent grasp of the underlying wholeness that makes them work as they do.

Not just physics, but biology and scholarship in general have exhausted the possibilities of object-mediated understanding. The latter doesn't only distort the picture of reality. It misleads society. As Arthur Koestler points out:

> "It has been said that science knows more and more about less and less. But that applies only to the fanning-out process of specialisation. One would be equally justified in saying that science knows less and less about more and more." [2]

2 The Power of Object-Mediated Understanding

Some epistemologists may protest against the view that 20th century advances in science have failed to impinge on the type of scientific thinking that is being done. They may point out that object-mediated conception (not to mention the object-mediated rationality it gives rise to) breaks down in quantum mechanics for the extremely small, in relativity for the extremely fast, in chaos theory for the extremely complex and in fuzzy logic for the extremely distinct.

The protestors may even remind us that the break-down of object-mediated conceptualisation was predicted as far back as 1720 by William Wollaston who wrote:

> "Both the beginnings and ends of things, the least and the greatest,... conspire to baffle us: which way ever we prosecute our inquiries, we still fall in with fresh subjects of amazement and fresh reasons to believe that there are infinitely more and more behind, that will for ever escape our earnest pursuits and deepest penetration." [3]

How can one answer the claim of epistemologists that the great advances in 20th century physics have changed the way scientists think? They certainly have a point when they claim that object-mediated understanding hasn't prevented science from discovering that in both the microcosm and the macrocosm one can no longer speak of objects in the usual sense. Careful examination shows however that this view applies only to what relativity, quantum mechanics, chaos theory and fuzzy logic have done to the *image* of reality. It doesn't apply to how people in the field actually *conceive* this image, leave alone how (and why) they *construct* it as they do.

For example, scientists know perfectly well that the level of organisation on which we humans exist — somewhere between the very large and the very small — is just one of many. But they keep trying to fathom the other levels on the basis of a conceptual framework that has been moulded entirely by how the human senses function. Thus most scientists are still convinced that the breakdown of object-based structures in the distant levels of physical organisation (like the very small or the very large) is inherent in nature herself, not in their mode of apprehending her or categorising her.

So such people go in for continuously more complex patterns of interaction and complicated forms of mathematical investigation to explain what they encounter in these 'remote' areas. The many paradoxes appearing at the far ends of the spectrum of understanding are the direct product of this tendency. It looks as though non-objects cannot be treated as objects with theoretical impunity.

3 Thinking about Ten Dimensions in Terms of Three

How important this discrepancy has become is revealed when one reflects on string theory — a typical product of the tendency to apply object-mediated thinking to non-object-based reality.

Only a few years ago string theory stipulated the existence of 28 dimensions. Now it stipulates only ten. But the current conceptual framework has been moulded by experiences in a three dimensional world — i.e. in an object-informed reality. When Einstein seemed to have added a fourth dimension (time) to the other three, there was a negative reaction not only in the scientific community, but in the educated public. People simply could not (and still cannot) conceive of a four-dimensional universe with a mindset moulded by three-dimensional experiences[a]

Einstein's relativity raises many fundamental questions about how we conceive reality — not least because he himself, contrary to Lorentz, had stipulated that there will be a change in the conceptual framework of humans approaching the speed of light. Lorentz had come up separately with the same equations as Einstein, but had failed to interpret them properly. As David Bohm and F. David Peat point out [4], the reason for Lorentz' failure is that "he held on to old ways of thinking in new situations that called for fundamental change".

[a]Three dimensional experiences are intimately tied up with three dimensional objects. The three dimensions are responsible for giving objects distinct boundaries, forms, possibilities and functions. These features appear to be permanent, so that the particular objects they refer to are always recognisable. Furthermore, the features are mutually exclusive.

This wasn't due to some special failure of Lorentz'. According to Bohm and Peat, it was due to

> "the mind's strong tendency to cling to what it finds familiar and to defend it against what threatens seriously to disturb its overall balance." [4]

As for Einstein, he dealt with the problem of thinking about a four-dimensional universe with a three-dimensional mindset simply by unifying space and time into a single dimension — spacetime. However, it is difficult to imagine how Einstein would have managed to squeeze a ten-dimensional universe into a three dimensional conceptual framework.

More than any other, this mental squeezing of physical operations into pre-existing theoretical schemes illustrates the conceptual problem of modern physics. Edward Witten, a string theory protagonist, is so bedevilled by it that he recently told Dennis Overbye of the New York Times:

> "The lesson may be that time and space are only illusions or approximations, emerging somehow from something [even] more primitive and fundamental about nature. It's a new aspect of the theory. Whether we are getting closer to the deep principle, I don't know"... It's plausible that we will one day understand string theory." [5]

That is a strange situation for a string theorist to have ended up in — for three reasons. The first is that Witten acknowledges that the people working on strings don't really understand the theory. The second reason is that, not really understanding what they are working on, string theorists expose themselves to the danger of making a lot more mistakes than others who do understand what they are doing. The third reason, pointed out by Leonard Susskind [6], is that "string theory has so many solutions that [it opens up] an incredible landscape of possibilities". This is perhaps why cosmologist Lawrence Krauss [6] — typical of a growing number of string theory detractors — has called it "a colossal failure".

Quite regardless of the above, string theorists are positing a series of interlinked profound epistemological questions without even being aware of so doing. For example:

Is the current conceptual framework capable of grasping what it means to exist without space and time, as Witten suggests? If not, is it desirable (and of course possible) to broaden scientists' current three dimensional conceptual framework so that it can deal with a ten-dimensional universe on its terms? If that again cannot be done, is it possible to imitate Einstein's example and enter the perceived extra dimensions into the three dimensioanl picture?

In so many words, can the current three dimensional conceptual framework of physics be stretched in a way that it not only accounts for what happens in a ten-dimensional universe, but assists people to actually experience it?[b] This would represent a very important contribution because the main reason we have such good knowledge of the object-mediated world is that we are able to experience it. Can we be expected to acquire good knowledge of a ten-dimensional world without experiencing it?

4 The Price of Self-Locking Objectification

The first thing we must do if we want to find satisfactory answers to just these questions is to examine not so much what consciousness is, but how it operates, why it operates as it does and how its operations affect our understanding. If we do that we will soon discover that we all engage in a specific mental practice which enables us to reify both the external and the internal world. Under certain circumstances, this practice can be derailed into an exclusive self-centred focus. Called 'self-locking objectification' when crystallised, this focus has negative long-term effects on the pursuit of truth in any form — scientific or philosophical.

'Self-locking objectification' unfolds in five stages. In the first we pick out those elements from our perceptions that are relevant both to our survival and our unique personal imperatives.[c] In the second stage we concretise these elements. In the third we abstract them from their natural imbeddedness in reality. In the fourth we lock mentally not just into the abstractions of these elements, but into their most obvious conceptual im-

[b] One way to do that would be to consider the additional dimensions (from No 5 to No 10) as mere extensions of the three originally accepted dimensions.

[c] It is here that the most striking qualitative difference between animals and humans comes to light. In both cases the brain acts like an all powerful filter. It doesn't only allow a small portion of the electromagnetic and sound waves bombarding the senses to come through. It edits out the vast majority of those that do. Life would be impossible without such a filtering process. However there is a marked difference in how animals and humans treat the filtering process. Animals blindly accept the relevant selection of waves that are admitted into their brains. They are happy merely to survive. Humans occasionally want something more — consciously or subconsciously. Thus they not only arrive at the conception of a whole, they develop a passion for actually becoming one with it. That is what explains the need for pursuing unification that informs mystics and scientists. Man knows that nature and his unique persona severely restrict his understanding of reality, but he also seeks ways to get around this limitation.

plications. In the fifth stage finally we project the abstractions both on all that we subsequently perceive and on how we make sense of it.

The net outcome of developing self-locking objectification is that we are incapable of seeing the world as a whole, across dimensions, potentialities, activities and formal expressions. We construct it as we carve it up in the light of our experience in the middle world, sandwiched between the micro- and the macro-cosm.[d]

For example, if we measure the position of a quantum system we obtain a position — i.e. particles; if we measure its momentum we obtain a momentum — i.e. waves; if we measure its charge we obtain a charge — i.e. energy. But all these self-locking objectifications don't allow us to identify a unity at the base of what we observe. By focusing on the particulars we lose the general picture. We see in terms of exclusions rather than inclusions; of forces rather than adjustments; of influences rather than interpenetrations.

It is not all that different from the situation referred to by Xenophanes in the 6th century B.C.. In describing the way we project our patterns of understanding onto what we perceive, Xenophanes [7] observed:

> "The Ethiopians maintain that their gods are snub-nosed and black, the Thracians that theirs have light blue eyes and red hair!"

5 Synthesis in Terms of Analysis

That's not the end of the story either. Because self-locking objectification has taught us to analyse in order to understand, we are stuck on analytical thinking. It is difficult for us to develop synthetic thinking — even when we are confronted with the need to put things together. Because we have learnt to perceive things exclusively, we don't really compose them, we merely add them up or place them next to one another in a series. It is difficult for us to develop inclusive perception — even when all we perceive cries out for it.

The same applies to other conceptual practices. In the physical world we have discovered many non-linear links; but we still use linear ways to study them. Increasingly we detect dynamic relationship; but we still see this like a series of static states in rapid succession to one another. We have come to learn that reality is shot through with non-local interactions; we

[d]An indication of this means may be derived from the fact that the two universal extremes are separated by 60 orders of magnitude.

still insist on studying these with the help of conceptual tools fashioned for the handling of local phenomena.

As Arthur Koestler [8] comments:

> "It is time for us to draw the lessons from 20th century post-mechanistic science and to get out of the strait-jacket which the 19th century... imposed on our philosophical outlook.... Had that outlook kept abreast with modern science itself, instead of lagging one century behind it, we would have been liberated from the strait-jacket long ago."

Incidentally, this was written some 40 years ago.

6 Many Modes of Knowing

Nothing of what has been said means that we need a new epistemology or a new paradigm, as many theorists maintain. We just need to learn to think in terms of what we apprehend, so that we can then see it as much as possible in its own light. Conversely, we need to stop apprehending in terms of what we think, so that *what* we apprehend can be free to reveal its face. How can this be achieved?

Through an in depth investigation of consciousness and the ways in which its operations inform what we feel, think and do — including science. Such an in depth investigation must have two prongs. The first is theoretical. Just as an object has many levels and aspects of organisation, so understanding involves many levels and aspects of conceptualisation. In examining a phenomenon, the first step is to establish which level and aspect of conceptualisation is used for which level and aspect of organisation. The second step is to become clear about which particular level and aspect of both organisation and conceptualisation are used as starting points for understanding.

Different people start from different levels and emphasize different aspects. It depends on their idiosyncrasy and on circumstance. So long as they are sensitive to the presence of other levels and aspects in both organisation and conceptualisation, there is clarity — and there is communication. Just as nature points to more than form, language points to more than meaning. The problem never is exhaustive analysis. The problem always is what informs the analysis, why and how.

Tacit awareness of other levels and aspects below, above, around or beyond the one on which a phenomenon occurs and is conceptualised, helps the investigator grasp it far better than if he perceived it in isolation, or through one conceptual framework alone. Phenomena are best understood when apprehended both in themselves and in their imbeddedness. One then gets to appreciate them simultaneously through different modes of knowing.

Thought doesn't depend on bringing together just object-mediated abstractions of the type science exclusively relies on. Other modes of knowing also contribute to the process of thinking — among them prehensions of fuzzy ontological articulations; glimpses into the ebb and flow of nature; intuitions of intractable units or patterns; and non-conceptual experiences of things, events and actions. Ordinary objectification, non-local receptivity, intuition, feeling, contemplation and mindfulness all conspire to illumine nature through their silent and seamless interpenetration.

The one mode of knowing doesn't obscure, adulterate, or exclude the other. It deepens, broadens and complements it. One perceives phenomena as they manifest because one also perceives in them more than they manifest — and more than they achieve. Inter-level, inter-aspected, inter-conceptual and inter-attitudinal understanding represent the first steps to a type of wholistic approach that doesn't get trapped in its image, lost in its parts, or stuck in its mechanics — *should* such exist.

7 Have Consciousness Studies Failed?

The second prong of an in-depth investigation of consciousness is experimental. It started already in the early eighties through the pioneering work of such people as John Searle, Francis Crick, Antonio Damasio, Joseph Le Doux, Suzan Greenfield, Stewart Hameroff and others. Today, 25 years later, we have accumulated lots of information on how the brain works. Even so, we have yet to understand what consciousness is or how it appears — *if* synaptic firing produces it, *if* synaptic firing merely correlates with it[e] or *if* consciousness generates synaptic firing so that the brain then focuses it and enhances it.

The reason we haven't come up with answers on these questions is that our conceptual framework is object-dominated. All the major people involved in consciousness research go about their subject as though consciousness is some virus or unknown force, which can be discovered and investigated like other viruses or forces. They think in terms of self-locking objectification. Consciousness, they believe, is an objective entity or state — elusive perhaps in its nature like the neutrino — but an entity all the

[e]The planet Venus correlates with the darkening of the sky every evening. But Venus neither produces the darkening of the sky at night, nor is it produced by the darkening of the sky.

same. With more refined machinery and more sophisticated analysis it cannot but yield its secrets.

Little attention has been paid to the fact that consciousness must before anything else act like a mirror to its own self. It bridges the famous subject-object divide. We cannot examine it without at the same time becoming conscious of what we are investing in that examination. As Aristotle [9] put it, "understanding is the understanding of understanding."

So let us briefly look at where this notion of self-reflexion comes from and how it can help us in our quest of a new conceptual framework for physics to begin with and for science as a whole a little later.

8 A Consciousness Conscious of Itself

The first great exponent of Aristotle's self-reflective epistemological premise was Socrates. He criticised the thinkers before him because they expounded on nature without first examining their own selves. Without such examination, Socrates maintained, it is impossible to know what you project from, edit out or value in your perceptions — leave alone your conceptions. As both Plotinus and Goethe reformulated the Socratic principle, the understanding of the knower must be adequate to the thing known.

Of course, on the face of it, science *does* seek self-reflection. It must be critical of its operations or it fails to achieve what it is supposed to. However, today self-reflection in science refers mainly to research protocols, to the accuracy of collected information, or to the tampering with results. It doesn't refer to the conceptual foundations underlying research itself.

There isn't even agreement on what exactly constitutes a scientific fact. As Andrew Marino points out, science today accepts several kinds of evidence as 'scientific'. However people don't agree on which kind is appropriate for which area of research [10]. The old classical saying that "a fact is a fact is a fact etc. *ad infinitum*" — seems not to be true after all. A fact *is* what we agree is a fact.

A degree of self-reflection on the part of future consciousness researchers would allow them to establish a level of discussion that will be better suited for examining their findings. This should also take into account two additional components. The first is experimental data showing robust interaction between human intention and animate, as well as inanimate, systems [11].[f] The second factor is the various mental attitudes, professional

[f] The work of Tiller and collaborators is similar to that of Bob Jahn at Princeton in the last 27 years.

interests and paradigmatic constraints which shape most thinking in the scientific discussion of consciousness.

Both these components demand of the consciousness researcher to go much deeper than paradigm, psychology, brain research, air-tight protocols or even epistemology dictate. A level of understanding needs to be accessed which, for lack of a better word, is here called *'pre-epistemic'*. What exactly happens on that level?

9 A Pre-Epistemic Examination of Objectification

Conception is not possible without perception; perception is not possible without recognition; and recognition is not possible without reification. Thus, if epistemology is concerned with how we know what we know all the way down to representation, pre-epistemology is concerned with how we objectify what we objectify, so that we *can* know what we do know. Usually objectivity is believed to apply only to how we think about things. It should be applied also to how we apprehend them to begin with. You cannot be objective about the world without being objective about objectivity itself.

The question of objectification relates specifically to Heisenberg's uncertainty principle. People usually take it to mean that knowledge in the micro-cosm is uncertain. Here Heisenberg's principle is taken to mean that we can never know the micro-cosm in its entirety, or even only a portion of it, through objectification. The same probably goes for the macro-cosm.

Of course, objectification is imperative in science. But we need to understand the processes whereby it happens. Throughout his many papers and books, consciousness researcher Max Velmans has repeatedly drawn attention to the issue of gradual objectification from the unconscious to the pre-conscious and the conscious [12]. Objectification processes in the brain are gradual — in both electrochemical and temporal terms.

10 The Many Aspects of Objectification

It means that objectification has many aspects and involves several questions. They all need to be thoroughly investigated. We must learn how we objectify the world so that we can then better secure the objective understanding of it.

One question that comes up is how we distinguish among fully objectified entities[g] and entities that haven't yet objectified themselves fully. A

[g] By 'fully objectified entities' are here meant those units of perception which have reached the full expression of their formal potentialities.

second question is whether we ourselves have fully objectified these entities or not. A third is what causes objectification to begin with. Does it depend on the ontological predilection of the apprehending individual, is it an independent process, or is it perhaps a combination of the two? What are the conditions for an external or internal event to thrust itself on our attention regardless of personal predilections?

More importantly, where does the objectification process begin? Could it start during the initial sensing stage, when we merely suspect that something like a virtual particle may be articulating itself? What then is the feel associated with this initial sensation and to what extent is it woven into the objectification process itself?

Equally important is whether we choose to objectify certain entities rather than others. Or whether (and why) we choose to objectify certain *kinds* of entities rather than others. Or how we evaluate what we objectify both in itself and in relationship to other entities. Who or what dictates the criteria informing this evaluation?

11 A Language Adequate to What It Describes

A good part of the answer to these questions depends on whether we extrapolate from vision[h] onto how we work our objectifications into representations, as Aristotle did. Do we perceive our objects as building blocks, or as local manifestations of the whole? This needs to be thoroughly looked into. If we see objects as local manifestations of the whole, we need to examine whether we are accessing wholeness on its own terms, or we are accessing it only through an expansion of, or reaction to, fragmentation.

Which also forces us to ask: do we really apprehend anything as it is? Can we claim, like Socrates, that there exist 'things in themselves'? More significantly, can we say that our abstractions of objects reflect the same qualities as the objects themselves — and if not to what degree? Can we create such symbols as will allow us to both specify and point away from specification, without losing their specificity in the process?

But the most significant question is the following: do we release our objectifications after they've served their purpose, or do we lock into them, thereby influencing future objectifications? The fact that on the whole

[h]Alfred North Whitehead wrote a whole book [13] to show that even such seemingly objective concepts as time and space actually originate in the senses — and are therefore aspects of conscious experience. They cannot be considered objective components of reality. To illustrate how much we edit what comes in through the eyes, Evan Harris Walker mentions in [14] "that the information carried by the optic nerve occupies ten-to-the-fourth channels [fibres], each capable of transferring about ten-to-the-sixth bits/sec!"

we *don't* release our objectifications, has bedevilled civilisation ever since the invention of alphabetic writing, if not earlier. By not releasing our objectifications once we are done with them, we extend the rationale of what we conceive in one area, or at one moment, into other areas or other moments, glossing over possible differences.

12 Function Exceeds Structure

The realisation that what we apprehend in all probability doesn't reflect faithfully either what is going on in the brain or what is going on in the world, has profound implications [15]. For example, in inorganic matter the scientist gains a lot from observing physical and chemical interactions. In organic matter he gains less. Physicist Walter Elsasser and biochemist Marian J. Wnuk point out why [16].[i] Organic matter, they say, is more complex functionally than it is structurally. A complicated operation doesn't require an equally complicated physical substrate of the kind that correlates function to structure in inanimate matter.[j]

One can go even further than Elsasser and Wnuk. One can maintain that the above disparity between structure and function outlines the essential difference between animate and inanimate matter. In nature there is no parity between being and doing. If inanimate matter is usually more than it does, animate matter always does more than it is — and of course consciousness does even more.

13 Relevant Knowledge

The little that has been said about the domain of pre-epistemology shows that epistemology too requires fundamental rethinking. The propriety of information cannot depend on some pre-determined conception. It can depend only on the living relevance of you, the researcher, to the circumstances surrounding the subject you are researching. That covers equally the present state of the subject you are researching; its relevance to you personally; the whole informing both the object and yourself; and finally your willingness (and ability) to be critical of all these without wallowing in either doubt or self-assertion.

The universe is multiaspected and obliging enough to respond to any

[i] Having first made the point that living organisms are much more complex than inorganic matter, Elsasser makes the following observation: "If a complex heterogeneous structure... is large enough, the number of possible patterns [of interaction] might vastly exceed the number of members of the class that can exist in a finite world."

[j] This applies particularly to those levels of organisation determined by unchanging basic laws — those rooted in Planck's constant.

inquiry into its ways — provided the inquiry has been initiated by the universe itself. The latter must act this way because, as Karl Gustafson [17] points out,

> "each of us is a relatively coarse observational filter upon a world far more complex and rich than our perceptions will ever allow us to know."

We can understand the universe only to the extent that we invite it to illumine us on its own terms.

This doesn't mean that we should abandon the well tested methods of observing and studying physical existence. It just means that we should stop seeing objectivity in terms of objects. Instead we should start seeing it in terms of a keen interest in how natural and personal bias skew reality. Since organisational bias is responsible for how nature has evolved and personal bias is responsible for how we bias that bias, getting to know where the first ends and the second begins is the key to objectivity.

That is why the common mathematical language describing reality has only limited possibilities. As Tony Rothman and George Sudarshan [18] put it:

> "Because we can make a precise mathematical description of a phenomenon, we fool ourselves into thinking that we have described the physical world."

In reality we have described very little of it. As Bertrand Russell [19] observes:

> "Physics is mathematical not because we know so much about the world, but because we know so little: it is only its mathematical properties that we can discover."

14 The Scientific Philosopher and the Philosophical Scientist

Not just every object differs; every piece of knowledge does. Specific knowledge constitutes as much a unique entity as the object it illumines. It changes as much as the object. When reality appears tentative, so appears the knowledge of it; when reality appears permanent, a permanent watch is kept over it just in case it turns out not to be permanent. Willard Van Orman Quine [20] says:

> "Even our epistemological convictions about what it means to acquire knowledge and about the nature of explanation, justifi-

> cation and confirmation — i.e. about the nature of the scientific enterprise itself — may be subject to revision and correction."

Ultimately three things matter only in the pursuit of science. The first is that we keep systems and minds open. The second is that in fragmenting and abstracting nature, we never lose sight of its oneness. The third is that in pursuing the mathematical description of reality we make certain that what we count doesn't dictate for us what counts.

Plato's well known dictum in the *Republic* [21] that kings should become philosophers and philosophers kings, requires some editing to meet the needs of improved understanding in science today. Such an edited version might read as follows:

Scientists should become philosophers and philosophers scientists. Scientists need to learn more about how to think, thinkers need to learn more about how science operates. Both need to learn more about what informs their science and their thinking. Hence the requirement for a new conceptual framework for physics. We want to create a science that is not only about the world, but about itself as a student of the world. It's the only way to develop the kind of certainty that knows both its area of applicability and its limitations — without confusing the one with the other.

References

1. Heisenberg, W. (1974) *Across the Frontiers*, Harper & Row, New York, p. 162.
2. Koestler, A. (1974) *The Roots of Coincidence*, Picador (published by Pan Books), London, p. 139.
3. Wollaston, W. (1720) *The Religion of Nature Delineated*, I. and P. Knapton (7th edition), p. 144.
4. Bohm, D., and David Peat, F. (1989) *Science, Order and Creativity*, Routledge, London, pp. 21–22.
5. Overbye, D. (2004) String theory may explain all, but scientists remain perplexed, *New York Times*, December 17 Issue.
6. 't Hooft, G., *et al.* (2005) A theory of everything?, *Nature* **433** (January 20 Issue), 257–259.
7. Xenophanes, *Fragment 16*, translated by G. S. Kirk and J. E. Raven.
8. Koestler, A. (1974) *ibid.*, pp. 138–139.
9. Aristotle, *Metaphysics*, 11. 1074.
10. Marino, A. (2000) In the eye of the beholder: The role of style of thought in the determination of health risks from electromagnetic fields, *Frontier Perspectives* **9**(2), 22–27.
11. Tiller, W.A., Dibble, W.E. Jr., and Kohane, M.J. (2000) Exploring robust interactions between human intention and inanimate/animate systems, *Frontier Perspectives* **9**(2), 6–21.

12. Velmans, M. (2000) *Understanding Consciousness*, Routledge, London; see also Velmans, M. (2002) How could conscious experience affect brains?, *Journal of Consciousness Studies* **9**(11), 3–29, and Velmans, M. (1998) Goodbye to reductionism, in S. Hameroff, A. Kaszniak and A. Scott (eds.), *Towards a Science of Consciousness II: The Second Tucson Discussions and Debates*, MIT Press, Cambridge (MA).
13. Whitehead, A.N. (1920) *The Concept of Nature*, Cambridge University Press, Cambridge.
14. Walker, E.H. (1970) The nature of consciousness, *Mathematical Biosciences* **7**, 131–178.
15. See also the 2002 special issue of the *Journal of Consciousness Studies* under the general title "Is the Visual World a Grand Illusion?", **9**(5/6); especially the articles by Noe, A., 'Is the visual world a grand illusion?', Hoffman, D.D., and Rodriquez, A.M., 'Visual world: Construction or reconstruction?', and by Rowlands, M., 'Is seeing all it seems? Action, reason and the grand illusion'.
16. Wnuk, M.J., and Bernard, C.D. (2001) The electromagnetic nature of life: The contribution of W. Sedlak to the understanding of the essence of life, *Frontier Perspectives* **10**(1), 32–35; Elsasser, W. (1987) *Reflections on a Theory of Organisms*, Editions Orbis Publishing, Frelighsburg (Quebec), p. 41.
17. Gustafson, K. (2002) Time, temporality, now, *Journal of Scientific Exploration* **16**(2), 278–280.
18. Rothman, T., and Sudarshan, G. (1998) *Doubt and Certainty*, Helix Books, Reading (MA), p. 39.
19. Quoted in Koestler, A. (1974) *ibid.*, p. 99.
20. Harman, W.W. (1974) Taking Holons seriously: Toward a more adequate epistemology for the study of consciousness, paper presented in the Tucson Medical School conference *Toward a Science of Consciousness II.*
21. Plato, *Republic*, 5–473c.

CHAPTER II:

~TIME~

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 113–130

THE NATURE OF TIME AS A CONSEQUENCE OF HOW WE CONSTRUCT THE WORLD

DIEDERIK AERTS and BART D'HOOGHE
Leo Apostel Centre for Interdisciplinary Studies (CLEA)
Vrije Universiteit Brussels, Krijgskundestraat 33
1160 Brussels, Belgium
(diraerts@vub.ac.be, bdhooghe@vub.ac.be)

Abstract: In classical physics there was a clear understanding of what physical space and time are: physical space is the theatre of the collection of all events that are actual at a certain moment of time, and physical time is the parametrization of the flow of time. 3-dimensional space and 1-dimensional time have been substituted by 4-dimensional time–space in relativity theory. But if reality is the 4-dimensional time–space manifold of relativity theory, what is then the meaning of 'change in time'? We investigate this problem of relativity theory by following an operational approach originally elaborated for quantum mechanics. We show that the contradiction between a geometric view and process view of reality is due to a misconception in the interpretation of relativity theory. We argue that it is not time which is space-like, with the inevitable paradoxical situation of a block universe as result, but on the contrary, it is space which is time-like. This 'dynamic', 'time-like' conception of space answers the question of the meaning of 'change in time' within the 4-dimensional reality of relativity theory, and puts forward a new view on other aspects of the theory.

Keywords: Time – Space – Reality – Relativity Theory – Quantum Mechanics

1 Introduction

> *Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality.*
>
> Hermann Minkowski

> *The scene of action is not a three-dimensional Euclidean space, but rather a 4-dimensional world, in which space and time are linked together indissoluble. However deep the chasm may be that separates the intuitive nature of space from that of time in our experience, nothing of this qualitative difference enters into the objective world which physics endeavours to crystallise out*

> *of direct experience. It is a 4-dimensional continuum, which is neither 'time' nor 'space'. Only the consciousness that passes on in one portion of this world experiences the detached piece which comes to meet it and passes behind it, as history, that is as a process that is going forward in time and takes place in space.*
>
> Hermann Weyl

What is reality? What is space? And what is time? These are three questions that we want to investigate. Our intuitive pre-scientific conception of the world in relation with these three notions is not very precise but could be summarised as follows.

- Reality is everything that exists now in the present. The past has been real but is no longer and the future is what shall become real but is not yet.
- Space is the theatre where reality is in. It englobes all of reality.
- What is real changes continuously and time describes and parametrises this change of reality.

Till the birth of relativity theory all physical theories where compatible with this intuitive scheme. But when relativity theory entered the scene, these intuitive conceptions of space and time, and what is less recognised even till today, also the conception of reality, has got into problems. We deliberately state the revolution that happened in the beginning of this century in this vague way, because we believe that the trouble that relativity theory has brought to our understandings of space, time and reality has still not been resolved. It has not even be identified fully, because in many textbooks about relativity theory the impression is given that we fully understand this strange theory and its implications on the nature of space, time and reality. Perhaps historically this is due to the fact that very shortly after the conceptual earth-quake that was generated by relativity theory, quantum mechanics appeared on the scene. The conceptual problems introduced by quantum mechanics, also related to the fundamental nature of space, time and reality, were much bigger still. And partly because of this reason — many brilliant young theoretical physicists started to work on quantum mechanics struggling with the multitude of conceptual and technical problems that appeared there — relativity theory started to get considered more and more as a well understood physical theory. The problem with the interpretation of quantum mechanics was, and partly still is, also a problem related directly to the question 'What is reality?'. Many investigations stimulated by this question have been undertaken in relation with quantum mechanics, and many aspects have been clarified meanwhile. In this paper we shall use some of the insights that have been gained about the three fundamental questions that we have put forward by the investigations on the interpretation of quantum mechanics — more specifically the progress that has been made to axiomatise quantum mechanics in an operational way [1]–[19] — and apply them to relativity theory. We shall be able in this way to understand certain fundamental questions about time, space and reality [20]–[25]. As a rather amazing result we will show that physical reality is 4-dimensional, as presented in [20, 21, 22], or 3-dimensional, depending on whether we accept the Einsteinian or Lorentzian interpretation of relativity theory. The way in which this 4-dimensionality shows itself is however fundamentally different from the way imagined by Minkowski and Weyl. The reflections and results presented in this paper are a continuation of the material exposed in [16, 18], but we have written the paper in such a way that it is self-contained.

2 What is Reality? An Operational Criterion

If we repeat our intuitive conception of time - formulated as 'Time describes and parametrises the change of reality' - it becomes obvious that we cannot understand the nature of time until we have obtained a clear understanding of the nature of 'reality'. Therefore, before coming to our analysis of the concept of time in modern physics, we will concentrate on the concept of reality. Let us again repeat our intuitive notion of reality as 'everything that exists now in the present' and then put forward the way in which we shall analyse this concept in a rigorous manner. Here we use the idea of 'now' and 'present'. If we would like to define also these concepts, we would come into a circular situation, needing time to define reality. Therefore, and also because it seems to us the most profound approach, we will consider as a primary — and hence undefined — concept the concept of 'present experience'.

2.1 Experiences

We consider an experience to be an interaction between a participator — we consciously use here the word 'participator' instead of the word 'observer' to indicate that we consider the cognitive receiver to participate creatively in his or her cognitive act — and a piece of the exterior world. When the participator lives such an experience, we will say that this experience is present, and we will call it the present experience of the participator. When we consider the situation of a measurement then we conceive this as the experimentator and his experimental apparatus together being the participator, and the physical entity under study to be the piece of the exterior world that interacts with the participator. The experiment is then the experience. Let us give some examples of experiences. We consider the following situation: I am inside my house in Brussels. It is night, the windows are shut. I sit in a chair, reading a novel. I have a basket filled with walnuts at my side, and from time to time I take one of them, crack it and eat it. My son is in bed and already asleep. Paris 'by night' exists and is busy. Let us enumerate the experiences that are considered in such a situation: E_1: *I read a novel*, E_2: *I experience the inside of my house in Brussels*, E_3: *I experience that it is night*, E_4: *I take a walnut, crack it and eat it*, E_5: *I see that my son is in bed and asleep*, E_6: *I experience that Paris is busy.*

The first very important remark I want to make is that obviously I do not experience all these experiences at once. On the contrary, in principle, I only experience one experience at once, namely my present experience. Let us suppose that my present experience is E_1: *I read a novel.* Then a lot of other things happen while I am living this present experience. These things happen in my present reality. While 'I am reading the novel' some of the happenings that happen are the following: H_1: *the novel exists*, H_2: *the inside of my house in Brussels exists*, H_3: *it is night*, H_4: *the basket and the walnuts exist, and are at my side*, H_5: *my son is in bed and is sleeping*, H_6: *Paris exists and is busy.* All the happenings, and much more, happen while I live the present experience E_1: *I read a novel.*

Why have I ordered the collection of my possible experiences in such a way that what I am just saying is evident for everybody (and therefore shows that we are not conscious of the specific ordering that is behind this evidence)? Certainly it is not because I experience also these other happenings. My only present experience is the experience of reading the novel. But, and this is the reason for that I have chosen fruitfully to order the collection of my possible experiences in this way, I could have chosen to live an experience including one of the other happenings in replacement of my present experience. Let me put down the list of these experiences that I could have chosen to experience in replacement of my present experience: E_2: *I observe that I am inside my house in Brussels*, E_3: *I see that it is* *night*, E_4: *I take a walnut, crack it and eat it*, E_5: *I go and look in the bedroom to see that my son is asleep*, E_6: *I go to Paris and see that it is busy.*

This example indicates how we have started to model reality. First of all we have tried to identify two main aspects of an experience. The aspect that is controlled and created by me, and the aspect that just happens to me and can only be known by me. Let us introduce this important distinction in a formal way.

2.2 Creations and happenings

To see what I mean, let us consider the experience E_4: *I take a walnut, crack it and eat it.* In this experience, there is an aspect that is an action of me, the taking and the cracking, and the eating. There is also an aspect that is an observation of me, the walnut and the basket. By studying how our senses work, I can indeed say that it is the light reflected on the walnut, and on the basket, that gives me the experience of walnut and the experience of basket. This is an explanation that only now can be given; it is, however, not what was known in earlier days when the first world models of humanity were constructed. But without knowing the explanation delivered now by a detailed analysis, we could see very easily that an experience contains always two aspects, a creation aspect, and an observation aspect, simply because our will can only control part of the experience. This is the creation aspect.

For example, in E_1: *I read a novel* the reading is created by me, but the novel is not created by me. In general we can indicate for an experience the aspect that is created by me and the aspect that is not created by me. The aspect not created by me lends itself to my creation. We can reformulate an experience in the following way: E_4: *I take a walnut, crack it and eat it* becomes E_4: *The walnut is taken by me, and lends itself to my cracking and eating* and E_1: *I read a novel* becomes E_1: *The novel lends itself to my reading.*

The taking, cracking, eating, and reading will be called creations or actions and will be denoted by C_4: *I take, crack and eat* and C_1: *I read.* The walnut and the novel will be called happenings and will be denoted by H_4: *The walnut* and H_1: *The novel.*

Statement 1 (Creation, Happening) *A creation is that aspect of an experience created, controlled, and acted upon by me, and a happening is that aspect of an experience lending itself to my creation, control and action.*

An experience is determined by a description of the creation and a description of the happening. Creations are often expressed by verbs: to take, to crack, to eat, and to read, are the verbs that describe my creations in the examples. The walnut and the novel are happenings that have the additional property of being objects, which means happening with a great stability. Often happenings are expressed by a substantive.

Statement 2 (Experience) *Every one of my experiences E consists of one of my creations C and one of my happenings H, so $E = (C, H)$.*

A beautiful image that can be used as a metaphor for our model of the world is the image of the skier. A skier skis downhill. At every instant he or she has to be in complete harmony with the form of the mountain underneath. The mountain is the happening. The actions of the skier are the creation. The skier's creation, in harmony fused with the skier's happening, is his or her experience.

2.3 The most basic modelling of the world: reality, present, past and future

Let us again consider the collection of experiences: E_1: *I read a novel*, E_2: *I observe that I am inside my house in Brussels*, E_3: *I see that it is night*, E_4: *I take a walnut, crack it and eat it*, E_5: *I go and look in the bedroom to see that my son is asleep* and E_6: *I go to Paris and see that it is busy.* Let us now represent the basic model of the world that is made out of this small collection of experiences. E_1: *I read a novel* is my present experience. In my past I could, however, at several moments have chosen to do something else and this choice would have led me to have another present experience than E_1: *I read a novel.* For example:

- One minute ago I could have decided to stop reading and observe that I am inside the house. Then E_2: *I observe that I am inside my house in Brussels* would have been my present experience.
- Two minutes ago I could have decided to stop reading and open the windows and see that it is night. Then E_3: *I see that it is night* would have been my present experience.
- Three minutes ago I could have decided to stop reading, take a walnut from the basket, crack it, and eat it. Then E_4: *I take a walnut, crack it and eat it* would have been my present experience.
- Ten minutes ago I could have decided to go and see in the bedroom whether my son is asleep. Then E_5: *I go and look in the bedroom to see that my son is asleep* would have been my present experience.

- Two hours ago I could have decided to take the plane and fly to Paris and see how busy it was. then E_6: *I go to Paris and see that it is busy* would have been my present experience.

Statement 3 *Even when they are not the happening aspect of my present experience, happenings 'happen' at present if they are the happening aspect of an experience that I could have lived in replacement of my present experience, if I would have decided so in my past.*

The fact that a certain experience E consisting of a creation C and an happening H is for me a possible present experience depends on two factors: (i) I have to be able to perform the creation, (ii) The happening has to be available. For example, the experience E_2: *I observe that I am inside my house in Brussels* is a possible experience for me, if: (i) I can perform the creation that consists in observing the inside of my house in Brussels. In other words, if this creation is in my personal power, (ii) The happening 'the inside of my house in Brussels' has to be available to me. In other words, this happening has to be contained in my personal reality.

Statement 4 *The collection of all creations that I can perform at the present I will call my present personal power.*

Statement 5 *The collection of all happenings that are available to me at the present I will call my present personal reality.*

I define as my present personal reality the collection of these happenings that are available to one of my creations if I would have used my personal power in such a way that at the present I can fuse one of these creations with one of these happenings. Happenings can happen at once, because to happen, a happening does not have to be part of my present experience. It is sufficient that it is available, and things can be available at once. Therefore, although my present experience is only one, my present personal reality consists of an enormous amount of happenings all happening at once. This concept of reality is not clearly understood in present physical theories. Physical theories know how to treat past, present and future. But reality is the order that we find in the 'possible'. We describe it by means of a modelization of the experiences that I could have lived but probably will never live.

2.4 Material time and material happenings

From ancient times humanity has been fascinated by happenings going on in the sky, the motion of the sun, the changes of the moon, the motions of the planets and the stars. These happenings in the sky are periodic.

By means of these periodic happenings humans started to co-ordinate the other experiences. They introduced the counting of the years, the months and the days. Later on watches were invented to be able to co-ordinate experiences of the same day. And in this way material time was introduced in the reality of the human species. Again we want to analyse the way in which this material time was introduced, to be able to use it operationally if we analyse later on the paradoxes of time and space.

My present experience is seldom a material time experience. But in replacement of my present experience, I always could have consulted my watch, and in this way live a material time experience E_7: *I consult my watch and read the time.* In this way, although my present experience is seldom a material time experience, my present reality always contains a material time happening, namely the happening H_7: *The time indicated by my watch*, which is the happening to which the creation C_7: *I consult* is fused to form the experience E_7.

We can try to use our theory for a more concrete description of that layer of reality that we shall refer to as the layer of 'material or energetic happenings'. We must be aware of the fact that this layer is a huge one, and so first of all we shall concentrate on those happenings that are related to the interactions between what we call material (more generally energetic) entities. We have to analyse first of all in which way the 4-dimensional manifold that generally is referred to as the 'time–space' of general relativity theory, is related to this layer of material or energetic reality. We shall take into account in this analysis the knowledge that we have gathered about the reality of quantum entities in relation with measurements of momentum and position.

3 Relativity and Reality

We consider now the set of all material or energetic happenings, and following our analysis in the foregoing section, this set represents physical reality. Let us try to find out now 'what reality is taking into account relativity theory?'. We'll make a rigorous analysis using our criterion of reality.

3.1 The nature of reality taking into account relativity theory

Let us suppose that I am here and now in my house in Brussels, and it is December 28, 2004, 4 PM exactly. I want to find out 'What is the material reality for me now?'. Let us consider a place in Paris, for example at the entrance of the Eiffel Tower, and let us denote, the centre of this place by (x_1, x_2, x_3). I also choose now a certain time, for example December

28, 2004, 4 PM exactly (always referring to Greenwich time), and let me denote this time by x_0. I denote the happening that corresponds with the spot (x_1, x_2, x_3) located at the entrance of the Eiffel Tower, at time x_0 by M. I can now try to investigate whether this happening M is part of my personal material reality. The question I have to answer is, can I find a creation of localisation L, in this case this creation is just the observation of the spot (x_1, x_2, x_3) at the entrance of the Eiffel Tower, at time x_0, that can be fused with this happening M. The answer to this question can only be investigated if we take into account the fact that I, who want to try to fuse a creation of localisation to this happening, am bound to my body, which is also a material entity. I must specify the question introducing the material time co-ordinate that I co-ordinate by my watch. So suppose that I co-ordinate my body by the 4 numbers (y_0, y_1, y_2, y_3), where y_0 is my material time, and (y_1, y_2, y_3) is the centre of mass of my body. We apply now our operational definition of reality. At this moment, December 28, 2004 at 4 PM exactly, my body is in my house in Brussels, which means that (y_0, y_1, y_2, y_3) is a point such that y_0 equals December 28, 2004, 4 PM, and (y_1, y_2, y_3) is a point, the centre of mass of my body, somewhere in my house in Brussels. This shows that (x_0, x_1, x_2, x_3) is different from (y_0, y_1, y_2, y_3), in the sense that (x_1, x_2, x_3) is different from (y_1, y_2, y_3) while $x_0 = y_0$. The question is now whether (x_0, x_1, x_2, x_3) is a point of my material reality, hence whether it makes sense to me to claim that now, December 28, 2004, 4 PM, the entrance of the Eiffel Tower 'exists'. If our theoretical framework corresponds in some way to our pre-scientific construction of reality, the answer to the foregoing question should be affirmative. Indeed, we all believe that 'now' the entrance of the Eiffel Tower exists. Let us try to investigate in a rigorous way this question in our framework. We have to verify whether it was possible for me to decide somewhere in my past, hence before December 28, 2004, 4 PM, to change some of my plans of action, such that I would decide to travel to Paris, and arrive exactly at December 28, 2004, 4 PM at the entrance of the Eiffel Tower, and observe the spot (x_1, x_2, x_3). We could give many concrete ways to realise this experiment, and we will not give here one in detail, because we shall come back to the tricky parts of the realisation of this experiment in the following example. But hence the answer is indeed affirmative: I could have experienced the spot (x_1, x_2, x_3) at December 28, 2004, 4 PM, if I would have decided to travel to Paris somewhere in my past. Hence (x_0, x_1, x_2, x_3) is part of my reality. It is sound to claim that the entrance of the Eiffel Tower exists right now. And we remark that this does not mean that I have to be able to experience this spot at the entrance of the Eiffel Tower now, December 28, 2004, 4 PM, while I am inside my house in Brussels. I repeat again, reality is a construction about the possible happenings that I could have fused with my actual creation. And since I could have decided so in my past, I could have been at the entrance of the Eiffel Tower, now, December 28, 2004, 4 PM.

Until this moment one could think that our framework only will confirm our intuitive notion of reality but our next example shows that this is certainly not the case. Indeed, let me consider the same problem, but now consider another point of time–space. I consider the point (z_0, z_1, z_2, z_3), where $(z_1, z_2, z_3) = (x_1, x_2, x_3)$, hence the spot we envisage is again the entrance of the Eiffel Tower, and z_0 is December 29, 2004, 4 PM exactly, hence the time that we consider is, tomorrow 4 PM. If I ask now first, before checking rigorously by means of our operational definition of reality, whether this point (z_0, z_1, z_2, z_3) is part of my present material reality, the intuitive answer here would be 'no'. Indeed, tomorrow at the same time, 4 PM, is in the future and not in the present, and hence it is not real, and hence no part of my present material reality (this is the intuitive reasoning). If we go now to the formal reasoning in our framework, then we can see that the answer to this question depends on the interpretation of relativity theory that we put forward. Indeed, let us first analyse the question in a Newtonian conception of the world to make things clear. Remark that in a Newtonian conception of the world (which has been proved experimentally wrong, so here we are just considering it for the sake of clarity), my present material reality just falls together with 'the present', namely all the points of space that have the same time co-ordinate December 28, 2004, 4 PM. This means that the entrance of the Eiffel Tower tomorrow 'is not part of my present material reality'. The answer is clear here and in this Newtonian conception, my present personal reality is just the collection of all (u_0, u_1, u_2, u_3) where $u_0 = y_0$ and (u_1, u_2, u_3) are arbitrary. The world is not Newtonian, but also if we put forward an ether theory interpretation of relativity theory (let us refer to such an interpretation as a Lorentz interpretation) the answer remains the same. In a Lorentz interpretation, my present personal reality coincides with the present reality of the ether, namely all arbitrary points of the ether that are at time y_0, December 28, 2004 4 PM, and again the entrance of the Eiffel Tower tomorrow is not part of my present material reality. For an Einsteinian interpretation of relativity theory the answer is different. To investigate this I have to ask again the question of whether it would have been possible for me to decide in my past such that I would have been able to make coincide (y_0, y_1, y_2, y_3) with (z_0, z_1, z_2, z_3). The answer here is that this is very easy to do, because of the well known, and experimentally verified, effect of 'time dilatation'. Indeed, it would have been sufficient that some weeks ago in my past, let us say November 28, 2004, 4 PM, I would have decided to step inside a space ship that can move with almost the velocity of the speed of light, such that the time when I am inside this space ship slows down in such a way, that when I return with the space ship to planet earth, still flying with a speed near the velocity of light, I arrive in Paris at the entrance of the Eiffel Tower while my personal material watch indicates December 28, 2004 4 PM, and the watch that remained at the entrance of the Eiffel Tower indicates December 29, 2004 4 PM. Hence in this way I make coincide (y_0, y_1, y_2, y_3) with (z_0, z_1, z_2, z_3), which proves that (z_0, z_1, z_2, z_3) is part of my present material reality.

First we have to remark that in practice it is not yet possible to make such a flight with a space ship. But this is not a crucial point for our reasoning. It is sufficient that we can do it in principle. Indeed, we have not yet made this explicit remark, but obviously if we have introduced in our framework an operational definition for reality, then we do not have to interpret such an operational definition in the sense that only operations are allowed that actually, taking into account the present technical possibilities of humanity, can be performed. If we would advocate such a narrow interpretation, then even in a Newtonian conception of the world, the star Sirius would not exist, because we cannot yet travel to it. What we mean with operational is much wider. It must be possible, taking into account the actual physical knowledge of the world, to conceive of a creation that can be fused with the happening in question, and then this happening pertains to our personal reality.

3.2 Einstein versus Lorentz: has reality 4 dimensions?

We can come now to one of the points that we want to make in this paper, and that clarifies the paradox of time that makes the difference between an ether interpretation of relativity (Lorentz) and an Einsteinian interpretation of relativity. Why would we come to a different result concerning the foregoing question, depending on whether we advocate an Einsteinian interpretation of relativity theory or an ether interpretation? To see clear in this we have to come back to the essential aspect of the construction of reality of our framework, which is the difference between a creation and a happening. We have to give first another example to be able to make clear what we mean.

Suppose that I am a painter and I consider again my present material reality, at December 28, 2004, 4 PM, as indicated on my personal material watch. I am in my house in Brussels and let us specify: the room where I am is my workshop, surrounded by paintings, of which some are finished and others I am still working on. Clearly all these paintings exist in my present reality, December 28, 2004, 4 PM. Some weeks ago, when I was still working on a painting that now is finished, I could certainly have decided to start to work on another painting, a completely different one, that now does not exist. Even if I could have decided this some weeks ago, all of you will agree that this other painting, that I never started to work on, does not exist now, December 28, 2004, 4 PM. The reason for this conclusion is that the making of a painting is a 'creation' and not a happening. It is not so that there is some 'hidden' space of possible paintings such that my choice of some weeks ago to realise this other painting would have made me to detect it. If this would be the situation with paintings, then indeed also this painting would exist now, in this hidden space. But with paintings this is not the case. Paintings that are not realised by the painter are potential paintings, but they do not exist.

With this example of the paintings we can explain very well the difference between Lorentz and Einstein. For an ether interpretation of relativity the fact that my watch is slowing down while I decide to fly with the space ship nearly at the speed of light and return at the entrance of the Eiffel Tower while my watch is indicating December 28, 2004, 4 PM and the watch that remained at the Eiffel Tower indicates December 29, 2004, 4 PM, is interpreted as a 'creation'. It is seen as if there is a real physical effect of creation on the material functioning of my watch while I travel with the space ship, and this effect of creation is generated by the movement of the space ship through the ether. Hence the fact that I could observe the entrance of the Eiffel Tower tomorrow December 29, 2004 4 PM, when I would have decided some weeks ago to start travelling with the space ship, only proves that the entrance of the Eiffel Tower tomorrow is a potentiality. Just like the fact that this painting that I never started to paint could have been here in my workshop in Brussels is a potentiality. This means that as a consequence the spot at the entrance of the Eiffel Tower tomorrow is not part of my present reality, just as the possible painting that I did not start to paint is not part of my present reality. If we however put forward an Einsteinian interpretation of relativity, then the effect on my watch during the space ship travel is interpreted in a completely different way. There is no physical effect on the material functioning of the watch, but the flight at the velocity nearly the speed of light 'moves' my space ship in the time–space continuum such that time co-ordinates and space co-ordinates get mixed. Certainly if we take into account that most of the time dilatation takes place not during the accelerations that the space ship undergoes during the trip, but during the long periods of flight with constant velocity nearly at the speed of light. This means that the effect of the space ship travel is an effect of a voyage through the time–space continuum, which brings me at my personal time of December 28, 2004, 4 PM at the entrance of the Eiffel Tower, where the time is December 29, 2004, 4 PM. And hence the entrance of the Eiffel Tower is a happening, an actuality and not just a potentiality, and it can be fused with my present creation. This means that the happening (z_0, z_1, z_2, z_3) of December 29, 2004, 4 PM, entrance of the Eiffel Tower, is a happening that can be fused with my creation of observation of the spot around me at December 28, 2004, 4 PM. Hence it is part of my present material reality. The entrance of the Eiffel Tower at December 29, 2004, 4 PM exists for me today, December 28, 2004 4 PM.

If we advocate an Einsteinian interpretation of relativity theory we have to conclude from the foregoing section that reality is 4-dimensional. This conclusion will perhaps not amaze those who always have considered the time–space continuum of relativity representing the new reality. Now that we have however defined very clearly what is the meaning of this, we can start investigating the seemingly paradoxical conclusions that often are brought forward in relation with this insight.

3.3 The process view confronted with the geometric view

The paradoxical situation that we can try to solve now is the confrontation of the process view of reality with the geometric view. Often it is claimed that an interpretation where reality is considered to be related to the 4-dimensional time–space continuum contradicts another view of reality, namely the one where it is considered to be of a process-like nature. By means of our framework we can now understand exactly these two views and see that there is no contradiction. Let us repeat now what is the meaning in our framework of the conclusion that reality is 4-dimensional. It means that, at a certain specific moment, that I call my 'present', the collection of places that exist, and that I could have observed when I would have decided to do so in my past, has a 4-dimensional structure, well represented mathematically by the 4-dimensional time–space continuum. This is indeed my present material reality. This does not imply however that this reality is not constantly changing. Indeed it is constantly changing. New entities are created in it and other entities disappear, while others are very stable and remain into existence. This is as much the case in all of the 4 dimensions of this reality. Again I have to give an example to explain what I mean. We came to the conclusion that now, at December 28, 2004, 4 PM the entrance of the Eiffel Tower exists for me while I am in my house in Brussels. Then this is not a statement of deterministic certainty. Indeed, it is very well possible that by some extraordinary chain of events, without me knowing about these events, the Eiffel Tower had been destroyed, such that my statement about the existence of the entrance of the Eiffel Tower 'now', although almost certainly true, is not deterministically certain. The reason is again the same, namely that reality is a construction of what I would have been able to experience, if I would have decided differently in my past. The knowledge that I have about this reality is complex and depends on the changes that go on continuously in it. What I know from experience is that there do exist material objects, and the Eiffel Tower is one of them, that are rather stable, which means that they are into existence without changing to much. To these stable objects, material objects but also energetic fields, I can attach the places where I could observe them. The set of these places has the structure of a 4-dimensional continuum. At the same time all these objects are continuously changing and moving in this 4-dimensional scenery. Most of the objects that I used to shape my intuitive model of reality are the material objects that surround us here on the surface of the earth. They are all very fixed in the dimension indicated by the 0 index, usually referred to as the time-dimension, while they move easily in the dimensions indicated by the 1, 2, and 3 index, called the space dimensions. Other objects, for example the electromagnetic fields, have a completely different way of being and changing in this 4-dimensional scenery. This means that in our framework there is no contradiction between the 4-dimensionality of the set of places and the process-like nature of the world. If we came to the conclusion that the entrance of the Eiffel Tower, tomorrow, December 29, 2004, 4 PM exists also for me now, then our intuition reacts more strongly to this statement, because intuitively we think that this would mean that the future exists also and hence is determined and hence no change is possible. This is a wrong conclusion which comes from the fact that during a long period of time we have had an intuitive image of a Newtonian present, that would be determined completely. We have to be aware of the fact that it is the present, even in the Newtonian sense, which is not determined at all. We can only say that the more stable entities in my present reality are more determined to be there, while the places where they can be, because these places are stable with certainty, are always there.

3.4 The singularity of the reality construction

We want to come back to the construction of reality in our framework that we have confronted here with the Einsteinian interpretation of relativity theory. Instead of wondering about the existence of the entrance of the Eiffel Tower tomorrow, December 29, 2004, 4 PM, I can also question the existence of my own house at the same place of the time–space continuum. Clearly I can make an analogous reasoning and come then to the conclusion that my own house, and the chair where I am sitting while reading the novel, and the novel itself, and the basket of wall nuts beside me, etc..., all exist in my present reality at December 29, 2004 4 PM, hence tomorrow. If we put it like that, we get confronted even more with a counter-intuitive aspect of the Einsteinian interpretation of relativity theory. But it is a correct statement in our framework. We have to add however that all these objects that are very close to me now December 28, 2004, 4 PM, they indeed also exist in my present reality at December 29, 2004, 4 PM, but the place in reality where I could have observed them is of course much further away for me. Indeed, to be able to get there, I have to fly away with a space ship at nearly the velocity of light. We now come to a very peculiar question that will confront us with the singularity of our reality construction.

Where do I myself exist? Do I also exist tomorrow December 29, 2004, 4 PM? If the answer to this question would be affirmative, we would be confronted with a very paradoxical situation. Because indeed, I myself, and this counts for all of you also, cannot imagine me to exist at different places of time. But indeed our framework clarifies this question very easily. It is impossible for me to make some action in my past such that I would be able to observe myself tomorrow December 29, 2004 4 PM. Indeed, if I would have chosen to fly away and come back with the space ship such that I observe now, December 28, 2004, 4 PM on my personal watch, the inside of my house tomorrow December 29, 2004, 4 PM, then I can do this, and as we remarked already, it proves that this inside of my house tomorrow is part of my present personal reality. But I will not find myself in it. Because to be able to observe my house tomorrow December 29, 2004 4 PM, I have had to move out of it. Hence, in this situation I will enter my house, for myself being still at December 28, 2004, 4 PM, but my house and all things in it, being at December 29, 2004, 4 PM. This shows that there is no paradox.

4 Conclusions: What about Time, Space and Reality?

We have shown that relativity theory, interpreted as advocated by Einstein, forces us to conclude that reality is 4-dimensional. More specifically, the collection of objects (happenings in our framework) that exists is spread over a structure of places that has 4 degrees of freedom and hence is 4-dimensional. When this was claimed by scientists as Minkowski and Weyl it seemed to entail an intrinsic paradox. Indeed, how can 'the future' already be 'real'? How then can there be any 'becoming'? After our analysis the situation presents itself in a completely different way. Indeed, our actual present experience is always only at one spot in the 4-dimensional time-space manifold. It is by means of the operational construction that we have put forward here that we can see that the 'places' in the $1, 2$ and 3 coordinates of which we suppose their simultaneous (not simultaneous in the sense of Einstein, but in the sense of our construction) existence, do not exist more simultaneous, than the places in the 0 coordinate of which we suppose their simultaneous existence. It is because we have such a strong intuitive feeling about the simultaneous existence of the places in space, that we have psychological difficulties to consider the places in time at the same level of existence. Hence to be able to cope with the situation we have to see the real meaning of the simultaneous existence of places in the $1, 2$ and 3 coordinate and then understand that this is the same as for the places in the 0 coordinate. But, and this is an important result of our analysis, time still indicates and co-ordinates the changes that take place in reality, it indicates these changes for pieces of reality that are spread out in a 4-dimensional region. This means that if we accept physical reality to be represented by the 4-dimensional time–space continuum, we do not have to conclude that there is no becoming in this reality. It is only such that the becoming takes place in 4 dimensions.

Another result of our analysis that is worth mentioning is the following. Time–space defined as the collection of places that exist simultaneous with our present experience, in the sense defined in this article, namely that it would have been possible to substitute our present experience with an experience involving one of these places, is in fact primarily 'empty time–space'. Let us explain what we mean. In Newtonian physics, when talking about 'space', this meant in principle, 'empty space'. Indeed, 'space' was considered to be the substratum with the capacity of being able to contain physical entities, and hence 'space' itself is empty for Newton, because it is the collection of the places that can be occupied by physical entities. That is the reason that mathematically space was described by a 3-dimensional

Euclidean manifold, empty in its normal state, and being able to be filled up with physical entities. In this sense it was said that each of these physical entities occupies a part of space.

Since in the beginning days of relativity theory operationalism, not only as a method, but also as a philosophical conception, was very much in fashion, together with the profound problems concerning the conception of reality, time and space, which we considered in this article, it was often claimed that relativity theory did away with the idea of empty space, *i.e.* 'empty time–space'. We point out that it is the same confusion that we investigated in this article that is at the origin of the conviction about the operational non-validity of the notion of 'empty time–space'. Indeed, a place is per definition 'empty', since it is the substratum that can contain any physical entity. If the physical entity occupies a certain place, then there is 'no longer place', which explains well that with 'place' we mean 'empty place'. Since time–space is the collection of all 'places' it is empty. This is a very important aspect, since it allows the mathematical representation of 'time–space' by means of a 4-dimensional manifold. But also philosophically it is an important aspect to put forward. The operational construction that we outlined in this article arrives at the notion 'place' as its only completely stable substratum in time. Hence the statement 'A place does not change in time' is a correct statement within our operational approach to relativity theory. And as a consequence 'time–space' itself does not change in time. What changes in time are the physical entities contained in 'time–space', hence what changes in time is the 'reality' contained in the 4-dimensional 'time–space'.

Acknowledgements

We thank the organisers of the workshop 'Endophysics, Time, Quantum and the Subjective' for the invitation to present the material of this article at their workshop.

References

1. Birkhoff, G., and von Neumann, J. (1936) The logic of quantum mechanics, *J. Ann. Math.* **37**, 823–843.
2. Jauch, J.M. (1968) *Foundations of Quantum Mechanics*, Addison–Wesley, Reading (MA).
3. Piron, C. (1976) *Foundations of Quantum Physics*, Benjamin, Reading (MA).
4. Randall, C., and Foulis, D. (1979) The operational approach to quantum mechanics, in C. A. Hooker (ed.), *Physical Theory as Logico-Operational Structure*, Reidel, Dordrecht, pp. 167–201.

5. Aerts, D. (1981) *The One and the Many*, Doctoral Thesis, Free University of Brussels.
6. Aerts, D. (1982) Description of many physical entities without the paradoxes encountered in quantum mechanics, *Found. Phys.* **12**, 1131–1170.
7. Aerts, D. (1983) Classical theories and non classical theories as a special case of a more general theory, *J. Math. Phys.* **24**, 2441–2453.
8. Randall, C., and Foulis, D. (1983) A mathematical language for quantum physics, in C. Gruber *et al.* (ed.), *Les Fondements de la Mécanique Quantique*, A.V.C.P., Lausanne, pp. 193–226.
9. Aerts, D. (1985) A possible explanation for the probabilities of quantum mechanics and a macroscopic situation that violates Bell inequalities, in P. Mittelstaedt *et al.* (eds.), *Recent Developments in Quantum Logic*, in *Grundlagen der Exacten Naturwissenschaften — Volume 6*, Wissenschaftverlag, Bibliographisches Institut, Mannheim, pp. 235–251.
10. Piron, C. (1985) Quantum Mechanics: Fifty Years Later, in P. Lahti and P. Mittelstaed (eds.), *Proceedings of the Symposium on the Foundations of Modern Physics*, World Scientific, Singapore.
11. Aerts, D. (1986) A possible explanation for the probabilities of quantum mechanics, *J. Math. Phys.* **27**, 202–210.
12. Gudder, S.P. (1988) *Quantum Probability*, Academic Press, Inc. Harcourt Brave Jovanovitch Publishers.
13. Piron, C. (1988) Recent developments in quantum mechanics, *Helv. Phys. Acta.* **62**, 82–90.
14. Aerts, D. (1990) An attempt to imagine parts of the reality of the micro-world, in J. Mizerski, A. Posiewnik, J. Pykacz and M. Zukowski (eds.), *Problems in Quantum Physics*, World Scientific, Singapore, pp. 3–25.
15. Piron, C. (1990) *Mécanique Quantique, Bases et Applications*, Presses Polythechniques et Universitaires Romandes, Laussane.
16. Aerts, D. (1992) The construction of reality and its influence on the understanding of quantum structures, *Int. J. Theor. Phys.* **31**, 1815–1837.
17. Aerts, D. (1994) Quantum structures, separated physical entities and probability, *Found. Phys.* **24**, 1227–1259.
18. Aerts, D. (1996) Framework for possible unification of quantum and relativity theories, *Int. J. Theor. Phys.* **35**, 2399–2416.
19. Piron, C. (1996) Quantum theory without quantification, *Helv. Phys. Acta.* **69**, 694–701.
20. Einstein, A. (1905) Zur elektrodynamik bewegter Körper, *Ann. Phys.* **17**, 891—921.
21. Weyl, H. (1922) *Space–Time–Matter*, Methuen, London.
22. Minkowski, H. (1923) *The Principle of Relativity*, Methuen, London.
23. Weyl, H. (1949) *Philosophy of Mathematics and Natural Science*, Princeton University Press, Princeton (NJ).
24. Misner, C.W., Thorne, K.S., and Wheeler, J.A. (1973) *Gravitation*, W. H. Freeman and Company, San Francisco.
25. Whitrow, G.J. (1980) *The Natural Philosophy of Time*, Clarendon Press, Oxford.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 131–147

TIME, MEMORY, AND CONSCIOUSNESS A VIEW FROM THE BRAIN

HANS J. MARKOWITSCH
Physiological Psychology, University of Bielefeld, Universitaetsstr. 25
D-33615 Bielefeld, Germany
(hjmarkowitsch@uni-bielefeld.de)

Abstract: Memory can be defined as mental time traveling. Seen in this way, memory provides the glue which combines different time episodes and leads to a coherent view of one's own person. The importance of time becomes apparent in a neuroscientific comparison of animals and human beings. All kinds of animals have biorhythms — times when they sleep, prefer or avoid sex, or move to warmer places. Mammalian brains have a number of time sensitive structures damage to which alters a subject's behavior to his or her environment. For human beings, damage to certain brain regions may alter the sense of time and consciousness of time in quite different ways. Furthermore, brain damage, drugs, or psychiatric disturbances may lead to an impaired perception of time, sometimes leading to major positive or negative accelerations in time perception. An impaired time perception alters consciousness and awareness of oneself. A proper synchronized action of time perception, brain activation, memory processing, and autonoetic (self-aware) consciousness provides the bases of an integrated personality.

Keywords: Amnesia – Episodic Memory – Autonoetic Consciousness

1 Introduction

Ewald Hering [1], a physiologist known for his opponent-color theory or the Hering-Breuer reflex, stated that memory unites the countless single phenomena to a whole and that without its binding power our consciousness would disintegrate into as many fragments as there are moments. With this statement he expressed that we live as an integrated personality because of our brain's ability to order and logically combine the events we have experienced throughout our life and because new happenings can be associated, bound, or compared with existing ones into a comprehensive unity. Patients who have lost this capacity state: "Every day is alone, whatever enjoyment I've had, and whatever sorrow I've had" (p. 217; Patient H.M.; [2]). Some forms of brain damage or of psychic stress and trauma states may lead to loss of an individual's personal past — they no longer know how they have behaved, who are their relatives and what was more or less important to them. Other patients may lose their ability to encode new information long term — they remain with their learned facts and events at that time point where their brain condition changed. And still others have an inability to retrieve certain time epochs or certain events. Finally, there are groups of patients for whom the time shrinks or expands with reference to the physical time which can be followed from a watch or a calendar. All these patient groups point to the crucial importance of time for an integrated personality and for normal consciousness ("consciousness," as used herein, refers to the form given in the last line of Table 1). In the following I will discuss the interdependence between time, memory, and consciousness on the basis of such patients and their possible brain changes.

Table 1. Varieties of consciousness.

•	Wakefulness (no sleep, no coma)
•	Directed attention (conscious perception)
•	Inner knowledge or certainty
•	Body consciousness (the body surrounding me is my own)
•	Completeness of the thinking of an individual
•	Consciousness as mental state (hoping, believing, expecting, wishing, suffering, fearing)
•	Self-reflection, feeling of time, proscopy

2 Time in the Neurosciences

From a philosophical point of view time may be viewed as an *a priori* given *absolutum* which exists even independently of the world. Other views of time point to the distinction between the experienced "I-time" and the objective "world-time," or use the term "*eigen*-tempo" to describe the self-paced time of the individual. Generally, it seems that in the life sciences, the last view is favored as different species have their different life speeds and as even within a species and an individual time perception may change, depending on the inner and outer conditions, the subject is exposed to.

For species like a snail the psychic time moment is a quarter of a second — consequently the world and environmental events appear accelerated for a snail. Vice versa, for a fighting fish the psychic time moment is 1/30 of a second — the fish has a reduced extraspective perception of the tempo of environmental events. In comparison, for us as humans the psychic time moment is 1/18 of a second.

Within a given subject time may last long, when the surroundings appear boring; time may be perceived as short, when much is happening in life and when individuals get older. Probably, time becomes more relative, depending on the amount of mental time traveling, an individual performs. The more a person thinks back in time and anticipates future happenings, the more time loses its character of chronometry.

In the view of Tulving [3,4] and Tulving and Markowitsch [5] it is unlikely that non-human animals possess the possibility to "look into future," that is, to anticipate what will or might happen in days, weeks, or years ("prospective memory," "proscopy"). In fact, Tulving and Markowitsch propose that this ability is dependent on age (i.e. development of a child; [cf. 6,7]) and intellect (i.e. a debile person, e.g. a patient in the advanced stage of Alzheimer's disease will not possess the ability of proscopy). Therefore, conscious awareness or 'autonoetic consciousness' [8] (Fig. 1) is a prerequisite of what Tulving [3] defined as 'chronesthesia' (cf. Table 1). Attempts to structure the terminology of time are given in Table 2.

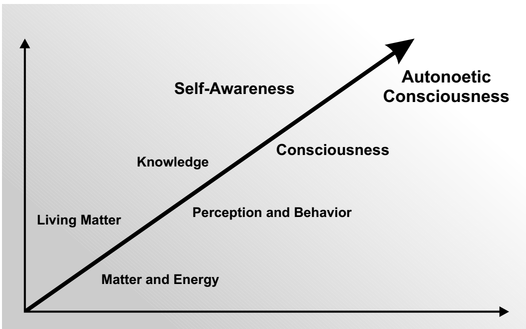


Figure 1. From matter to autonoetic consciousness.

3 Memory and Time

The idea that some individuals possess the ability of mental time traveling and others not, is related to that that mental time traveling is dependent on a proper functioning of memory. We all know that memory is a time dependent process (Table 3) which is divided into short-term and long-term memory (Fig. 2). Short-term memory refers to on-line holding of limited amounts of information (a few bits, usually 4–7) for a few seconds or — at best — a few minutes. Everything beyond this is considered as long-term memory.

Table 2. Sensation, perception, forms of time and levels of consciousness. Chronognosia, chronologia, and chronometria are defined after Bouman and Gruenbaum [9], chronesthesia, anoetic, noetic, and autonoetic consciounessness after Tulving [3,4].

Expression	Explanation
Sensation	The physiological processing of (usually physical) stimuli the brain is exposed to
Perception	The (partly conscious) interpretation of stimuli by neuronal nets
Chronognosia	Unreflected, immanent experience of time
Chronologia	Comparing the inner history with the external
Chronometria	Total objectivity and measurement of time
Chronesthesia	Conscious awareness of subjective time
Anoetic consciousness	Capacity that all animals have that can be used to gain awareness of changes in stimulation
Noetic consciousness	Capacity that all animals have that can be used to gain awareness of objects, situations, and states of the world not present to the senses
Autonoetic awareness	Capacity that humans have that can be used to gain consciousness of personal experiences in subjectve time in the past and in the future

In the neurosciences, a further distinction made is that to divide memory into facts and events which happened prior to a given time and which happened thereafter (Fig. 3). The reference time point usually is that of brain injury, but may also include an intensely stressful or traumatic psychic event. Information to which an individual is exposed thereafter, has to be encoded anew, information which happened before, has to be retrieved. If these processes fail, one speaks of anterograde amnesia (inability to suc-

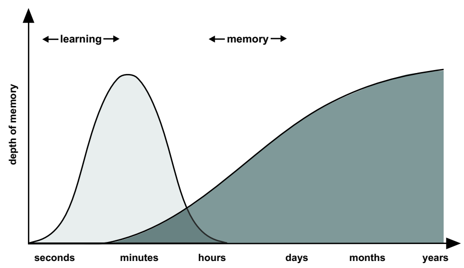


Figure 2. Sketch of the relations between memory strength and duration for the two principal time-related memory systems, short-term and long-term memory.

Table 3. Stages of information processing.

Registration	The perception of stimuli via the sensory channels and the immediately following specific nuclear and cortical structures
Encoding	The further processing of information with the aim of identifying and associating the perceived information
Consolidating	The integration and embedding of preprocessed information in existing anatomical frameworks
Storage	The "final" addressing of information to specific structural constellations ('engram formation')
Retrieval	The reproduction of successfully stored material; when this occurs consciously, it takes the form of ecphorizing
Ecphory	The term 'ecphory' describes the process by which retrieval cues interact with stored information so that an image or a representation of the information in question appears

cessfully encode new information) or of retrograde amnesia (inability to successfully retrieve old information). It is frequently found that old individuals have a high number of very old memories they can retrieve or better ecphorize (Table 3), but only a small number of recent events. This is probably based on several reasons: The very old memories have probably been ecphorized many times throughout life and each ecphory leads to a re-encoding process which stabilizes the information further. There is also the phenomenon of state-dependent encoding and retrieval which means that our brain does not work like a computer for whom input equals output, but includes the momentary emotional and motivational condition of the indi-

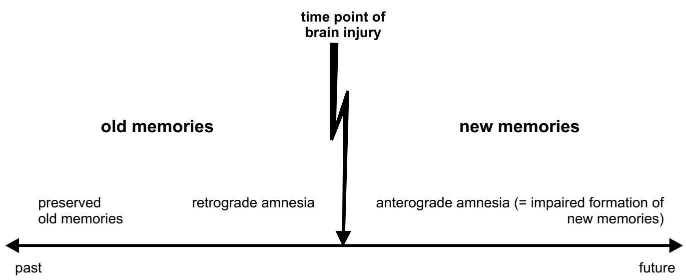


Figure 3. Possible consequences of brain injury on old and new memories.

vidual. That means, in a depressed mood, more "dark-colored" memories would be ecphorized, in an euphoric mood more positive and joyful ones.

Aside from this time-dependent distinction, a further one — based on material and content — resulted out of the work of Endel Tulving [3,10,11] on the human level, and of Mishkin and Petri [12] and Squire and Zola-Morgan [13] based on work with animals, though some preliminary attempts had been made earlier (reviewed in Markowitsch [14]). We presently divide into five long-term memory systems which are depicted in Fig. 4. These memory systems are considered to be hierarchically ordered starting with *procedural memory* as the lowest and ending with episodic (or *episodic-autobiographical*) memory as the highest system. *Procedural memory* stands for motor-related skills (e.g. driving a car, riding a bike, swimming, playing cards or piano), *priming* stands for a higher likeliness to re-identify stimuli which one had perceived (non-consciously or sub-consciously) in the same or a similar way at a previous time point. *Perceptual memory* refers to being familiar with a stimulus on the basis of pre-semantic features. Fact-like, context-free information is represented in the *semantic memory system*. Tulving [3] sees the *episodic memory system* as the conjunction of subjective time, autonoetic consciousness, and the experiencing self; frequently it is affect-related. Tulving defines episodic memory in the following words: "Episodic memory is a recently evolved, late-developing, and early-deteriorating brain/mind ('neurocognitive') memory system. It is oriented to the past, more vulnerable than other memory systems to neuronal dysfunction, and probably unique to humans. It makes possible mental time travel through subjective time — past, present, and future. This mental time travel allows the 'owner' of episodic memory ("self"), through the medium of autonoetic awareness, to remember one's own previous "thought-about" experiences, as well as to 'think about' one's own possible future experiences. The operations of episodic memory require, but go beyond, the semantic memory system. Retrieving information from episodic memory ('remembering') requires the establishment and maintenance of a special mental set, dubbed episodic 'retrieval mode.' The neural components of episodic memory comprise a widely distributed network of cortical and subcortical brain regions that overlap with and extend beyond the networks subserving other memory systems. The essence of episodic memory lies in the conjunction of three concepts — self, autonoetic awareness, and subjective time."

An example of a case without any ability to learn new information long term and therefore with his subjective time standing still and remaining

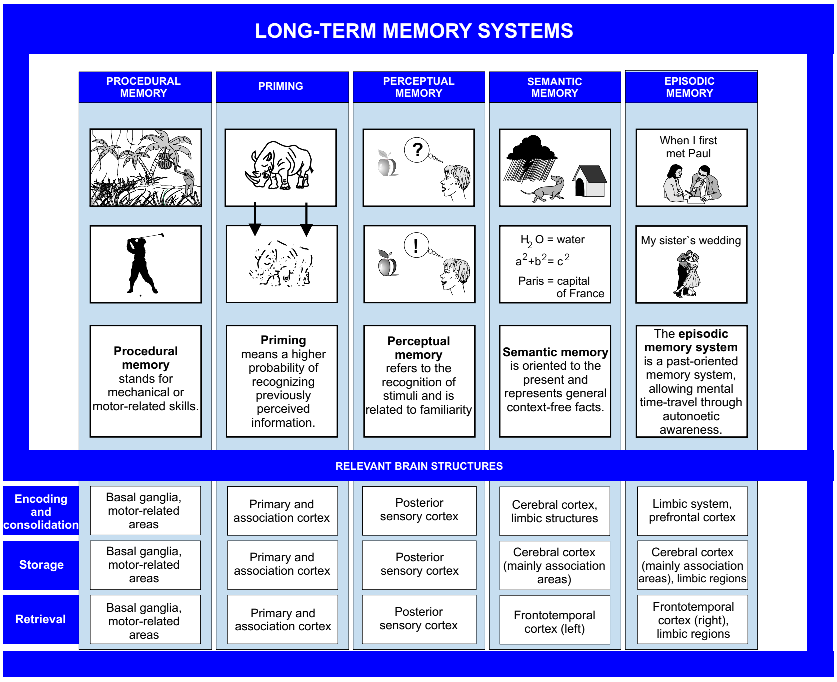


Figure 4. The five principal memory systems important for human information processing. The episodic memory system is context-specific with respect to time and place. It allows mental time travel. Examples are episodes such as the last vacation or the dinner of the previous night. Declarative memory is context-free and refers to general facts. It is termed semantic memory or the knowledge systems as well. Procedural memory is largely motor-based, but includes also sensory and cognitive skills ("routines"). Priming refers to a higher likeliness of re-identifying previously perceived stimuli.

at the time point where his brain damage occurred (in 1983) was patient A.B. He suffered in 1983 from a tiny, but bilateral infarct in the center of his brain (the dorsal diencephalon). A.B. still had the appearance of a jovial and respectable professor of medicine, a few minutes of conversation would be sufficient to reveal that he was completely unable to retain new information and that he had to be constantly prompted by his patient and caring wife. Asked about the current year, he always responded with the year of his infarct; asked to repeat a short story of less than 50 words, which had just been told to him, he could not accurately retrieve even one item of information. Similarly, he was totally unable to reproduce a complex figure which he had just copied without error two minutes ago. On the other hand, A.B. still had above average intelligence, high motivation, and excellent attentive and short-term memory functions. He still had good retrograde memory abilities (cf. Fig. 3); so he was able to recall street names of places where he had lived as a child. He also could name former teachers and relatives such as aunts and uncles from his youth. However, when asked about more recent events related to current news, he was unable to recall anything that had happened since his brain damage and occasionally tended to confabulate.

A.B.'s severe anterograde amnesia prevented him from reflecting on his memory problems. When asked about his memory he judged it as "good." When asked in more detail whether he could mention problems in certain areas of his memory, he responded that he had problems in remembering his dreams and in repeating jokes. A psychologist who had worked with him for a long time, remarked that he once stated "I have no memory at all, isn't that terrible?," but immediately thereafter had forgotten this statement and its consequences.

A.B.'s performance can also be used as an example for the validity of the different memory systems, depicted in Fig. 4. While he was unable to acquire new life events, his jovial appearance, other social skills, and his knowledge of general facts demonstrated that his semantic memory still worked. The same held true for acquiring new perceptuo-motor skills (procedural memory) and demonstrating memory on the priming level. However, coming back to episodic memory, he never consciously remembered that he had been involved in learning the skill and priming tasks.

While patients such as A.B. and H.M. are deficient in encoding new information and are therefore "stuck in time" as Roberts [18] formulated it, other patients lack the ability to ecphorize old memories. Usually this deficiency is confined to the episodic-autobiographical memory domain, while the other memory systems still function more or less normally. Such patients either may have had a sudden — so-called traumatic — brain damage (like a car accident or bumping with their head against the branch of a tree while trying to ride below it) [19,20], or they may have had a severe and stressful shock or psychic traumatic experience [21–23]. Some patients lose their ability to memorize due to "internal" damage of portions of their brain — so-called degenerative diseases. These may be local as in Korsakoff's syndrome, a degenerative disease which occurs mostly due to heavy, long-term alcohol abuse [24,25], or may affect major portions of the cerebral cortex as in Alzheimer's disease [26].

Interestingly, the memory impairments are very similar in the patients with focal traumatic brain injuries and in those with psychogenic forms of amnesia: These patients no longer remember their personal past and consequently remain unconscious with respect to their personality. As they also are unable to do mental time traveling into their past, their condition again emphasizes the interdependence of time, conscious, and memory. As it seems, such a condition may arise from manifest organic tissue, as in the neurological patients, or from environmental influences leading to a major release of stress hormones on the brain level which block the normal information flow in those brain regions which usually synchronize emotional and cognitive-rational aspects of memories [27,28].

Other syndromes following circumscribed brain damage, are confined to the dimension time. Already half a century ago, Spiegel *et al.* [29] noted that patients after stereotactically induced small brain lesions may have "an inability to identify the date; the patient may not know the time of the day, may make incorrect statements regarding the season of the year though this is obvious if he looks through the window." The authors termed this phenomenon 'chronotaraxis.' Other neurological patients may show accelerations or prolongations (time lens phenomenon) of time perception. These phenomena have been described for patients with damage to various regions within the cerebral cortex — both posteriorly and anteriorly [30–39].

Usually, our internal clocks (biorhythms, pacemakers) help us to keep an accurate time perception [40–42]. However, changes in time perception, memory, and consciousness occur also — at certain times or under certain conditions — in "normal" human beings. The most obvious one is sleep (or, more accurately, the transition stage between sleep and awakening). Freud [43] gave an unsurpassed example:

> A dream which was experienced by M a u r y (Le sommeil, p. 161) became famous. He was suffering in his bed; his mother was sitting next to him. He dreamed from the cruel regime during the time of the French Revolution, perceived disgusting murdering scenes and finally was accused himself. At the court he saw Robespierre, Marat, Fouquier-Tinville and all the sad heroes of that cruel epoch, discussed with them and was — after a number of circumstances which remained unfixed in his memory — sentenced to death and then, accompanied by a huge crowd, brought to execution. He mounted the scaffold, was fixed to a board by the hangman; the board turned around and the guillotine fell down; he feels his head being cut from his body, awakens in horrible anxiety - and realizes that the top piece of

> his bed had fallen down and hit his cervical vertebra similar to the blade of the guillotine.

Other examples are states of hallucinating as under LSD or mescalin [44–45], or under hypnosis [46]. Under all these states, autonoetic consciousness [8] and self-reflection, and the possibilities of memory encoding and retrieving are severely disturbed.

4 Consciousness

Autonoesis, the embedded consciousness in an integrated frame of both subjective (psychical) and objective (physical) time with the possibility to access one's personal past and foresee more or less likely events of the future, constitutes the essence of an adult, intellectually normal human being. Whether the feeling of being aware of one's present, past, and future includes the freedom of deciding otherwise, is up to present a widely disputed question. Our limbic system (Fig. 5) — that part of the brain which has to do with evaluating one's own state and that of the surrounding world and which is central for evaluating new information with respect to its social and biological significance for oneself [49,50] — argues in favor of free will and free decisions.

On the other hand, evidence which demonstrates that our minds are rigidly influenced by our brains and environmental influences, from visual [51] and auditory illusions [52] to false memories [53–55], points to a principal determinism of our mental condition. Examples of changes in personality after brain damage [56–58] and after psychic stress and trauma conditions [22,23,59,60] reinforce this view as do changes in personality states over time [61,62]. Such a view culminates in the proposals of Hameroff [63], Sheldrake [64] and Romijn [65,66]. Romijn, for example, considers a submanifest order of being as the principal storage place of memories. He is of the opinion that the whole universe in its spatial-temporal configuration would be permanently present in the submanifest order of being. Of this, a small portion would continuously materialize and thereby become available for psychic processing. Episodic memory would be found somewhere in the individual area of the submanifest order of being (Fig. 6). While the empirical evidence for his hypotheses and those of Hameroff and Sheldrake is scarce, these authors even include assumptions from quantum mechanics and other modern physical theories in their ideas and interpret existing data in a way that they fit their proposals.

All in all, while we are conscious and are of the opinion to guide ourselves according to our wishes and imaginations, this view does not correspond

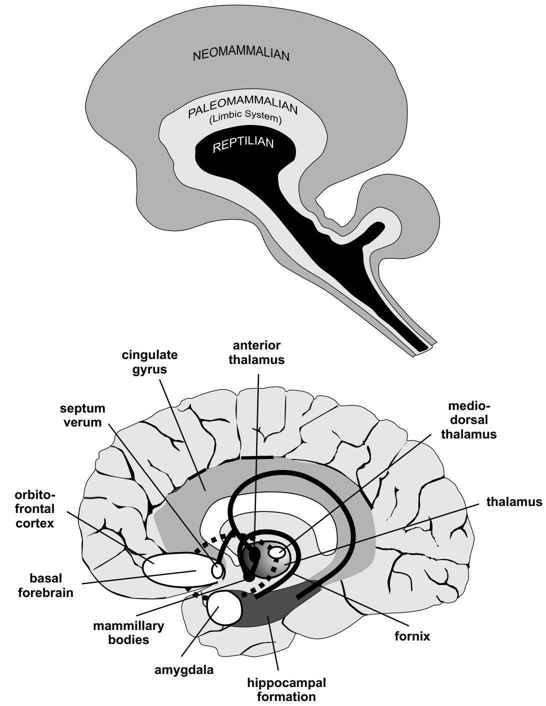


Figure 5. Top: A schematic view of the interface position of the limbic system within the mammalian brain (after MacLean [47,48]). The limbic system modulates the information between the neomammalian brain (mainly the neocortex; "the cognitive-rational brain") and the reptilian brain (brainstem; responsible for all live-conserving functions). Bottom: A schematic view through the human brain showing the structures of the limbic system *in situ*.

to the knowledge we have about our brain and its action. We live a life of illusion [67–69]. Instead of acting on the basis of a free will — defined as possessing the possibility to act differently, our limbic portions of our brain provide us with the illusion of acting freely, while in trueness we act on the bases of our genes and of that external input which bombarded us from the start of our life and modified our brain up to the present. Similarly, as the brain-damaged may convert from a criminal to an artist when his brain changes [57], so our behavior changes continuously on the basis of environmental inputs. All of these incoming stimuli result in a trace in the nervous system, alter its biochemistry and its morphology. And as a consequence our so-called free will changes with every new trace, however, in conformity with our neural signals, in particular with those of the structures

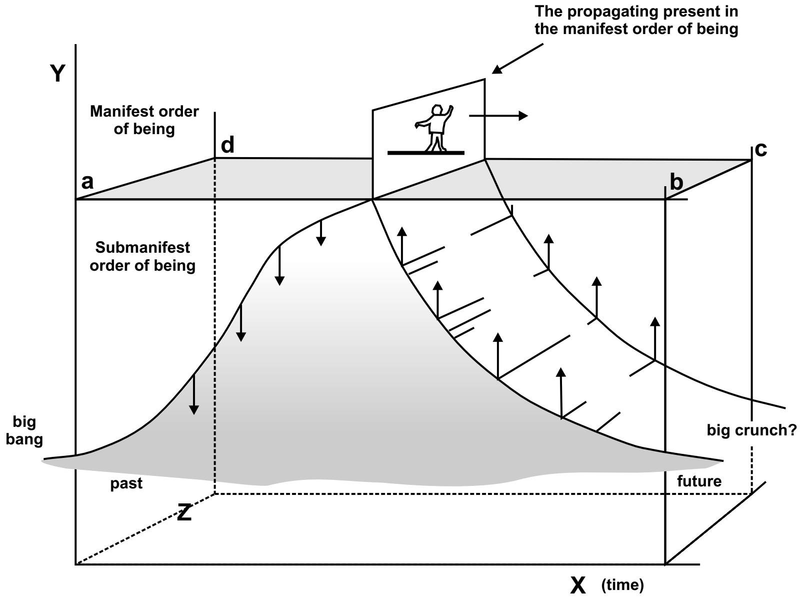


Figure 6. Sketch of Romijn's conception of the submanifest order of being. (After Fig. 5 of Romijn [65].)

of the limbic system. These structures integrate cognitive and emotional stimuli and provide us with a united view on our being and acting. If this view becomes disintegrated, our behavior dissociates. Psychiatrists speak of dissociative syndromes, when one portion of our personality dominates another one instead of integrating all components in a balanced outcome. Patients with dissociative amnesia, for instance, may only evoke the emotional components of their personal past, but not the cognitive ones [70,71].

For instance, a woman who had been sexually abused by her father during childhood, still was in therapy at age 55 and still could not remember any personal events from the period between age 10 and 16 [70]. However, she could draw paintings from that time period which, though frequently painted in an abstract manner, represented the negative emotional aspects of that epoch. When scanning her brain with functional imaging methods, the presentation of her paintings resulted in a strong activation of those portions of her limbic system, engaged in emotional processing. Similarly, patients with posttraumatic stress disorder who are confronted with their traumatic experiences while their brains are scanned with functional magnetic resonance imaging [71], showed strong activations of their right amygdala and hippocampus regions, that is, of those regions which process the retrieval of emotionally colored personal events. This can be interpreted as a preponderance of emotional over cognitive aspects of their trauma-related memories and as a suppression of those conscious memories with which the patient apparently is still unable to cope. The mental time traveling which was regarded as an essential component of autonoetic consciousness is therefore blocked are reduced to emotional aspects in these patients.

5 Conclusions

The complexity of human beings is reflected by their abilities to properly integrate time-sensitive information which refers to themselves as individuals. Episodic memory as the conjunction of subjective time, autonoetic consciousness, and the experiencing self constitutes the basis of our personality. Impairments in the processing of one component — time or memory or consciousness/self-awareness — always affects all of them and results in dissociated personality states. Both focal brain damage and inappropriate environmental stimulation (such as stress and psychic trauma experiences) can alter the neuronal nets to a degree that personality changes occur. But even if such major life events do not occur individuals are dependent on their genes and their environmental stimulation to act properly in order to survive comfortably. The idea of acting freely on the basis of alternatives of possible action is, however, an illusion: We are determined from birth to graveyard. This determined action — and perception — is however, under normal circumstances in conformity with our expectations and with those of our environment so that it gives the illusion of a free act.

Acknowledgements

While writing this chapter, my research was supported by grants from the VolkswagenStiftung and the Deutsche Forschungsgemeinschaft.

References

1. Hering, E. (1870) *Ueber das Gedächtnis als eine Allgemeine Funktion der Organisierten Materie. Vortrag gehalten in der feierlichen Sitzung der Kaiserlichen Akademie der Wissenschaften in Wien am XXX. Mai MDCCCLXX*, Akademische Verlagsgesellschaft, Leipzig. (Transl. as: Hering, E. (1895) *Memory as a General Function of Organized Matter*, Open Court, Chicago.)
2. Milner, B., Corkin, S., and Teuber, H.L. (1968) Further analysis of the hippocampal amnesic syndrome: Fourteen year follow-up study of H.M., *Neuropsychologia* **6**, 215–234.

3. Tulving, E. (2002) Chronesthesia: Awareness of subjective time, in D. T. Stuss and R. C. Knight (eds.), *Principles of Frontal Lobe Function*, Oxford University Press, New York, pp. 311–325.
4. Tulving, E. (2005) Episodic memory and autonoesis: Uniquely human?, in H. S. Terrace and J. Metcalfe (eds.), *The Missing Link in Cognition: Self-Knowing Consciousness in Man and Animals*, Oxford University Press, New York, pp. 3–56.
5. Tulving, E., and Markowitsch, H.J. (1998) Episodic and declarative memory: Role of the hippocampus, *Hippocampus* **8**, 198–204.
6. Friedman, W.J. (1978) Development of time concepts in children, *Adv. Child Dev. Behav.* **12**, 267–297.
7. Piaget, J. (1981) Time perception in children, in J. T. Fraser (ed.), *The Voices of Time*, Massachusetts Press, Cambridge, MA, pp. 202–216.
8. Markowitsch, H.J. (2003) Autonoëtic consciousness, in A. S. David and T. Kircher (eds.), *The Self in Neuroscience and Psychiatry*, Cambridge University Press, Cambridge, pp. 180–196.
9. Bouman, L., and Gruenbaum, A.A. (1929) Eine Störung der Chronognosie und ihre Bedeutung im betreffenden Symptomenbild, *Monatsschrift für Psychiatrie und Neurologie* **73**, 1–39.
10. Tulving, E. (1972) Episodic and semantic memory, in E. Tulving and W. Donaldson (eds.), *Organization of Memory*, Academic Press, New York, pp. 381–403.
11. Tulving, E. (1983) *Elements of Episodic Memory*, Clarendon Press, Oxford.
12. Mishkin, M., and Petri, H.L. (1984) Memories and habits: Some implications for the analysis of learning and retention, in L. R. Squire and N. Butters (eds.), *Neuropsychology of Memory*, Guilford Press, New York, pp. 287–296.
13. Squire, L.R., and Zola-Morgan, S. (1988) Memory: brain systems and behavior, *Trends Neurosci.* **11**, 170–175.
14. Markowitsch, H.J. (1992) *Intellectual Functions and the Brain. An Historical Perspective*, Hogrefe & Huber Publishers, Toronto.
15. Richards, W. (1973) Time reproductions by H.M., *Acta Psychol.* **37**, 279–282.
16. Perbal, S., Pouthas, V., and Van der Linden, M. (2000) Time estimation and amnesia: a case study, *Neurocase* **6**, 347–356.
17. Markowitsch, H.J., von Cramon, D.Y., and Schuri, U. (1993) Mnestic performance profile of a bilateral diencephalic infarct patient with preserved intelligence and severe amnesic disturbances, *J. Clin. Exp. Neuropsychol.* **15**, 627–652.
18. Roberts, W.A. (2002) Are animals stuck in time?, *Psychol. Bull.* **128**, 473–489.
19. Kroll, N., Markowitsch, H.J., Knight, R., and von Cramon, D.Y. (1997) Retrieval of old memories — the temporo-frontal hypothesis, *Brain* **120**, 1377–1399.
20. Markowitsch, H.J., Calabrese, P., Liess, J., Haupts, M., Durwen, H.F., and Gehlen, W. (1993) Retrograde amnesia after traumatic injury of the temporo-frontal cortex, *J. Neurol. Neurosurg. Psychiatry* **56**, 988–992.
21. Markowitsch, H.J. (2003) Psychogenic amnesia, *NeuroImage* **20**, 132–138.

22. Markowitsch, H.J., Kessler, J., Van der Ven, C., Weber-Luxenburger, G., and Heiss, W.-D. (1998) Psychic trauma causing grossly reduced brain metabolism and cognitive deterioration, *Neuropsychologia* **36**, 77–82.
23. Markowitsch, H.J., Kessler, J., Weber-Luxenburger, G., Van der Ven, C., and Heiss, W.-D. (2000) Neuroimaging and behavioral correlates of recovery from 'mnestic block syndrome' and other cognitive deteriorations, *Neuropsychiatry Neuropsychol. Behav. Neurol.* **13**, 60–66.
24. Korsakoff, S.S. (1890) Eine psychische Störung kombiniert mit multipler Neuritis (psychosis polineuritica seu Cerebropathia psychia toxaemica), *Allgemeine Zeitschrift für Psychiatrie* **46**, 475–485.
25. Markowitsch, H.J., Kessler, J., Bast-Kessler, C., and Riess, R. (1984) Different emotional tones significantly affect recognition performance in patients with Korsakoff psychosis, *Int. J. Neurosci.* **25**, 145–159.
26. Alzheimer, A. (1907) Ueber eine eigenartige Erkrankung der Hirnrinde, *Allgemeine Zeitschrift für Psychiatrie* **64**, 146–148.
27. Markowitsch, H.J. (1996) Organic and psychogenic retrograde amnesia: two sides of the same coin?, *Neurocase* **2**, 357–371.
28. Markowitsch, H.J. (2002) Functional retrograde amnesia — mnestic block syndrome, *Cortex* **38**, 651–654.
29. Spiegel, E.A., Wycis, H.T., Orchinik, C., and Freed, H. (1956) Thalamic chronotarxis, *Am. J. Psychiatry* **113**, 97–105.
30. Berlin, H.A., Rolls, E.T., and Kischka, U. (2004) Impulsivity, time perception, emotion and reinforcement sensitivity in patients with orbitofrontal cortex lesion, *Brain* **127**, 1108–1126.
31. Binkofski, F., and Block, R.A. (1996) Accelerated time experience after left frontal cortex lesion, *Neurocase* **2**, 485–493.
32. Brown, J.W. (1990) Psychology of time awareness, *Brain and Cognition* **14**, 144–164.
33. Gloning, I., Gloning, K., and Hoff, H. (1955) Die Störung von Zeit und Raum in der Hirnpathologie, *Wiener Zeitschrift für Nervenheilkunde* **10**, 346–377.
34. Häfner, H. (1953) Psychopathologie der cerebralorganisch bedingten Zeitsinnesstörungen, *Archiv für Psychiatrie und Nervenkrankheiten* **190**, 530–545.
35. Häfner, H. (1954) Über Zeitdehnungs- und Zeitbeschleunigungsphänomen im Rahmen von Zwischenhirnstörungen, *Monatsschrift für Psychiatrie und Neurologie* **127**, 336–348.
36. Hoff, H., and Pötzl, O. (1938) Anatomischer Befund eines Falles mit Zeitrafferphänomen, *Deutsche Zeitschrift für Nervenheilkunde* **145**, 150–178.
37. Jones, C.R.G., Rosenkranz, K., Rothwell, J.C., and Jahanshahi, M. (2004) The right dorsolateral prefrontal cortex is essential in time reproduction: an investigation with repetitive transcranial magnetic stimulation, *Ex. Brain Res.* **158**, 366–372.
38. Pötzl, O. (1951) Weiteres über das Zeitraffer-Erlebnis, *Wiener Zeitschrift für Nervenheilkunde* **4**, 9–39.
39. Pötzl, O. (1958) Zur Hirnphysiologie des Zeiterlebens, *Wiener Zeitschrift für Nervenheilkunde* **15**, 370–393.

40. Colwell, C.S., and Michel, S. (2003) Sleep and circadian rhythms: do sleep centers talk back to the clock?, *Nature Neuroscience* **6**, 1005–1006.
41. Lee, H.S., Nelms, J.L., Nguyen, M., Silver, R., and Lehman, M.N. (2003) The eye is necessary for a circadian rhythm in the suprachiasmatic nucleus, *Nature Neuroscience* **6**, 111–112.
42. Meck, W.H., and Benson, A.M. (2002) Dissecting the brain's internal clock: how frontal-striatal circuitry keeps time and shifts attention, *Brain and Cognition* **48**, 195–211.
43. Freud, S. (1900) *Die Traumdeutung*, Franz Deuticke, Leipzig and Wien.
44. Beringer, K. (1927) *Der Meskalinrausch* (Monographien aus dem Gesamtgebiet der Neurologie und Psychiatrie, No. 49), Springer, Berlin.
45. Fischer, R. (1946) Selbstbeobachtungen im Mezkalin-Rausch, *Schweizer Zeitschrift für Psychologie* **5**, 308–313.
46. Aaronson, B.S. (1968) Hypnotic alterations of space and time, *International Journal of Parapsychology* **10**, 5–36.
47. MacLean, P.D. (1949) Psychosomatic disease and the "Visceral Brain," *Psychosom. Med.* **11**, 338–353.
48. MacLean, P.D. (1990) *The Triune Brain in Evolution*, Plenum Press, New York.
49. Markowitsch, H.J. (1999) Limbic system, in R. Wilson and F. Keil (eds.), *The MIT Encyclopedia of the Cognitive Sciences*, MIT Press, Cambridge MA, pp. 472–475.
50. Markowitsch, H.J. (1999) *Gestalt* view of the limbic system and the Papez circuit — another approach on unity and diversity of brain structures and functions, *Behav. Brain Sci.* **22**, 459–460.
51. Grabowska, A., Nowicka, A., and Szymanska, O. (1999) Sex related effect of unilateral brain lesions on the perception of the Mueller-Lyer illusion, *Cortex* **35**, 231–241.
52. Fukutake, T., and Hattori, T. (1998) Auditory illusions caused by a small lesion in the right medical geniculate body, *Neurology* **51**, 1469–1471.
53. Schacter, D.L., Verfaellie, M., and Pradere, D. (1996) The neuropsychology of memory illusions: False recall and recognition in amnesic patients, *Journal of Memory and Language* **35**, 319–334.
54. Loftus, E. (2003) Our changeable memories: Legal and practical implications, *Nature Neuroscience* **4**, 232–233.
55. Payne, D.G., Neuschatz, J.S., Lampinen, J.M., and Lynn, S.J. (1997) Compelling memory illusions: The qualitative characteristics of false memories, *Current Directions in Psychological Science* **6**, 56–60.
56. Burns, J.M., and Swerdlow, R.H. (2003) Right orbitofrontal tumor with pedophilia symptom and constructional apraxia sign, *Arch. Neurol.* **60**, 437–440.
57. Giles, J. (2004) Change of mind. A brain haemorrhage turned an ex-convict into an obsessive artist. Jim Giles meets him and the scientist studying his case, *Nature* **430**, 14.
58. Hornak, J., Bramham, J., Rolls, E.T., Morris, R.G., O'Doherty, J., Bullock, P.R., and Polkey, C.E. (2003) Changes in emotion after circumscribed surgical lesions of the orbitofrontal and cingulated cortices, *Brain* **126**, 1691–1712.

59. Mollon, P. (1998) *Remembering Trauma. A Psychotherapist's Guide to Memory and Illusion*, Wiley, Chichester.
60. Markowitsch, H.J., Kessler, J., Russ, M.O., Frölich, L., Schneider, B. and Maurer, K. (1999) Mnestic Block Syndrome, *Cortex* **35**, 219–230.
61. Friedman, W.J., and Winstanley, P.A. de (1998) Changes in the subjective properties of autobiographical memories with the passage of time, *Memory* **6**, 367–381.
62. Johnson, J.G., Cohen, P., Kasen, S., Skodol, A.E., Hamagami, F., and Brook, J.S. (2000) Age-related change in personality disorder trait levels between early adolescence and adulthood: a community-based longitudinal investigation, *Acta Psychiatr. Scand.* **102**, 265–275.
63. Hameroff, S.R. (1998) 'Funda-Mentality': is the conscious mind subtly linked to a basic level of the universe?, *Trends Cogn. Sciences* **2**, 119–124.
64. Sheldrake, R (1988) *The Presence of the Past*, Times Books, New York.
65. Romijn, H. (1997) About the origin of consciousness. A new, multidisciplinary perspective on the relationship between brain and mind, *Proceedings van de Koninklijke Nederlandse Akademie van Wetenschappen* **100**, 181–267.
66. Romijn, H. (2002) Are virtual photons the elementary carriers of consciousness?, *Journal of Consciousness Studies* **9**, 61–81.
67. Wegner, D.M. (2002) *The Illusion of Conscious Will*, The MIT Press, Cambridge, MA.
68. Wegner, D.M. (2003) The mind's best trick: how we experience conscious will, *Trends Cogn. Sci.* **7**, 65–69.
69. Markowitsch, H.J. (2004) Warum wir keinen freien Willen haben. Der sogenannte freie Wille aus Sicht der Hirnforschung, *Psychol. Rdsch.* **55**, 173–168.
70. Markowitsch, H.J., Thiel, A., Kessler, J., von Stockhausen, H.-M., and Heiss, W.-D. (1997) Ecphorizing semi-conscious episodic information via the right temporopolar cortex — a PET study, *Neurocase* **3**, 445–449.
71. Driessen, M., Beblo, T., Mertens, M., Piefke, M., Rullkötter, N., Silva Saveedra, A., Reddemann, L., Rau, H., Markowitsch, H.J., Wulff, H., Lange, W., and Woermann, F.G. (2004) Different fMRI activation patterns of traumatic memory in borderline personality disorder with and without additional posttraumatic stress disorder, *Biol. Psychiatry* **55**, 603–611.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 149–162

THE SIGNIFICANCE OF CAUSALLY COUPLED, STABLE NEURONAL ASSEMBLIES FOR THE PSYCHOLOGICAL TIME ARROW

HARALD ATMANSPACHER[a] and THOMAS FILK[b]
Institute for Frontier Areas of Psychology and Mental Health
Wilhelmstr. 3a, 79098 Freiburg, Germany
(haa@igpp.de and filk@igpp.de)

HERBERT SCHEINGRABER
Max-Planck-Institut für extraterrestrische Physik
85740 Garching, Germany
(hrs@mpe.mpg.de)

Abstract: Stable neuronal assemblies are generally regarded as neural correlates of mental representations. Their temporal sequence corresponds to the experience of a direction of time, sometimes called the psychological time arrow. We show that the stability of particular, biophysically motivated models of neuronal assemblies, called coupled map lattices, is supported by causal interactions among neurons and obstructed by non-causal or anti-causal interactions among neurons. This surprising relation between causality and stability suggests that those neuronal assemblies that are stable due to causal neuronal interactions, and thus correlated with mental representations, generate a psychological time arrow. Yet this impact of causal interactions among neurons on the directed sequence of mental representations does not rule out the possibility of mentally less efficacious non-causal or anti-causal interactions among neurons.

Keywords: Causation – Coupled Map Lattices – Neuronal Assemblies – Psychological Time Arrow – Stability

1 Introduction

It was one of the great insights of Isaac Newton to disentangle the dynamical laws of nature from their initial and boundary conditions. The dynamical laws in all fundamental physical theories are time-reversal invariant. This is to say that any of their solutions describing the temporal evolution of a

[a]Also at Max-Planck-Institut für extraterrestrische Physik, Garching.
[b]Also at Institute of Physics, University of Freiburg, and Parmenides Foundation, Munich.

physical system in one direction of time has a time-reversed copy which is equally possible. This feature is distinctly at variance with the empirical experience of a distinguished, forward direction of processes in time from past to future, observed in thermodynamics, electrodynamics, quantum mechanics and cosmology. The standard attempt to resolve this apparent contradiction is to ascribe the directedness of time to particular initial or boundary conditions (cf. [1]).

Another option to enter and entertain this debate uses the relation between causation and the direction of time. Based on arguments presented earlier by Reichenbach [2], such an approach has been developed in detail by Price [3]. He emphasizes that an intuitive, subjective causal asymmetry, associated with a psychological arrow of time, needs to be properly distinguished from objective causation and a corresponding arrow of time of the physical world. Price argues that, in an important way, "the asymmetry of causation is a projection of our own temporal asymmetry as agents in the world" ([3], p. 264). Pruning off this anthropocentric element revitalizes the idea to take bidirectional (forward and backward) causation in the physical world seriously.

Broadly speaking, the notion of a psychological arrow of time stands for the experience that the flow of consciousness is directed from the past to the future, such that past events can causally influence future events (in the sense of efficient causation), but not *vice versa*. This means that the temporal sequence of thoughts, emotions, volitions and other conscious experiences has a distinguished direction in which past experiences precede future experiences.

There is a huge amount of literature on time and consciousness which cannot be comprehensively reviewed here. A fairly recent and compact overview concerning philosophical views and psychological evidence is due to Treisman [4]. An earlier account by Dennett and Kinsbourne [5], focusing on the neurobiological basis of time in the brain, is also readable, especially since it is published together with a number of controversial commentaries. Physical, neurobiological and psychological notions of time have been addressed by Ruhnau [6].

In this paper we present arguments and results intended to explicate a particular variant of Price's proposal. Our approach is based on a broadly assumed intrinsic relationship between material brain states and mental subjective states, often expressed by the term "neural correlates of consciousness". Although correlations between brain states and mental states should in general not be considered one-to-one, they may nevertheless be used to analyze the relationship between the properties of brain states and mental states to some degree (cf. [7]). In particular, we will be interested in this relationship as far as causal and temporal asymmetries in the dynamics of brain states and of mental states are concerned.

For this purpose, section 2 introduces a class of formal models for neuronal assemblies that are usually assumed to be correlated with mental representations. The model is essentially a lattice of coupled maps, whose parameters can be set such that they mimick the neurobiological situation as good as possible. Section 3 discusses numerical and analytical results for these lattices under different kinds of causation (forward, simultaneous, backward) for interactions among individual sites (neurons) in the lattice (assembly). Section 4 extends the discussion to genuinely time-reversal invariant equations for coupled map lattices. Finally, the basic results and some consequences will be summarized in section 5.

2 Coupled Map Lattices as Models for Neuronal Assemblies

In much current literature, conscious experiences are expressed as contents of mental representations. In this framework, the psychological arrow of time corresponds to the temporal sequence of mental representations. From a neurobiological point of view, mental representations are usually addressed in terms of their neural correlates. It is generally agreed that these correlates are to be found at a mesoscopic level of description referring to assemblies of several thousand functionally cooperating neurons.[c] In order to be a neural correlate of a mental representation, it is essential that the behavior of a neuronal assembly is stable.

A convenient way to investigate the stability of neuronal assemblies uses plausible models of such assemblies. A specific class of such models, particularly proposed for brain studies by Kaneko and collaborators [10], is called coupled map lattices (CMLs). In the remainder of this section we will briefly introduce their main features and, in the following section, summarize recent results [11] of a surprising relation between their stability and the extent to which their internal interactions are causal in the sense that past events effectuate future events. Insofar as (1) this neurobiological causality is necessary for stable neuronal assemblies, and (2) the stability of neuronal assemblies is necessary for them to be correlates of mental

[c] Although these assemblies, or networks, are constituted by neurons, they have properties which are not derivable from the microscopic level of individual neurons alone. As indicated recently [8, 9], the scheme of contextual emergence is a good candidate to describe such micro-meso relations already within the neurobiological domain.

representation, it will be argued that a psychological arrow of time emerges from the neurobiological level of description.

A compact characterization of a CML with one time parameter is given by

$$u(n+1,x) = (1-\epsilon)f(u(n,x)) + \frac{\epsilon}{n_x}\sum_{y\sim x} g(u(n,y)) \ , \qquad (1)$$

where x represents the sites of the lattice, $x = 1, ..., N_{tot}$, and n represents the time step of the iteration. The parameter ϵ specifies the coupling between each cell and its neighborhood. It is here considered as constant over time and space, disregarding neural plasticity. The sum over $y \sim x$ is the sum over all n_x neighbors y of vertex x. The function g characterizes the interaction of a vertex with its neighborhood and will be explained below.

As in many other studies of CMLs, $f(x)$ is the logistic map on the unit interval,

$$f(x) = rx(1-x) \, ,$$

with $0 \leq r \leq 4$. For $r \geq 1$ the logistic map has a critical point at $\frac{r-1}{r}$ which is unstable for $3 < r \leq 4$. The relevance of maps with quadratic maximum (such as the logistic map) for models of neurobiological networks was recently substantiated by novel results concerning a non-monotonic (rather than sigmoid) transfer function for individual neurons [12].

For $\epsilon \to 0$, there is no coupling at all; hence, local neighborhoods have no influence on the behavior of the CML. This situation represents the limiting case of N_{tot} independently operating local objects at each lattice site. In the general case $0 < \epsilon < 1$, the independence of individual cells is lost and the lattice behavior is governed by both local and global influences, depending on the chosen neighborhood. CMLs with a maximal neighborhood, $n_x \approx N_{tot}$, are often denoted as globally coupled maps. Their behavior is determined by global properties alone (mean field approach).

The function

$$g(x) = \alpha x + \beta f(x) + \gamma f(f(x)) \ , \qquad (2)$$

with

$$\alpha + \beta + \gamma = 1 \qquad \alpha, \beta, \gamma \geq 0 \ ,$$

allows us to treat the interaction between each vertex and its neighborhood in different ways, depending on its time scale Δt. If the interaction can be regarded as instantaneous, $\Delta t \approx 0$, the situation can be approximated by $\alpha = \gamma = 0$ and $\beta = 1$. Such a type of coupling, sometimes called "future coupling" [13], will be referred to as *non-causal coupling* [11] in the following, since the simultaneity of the interaction between vertex and neighbors makes the distinction of cause and effect impossible.

The situation of a finite interaction time $\Delta t > 0$ can be properly modeled by $\beta = \gamma = 0$ and $\alpha = 1$. In this way, past states in the neighborhood of a vertex are considered to act on the present state of the vertex with limited signal speed, so that the effect of an interaction is delayed with respect to its cause. Such a type of coupling will therefore by denoted as *causal coupling* in the following [11].

A third, somewhat exotic possibility arises for $\alpha = \beta = 0$ and $\gamma = 1$. This case reflects the idea to model the action of future states of a vertex neighborhood on a present vertex state. More precisely, this refers to *locally extrapolated* future states and is justified for small ϵ since then $u(n+1, y) \approx f(u(n, y))$. In this interpretation, the case of non-vanishing γ is in contradiction with causality; thus we refer to such a situation as *anti-causal coupling.* Its investigation can be of particular interest from a fundamental point of view, where forward and backward directions of time result from a decomposition of a time-reversal symmetric, or briefly reversible, evolution into these two components.

Another important feature for the interpretation of Eq. (1) is the time interval $\Delta\tau$ assumed for the updating mechanism, i.e. for the physical integration of signals from the neighborhood states with the state considered. If signals between cells are transmitted much slower than the time scale assumed for the updating mechanism, $\Delta\tau \ll \Delta t$, the updating can be implemented (almost) instantaneously, or synchronously. If this is not the case, $\Delta\tau \gtrsim \Delta t$, updating must be implemented in an asynchronous way. (In this case, an equation different from Eq. (1) has to be solved; see [14].) This entails the additional problem of determining a proper updating sequence, which can be random or depend on particular features of the situation considered.

Most of the work on CMLs (cf. [10]) was based on synchronous updating. However, asynchronous updating rules have been suggested as particularly relevant for neurobiological networks. For asynchronous updating, as first studied by Lumer and Nicolis [15], it was found that the behavior of CMLs differs strongly from that of CMLs with synchronous updating. As a common feature of asynchronous updating, it has been reported that it facilitates the synchronization and stabilization of CMLs decisively. In particular, Mehta and Sinha [13] demonstrated that the dynamics at individual lattice cells is strongly synchronized by coupling among cells. Atmanspacher and Scheingraber [11, 16] showed that unstable fixed points at individual vertices can be inherently stabilized as a consequence of their coupling to neighboring unstable fixed points.

3 Causal, Non-Causal, and Anti-Causal Interactions

Following up on earlier investigations of CMLs using the logistic map at $r = 4$ with synchronous and asynchronous updating for small neighborhoods, Atmanspacher and Scheingraber [11] presented numerical results for the stabilization of CMLs for different degrees of causal versus non-causal coupling. As mentioned above, the limiting cases are instantaneous interactions on the one hand ($\alpha = 0$; non-causal coupling) and finite-time interactions on the other ($\alpha = 1$; causal coupling). It was found both numerically [11] and analytically [14][d] that the degree $\alpha = 1 - \beta$ of causal versus non-causal coupling in a CML and its stabilization behavior are related in surprising ways.

- For *asynchronous updating*, the critical coupling strength $\epsilon_{crit} = 0.5$ for stabilization onset is in general robust against variations of both the degree of causal coupling and the type and size of neighborhood. The von Neumann neighborhood of order 1 shows an additional destabilization in the regime of small causal coupling, which is not observed for all other neighborhoods.

- For *synchronous updating*, there is no stabilization at all for small causal coupling $\alpha < 1/3$. In the regime $1/3 < \alpha < 1$, the influence of causal coupling induces stabilization at different critical coupling strengths. For global coupling with a causal degree $\alpha > 2/3$, the stabilization onset coincides with that of asynchronous updating.

These observations are summarized in Fig. 1, where symbols show numerical results and lines show analytical results. It is interesting to discuss the relation between stability and causality in terms of an interlevel scheme recently introduced under the notion of contextual emergence [8, 9] with particular emphasis on neurobiological and mental, or psychological, levels of description. The existence of assemblies at the neurobiological level of description is necessary but not sufficient to describe mental representations at the psychological level exhaustively. In addition, it is crucial that the neural correlates of mental representations be stable. This condition

[d]The analytical approach in [14] (similarly in [17, 18]) considers CMLs as graphs and analyzes their stability properties in terms of the spectrum of eigenvalues of their normalized adjacency matrix. See Sec. 4 for an explicit implementation of the approach for time-reversal invariant CMLs.

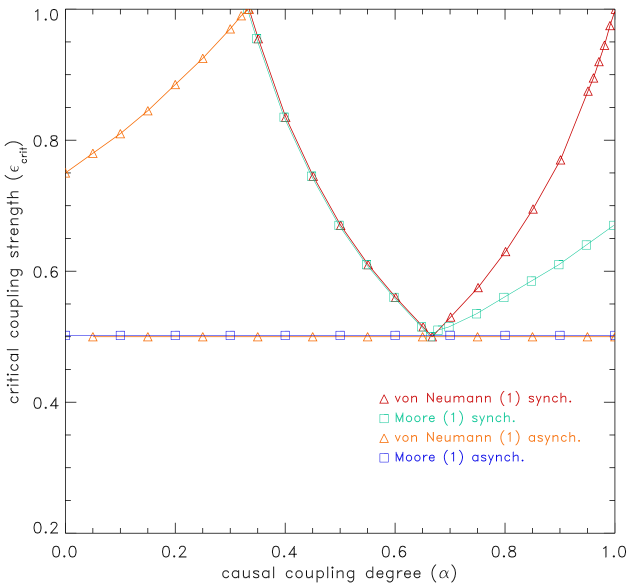


Figure 1: Critical coupling strength ϵ_{crit} for stabilization onset as a funtion of the degree $\alpha = 1 - \beta$ of causal coupling. Different symbols refer to different updating procedures and different neighborhoods as explained in the figure.

does not derive from the neurobiological level alone. It can only be reasonably motivated by features of mental representations at the psychological level. In this sense, stability conditions for neuronal assemblies represent a contingent context in addition to the neurobiological description. Only together with such an extra context is the neurobiological level of description sufficient to treat mental representations comprehensively.

The contingent context of *stable* neuronal activity is satisfied best if the coupling between interacting neurons is causal. Thus, forward causation at the neurobiological level of description is of crucial significance for mental representations as the key concepts at the psychological level. Insofar as this applies to their temporal sequence as well we can speak of an emergent arrow of time at this level. It should be emphasized that the contextual emergence of a psychological arrow of time consistent with forward causation does not imply that backward causation must be ruled out at the neurobiological level. Indeed, it is only possible to demonstrate forward causation as a selection criterion for stability if there are alternatives.

Since CMLs can be considered as discretized partial differential equations, our approach is a potential candidate for studying superpositions of advanced and retarded solutions of time-reversal invariant signal transmission in general. In addition to the non-causal alternative to causal coupling it was recently shown [14] that anti-causal interactions ($\gamma \neq 0$) within neuronal assemblies obstruct their stability even more than non-causal interactions. However, as mentioned above, anti-causal interactions in that context have so far been implemented only in terms of local extrapolations in CMLs. An appropriate way to study time-reversal invariant equations in a truly symmetric way will be discussed in the following section.

4 Time-Reversal Invariant Equations

So far the notions of "causal", "non-causal", and "anti-causal" interactions referred to specific implementations of interactions in Eq. (1), but not to its mathematical structure itself. The iterative Eq. (1) is always "causal" in the sense that it allows to determine the configuration $\{u(n+1,x)\}$ at time-step $n+1$, given the configuration $\{u(n,x)\}$ at time-step n. In this section, we study an equation which can be considered as a generalization of Eq. (1). Although it does not describe an actual "influence of the future", it allows us to investigate the role of time-reversal invariance in more detail.

The most straightforward way to extend Eq. (1) to a time-reversal invariant equation is to add a "future term" in the following way:

$$\begin{aligned} u(n,x) &= \tau\left((1-\epsilon)f(u(n-1,x)) + \frac{\epsilon}{n_x}\sum_{y\sim x} g(u(n-1,y))\right) \qquad (3)\\ &\quad +(1-\tau)\left((1-\epsilon)f(u(n+1,x)) + \frac{\epsilon}{n_x}\sum_{y\sim x} g(u(n+1,y))\right) . \end{aligned}$$

For $\tau = 1$ one recovers Eq. (1), and for $\tau = \frac{1}{2}$ the equation is invariant under time reversal, i.e., for any solution $\{u(n,x)\}$ $\{u(-n,x)\}$ is a solution as well. Although we may use Eq. (3) to *check* whether or not a given series $\{u(n,x)\}$ of configurations is indeed a solution, we cannot use this equation to *construct* such a solution unless we are able to solve Eq. (3) for $u(n+1,x)$. In this sense Eq. (3) does not represent an "algorithm" but only a necessary and sufficient constraint.

Another way to construct a time-reversal invariant form of Eq. (1) is given by:

$$\tau u(n+1,x)+(1-\tau)u(n-1,x) = (1-\epsilon)f(u(n,x))+\frac{\epsilon}{n_x}\sum_{y\sim x} g(u(n,y)) \; . \qquad (4)$$

Again, we recover Eq. (1) for $\tau = 1$, and the equation is time-reversal invariant for $\tau = \frac{1}{2}$. This time, however, it is easy to solve Eq. (4) for $u(n+1,x)$ and, thus, use it as an algorithm to generate solutions.

Both Eqs. (3) and (4) contain convex combinations of terms that are confined to the unit intervall $(0,1)$. Therefore the combinations, representing weighted averages, are confined to the same interval. However, solving the equations for $u(n+1,x)$, the restriction of $u(n+1,x)$ to $(0,1)$ is lost even if it still holds for $u(n-1,x)$ and $u(n,x)$ individually.[e] It would be a highly non-trivial task to choose initial configurations for $u(0,x)$ and $u(1,x)$ such that their iterations remain bounded in the unit interval.

Therefore, we relax the constraint on the domain of $\{u(n,x)\}$ and use functions f and g, for which this constraint is not necessary. We can, for instance, interpret the logistic map "modulo 1", or we can replace it by some analytic function such as $f(x) = \sin^2 \pi x$, which is known to be in the same "universality class" as the logistic map (the class of functions with quadratic maximum).

For technical reasons, we use a slightly modified version of Eq. (4) in the following discussion:

$$u(n+1,x) = (1-\epsilon) f(u(n,x)) + \frac{\epsilon}{n_x} \sum_{y \sim x} g(u(n,y)) + A\big(u(n,x) - u(n-1,x)\big) \; . \tag{5}$$

The original Eq. (1) for CMLs is recovered for $A = 0$, while a time-reversal invariant equation is obtained for $A = 1$. It turns out that the conditions for stable constant solutions of this equation can be worked out analogous to the special case $A = 0$. This connection becomes more obvious if we first investigate the one-dimensional problem, i.e. the case of a simple iterative equation for a field defined on a single point.

4.1 The One-Dimensional Problem

We consider the following second-order iterative equation:

$$u_{n+1} = f(u_n) + A(u_n - u_{n-1}) \; . \tag{6}$$

This equation has the following properties:

– For $A = 0$ it reduces to the simple first-order iterative equation:

$$u_{n+1} = f(u_n) \, . \tag{7}$$

[e] The average value $\bar{a}$ of two numbers a_1 and a_2, each confined to the unit interval, is always in the unit interval. If, however, a_1 and $\bar{a}$ are given in the unit interval, then a_2 may be larger than 1.

- For $A = 1$, Eq. (6) is invariant under time reversal:

$$u_{n+1} + u_{n-1} = f(u_n) + u_n \; .$$

  Rewriting this as

$$u_{n+1} - 2u_n + u_{n-1} = f(u_n) - u_n \; ,$$

  one can easily recognize the second difference quotient on the left hand side.

- The constant solutions $\bar{u}$ of Eq. (6) are independent of A and, therefore, the same as for the first-order iterative equation (7).

We can now express the "second-order" version of Eq. (6) as a coupled system of "first-order" equations in the variables u_n and p_n:

$$\begin{aligned} u_{n+1} &= f(u_n) + A(u_n - p_n) \\ p_{n+1} &= u_n \; . \end{aligned}$$

Small variations of u and p around the constant solution $u_n = \bar{u}$ and $p_n = \bar{u}$ yield in linear approximation:

$$\begin{aligned} \delta u_{n+1} &= f'(\bar{u})\delta u_n + A(\delta u_n - \delta p_n) \\ \delta p_{n+1} &= \delta u_n \; , \end{aligned}$$

or:

$$\begin{pmatrix} \delta u_{n+1} \\ \delta p_{n+1} \end{pmatrix} = \begin{pmatrix} f'(\bar{u}) + A & -A \\ 1 & 0 \end{pmatrix} \begin{pmatrix} \delta u_n \\ \delta p_n \end{pmatrix} \; . \tag{8}$$

For simplicity we define

$$f' := f'(\bar{u})$$

and obtain for the eigenvalues of the matrix in Eq. (8):

$$\lambda_{1/2} = \frac{f' + A}{2} \pm \frac{1}{2}\sqrt{(f' + A)^2 - 4A} \; .$$

The constant solution is stable if the absolute values of both of these eigenvalues are smaller than one. This leads to the following stability conditions:

- For $f' > 1$ or $f' < -3$ the system is unstable for all $0 \leq A \leq 1$.

- For $0 \leq A < 1$ the constant solution is stable, if

$$-2A - 1 < f' < 1 \, .$$

- For $A = 1$ (the case of time-reversal invariance) the system is at the margin of stability (provided that $-3 < f' < 1$), i.e., the absolute values of the eigenvalues of the matrix in Eq. (8) are 1.

4.2 The CML Problem

We now consider the case of an iterative mapping on a graph with N vertices. The general equation reads

$$\begin{aligned} u_{n+1}(x) &= F(x;\{u_n(z)\}_{z=1,\ldots,N}) + A(u_n(x) - u_{n-1}(x)) \\ &\text{for all } \ x = 1,\ldots,N \ , \end{aligned} \tag{9}$$

where F depends on the adjacency matrix of the graph and is some functional of the fields.

For $A = 0$ we obtain an iterative equation of "first order", and for $A = 1$ the equation is time-reversal invariant. We assume the existence of constant solutions (constant with respect to the vertices and with respect to time):

$$u_n(x) \equiv \bar{u} \ .$$

These solutions are independent of A.

As we in the one-dimensional case we rewrite Eq. (9) as a coupled system of first-order equations:

$$\begin{aligned} u_{n+1}(x) &= F(x;\{u_n(z)\}_{z=1,\ldots,N}) + A\big(u_n(x) - p_n(x)\big) \\ p_{n+1}(x) &= u_n(x) \ . \end{aligned}$$

Let

$$\Phi(x,y) = \left.\frac{\partial F(x;\{u(z)\}_{z=1,\ldots,N})}{\partial u(y)}\right|_{\{u(z)\}\equiv\bar{u}}$$

be the first derivative of $F(x;\{u(z)\})$ with respect to $u(y)$, evaluated at the constant solution $\bar{u}$, and let Λ_k be the eigenvalues of the matrix F. The stability analysis leads to the same conditions as for the one-dimensional case, where now f' has to be replaced by $\{\Lambda_k\}$. In particular, for $0 < A < 1$ the constant solution is stable only if

$$-2A - 1 < \Lambda_k < 1 \qquad \text{for all } k \, ,$$

and for $A = 1$ the system is at the margin of stability, as in the one-dimenisonal case. (If some of the eigenvalues Λ_k are outside the interval (-3,1), the constant solution is unstable.)

For Eq. (5) we have:

$$\Lambda_k = (1-\epsilon)f'(\bar{u}) + \epsilon\lambda_k g'(\bar{u}) \ ,$$

where λ_k are the eigenvalues of the adjacency matrix multiplied by the inverse of the valence matrix of the graph.

5 Conclusions

This contribution addresses the question of how a psychological arrow of time, i.e. a directed temporal sequence of mental representations, is related to the behavior of neuronal assemblies. At the neuronal level we approach this question in terms of coupled map lattices (CMLs) as models of neuronal assemblies with neurobiologically motivated parameters. The stability properties of CMLs are influenced by different types of interactions (forward causal, simultaneous, and backward causal) among individual maps.

A straightforward way to analyze the stability of constant solutions of CMLs against perturbations is presented in section 3. It allows us to implement forward causal and non-causal (simultaneous) interactions rigorously, but anti-causal (backward causal) interactions are treated only in terms of local extrapolations. This introduces a temporal asymmetry, which prohibits an interpretation of forward and backward causal components as a symmetric decomposition of a time-reversal invariant evolution. Nevertheless, there are indications that anti-causal interactions obstruct the stability of CMLs in a way similar to non-causal interactions. The comparison of forward causal and non-causal interactions shows convincingly that forward causation supports the stability of CMLs.

An analytical investigation of a rigorously time-reversal invariant evolution has been carried out in section 4. In this framework, time-asymmetric equations can be demonstrated to support the stability of constant solutions of CMLs against perturbations as compared to a strictly time-symmetric version. This result represents an intriguing application of a quotation by the 2004 physics Nobel laureate Frank Wilczek:[f] "The fundamental equations have the symmetry, but the stable solutions of these equations do not" [19].

Applying the obtained relation between causation and stability to the discussion of mind-brain issues yields an interesting argument with respect to the psychological arrow of time. This argument can be systematically expressed in five steps.

1. The psychological time arrow is related to the temporal sequence of mental representations.

[f]The reader may recognize that we are slightly misusing Wilczek's statement, which actually refers to symmetries and symmetry breakings in elementary particle physics. Although the mathematical details there are different from our scenario, the basic idea is the same.

2. Mental representations are correlated with the activity of stable neuronal assemblies.
3. The stability of neuronal assemblies is supported by causal neuronal interactions.
4. Causal neuronal interactions distinguish a forward direction of time.
5. As a consequence, the direction of the psychological time arrow coincides with the forward direction of time of causal neuronal interactions.

The converse of the argument, that the psychological time arrow implies forward causation at the neuronal level, would be wrong insofar as (2) does not exclude the possibility of non-causal or anti-causal neuronal interactions. Statement (2) simply says that causal interactions support the existence of mental representations. It does not say that non-causal or anti-causal interactions are impossible in principle. This result is in striking correspondence with Price's proposal [3] to take bidirectional causation seriously once the psychological time arrow is cleanly separated from the discussion.[g]

It is essential for the presented argument that properties at the mental level of description *emerge* from properties at the neuronal level of description and cannot be strictly reduced to that level. The key issue for the scheme of contextual emergence applied here [8, 9] is that a particular kind of stability condition is required, though not already given, as a contingent context at the neuronal level. Only if such a context were included in the "first principles" of the neuronal level, a strict version of reduction would be more plausible than emergence.

If neuronal assemblies are not stable enough, which is the case for non-causal (or anti-causal) neuronal interactions, then there are no mental representations whose temporal sequence could provide a psychological time arrow. We do not yet have a final answer to the interesting question of a psychological correlate of unstable (or marginally stable) neuronal behavior. Some speculative ideas may be found in the option of so-called *acategorial* mental representations [21] situated *between* the usual mental representations that are associated with stable behavior.

[g]Price himself seems to be mainly interested in causal and temporal bidirectionality in quantum theory rather than invoking mind-brain relations directly. It is a current topic of controversial discussion whether or not quantum approaches may be relevant for brain dynamics [20].

References

1. Zeh, H.D. (1992), *The Physical Basis of the Direction of Time*, Springer, Berlin.
2. Reichenbach, H. (1956), *The Direction of Time*, University of California Press, Berkeley.
3. Price, H. (1996), *Time's Arrow and Archimedes' Point*, Oxford University Press, Oxford.
4. Treisman, M. (1999), The perception of time, in J. Butterfield (ed.), *The Arguments of Time*, Oxford University Press, Oxford, pp. 217–246.
5. Dennett, D.C., and Kinsbourne, M. (1992), Time and the observer: The where and when of consciousness in the brain, *Behav. Brain Sciences* **15**, 183–247.
6. Ruhnau, E. (1997), The deconstruction of time and the emergence of temporality, in H. Atmanspacher and E. Ruhnau (eds.), *Time, Temporality, Now*, Springer, Berlin, pp. 53–69.
7. Fell, J., Elger, C.E., and Kurthen, M. (2004), Do neural correlates of consciousness cause conscious states?, *Medical Hypotheses* **63**, 367–369.
8. Bishop, R.C., and Atmanspacher, H. (2005), Contextual emergence in the description of properties, submitted.
9. Atmanspacher, H. (2005), Stability conditions in contextual emergence: From physics to cognitive neuroscience, submitted.
10. Kaneko, K., and Tsuda, I. (2000), *Complex Systems: Chaos and Beyond*, Springer, Berlin.
11. Atmanspacher, H., and Scheingraber, H. (2005), Causally and non-causally coupled map lattices, *Physica A* **345**, 435–447.
12. Kuhn, A., Rotter, S., and Aertsen, A. (2004), Neuronal integration of synaptic input in the fluctuation-driven regime, *Journal of Neuroscience* **24**, 2345–2356.
13. Mehta, M., and Sinha, S. (2000), Asynchronous updating of coupled map lattices leads to synchronization, *CHAOS* **10**, 350–358.
14. Atmanspacher, H., Filk, T., and Scheingraber, H. (2005), Stability analysis of coupled map lattices at locally unstable fixed points, *European Physical Journal B*, in press.
15. Lumer, E.D., and Nicolis, G. (1994), Synchronous versus asynchronous dynamics in spatially distributed systems, *Physica D* **71**, 440–452.
16. Atmanspacher, H., and Scheingraber, H. (2005), Inherent global stabilization of unstable local behavior in coupled map lattices, *International Journal of Bifurcation and Chaos*, in press.
17. Jost, J., and Joy, M.P. (2002), Spectral properties and synchronization in coupled map lattices, *Physical Review E* **65**, 016201.
18. Belykh, V.N., Belykh, I.V., and Hasler, M. (2004), Connection graph stability method for synchronized coupled chaotic systems, *Physica D* **195**, 159–187.
19. Wilczek, F. (2004), From 'not wrong' to (maybe) right, *Nature* **428**, 261.
20. Atmanspacher, H. (2004), Quantum approaches to consciousness, in *The Stanford Encyclopedia of Philosophy*, ed. by E. N. Zalta, http://plato.stanford.edu/entries/qt-consciousness/.
21. Atmanspacher, H., and Fach, W. (2005), Acategoriality as mental instability, *Journal of Mind and Behavior*, submitted.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 163–188

A STRUCTURE OF EXPERIENCED TIME

IVAN M. HAVEL
Center for Theoretical Study
Charles University and the Academy of Sciences of the Czech Republic
Jilska 1, 110 00 Prague 1, Czech Republic
(havel@cts.cuni.cz)

Abstract: The subjective experience of time will be taken as a primary motivation for an alternative, essentially discontinuous conception of time. Two types of such experience will be discussed, one based on personal episodic memory, the other on the theoretical fine texture of experienced time below the threshold of phenomenal awareness. The former case implies a discrete structure of temporal episodes on a large scale, while the latter case suggests endowing psychological time with a granular structure on a small scale, i.e. interpreting it as a semi-ordered flow of smeared (not point-like) subliminal time grains. Only on an intermediate temporal scale would the subjectively felt continuity and fluency of time emerge. Consequently, there is no locally smooth mapping of phenomenal time onto the real number continuum. Such a model has certain advantages; for instance, it avoids counterintuitive interpretations of some neuropsychological experiments (e.g. Libet's measurement) in which the temporal order of events is crucial.

Keywords: Time – Subjectivity – Memory – Present – Consciousness

1 Introduction

Hypothetically, time might be smooth
or rough, prickly or silky, hard or soft.
Alan Lightman

In this essay I intend to question the usual conceptualizations of time that either utilize the mathematically motivated idea of a linearly ordered homogeneous continuum, or rely on folk psychology of common experience of events smoothly and orderly flowing from the future through the present to the past.

With only few exceptions the mathematically idealized concept of homogeneous time is taken for granted in most sciences with the role of the best, if not the only, model of absolute objective (meta)physical time. Indeed, there are at least two advantages of such an approach, one of them coming from the fact that the properties of mathematical continuum allow for the use of the most powerful tools of infinitesimal calculus (utilized most in physical sciences); the second advantage stemming from the universality of absolute objective time that provides a basis to link up ideas (and empirical data) of diverse disciplines.

On the other hand, in philosophical phenomenology and, in particular, in the newly emerging consciousness studies, the idea of subjective temporal experience, characterized by the triad of the past, present, and future, plays a dominant role. However, attempts to unify the two conceptions of time realistically are doomed to failure. McThaggart [1] demonstrated that two models of time, one called the A-series (with the subjective past-present-future distinction) and the other called the B-series (with the objective earlier-later ordering), are mutually incompatible under the supposition of realism.

The prevailing practice is pushing aside the one or the other conception as irrelevant for a particular area of study. Thus, in physical sciences (perhaps excluding subquantum theories), the Newtonian claim that "absolute true and mathematical time, on itself and by its own nature, flows uniformly, without regard to anything external" (cited in [2]) has an enduring influence. In classical physics the basic attributes of time followed from its homogeneity, including its infinity, continuity, and uniformity. As Čapek points out:

> No matter how narrow a temporal interval may be, its limits remain always in the relation of succession, the first being earlier, the second later. Time flows even within its smallest intervals, because, strictly speaking, there are no smallest intervals. ([2], p. 40)

Even the relativistic view of time as dependent on (the relative motion of) the observer does not open the question of the first-person temporal experience. As Einstein himself writes:

> For us who are convinced physicists, the distinction between past, present, and future is only an illusion, however persistent. [3]

On the contrary philosophical phenomenology since Husserl [4] follows the program of "bracketing" all objective scientific ideas and concentrates on the analysis of human internal experience including temporal consciousness.

However, even before Husserl, William James [5] developed the idea of *specious present* (Clay's term) to capture the intuited duration of conscious present with a "vaguely vanishing backward and forward fringe" ([5], p.

613) and he cited various psychological measurements of the duration of the present in the standards of objective time. More recently philosophers of the analytical tradition have turned their attention to temporality and posed the question of relationship between subjective and objective time. John Searle somewhat modestly writes:

> Notoriously, phenomenological time does not exactly match real time, but I do not know how to account for the systematic character of the disparities. ([6], p. 127)

Other philosophers, like Daniel Dennett [7,8], make the effort to include observations of brain research into the account. In this respect the program of "neurophenomenology" should be mentioned, launched by the late Francisco Varela [9]. For the approach in this paper the work by Shaun Gallagher [10] is particularly relevant and I take the liberty to start by quoting his somewhat metaphorical statement that could be a watch-phrase of the present study:

> Instead of experience organized in a temporal stream, experience may be more like a rain against a finite surface, droplets of experience splashing together forming puddles of meaning which only sometimes flow together to create a short-lived stream. (p. 201)

I intend to propose a formal structure of time (to be called "granular" time later on) that radically differs from, but not replaces, both the commonsense and the conventionally scientific (linear and continuous) structure of time. By inserting the phrase "but not replaces" I want to entertain the idea of complementarity (epistemological as well as metaphysical) of the two conceptions. Correspondingly, Gallagher continues:

> If time is indeed a mystery that resists final definition [. . .] then we need [. . .] an incomplete set of theories that keep each other off balance, that undermine the formation of a Grand Theory of time. We need a metaphor of stream as much as the metaphor of incessant rain. ([10], p. 202).

2 The Twofold Way of Reflecting Temporal Experience

A promising point of departure might be to distinguish two ways that the originally pre-reflective lived experience may be submitted to subsequent reflective scrutiny. In any such reflection two tendencies can be distinguished: one aiming at a first-person, subject-oriented phenomenal account of experience; the other relying on a third-person, intersubjective or objective description of a situation behind such experience. In both cases we focus on temporal modality of lived situations that is only one of several basic *experiential modalities* (let us call them so; the others may be space, scenic structure, various types of efficacy or causality, movement in the most general sense, own body, own self, other selves, significance of situation *etc.*, see [11]). To focus on temporality does not mean neglecting other modalities since all modalities are mutually interconnected and the analysis of one requires (at least) a reference to others (for instance the spatial and temporal modalities are tightly connected in the notion of movement).

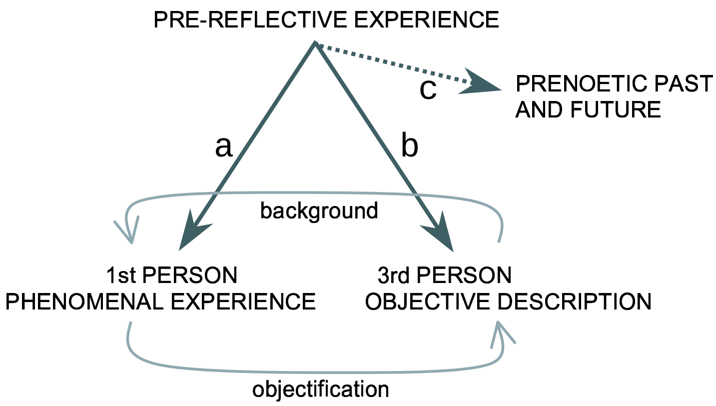


Figure 1. The diagram of reflections of experience; (a) the phenomenal account, (b) the objective account, (c) the relevance of the prenoetic past (forgotten autobiography, common cultural practices) and future (like death).

In Fig. 1 there is a general schema that may help to clarify our framework (it holds for other modalities as well). Here "pre-reflective" does not mean non-conscious; in fact it is the other way around: when I *reflect on* a particular experience I think *about* it, and even if such thinking is also a sort of experience, it is not *the* experience that I thematize in my reflection (correspondingly one should distinguish introspection from real experience of one's self).

The arrows (a) and (b) in Fig. 1 represent two extreme types of tendency in common-sense reflection. Type (a) leads to a phenomenal, or "first-person" account, type (b) yields an objective or intersubjective "third-person" account, typically based on, or influenced by, the scientific vocabulary. (In this essay I occasionally use the grammatical first-person singular or even the rhetorical second-person singular to stress the type (a) tendency in reflection of our experience. However, once anything is expressed in words, it automatically acquires a semi-objectified nature.)

The fact that I experience some events as *present* (or *just* past), I remember some events as *past*, and I anticipate some events as *future* is related to the type (a) of reflection. I can *objectify* some experiences (horizontal arrow from the right to the left in Fig. 1) by associating some objective dates with events and sorting them with respect to the earlier–later relation of the mentioned McTaggard's B-series. As a matter of fact, A-series can be dealt with as it were an outcome of an objectification of common human experience of the past–present–future triad.

Now, due to the essential role of objective linear time, whether in historiography, in our daily routines, or in science, it is hard to imagine *pure* first-person temporality. The idea of objective time plays the role of an ever present *background* for any such imagination.

Gallagher [10] emphasizes the role of much more and deeper background, called *prenoetic past*: "traditions, linguistic structures, social-economic forces that are hidden, yet operative within intentional life" (p. 166) and *prenoetic future*: "that which is not yet and is completely indeterminate affects our possibilities and constrains what we can project from out of the present, above all undoubtedly our death" (p. 175). In this study I do not take into account the pre-reflexive nature and origin of experience, as for instance the inter-subjective origin of temporality. Rather I would like to open up a theoretical/scientific analysis of any possible *common-sense reflection* (as opposed to informed philosophical reflection) of experience of temporality.

3 Multiplicity of Temporal Scales

Most natural sciences study events and processes occurring in objective time. Besides certain obvious facts about typical time scales of particular study areas (cosmology, paleontology, history. . . , all the way down to molecular reactions and interactions of elementary particles) there are relatively few studies concerned with the multiplicity of scales as such and their ordering and interrelationship ([12,13]). Imagine a collection of time arrows, each with its own characteristic time-scale unit, and order the arrows according to the length of that unit (e.g. microseconds, minutes, hours, years, decades, centuries, millennia, *etc.*). Imagine further that this ordered collection of arrows is arbitrarily extended in both directions, and moreover, that arbitrary number of new intermediate arrows can be inserted between any already existing pair of arrows. This yields a new imaginary continuum that I will call the *temporal scale axis* (TS). Each point of this axis corresponds to a time arrow of a certain specific scale (cf. Fig. 2, upper line).

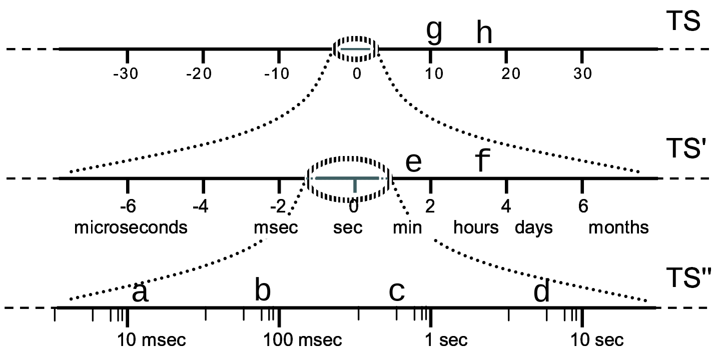


Figure 2. Temporal scale axis (TS) and some of its enlargements; (a – h): various scales relevant to cognition. (Numbers at TS and TS' are powers of 10 in seconds.)

This construction enables formulating various ideas in geometrical language. For instance the discourse of a typical scientific discipline is often restricted to a certain segment of TS with fuzzy boundaries towards the small as well as towards the large scales. In Fig. 2 a segment corresponding (roughly) to the span of scales more or less relevant to human cognition is depicted by the small ellipse on the TS axis. (It may range from microseconds of neural events to months of medium-term learning and memory). By zooming in this segment we obtain a more detailed scale axis TS' and zooming in once more yields a segment relevant to human consciousness (axis TS"). This last segment turns out to be particularly important for discussions about possibilities of projecting the present-time consciousness onto the objective time-line.

Several significant temporal scales (with respect to physical time) are marked in Fig. 2: (a) sensory fusion thresholds [14, p. 108], (b) micro-cognitive phenomena (e.g. shape and color detection), (c) cognitive acts (perceptual recognition, delays in conscious experience), (d) descriptive and narrative assessments (typical utterances), conscious control of action, (e) preplanning of action, (f) reasoning, typical period of stable concentration (lectures, movies, masses etc.), (g) formation of individual character (life-long), (h) evolution. (Compiled mainly from [9,14–16].)

One of the characteristics of human consciousness is the limited span of relevant temporal scales of experience. On one side of the spectrum there is the liminal discernability in conscious perception of short temporal intervals (tens to hundreds of milliseconds); on the other side there is the ability of autobiographic memory to grasp extended periods of personal life (decades). Everything below or above these two horizons is accessible only through indirect knowledge, either from scientific measurements or from historical data.

In spite of the scientific assumptions about the absolute objective time, particular disciplines or areas of study have their own, seldom explicitly thematized, horizons of relevant scales.

Events with duration near the scale horizon cease to be relevant; those of duration beyond the horizon are irrelevant. I will use the term *domain of discourse* to capture this feature (among others) of various areas of scientific (and not only scientific) investigation. In view of the fact that besides the time-scale limitation there are other boundaries of a given domain of discourse (for instance space-scale horizon) I suggest the general concept of the *domain horizon* to capture the intuition of the shadowy fringes of the expressive and explanatory power of concepts, laws, and theories of the area in question.

Besides the domain horizon there are other attributes that characterize a domain of discourse, for instance domain-specific types of causal efficacy and pertinent causal laws. One of the advantages of talking about domains of discourse is that it enables a distinction between two kinds of concepts, relations and facts: those that are "endemic" (specific to a particular domain) and those that *link up* two or more domains (are shared by them, bind them causally, are correlated *etc.*).

There are at least three domains of discourse particularly relevant to experience of temporality: the *phenomenal domain* (the domain of first-person conscious experience), the *psychological domain* (the causal or explanatory basis for behavior described in the third-person way) and the *neuroscientific domain* (concerned with neural and brain functioning). The distinction between the first two domains is more philosophical (cf. Chalmers [17]), while the psychological and neuroscientific domains differ more or less in the scale of phenomena under study. Part of the tentative strategy of this study will be treating the concept of time as if it were *endemic* to a particular domain. This would give a certain freedom in considering various alternatives for the fine texture of time.

Specifically, I will be concerned with the option of discrete, granular texture of time at the subliminal level. First let me point out a supporting intuition based on the large-scale structure of phenomenal time.

4 The Emergence of Autobiographical Time

Close your eyes and try to recall a concrete situation or event from your past life that persists in your memory. It may be, for instance, an event from your childhood, a party, your wedding ceremony, your yesterday's searching for lost glasses. Let us call any such event, in general, an *episode* of your life. Even if you may recall the episode very vividly you do not repeat your living through it and your present experience is experience of something else: an experience of recollection of the episode. There are some processes in the brain that make it possible but brain science does not know yet where exactly and how it happens. There is at least a term for it used by Tulving [18], namely the *episodic* (or *autobiographic) memory*:

> Episodic memory is a recently evolved, late-developing, and early-deteriorating past-oriented memory system, more vulnerable than other memory systems to neuronal dysfunction, and probably unique to humans. It makes possible mental time travel through subjective time, from the present to the past, thus allowing one to re-experience, through autonoetic awareness, one's own previous experiences. [...] The essence of episodic memory lies in the conjunction of three concepts — self, autonoetic awareness, and subjectively sensed time.

Note that physiological discourse is here somewhat carelessly linked to a subjective mental discourse. Moreover, some authors mention "preservation of some sort of place keeping and time tagging" ([19], p. 262) as a central characteristic of episodic processing.

In our view, however, no a priori temporal coordinate line exists that would make such a "time tagging" exact. Yet, in my intuitive reflection, I apprehend all past episodes of my life as if they were spread over (an a priori intuited) time-line. Let us call such a totality of episodes a *panorama* of personal life (I borrow the word from the title of H. G. Adler's novel [20]).

Let us examine the idea of panorama of personal life as it appears to a reflecting person (e.g. to myself). There are several evident observations. First, one (and only one) of the episodes is the *actual*, presently-lived episode, other episodes are past or imagined. The past episodes may in principle reappear into the present as *memories* either due to intentional recollection or spontaneously. There exist also purely imagined, *contingent*, or even dreamed episodes which should not be counted as parts of the panorama in the strict sense; it should be noted, however, that only the subject can draw a dividing line between (possibly) distorted memories of real episodes and episodes that are only imagined or dreamed (which may be "located" into the past, the future, or without any temporal label).

The second observation concerns the questionable temporal ordering of experienced episodes. I can recall the memories of past episodes in arbitrary order, and, more importantly, I cannot always decide about the actual order of their past occurrences. Since a part of our cultural background is the certitude about linearity and connectedness of our autobiography as if all experienced episodes orderly followed one after another (I will mention mutual inclusion of episodes later on) we automatically ascribe the disorder and gaps merely to our forgetfulness and unavailability of complete chronological records. However, for the sake of discussion, let us follow the strategy of separating our phenomenal first-person experience from the background intuition of linearity (and continuity) of time.

Up to now we have dealt with the overall structure of the panorama of episodes as if episodes themselves were primitive atomic entities. They are not. Our third observation applies to the inner structure of a typical episode, namely to its *inner temporality.* Such an episode can be associated with a smaller or larger temporal extension and with a certain narrative content. Normally the narrative content is more characteristic: think, for instance, about meeting with a friend, having a lecture, writing a letter. Such episodes comprise many further features: space, scene, participating persons, things, processes, events, and also your mental states (there is no essential distinction in this context between episodes and situations mentioned in Sec. 2). Both duration and spatial extension of an episode are not unlimited but there do not exist any strict spatial or temporal boundaries: the inner episodic time and space cannot surpass the *subjective* horizon of the episode that depends on the position, interests and intentions of the subject, and, in general, on the meaning of the episode for him.

Think about an actual episode you live through right now. In its inner perspective you can experience other, non-actual episodes only indirectly, through intentional recollection or imagination. They are, so to speak, behind the horizon of the actual episode, not just next to it (there is no "next" in this sense). Thus if you recall, say, a past episode of your life not just by reference but re-experiencing it, you actually live in *two* times simultaneously (in different mode only): you live in the virtual replayed time of the episode that you are recalling *and* you live in the time of the actual episode in which you perform the recalling. In fact, there is also a *third* time, the seldom-reflected *background time* of the panorama of you life as a whole, in which all the episodes flow.

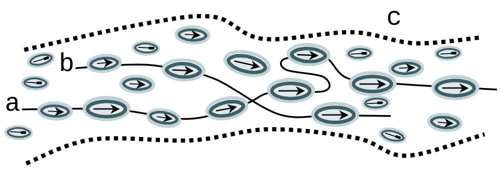


Figure 3. A graphical metaphor for the stream of episodes. The arrows correspond to the inner time of episodes; lines (a) and (b) connect some of the episodes; complex (c) depicts a segment of the panorama of personal life.

Most of the theories of personal time take for granted the metaphysical assumption that all three mentioned times coincide and hence that it is nothing else but the weakness of our memory and narrowness of consciousness that prevent us from projecting all the episodes of our life densely onto one common measurable time-line. Analogously, most natural sciences entertain the notion of objective physical time endowed with the structure of the ideal mathematical continuum, formally identifiable with the continuum of real numbers. (Let us put aside speculations of contemporary sub-microscopic physics that apply to scales remote from anything relevant to human experience.) The same notion of time is tacitly used in research on consciousness in spite of the fact that human consciousness has no access beyond the temporal scale-horizon (towards the small scales) of tens of milliseconds.

What is the origin of the certainty about such linearity and continuity of objective time? Does it come from experience of the lived present (to be discussed later)? Or is it our inherent view that our past life consists of episodic memories glued together into a single amorphous whole? Marcel Proust in his famous search for "lost time"[21] writes:

> All these memories, following one after another, were condensed into a single substance, but had not so far coalesced that I could not discern between my oldest, my instinctive memories, those others, inspired more recently by the taste or "perfume," and those which were actually memories of another, from whom I had acquired them at second hand — no fissures, indeed, no

> geological faults, but at least those veins, those streaks of color which in certain rocks, in certain marbles, point to differences of origin, age, and formation. (p. 164)

Let us try to suppress the view of our past "condensed into a single substance" and let us take notice that, after all, our memory only offers discrete, episodic clips that *are* divided by "fissures" and "faults". The experienced episodes have their own inner *episodic time* and most of them are separated by gaps of unrecoverable memory. "Fissures" and "faults" (perhaps even "veins" and "streaks") in Proust's reflection may only be products of our effort to secure temporal continuity of our selves and of the surrounding world.

Reflecting, in the abstract, the personal life panorama comprised of all episodes that have become or will become the content of the episodic memory we may formally identify some general relationships among mutually distinguishable episodes. This may be *disjunction* (temporarily distant episodes are separable), *overlap* (two episodes share certain events), or *inclusion* (one episode being a component of a more extensive episode). This is, indeed, a somewhat static view. As some episodes are refreshed in new recollections, others lost from memory entirely, still others become overlapped, the structure of the panorama perpetually evolves.

In spite of that, the idea that, in principle, all episodes of the panorama may be glued together into a single linear chain of connected or overlapping episodes seems to me somewhat counterintuitive: there are rare cases, indeed, that two not overlapping events are in some way linked together (whether due to a causal link, evolution of involved entities, or something else — see Sec. 7).

Now, if there are gaps between episodes in the life panorama, we may naturally ask: what is *inside* these gaps, what is *between* episodes? But do we really expect something to fill the gaps? Indeed, we are accustomed to say "some time elapsed between them". When saying it, we mean, however, *another* time, not the authentic time of narratives and episodes, but the pervasive background time of inner intuition.

I propose to speculate about a sort of *granular time* composed of "droplets of experience", for which Fig. 3 may serve as a graphical metaphor. Lines (a) and (b) may be two alternative quasi-linear lines, each consistent with experience but mutually incompatible. Only on a higher level the lines may "flow together to create a short-lived stream" or, on the topmost level, they merge into the panorama of personal life (c). As O. Sacks writes (motivated by observation of a patient with Korsakov syndrome) [22]:

> We have, each of us, a life-story, an inner narrative — whose continuity, whose sense, *is* our lives. It might be said that each of us constructs and lives, a "narrative", and that this narrative *is* us, our identities. (p. 105)

Obviously, our life panorama evolves throughout life owing to our ability to preserve episodic memories. Antonio Damasio observes [23]:

> The ability to form memories is an indispensable part of the construction of a sense of our own chronology. We build our time line event by event, and we connect personal happenings to those that occur around us. (p. 50)

Incidentally, this may be one of the areas of study that may link up three domains of discourse, related to experience of temporality (see end of the previous Section).

Certain disorders may help to find a neural basis for consciousness:

> In patients with damage of temporal lobe cortex, years and even decades of autobiographical memory can be expunged irrevocably. [...] The patient inhabits a permanent present, unable to remember what happened a minute ago or 20 years ago. ([23], p. 51)

Sometimes such a patient becomes a "confabulatory genius" — he "must literally make himself (and his world) up every moment" [22]. This points to the importance of the narrative content. Paul Ricoeur aptly writes:

> [T]ime becomes human to the extent that it is articulated through a narrative mode, and narrative attains its full meaning when it becomes a condition of temporal existence. ([24], p. 52)

Next we shall turn to the opposite end of the span of relevant scales, to phenomena on the threshold of consciousness. Again, some important links between different domains may emerge.

5 A Lesson from Libet's Experiments

Among the research areas where the inner experience meets objective measurements and where precise timing plays an essential role may be the study of processes on the threshold of conscious detection. The neuroscientist Benjamin Libet recently summarized in a book [15] his famous experiments from the 70s and 80s of the last century dealing with human

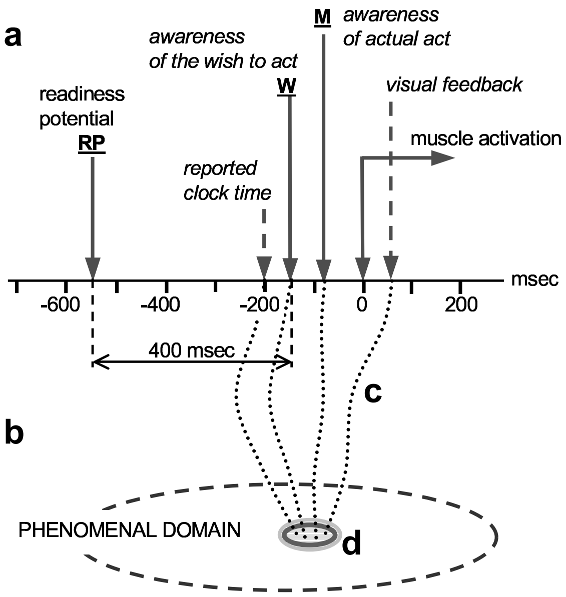


Figure 4. Libet's experiment; (a) diagram of measured times, (b) an interpretation of the experiment.

affairs as intimate as free decisions. They seem to indicate that our cortex "knows" the outcome of our voluntary decisions long before we make them. Let us briefly summarize the most interesting experiment (cf. Fig. 4(a)): the subject is instructed to decide freely when to make a certain movement (flexion of the wrist). At the same time a readiness potential (RP) from his scalp is recorded that always accompanies such a voluntary act. The surprising outcome is that the onset of RP not only precedes the act but also, by 400 whole milliseconds, precedes the time of subject's free decision (or wish) to act (inferred from his reading the time from a special clock). This temporal difference is substantially larger than any neuronal delays can explain. The question arises whether it is the neuronal network itself that is responsible for our action. Is free will, after all, just our subjective illusion?

Even if we put aside the strongly antilibertarianist view (that human action is just a result of purely causal physical processes in the brain, possibly combined with blind randomness at a lower level) we can still speculate about at least five different interpretations of Libet's experiment, the first two being somewhat radical (and I mention them for the sake of completeness):

(1) There may exist a *retrograde causation*, i.e. neuronal behavior is a direct consequence of our future decisions. This would obviously require a radical revision of our notion of causality or time or both.

The second option seems equivalent (but need not be so):

(2) The neuronal level may be capable *of precognition* whereby neuronal structures might predict our future decisions in order to be prepared for action.

The following three options seem more plausible:

(3) A decision may be intentionally *delegated to unconscious processes*, while consciousness only retains the power of veto (or trigger) their activity. Libet himself suggests this interpretation on the grounds that his experiments actually prove the possibility of vetoing the decision (the deadline for veto is 50 msec prior to muscle activation). What we call free will may be just a surveillance of consciousness that, especially in cases of routine and meaningless behavior, may be relatively weak and/or reduced just to the veto.

(4) Subjective timing may be *postdated*. Conscious decision is the actual cause of neuronal processes but there is a subjective referral of the timing for that decision to the actual time of muscle activation. Note that there exists experimental evidence (mentioned also by Libet [15], Chapt. 2) for antedating of delayed sensory experience (by 500 msec). Note that behind all previous interpretations there is a tacit presupposition that for each event in the phenomenal domain there exists an objective — and thus "correct" — reference point in the physical time-line. Only with such a presupposition can one use terms such as displacement, antedating, postdating, simultaneity, or even temporal kinks described by Dennett [8]. The following last option questions the very possibility of correct datation:

(5) Subjective timing (the endemic time of the phenomenal domain) is *in principle incomparable* with the objectively measurable time of physical sciences. The term "in principle" means here that there may be a radical difference between subjective experience of temporality and the idea of the continuous real line.

Let us illustrate this last point by Libet's experiment. In part (a) of Fig. 4 there are shown four conceptually distinguishable events that can contribute to conscious sensation in the experiment: detection of the clock time, becoming aware of the wish to act (W), becoming aware of actual act (M), and possible visual perception of the actual movement of the hand (in a more complex action such perception would play the role of feedback). The indicated objective (measured or calculated) timing of these events is used in customary interpretations of the experiment, including the claim of the illusoriness of free will.

My thesis is that the objective timing of these events cannot serve as a basis for any conclusions about conscious experience, not even in the case when some of the time intervals between the events are supraliminal (e.g. more than 100 msec as in the discussed case). The idea is that in the phenomenal domain (the domain of our inner consciousness, cf. Fig. 4(b)), all the mentioned events, being semantically related, clump together into a single meaningful whole (d) — in our case "one's willful wrist flexion".

For reasons to be seen soon I shall call any such meaningful whole a (phenomenal) *atomic episode* and the imagined "process" of its formation *semantic binding* (cf. Fig. 4(c)). Thus, the objective timing of individual participating events is lost in semantic binding and consequently the resulting atomic episode cannot be associated with any concrete point in the objective time-line. Incidentally, another set of events may form a different atomic episode, that is in conscious experience distinguished from the first one, even if the original events of both episodes were intermingled when projected to the objective time-line.

In general, the statement that an episode preceded or followed some physical event (for instance the change of the readiness potential) or that it preceded or followed another episode may be meaningless.

I use the modifier "atomic" in order to stress the fact that normally we do not feel any inner temporal structure of such episodes: the explicit temporal layout of participating events is not phenomenologically accessible. This makes them different from life episodes discussed in Sec. 4.

6 Present-Time Consciousness

At this point it is natural to open the issue of inner experience of time at the smallest temporal scales. Phenomenology of present-time consciousness is an area of intensive philosophical and psychological study since the already cited works of James [5] and Husserl ([4], cf. also [25]) who both were concerned with the temporal structure as the principal feature of consciousness. Here I will mention just those intuitively discernible aspects of temporal consciousness that are related to the present study.

Various analyses of psychologists (James), philosophers (Husserl, Bergson, Merleau-Ponty, more recently Gallagher and others) and neurophenomenologists (Varela, van Gelder) are in agreement that the actual, *lived* *present* (the Jamesian “specious” present) is not a strict durationless point (the instant “just now”). Most of the authors are, on the other hand, reluctant to associate with the lived present an extended, or even measurable, interval of the physical time continuum. Rather they characterize it by a Husserlian threefold structure of *primal impression, retention,* and *protention*. Let me suggest a way of intuiting this structure.

Imagine that you are perceiving an object (or performing an act or contemplating an idea) right “now”, in the present. The primal impression presents the object in its simultaneity with your intentional act of perceiving it. At the same time you perceive the object (in the present) in the light of your *just-past* intentional act of perceiving the same object (including its just-past primal impression) as well as in the light of your *about-to-be* intentional act of perceiving it. Thus, besides the primal impression, there is also the retentional and the protentional dimension of the present that yields the intuition of its non point-like character.

The expressions “just-past” and “about-to-be” should hint at three features of retention and protention: immediacy, smoothness, and fading away towards the past (or future). *Immediacy* indicates that retentioning is not the act of recollection from memory and protentioning is not the act of imagining the future: they are both firmly tied to the lived present. *Smoothness* reflects the absence of any recognizable fine structure of retention and protention. And *fading away* corresponds to the absence of strict borders. The lived present in this sense only has fogged horizons (Jamesian “vanishing fringes”) towards the past and towards the future.

Retentioning and protentioning, besides the mentioned common features, are distinctly asymmetrical in our experience due to the determinate and actualized character of the just-past in contrast to the indeterminate, contingent character of the about-to-be. Consequently the essentially formless present has a salient feature: an *inherent polarization*.

There have been various attempts to represent the structure of present-time consciousness in a diagram (cf. [10], Chapt. 3); in my own visualization (Fig. 5) the lived present is represented by a small ellipse (a) with fuzzy contour (the local horizon). It is stretched around the imaginary point-like “now” (b); its inherent retentional-protentional polarization is indicated by arrow (c) pointing from the past to the future.

When discussing the pictorial representation I should first of all warn the reader: any such graphical representation of subjective states or processes (i.e. most of the drawings in this essay) may only have a heuristic value and does not depict anything real. Referring to the methodological

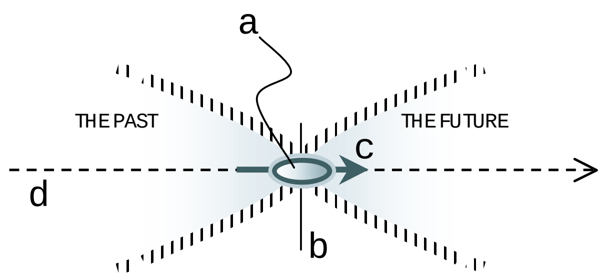


Figure 5. Pictorial representation of (a) the lived present, (b) the idealized "now", (c) the retentional-protentional polarization, (d) the constituted time-line.

framework outlined in Sec. 2, we may think of Fig. 5 and of the related commentary in two different ways. Firstly, it may be viewed as a step towards objectification of the subjective experience of time. Secondly, we should be aware that this very step is enabled by, and based on, the common objective conceptual background. Thus, for instance, the dotted line (d) in Fig. 5 can be interpreted in two manners. It represents our a priori view of objective linear time that is in the *background* of all our reflections; without it I could not even draw the picture putting the past to the left and the future to the right. At the same time we can interpret the line as something *constituted* in the course of our reflection of our inner experiences. In such a reflection the time-line represents the flow of present moments as if viewed from a distance so that each such moment seemingly shrinks to a point-like "now" (b).

When the object perceived in the actual present has itself a successive nature, as for instance a moving thing, a melody, or our own gesture, we should not identify such a presently perceived succession with a succession of lived presents (this relates to the "cognitive paradox" discussed by Gallagher [10]). In fact, Husserl and other philosophers often use a two-dimensional diagram with a vertical line corresponding to the retentional-protentional structure of the present conscious and a horizontal line representing successive conscious acts.

Let me propose a general account of the situation. First let us note the similarity of the concept of atomic episode from Sec. 5 and the notion of lived present from this section. The difference is only in the aspect emphasized: in the former it was the absence of a phenomenologicaly accessible inner structure, while in the latter it was the inherent retentional–

protentional polarization. Since any atomic episode can also be viewed as a possible content of lived present it adopts the polarization from it. Thus we can assume that such a polarization is an inherent objective feature of any atomic episode. (This assumption can be viewed as a step in objectification in the sense of Sec. 2.) It is also its *inner* feature in the sense that we cannot automatically take it as something concurrent with the external objective time-line (remember that according to one of the interpretations mentioned above the time-line can be viewed a secondary, constituted object). With this precaution the polarization arrow (c) in Fig. 5 is yet drawn collinear with the time-line (d).

In his important study [9] Varela suggests a neurophenomenological account of the relationship between brain dynamics and the concept of lived present. He writes:

> [A]ny mental act is characterized by the concurrent participation of several functionally distinct and topographically distributed regions of the brain and their sensorimotor embodiment. From the point of view of the neuroscientist, it is the complex task of relating and integrating these different components that is at the root of temporality. A central idea pursued here is that these various components require a *frame or window of simultaneity that corresponds to the duration of lived present.* [...] These endogenously constituted integrative frameworks account for perceived time as discrete and nonlinear, since the nature of this discreteness is a horizon of integration rather than a string of temporal "quanta". (pp. 272–273)

Now, "relating and integrating different components" may also be a basis of what I call semantic binding. Note that the phrase "the nature of discreteness is a horizon of integration" can be interpreted as another way of pointing to the "fading away" feature of retention and protention. In the same study Varela also deals with the property of lived present that I called "polarization". He (unlike Husserl) points to affective and emotional aspects of the asymmetry of the present:

> There are at least two main sources of evidence to conclude that protention is generically *not* symmetrical to retention. The first is, precisely, that the new is always suffused with affect and emotional tone that accompanies the flow. In fact, protention is not a kind of expectation that we can understand as "predictable",

> but an openness that is capable of self-movement, indeterminate but about to manifest. [...] The second is that retention has the structure of a continuum, but protention can only be a bounded domain, since we cannot anticipate that which is yet to come. While the threads of retention set the stage of protention, protention cannot modify the retentional threads retroactively. ([9], p. 296)

Here "the structure of continuum" may refer to the idea that fading away of retention is gradual and unbroken, while protention does not reach too far. In my understanding the feature of being "smooth" and of "fading away" is shared by retention and protention; the asymmetry relates more to the prenoetic "attitude" to the intentional content of lived present with a certain deficit of freedom towards the just-past.

7 Stream of Episodes

In Sec. 5, I used the term "atomic episode" to capture the cases when due to the semantic binding, several events, which are distinguishable theoretically (or empirically) in the neuroscientific domain of discourse, are clumped together. Atomic episodes are too brief to have consciously accessible temporal duration and yet they are not simply point-like entities with respect to objective physical time. In the previous section such episodes were enriched with inherent polarization due to the conceivability of their occurrence as contents of lived present with retentional–protentional polarity. It is then natural to extend the concept of atomic episode to cover *any* episodic experience that can possibly be the content of a lived present. It is then enough only to distinguish the *present* (i.e. actual) atomic episode from all past (or temporally indefinite) atomic episodes.

Let us now discuss how atomic episodes, successively present, can create a stream of episodes flowing away to the past (or to nothingness), which may produce, on the side of the experiencing person, the feeling of continuity of time. In my opinion there are two complementary options how to consider it.

(1) The first option is to take continuity as the primal idea and base on it the intuition that each present atomic episode, while smoothly fading on the horizon of the lived present, is immediately and indiscernibly overlaid with a subsequent atomic episode. Thus, in the words of our introductory quotation, "puddles of meaning [...] sometimes flow together to create a short-lived stream." The experience of my concrete act of wrist flexion is dissolved in the flux of other important happenings of my conscious life.

This option applies primarily to the experience of succession (mentioned in Sec. 5). Note that the very description of this option plainly presupposes the background of a linearly ordered continuous time-line.

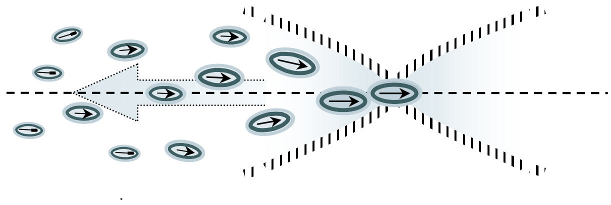


Figure 6. Atomic episodes dripping off from the present time.

(2) In contrast, the second option is based on the presupposed disjoint character of individual episodes. For superficial intuition I refer to Fig. 6 that is an extension of Fig. 5. The idea is that the present atomic episode is not overlaid with the next atomic episode but that it "drips off" from the present to the past without loosing identity. My concrete wrist flexion remains "the same" wrist flexion even after many other things happen.

Clearly the second option yields a more objectivistic view than the first and as such it is more appropriate as a basis for episodic memory as discussed in Sec. 4. Before an episode is stored in episodic memory it has to leave the present-time window of consciousness altogether, while preserving its own integrity. Only after episodes are, so to speak, lost from the sight can they be brought back in recollections; and the recollections can have an arbitrary order.

The same picture as in Fig. 6 may apply here, with the main difference (besides entirely different assumed time scales) in the interpretation of the little arrows inside episodes: in the case of episodic memory they correspond to the inner, narrative temporality of episodes while in the case of atomic episodes they stand for retentional-protentional polarization.

There may be various types of semantic linkage between different episodes in memory, some links undirected, some directed. A directionless linkage may be derived from the apprehended identity of objects and events that take part in different episodes, and trivially, but most importantly, from the self-identity of the experiencing person himself. Examples of directed links between different episodes are efficacious relationships (what happened in one episode brought about something that happened in another episode), identity preserving changes (for instance growth), and datings (different episodes are tagged with different dates, the tags being ordered). Some orderings of episodes may be remembered, some not. If we theoretically bracket out any a priori intuition of a background linear time, we have still a possibility of imposing a relation of partial order upon the set of episodes. Under certain conditions the partial order may be embedded in a quasilinear global "stream".

This brings us again to the pictorial representation of the time stream in Fig. 3. The speculative idea the picture suggests is to give a more weight to option (2) above and reflect our subjective experience, and therefore also our subjective experience *of* time, as something that emerges from a discrete underlying structure. I propose to call it *granular time*.

In my view, the ordinary commonsense view of a smooth, continuous flow of time may be a combined outcome of several sources of intuition: on a smaller scale it is our inability to discriminate time differences of subsequent episodes (which relates to the first option above), on a larger scale it is our common practice to refer to clocks and calendars, and in general, it is our inherent cognitive and cultural reliance on the linear model of time. Thus we may be tempted to say that the continuity of time is an illusion. Here, for example, is a statement by the neuroscientist Ernst Pöppel [14]:

> [The] apparent continuity of time is a secondary phenomenon — actually an illusion —, which is only made possible by discrete information processing on different temporal levels. (p. 107)

However, I would rather speak about "emergent phenomenon" since the term "illusion" seem to suggest, on the part of its user, knowledge of something that is *not* illusion: that is the "true" nature of things.

My favorite image for the two mentioned complementary views of a stream is an hourglass. If you look at it from a certain distance you can see a continuous yellowish strip just under the neck of the hourglass. If you look closer you may discriminate little grains of sand incessantly falling down from the neck. The source of difference between these two views is simple: a zoom. Thus the hourglass may be an apt metaphor for the idea of granular time. (An open-eyed reader could notice a hidden circularity in both cases: the falling of grains of sand is itself a continuous movement and speaking about stream of episodes would not be comprehensible without an a priori experience of continuity.)

8 From Subliminal Events to Narrative Episodes

From different interpretations of Figs. 3 and 6 we learn that much of what has been said may apply to situations on various temporal scales. Let us examine several cases of particular relevance to the idea of a granular structure of experience and possibly of time itself.

(1) *Subliminal events.* In the domain of smallest scales relevant to cognition (10 to 100 msec, cf. Fig. 2(a, b)) there are quite a few empirical results to do with the discontinuity of human perception. Let me briefly mention just one: the saccadic movement of eyes. Due to this movement the brain receives a discrete sequence of snapshots of a visual scene, each as short as 120–130 msec, with intermediate blind periods of less than 100 msec (when the eyes are in transit). In the visual area of the brain, the data are interpreted still under the threshold of conscious discrimination and only the result is accessible to awareness. In general, it appears that perceptually relevant data are never available in the brain in proper order (or simultaneity), but yet no discrepancies are phenomenologically noticeable. For many impressive examples see [7,14].

(2) *Liminal events.* This category may include the atomic episodes mentioned at the end of Sec. 5 (semantic binding at 100 to 500 msec – see Fig. 2(c)). The characteristic feature is that several events, which otherwise could be accessible to awareness separately, are semi-consciously clumped together to form a single episode. Thus meaning not only may override sequential ordering but also continuity. As discussed in Sec. 6, retentional–protentional polarity is a salient feature of liminal events.

(3) *Supraliminal (continuous) events.* Smooth progression of mutually overlapping episodes, as described in option (1) in the previous Section, may be a source of apparent continuity as a secondary, emergent phenomenon. Typical span of scales on which conscious experience of continuity may trump discontinuity may range from seconds to minutes or more — depending on human ability to maintain concentration on a single object or topic (see Fig. 2 (d, e)).

(3) *Narrative episodes* were already discussed in Sec. 4. The typical scales of their episodic time may range from minutes to days (see Fig. 2 (e, f)).

It is natural to treat a collection of episodes (even the atomic ones) that are in one way or another related as a single higher-level episode. In fact, we may view the whole panorama of life as a tangled hierarchy of episodes within episodes within episodes (cf. [26]). Such a hierarchy could be explicitly encountered perhaps only in fiction (The Arabian Nights); an interesting feature of a fictional hierarchy of narrative episodes may be the peculiar coexistence of a multitude of mutually disjoint and incomparable episodic times.

When suggesting the notion of granular time I cannot resist alluding to analogous experiences in altered states of consciousness. One is reported by C. Castaneda [27]:

> All I could remember was a series of dreamlike images or scenes. They had no sequential order. I had the impression that each one of them was like an isolated bubble, floating into focus and then moving away. They were not, however, merely scenes to look at. I was inside them. I was part of them. (p. 168)

A similar experience (under mescaline) is described by Beringer ([28], p. 148, here quoted from [29]):

> At the top of the stairway *there seemed to be no continuity of time at all, the whole course of events was only a mess of separate situations without any connection.* And these situations, in case of active work, could later have been connected in the same way in which one can observe a celluloid film. Yet at the same time these situations — in both experiencing and a direct reproduction of the happening afterwards — carried the character of the *in*dependent and *dis*connected. *A strange next-to-each-other-ness, not a one-after-the-other-ness*; they have no position in time, time has no sense here...

I have not quoted these reports with any intention of using them as proof of anything; rather I view them as a possible heuristic hint for the reader's imagination.

9 Concluding Remarks

As mentioned earlier, in science time is usually intuited as an absolute universal background common to all natural phenomena and thus also common to various domains of discourse. In those cases where particular domains differ in their references to time, it may be only due to the typical scale of durations of events and processes pertaining to individual disciplines. Physics, working with the smallest scales in nature, is generally considered to be the most competent discipline to deal with the true nature of objective time even in the finest texture.

Even psychology and cognitive science uses a vocabulary that is dependent, at least implicitly, on the homogeneity, linearity and continuity of time. Inner experiences of time may be distorted, shifted, rearranged, even tangled — however, even these words are meaningful only under a presumption of the underlying "real" and "true" progression of time.

It was not the purpose of this study to shake any of several well-established scientific and philosophical conceptions of time. Rather I was trying to suggest a reflective grasp of human conscious experience under the working assumption that subjective experience is prior to any theoretical conception of temporality. Specifically, I was focusing on those structural properties of time that may support the phenomenal structure of corresponding experience. I proposed the thesis that to the extent that human experience has a discrete, granular, or episodic structure, the experienced time may adopt essentially the same structure. It is worth noting that such a discrete structure of time can be supported by our experience on scales of time as different as, on the one hand, human autobiographical time, and on the other hand, time on the scale of subliminal events in the brain.

There is no way of reflecting, and theorizing about individual experiences without a certain step towards their objectification. As a consequence, some of our reflections (as well as our heuristic pictorial representations) cannot avoid references to an objective, linearly ordered time-line in the background but such a background does not contradict the putative discrete structure of phenomenal time. On the other hand, nothing in the observed nature of phenomenal time gives grounds to assume continuity of the underlying physical time, and less still continuity in the mathematical sense (the real number continuum).

The metaphorical statement quoted in the introduction, namely "that we need a metaphor of stream as much as the metaphor of incessant rain," entitles us to play freely with the idea of granular time. Whether it brings certain advantage or not, it may be early to conclude. At least it helped us to avoid counterintuitive interpretations of Libet's experiments by putting into questioning the tacit assumption that temporal data from different domains of discourse are comparable in principle.

I mentioned three such domains, relevant to consciousness. In the phenomenal domain we should pay attention to the actual nature of phenomena available to us in their immediacy. We may choose to think about episodic memories as if they were either separate entities or segments carved out of a continuous life panorama; the choice depends on the perspective (mental "zoom") that we adopt. We may think about primal impressions as something that continuously flows through the bottleneck of the present. On the other hand, we cannot, take into consideration within the phenomenal domain any subliminal events as well as events that are "clumped together" in an atomic episode. My wrist flexion is my wrist flexion, independently of what a neuroscientist may tell me about stimuli and signals in my brain.

The psychological (or cognitive) domain of discourse is different: there we deal with objective knowledge about mental states and events, which partly may be obtained from objectification of phenomenal experience, partly from independent scientific observations and experiments. Here a composition of atomic episodes from more elementary events may be quite relevant. But there is no need to stick to a particular theory about texture of time on the scale of, say, nanoseconds. Maybe, granular time which can only be measured on a coarse scale is more appropriate than a formal mathematical continuum. On the other hand, continuity of time may be preferred in the neuroscientific domain of discourse that resorts to differential equations in studying the dynamics of brain processes.

Various domains of discourse may "interact" on a methodological level. An interesting program may be Varela's neurophenomenological working hypothesis [30]: "Phenomenological accounts of the structure of experience and their counter parts in cognitive science relate to each through reciprocal constraints." Obviously, any specification of such constraints requires trans-domain theories, in particular theories of domain-relative conceptions of time.

Acknowledgement

This research was supported by the Research Program CTS MSM 110000001.

References

1. McTaggart, J.M.E. (1908) The unreality of time, *Mind* **17**, 457–474.
2. Čapek, M. (1961) *Philosophical Impact of Contemporary Physics*, Van Nostrand Co., Princeton (NJ).
3. Einstein, A., and Besso, M. (1972) *Correspondence 1903–1955*, Hermann, Paris.
4. Husserl, E. (1928/1964) *The Phenomenology of Internal Time Consciousness*, Indiana University Press, Blomington.
5. James, W. (1898/1988) *Principles of Psychology*, 2 Vols., Dover, New York.
6. Searle, J. (1992) *The Rediscovery of the Mind*, MIT Press, Cambridge (MA).
7. Dennett, D.C., and Kinsbourne, M. (1991) Time and the observer: The where and when of time in the brain, *Behavior and Brain Sciences* **15**, 183–247.
8. Dennett, D.C. (1991) *Consciousness Explained*, Little, Brown and Co., Boston.
9. Varela, F. (1999) The specious present: A neurophenomenology of time consciousness, in J. Petitot *et al.* (eds.), *Naturalizing Phenomenology*, Stanford University Press, Stanford (CA), pp. 266–314.

10. Gallagher, S. (1998) *The Inordinance of Time*, Northwestern University Press, Evanston.
11. Havel, I.M. (2005) Experiential modalities of lived situations, in *Towards a Science of Consciousness 2005* (Conference Abstracts), Copenhagen, to appear.
12. Salthe, S.N. (1985) *Evolving Hierarchical Systems: Their Structure and Representation*, Columbia University Press, New York.
13. Havel, I.M. (1996) Scale dimensions in Nature, *Int. Journal of General Systems* **24**, 295–324.
14. Pöppel, E. (1997) The brain's way to create "nowness", in H. Atmanspacher and E. Ruhnau (eds.), *Time, Temporality, Now*, Springer-Verlag, Berlin, pp. 107–120.
15. Libet, B. (2004) *Mind Time: The Temporal Factor in Consciousness*, Harvard University Press, Cambridge (MA).
16. Cairns-Smith, G. (2005) Remarks on evolution and time-scales, *Journal of Consciousness Studies* **12**, 20–75.
17. Chalmers, D.J. (1996) *The Conscious Mind: In Search of a Fundamental Theory*, Oxford University Press, Oxford.
18. Tulving, E. (2002) Episodic memory: from mind to brain, *Annual Review of Psychology* **53**, 1–25.
19. Pribram, K. (1991) *Brain and Perception: Holonomy and Structure in Figural Processing*, Lawrence Erlbaum Associates, New Jersey.
20. Adler, H.G. (1968/1988) *Panorama*, Piper, München.
21. Proust, M. (1913/2002) *Swan's Way* (translated from French by C. K. Scott Moncrieff), Dover Publications, Mineola (NY).
22. Sacks, O. (1986) *The Man Who Mistook His Wife for a Hat*, Pan Books, London.
23. Damasio, A.R. (2002) Remembering when, *Scientific American* **287**(Sept), 48–55.
24. Ricoeur, P. (1984) *Time and Narrative – Volume 1* (translated by K. McLaughlin and D. Pellauer), The University of Chicago Press, Chicago.
25. Kortooms, T. (2002) *Phenomenology of Time: Edmund Husserl's Analysis of Time-Consciousness*, Kluwer Academic Publishers, Dordrecht.
26. Hofstadter, D.R. (1979) *Gödel, Escher, Bach: An Eternal Golden Braid*, Harvester Press, Brighton.
27. Castaneda, C. (1968) *The Teachings of don Juan: A Yaqui Way of Knowledge*, Pocket Books, New York.
28. Beringer, K. (1969) *Der Meskalinrausch, Seine Geschichte und Erscheinungsweise*, Springer–Verlag, Berlin–Heidelberg–New York.
29. Saniga, M., and Buccheri, R. (2004) The psychopathological fabric of time (and space) and its underpinning pencil-borne geometries, preprint `physics/0310165`.
30. Varela, F.J. (1996) Neurophenomenology: a methodological remedy for the hard problem, *Journal of Consciousness Studies* **3**, 330–349.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 189–208

EXPERIENCE OF TIME PASSAGE: PHENOMENOLOGY, PSYCHOPHYSICS, AND BIOPHYSICAL MODELLING

JIŘÍ WACKERMANN
Dept. of Empirical and Analytical Psychophysics
Institute for Frontier Areas of Psychology and Mental Health
Wilhelmstrasse 3a, Freiburg i. Br., D-79098, Germany
(jw@igpp.de)

Abstract: The experience of time's passing appears, from the 1st person perspective, to be a primordial subjective experience, seemingly inaccessible to the 3rd person accounts of time perception (psychophysics, cognitive psychology). In our analysis of the 'dual klepsydra' model of reproduction of temporal durations, time passage occurs as a cognitive construct, based upon more elementary ('proto-cognitive') function of the psychophysical organism. This conclusion contradicts the common concepts of 'subjective' or 'psychological' time as readings of an 'internal clock'. Our study shows how phenomenological, experimental and modelling approaches can be fruitfully combined.

Keywords: Dual klepsydra model – Psychophysics – Retrospective Time Measure – Time Passage – Time Reproduction

1 Introduction

Tempus fugit, 'time passes', remind us inscriptions on some ancient sundials and clocks. But even without being reminded we all 'know', and under circumstances say, that time 'flows', 'passes', or 'flies'. An ubiquitous feeling of time's passing is apparently a common human experience. The physicist A. S. Eddington expressed this experience as follows:

> 'When I close my eyes and retreat into my inner mind, I feel myself enduring [...] It is this feeling of time as affecting ourselves and not merely as existing in the relations of external events which is so peculiarly characteristic of it.' [1]

In a similar vein, H. E. Lehmann maintained that

> '[p]erceiving the ongoing flow of time is one of man's immediate experiences. Like feelings and sensations, the perception of the passing of time is a private experience. It is 'immediately given' in the terms of phenomenological analysis.' [2]

According to these quotations, time passage is an original and immediate datum of consciousness, independent from the worldly time of appointments, schedules and clocks. Deprived of all relations to external events, the time of inner evidence can refer only to a continuous duration of Self.[a] But we usually realise the time's passing (and wonder about it) only when we relate to objective, external time data. Further, we refer to time in connection to a process involving creation or destruction, motion or alteration and change.[b] How can this notion be reconciled with the intuition of a duration of something immovable und constantly enduring?

We are obviously facing serious and intriguing problems. Indeed, there is a long tradition of calling time a 'mystery' or 'enigma', and perseverating with St. Augustine, '*quid est tempus?*' [3]. This is, in our opinion, an ill-posed question: when we are dealing with fundamental notions rooted in primordial experience, questions of 'what is. . . ?' type usually do not lead to any useful answers. As G. Berkeley wrote in his *Treatise*,

> '[t]ime, place, and motion, taken in particular or concrete, are what everybody knows; but having passed through the hands of a metaphysician, they become too abstract and fine, to be apprehended by men of ordinary sense. Bid your servant meet you at such a *time*, in such a *place*, and he shall never stay to deliberate on the meaning of those words [. . .] But if *time* be taken for [. . .] duration in abstract, then it will perhaps gravel even a philosopher to comprehend it.' [4]

We keenly agree with Berkeley's common-sense position; and so we shall not follow philosophical speculations but rather observe how we are dealing with time in our activities, and how a subjective measure of time passage arises from our acting in time.

2 Study of Time Experience: Sources and Methods

2.1 Varieties of time experience

Introspective evidence informs us not only about the time's passing, but also about its remarkable variability and elasticity. Time of inner experience is frequently referred to as 'flowing faster' or 'slower', depending on

[a] Eddington's *récit* reminds us of Newton's famous scholium, 'Absolute, true, and mathematical time, of itself and from its own nature, flows equably without relation to anything external, and by another name is called duration' [5], only without the attribute 'absolute' and applied to the being of Self, not of the material world.

[b] This is in line with Aristotle's reasoning (*Phys. 218b*): 'Clearly it [time] is not movement. But neither does time exist without change; for when the state of our minds does not change at all [. . .] we do not think that time has elapsed.' [6] For a concise account of the Aristotelian concept of time (and further history of the problem) see Kronz [7].

organismic or environmental factors, *e. g.* attention, mental activity, sensory overload or deprivation, emotional state, *etc.* — 'Why time in pain, longer than time in pleasure?', wrote Berkeley in his *Notebooks* [8]. We find similar observations in many popular accounts on so-called 'subjective' or 'psychological' time [9].

Extreme 'speeding up' of inner time has been reported in dreams [10], near-death experiences [11], and in altered states of consciousness induced *e. g.* by hypnotic suggestions [12] or psychoactive substances [13]. But do these reports really support the notion of the time's flowing as a perceptual datum? Interpreting them properly, we realise that in most such reports, the words 'faster' and 'slower' merely serve to express the fact that, at a certain moment, the objective time, as given by an external clock,[c] differs from the expected clock reading. Accordingly, B. Schlesinger proposed a pragmatic classification of altered time experience, based on clinical observations, and stated in terms of variant mappings between the 'objective' and 'subjective' time scale [14].

In severe psychotic disturbances or ecstatic states experience of time of a different *quality* is sometimes reported, *e. g.*, collapse of time perspective, time 'standing still', 'eternal now', *etc.*. These limiting cases of altered time experience were studied mostly by existentially oriented psychiatry of phenomenological provenience [15]. (For examples and further bibliography see [2], and also articles [16, 17] in the present volume.)

2.2 Phenomenology of time consciousness

In everyday life, we usually take objective time for granted; only remarkable *deviations* of subjective time experience from the objective time are noticed and reported (Sec. 2.1). Nonetheless, the temporal aspect is a permanent and essential constituent of our consciousness of the world, and lends itself to psychological introspection and philosophical elaboration.

William James devoted a whole Chapter 15 of his *Principles* [18] to perception of time, intermingling experimental findings on discrimination and reproduction of temporal durations with his own observations on various aspects of time awareness (extent of the 'specious present', factors influencing subjective estimates of durations, *etc.*). James' original contribution to study of time experience is a kind of introspective evidence extrapolated to a neurobiological conjecture. He demonstrated that the primary intuition

[c] Here the term 'clock' refers to any external time-keeper, *i. e.*, an objective process in the world of intersubjectively shared experience that serves as a kind of time standard. In later sections we will use the term 'clock' in more restrictive sense for a certain sub-class of such processes.

of time and temporal succession originates in the co-existence of the past in the present, 'a sort of perspective projection of past objects upon present consciousness' [p. 630]; and speculated about the mechanism underlying this superposition, a hypothetical 'brain-process to which the consciousness is tied' [*loc. cit.*], leaving fading traces co-existing with sensations of the present moment.

Henri Bergson made the temporality of consciousness a central point of his early philosophical investigations [19]. He refused transposition of the notion of physical time to time experienced: the former is a space-like, measurable quantity, while the latter is a domain of pure duration, *durée*, given to immediate sensation in its qualitative aspect, but escaping any mechanistic representation and quantification. In spite of his utterly anti-physicalist approach, Bergson has valuable observations on the structure of time experience. As to the relation of the present and the past, he arrives to a conclusion close to that of James; expressed in his brilliant literary style: 'Nous ne percevons, pratiquement, que le passé, le présent pur étant l'insaisissable progrès du passé rongeant l'avenir.' [20, p. 163]

Edmund Husserl's phenomenological approach to 'inner time consciousness' [21] is the most radical: he aims at the 'immanent time' of human consciousness, *i. e.*, pure temporal data as given in subjective experience, excluding (*Ausschaltung*) any reference to objective physical, physiological or psychological reality. His investigations start with exploration of typical phenomenal forms of 'temporal objects' (*Zeitobjekte*), from where he proceeds to the problem of constitution of objective time. Because of space limitations we have to focus only on the key notions of our interest: these are *retention*, a specific modus in which a past event is given to the consciousness at actual 'now', and *reproduction*, as another modus of active re-presentation (*Vergegenwärtigung*). Husserl also denotes retention and reproduction as 'primary' and 'secondary remembrance' (*Erinnerung*). This complex structure of present 'now' with the co-present past is schematically shown in Husserl's famous '*Diagramm der Zeit*' (Fig. 1).[d]

Introspective accounts as well as precise phenomenological analyses thus invariantly reveal a fundamental structure of time experience, which consists in *co-presence of the past* with the present 'now'. This is merely a qualitative statement based on subjective evidence. For further development we have to turn to experiments and measurement procedures.

[d] Historical predecessors to Husserl's diagram can be found in James' remarks at *loc. cit.*, and in J. Ward's article in *Encyclopaedia Britannica*, to which James refers. For earlier variants of Husserl's diagram *cf.* [22].

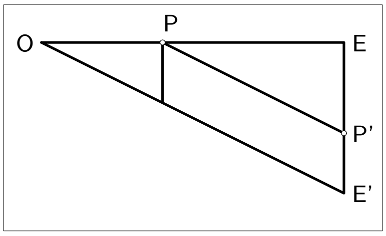


Fig. 1. Diagram of experienced time. — OE = sequence of 'nows'; EE' = 'phase continuum' = actual 'now' with a 'past horizon'. The process of 'decline' of past events along the 'phase continuum' is exemplified by the trajectory PP'. Redrawn from Husserl's original figure [21].

2.3 Psychophysics of time perception

Psychophysics, in G. Th. Fechner's[e] definition, is the 'exact science of the functional relations of dependence among body and soul, more generally, between the corporeal and the mental, the physical and the psychological, world' [23], searching expression of these psycho-physical relations in form as mathematical functions. Consequently, psychophysics extended the notion of measurement to dimensions of subjective experience, elaborated a number of experimental methods to this purpose, and developed thus (in a narrower definition) to an art of 'measurement of sensations'.[f]

Experimental research on time perception begins with early phases of psychophysics in studies of Mach[g] [24], Vierordt [25], and others. However, application of the sensations measurement paradigm to experience of time and space is somewhat problematic. In a typical psychophysical experiment we have clearly defined physical properties and their experiential correlates, *e. g.*, wavelentgth ↔ colour, radiation energy ↔ brightness, temperature ↔ sensation of warmth, *etc.* This is not the case with properties like spatial or temporal extension: we have no immediate *sensations* of these properties

[e] Gustav Theodor Fechner (1801–1887), German physicist and philosopher, the founding father of psychophysics. For a detailed account of his life, work, and impact of his thought on later science and philosophy, see M. Heidelberger's monograph [26].

[f] The psychophysics' claim to measure sensations, *i. e.*, private data of subjective experience, was repeatedly attacked by psychologists and philosophers. The first part of Bergson's essay [19], mentioned in the preceding section, is an eloquent dispute with Fechner's psychophysics.

[g] Ernst Mach (1838–1916), physicist and philosopher of science. Young Mach keenly embraced the idea of psychophysics, as wittnessed by his letter to Fechner from 1861: 'Seit längerer Zeit beschäftigte ich mich mit mathematischer Psychologie; mein Streben ging dahin, für die Psychologie ähnliche Methoden des Experimentes und der Beobachtung ausfindig zu machen, wie sie in der Physik längst bekannt sind. Ich konnte aber für meine Ideen keine rechte Basis finden bis endlich Ihre Psychophysik erschien. Mit Fieber las ich das Buch und fand meine Erwartungen weit übertroffen. [. . .] Unter Anderem stellte ich auch einige vorläufige Messungen an, um zu untersuchen ob die Formel $\gamma = \log \beta$ für Zeitgrößen z. B. die Dauer der Pendelschwingungen ebenso gelte wie für Raumgrössen was ich nahezu bestätigt fand.'

but rather *judgments* about relations between things and events occurring in the external, physical world. There is nothing like 'sensation of time',[h] unless we identify it with allegedly self-evident—but, as we will see in the following, rather questionable—subjective datum of 'time flow'.

Experimental psychology inherited[i] and further developed methods exploring time perception [28, 29]; the four most frequently used methods are summarised in Table 1. Durations are presented to the subject by means of sensory perceivable 'carriers', *i. e.*, visual or acoustical stimuli (in Table 1 symbolised by grey bars on time axes), controlled by the experimental apparatus and/or by the subject's motor action.

Table 1. Experimental methods used in studies of 'time perception'.

	Method	Stimulus	Response	Example	
1	production	numeric	motor	'4'	
2	estimation	sensory	numeric		'3'
3	reproduction	sensory	motor		
4	comparison	2×sensory	binary		'first longer'

While estimation and production are most wide-spread methods, of our prime interest is the reproduction method (Table 1, item 3). In the time reproduction task, the subject has to reproduce duration of the first carrier, *e. g.*, by pressing a pushbutton when, in his perception, duration of the second carrier equals the first [25, 30]. This method operates with 'pure durations', without referencing external standards or units.

3 Psychological Approach to Time

3.1 Reality of subjective time

Discrepancies and incongruities between objective time 'out there' and time of subjective, inner experience, seemingly support a notion of 'subjective' or 'psychological' time as something parallelising physical, objective time, but existing independently of it.

Among early authors, A. O. Weber took decidedly Bergson's dualistic position (*cf.* Sec. 2.2):

[h] Mach's comment, '[m]an muß zwischen der unmittelbaren Empfindung einer Dauer und einer Maßzahl so scharf unterscheiden, wie zwischen Wärmeempfindung und Temperatur' [32, p. 433], is rather misleading, unless interpreted in the context of his idiosyncratic use of the term '*Empfindung*', 'sensation'.

[i] The notion of psychophysics as a special discipline within psychology is neither historically nor conceptually correct, although at present most of psychophysical research is being done by psychologists. Experimental psychology developed *out of* psychophysics, and the scope of psychophysics is *by definition* broader than that of psychology.

> 'Variations in the rate of flow of time under different conditions must be regarded as errors if the old physical conception of a single, homogeneous duration is accepted, but with the Bergsonian conception we have a basis for regarding the psychological flow of time as a normal and valid adaptation to fit the existing conditions, since it implies that the individual flow of time is just as real as physical time.' [31]

Or, in H. E. Lehmann's wording,

> '[e]xternal time is objective, universal, and absolute. It is physical clock time measured by instruments [...] Internal time is subjective, individual, and relative.' [2]

Although in the contemporary literature rather neutral expressions are preferred ('timing', 'time-related behaviour'), the concept of 'psychological time, the subjective time that for each person is more or less independent of objective time' [9] survives in a transformed form, as a private datum given by an internal clock.

3.2 Internal clock model

Living organisms display a variety of (quasi)periodic processes of different frequencies and degree of regularity. This fact inspired many authors to search for an internal time base in these physiological activities: respiration and heart action [32, 33], or electrical activity of the neural system [34, 35, 36]. Some authors even coined a metaphor of the 'brain as clock' [37] (*cf.* also article [38] in this volume). The hypothesis of an 'internal clock' [39], abstracted and progressively deprived of (neuro)biological content, was eventually adopted by cognitive psychologists as a so-called *internal clock model* (i. c. m.). Nowadays, the i. c. m. is presented as the standard model of internal time [40, 41].

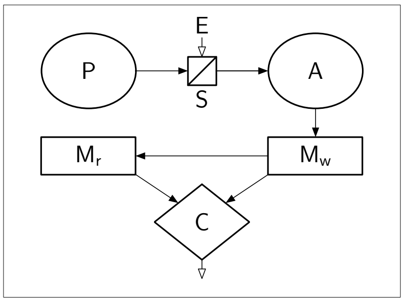


Fig. 2. Internal clock model. — P = pacemaker; S = switch; E = external event controlling the switch; A = pulse count accumulator; M_{w} = working memory register; M_{r} = long-term reference memory; C = comparator. Freely adapted from Church [42].

The i. c. m. is actually nothing else than a 'mental stop-watch' (Fig. 2), an accumulator A (counter) of pulses emitted by a pacemaker P, state of which is copied to register M_{w} and compared with a 'standard' stored in register M_{r}. Variations in a subject's production or estimation of time intervals (Sec. 2.3) can thus be conveniently explained in terms of increased or decreased frequency of pacemaker P. If, for example, a subject estimates duration of a 5 second tone to 6 seconds, we may infer that her/his internal clock runs at frequency by factor $6/5 = 1.2$ faster than standard, or, equivalently, that her/his subjective time 'flows faster'.

However, this simplistic model fails to fit experimental data obtained with the reproduction method, showing a progressive shortening of response times with increasing stimulus duration [43] (*cf.* Fig. 3). We thus have to search for an alternative model of time representation, which would match better with time reproduction data.

4 A Model for Time Reproduction

4.1 Two principles of time measurement

Our culture has developed special time-keeping devices, *clocks*, which are counters of discrete events generated by a periodic physical process, *e. g.*, swings of a pendulum [44]. The model (or rather metaphor) of internal clock relies on a naïve and actually unsupported assumption: if we have an internal measure of time, then we must have something like a 'clock inside', operating on the same principle as human-made clocks, *i. e.*, counting time units. But *ticks counting is not the only possible principle of time accounting.* As Reichenbach has it, 'we never measure a 'pure time', but always a process, which may be periodic as in the case of the clock, or nonperiodic' [45]. Indeed, early cultures used in daily life a variety of time-keeping technologies based on a-periodic, irreversible physical processes: burning candles or oil lamps, leaky water-clocks, *etc.*[j] [44]

The latter devices, water-clocks, are of particular interest here. The history of chronometry knows two types [46]: the archaic, 'outflow' type, and later, 'inflow' type. The former were leaky vessels, measuring a certain time period—*e. g.*, the time allotted for a speaker at the court of law—until all water elapsed. The latter accumulated water flowing into a non-leaky container, so that the water level showed the 'current' time. The name *klepsydra*, derived from the outflow type (Greek *kleptō*=steal, *hydōr*=water), was later used for water-clocks of both types.

Biological systems are characterised by complex chains of irreversible, energetically 'lossy' biochemical transformations. Biological periodicities,

[j] Even modern chronometry has methods based on such irreversible processes, *e. g.*, the radiocarbon ^{14}C method used by archeologists to determine the age of organic materials.

the alleged basis of a 'physiological clock' (*cf.* Sec. 3.2), have their origin in relaxation oscillations, and are thus based on energy-dissipating processes, in contrast to reversible, energy-preserving harmonic oscillations.[k] Thus the '[t]iming mechanisms based on such irreversible processes may provide metaphors or models more adequate to biological reality than mechanical tick-counter models' [43].

Furthermore, biological systems are characterised by a *dynamic equilibrium* between energetic input and output. This gives us the idea to combine the two types of klepsydrae, inflow and outflow, into more general *inflow/outflow* systems (i. o. s.) which could serve as functional units of a biologically realistic model of time-keeping. We should emphasise that the 'leaky klepsydra' as a prototype of such i. o. s.'s is merely a convenient metaphor. Other physical systems, *e. g.*, an RC-circuit accumulating electric charge, chemical reaction systems, *etc.*, may serve as model i. o. s.'s.

4.2 ***Dual klepsydra model*** [47]

The *dual klepsydra model* (d. k. m.) was originally proposed to model the processes underlying subjective time reproduction (Sec. 2.3). The model consists of two i. o. s.'s described by an ordinary differential equation,

$$\dot{y} = i - f(y)\,, \tag{1}$$

where $i \geq 0$ is the inflow rate, and f is a non-negative function such that $f(0) = 0$, relating the outflow rate to the momentary state. At the beginning of an experimental trial, both klepsydrae are empty $y_{1,0} = y_{2,0} = 0$. During the presentation phase ($0 \leq t \leq s$) klepsydra 1 is filled at inflow rate $i_1 > 0$; during the reproduction phase ($s + w \leq t \leq s + w + r$), klepsydra 2 is filled at inflow rate $i_2 > 0$; otherwise the inflows are zero. States of klepsydrae 1 and 2 are not directly observable;[l] only the result of their comparison is mentally represented. When at time $t = s + w + r$ the klepsydrae states are equal, $y_{1,t} = y_{2,t}$, this results to a subjective experience 'the two

[k] This point is too often missed in superficial comparisons between mechanical and biological time-keepers. Harmonic oscillators like pendulum need energy input only to compensate for energy loss due to friction, *etc.*; an ideal pendulum in an absolute vacuum would swing *ad infinitum.* To improve precision of clocks, the horologists had to *minimise* the energy exchange between the pacemaker and its environment. Relaxation oscillators, on the other hand, require a permanent flow of energy to keep swinging, and could not operate in absence thereof.

[l] Introspective reports on subjective experience during time reproduction experiments are rather rare. However, Woodrow mentions 'numerous reports' delivered by participants in his experiments 'which frankly recognised the impossibility of detecting the nature of the time-reproduction process by means of introspection.' [30, p. 495].

elapsed durations are equal'.[m]

Hereinafter we consider only i. o. s.'s with a linear 'leakage term' in eq. (1), $f(y) = \kappa\, y$, where $\kappa > 0$ is constant and equal for both klepsydrae. The model then yields so-called *klepsydra reproduction function* (k. r. f.)

$$r(s, w) = \kappa^{-1} \log \left(1 + \eta\,(1 - \mathrm{e}^{-\kappa s})\,\mathrm{e}^{-\kappa w}\right)\,, \tag{2}$$

where $s \equiv$ stimulus duration, $w \equiv$ waiting time between the end of the perceived stimulus and beginning of the reproduction, and $\eta \equiv i_1/i_2$ is the ratio of the inflow rates. The k. r. f. is fully specified by the two parameters, κ and η. We assume that κ characterises internal, organismic conditions, while η depends on properties of the sensory carriers of the presented and reproduced durations. If both carriers have the same physical properties, then $\eta = 1$, and the k. r. f. is determined only by the parameter $\kappa \in \mathbb{R}_+$.[n]

Table 2. Estimates of parameter κ from experimental data.

Ref.	Type of data	Stimulus range [s]		Parameter estimates	
		$s_{\min}$	$s_{\max}$	$\widehat{\kappa}$ [s^{-1}]	$\widehat{\kappa}^{-1}$ [s]
[50]	group averages*	2.8	16	0.0075	133
[51]	individual data	3.0	24	0.038	26
[52]	group averages†	2.0	20	0.0166	60
[52]	group averages‡	2.0	20	0.033	30

* German population † Swedish population ‡ African population

4.3 Experimental results

The k. r. f. fits experimental time reproduction data with good accuracy (example given in Fig. 3). Data reported by different authors for different populations are shown in Table 2. The inverse values κ^{-1} give us estimates of relaxation times of the hypothetical i. o. s. underlying the reproduction process, which are roughly in the range from $\frac{1}{2}$ to 2 minutes. Knowledge of these values is important for the interpretation of the model (i) in terms of subjective experience (finite horizon of the past: Sec. 5.3), and (ii) in terms of objective (neurophysiological) mechanisms involved in internal time representation.

[m] This section presents only the deterministic version of the d. k. m.. In a more realistic version of the model we assume randomly fluctuating inflows; eq. (1) then becomes a stochastic diff. equation, and the response times are random variables, so that the model naturally accounts for intra-individual variance. For more details see [43, 48, 49].

[n] For $\kappa \to 0$ we have $r \to \eta s$, so we can continuously extend the parametric space to $\mathbb{R}_{0+}$; the i. c. m. then appears as the limiting case of the d. k. m. for $\kappa = 0$ ('no leakage').

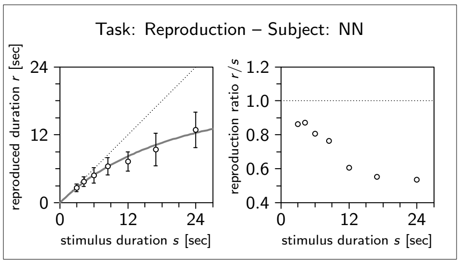


Fig. 3. Time reproduction data from a single subject [51]. — Shown are arith. means ± 1 s. d. calculated from 15 repetitions of each stimulus duration s, which was varied at 7 levels from 3 to 24 seconds. — Left: average reproduced times r; right: average ratios r/s. Solid grey line: k. r. f. fitted to data, $\widehat{\kappa} = 0.038$. Dotted line: 'correct' response $r = s$.

4.4 Properties of the k. r. f.; serial additivity [53]

For comparison with experimental data, we consider the k. r. f. defined by (2) as a function of a single argument, stimulus duration s, with w being usually fixed. The reproduced time r is a monotonically increasing function of s, with a negative curvature, and an upper bound $r_\infty \equiv \lim_{s\to\infty} r(s,0) = \kappa^{-1}\log(1+\eta)$. The negative curvature fits well with the progressive shortening of reproduced times r as the stimulus duration s increases (Fig. 3).

Now we consider the k. r. f. as a function of *two* arguments, s, the 'attended' duration to be reproduced, and w, the 'unattended' duration between the end of the presented duration s and the beginning of the reproduction phase. For the sake of simplicity, we simply write '$s|w$' instead of '$r(s,w)$', and read 's reproduced after w'. It is easy to prove that for any $t_1, t_2, w \geq 0$, the following equality holds,

$$\underbrace{t_1|(t_2+w)}_{r_1} + t_2|(w+r_1) = (t_1+t_2)|w\,. \tag{3}$$

This can be generalised to any number $N > 1$ of partial durations t_n ($n = 1, \ldots, N$). The sum of partial reproductions $r_n \equiv t_n|u_n$, where

$$u_n \equiv t_{n+1} + \cdots + t_N + w + r_1 + \cdots + r_{n-1}$$

is the time separating the end of duration t_n from the beginning of its reproduction, equals the reproduction of the total duration,

$$\sum\nolimits_n t_n|u_n = \left(\sum\nolimits_n t_n\right)|w\,. \tag{4}$$

We call this property *serial additivity* of the k. r. f.

5 Subjective Experience and Metric of Time Passage

5.1 The meaning of time representation

From a neuroscientist's point of view, inner representation of X is a specific state of the neural substrate, which is correlated with experience of X; *e. g.*, activation of certain brain structures is correlated with experience of 'green' as a response to stimulation by light of a certain wavelength.

The phenomenologist's view is radically different. The very locus of represented experience is not the subject's neural apparatus but her/his active conduct [54]. Literally, '*re-presented*' means presently actualised on a basis of preceding experience. Re-presentation of a time passed thus means the ability of the subject to *re*-produce the past duration at *present*.

From a conventionally psychological point of view, estimation and production of time intervals could be considered the elementary operations, translating the perceived duration to some inner representation, and *vice versa*. Reproduction would then be a composition of those operations, with the inner representation as an intervening variable [55]. We suggest an entirely different concept, in which reproduction of durations plays the fundamental role, and gives rise to the subject's measure of elapsed time.

5.2 Retrospective measure of elapsed time [53]

Consider a time interval $[0; s]$, and time moments $0 \leq t_1 \leq t_2 \leq s$; assume, for convenience, $w = 0$. The sum of subsequent reproductions of subintervals $[0; t_1)$, $[t_1; t_2]$, and $(t_2; s]$ equals the reproduction of the entire interval $[0; s]$ (serial additivity, *cf.* eq. 4). The quantity $r(t_2, s{-}t_2) - r(t_1, s{-}t_1)$ can be considered—in line with the argumentation of the preceding section—as a *measure* of the interval $[t_1; t_2]$,

$$\mathcal{T}_s(t_2) - \mathcal{T}_s(t_1) = \int_{t_1}^{t_2} \mathrm{d}\mathcal{T}_s = \int_{t_1}^{t_2} \rho(t)\,\mathrm{d}t\,, \tag{5}$$

where

$$\mathcal{T}_s(t) \equiv r(t, s-t)\,, \quad t \in [0; s]\,, \tag{6}$$

is a so-called *cumulative reproduction function* (c. r. f.) (over s), and ρ is its derivative w. r. t. physical time t. The retrospective measure of an elapsed time interval can be formally written as an integral of ρ across the interval of interest, and thus we may call ρ the '*density of the subjective time flow*'.

The c. r. f. is a monotonically increasing function, showing a positive curvature with $\kappa > 0$; the density function ρ is thus a positive and increasing function. This (i) explains the subjective 'speeding up of time flow' during a reproduction of a finite duration, and (ii) is in agreement with findings on so-called 'time order error' in comparison of temporal durations [56].

5.3 Finite horizon of the past

The finite upper bound on the k. r. f., mentioned in section 4.4, seemingly offenses the common sense: should we really believe that a human subject would reproduce an almost infinite duration—*e. g.*, many hours—in about a minute, unaware of the discrepance?

This apparent paradox, however, does not invalidate our model and the concepts based thereupon; it only points out the limits of their applicability. For durations in the order of magnitude of κ^{-1} (relaxation time of the underlying i. o. s.), the initial segment of the c. r. f. is very flat, representation of distant past is thus extremely compressed, and the klepsydraic mechanism becomes vulnerable to endo- or exogeneous perturbations, and thus unreliable for reconstruction of the past.

Building on this interpretation we propose a revised, 'metricised' version of Husserl's diagram of experienced time (Fig. 4): the past time moments P_n ($n = 1, \ldots, N$) are mapped onto the co-presence line EE' at 'depths' $\overline{EP'_n}$ proportional to $r(t_n, 0)$, $t_n \equiv \overline{EP_n}$. Note that the co-present past has a finite horizon at depth r_∞.

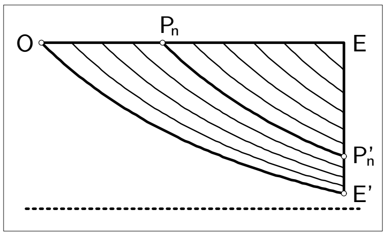


Fig. 4. A revised revision of Husserl's diagram (*cf.* Fig. 1). — Note the increasing 'compression' of remote past events along the 'phase continuum'. The dashed horizontal line indicates the finite horizon of the reproducible past.

What is *beyond* the reproducibility horizon? Of course, we do not lose memories of all events older than κ^{-1}! The horizon separates the 'fluid past', still available to actual re-presentation, from the 'crystallised past'.[o] Within the horizon, the temporal order of past events is given by the order of their 'depth' on the co-presence dimension. The temporal order of events located beyond the horizon is merely cognitive: we *know* that an event A preceded an event B, either because the memory of B involves a reference to A as an already occurred event, or by logical inference from A to B.

Similarly, W. James pointed out 'that the reproduction of an event, after it has once completely dropped out of the rearward end of the specious present, is an entirely different psychic fact from its direct perception [...]

[o] A reader with psychological erudition may have noticed a parallel with the notions of 'fluid' and 'crystallised' intelligence; this parallel has no deeper meaning here.

as a thing immediately past' [*loc. cit.*]. Henri Poincaré summarised the difference between the fluid, still vividly co-present past, and the crystallised, merely cognitive past in an insightful remark:

> 'For an aggregate of sensations to have become a remembrance capable of classification in time, it must have ceased to be actual, we must have lost the sense of its infinite complexity, otherwise it would have remained present. It must, so to speak, have crystallised around a center of associations of ideas which will be a sort of label. It is only when they thus have lost all life that we can classify our memories in time as a botanist arranges dried flowers in his herbarium.' [57]

6 Concluding Remarks

6.1 Reality of subjective time reconsidered

In the introduction we abstained from metaphysical questions like 'what is time?', or 'does time exist?' But what conclusions can be drawn from our interpretation of the perception of 'time passing'?

Firstly, we do not deny the objective order of events, given by the experiential relation 'A precedes B', and metricised by outstanding series of events, *i. e.*, readings of physical clocks. Indeed, *we take physical time for granted*, as is indispensable for biophysical or psychophysical modelling.

We recently wrote that 'subjective time flow appears as a kind of convenient illusion' [53, p. 168]; this statement may need a brief explanation. In our conception, the metric of experienced time is derived from elementary reproductive operations; these not-yet-cognitive—in our nomenclature: *proto-cognitive*—operations provide a basis for cognitive acts and concepts.[p] Our analysis thus leads to deconstruction of the reified concept of 'psychological time' as flowing in parallel with physical time, and directly cognised by the subject. As shown in Sec. 5.2, the retrospective measure of elapsed time can be *formally interpreted* as a result of integration of the flow density function, ρ; but this interpretation does not legitimate its hypostasis as objectively real: *in this sense* the perception of time's flow is illusory.

6.2 Directions of further research

We have demonstrated that a multi-perspectivic approach to time experience, combining introspective and phenomenological observations with methods of experimental psychophysics and mathematical modelling, is conceivable and productive. Further research should involve:

[p] *Cf.* Husserl on 'pre-objective time' (*vorobjektivierte Zeit, die zur Empfindung gehört*) [21, p. 427] as the foundation for the notion of objective time.

1. Experimental studies. Our forthcoming studies on time reproduction will focus specifically on separation of the organismic state-dependent and the stimulus-dependent effects. Of particular interest are investigations of the neural basis of time experience—in spite of amounting clinical and experimental data [58, 59], no unified neurobiological model of internal time representation is available as yet. In a recent study, combining functional magnetic resonance brain imaging with a time reproduction task, Jech *et al.* [60] have localised brain areas showing incremental/decremental activation as a monotonic function of the retained stimulus duration. These structures could be candidates for neural implementation of the klepsydraic mechanism.

2. Modelling and analytical studies. Networks of excitable neuron-like elements show features similar to the inflow/outflow systems (Appendix A) in our dual klepsydra model, and may thus provide computational models closer to neurobiological reality yet still analytically tractable.

Special properties of the reproduction function yielded by the d. k. m. (serial additivity: Sec. 4.4) suggest a reverse approach, proceeding from *a priori* requirements to characterisation of time metrics in terms of their global properties, and from these to their possible biophysical implementation. Axiomatic approach and apparatus of functional equations may play an important role on the way towards a general theory of time representation in psychophysical systems.

Acknowledgements

The author wishes to thank Werner Ehm for his critical comments on an earlier draft of the present paper.

Appendix A: Excitable Cell Ensembles as Time-Keepers

Consider an ensemble of N cells with binary states, 0=base state, 1=excited. Excited cells send at random times excitatory pulses which are randomly distributed across the ensemble; cells which do not receive excitatory pulse spontaneously de-excite. In addition, the ensemble may be exposed to excitatory input from an external source. The total of excited cells in the ensemble $\{X_t | t \in \mathbb{R}_{0+}\}$ is a stochastic process of birth/death type. Of interest is the mean excitation of the ensemble, $x_t \equiv \langle X_t \rangle / N \in [0; 1]$, which evolves according to the diff. equation

$$\dot{x} = \alpha\,(1 - x) - \beta\,x + \gamma\,x\,(1 - x)\,, \tag{A.1}$$

with the α-term representing excitation due to the external input ($\alpha \geq 0$), the de-excitation β-term, and the self-excitation γ-term. In the following we assume $\gamma > \beta > 0$. In absence of the external input ($\alpha = 0$), the system has two fixpoints, $x = 0$ (unstable) and $x = \bar{x}_0 \equiv 1 - \beta/\gamma$ (stable equilibrium). If the system is exposed to an external input with intensity $\alpha > 0$, the equilibrium shifts to $\bar{x}_\alpha = \bar{x}_0 + \delta$ (Fig. 5a).

Solution of eq. (A.1) generally leads to a rather complicated expression in terms of hyperbolic functions. For states close to the equilibrium point $\bar{x}$, however, eq. (A.1) can be approximated by a linear function,

$$\dot{x} \approx -\kappa\,(x - \bar{x})\,, \tag{A.2}$$

where $-\kappa \equiv (\mathrm{d}\dot{x}/\mathrm{d}x)_{x=\bar{x}}$. Then the dynamics of x_t is roughly equivalent to that of the linear i. o. s.'s introduced in Sec. 4.1 (Fig. 5b).

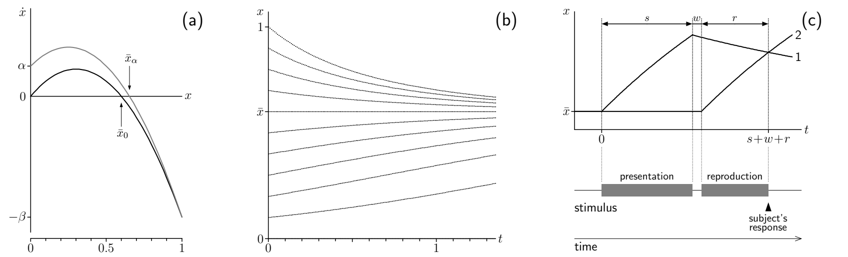


Figure 5. Dynamics of e. c. e.'s. — (a) Plots of $\dot{x}$ *vs.* x for an ensemble without (black) and with (grey) external input; equilibria marked by vertical arrows. (b) Evolution of mean excitation x_t as a function of time t; time axis labeled in κ^{-1} units. (c) Klepsydra-like mechanism of time reproduction, based on a comparison of excitation states of two ensembles 1 and 2.

Now we consider two such excitable cell ensembles (e. c. e.), 1 and 2, of same size N, connected to a comparator, and operating as a dual klepsydra system (Sec. 4.2). At time $t = 0$ both ensembles are at their equilibrium states; during the presentation of a duration s ensemble 1 is driven with input α_1; during the reproduction phase ensemble 2 is driven with input α_2 while ensemble 1 relaxes; subjective equality of the two durations occurs when the comparator signals equality $X_{1,t} = X_{2,t}$ (Fig. 5c).[q]

The model is by its nature stochastic: the discussion above applies only to mean expected values. The proportion between the deterministic and stochastic components—in other words, the signal-to-noise ratio of the

[q] Even with the linear approximation (A.2) this system is not exactly equivalent to the linear d. k. m., because the slopes κ differ between fixpoints $\bar{x}_0$ and $\bar{x}_\alpha$. However, for small $\delta = \bar{x}_\alpha - \bar{x}_0$ the difference between κ's is negligible. Thus the linear d. k. m. occurs at least as an idealised, limiting case of the model based on e. c. e.'s.

klepsydraic mechanism, and thus the accuracy of time representation—depends only on the ensemble size N.[r] For $N \to \infty$ purely deterministic behaviour prevails.

The model as presented here has only one type of excitable elements and passive relaxation, while in real neural systems both excitation and active inhibition play role. Nonetheless, the model comes closer to neurobiological reality than the original 'water-clock' metaphor. Particularly, the model reconciles short relaxation times of single elements (β^{-1}) with much longer relaxation times of the entire ensemble (κ^{-1}), as inferred from time reproduction data (Sec. 4.3). The equilibrium $\bar{x}_0$ is determined by the de-excitation to self-excitation ratio, β/γ, while the stabilising term κ is a function of the *difference* $\gamma - \beta$. We may hypothesise that the proportion between de-excitation and self-excitation is finely tuned during the ontogeny to ascertain the optimal balance between the stability of the e. c. e. and its reactivity to external input. (The same applies, *mutatis mutandis*, to real neural systems consisting of two neuronal populations, excitatory and inhibitory.) The e. c. e. model, even in its simple form, thus reveals the crucial role of built-in stability conditions for intra-organismic time representation (*cf.* also article [61] in this volume).

References

1. Eddington, A. S. (1945) *The Nature of the Physical World*, MacMillan, New York, quoted in [2], p. 798.
2. Lehmann, H. E. (1967), Time and psychopathology, *Ann. N. Y. Acad. Sci.* **138**, 798–821.
3. Augustine (1921) *The Confessions of Saint Augustine* (transl. by E. B. Pusey), Chatto and Windus, London.
4. Berkeley, G. (1710) *A Treatise Concerning the Principles of Human Knowledge*, in G. B., *Philosophical Works, Including the Works on Vision*, ed. by M. R. Ayers, Dent, London 1996, pp. 71–153.
5. Newton, I. (1687) *Philosophiae Naturalis Principia Mathematica*, London.
6. Aristotle (1984) *Physics,* in J. Barnes (ed.), *The Complete Works of Aristotle*, Vol. I, Princeton University Press, Princeton.
7. Kronz, F. M. (1997) Theory and experience of time: philosophical aspects, in H. Atmanspacher and E. Ruhnau (eds.), *Time, Temporality, Now*, Springer, Berlin, pp. 7–22.
8. Berkeley, G. (1707) *Philosophical Commentaries*, in G. B., *Philosophical Works, Including the Works on Vision*, ed. by M. R. Ayers, Dent, London 1996, pp. 305–412.

[r] This is an important difference from the stochastic d. k. m. [48, 49], in which the fluctuations are modelled by white noise added to constant inflows to klepsydrae 1 and 2, and scaled by independent parameters σ_1, σ_2.

9. Cohen, J. (1964) Psychological time, *Sci. Amer.* **211**, 116–124.
10. Siebenthal, W. von (1953) *Die Wissenschaft vom Traum. Ergebnisse und Probleme*, Springer, Berlin.
11. Nevole, S. (1943) O náhlém znovuprožití života 'jako ve filmu', při nebezpečí smrti a o jevech podobných, *Čas. lék. čes.* **82**, 1306.
12. Cooper, L. and Erickson, M. (1959) *Time Distortion in Hypnosis.* Williams & Wilkins, Baltimore.
13. Fischer, R. (1967) The biological fabric of time, *Ann. N. Y. Acad. Sci.* **138**, 441–488.
14. Schlesinger, B. (1955) Time, neurologically considered, *Mschr. Psychiat. Neurol.* **129**, 354–375.
15. Strauss, E. (1967) An existential approach to time, *Ann. N. Y. Acad. Sci.* **138**, 759–766.
16. Markowitsch, H. J. (2005) Time, memory, and consciousness: a view from the brain, *this volume.*
17. Saniga, M. (2005) A geometrical chart of altered temporality (and spatiality), *this volume.*
18. James, W. (1890) *Principles of Psychology*, vol. I, Holt, New York.
19. Bergson, H. (1888) *Essai sur les donnés immédiates de la conscience*, Alcan, Paris.
20. Bergson, H. (1896) *Matière et mémoire. Essai sur la relation du corps à l'esprit.* Alcan, Paris. [Quotation from the 22nd ed., 1926.]
21. Husserl, E. (1928) *Vorlesungen zur Phänomenologie des inneren Zeitbewußtseins*, ed. by M. Heidegger, Niemeyer, Tübingen.
22. Husserl, E. (1908) Die primäre Erinnerungsmodifikation, in *Texte zur Phänomenologie des inneren Zeitbewusstseins (1893–1917)*, ed. by R. Bernet, Meiner, Hamburg, 1985.
23. Fechner, G. Th. (1860) *Elemente der Psychophysik*, Vol. I, Härtle und Breitkopf, Leipzig.
24. Mach, E. (1865) Über den Zeitsinn des Ohres, *Sitzungsber. d. Wiener Akad. d. Wiss.* **51**, 542–548.
25. Vierordt, K. (1868) *Der Zeitsinn nach Versuchen*, Laupp, Tübingen.
26. Heidelberger, M. (2004) *Nature from Within. G. Th. Fechner and His Psychophysical Worldview*, University of Pittsburgh Press, Pittsburgh.
27. Mach, E., letter of January 16, 1861, quoted in *G. Th. Fechner (1801–1887)*, CD-ROM edition, G. Th. Fechner Gesellschaft e. V., Leipzig, 2001.
28. Woodrow, H. (1951) Time perception, in S. S. Stevens (ed.), *Handbook of Experimental Psychology*, Wiley, New York, pp. 1224–1236.
29. Bindra, D. and Waksberg, H. (1956) Methods and terminology in studies of time estimation, *Psychol. Bull.* **53**, 155–159.
30. Woodrow, H. (1930) The reproduction of temporal intervals, *J. Exp. Psychol.* **13**, 473–499.
31. Weber, A. O. (1933) Estimation of time, *Psychol. Bull.* **30**, 233–252.
32. Mach, E. (1905) *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*, 5th ed., Leipzig 1926. [Reprint: Parerga, Berlin 2002.]

33. Goudriaan, J. C. (1921) Le rhythm psychique dans ses rapports avec les fréquences cardiaques et respiratoires, *Arch. Néerl. Physiol.* **6**, 77–110.
34. Hoagland, H. (1933) The physiological control of judgments of duration: evidence for a chemical clock, *J. Gen. Psychol.* **9**, 267–287.
35. Holubář, J. (1969) *The Sense of Time. An Electrophysiological Study of Its Mechanisms in Man*, MIT Press, Cambridge (MA).
36. Pöppel, E. (1972) Oscillations as possible basis for time perception, in J. T. Fraser *et al.* (eds.) *The Study of Time*, Springer, Berlin, pp. 219–241.
37. Goody, W. (1958) Time and the nervous system: the brain as a clock, *Lancet*, p. 1139.
38. Pettigrew, J.D. and Tilden, J.D. (2005) Time within: The perceptual rivalry switch as a neural clock, *this volume*.
39. Treisman, M. (1963) Temporal discrimination and the indifference interval: Implications for a model of the 'internal clock', *Psychol. Monogr.* **77**, whole No 576; see also Treisman, M. (1984) Temporal rhythms and cerebral rhythms, *Ann. N. Y. Acad. Sci.* **423**, 542–565; and Treisman, M. *et al.* (1990) The internal clock: evidence for a temporal oscillator underlying time perception with some estimates of its characteristic frequency. *Perception* **19**, 705–748.
40. Block, R. A. (1990) Models of psychological time, in R. A. Block (ed.) *Cognitive Models of Psychological Time*, Lawrence Erlbaum, Hillsdale, pp. 1–35.
41. Grondin, S. (2001) From physical time to the first and second moments of psychological time, *Psychol. Bull.* **127**, 22–44.
42. Church, R. M. (1984) Properties of the internal clock, *Ann. N. Y. Acad. Sci.* **423**, 566–582.
43. Wackermann, J. and Ehm, W. (2005) The klepsydra model of internal time representation and time reproduction, *J. Theor. Biol.*, submitted.
44. Whittrow, G. J. (1988) *Time in History*, Oxford University Press, Oxford.
45. Reichenbach, H. (1957) *The Philosophy of Space and Time*, Dover, New York.
46. Janich, P. (1980) *Die Protophysik der Zeit. Konstruktive Begründung und Geschichte der Zeitmessung*, Suhrkamp, Frankfurt a/M.
47. Wackermann, J., Ehm, W., and Späti, J. (2003) The 'klepsydra model' of internal time representation, in B. Berglund and E. Borg (eds.) *Fechner Day 2003*, Intl. Soc. for Psychophysics, Stockholm, pp. 331–336.
48. Ehm, W. and Wackermann, J. (2003) Analysis of a stochastic version of the 'klepsydra' model, in B. Berglund and E. Borg (eds.) *Fechner Day 2003*, Intl. Soc. for Psychophysics, Stockholm, pp. 59–64;
49. Ehm, W. and Wackermann, J. (2004) Estimating the parameters of the stochastic klepsydra model, in A. Oliveira *et al.* (eds.) *Fechner Day 2004*, Intl. Soc. for Psychophysics, Coimbra, pp. 350–355.
50. Wackermann, J. and Miener, M. (2002) Reproduction of time intervals under photic driving of the brain's electrical activity, in J. A. da Silva *et al.* (eds.) *Fechner Day 2002*, Intl. Soc. for Psychophysics, Rio de Janeiro, pp. 558–563.
51. Wackermann, J. and Späti, J. (2005) unpublished data.
52. Eisler, A. D. (2003) The human sense of time: biological, cognitive and cultural considerations, in R. Buccheri *et al.* (eds.) *The Nature of Time: Geometry, Physics and Perception*, Kluwer, Dordrecht, pp. 5–18.

53. Wackermann, J. (2004) From neural mechanics to the psychological measure of time: the klepsydra model, in A. Oliveira *et al.* (eds.) *Fechner Day 2004*, Intl. Soc. for Psychophysics, Coimbra, pp. 164–169.
54. Merleau-Ponty, M. (1963) *The Structure of Behavior* (transl. A. L. Fisher) Beacon Press, Boston.
55. Eisler, H. (1987) Subjective duration as an intervening variable, in M. Teghtsoonian and R. Teghtsoonian (eds.) *Fechner Day '87*, Intl. Soc. for Psychophysics, Northampton, pp. 77–81.
56. Allan, L. G. (2002) Temporal memory, in J. A. da Silva *et al.* (eds.) *Fechner Day 2002*, Intl. Soc. for Psychophysics, Rio de Janeiro, pp. 91–97.
57. Poincaré, H. (2003) Simultaneity and the measure of time, in L. M. Dolling *et al.* (eds.) *The Tests of Time. Readings in the Development of Physical Theory*, Princeton University Press, Princeton 2003, pp. 290–298. [French original, 'La mesure du temps', published in 1898.]
58. Harrington, D. L. and Haaland, K. J. (1999) Neural underpinnings of temporal processing. A review of focal lesion, pharmacological and functional imaging research, *Rev. Neurosci.* **10**, 91–116.
59. Rubia, K. and Smith, A. (2004) The neural correlates of cognitive time management: a review, *Acta Neurobiol. Exp.* **64**, 329–340.
60. Jech, R. *et al.* (2005) Cumulative BOLD signal changes support the 'time accumulator' hypothesis, *NeuroReport*, submitted.
61. Atmanspacher, H., Filk, T., and Scheingraber, H. (2005) The significance of causally coupled, stable neuronal assemblies for the psychological time arrow, *this volume*.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 209–225

EMOTIONAL TIME, CREATIVITY AND CONSCIOUSNESS: ON TIME EXPERIENCE IN DEPRESSION

HINDERK M. EMRICH
Department of Clinical Psychiatry & Psychotherapy, Medical School Hannover
Carl-Neuberg-Str. 1, D-30625 Hannover, Germany
(emrich.hinderk@mh-hannover.de)

DETLEF D. DIETRICH
Department of Clinical Psychiatry & Psychotherapy, Medical School Hannover
Carl-Neuberg-Str. 1, D-30625 Hannover, Germany
(dietrich.detlef@mh-hannover.de)

Abstract: Emotionality of subjective time-experience in depressed patients is related to the concept of Michael Theunissen as to the dominance of the past in relation to the spontaneity of the subject within a present moment of time. Electrophysiological measurements, using event-related potentials point to the view that negative emotions can induce a value-related cognitive/emotional blockade of valuation processes. The role of creativity to overcome such memory-related impairments is discussed within the context of possible functions of consciousness.

Keywords: Time-Experience – Creativity – Affective Disorders – Event-Related Potentials

1 The Brain as a Time-Machine

"Time is the way how we perceive the world around us." [1]. This fundamental sentence by Ehlers gives the opportunity to raise the question how the brain may act as a "time-machine" to enable this. Indeed one may envisage the brain as containing aspects of a "time-machine" in three different ways of understanding:

- Firstly the brain is a neurobiological physical system like other systems — existing in time — being an object of understanding by physics, by biophysics, especially of neurochemical oscillators and thus is subject to the concepts of chronobiology.
- Secondly, in a completely different way of understanding, the human brain is a "time-machine," since it can memorize "stored regularities" and can recall them. The brain thus contains aspects of "time-

transcendence" — to use a term introduced by the Berlin philosopher Michael Theunissen [2]. Human beings are — in the sense of the phenomenology of Edmund Husserl — able to perform protension, i.e. the conceptualization of the future as well as retention, the recall of the past. Furthermore, we are able to generate the time-experience of the "now," of the "presence within time." One special problem herein is, how to relate, how to synchronize the "outer," the so called Aristotelian or "physical" time to the "time of inner experience," i.e. the time of Augustinus, and the Bergsonian time. The psychiatric disorders as well as extraordinary experiences of normal life tend to induce problems within this type of coordination, and depression represents a mood-disorder, within which, also experimentally, a disturbance of the inner organization of time in relation to objective time can be demonstrated.

- Thirdly, there is the aspect of a "time-machine" in a Kantian understanding, namely that human mind — apparently on the basis of brains — can construe the universals of perception, especially the category of "time."

How are the functions of such a "time-machine" realized within ourselves?

2 Time and Affect: Something about Anxiety

One of the main ideas within the neuropsychological research is that affective changes are great determinants in the construction- (and deconstruction-) processes of cognition and thus of the constitution of consciousness [3]. This was demonstrated in illusion research, in psychosis-research, in the understanding of the action of psychedelic drugs as well as in "synaesthesia," a fabulous way of healthy subjects to construe hyperintegrative inner perceptual worlds [4].

Interestingly, this emotional determination ("emotional tone") behind cognition and self- and world-experience, contains fundamental aspects of neurobiology of time as well as philosophy and psychopathology of time. Pöppel [5] as well as Singer [6] in physiology and Theunissen [2] in philosophy have given great contributions to this.

We would like to demonstrate the basic principles of the fundament of a neurobiological theory of anxiety and depression in relation to time, established by the neuropsychologists Gray and Rawlins [7]. An understanding of this concept, however, requires a representation of the basic principles, according to which our brains are functioning.

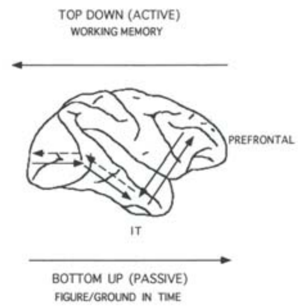


Figure 1. From Desimone *et al.* [9].

As the neurophysiologist von der Maalsburg [8] stated, the brain — as a machine — represents a "significance-detector"; that means that it is able to detect — within the enormous amount of noise — a special event, which contains the quality of being "meaningful." To exert this function, the brain is composed — as a multi-systems-parallel-processor — from many more or less independent "modules," which interact in an intricate way. There are systems of conceptualization within the frontal lobe, there are systems of processing of sensory data within the occipital brain and systems of emotionality, of valuation, within the inner temporal lobe and limbic system.

These functions can be demonstrated by functional brain imaging tecniques, e.g. in positron emission tomography (PET) or functional nuclear magnetic imaging scans (fMRI). The neuropsychologist Desimone [9] has proposed a general organization scheme of the flow of processing in the way that so called top-down processes are realized from prefrontal to occipital and that "bottom up processes" are functioning from occipital to prefrontal (compare Fig. 1). What does this mean from the point of view of experience of time? Interestingly in this understanding the theory of time starts from future (in an analogy to Heidegger), from the conceptualization of "what comes next?" It is the world of predictions and desires, from which we start in the sense of the neurobiologist Martin Heisenberg [10], who construes the world of activities of a biological system not from reflex, from reaction to outer changes but from novelty-seeking, a mode of action, he calls "initial activity." The presence, the "now" is, accordingly, construed from actual sensory data in relation to these conceptualisations, i.e. from bottom-up informations in relation to expectations. This is real-

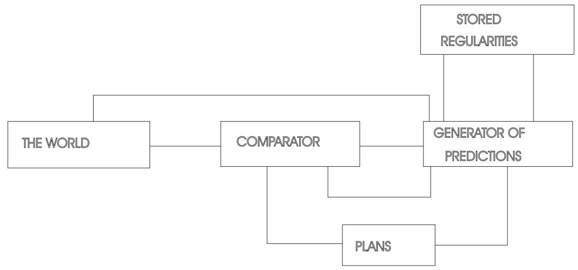


Figure 2. Hippocampal comparator system [7].

ized within the intermediate part of the brain, namely the temporal lobe. However, very interestingly, here the entrance to limbic structures and to memory structures is realized. How do we come to the past? How do we enter Marcel Prousts [11] inner memory-world within his "recherche" as to the "lost past"?

We have to go into the physiology of memory, which is a physiology of the hippocampus, as a temporal organizer, in relation to cortical feedback-loops. From these basic principles, we can understand, how anxiety is organized within our brains. It is an extreme form of "significance detection" of something which turns out to be aversive. The model is called the "hippocampal comparator system." We demonstrate this concept since the components of the generation of inner time are represented here (compare Fig. 2).

We start again — in the sense of Heisenberg [10] — from the future, from the "what comes next?". *T e ed c d a e e e ce e.* On the predictions — and we can add: on the emotionality, the emotional climate, the "emotional tone" of the predictions, it depends what the "measurement of significance" in the sense of von der Maalsburg [8] will find out within the present situation. These predictions are possible from the special type of actualisation of the "stored regularities" of the past only. Here the cortico-cortical loops containing memory traces come into function. And now, from the sensory data of the occipital lobe the presence, the data of "now," of the world ask for the "comparator"-function: if there occurs an unexpected possible dangerous situation, the system generates an "alarm-signal," which activates the limbic system. This input creates "arousal," "motor inhibition" and increased attention via a behavioural inhibiting system. Interestingly, this is the place, where the famous anxiolytic drugs, the benzodiazepines, act, since they can down-regulate the intensity of this internal alarm-signal and thus reduce the anxiety reaction. If there is a malfunction of these binding sites, anxiety and epilepsy can occur.

This concept of constitution of time within our internal "time-machine" is also plausible from another point of view: the neuropsychology of synaesthesia [4]. Here an additional intermodal integration within one moment of presence is realized. This integration apparently is manifestated by a so called "limbic bridge," in which in a synthetic "fusing" integration of e.g. a digit and a colour is realized. If this limbic integration is performed by chronobiological oscillators [5,6] or by a special neurobiological "wiring," is a problem to be solved [4,6].

3 Internal Balance of Values

Disturbances of the inner equilibrium of the components of the self which shape identity, brought about by processes of re-presentating by remembering, and the consequences these disturbances have, clarify the potential for explanation inherent in a theory of the processes of identity formation, based on the psychology of the self.

It is important to consider the structural principles of forgetting in relation to overvaluation with respect to the stability of "promise contexts." The sociologist Hans-Dieter Gondek [12] has emphasised the specific value of promise contexts in evaluating personal identity, something which is essential in connection with the problem of forgetting: a forgotten promise, after all, is not really a promise. To put it differently: how does identity change when forgetting takes place? Identity would seem to imply the promise that one is — and will remain — the person one is at the moment, quite the opposite of Nietzsches "You must become the person you are." Of course, people do not generally behave in this way; they do not accept that they and others are, or can be, only what they manifestly are at the present moment. They do in fact intuitively behave in the way Nietzsche demands; they expect developments in other persons which they assume would also take place within themselves. We arrange to meet the person whom the other person will have become by the time the appointment takes place, at least we do if we are sensible. We form an opinion of others according to the available possibilities, according to tendencies rather that according to "faculties." Falling back or surpassing oneself can both occur; both must be possible and are indeed necessary. Within the framework of psychoanalytic therapies, but also spontaneously in everyday life, people can in fact take themselves completely by surprise. During the therapeutic process, is may happen — indeed it is the intention — that alien-image and self-image approach one another or at least interact with one another, something which can lead to the most radical of changes.

From what we have seen so far, it is clear that the formation of identity is always accompanied by complex processes of adjusting the inner balance of values, so that it is to be expected that any disturbance of the processes aimed at restoring such equilibrium will lead to psychopathological phenomena. Disturbances in the internal balance of values normally lead to "coping" processes, i.e. processes of management and increased performance, which ensure that ones self-demands and ones self-image fit together better once more. In cases where this is not successful, or when it cannot succeed, a whole range of changes in behaviour are possible ranging form grieving to processes during which the balance of values is distorted, to processes of denial, of encapsulation or repression. Nietzsches famous statement [13] is appropriate here: "'I did this,' says my memory. 'I cannot have done it,' says my pride, and remains relentless. Ultimately it is my memory which gives in."

4 System Theory and Forgetting

How should — from the perspective of a system theory model — such a process of coping alteration of the past and thus also the process of "forgetting" being viewed upon? How does such a system behave in a concrete situation when what is involved is effecting plans and relating them to the past? Suggestions as to such decision-making processes can be found in the theory of non-linearly dynamic processes. As Friedrich Cramer [14] demonstrated in his book on the theory of time, complex systems which are evolving constantly display successive branching, with "the mutual influence of three aspects of dynamic systems, namely structure, function and fluctuations, leading to unexpected phenomena." If one applies this description of a complex system in the field of physical chemistry as a metaphor for the biographical development of a biological system, one can compose — with Peitgen [15] — a tree diagram in which it is not possible to predict how the final state of the system will actually be filled in. After the evolution of a complex system, a large number of unstable final situations arise whose variety can be greatly reduced by impaired development ("trauma"). Instead of sixteen final situations (as shown in Fig. 3), only three or four such states can actually be filled in.

Examining this disturbance chronologically and using the metaphor of the "path travelled," one finds that influences on the system have caused the path to be a specific and extremely restricted one. The question which arises

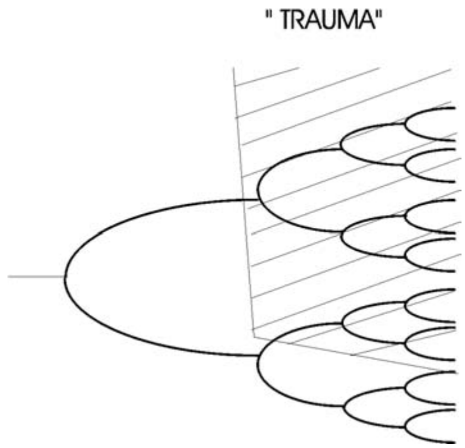


Figure 3. Scheme of reduced evolution of a complex system due to impairment by "trauma" [4].

is how, looking back, one should deal with this enforced path in a "coping" manner. If one decides to use this method of description as a metaphor for the reconstruction of the "path" along which an individual develops from a plurivalent initial situation to a final situation moulded by the various factors relevant to development, one can also describe the influences — both favourable and harmful — which have served to determine this path. Early traumas may have had such a powerful negative influence on the available choices in a vulnerable phase of development that these events — which are later generally "forgotten" later on — entirely determine, modify and restrict the rest of the subjects life. A whole range of options, lives and choices as potential system states have thus been eliminated. Thus there are three ways for the subject to deal with the consequences of this development. The first deals purely with certain points: it is only a result as it actually is which is considered: one must base oneself on the facts. The second possibility is — in Hegels sense — to consider the truth in the context of both the path and the results. The third and final way of looking at things does not only involve reconstructing the path but also reconstructing the other options which would have been possible at each given turn-off. This way of looking at things might be understood in terms of Prousts [11] "recherche du temps perdu" as an associative recalling of subliminal truths form the past; this is dealt with in Michael Theunissens book on the "negative theology of time" [2]. Theunissen says that "Prousts 'spontaneous remembering' uncovers, to put it traditionally, the eternity element in the past. What he finally calls 'time regained' is time only as the self's own other."

5 Neurobiological Experience

The fact that the dimension of time is an extremely relevant aspect within the experience of depression is indicated e.g. by the time-dependent typical course of the intensity of the symptoms in endogenous kinds of depression. Therefore, the dimension of time in melancholia was recognized to be a dominant factor, to perform a special kind of "dominance of time." Another important aspect, however, regarding the pathogenesis of depressive diseases was also recognized: this is the impact of the neurophysiology of memory systems. Is depression a type of memory deficit, a lack of forgetting in the sense of Nietzsche? Regarding this, depression may be suggested as an extreme and rigid keeping to the "facts of the past." As a consequence, this may lead to an intense pressure without having creative possibilities or options of future intentional acting.

We have tried to measure phenomenological aspects of the concept of Theunissens time philosophy, using objective neurophysiological parameters. It should be possible to gain more information about a main problem in psychiatry, the coupling between emotional and cognitive processing. How do thoughts and emotions interact? Which part does the memory system play with this regard?

Therefore, we made use of a continuous word recognition experiment [16], which we modified specifically regarding the emotional connotation of the presented words. We presented words with negative, positive and neutral emotional content on a video monitor, and in parallel, we measured the electrophysiological activity, the EEG. One method, however, to measure the stimulus related electrical activity, to measure the activity which is related to the presentation of the words, is to record so called event-related brain potentials (ERPs). These are minute voltage fluctuations which can be recorded non-invasively from the intact human scalp occurring in response to stimulus events in parallel to their cognitive processing. These ERPs have been shown to be sensitive to memory processes and to be sensitive to emotional factors on cognitive processes, e.g. face recognition. In addition, a frontal positive activity starting around 250 ms after stimulus presentation has been described for emotional stimuli which were more pronounced when subjects were instructed to focus on the emotional connotation of the stimulus.

We identified ERPs as tool to investigate memory processing in depressive patients with a special emphasis on electrophysiological correlates of the emotion/cognition-coupling.

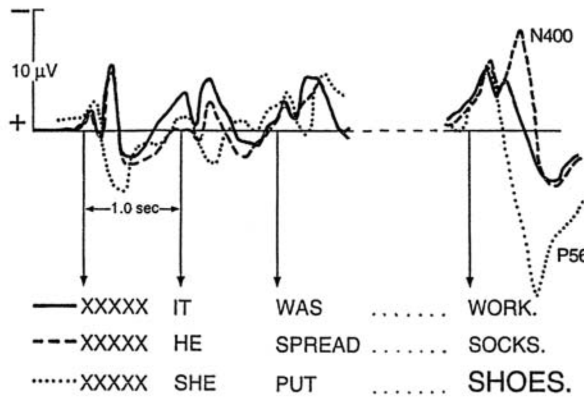


Figure 4. ERPs to sentences ending with a non-anomalous, semantically anomalous, or physically anomalous word. (Modified from Kutas & Hillyard [17]).

To our experiment one ERP-component is of specific importance and should be explained in more detail, namely the N400. Kutas & Hillyard [17] investigated ERPs evoked by the last word of a sentence which was presented to build a certain (semantic) context. They reported that semantically inappropriate final words of these sentences (e.g. "he spread the warm bread with *c* ") elicited a large amplitude negative ERP–component with a peak latency of 400 ms (the N400 component, compare Fig. 4) relative to the ERPs elicited by semantically appropriate words (e.g. "it was his first day at "). Contrasting, semantically appropriate but physically abberant words (e.g. word printed in a larger type) elicited a positive-going potential in the same time window as the N400 ("she put on her high heeled *SHOES*"). Kutas & Hillyard speculated the N400 may be an "electrophysiological sign of the 'reprocessing' of semantically anomalous information," but other explanations were given as well. Regarding our experimental approach it is relevant to realize that the better a word fits into the preceeding context and the more it was expected, the smaller was the N400 and more pronounce was a positive ERP-component in the time range between 300 and about 700 ms.

In our experiment we presented words on a video monitor with some of them being repeated after some intervening items in a continuous word recognition paradigm. For every presentation of the words, the depressive patients or control subjects had to decide, whether this word was presented for the first time (first presentation = "new" word) or a second time (repetition = "old" word).

For the repeated words the event-related potentials have more positive potentials (deflection) between about 200–800 ms post stimulus, which is the result of a priming or repetition effect (compare Fig. 5). This ERP–difference is called old/new effect and is mainly a result of a reduced N400 and an enhanced late positive ERP–component.

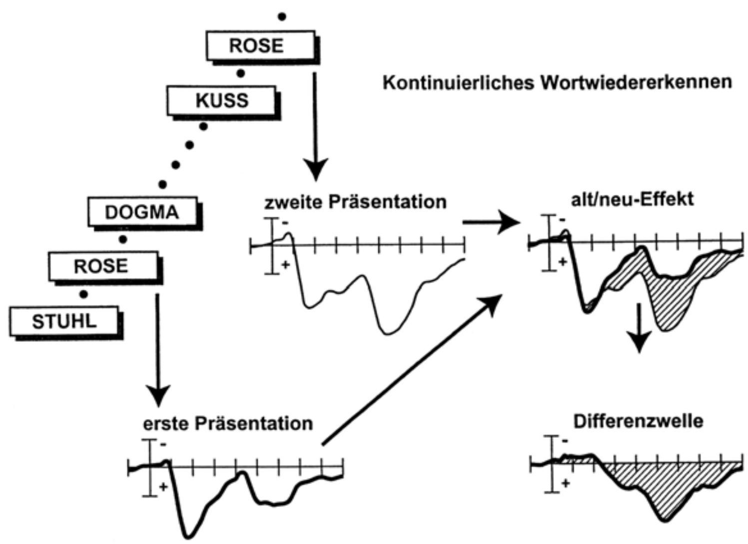


Figure 5. Continuous word recognition experiment in which a typical old/new effect is evoked. (erste Präsentation = first presentation, zweite Präsentation = second presentation, alt/neu-Effekt = old/new effect, Differenzwelle = difference wave).

The presented words in our experiment were classified into three groups of different emotional content: negative words like "to die," positive words like "to kiss" or neutral words like "to go." This differentiation was not known by the subjects.

The question arises, how do depressive patients respond to the presentation of the words with different emotional content compared to healthy control subjects? Fig. 6 shows the average ERPs for the 3 different categories of words for 11 healthy control subjects for the midline electrode positions (from frontal to parietal). Especially frontally the negative and

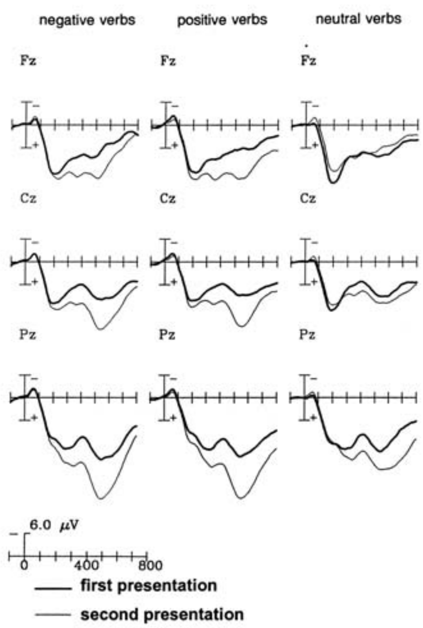


Figure 6. Grand average (n=11) ERP waveforms to correctly detected first (thick line) and second (thin line) presentations of the words (verbs) for the control subjects. The second presentations of words elicited a more positive waveform starting at about 200 ms after onset of the stimulus. This old/new effect demonstrated here for the central electrodes (Fz, Cz, Pz) is more pronounced for the presentation of the "emotionally toned" negative and positive words.

positive toned words (verbs) induced a bigger difference between the first and second presentation compared to the neutral words. This difference is called old/new effect ("new" for the first presentation and "old" for a second presentation of the words). In the depressive patients (Fig. 7) this difference is nearly abolished.

These findings may be understood, by suggesting that the cognitive hippocampal memory system including the frontal cortical structures was influenced by the negative emotional memory system: it appears to be primed and influenced especially by negative cognitions and memories which leads to this massive reduction of the old/new-difference. The system appears to be precharged with negative cognitions. This may be clarified by demonstrating the ERPs for the first presentations only as shown in Fig. 8).

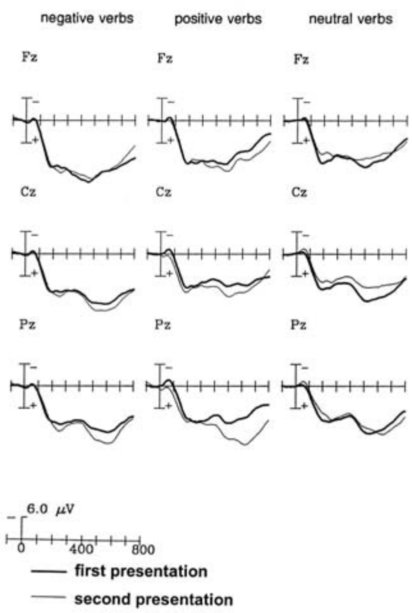


Figure 7. Grand average (n=9) ERP waveforms to correctly detected first (thick line) and second (thin line) presentations of the words (verbs) for the depressive patients. The old/new effect is significantly reduced compared to the control subjects.

The depressive patients event-related potentials for the first presentation are so pronounced, as if they had been presented before. The N400 component relevant to context integration processing appeared to be absent. No context integration seemed to happen for the negative items especially. In other words negative words were much more expected than positive and neutral items. This is congruent with the concept of Theunissen, that depressive patients appear to be under massive pressure by their negatively toned cognitions, by the negatively charged memory system, and by the dominance of time.

6 Creativity, Consciousness and Forgetting

The problems of voluntariness in neurobiological terms hae been discussed within a Dahlem-conference 1994 on the flexibility and constraints in behavioral systems: "One may define an *a* *a* *e* along which animals can be classified. Animals should never be perceived to be climb-

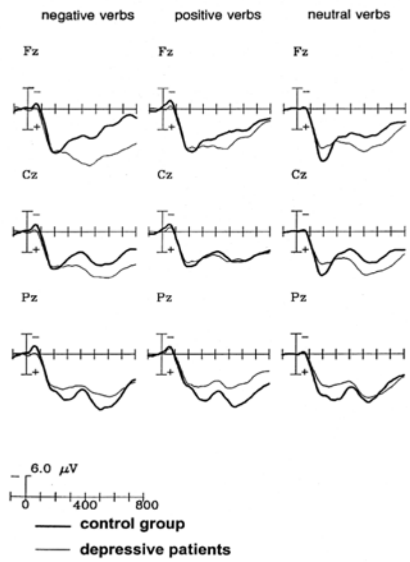


Figure 8. Grand average ERP's to correctly detected first presentations of the words only for the control group (n=11; thick line) and for the depressive patients (n=9; thin line).

ing this axis towards voluntary behavior. Indeed, phylogenetic and adaptive conditions (e.g. change in body size or predictability of the environment) could conceivably cause animals to evolve less voluntary states. Although for the sake of simplicity one may discuss an unidimensional axis, there is no need to restrict it to one dimension. Finally, one may hope that this axis, and those that evolve from it, will replace the anthropomorphic, human-centered axis that now exists. That is, while primates may occupy one end of the scale, that highly derived animal group should not be the standard against which all animals are judged. Indeed one may wish to be more objective than are present definitions of voluntariness." [18].

And further: "A concept of voluntariness contains attainment of a goal, which embodies the animal's intentionality. Any useful goal concept would vary considerably with the level of complexity of both the animal and the behavior studied. So a description of the goal state in terms of its richness of representation must be specified in detail. It is trivial to say that a hungry animal has a goal of obtaining food.

A goal of voluntary behavior must contain the purpose behind the movement. It must in a sense reduce the discrepancy between an existing sensory state and a desired state. In a simpler sense the goal can be represented by external stimuli in the immediate sensory world of an animal. Any behavior to which we can attribute a chain of causes, that is, a series of stimuli each of which serve to release the next few stimuli in the sequence, would clearly not fulfill our predispositions for thinking about voluntariness. Yet that kind of behavior attains a goal. Bacteria, for example, will move within a chemical gradient toward food according to sensory cues that directly regulate the orientation behavior. More complex representations of goal states must be defined. Levels of voluntariness manifest themselves in how goals are formed. One possible concept is the idea of "fitting" between "concepts" and "sensory data," i.e. the consideration that neuronal systems generally perform comparisons between expected and actual states. Perception means to find the optimal internal neuronal state ("concept," "model"), which fits to a set of sensory data, whereas goal-directedness means to establish a definite internal pattern and to "quantify," and the difference between these two values is interpreted by the system as "dissatisfaction." [18].

From this point of view the following relation between the basic mechanisms of perception and goal-directedness would arise. In the case of perception the aim is to find an optimized internal "model" pattern (as a conceptualization) to fit an external set of uninterpreted sensory data. If there is no optimum fit the system is unsatisfied and has to apply internal "conceptualization-pressure" to generate alternative conceptualizations for a better "understanding" of the external sensory-data-pattern. Satisfaction occurs when the optimum fit between "sensory data" and "model" is realized, which is disturbed in depression.

The principles, under which the generation of creative new "meanings" are generated may be exemplified in a schematic drawing about the elementary process in relation a "reactive conceptualization pressure." Reactive conceptualization pressure appears to be a relevant feature in a circuit when no plausible fit is reached between conceptualization and not yet interpretable data (Fig. 9). It is assumed, that in this situation the system generates "variants" of already established conceptualizations, leading to a special type of "neuronal darwinism" in the sense of Gerald Edelman.

It is assumed that the generation of "consciousness" is the above-mentioned fitting-process between internal "model" and a set of sensory data in a convergence zone (the concept presented here has partially been elabo-

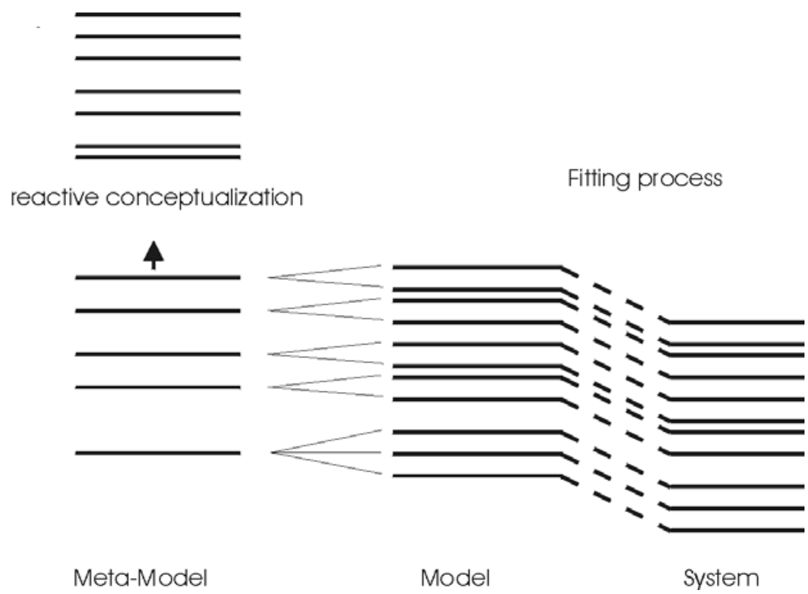


Figure 9. Schematic representation of the concept of fitting-processes in perception and the role of "reactive conceptualization" in formation of new models and meta-models.

rated in cooperation with Harald Atmanspacher, Freiburg). The difference between "conscious" perception and "conscious" goal-directedness is as follows: in perception the system tries to find the optimal internal "model" to represent the actual state of sensory data ("lottery of models"). In the case of goal-directedness the system pre-establishes an internal model and the sensomotor-system has to play a kind of game to vary the external data until the fitting between the pre-established internal model and the sensory data is optimized, i.e. until the difference between model and sensory data is minimized ("lottery of proposals").

Such a concept, however, implies that an internal world of values is constructed by the system in which the differences between different degrees of fit are defined in a rank-order, i.e. the "game rules" imply that the better the fit, the higher the value of the acquired state as well as in goal-directedness. The difference is that in perceptual processes the system ranks and tests the different conceptualizations with the aim to "understand" what's going on, whereas in goal-directedness the game is to vary sensomotor states to reach an optimal fit between a pre-established internal model and actual sensory data.

Within this context, a goal of human voluntary behavior in depressive patients may be to overcome the disease, to overcome the dominance of the past. In such a situation, creative reactive conceptualisations may help to induce optimized fitting processes, and therefore, should reduce depression.

Following Theunissen's concept of "resistance to the dominance of time" [2], we will deal with a type of "active" dis-acknowledgement as a type of "forgetting process," namely dis-acknowledgement in the sense of forgetting as a creatively interpretative representating. Involved is a means of dealing with the past by using the imagination to access the life-path that lies behind while including all the options which were not chosen and by using the imagination to bring to life subliminal "experiences" in the context of the "processes of choosing" which took place when travelling along this path. One might term this the "Proustian method." Theunissen describes it as follows: "Proust is able to recall "regained time" precisely by destroying it. Memory, which functions as an organ of reconciliation, is spontaneous in that it leaps out from the solid context of occurrences and opens itself to the unique in which the subject perceives the internal subjective world which he has continually suppressed on the basis of what appeared to be external. With this it opens the surface of memory." It has something of Hegel's "re-collection" [19]. This type of active forgetting means an imaginative time travel to the past and integrating it into present life. Thereby it is possible to forget, and thus "solve" depression, which finally appears to be a very creative process.

References

1. Ehlers, J. (2003) Concepts of time in physical theories. Insights obtained and open questions, Vortrag International Conference "On Time," Einstein Forum, Potsdam, May 22–24, 2003.
2. Theunissen, M. (1992) *Negative Theologie der Zeit*, Suhrkamp Verlag, Frankfurt a.M.
3. Emrich, H.M. (1992) Konstruktivismus: Imagination, Traum und Emotionen, in S. J. Schmidt (ed.), *Kognition und Gesellschaft. Der Diskurs des Radikalen Konstruktivismus 2*, Suhrkamp, Frankfurt a. M., pp. 76–96.
4. Emrich, H.M. (1998) Synästhesie, Emotion und Illusion, in Kunst- und Ausstellungshalle der Bundesrepublik Deutschland, in U. Brandes and C. Neumann (eds.), *Der Sinn der Sinne*, Schriftenreihe Forum Band 8, Steidl, Göttingen, pp. 126–139.
5. Pöppel, E. (1985) *Die Grenzen des Bewußtseins*, DVA, Stuttgart.
6. Singer, W. (1990) Search for coherence: a basic principle of cortical self-organization, *Concepts in Neuroscience* **1**, 1–26.

7. Gray, J.A., and Rawlins, J.N.P. (1986) Comparator and buffer memory: an attempt to integrate two models of hippocampal functions, in R. L. Isaacson and K. H. Pribram (eds.), *The Hippocampus*, Plenum, New York, pp. 151–201.
8. Maalsburg, Ch. von der (1993), *private communication.*
9. Desimone, R., Miller, E.K., Chelazzi, L., and Lueschow, A. (1995) Multiple memory systems in the visual cortex, in M. Gazzaniga (ed.), *The cognitive Neurosciences*, MIT Press, Cambridge (MA), pp. 475–486.
10. Heisenberg, M. (1990) Über Universalien der Wahrnehmung und ihre genetischen Grundlagen, in H. von Ditfurth and E. P. Fischer (eds.), *Mannheimer Forum 1989/90*, Piper, München, pp. 11–69.
11. Proust, M. (1993) *Auf der Suche nach der verlorenen Zeit*,. Suhrkamp Verlag, Frankfurt a. M.
12. Gondek, H.-D. (1990) Das Versprechen und seine Verbindlichkeit, in K. Holz (ed.), *Soziologie zwischen Moderne und Postmoderne. Untersuchungen zu Subjekt, Erkenntnis und Moral*, Focus, Gießen, pp. 39–65.
13. Nietzsche, F. (1981) *Unzeitgemäße Betrachtungen*, Insel Verlag, Frankfurt a. M.
14. Cramer, F. (1993) *Der Zeitbaum. Grundlegung einer allgemeinen Zeittheorie*, Insel Verlag, Frankfurt a. M.
15. Peitgen, H.-O. (1993) Fraktale — gezähmtes Chaos, presented at the XVI. Deutscher Kongress für Philosophie, Berlin, September 20 – 24, 1993.
16. Rugg, M.D. (1995) ERP studies of memory, in M. D. Rugg and M. G. H. Coles (eds.), *Electrophysiology of Mind, Event-Related Brain Potentials and Cognition*, Oxford Psychology Series No. 25, Oxford University Press, Oxford, pp. 130–170.
17. Kutas, M., and Hillyard, S.A. (1980) Reading senseless sentences: Brain potentials reflect semantic incongruity, *Science* **207**, 203–205.
18. Smith, B.H., Altman, J.S., Bargmann, C.I., Carew, T., Emrich, H.M., Freeman, W.J., Heisenberg, M., Homberg, U., Menzel, R., Meyrand, P., and Ohl, F. (1994) Group Report: How flexible and how constrained is the concept of voluntary behavior?, in R. J. Greenspan and C. P. Kyriacou (eds.), *Flexibility and Constraint in Behavioral Systems*, John Wiley & Sons, Chichester, pp. 195–208.
19. Hegel, G.W.F. (1973) *Phänomenologie des Geistes*, Suhrkamp Verlag, Frankfurt a. M.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 227–243

A CONTAINER VIEW OF CONSCIOUSNESS AND ALTERED TIME EXPERIENCES

MARTIN JANKOVIČ
Philosophy Department, Central European University, Nádor u. 9
H–1051 Budapest, Hungary
(fphjam01@phd.ceu.hu; jankovic.m@zoznam.sk)

Abstract: In the contemporary philosophy of mind, the notion of subjective experience plays a central role. One of the most interesting dimensions of the subjective experience is its time dimension. In this paper I will attempt to develop a plausible model of subjective experience of time based on the following conceptual tools: on the metaphor of the 'Specious Present' developed by William James and on the concept of the 'Thick Moment' of consciousness, introduced by the British psychologist Nicholas Humphrey. Subsequently, I will deal with two basic properties of time experience: change and duration. I will examine their relation to the previously introduced container view of consciousness. In the second part of this paper, I will apply this model of conscious time experience on some 'extraordinary' time experiences to see how this model can accommodate this type of experiences.

Keywords: Time Experience – Duration – Scope – Container – Consciousness

1 Introduction

Subjective experiences, and especially time experience, rank among the hardest scientific problems. There is no commonly shared and generally accepted theory of subjective and time experience. Apart from the current situation in scientific community, from accounts of altered time perception arise very interesting problems for both our intuitive conception of time and scientific theories of time perception. Paradoxically, it seems that the theory, which would be able to deal with the so-called psychopathological experiences of the time, could be regarded as a reasonable candidate for the theories of commonly shared experience. Slightly rephrased, the theory aspiring to explain our common time experience should also satisfactory deal with not so commonly shared experiences.

I do not propose any kind of definite answer to these puzzling issues. I would like to rather draw the attention to the features of everyday experience and its scientific/philosophical elaboration which I find convincing and with explanatory efficacy. In the first part of my article, I will introduce and elaborate thoughts of American psychologist and philosopher William James and British psychologist and philosopher Nicholas Humphrey. These two authors provide us with the following two important conceptual pillars:

- Metaphors of the Specious Present and the Thick Moment, which will be frequently addressed with the term container view of consciousness. Next, I will concentrate on necessary properties of such a container and their implications for time perception.
- In the end of the first section, I will introduce a distinction between sensation and perception based, again, on the work of already mentioned authors.

In the second section, I will test this model of time perception on certain types of altered time experiences to see whether they will be able to deal with some of these types of experiences.

2 Experience and Time

In the first place, I want to point out the ambiguity of the term 'time perception'. A common reading of this term suggests that there is something like a perception of time as something objectively existing. Time alone cannot be perceived anymore than one can perceive his self. I will rather use the term time experience but the term experience of time would be more illustrative.

The question is whether the time dimension of our experience comes from outside the experience or emerges within its scope. In this article, I will employ the following strategy: time experience depends primarily on the content of experience and experience itself gives rise to its time dimension. To claim something is one thing and to show and see how it actually works is something different.

Our experience is an incredibly complex, vivid and often hardly expressible phenomenon so that to choose and describe some of its most general features (in respect to time) is a quite ambitious and speculative task. In order to keep at least one foot on the ground, I will restrict myself to describing only some features of experience and its content, which are useful in the explanation of its time dimension. This strategy will prevent us from making strong ontological claims towards the existence of time — except for mentioning of the subjective basis for time experience — and will enable us to see possible sources of some characterizations of time with respect to its ontological status.

2.1 The scope of the conscious present

It is highly recommended — when one speaks of consciousness — to precisely define what he/she is actually going to talk about. For consciousness is such a multilayered phenomenon — ranging from the facts of brute sensory awareness to solving highly complicated social tasks — that mentioning only some of its dimensions never satisfies everybody. I will try to escape from this muddle to a more general and metaphorical sphere. The concept of 'container' may serve our purpose perfectly. It is quite general and encompassing, but one of the most interesting facts about it is its content — and the same is the interesting point about consciousness. For this reason I will mostly deal with its actual content and further implications for time experience. But let's at first define its necessary properties from which the most striking property is its scope.

William James in his Principles of Psychology [1, p. 573] further developed E. R. Clay's notion of 'specious present'. He expressed the main idea of specious present — its illusive zero time duration — in the following passage [1, p. 574]:

> In short, the practically cognized present is no knife-edge, but a saddle-back, with a certain breadth of its own on which we sit perched, and from which we look in two directions into time.

And later he adds:

> 'the prototype of all conceived times is the specious present, the short duration of which we are immediately and incessantly sensible'... and this duration (with its content perceived as having one part earlier and another part later) is the original intuition of time.

Here we can find almost all important 'ingredients' needed for the purpose of this paper. The present moment is not that proverbial uncountable moment, the barely registerable 'blink of the eye', but rather like hearing and experiencing a melody of a certain duration. And we have to add that the importance of 'the original intuition of time' also consists of the immanent directedness of experience — its past-present-future structure.

It is quite reasonable to suppose that without a certain scope of conscious experience, one could not acquire the sense of passing time.

2.2 The structure of the present moment

There is a quite interesting congruence between the views on the structure of the present in the ideas of W. James and E. Husserl. Husserl's notions of retention and protention have similar consequences as James' two directions in which one can look — into the just vanishing past and the just approaching future. I think that James would agree with Varela's following characterization of experience along Husserlian lines [2]:

> There is always a center, the now moment with a focused intentional content (say, this room with my computer in front of me on which the letters I am typing are highlighted). This center is bounded by a horizon or fringe that is already past (I still hold the beginning of the sentence I just wrote), and it projects towards an intended next moment (this writing session is still unfinished).

This leads us to the characterization of the structure of the present moment. From the time-point of experience it has two fringes, peripheries and a center on which consciousness is focused. The intensity of the fringe-experience is not as high as in the center of intentional awareness. This may provide us with the Jamesian original intuition of time, being perched in the saddle-back but still aware of what is happening on the periphery. The present moment would thus consist of the 'peak present', the dying away past experience, and emerging future experience.

This sketch of the structure of the conscious present leaves aside two essential characteristics of time experience — duration and change.

2.3 Change, duration and phenomenal flow

If we were to return some 2500 years back into the ancient Greece, we would find that notions of change and duration presented the hot spot in metaphysical discussions. For example, Heracleit claimed that change is a fundamental feature of reality. On the other hand, Parmenides (followed by Plato) maintained that the ultimate reality is changeless and complete. It is an interesting thing to note how germs of these metaphysical views are traceable to the basic features of everyday time experience. Another notable thing is the identification of the culprit responsible — from Parmenides' and Plato's point of view — for the creation of the illusion of change. They declared the senses guilty and pushed them into a stigmatized position.

Nevertheless, I will claim that we should be grateful to our senses for providing us with the fundamental properties of time experience; with the sense of duration and change. Notions of duration and change are intrinsically interconnected and are hardly specifiable without each other. In order to their relation, we will need an answer to the question: "Is it possible to experience duration without change and *vice versa*?"

Let's take one of the most mundane and frequently mentioned examples — the experience of hearing a succession of tones. Barry Dainton, in his Space and Time [3], describes the notion of phenomenal flow with the following example. At first you hear a C-tone, but shortly after you hear D. Can you explain why you hear "D-being-followed-by-C" without taking into account memory? Until now, we have introduced two possible theoretical tools capable of explaining this phenomenon without taking into account any sort of memory — concept of Specious Present and its subsequent past-present-future structure. Dainton introduces the notion of co-consciousness and adds another feature of sensation — its flowing, dynamical character.

> This immanent flow is an essential ingredient of any auditory content, just as essential as timbre, pitch or volume... The same applies to bodily sensations, such as pains or tickles, as well as to olfactory and gustatory contents. [3, p. 105]

In advance, I would like to alert the reader to the connection of immanent flow to sensations of all modalities. In the subsequent pages, it will be the role of sensations, which will be treated as essential to our sense of time. Dainton's previous characterization of phenomenal flow can be easily and suitably accommodated in our container view of consciousness; as far as we admit that everything situated inside the container is at the same time also a content of consciousness and flowing. On the other hand, the dynamical character of sensations can be accommodated by the varying intensity of experience in the centre and on the fringes of consciousness. In the next section I will introduce a possible physiological instantiation of these properties of time experience. But before we get there, we should see how these conceptual tools can deal with a certain thought experiment.

Imagine that you are looking at a white wall in ideal circumstances (with constant level of illumination, fixed gaze, no flashes in the visual field, *etc.*). Your experience will consist solely of white sensation. But will it be an experience of duration without any change? Barely, but the answer is not so obvious. Evidently, one will experience a persistent sensation of white. Given that we have previously established that the present moment consists of the past-present-future structure, we have already approached the essence of the notion of 'phenomenal flow'. Phenomenal flow presupposes not only an intrinsic direction of experience from past to the future, it also presupposes immanent and inescapable change. But what changes, what is flowing in such an enduring sensation? There is the quite common answer — the time itself passes and is responsible for the sense of change. To translate this statement into 'subjective language'; even though one's experience consists only of one enduring sensation of white, one still has a sense of change. We can base our explanation solely on the level of subjective experience. Given that the intrinsic property of each sensation is its flowing, dynamical character (experience of the co-conscious sensation of white on the past fringe of consciousness is less intense that the same sensation in the focus of consciousness), change is present even in the most monotonous experience. Duration is inevitably tied with the notion of change, even the change is realized by the immanent flow of the same sensation of white.

William James claimed that we have no sense for empty time [1, p. 583]. I believe that the previous examples show the validity of his conviction. Time experience is necessarily bound with the content of experience itself. Even with the seeming absence of content of experience, the sense of passing time still lingers on. Let me shortly state what exactly I have in mind. *One can only be aware of the passage of time with respect to experiential content, and also in the case of seeming absence of experiential content.*

In the subsequent section, I will introduce a possible physiological instantiation of the previously stated properties of time experience. The crucial role in this model will play a very interesting feature of sensations — their indication of the present moment of experience.

2.4 Sensations and reverberation loops

Nicholas Humphrey, in his sensational book 'A History of the Mind' [4], presented an original and promising theory of consciousness. There is not enough space herein to go into details, let me just briefly introduce the main parts of this theory. Humphrey coins a term 'Thick Moment' of consciousness. Thickness primarily refers to the temporal thickness of consciousness but it may also in this case refer to the intensity of sense experience. According to this theory, one lives his embodied existence in the sensory rich present moment. One of its essential parts presents the theory of reverberation loops.

In order to illuminate this theory, we have to listen to a short, condensed evolutionary story. Along with the formation of the first amoeba-like organisms, sensitivity came into being — such organisms were reacting to stimulation of their bodily surfaces. But such stimulation wasn't 'processed' by any kind of neuronal structure — response to bodily stimulation was realized in the form of bodily activity. A few million years later, a ganglion evolved. The bodily stimulation did not end up on the surface but was transferred via nerve fibres to the place of its neural processing. But this invention also had its negative side. After the signal from the body surface reached the neural node, another signal had to be sent back to the place of stimulation to evaluate the 'actual situation' on the bodily surface. The negative side to this so-called perceptual evaluation was that the fidelity of this loop was decreasing with the distance the signal had to travel. As a solution, the returning signal did not have to reach the original place of stimulation, but was targeted to the incoming sensory nerve. These two stages are illustrated in Fig 1. The final, third stage represents our own neural system with its surrogate sensomotoric map of the whole body. The returning signals do not have to travel to the bodily surface, but their major part is targeted on the surrogate sensomotorical map. But what does this story tell about the time dimension of our experience?

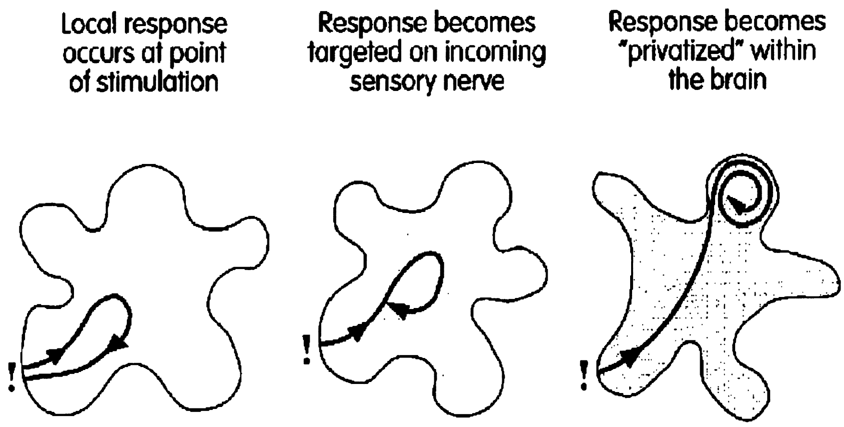


Figure 1. This picture — reproduced from [12] — illustrates progressive shortening of the sensory loop in the course of evolution.

The essential point about this reverberating activity is the following: The recurrent activity in sensory loops consists of continual 'communication' between the perceptual center and surrogate map. Because of the progressive shortening of this loop, the neural signal — traveling back and forth — maintains its intensity for a significantly longer time period than before. Let's see what use we could make of this model in the case of hearing a succession of tones C, D and E.

In normal circumstances, one's experience consists of hearing 'C-followed-by-D' and 'D-followed-by-E'. Reverberation loops allow us to explain this phenomenon in accordance with the previously introduced structure of the present moment. After one hears a sounding C-tone, one hears the subsequent D-tone. But even though the C-tone is not actually resonating in the external world, it is still resonating in the dying away neural activity in the sensory loops. In this way, one can still have a fringe awareness of the previously sounding tone and at the same time can be aware of the currently playing tone. If the present moment did not have this kind of structure and given that we would want to explain the experience with the help of memory, one would rather hear the whole C major chord and not a succession of tones C, D and E.

2.5 Sensation and perception

Since I don't have enough space herein to sufficiently justify (and persuade sceptics) that there really is a significant distinction between sensation and perception — both the terms should be read as verbs — I will have to call the authority of thinkers who recognized their distinctiveness. Two hundred years ago, the Scottish philosopher Thomas Reid [5, p. 265] said the following:

> The external senses have a double province — to make us feel, and to make us perceive... conception and belief which nature produces by means of the senses, we call *perception*. The feeling which goes along with perception, we call *sensation*.

William James expressed his view on distinctness of sensation and perception in the following way [1, p. 652]:

> Sensation... differs from Perception only in the extreme simplicity of its object or content. Its function is that of mere acquaintance with a fact. Perception's function, on the other hand, is knowledge about a fact; and this knowledge admits of numberless degrees of complication.

And according to Nicholas Humphrey Sensation and Perception provide us with *answers* to two *different questions*. Sensation provides us with the answer to the question: '*What is happening to me?*' and Perception to the question: '*What is happening out there?*'

But we will be primarily interested in a different kind of time experience which they also provide. Sensations are entities characteristically existing in the *present moment.* Their only time reference point is the present moment, the thick now. If you will feel pain in your back tomorrow, the reality of feeling the pain will be bound to that moment. Simply, in a certain sense, to feel a pain means to be in pain in the present moment. In words of Richard Gregory, sensations 'flag the present' — sensations fix us to the existence in the present moment.

On the other hand, perception isn't bound to the present moment in such a strict way as sensation. The objects of perception are usually entities existing in the external world, and since these objects do not exist only in the present moment, time-reference points of perception may stretch from the past through the present to the distant future (out of the actual scope of the present moment).

We now have available a very simple, but illustrative, picture of sensation and perception. Sensations have only one time reference point while the content of perception may refer to three time reference points — past, present and future. Moreover, perceptual content shares this triple time reference with the other 'products' of cognition: thoughts, images, *etc.* The whole distinction boils down to the question of intentionality — to the intentional content of mental states. And as far as we know, some mental states may refer even to non-existing entities, like Pegasus. To make this picture more illustrative imagine sensation as a constantly flowing stream with some discrete islands of still refining perceptual content.

Before we move to the next section let me summarize some vital points, which will play an important role in the subsequent pages. The container view of consciousness (and primarily its structure) suggests that it has a certain scope which encompasses all actual conscious experience. Further, I want to suggest that there is a certain relation between *scope* and *span* of consciousness. Metaphorically, scope will refer to the 'spatial' properties of container, to its horizontal dimension and limitation of actual amount of conscious content (and in the case of raw sensations, the role of amount of experienced content will be substituted by intensity of sense experience). On the other hand, 'span' will refer to the time dimension of conscious experience.

I take it to be a generally-acknowledged fact that it is impossible to define time without reference to space. So I propose to examine relations between the spatial and time dimension of this conscious 'container' together with referring to its quantitative and qualitative properties. It is certainly peculiar to treat the quality experience in quantitative terms and I don't want to push this strategy to the claim that experience can be described in quantitative terms. My only intention is to show that there is a nontrivial correlation between the amount of experienced content together with the intensity of experience and time dimension of experience.

In the following section I will examine possible alterations of relations between the scope and span of consciousness on the effects of two basic types of psychedelics (interestingly corresponding to the sensation/perception distinction).

3 Eros/Thanatos

There is a striking resemblance between our characterization of the role of sensations for grounding the time experience into the present moment and effects of two main groups of psychedelics. Convincing classification introduces the following description of serotonergic (altering the level of serotonin) psychedelics and dissociative anaesthetics [6]:

> Serotonergic psychedelics are Eros, and dissociatives are Thanatos. The serotonergics are Birth, they are sensory overload, focus on the details, awareness of the external universe. The dissociatives are Death, sensory shutdown, focus on the archetypes, awareness of the internal universe.

The Deity Eros embraces psychedelics like *LSD, mescaline* or *magical mushrooms.* On the other hand, *dissociative anaesthetics* like *ketamine, PCP* and *DXT* are usually described as belonging to the Deity of Thanatos. This classification is based on their overall psychological effect. Under the influence of Eros, the intensity of one's sense experience is significantly escalated and reaches new dimensions (details, colours and sounds are experienced with new qualities). On the contrary, Thanatos generally wipes away all interest in sense experience (because sensory input is dramatically cut down) and one may become captured inside his own realm of psyche.

While serotonergic psychedelics are responsible for intensification of sense experience, dissociative anaesthetics have the right opposite effect. Anyway, their common resulting effect is the alteration of time experience. And it will be an interesting thing to see how it is possible.

3.1 Eros

Given that the extended conscious present is largely constituted by the immediate afterglow of sensory stimuli — by the dying-away activity in reverberating sensory loops — there is available a possibility to explain, for example, one dimension of mescaline intoxication in the following way.

Subjects often report that the time dimension of their experience gets, somehow, broader/thicker. The 'speciousness' of the duration of present moment may thus become quite obvious. The estimation of duration of some experience under the influence of, for example, mescaline, usually significantly differs from the duration measured in objective time. The most natural supposition is that the intensification of experience leads to overestimation of its actual duration. Let's suppose that intensification of experience leads to broadening of the container's scope and subsequently to the prolongation of the time span of consciousness.

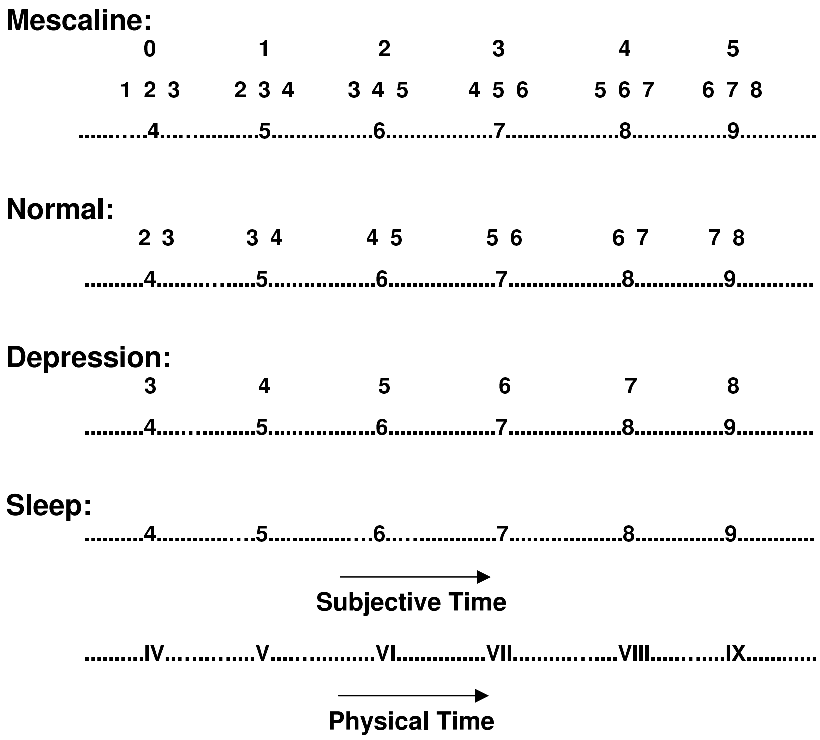


Figure 2. This diagram (taken from [4, p. 190]) shows various possible alteration of the scope of the present moment.

Given this speculative postulation, we could easily explain one dimension of this type of experience. It is reasonable to assume that the dying away activity in the sensory loops is maintained sufficiently longer in order to stretch the scope (and also span) of the present moment. As we can see in Fig. 2; the reverberating activity lingers on significantly longer than in normal circumstances. Accordingly, the two dimensions of container — intensity, scope or its thickness gets altered. So we can establish the following correlation. The higher the intensity of reverberation, the thicker the present moment becomes.

The diagram illustrates two main types of possible alteration of the reverberation level in sensory loops. In normal circumstances, one's reverberation activity thickens the present moment so that the activity in sensory loops remains quite intense even though the actual sensory stimulation already does not exist — the stimulus objectively does not exist but on the level of subjective experience (in subjective time) still lingers on.

Even though there seems to be significant correlation between the content and time scope of experience, we have tackled only one partial direction of alteration. Depression and sleep point to another possibility. In depression, the intensity of reverberation does not reach the peak of normal experience. The scope of present moment is contracted; nothing seems to be of special interest, time is slowly dragging. In the next section, we will closely specify relations between the scope/span of consciousness and the rate of passing time.

Apart from previous descriptions, sleep presents another group of interesting experiences with time alteration. And even in the case of sleep we may use the metaphorical container for explanation of this type of time experience. The only difference is that it is not filled with experience originating from direct sense experience.

3.2 Thanatos

The second group of psychedelics share their effect comprising attenuation of sense experience with the group of experiences that interestingly don't share their prism of illegality: sleep, sensory deprivation and meditation. During all these experiences, whether usual or unusual, time experience undergoes quite serious alternation. Given that the sensory channel is turned down in a significant way, 'flagging the present' role of sensations ceases to be decisive. Here is a description of the most characteristic sensory deprivation experiences [7]:

> Relatively complete sensory deprivation (such as may be experienced, for example, by persons undergoing prolonged stays in experimental isolation chambers) compresses the experience of time to the point that short or long intervals (from about a minute to a day) seem to pass about twice as fast as usual. Time spent under these unpleasant conditions paradoxically seems shorter than normal time. Thus, the 58 objective days of a subject's first stay in a cave were underestimated as 33 days.

This description suggests the following: Since here it is not much happening in the sensory channel, we cannot assume that responsibility for the time alteration should be credited to the intensification of sense experience. The metaphorical container is mostly bereft of direct sense stimulation but it is instead filled with awareness of inner mental experience: thoughts, images, *etc.* The actual cause of the alteration of time experience is a significant lack of sensations.

Anyway, all that has been said about the relation between scope and span of container still holds. In the case of Eros, one's scope of consciousness is broader and that results in the impression of a faster rate of passing time. The previous quotation shows that in the case of Thanatos — with the absence of sensation — time also seems to pass faster. So we should suggest that the scope/span of consciousness is broader, embracing more content. We have approached an interesting ambiguity. Now it seems that both sensory overload and actual lack of sensations leads to the underestimation of the 'objective' rate of passing time. The solution to this puzzle is the following. In both the cases, the metaphorical container is filled more than in normal circumstances. In one case it is filled with sensory overload, in the other with overload of inner mental events.

We can establish a certain correlation between the rate of experience and the scope/span of consciousness. The bigger scope/span, the faster the rate of passing time and vice versa. Given that the amount of experienced content is greater than in normal circumstances, and given that sensations cease to fulfill their role of fixation to the present, one can easily experience altered sense of time. But as we will see, the situation can get a little more complicated.

Let's take the most mundane example; the time one spends while she/he is lost in thoughts. It is quite hard to estimate the duration of this experience. From the previous correlation it should follow that the experience of 'being lost in thoughts' implies the sense of faster time passage. And as many readers know themselves, one is often surprised how much time have passed.

Apart from this case of 'quasi-sensory deprivation', a very good example of complete sensory deprivation is regular dreaming. One usually makes no effort to estimate duration of his/her sleep after waking up. But as far as known, dreaming periods last objectively significantly shorter than the dream experience (from inside) itself implies. Simply, during one particular dream it happens much more than it would happen in waking state; for example, in the period of one minute. The boundaries of this metaphorical container thus get stretched to the extent which the normal waking state — because of the grounding function of sensations — does not allow. We can establish the following correlation:

- the narrower scope of consciousness, the slower rate of subjective time (approximate to the objective rate of time);
- the broader scope of consciousness, the faster rate of subjective time (and underestimation of the objective rate of time).

But as I have already said, things can get a little more complicated. The following is a description of experience under the influence of ketamine [8]:

> The most profound impact of Ketamine is it's effect on time. . . time begins to slow to a shuddering, thugging crawl — each moment stretches out into a sea of infinity and rolls sluggishly into the next. Seconds become minutes, minutes become hours, and eventually, in the peak, time ceases to have any meaning whatsoever.

What can we say with respect to this enormous stretching of the present 'into a sea of infinity' and time losing its meaning?

3.3 Empty time and eternity

Until now, we have dealt with the linear time structure of experience. This structure may serve us quite well in our project of explaining the concept of empty time. W. James defines empty time in this way [1, p. 589]:

> . . . from the relative emptiness of content of a tract of time, we grow attentive to the passage of time itself. Expecting, and being ready for, a new impression to succeed; when it fails to come, we get empty time instead of it. . . empty time is most strongly perceived when it comes as a pause in music or in speech.

James claimed that we have no sense for empty time and I think we can agree with him. Even though we can admit that the term empty time suits the previous description, time in this case is not that empty. It is full of expectation, orientation toward the future. His other quote shows a very similar account of time passage presented herein:

> A day full of excitement, with no pause, is said to pass 'ere we know it' On the contrary, a day full of waiting, of unsatisfied desire for change, will seem a small eternity.

It is worth noting that even when there is nothing to expect, one can also have an experience of eternity. And other interesting fact is that both of Eros and Thanatos substances — despite their opposite psycho-physiological effects — often lead to the experience of eternity, or rather to the impression of the present moment stretching into infinity. Let's see how the container view of consciousness can deal with the experience of time losing its meaning and its actual disappearing.

Douglas Stokem [9] claimed that "... it is impossible to imagine experience in the absence of time." Well, but maybe there is one way to get there. This is a description of one experience of William Braud [10]:

> I begin to collapse time, expanding the slice of the present, filling it with what has occurred in the immediate "past." ... The present slice of time slowly enlarges, encompassing, still holding, what has gone just before, locally, but increasingly nonlocally as well. ... I am out of time and in an eternal present. In this present is everything and no-thing.

We have seen that, for example, during dreaming, the container can embrace a lot more content than it usually does with respect to the 'objective' rate of time. Here we see that the scope of present moment can be much more flexible than one would expect. Taking the ability of its infinite stretching at least as a theoretical possibility, implications of this infinite stretching may be very interesting.

The previously defined structure of the present moment, it past-present-future organization, allows manipulation mentioned in Braud's report. The notable corollary seems to be that if the present moment encompasses the whole of the possibly experienced events, the sense of time may altogether vanish. Given that in such present stretching into infinity everything already happened, one has a sense of all embracing consciousness, is there some need to postulate the ordinary past-present-future structure? This linear time structure has its justification only in the ordinary types of time experiences, when one is situated on the nexus of past and future. The main moral of such an experience may be that if the present moment has nowhere to move, there is no approaching future; the sense of time in a certain sense disappears.

At this point, I would like to stress that now it becomes much harder to separate the ontological status of time and its subjective counterpart. What I hope the previous experience shows is that if one's awareness becomes infinite and given that one is used to treat time as an all encompassing and all pervading 'substrate' then, in a certain sense, one becomes the time itself.

4 Conclusion

In this article I have introduced and described a quite simple and intuitive model of time experience. I have tried to show how this model can deal with certain types of altered time experiences. I am aware that this is only a partial, incomplete, and speculative approach and a lot of very interesting experiences are left aside (like, for example, time "flowing backwards" or "disordered/fragmented" time — see, e.g., [11]). Nevertheless, I suppose that this model could also deal with other types of experiences. But what it shows is the entanglement of the basic types of time experiences with some kinds of extraordinary experiences and their connection to our metaphysical notions of time and eternity — their correlation to the basic features of subjective time experience.

References

1. James, W. (1983) *The Principles of Psychology*, Harvard University Press, Cambridge–London.
2. Varela, F.J. (1999), The specious present. A neurophenomenology of time consciousness, in J. Petitot, F. J. Varela, B. Pachoud, and J.-M. Roy (eds.), *Naturalizing Phenomenology: Issues in Contemporary Phenomenology and Cognitive Science*, Stanford University Press, Stanford, pp. 266–314; also available at `http://web.ccr.jussieu.fr/varela/human_consciousness/article02.html`.
3. Dainton, B. (2001) *Time and Space*, Chesham, Acumen.
4. Humphrey, N. (1992) *A History of the Mind*, Chatto and Windus, London.
5. Reid, T. (1785/1969) *Essays on the Intellectual Powers of Man,* Part II, Chpt. 17, MIT Press, Cambridge (MA).
6. An account posted at `http://www.erowid.org/chemicals/dxm/dxm_health-1.shtml`.
7. An account posted at `http://www.britannica.com/eb/article?tocId=46665`.

8. An account posted at `http://users.lycaeum.org/~lux/alchem/konunb.htm`.
9. Taken from `http://www.integral-inquiry.com/docs/649/experience.pdf`.
10. Braud, W.G. (1995) An experience of timelessness, *Exceptional Human Experience* **13**, 64–66.
11. Saniga, M. (2005) A geometrical chart of altered temporality (and spatiality), *this volume*.
12. Humphrey, N. (2000) The privatization of sensation, in C. Heyes and L. Huber (eds.), *The Evolution of Cognition*, MIT Press, Cambridge (MA), pp. 241–252; also available online at http://www.humphrey.org.uk/papers/2000Privatization.pdf.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 245–272

A GEOMETRICAL CHART OF ALTERED TEMPORALITY (AND SPATIALITY)

METOD SANIGA
Astronomical Institute, Slovak Academy of Sciences,
SK-05960 Tatranská Lomnica, Slovak Republic
(msaniga@astro.sk)

Abstract: The paper presents, to our knowledge, a first fairly comprehensive and mathematically well-underpinned classification of the psychopathology of time (and space). After reviewing the most illustrative first-person accounts of "anomalous/peculiar" experiences of time (and, to a lesser degree, space) we introduce and describe in detail their algebraic geometrical model. The model features six qualitatively different types of the internal structure of time dimension and four types of that of space. As for time, the most pronounced are the ordinary "past-present-future," "present-only" ("eternal/everlasting now") and "no-present" (time "standing still") patterns. Concerning space, the most elementary are the ordinary, i.e., "here-and-there," mode and the "here-only" one ("omnipresence"). We then show what the admissible combinations of temporal and spatial psycho-patterns are and give a rigorous algebraic geometrical classification of them. The predictive power of the model is illustrated by the phenomenon of psychological time-reversal and the experiential difference between time and space. The paper ends with a brief account of some epistemological/ontological questions stemming from the approach.

Keywords: Mental Space-Times – Pencil of Conics/Lines – Cremona Transformations

1 Introduction

Time — "the supreme law of nature" after Sir Arthur Stanley Eddington, a world-famous astrophysicist of the last century — is undoubtedly one of the deepest mysteries science has ever faced. Indeed, one would hardly find something that is, on the one hand, so intimately connected with our experience and yet, on the other, so difficult to come to grips with. Nothing, perhaps, can better illustrate this point than a large group of phenomena that are collectively referred to as the *psychopathology* of time, that is, all "anomalous/peculiar" experiences of time as invariably encountered and reported in various mental psychoses, drug-induced states, deep meditative and mystical states as well as in many other "altered" states of consciousness [1–7]. For such peculiar fabric of psychological time comprises, as we shall see in more detail, such bizarre, paradoxical and mind-boggling forms as "eternity, everlasting now," "arrested/suspended" time, time "going backward," and even "disordered/fragmented" time, to mention the most pronounced of them.

Up to date, there exists no acceptable psychological/neurological model capable of properly dealing with these fascinating time constructs and underpinning any logical classification of them. The reason why this is so rests, in our opinion, upon the following two facts. First, these extraordinary experiences of time (and, of course, space as well) are inherently participatory, non-reproducible and subjective and, so, seriously at odds with current methodologies/paradigms of science, which strive for reproducibility and objectivity. Second, the most pronounced departures from the "consensus" reality are so foreign to our "waking" mind that their properties defy our common sense logic and cannot be adequately communicated in words; an interested scholar has to go through a large number of relevant first-hand accounts/narratives and acquire the ability to read between the lines in order to spot an(y) underlying conceptual pattern. We are therefore convinced that further progress in our understanding of these phenomena will inevitably entail a serious shift in the corresponding scientific paradigms to reveal their true epistemological/ontological status and be accompanied by the increasing use of sufficiently abstract mathematical concepts to properly grasp their qualitative properties.

Our study of psychopathological (space-)times has, from the very beginning, been pursued in accordance with this strategy [7–9]. The model discussed in the second part of the paper thus features not only a fairly high level of abstraction, but it also poses a serious challenge to some generally accepted dogmas in natural sciences. Formally, it employs advanced geometrical concepts, like a projective space and/or Cremona transformations. Conceptually, it relies on a daring and far-reaching assumption that the anecdotal, first-person descriptions of extraordinary states of consciousness are *on a par with* standard observational/experimental evidence in natural sciences. It is this "abstract geometrization of the first-person perspective" that gives our approach a remarkable unifying and predictive power and makes it a very promising conceptual step towards the ultimate unveiling of the riddle of time. The purpose of the paper is to demonstrate this. The presentation is focussed on conceptual issues rather than mathematical technicalities, the latter being reduced to the extent that also the reader with a comparatively slight mathematical background can easily follow the main line of reasoning.

2 Mental (Space-)Times: Most Illustrative Cases

We shall start with a compact, yet comprehensive enough, review of the most distinguished forms of "anomalous" experience of time. This review is unique in that it consists solely of first-person accounts/narratives, three or four per each mode. This way even the uninitiated reader can get a fairly clear idea about the nature of experiences involved and realize the source and character of possible difficulties one is likely to face when attempting to mathematically model these experiences.

2.1 "Eternity," alias "eternal/everlasting now"

This is perhaps the most pronounced and in the literature best-documented kind of profoundly "distorted" sense of time. It is a sort of compressing, telescoping of past, present and future into the present moment that is experienced as "eternal/everlasting now." One of the best portrayals of what this experience looks like is found in the following account [10, p. 46]:

> I woke up in a whole different world in which the puzzle of the world was solved extremely easily in a form of a different space. I was amazed at the wonder of this different space and this amazement concealed my judgement, this space is totally distinct from the one we all know. It had different dimensions, everything contained everything else. I was this space and this space was me. The outer space was part of this space, I was in the outer space and the outer space was in me...
>
> Anyway, I didn't experience time, time of the outer space and aeons until the second phase of this dream. In the cosmic flow of time you saw worlds coming into existence, blooming like flowers, actually existing and then disappearing. It was an endless game. If you looked back into the past, you saw aeons, if you looked forward into the future there were aeons stretching into the eternity, and this eternity was contained in the point of the present. One was situated in a state of being in which the "will-be" and the "vanishing" were already included, and this "being" was my consciousness. It contained it all. This "being-contained" was presented very vividly in a geometric way in form of circles of different size which again were all part of a unity since all of the circles formed exactly one circle. The biggest circle was part of the smallest one and vice versa...

This narrative is remarkable in a couple of aspects. Not only does the subject try to understand his uncanny experience of time in terms of a simple *geometrical* model, but he also pays particular attention to the spatial fabric of his extraordinary state, which also differs utterly from what is regarded as a normal/ordinary perception of space; in fact, the subject finds himself to be one/fused with space!

Another description of the same kind of mental space-time structure is taken from Atwater [11, Chpt. 2]. It is based on one of many author's near-death experiences, which was also accompanied by a fascinating archetypal imaginery:

> This time, I moved, not my environment, and I moved rapidly.... My speed accelerated until I noticed a wide but thin-edged expanse of bright light ahead, like a "parting" in space or a "lip," with a brightness so brilliant it was beyond light yet I could look upon it without pain or discomfort... The closer I came the larger the parting in space appeared until... I was absorbed by it as if engulfed by a force field... Further movement on my part ceased because of the shock of what happened next. Before me there loomed two gigantic, impossibly huge masses spinning at great speed, looking for all the world like cyclones. One was inverted over the other, forming an hourglass shape, but where the spouts should have touched there was instead incredible rays of power shooting out in all directions... I stared at the spectacle before me in disbelief... As I stared, I came to recognize my former Phyllis self in the midupperleft of the top cyclone. Even though only a speck, I could see my Phyllis clearly, and superimposed over her were all her past lives and all her future lives happening at the same time in the same place as her present life. Everything was happening at once! Around Phyllis was everyone else she had known and around them many others... The same phenomenon was happening to each and all. Past, present, and future were not separated but, instead, interpenetrated like a multiple hologram combined with its own reflection. The only physical movement anyone or anything made was to contract and expand. There was no up or down, right or left, forward or backward. There was only in and out, like breathing, like the universe and all creation were breathing — inhale/exhale, contraction/expansion, in/out, off/on.

The last example, but by no means less astounding than the former two, is borrowed from Braud [12] and depicts in great detail and clarity a gradual transformation of our ordinary, waking sense of time (and space) into that of "eternity" (and "omnipresence"):

I get up and walk to the kitchen, thinking about what a timeless experience would be like. I direct my attention to everything that is happening at the present moment — what is happening here, locally, inside of me and near me, but non-locally as well, at ever increasing distances from me. I am imagining everything that is going on in a slice of the present — throughout the country, the planet, the universe. It's all happening at once.

I begin to collapse time, expanding the slice of the present, filling it with what has occurred in the immediate "past." I call my attention to what I just did and experienced, what led up to this moment, locally, but keep these events within a slowly expanding present moment. The present slice of time slowly enlarges, encompassing, still holding, what has gone just before, locally, but increasingly non-locally as well. By now, I am standing near the kitchen sink. The present moment continues to grow, expand. Now it expands into the "future" as well. Events are gradually piling up in this increasingly larger moment. What began as a thin, moving slice of time, is becoming thicker and thicker, increasingly filled with events from the "present," "past," and "future." The moving window of the present becomes wider and wider, and moves increasingly outwardly in two temporal directions at once. It is as though things are piling up in an ever-widening present.

The "now" is becoming very thick and crowded! "Past" events do not fall away and cease to be; rather, they continue and occupy this ever-widening present. "Future" events already are, and they, too, are filling this increasingly thick and full present moment. The moment continues to grow, expand, fill, until it contains all things, all events. It is so full, so crowded, so thick, that everything begins to blend together. Distinctions blur. Boundaries melt away. Everything becomes increasingly homogeneous, like an infinite expanse of gelatine. My own boundaries dissolve. My individuality melts away. The moment is so full that there no longer are separate things. There is no-thing here. There are no distinctions.

A very strong emotion overtakes me. Tears of wonder-joy fill my eyes. This is a profoundly moving experience. Somehow, I have moved away from the sink and am now several feet away, facing

> in the opposite direction, standing near the dining room table. I am out of time and in an eternal present. In this present is everything and no-thing. I, myself, am no longer here. Images fade away. Words and thoughts fade away. Awareness remains, but it is a different sort of awareness. Since distinctions have vanished, there is nothing to know and no one to do the knowing. "I" am no longer localized, but no longer "conscious" in the usual sense. There is no-thing to be witnessed, and yet there is still a witnesser.
>
> The experience begins to fade. I am "myself" again. I am profoundly moved. I feel awe and great gratitude for this experience with which I have been blessed...

2.2 Time "standing still," alias "arrested/suspended" time

Another well-documented and quite abundant anomalous temporal mode. A couple of examples are found in Tellenbach [13, p. 13]:

> I sure do notice the passing of time but couldn't experience it. I know that tomorrow will be another day again but don't feel it approaching. I can estimate the past in terms of years but I don't have any connection to it anymore. The time standstill is infinite, I live in a constant eternity. I see the clocks turn but for me time does not flow... Everything lies in one line, there are no differences of depth anymore... Everything is like a firm plane...

and [*ibid*, p. 14]

> Everything is very different in my case, time is passing very slowly. Nights last so long, one hour is as long as usually a whole day... Sometimes time had totally stood still, it would have been horrifying. Even space had changed: Everything is so empty and dark, everything is so far away from me...
>
> I don't see space as usual, I see everything as if it were just a background. It all seems to me like a wall, everything is flat. Everything presses down, everything looks away from me and laughs...

Both reports are given by depressive (melancholic) patients. It is worth noticing here that when time comes to a stillstand, perceived space seems to lose one dimension, becoming thus two-dimensional. A slightly more detailed description of this time pattern we succeeded in finding in a paper by Muscatello and Giovanardi Rossi [14, p. 784]:

> Time is standing still for me, I believe. It is perhaps only a few moments that I have been so bad. I look at a clock and I have the impression, if I look at it again, that an enormous period of time has passed, as if hours would have passed instead only a few minutes. It seems to me that a duration of time is enormous. Time does not pass any longer, I look at the clock but its hands are always at the same position, they no longer move, they no longer go on; then I check if the clock came to a halt, I see that it works, but the hands are standing still. I do not think about my past, I remember it but I do not think about it too much. When I am so bad, I never think about my past. Nothing enters my mind, nothing... I did not manage to think about anything. I did not manage to see anything in my future. The present does not exist for me when I am so bad... the past does not exist, the future does not exist.

The following vignette is taken form a treatise on mescaline-induced experimental psychoses by Beringer [15, p. 311]:

> The strangest thing was that every once in a while my normal time-awareness, as far as these figures were concerned, got totally lost; time was no longer a stream, which flew away and whose flux could have been measured, but it was rather similar to a sea, which as a whole stood still and which was in itself only a chaotic and utter jumble. I was no longer able to understand the continuous becoming of the figures as a sequence in a certain time direction, but sometimes the colours and forms flew into an indescribable jumble, as if the previously alternating figures were now experienced all simultaneously. Had I previously seen these figures in a constant motion, so now it was only a colorful and inexpressible manifold there in which I was not able to perceive any motion anymore. When I totally sank into the show of the figures, it happened every now and then that I also sank into this time-still-standing, where the succession was transformed into a still standing present. Not only am I now not able to formulate these interruptions of the normal time experience, I am also almost unable to imagine my experience

> of them any more. When I tore myself away from these figures and violently turned myself to the outer world, this anomalous time experience was no longer here, but this disturbance of the sense of time found its expression in a form of illusion that an immense long time must have passed since my last waking-up.

2.3 Time "going/flowing backward"

This kind of time pathology is very often found in mental psychoses [1,2,5,16–18]. Here is a representative case, communicated by a schizophrenic patient of Fischer [19, p. 556]:

> Yesterday at noon, when the meal was being served, I looked at the clock: why did no one else? But there was something strange about it. For the clock did not help me any more and did not have anything to say to me any more. How was I going to relate to the clock? I felt as if I had been put back, as if something of the past returned, so to speak, toward me, as if I were going on a journey. It was as if at 11:30 a.m. it was 11:00 a.m. again, but not only time repeated itself again, but all that had happened for me during that time as well. In fact, all of this is much too profound for me to express. In the middle of all this something happened which did not seem to belong here. Suddenly, it was not only 11:00 a.m. again, but a time which passed a long time before was there and there inside — have I already told you about a nut in a great, hard shell? It was like that again: in the middle of time I was coming from the past towards myself. It was dreadful. I told myself that perhaps the clock had been set back, the orderlies wanted to play a stupid trick with the clock. I tried to envisage time as usual, but I could not do it; and then came a feeling of horrible expectation that I could be sucked up into the past, or that the past would overcome me and flow over me. It was disquieting that someone could play with time like that, somewhat daemonic...

A brief and concise description of "psycho-time-reversal" is found in Laing [20, p. 148]:

> I got the impression that time was flowing backward; I felt that time proceeded in the opposite direction, I had just this extraordinary sensation, indeed... the most important sensation

> at that moment was, time in the opposite direction.... The perception was so real that I looked at a clock and, I do not know how, I had the impression that the clock confirmed this feeling, although I was not able to discern the motion of its hands....

A similar depiction is also furnished by a depressive patient of Kloos [21, p. 237]:

> As I suddenly broke down I had this feeling inside me that time had completely flown away. After those three weeks in a sick-camp, I had this feeling that the clock hands run idle, that they do not have any hold. This was my sudden feeling. I did not find, so to speak, any hold of a clock and of life anymore, I experienced a dreadful psychological breakdown. I do not know the reason why I especially became conscious of the clock. At the same time, I had this feeling that the clock hands run backward. . . There is only one piece left, so to speak, and that stands still. I could not believe that time really did advance, and that is why I thought that the clock hands did not have any hold and ran idle. . . As I worked and worked again, and worried and did not manage anything, I simply had this feeling that everything around us (including us) goes back. . . In my sickness I simply did not come along and then I had this delusion inside me that time runs backward. . . I did not know what was what anymore, and I always thought that I was losing my mind. I always thought that the clock hands run the wrong way round, that they are without any meaning. I just stood-up in the sick-camp and looked at the clock — and it came to me then at once: well, what is this, time runs the wrong way round?!. . . I saw, of course, that the hands moved forward, but, as I could not believe it, I kept thinking that in reality the clock runs backward. . .

2.4 "Disordered/fragmented" time

The following experience, voluntarily induced by mescaline, is the most representative one we have been able to find in the literature available [22, p. 295]:

> For half an hour nothing happened. Then I began feeling sick; and various nerves and muscles started twitching unpleasantly.

> Then, as this wore off, my body became more or less anaesthetized, and I became "de-personalized," i.e., I felt completely detached from my body and the world...
>
> This experience alone would have fully justified the entire experiment for me..., but at about 1.30 all interest in these visual phenomena was abruptly swept aside when I found that time was behaving even more strangely than color. Though perfectly rational and wide-awake... I was not experiencing events in the normal sequence of time. I was experiencing the events of 3.30 before the events of 3.0; the events of 2.0 after the events of 2.45, and so on. Several events I experienced with an equal degree of reality more than once. I am not suggesting, of course, that the events of 3.30 happened before the events of 3.0, or that any event happened more than once. All I am saying is that I experienced them, not in the familiar sequence of clock time, but in a different, apparently capricious sequence which was outside my control.
>
> By "I" in this context I mean, of course, my disembodied self, and by "experienced" I mean learned by a special kind of awareness which seemed to comprehend yet be different from seeing, hearing, etc.... I count this experience, which occurred when, as I say, I was wide awake and intelligent, sitting in my own armchair at home, as the most astounding and thought-provoking of my life....

And here is another mescaline-borne episode of a very similar time's sense [15, p. 148]:

> While walking upstairs, a sudden and as if nailed-down picture of this moment, the momentary view of Dr. M., Dr. St. and myself in space, attracted my attention. This repeated itself on different stairs. At the top of the stairway there seemed to be no continutity of time at all, the whole course of events was only a mess of separate situations without any connection. And these situations, in case of active work, could later have been connected in the same way in which one can observe a celluloid film. Yet at the same time these situations — in both experiencing and a direct reproduction of the happening afterwards — carried the character of the independent and disconnected. A

> strange next-to-each-other-ness, not a one-after-the-other-ness; they have no position in time, time has no sense here...

From these first-hand accounts it is quite obvious that the fabric of psychological time is so intricate, complex and multifarious that, at first sight, it may seem to lie completely beyond grasp of any mathematical framework. Yet, the contrary is true. In what follows we shall introduce and describe in detail a simple algebraic geometrical model that not only is capable of qualitatively accounting for all the "non-ordinary" time structures mentioned above, but also predicts some novel forms of these.

3 Pencil Dimensions of Time/Space and Their Mental Counterparts

3.1 Time dimension viewed as a pencil of conics and its (mental) patterns

A cornerstone of our model of the perceived time dimension is *conics* and their simplest, i.e., linear and single parametrical, aggregates, usually called *pencils* [23–25]. A conic is an algebraic curve analytically defined by a second order (i.e., quadratic) equation. It is *composite* (singular) or *proper* according as this equation is factorable or not. A hyperbola, a parabola and an ellipse are all familiar (and the only) examples of proper conics (with a non-empty image). A composite conic consists of either a pair of (straight-)lines, which can be distinct or coincident, or of a single point. Two distinct conics lying in the same plane have, in general, four points in common (see Fig. 1, *left*); these, of course, need not be all distinct and/or real. Any two coplanar conics define a unique pencil of conics, viz. the totality of conics that pass through each of the points shared by the two conics (see Fig. 1, *right*); these common points are called *base* points of the pencil. Any pencil of conics in the real plane contains at least one composite conic, and maximum three (not necessarily distinct and/or of the same type). Given a pencil of conics, a point of the plane that is not a base point of the pencil lies on *exactly one* (possibly composite) conic of the pencil, henceforth called the "*on*-conic." The remaining proper conics of the pencil ("off-conics") are found to form two different, infinitely large disjoint families: one family comprises those proper conics which have the point (henceforth the "reference point") in their *in*terior ("*in*-conics"), while the other features those conics which have this reference point in their *ex*terior ("*ex*-conics"). For a given proper conic, a point, not on the conic, is its exterior or interior point depending on whether or not it lies on a line

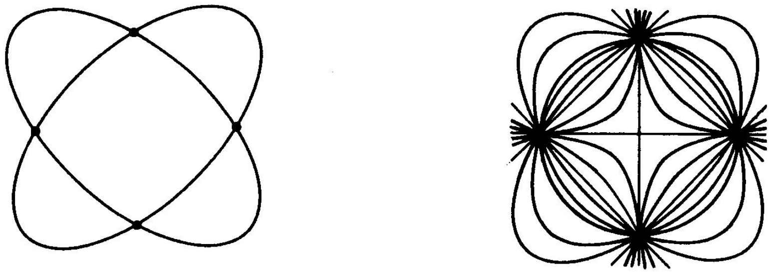


Figure 1. Two distinct conics (ellipses) in the real plane (*left*) define a unique pencil (*right*). This pencil, which is the most general one, features four distinct base points and three distinct composite conics (each being a pair of distinct lines). Out of its infinite number of proper conics only nine are shown: four ellipses, one circle and four hyperbolas.

tangent to the conic (see Fig. 2); the exterior/interior of the conic is thus the set of all its exterior/interior points.

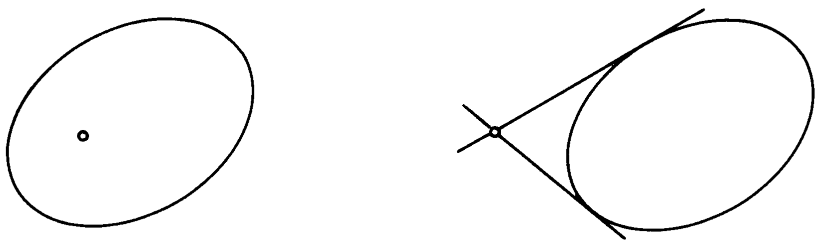


Figure 2. An interior (*left*) and exterior (*right*) point (small circle) of a given proper conic (drawn as an ellipse); the right hand side of the figure also illustrates existence of (two distinct) tangent lines issued from the point to the conic. If the point in question is regarded as the reference point, then the conic on the lef-hand side is an in-conic, whereas that on the right-hand side — an ex-conic.

Why do we pay so much attention, and ascribe so much importance, to this configuration? Simply because in the case when the reference point falls on a *proper* conic this configuration lends itself as an enunciation of our ordinary experience/sense of time (dimension). To spot this correspondence [26] we take the *reference point* as a representation of the *observer/subject* and conceive *each conic* of the pencil as a *single event/moment* of time, with the understanding that the *ex*-conics represent events of the *past*, the *in*-conics stand for events of the *future*, and that the unique *on*-conic answers, naturally, to nothing but the *present* moment, the *"now"* — as depicted in

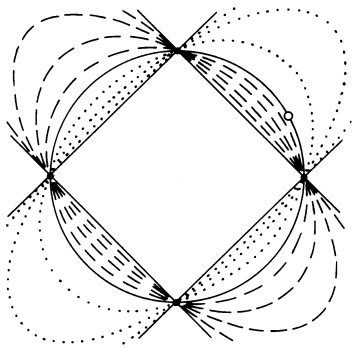


Figure 3. A non-trivial structure within a pencil of conics induced by a generic position of the reference point (small circle) and qualitatively reproducing our common perception of time. The single proper on-conic (solid curve, the present moment) separates the proper off-conics into two distinct domains; the domain of the in-conics (dotted, events of the future) and that of the ex-conics (dashed, events of the past). In both the cases, only a few conics are drawn.

Fig. 3. It is important for the reader to realize at this point a fundamental difference between the conventional, physical concept of time dimension and that of ours. While the former portrays time, loosely speaking, as a line and labels events by points on this line, our theory regards time as a nontrivial geometrical configuration consisting of a given point and an infinite collection of conics, each event being represented by a pair comprising the very point and a conic of the set. In other words, in our model an event/moment of time, rather than being a structureless element/point, possesses itself an *intrinsic* geometrical structure, in virtue of which we are able to introduce a *qualitative* distinction between individual events (or, better, groups thereof). And our next task is to show that this distinction is very sensitive to the position of the reference point with respect to the distinguished objects of the set. And, indeed, apart from the "past-present-future" pattern, our model gives rise to other two prominent, in a sense dual to each other, structures. These correspond, as the reader may have noticed, to the cases where the reference point coincides with a base point of the pencil (Fig. 4b), or falls on one of its composite conics (Fig. 4c). In the former case, clearly, all the proper conics are on-conics, whereas in the latter case the pattern is lacking any such conic, being endowed with ex- and in-conics only. Hence, the corresponding time dimension, in the former case, consists solely of the present moments (the "present-only" mode), whilst, in the latter case, it comprises only the past and future, being devoid

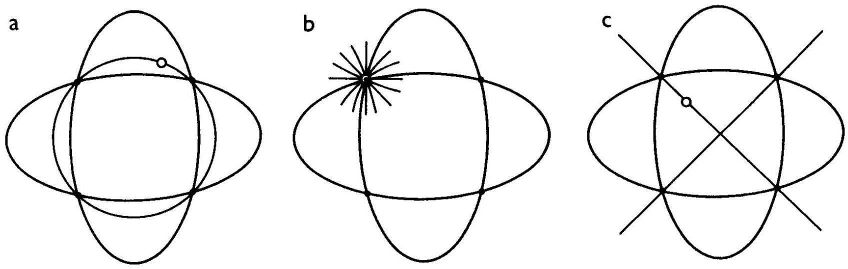


Figure 4. The three qualitatively different patterns of the pencil-borne temporal dimension according as the reference point (a small circle) is (*a*) incident with a proper conic (see Fig. 3), (*b*) coincides with one of the base points, or (*c*) falls on a composite conic of the generating pencil. In the case *b*, out of an infinity of conics incident with the reference point only (the segments of) a few of them are illustrated. The pencil is, as in Fig. 1, of the most general type.

of the proper moment of the present (the "no-present" mode). Let us try to rephrase these two unusual temporal arrangements in terms of pathological temporal constructs listed in the previous section. We readily find out that the *present-only* pattern accounts for nothing but experiences of *"eternity," "everlasting now."* The *no-present* design is seen to be a proper fit for the time *"standing still"* mode; for our feeling that time "flows," "proceeds" is unequivocally tied to the notion of the present moment, the "now," as the linking element between the past and future and so it is only too natural to assume that the absence of this element in the pattern should correspond to a complete suspension/cessation of the (sense of) time's flow.

At this point, it is instructive to make a slight digression and discuss a very interesting feature of our approach that has a serious bearing on the very meaning of the term "pathological" when it comes to the concept of time. This feature tells us about a relative probability of the occurrence of the above-discussed three patterns of time in the realm of psychopathology. This probability should not be understood in a strict sense of the word, but rather in a looser, algebraic geometrical sense. The reasoning goes as follows. The conics of any pencil sweep up the whole plane and as the latter contains ∞^2 (double infinity) of points, there are ∞^2 of potential past-present-future patterns. Next, as our pencil features three composite conics, each of these is a pair of distinct lines, and a line possesses ∞^1 (single infinity) of points, we have $3 \times 2 \times \infty^1 = 6 \times \infty^1 \approx \infty^1$ of no-present modes. And, finally, as our pencil features four base points, there are just four present-only structures. We see a clear predominance of the past-

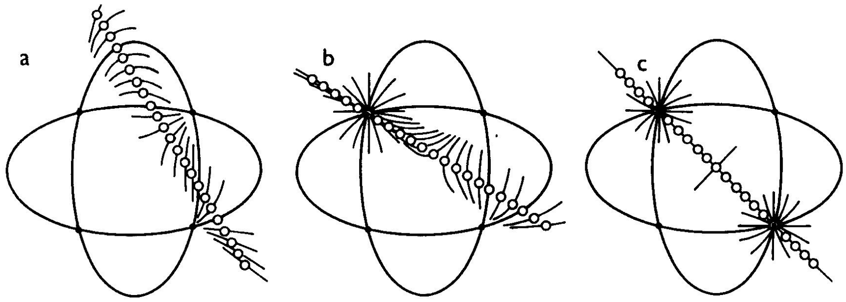


Figure 5. The three distinct types of "line-related" pencil-patterns of time in dependence on whether the reference line is incident with (*a*) zero, (*b*) one, or (*c*) two base points of the pencil. In each case, every illustrated point (a small circle) of the line is accompanied by a drawing of a small portion of the conic incident with this particular point.

present-future mode within the group; no wonder that it corresponds to our "ordinary," "consensus" experience of time. Equivalently, this explains why experiences of "eternity" and/or time "standing still" are regarded/referred to as "anomalous/peculiar;" for the relative probability of their occurrence with respect to our "ordinary" experience of time is truly negligible.

Let us examine next the other conceivable forms of generic pencil-time. We shall assume that instead of a single reference point there is a whole infinity of them, and these are, for simplicity, taken to form a line. What different kinds of time dimension do we find in this case? Remarkably, there are, like in the previous case, three of them. They differ from each other, as depicted in Fig. 5, in the position of this line with respect to the base points of the generating pencil of conics, being in the sequel labelled, respectively, as a zero-, one- and two-point pattern according as the reference line hits no, one or two of the base points. Obviously, these line-related temporal structures can each be regarded as composed of an infinite number of basic, point-related patterns. This composition reads:

type	past-present-future	present-only	no-present
zero-point	infinity	none	six
one-point	infinity	one	three
two-point	none	two	infinity

The numbers in the first two columns are readily discernible from Fig. 5 and the definition of the corresponding elementary modes. It is only the last (no-present) column that requires a word of explanation. Thus, the number in the first line (six) is the number of intersections of the reference line with the composite conics of the pencil; it follows from the facts that our pencil features three composite conics, each of these is a pair of distinct lines, and in a projective plane every line is incident with any other line. The number in the second line (three) answers to the fact that if the reference line passes through a single base point, the latter absorbs three of these six points. Finally, when the reference line joins two base points, it becomes a component of a composite conic, i.e., every point of it lies on the composite conic in question. We further see that, among the composites, only one, the one-point mode (Fig. 5b), features all the three types of elementary patterns, and, similarly, only one, the two-point mode (Fig. 5c), lacks the most familiar of them. On the other hand, there is only one elementary pattern, the no-present one, that enters all the three kinds of composites, and only one, the present-only mode, whose number is always finite. It is very intriguing to see that there is no homogeneous composite.

What are the phenomenological counterparts of these composite temporal patterns? Clearly, each of them must be a mixture/superposition of the time's experiences we have found to correspond to the elementary patterns involved. And these are strange constructs indeed. Thus, the zero-point mode corresponds to such an uncanny state of consciousness where the subject encounters an infinite tangle of "ordinary" experiences of time, differing from each other in the location of the moment of the present and, consequently, in the spans of the regions of past/future, this perception being accompanied by the sense of time "standing still." The one-point case is even more complex, as it includes, on top of the above, also the feeling of "eternity." And these experiences are very much like those of "disordered/fragmented" time given in the previous section! But what about the two-point structure, an intricate blend of the sense of "eternity/everlasting now" and that of time "standing still"? This kind of experience was privately communicated to one of us by Linda Howe [27], an instructor in the "akashic records" technique:

> One common scenario is when the sense of the self is so expanded, beyond any physical boundary.... In this aspect, the awareness of being one with, or a part of, all that is can be profound. The illusion of separation can be perceived as dissolving and, at the same time, the awareness of the oneness, or unity,...becomes heightened, sometimes acutely so... In this the experience of time is dramatic in its expansion and simultaneous contraction. There is a sense that there is only one moment, that all of time/eternity is held in that instant, very compressed and as powerful as one's imagination can conceive.

> Simultaneously, there is a sense that there is no time in the expansion. That all is holding still. Not even slow motion, but no motion. A total suspension of time is experienced. This is the all time/no time paradox.

There remains only one mode to be explained, namely the experience/sense of time "going/flowing backward." To this end, we shall return to our ordinary, past-present-future pattern (Fig. 4a) and examine what happens to this pattern as the reference point starts "moving" away from its original position. This "motion," as delineated in Figs. 6a-c, is assumed to take place in such a way that the point always remains incident with one and the same conic. As it is quite obvious from this figure, the qualitative structure of the original pattern (Fig. 6a) is preserved until the reference point, en route, hits a base point (Fig. 6b), in which case the pattern acquires its present-only type. Further motion of the reference point clearly leads to re-establishment of the original type, but with one remarkable difference – with the in-conics and ex-conics having *swapped* their roles (Fig. 6c)! This means nothing but that the time's arrows generated by the two past-present-future patterns, although *sharing* the same present moment, point in the *opposite* directions! One could hardly find a more elementary explanation of time-reversal.

3.2 Space dimension viewed as a pencil of lines and its (mental) patterns

It is evident that that the concept of a pencil, with conics as its constituting elements, turns out to be an extremely fertile framework for getting a

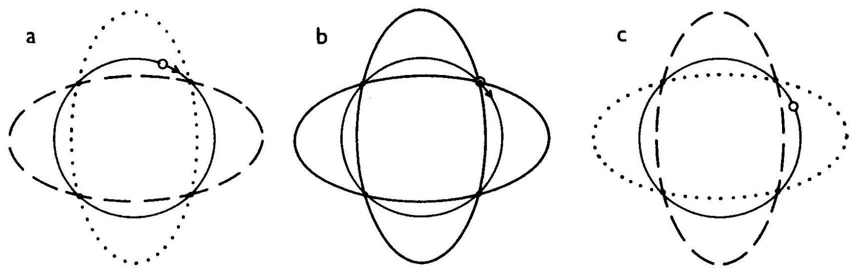


Figure 6. An elementary explanation of the phenomenon of a psychological time-reversal in terms of our pencil-borne model of time dimension. As in Fig. 3, the heavy curve(s) is (are) the on-conic(s), while those drawn as dotted/dashed represent the in-/ex-conics. A little arrow indicates the direction of the motion of the reference point (a small circle).

deeper qualitative insight into the fine structure of psychological time dimension. Motivated by this finding, it is only too natural to address also the structure of psychological space in a similar fashion, i.e., retaining the concept, replacing only its constituting elements. As to our senses, space appears to have a less complex structure than time, and a line is a simpler geometrical object than a proper conic; we shall take a *spatial* dimension to be represented by a pencil of *lines* [8,9,25,26,28]. Our reasoning will parallel that of the previous (sub)section, which will enable us to see how our approach gets to grips with the fundamental difference between time and space at the perceptual level. Two distinct lines in a plane suffice to define a unique pencil, i.e., the set of all lines of the plane that pass through the point shared by the two (the point in question being called the *vertex* of the pencil). As any two lines in a projective plane have always one, and only one, point in common, there exists only one type of a pencil of lines; this is the first fundamental difference from the case of conics. Given a pencil of lines, a point of the plane (the reference point) that is different from the vertex of the pencil is incident with *exactly one* line of the pencil (Fig. 7a); this line will henceforth be called the *on*-line, the remaining lines of the pencil being termed *off*-lines. This particular a-pencil-of-lines-and-a-point configuration qualitatively mimics our "ordinary," "here-and-there" sense of space, with the *on*-line standing for *"here"* and *off*-lines for *"there."* It is a spatial counterpart of the "ordinary," past-present-future pattern of time (Fig. 4a). However, it must be pointed out here that, unlike off-conics, off-lines have all *the same* footing with respect to the reference point; this feature thus serves as a nice explanation why, in our "ordinary" state of consciousness, perceived space has a rather trivial structure when compared to that of perceived time. Another point-related spatial pattern is the one where the reference point is identical with the vertex of the pencil (Fig. 7b); as now all the lines of the pencils are on-lines, we get the "here-only" structure. Being a twin of the "eternity," "everlasting now" mode (Fig. 4b), this structure must necessarily be inherent to those "non-ordinary" states of consciousness that are characterized by feelings of "omnipresence," or "fusion/oneness" with the universe. These here-and-there and here-only modes are obviously the only elementary patterns of pencil-space; for a line is so simple an object that there exist no singular forms of it and, so, there does not exist any spatial analogue of the no-present pattern. And as there are ∞^2 potential here-and-there modes, but just a single here-only one, it is only natural that it is the former that underlies our "consensus" perception of space.

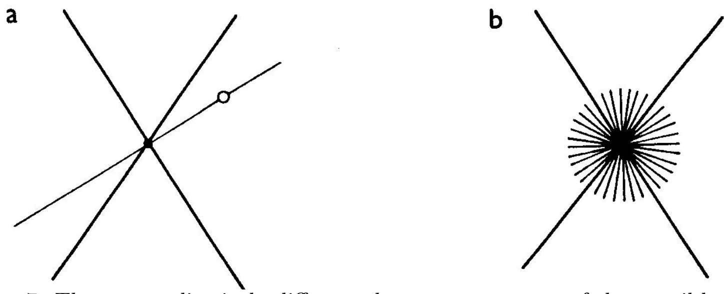


Figure 7. The two qualitatively different elementary patterns of the pencil-borne space dimension depending on whether the reference point is different (*a*) or not (*b*) from the vertex of the generating pencil of lines; in the latter case, out of an infinity of lines passing through the reference point only (the segments of) several of them are shown. Compare with Figures 4*a* and 4*b*, respectively.

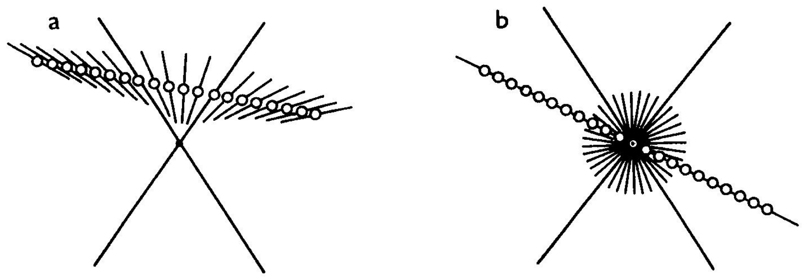


Figure 8. The two composite modes of space pencil-borne dimension, differing from each other in the position of the reference line (illustrated as a range of small circles) with respect to the vertex of the generating pencil of lines. Similarly to Fig. 5, every illustrated reference point goes with a drawing of a small part of the line incident with this particular point.

The cases with the reference line are also structurally simpler than those of time dimension. There are, as the analogy suggests, a couple of them according as the line avoids the vertex (Fig. 8a) or is incident with it (Fig. 8b). As it can easily be recognized from Fig. 8, the former case is a compound of a single infinity of sole here-and-there modes, whereas the latter features a combination of both the elementary modes, with the preponderance of the more familiar of them. Accordingly, a subject experiencing the "avoiding-vertex" mode feels to be localized at every point ("multipresent") along the particular space dimension, while that in a state backed by the "hitting-vertex" mode should feel to be both localized at a particular position of and simultaneously stretched out along the dimension in question.

4 Pencil-Borne Space-Time and the Varieties of its Internal Structure

So far we have treated time and space as two completely unrelated dimensions, which is of course in marked contrast to how the two aspects of reality are perceived to exist. Moreover, we have dealt with a single space dimension only, while our senses tell us that there are (at least) three of them. So we have to refine our model accordingly to comply with these constraints.

To furnish this task, it is necessary to move from the (projective) plane into the (projective) space and — following and extending our recent work [26,28] — consider a specific geometrical configuration comprising *three* distinct, non-coplanar pencils of lines (generating spatial dimensions) and a *single* pencil of conics (time). The planes carrying the pencils of lines are taken to be collinear, i.e., having a line in common, and none of the vertices of the pencils (denoted as B_i, i=1, 2, 3) is assumed to lie on this shared line ($\mathcal{L}^{\mathrm{B}}$). The pencil of conics is, naturally, situated in the plane defined by the three vertices (as these are assumed not to lie on a line), and its base points are these vertices and the point (L) of incidence of the plane and the line $\mathcal{L}^{\mathrm{B}}$, as portrayed in Fig. 9. The reader may get an impression that our option for this configuration is completely arbitrary. This is, however, not the case, for this configuration plays a prominent role in the theory of so-called Cremona transformations between two projective spaces of dimension three.[a] For what follows it suffices that the reader shares our intuitive belief that there is indeed something special to the above-described four-pencil configuration so that Nature found it worth making use of [26,28]. It is evident that this remarkable configuration, as it stands, can represent only a bare space-time, i.e., the space-time devoid of any subject/observer. So, in order to introduce the latter into our model, the configuration has to be endowed with an additional geometrical object. This can, of course, be done in a number of ways, one of the simplest being in terms of a single line (denoted as $\mathcal{L}^*$ in Fig. 9). Armed with this premise and the postulates and findings of the previous section, we are able to find out which kinds of spatial and temporal patterns discussed above are mutually compatible (i.e., can form and "live together" on a single manifold) and thereby arrive at a first fairly comprehensive and mathematically well-underpinned classification of the psychopathology of time and space. It is not hard to see that this task

[a] A proper explanation of what a Cremona transformation is and what kind(s) of distinguished structures it entails would, however, take us too far afield from the main topic of this paper: the interested reader is therefore referred to consult our above-mentioned papers [26,28] and/or a — though for first reading a bit difficult — book by Hudson [29].

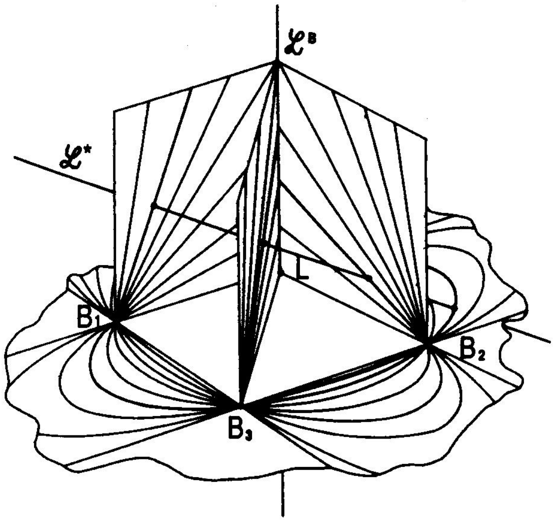


Figure 9. A particular geometrical configuration comprising three pencils of lines and a single pencil of conics, the latter being located in the plane defined by the vertices of the pencils of lines. Out of an infinity of lines, only several are drawn in each of the three pencils; similarly, only a few proper conics (all being ellipses) are shown in the pencil of conics. The symbols are explained in the text.

simply boils down to examining all possible positions of the reference line $\mathcal{L}^*$ within this configuration that lead to qualitatively different arrangements of pencil-patterns induced by the point(s) of intersection of the line with the four pencil-carrying planes.

We shall, of course, start with the case when the reference line is in a generic position with respect to the four planes. As it is obvious from Fig. 9, in this case the line cuts each of these planes in a unique point. As this point is clearly different from any of the three vertices and from the point L as well, it specifies in each of the three planes $\mathrm{B}_i\mathcal{L}^{\mathrm{B}}$ (henceforth simply l-planes) a unique line, and in the $\mathrm{B}_1\mathrm{B}_2\mathrm{B}_3$-plane ($c$-plane) a unique, in general proper, conic (see Fig. 9; the three lines and the conic in question being drawn bold). Each of the three pencils of lines thus generates the here-and-there mode, and the pencil of conics features the past-present-future pattern. So, our *generic* pencil-borne space-time is, as expected, the space-time as perceived in our *ordinary* state of consciousness.

In order to facilitate our subsequent discussion, we shall compactify our notation for different kinds of pencil-borne patterns. For each elementary pattern we shall reserve one letter, uppercase for time and lowercase for

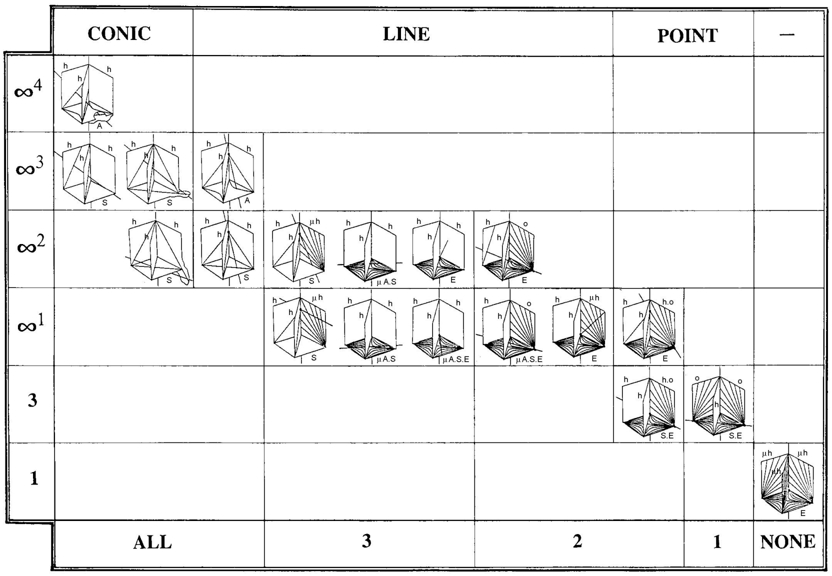


Figure 10. A diagrammatic sketch of an algebraic geometrical classification of pencil-borne space-times. Each subfigure features the reference line, the four "fundamental" planes and, in each of the latter, those fundamental elements that are "picked up" by the reference line; the cases where the reference line is incident with all the fundamental lines of a given *l*-plane and/or with an infinite number of the fundamental conics in the *c*-plane, are illustrated by drawing several lines and/or conics, respectively. The remaining symbols and notation are explained in the text.

space; a composite mode will then bear several letters, corresponding to the elementary modes it consists of. As for time pencil-patterns, we shall adopt the following symbols: "A" for the ordinary, past-present-future mode (the "arrow" of time); "E" for the present-only ("eternity") mode; and "S" for the no-present (time "standing still") mode. The composite modes will then have the following abbreviations: "μA·S" for the zero-point mode; "μA·S·E" for the one-point mode; and "S·E" for the two-point mode, with μ standing for "multi-" and signifying that the number of modes denoted by the letter immediately following this symbol is unlimited/infinite. Concerning space patterns, we shall use "h" for the ordinary, here-and-there mode and "o" for the here-only ("omnipresence") mode. Its composites will accordingly be denoted as "μh" (vertex-avoiding) and "h·o" (vertex-hitting).

So what are possible kinds of our pencil-borne, "Cremonian" psycho-space-times? From an algebraic geometrical point of view, there are altogether 19 different types of them, as depicted in Fig. 10. And they are seen to form a truly remarkable sequence, once being grouped into distinict rows according to their number/abundance (the first column) and into distinct columns according to the number of dimensions of localizability (the lowermost row) and/or the character of the Cremonian image of the reference line in the second projective space (the uppermost row). As easily discernible from the figure, the individual sub-figures differ from each other in the position of the reference line and each of them is accompanied by four of the above-introduced labels/acronyms so that the reader can readily find out the corresponding internal pattern of each spatial dimension and time as well. The number/abundance of a particular type within the structure is, as above, of a geometrical origin. Thus [30], there are ∞^4 (quadruple infinity) of lines in a three dimensional projective space and out of them ∞^3 are incident with a given line, ∞^2 with two different (possibly incident) lines, and ∞^1 pass through a given point and simultaneously lie in a given plane; a line is uniquely defined by two distinct points (their joint) or two different planes (their meet). Non-localizability in a particular dimension means that the reference line does *not* define a unique line in the corresponding l-plane, or a unique conic in the c-plane; this, obviously, happens when the reference line passes through a base point (or the point L), or lies completely in an l-plane/the c-plane. Hence, "o", "μh" and "h·o" are non-local patterns of space dimensions, while "E", "μA·S," "μA·S·E" and "S·E" are those of time; in Fig. 10, the former/latter are illustrated by drawing several lines/conics in the corresponding l-planes/c-plane so that they can readily be recognized.

A number of intriguing facts can be revealed from Fig. 10. First, and perhaps the most crucial fact, is that our consensus space-time (represented by the sub-figure in the top left-hand corner; this sub-figure is a fully equivalent version of Fig. 9) is, as expected, by far the *most* abundant type in the hierarchy, as there are ∞^4 of its potential cases. On the other hand, there is *just one* potential case of space-time where the subject is *completely* non-localized (the sub-figure in the bottom right-hand corner; the reference line is here identical with the line $\mathcal{L}^{\rm B}$). Next, it is fairly obvious that the most numerous patterns are those where the subject is completely localized (the "all" column); as the number of dimensions of non-localizability *in*creases (i.e., as we move in the figure from left to right), the number of potential cases *de*creases (i.e., we move from the top to the bottom of the figure). Further, we notice that if there are at least two dimensions of non-localizability (the last three columns), one of them is always time. Also, for the two non-ordinary elementary patterns of time, the S-mode prevails over the E-mode. The most variegated row is seen to be the ∞^2-one (featuring six different types of space-time patterns and spanning three different levels of non-localizability), the least variegated being the top and bottom ones. It is also worth stressing that out of the spatial modes it is the h-one that occurs most frequently, while amongst the temporal patterns it is the S- and E-modes that enjoy this property. Also, there exists no pencil-borne space-time whose space dimensions would be all of the o- or h·o-type. Interestingly, the least frequently encountered patterns are h·o (space) and S·E (time). Finally, there are pairs of patterns which are incompatible with each other: the o-mode with the μh-one, the S·E-mode with the μh-one and the S-pattern with the o-one.

From the information gathered in Fig. 10 and the findings of the previous section(s) it will represent no difficulty for the reader to infer and analyze the "experiential contents" for each type of space-time. We only add the following note. One of the most distinguished features of a great majority of extraordinary states of consciousness is a seriously altered sense of individuality, ego, or self-hood. In particular, the greater the departure from our consensus reality, the lesser the sense of ego; ultimately, in the most abstract states, the subject feels to completely transcend/surpass his/her sense of ego, and, so, the dichotomy between subject and object. That important feature, too, has a proper place in our model, once we identify the "degree" of the sense of ego with the level of localization of the subject in our pencil-borne space-times. From Fig. 10 we then readily discern that our consensus experience of space-time is characterized by the strongest sense of the self. As we move across the figure from left to right, the sense of ego accompanying the individual types of space-times (or, better, the corresponding states of consciousness) gradually "melts/dissolves," until it completely vanishes in the state represented by the sub-figure located at the very bottom of the figure. Here is a recently found first-person account that describes in great detail not only this transformation of the sense of "I," but also accompanying profound changes in the perception of both time and space, and which dovetails very nicely with the implications of our model [31]:

> For twelve hours I moved in and out of dimensions of both space and time. The incomprehensible became comprehensible. Realities within realities blossomed and faded. From the infinitely

large to the infinitely small, unbounded and unfettered mind flashed across landscapes of incredible depth and beauty.... I was looking into the source of my very being, and without question, my creator. And then I came to realize too that I was at the interface between individual mind and absolute mind.

Entheogens, or in my case psilocybes, provide the pivotal role of interfacing between individual consciousness and universal consciousness. It is the crucial link or conduit that bridge the two at a single point. That point then begins to widen, and both entities slowly merge. As the interface grows, what were initially two now opens into one. It's not just a random happening though, an alignment process between the two takes place. Actually it's more a matter of one aligning itself to the other. This is not a conscious operation, although consciousness is witness to it.... To experience this phase of the psychic event was an absolute revelation with all the glory and beauty imaginable. With my minds eye I was able to see the outline of the interface where the two became the One, where duality merged into unity.... I had the pleasant ability at the center of the interface to merge in and out at will. In one moment I was myself, a separate thinking entity with all my individual thoughts; as I merged out my self-hood ceased to exist; my individuality gone; my thoughts as unique things ceased to be, given way to absolute thought. Time and space played an interesting part in this experience. While in myself time existed, time flowed, there was past and future, but while merged in unity time ceased, there was no past or future. Everything was in a single instant; what Plotinus called the "Eternal Now." In myself space had dimension, there was up and down, limitations existed. Merged in the other, there was no up, no down, no limitation, all was infinite and absolute. This gave rise to another incredible phenomenon; with time suspended and space without boundary omniscience came into full awareness; yes, all things known; no limitations to knowledge.... Omnipotence, and omnipresence also became an awesome recognition, but not related to me personally since the I had ceased to be; they were aspects of that great Oneness that was the universe of consciousness. Merging back into my own ego left me with only a memory of being present to it all....

5 Conclusion

A few weeks before his death, in a letter of condolence to the family of his life-time friend Michele Besso, Albert Einstein wrote [32]: "For us believing physicists the distinction between past, present, and future is only an illusion, even if a stubborn one." We have, however, rigorously demonstrated that this "illusion" and its most pronounced "peculiarities/anomalies" are underlaid by a definite algebraic geometrical pattern. Does it mean that our math is a sort of illusion, too? Or, rather, is it physics that falls short of grasping the true nature of time [33]? To tackle this dilemma, we perhaps need a new conceptual framework for physics [34,35], like, for example, the relational blockworld proposed recently by Stuckey *et al.* [36]. The latter inverts the conventional physics paradigm/hierarchy by taking relations (modelled by matrix variables) to be fundamental to relata (modelled by single-valued variables) and viewing matrix variables as having no counterpart in diachronic/trans-temporal objects, i.e. not having ontological status as "real things." This inverted paradigm is perfectly in the spirit of, and lends support to, our model once we regard individual states of consciousness ("mental space-times") as relations not needing to have counterparts in the "material world," and so in the brain in particular. And this is a truly powerful paradigm shift, supported by a number of extraordinary human experiences, like the following one [37, pp. 26,27]:

> I experience myself as beyond everything, literally everything, ... I am a silent witness, vast and unchanging, beyond time and all space... The recognition, which is a direct perception, is that everything is in me. The body, the universe, essence, personality, everything that can become an object of perception, is not me, but is in me. I am pure awareness, mere witnessing, where everything arises and passes away... I am beyond space and time; both space and time are within me. All of time is a movement within me. Personality, or more accurately, the personal experience or soul, is time. Time is the flux of this personal consciousness. Essence is timelessness. I see time as the movement of the timeless within me. All of time, the time of the body and of all of physical existence, is a small process within me. I am beyond time and timelessness. I am the beyond, beyond all and everything.

Acknowledgements

I am very grateful to Mr. P. Bendík for painstaking drawing of the figures and Dr. R. Komžík for the help with conversion of the latter into postscript form. I would also like to express my cordial thanks to Miss D. Veverková and Mr. P. Hahman for translating into English all the excerpts taken from journals written in German. This work was supported in part by the 2001–2002 NATO/FNRS ARF "Algebraic Geometrical Structure of Spacetime," the 2000–2002 NATO CLG PST.CLG.976850 "Structure of Time and Quantum Computing," the joint 2001–2003 CNR–SAV research project "The Subjective Time and Its Underlying Mathematical Structure" and a 2004 SSHN Physics Fellowship of the French Ministry of Youth, National Education and Research (# 411867G/P392152B).

References

1. Cutting, J., and Silzer, H. (1990) Psychopathology of time in brain disease and schizophrenia, *Behavioural Neurology* **3**, 197–215.
2. Hartocollis, P. (1983) *Time and Timelessness, or the Varieties of Temporal Experience*, International Universities Press, New York.
3. Heimann, H. (1990) Zeistrukturen in der Psychopathologie, in J. Aschoff *et al.* (eds.), *Die Zeit: Dauer und Augenblick*, Piper, München, pp. 59–78.
4. Jaspers, K. (1923) *Allgemeine Psychopathologie*, Springer, Berlin.
5. Melges, E.T. (1982) *Time and the Inner Future: A Temporal Approach to Psychiatric Disorders*, John Wiley and Sons, New York.
6. Minkowski, E. (1933) *Le Temps Vécu — Études Phénoménologiques et Psychopathologiques*, Gauthier, Paris.
7. Saniga, M. (2000) Algebraic geometry: A tool for resolving the enigma of time?, in R. Buccheri, V. Di Gesù, and M. Saniga (eds.), *Studies on the Structure of Time: From Physics to Psycho(patho)logy*, Kluwer Academic/Plenum Publishers, New York, pp. 137–166.
8. Saniga, M. (1998) Unveiling the nature of time: Altered states of consciousness and pencil-generated space-times, *Int. J. Transdisc. Studies* **2**, 8–17.
9. Saniga, M. (1999) Geometry of psycho(patho)logical space-times: A clue to resolving the enigma of time?, *Noetic Journal* **2**, 265–273.
10. Huber, G. (1955) *Akasa, der Mystische Raum*, Origo Verlag, Zürich.
11. Atwater, P.M.H. (1988) *Coming Back to Life. The After-Effects of the Near-Death Experience*, Dodd, Mead and Company, New York.
12. Braud, W.G. (1995) An experience of timelessness, *Exceptional Human Experience* **13**, 64–66.
13. Tellenbach, H. (1956) Die Raumlichkeit der Melancholischen: I. Mitteilung, *Nervenarzt* **27**, 12–18.
14. Muscatello, C.F., and Giovanardi Rossi, P. (1967) Perdita della visione mentale e patologia dell'esperienza temporale, *Giornale di Psichiatria e di Neuropatologia* **95**, 765–788.

15. Beringer, K. (1969) *Der Meskalinrausch, seine Geschichte und Erscheinungsweise*, Springer, Berlin.
16. Israeli, N. (1932) The psychopathology of time, *Psychol. Review* **39**, 486–491.
17. Lehmann, H.E. (1967) Time and psychopathology, *Annals of the New York Academy of Sciences* **138**, 798–821.
18. Schilder, P. (1936) Psychopathology of time, *Journal of Nervous and Mental Disease* **83**, 530–546.
19. Fischer, F. (1929) Zeitstruktur und Schizophrenie, *Zeitschrift für die gesamte Neurologie und Psychiatrie* **121**, 544–574.
20. Laing, R.D. (1968) *La Politica dell'Esperienza*, Feltrinelli, Milano.
21. Kloos, G. (1938) Störungen des Zeiterlebens in der endogenen Depression, *Nervenarzt* **11**, 225–244.
22. Ebin, D. (1961) *The Drug Experience*, Orion Press, New York.
23. Berger, M. (1980) *Geometry II*, Springer, Berlin.
24. Levy, H. (1964) *Projective and Related Geometries*, The Macmillan Company, New York.
25. Saniga, M. (1998) Pencils of conics: A means towards a deeper understanding of the arrow of time?, *Chaos, Solitons and Fractals* **9**, 1071–1086.
26. Saniga, M. (2003) Geometry of time and dimensionality of space, in R. Buccheri, M. Saniga, and W. M. Stuckey (eds.), *The Nature of Time: Geometry, Physics and Perception*, Kluwer Academic Publishers, Dordrecht–Boston–London, pp. 131–143.
27. Howe, L. (1999) Time and space relationships in non-ordinary states of consciousness, *private communication*.
28. Saniga, M. (2001) Cremona transformations and the conundrum of dimensionality and signature of macro-spacetime, *Chaos, Solitons and Fractals* **12**, 2127–2142.
29. Hudson, H.P. (1927) *Cremona Transformations in Plane and Space*, Cambridge University Press, Cambridge (U.K.).
30. Sommerville, D.M.Y. (1951) *Analytical Geometry of Three Dimensions*, Cambridge University Press, Cambridge (U.K.).
31. Anonymous (2003) Mystical mushrooms, an anonymous account posted at `http://www.shroomery.org/index/par/22809`.
32. Dukas, H., and Hoffmann, B. (1972) *Albert Einstein: Creator and Rebel*, Hart-Davis and MacGibbon, London.
33. Elitzur, A.C., and Dolev, S. (2003) Is there more to t? Why time's description in modern physics is still incomplete, in R. Buccheri, M. Saniga, and W. M. Stuckey (eds.), *The Nature of Time: Geometry, Physics and Perception*, Kluwer Academic Publishers, Dordrecht–Boston–London, pp. 297–306.
34. Bouratinos, E. (2005) A new conceptual framework for physics, *this volume*.
35. Elitzur, A.C., and Dolev, S. (2005) Becoming as a bridge between quantum mechanics and relativity, *this volume*.
36. Stuckey, W.M., Silberstein, M.D., and Cifone, M. (2005) Reversing the arrow of explanation in the Relational Blockworld: Why temporal becoming, the dynamical brain and the external world are all "in the mind," *this volume*.
37. Almaas, A.H. (2000) *Luminous Night's Journey*, Shambhala, Boston–London.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 273–289

BECOMING, EVENTS AND THE ONTOLOGY OF PHYSICAL THEORIES

MAURO DORATO
Department of Philosophy, University of Rome 3, Via Ostiense 234
I-00146 Rome, Italy
(dorato@uniroma3.it)

Abstract: In the first part of the paper I present a definition of becoming that overcomes the irrelevant as well as misleading debates between presentists and eternalists. Since my definition essentially requires an ontology of events occurring in temporal succession, I go on showing that not only the theory of relativity, but also quantum mechanics, in its various interpretations, requires such an ontology, despite the limitations in the possibility of representing quantum processes in a spatiotemporal arena.

Keywords: Becoming – Events – The Ontology of Physical Theories

1 Becoming Explained

The non-negligible literature about the compatibility of space-time physics with an objective, mind-independent becoming of the universe has been persistently afflicted by the lack of a precise, universally shared, and clear analysis of the notion of becoming. Despite the confusion, the prevailing idea seems to have been that becoming ought to be connected with *ontological* issues, and in particular with the debate between the so-called "presentists" and "eternalists."[a] As a consequence, for quite some time, and by virtually all the authors engaged in the debate, the *unreality of the future* has been regarded as the main, *necessary* condition for an objective temporal becoming (see [1,2]).

[a]For our purposes, it will suffice to say that the former school defends the view that only present events exist while the latter assumes that past, present and future events are equally real.

Quite significantly, and despite their disagreement on how to interpret the ontology of Minkowski space-time, Putnam [3], Rietdijk [4], Weingard [5], and Stein [6] (just to name a few authors), all shared the view that the mind-independence of becoming involved the ontological status of future events in relation to the present and the past. For instance, Putnam claimed that since as a consequence of the relativity of simultaneity an event that is future with respect to a given inertial frame can be past for another frame, it follows that in Minkowski space-time the future has to be regarded as "real" as the present and the past. In the hypotheses that (i) becoming requires the unreality of future events, and that (ii) the special theory of relativity denies such a requirement, from arguments of Putnam's type one can conclude that becoming is no more than an anthropomorphic illusion. On the other hand, given certain hypotheses, Stein [6] has proven that for any point P of Minkowski space-time, the reality of becoming is equivalent to the claims that as of P, events in the past light cone of P are all definite, while the future light cone of P and the spacelike-related regions contain only events that, as of P, are "indefinite." It is essential to note that, following Nicholas Maxwell [7, p. 24], by "definite" Stein means "ontologically fixed" [6, p. 148], where the key word for my purpose is "ontologically." Once again, if Stein's hypotheses are plausible, and if becoming involves the ontic indefiniteness of future events, Stein's conclusion seems to secure the objectivity of becoming even in space-times in which simultaneity is merely relative and not absolute as it was in Newtonian space-time.

Rather than trying to adjudicate the debate between Putnam and Stein, here I simply want to point out that its fundamental premise rests on a very shaky ground. To put it simply, since it is not at all clear what it means to claim that the future is not real or determinate or definite, it is not clear what it means to deny or endorse the objectivity of becoming, at least to the extent that such a notion is explained in terms of the dispute between those that claim that the future is not real (as presentists together with possibilists or empty-view theorists have it)[b] and those who insist that it is as real as the present and the past (eternalists or block-view theorists).

While for a more thorough attack on the meaningfulness of this I refer the reader to [8], here it will suffice to remark that once we distinguish between a *tensed* and a *tenseless* sense of existence, there is no more room for a genuine disagreement between those who claim that only the present is real — and therefore can conceive, allegedly, that future events can become

[b]Possibilists or empty-view theorists are those philosophers endorsing the reality of past and present events, and denying such a status only to future events.

real in the present — and those that deny that such a becoming can occur, in virtue of the alleged fact that special relativity would enforce upon us the view that future, present and past events are equally real. Suppose that, along with the presentists, I want to claim that the future *is* not real. If the italicized "is" in the previous sentence is tensed, the claim is rather trivial, as it amounts to the assertion that future events are not occurring or existing *now*. Who is going to dispute this platitude? Certainly, the disagreement between presentists and eternalists cannot revolve around this triviality. On the other hand, if the italicized "is" is tenseless, the presentist's claim is false, to the extent that, as it is widely agreed upon, the tenseless existence of any event E just means that "E has existed, exists now, or will exist." How can the future be "tenselessly unreal" if its "tenseless reality" simply entails that some future event *will* occur? Presentists will not want to endorse an apocalyptic view of the world, according to which nothing will occur after the present moment, because the view that the present moment is also and always the last is fortunately refuted by our experience at any instant of time.

Given the importance that becoming has in our experience, if we still want to compare the experiential and physical models of time, namely the model of "endotime" with that of "exotime," this means that the notion of becoming must be defined in a radically different way. For this purpose, I want to put forward the following explication of our commonsensical notion of becoming, where "explication" is used in Carnap's sense.

DEF1: The claim that an event *e* "becomes" in an absolute sense (or "comes into existence") simply means that *e occurs* or *happens*, or *takes place*.

Before bringing to bear the ontology of physical theories, some clarifying remarks are appropriate. Notice that DEF1 — coherently with my critical attitude toward the debate between presentism and eternalism — is independent of questions concerning the ontological status of the future or of the past. Of course, we can have a *tensed* form of becoming, if the event *e* occurs in the present, or a tenseless form, if *e* becomes at some time-place. But nothing important hinges on this distinction, so that also the dispute between the tensed and the tenseless theories of time seems irrelevant to understand the view of becoming that I want to put forward here.

The adjective "absolute" in the definition above refers to the fact that DEF1 abstracts from the spatial and temporal relations that an event *e* bears to other events, so that we could have absolute becoming even in a universe with just one event. Of course, by not taking into account a particular space-time structure, this definition refers to events regarded as very abstract entities. Once we introduce spatio-temporal structure, we have a relational type of becoming, namely the becoming of an event relative to another event or relative to a class of such events.

One last remark about DEF1 is that the verbs "occur," "take place" or "happen," are to be regarded as *primitive*, non analyzable features of events, while events are, intuitively, entities locatable somewhere in space and time, that is, entities that either *have* temporal parts (like a concert, a war, the passage of current in a circuit, the reaching of equilibrium on the part of a gas) or are, as a result of a limiting process, to be regarded as *quasi-instantaneous*. In any case, events are by definition entities which occupy a part of space and time, or, better, space-time. Other philosophers take them just to be identical with more or less extended regions of space-time. Even though I cannot examine this metaphysical question in full here, I will very briefly return to the subtle distinction between events *occupying* space-time *versus* events *being* space-time in the next section.

2 Events in Classical Space-Times

As soon as we have more than one event and we add spatiotemporal structure to the universe, we abandon the rather abstract view of absolute becoming and have temporal and spatial becoming:

DEF2: The temporal becoming of a set of temporally separated (time-like related) events consists in the fact that such events occur successively, or at different instants of time.

DEF3: The spatial becoming of a set of spatially separated (space-like-related) events consists in the fact that such events occur at different locations in space.

Of course, the various constraints on spatial or temporal becoming are going to depend on the kind of space-time theory we are dealing with. In Newtonian space-time, thanks to an *absolute* relation of simultaneity, we can have spatial becoming, given by the simultaneous occurrence of a class of equivalence of events; all such events are linked by the equivalence relation "x occurs at the same time as y." In general relativity, if stable causality is available [9, p. 198], we can always introduce a cosmic time function, which can play a role that is, in some sense, similar to a Newtonian surface of simultaneity. However, in Minkowski space-time, one can have invariant temporal becoming only along worldlines, so that spatial becoming is banned. The possibility of having spatial becoming in Minkowski spacetime is going to depend, somewhat arbitrarily, on a conventional choice of an inertial reference frame adapted to some body from which one describes the evolution of the physical phenomena one wants to represent.

Since the most general model for becoming I will adopt is that typically used by classical general relativity — a manifold on which a Lorentzian metric is defined — one could raise questions about the legitimacy of introducing an ontology of events to interpret that space-time model. Here I will simply assume that the physical world is just a collection of physical events *instantiating* a certain spatio-temporal structure. What this structure is depends on the type of events we want to describe (electromagnetic, gravitational, quantum-mechanical, *etc*). In other words, in order to describe a local physical field exemplifying a certain spatiotemporal structure, I will just presuppose as much structure as is needed by the phenomena we need to describe (tangent spaces, affine connections, fiber bundles, *etc*). Without entering into complicated debates about substantivalism in space-time theories, I will also assume that physical events are not simply *denoted* by points of the bare manifold (where "bare" means manifold without the metric field): the differentiable and topological structure of the manifold *would not suffice to identify physical events.* The physical events I take to be existing are those which exemplify a given metric structure, or those belonging to a region of matter which enters Einstein's field equation by influencing the curvature of space-time. Finally, my events need not be point-like or unextended: even though in physics textbooks one always treats physical events as ideally temporally and spatially non-extended (the flashing of light), the protagonists of becoming can also be finite, non infinitesimally extended regions of space-time.

Are physical events to be distinguished from space-time or are they simply identical with spatiotemporal regions on which some physical field is defined? This question raises (i) the important problem of the possibility of becoming in an empty space-time, and (ii) calls into play the metaphysical problem of the identity of events: are we to identify events by their causes and effects, or by the region they occupy in space-time? Since I want to leave such metaphysical questions in the background, I can dismiss the kind of questions raised by (ii). As to (i), I am content to note that in the general theory of relativity, and possibly in any field theory, the age-old distinction between container (space and time) and contained (matter or atoms moving in the void)is ill-posed [10]. It is unclear whether the metric field, which encodes the causal as well as the spatio-temporal properties of the manifold of events, should be regarded as playing the role of the old empty, substantival space-time of the debate between Leibniz and Clarke, or should rather be considered a physical field as any other. Since the most plausible position to hold is that the metric field is neither empty space-time nor a physical field as any other [11], the question with which I opened this paragraph is not so worrisome for my project. Not only is a region of space-time with no matter carrying anyway gravitational energy, but also the void in quantum field theory is full of quite interesting events.

In a word, if we can admit the occurrence of events in a certain space-time theory T, then we can talk about events becoming in the world described by T. Put it differently, the claim that, in the physical world as it is described by T, temporal becoming is real just means that events (or a class thereof, depending on the space-time we are considering) *occur in temporal succession* independently of human minds. Furthermore, it would seem that we have the legitimacy of such a talk, so to speak, for free, or *a priori*, since the ontology of any space-time theory presupposes the occurrence of physical events, and the purpose of putting forward a certain spatio-temporal theory is advancing some conjecture as to which kind of structure the set of physical events exemplify or instantiate. As long as a temporal separation between events is introduced, that is, as long as events are not all simultaneous with each other, we have temporal becoming.

This way of putting my claim could raise some doubts with respect to the legitimacy of attributing *becoming* to events that, after all, *are* eternally located in space-time, where "eternally" stresses the fact that the spatio-temporal relationships between such events are unchangeable. Suppose that E is in the past light cone of F. In this case, it is always true to assert that "E is earlier than F," if it is ever true to assert it. However, relative to the temporal perspective of F, E is already objectively past, and relative to E, F is future: when one event is occurring, the other either still hasn't occurred or has already occurred. And this is all we need to make sense of our experience of temporal succession and nothing in space-time theories is going to take away this simple fact from us.

Another objection to my demystifying viewpoint is as follows: aren't events in the block-view of the universe "all given"? Aren't all of them "there"? The answer to these questions is quite simple. We can represent the events in spatio-temporal diagram as being all given, with time as a spatial dimension, but we shouldn't confuse the map with the territory. The block view is simply a picture, because events in time do not coexist as events in space, since they *occur* one *after* the other. There is a sense in which events coexist, of course, which we could call "tenseless coexistence," but this sense is quite innocuous, as it amount to saying that *tenselessly coexisting* events are in the same space-time, given that there is a well-defined temporal separation between them.

These platitudes serve to remind us that the *being* of an event just amounts to its *happening*, so that the meaning of the word event somehow contains in itself the germs for a reconciliation between a parmenideian philosophy of being and an heracliteian philosophy of passage, depending on whether we insist on the static "being located" of the event or on its dynamical "occurring." The crucial point is that being and occurring for an event are one and the same thing:

> Taking place is not a formality to which an event incidentally submits — *it is the event's very being*. World history consists of actual concrete happenings in a temporal sequence [12, p. 106; italics added].

It does not make sense to assume a world in which events only appear to happen but really don't, and it is in this sense that events become *a priori*. As in the case examined before concerning presentism and eternalism, we find good reasons to overcome a sterile metaphysical opposition, and take, at least for the theses in question, a decidedly irenic and pragmatic stance.

3 The Ontology of Events in the Interpretations of Quantum Mechanics

If becoming in spatiotemporal theories is as natural as it is presupposing timelike-related events in space-time models, the status of becoming might appear much more questionable in quantum theory, since the ontological implications of this theory are simply "up for grabs." Since there is no agreement as to how the formalism of non-relativistic quantum mechanics should be interpreted, there is also no agreement as to what role, if any, events should play in the theory. And if this is the case, the whole project of defining physical becoming as the coming into being or occurring of events is jeopardized. If DEF1 above could not account for quantum mechanical phenomena, my definition of becoming could not yield the physical counterpart for our subjective experience of the passage of time. It therefore behooves me to try to clarify the difficulties that an event ontology must face in the case of non-relativistic quantum theory. In this context, I will avoid to mention the relativistic extension, since none of the interpretive problems of quantum mechanics can be solved by going to quantum field theory. My discussion will try to sketch the different ways in which an event ontology might be presupposed in the various interpretations of quantum mechanics.

Let me begin to note that since any interpretation of quantum mechanics is going to need *well-defined measurement results*— as something that is obtained via an amplification of the properties of micro-phenomena due to an appropriate, classically describable, experimental apparatuses — there can be little disagreement over the fact that *the result of any measurement process is an event taking place in space and time.* Consequently, in order to be able to provide an empirical, experimental justification to any interpretation of quantum theory, we must once again presuppose an ontology of events. As Rudolf Haag put it:

> The measurement of the position of an object, however, means an interaction with another object, thus an event. The attribute of position in space and time refers to events, not to objects... while an individual event is considered as a real fact, the correlations between events due to quantum mechanical entanglement imply that an individual object [say, an atom] can be regarded as real only insofar as it carries a a causal link between two events [13, pp. 56–57].

As an example of an individual event, one can think of the interaction between a light quantum and an individual atom (an instance of an interaction between two individual quantum systems) or of measurement interactions between a classically described apparatus and a micro-system.

If this, I take it, is uncontroversial across the various interpretations, the main problem is rather that the experimental readings are in fact only the final stage of an interaction between a measurement apparatus and a microscopic system which we cannot still describe in full by a precise and agreed-upon quantum mechanical language. The question we must now face is, therefore, whether, and to what extent, we can assume an ontology of events *before* any measurement takes place. With this respect, in quantum mechanics there are two well-known and related obstacles to the claim that the basic ontology of quantum theories involves spatio-temporally extended stuff (like events typically are):

(i) Heisenberg's uncertainty principle, as, for instance, it has been codified in Bohr's Complementarity Principle and
(ii) quantum non-locality.

The first question involves the possibility of giving a complete spatio-temporal description of quantum phenomena, *i.e.*, a description of the positions of particles at different times. The impossibility of simultaneously and precisely measuring position and momentum (Heisenberg's indetermination principle) makes any description of the spatio-temporal evolution of a physical system possible only at the expense of the possibility of applying the conservation principles, involving magnitudes like momentum and energy (This is the essence of Bohr's Complementarity Principle). The second question, non-locality, involves the fact that spatial separation is not a sufficient criterion for a complete physical independence of two systems: as is well-known, the probability of getting certain measurement results in a wing of a Bell-type experiment depends on the result obtained in the other wing of the experiment [14]. The two "twin particles" emitted in a singlet state are holistically and non-locally related by the quantum correlations, a fact which may created difficulties for finding a precise criterion for the identification of events: are the measurement results *two* distinct events, given that they are spatially separated, or is the measurement process just *one* event, even if its parts are very distant from each other?

Non-locality is an experimental fact, and despite the difficulties it poses to our understanding of space and time, I think that from the perspective of this paper the former obstacle is more serious than the second, since it basically depends on *the indivisibility of the quantum of action*, a solid experimental, phenomenological fact, which so far has not been explained by a universally accepted, deeper, sub-quantum theory (see Bohm and Hiley's lucid treatment of this point [15]). Already Bohr, in putting forward his 1913's model, understood that the process of absorption of an indivisible light quanta by an atom was not describable in space-time. The main reason for this limitation was the conflict between the continuity of any spatio-temporal description on the one hand, and the discontinuity implied by the indivisibility of the quantum of action on the other. More specifically, when we associate a certain energy level to an electron's orbit and the electron jumps to a different energetic level by interacting with a photon, it does not go through all the intermediate values of the energy, since there are none. This means that this process cannot be represented in space-time with a visualizable model in which the distance from the nucleus represents the energy level. The indivisibility of the quantum of action also explains why events — that is, interactions of a measuring apparatus with a quantum microsystem and interactions of any kind between two microsystems — form an indivisible whole too.

3.1 Events in Bohr's interpretation of quantum mechanics

Likewise, the wave-particle duality, at least in Bohr's interpretation of quantum mechanics, implied that a microsystem is both a particle, and is therefore potentially well localizable in space-time as a result of certain experiments we decide to perform on it, *and* a wave, whose properties, however, can be revealed only thanks to *a different experiment*, an experiment which, however, prevents the possibility of a precise spatio-temporal description of the system in terms of its trajectory. In different words, this is the complementarity between the spatio-temporal description of phenomena and their causal description, as implied by the conservation of momentum or energy. Clearly in classical terms, events are in space-time time *and* are often identified via their causes and effects. In quantum mechanics, however, this dual aspect of events, namely their spatio-temporal and causal features, are both present in microsystems, but are somehow present only as aristotelian *potentiae* [15]. As David Bohm put it [16, p. 157]:

> ...instead of regarding space-time and causal aspects as existing in simultaneously well-defined forms, we now regard them as opposing potentialities, either of which can be realized in a more precisely defined form in interaction with an appropriate system...matter should be regarded as having potentialities for developing either comparatively well-defined causal relationships between poorly defined events or comparatively poorly defined causal relationships between comparatively well-defined events, but not both together.

The non-separability between the revealed properties of the microsystem (the revealed events) and the classically described macroscopical experimental apparatus, stressed by Bohr, is in fact a consequence of the potential, non intrinsic, relational nature of the properties of microentities. Such a potential nature, in its turn, depends, or is connected with, the indivisibility of the quantum of action, which, in any interaction between microsystems or microsystems and apparatus is *shared* by both: any microsystem is inseparably linked to the macroscopic system with which it couples. In conclusion, in the Copenhagen interpretation, it is this potential nature of micro-entities that makes it hard to find an event ontology that is independent of the kind of interactions that micro-entities go through. Clearly, while a dispositional or purely potential property like "flammability" or "fragility" inheres to the match or to the piece of glass, the quantum dispositional properties in question are highly relational, or context dependent. Analogously to classical disposition, however, they cannot be understood as something "occurring" like events, since it is only their manifestation that is an event. In a word, the difficulty of describing quantum mechanics as a theory that requires events also before measurement is linked to the potential and relational nature of most of the properties of micro-entities. *Dispositional properties, in fact, are not events, since only their manifestation are.*

3.2 Events in Bohm's interpretation of quantum mechanics

It is interesting to note how things can radically change in quantum mechanics by replacing an "r" with an "m", that is by going from Boh**r** to Boh**m**. In Bohmian mechanics, an ontology of events is made possible by the fact that the basic equations describe the evolution of a bunch of particles always possessing well-defined trajectories. If we write the wave equation of a single particle in polar form

$$\psi = R \exp(i\, S/\hbar), \tag{1}$$

insert this equation into the Schrödinger's equation

$$i\hbar \frac{\partial \psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2 \psi + V\psi, \tag{2}$$

and then separate the real part from the imaginary part, we obtain two equations:

$$\frac{\partial S}{\partial t} + \frac{(\nabla S)^2}{2m} + V - \frac{\hbar^2}{2m}\frac{\nabla^2 R}{R} = 0, \tag{3}$$

$$\frac{\partial R^2}{\partial t} + \nabla . \left(R^2 \frac{\nabla S}{m} \right) = 0. \tag{4}$$

By setting the velocity of the particle

$$v = \frac{\nabla S}{m} \tag{5}$$

we see that at any instant of time the particle has a well-defined position and velocity, and is subject to a classical force $-\nabla V$ and to a quantum force, given by $-\nabla Q$, where Q is a quantum potential given by

$$Q = -\frac{\hbar^2}{2m}\frac{\nabla^2 R}{R}, \tag{6}$$

which is the last term in Eq. (3).

Bohm's interpretation can be given in terms of a quantum potential, as, for simplicity, it has been done above for just one particle, or it can be expressed in terms of a velocity field dQ_k/dt, where $Q = Q(Q_1, ..., Q_N)$ is the function specifying the position of the N particles constituting the system. The velocity field guiding the k-th particle depends (non-locally) on the position of all the others:

$$dQ_k/dt = (\hbar/m_k)\frac{Im[\psi * \nabla_k/\psi]}{\psi * \psi}(Q_1, ..., Q_N). \qquad (7)$$

What is most important for our purpose is the fact that, in both of its versions, *Bohmian mechanics presupposes an ontology of events*, existing before and independently of measurement interactions. As it should be expected from what it has been said above, the possibility of representing quantum process in space-time automatically ensures the legitimacy of an ontology of events. In the one-particle case described above, the guiding wave, or the velocity-field, can be represented as being in space-time. However, when we are dealing with a system composed of n particles, the quantum potential of all the particles, or the total velocity field, lives in a $6n$–dimensional configuration space and *not* in space-time. And certainly, *there are no events in a 6n-dimensional configuration space*: what we should say is rather that one point in such a space represents a collection of events occurring at a certain moment of time, and that a curve in configuration space represents the spatio-temporal evolution of a system composed of n particles. However, the fact that events live in ordinary, four-dimensional space-time does create some trouble for the possibility of assigning an ontology of events even to the Bohmian interpretation.

If we assumed, along with David Albert [16], that the ordinary, four-dimensional space-time is just an "appearance" deriving from the interaction of a 6n-dimensional reality with the sensory systems of human beings, we would assign also to four-dimensional events the status of an appearance. Says Albert:

> ...the space we live in, the space in which any realistic understanding of quantum mechanics is necessarily going to depict the history of the world *as playing itself out...* is configuration space. And whatever impression we have to the contrary (whatever impression we have, say, of living in a three-dimensional space, or in a four-dimensional space-time) is somehow flatly illusory [16, p. 277].

I think that we should reject Albert's suggestion, and claim that configuration space is a mere mathematical instrument. And we could then point out that *each* particle can be represented as "guided" by its own velocity field or potential, defined in a three dimensional space at a certain time. The joint system formed by the n fields and the n particles, taken separately, could then be represented as a collection of individual events in space-time, even though the correct way to represent the motion of the whole system would still be the $6n$ dimensional configuration space. The essential point is this: while we can represent the evolutions of each particle in space-time as a collection of events that take place in succession by using a configuration space, we could not attribute an ontology of events directly to configuration space. However, we can and should interpret the changes in the shape of the wave function of the n-particles system as a collection of events becoming in time.

The other possibility we have to endorse an ontology of events in space-time within a Bohmian view of quantum mechanics, is to view the position of the particles of the system as being always well-defined and then consider the particles as acting on one another at a distance. In this case, there is no need of postulating a mediating or guiding field, or a quantum potential of the kind defined in (6).

3.3 Events in theories of dynamical reduction (GRW)

In the so-called GRW theories (from the acronym of their main inventors, Gian Carlo Ghirardi, Alberto Rimini and Tullio Weber), the definite, macroscopic world of our experience, threatened to be in a nebulous state by the universal validity of the principle of superposition, is obtained via a modification of the linearity of Schrödinger's equation. In GRW's original model [17], on which we will focus, the wave function of a system is multiplied by a localization function, which physically represents a spontaneous localization in a "limited" region of space of a previously non-localized quantum system.

In the attempt to unify the dynamics of microscopic and macroscopic systems, GRW suppose in other words that all quantum systems have an irreducibly probabilistic disposition to localize in a region of space whose dimension is approximately 10^{-5} cm, with a frequency f given by $10^{-16} sec^{-1}$. The probability that such a process occurs is defined as f times a second: this is tantamount to assume that a microscopic system (say, a proton) undergoes a localization process, on average, once every 10^{16} seconds (approximately corresponding to once every hundred million years) and this hypothesis explains why isolated quantum systems can typically remain for a very long time in non-localized or superposed state. However, since a macroscopic system is constituted in average by 10^{23} atomic components, and since in GRW's model the localization of a single particle drives the collapse of all the others, it follows that the components of a macroscopic apparatus that are correlated with the particle that we want to measure will undergo a localization every 10^{-7} seconds. In fact, the average number of particles that will collapse spontaneously in a second is given by $10^{-16}.10^{23} = 10^{7}$, which means that the macroscopic apparatus remains in a state of indefinite position (i.e., in a superposition of two position states) for no more that 10^{-7} seconds.

In spontaneous collapse theories of this kind, the event ontology is constituted by the collection of all localization processes occurring in spacetime, localizations or flashes mathematically described by the peaks of the wave functions. The difference between the dynamical reduction approach and the Copenhagen philosophy is given by the fact that the former describes in an exact and experimentally controllable way the *cut* between the quantum and the classical world (where the exactness is measured by the new constants of nature), while the latter leaves this distinction intentionally ambiguous and experiment-dependent.

3.4 Events in non-collapse interpretations of quantum mechanics

Among the non-collapse views of quantum mechanics heir to Everett's seminal paper [18], here I will focus on Carlo Rovelli's [19], thereby begging forgiveness for having neglected the other authoritative defenders of this view. Rather than assigning an ontological meaning to the wave function, Rovelli's relational interpretation focuses on the sequence of actual measurement outcomes $q_1, q_2, , q_n$, that he also calls *events*. As in Everett's interpretation, who on this point obviously follows Bohr (see Sect. 3.1), such outcomes are to be regarded as the result of correlations of quantum systems with particular "observing physical systems" S, and no absolute meaning is attached to the intrinsic properties of an isolated quantum system Q. A quantum system Q can be said to possess a certain property q only relative to a system S; relative to another observing system (measuring apparatus) *S'*, Q and S may be in an indefinite state, i.e., in a superposition. Relational quantum mechanics is therefore a way of reconciling the universality of application of the principle of quantum superposition with the fact that the observed world is characterized by uniquely determined events. In Rovelli's and Laudisa's words:

> ...there is no meaning in saying that a certain quantum event has happened or that a variable of the system S has taken the value q: rather, there is meaning in saying that the event q has happened or the variable has taken the value q for O, or with respect to O. If I observe an electron at a certain position, I cannot conclude that the electron is there: I can only conclude that the electron as seen by me is there. Quantum events only happen in interactions between systems, and the fact that a quantum event has happened is only true with respect to the systems involved in the interaction. The unique account of the state of the world of the classical theory is thus fractured into a multiplicity of accounts, one for each possible "observing" physical system [20, Sect. 2].

Note that "observing system" in Rovelli's case is deliberately ambiguous between human observers and measurements apparatuses: what matters for our purpose is that the non-collapse views make the existence of event relative to a particular correlation between two physical systems. Characteristically, the non-collapse views follow Bohr in refuting to consider attempts at describing in a more precise way the process leading from a pure, superposed state to the observation of a definite reading on an experimental apparatus. Rather, their approach is merely phenomenological. Historically, this attitude may be compared to that of the energetists, who at the end of the 19th century defended pure phenomenological thermodynamics against the attempts at giving a deeper mechanical description of thermal facts in terms of the behavior of microscopic components (the gas molecules).

Among the non-collapse views I should briefly mention also the many decoherent histories approach, where a history is simply a succession of temporal moments at which some events are assumed to take place. The probability of occurrence of certain events at a certain time, given a certain family of compatible histories, is equivalent to the probability that the system in question has at that time a certain, well-defined property. In order to take quantum interference into account (and therefore to make sure that the probabilities in question add up to 1) we must add the requirement that the family of histories in question be *consistent*. If we consider a particular observable, like the spin $\bar{S}$ of a particle, and we assert that the particle at a certain time has the spin s (s is the eigenvalue), a family of histories is a set of histories assigning to the particle one of its possible eigenvalues at that time, while the particular spin eigenvalue s represents the s-th history in the family. Since, given a particular families of consistent histories, the probability of the Born rule is the probability that a certain sequence of events occur (a given history), *also in this interpretation the notion of event is essential to interpret the formalism of the theory.*

4 Conclusion

Despite the fact that quantum gravity might force one day an abandonment of space-time as a fundamental physical entity, with a consequent relinquishment of the centrality of the notion of event, the current stage of our physical knowledge of the world authorizes us to assume that physics is not only compatible with becoming, but even requires it to the extent that it requires an ontology of spatio-temporally extended stuff as events are. The limitations of quantum theory in fact do not touch the phenomenological level, which involve a correlation between a microsystem and a measurement apparatus, while in certain causal interpretations, like Bohm's, we can assume the existence of events before and independently of any interaction between any two given systems.

Acknowledgements

I would like to thank the audience in Bielefeld for the challenging questions and comments. In particular, I want to mention Harald Atmanspacher for his question about an event ontology in quantum physics and Guido Bacciagaluppi, who gave me the idea of tackling this problem by looking at the various interpretations of quantum mechanics. I also hope to have answered, at least in part, to Olav Laudal's sharp criticism of a part of my presentation.

References

1. Dorato, M. (1995) *Time and Reality*, Clueb, Bologna.
2. Savitt, S. (2001) Being and becoming in modern physics, *Stanford Encyclopedia of Philosophy*, available at `http://plato.stanford.edu/entries/spacetime-bebecome/`.
3. Putnam, H. (1967) Time and physical geometry, *Journal of Philosophy* **64**, 240–247.
4. Rietdijk, C. (1966) A rigorous proof of determinism derived from the special theory of relativity, *Philosophy of Science* **33**, 341–344.

5. Weingard, R. (1972) Relativity and the reality of past and future events, *British Journal for the Philosophy of Science* **23**, 119–121.
6. Stein, H. (1991), On relativity theory and openness of the future, *Philosophy of Science* **58**, 147–167.
7. Maxwell, N. (1985) Are probabilism and special relativity incompatible?, *Philosophy of Science* **52**, 23–43.
8. Dorato, M. (2005), The irrelevance of the presentist/eternalist debate for the ontology of Minkowski spacetime, available as a preprint at `philsci-archive.pitt.edu/archive/00002214/`.
9. Wald, R. (1984) *General Relativity*, University of Chicago Press, Chicago.
10. Rynasiewicz, R. (1996) Absolute versus relational space-time: An outmoded debate?, *Journal of Philosophy* **43**, 279–306.
11. Dorato, M., and Pauri, M. (2005) Holism and structuralism in classical and quantum gravity, in S. French and D. Rickles (eds.), *Structuralism and Quantum Gravity*, Oxford University Press, Oxford, in press; preprint `philsci-archive.pitt.edu/archive/00001606/01/dora-pau.pdf`.
12. Williams, D.C. (1951) The myth of passage, *Journal of Philosophy* **48**, 457–472; reprinted in R. Gale (ed.) (1967) *The Philosophy of Time*, Anchor Books, Doubleday and Company, pp. 98–116.
13. Haag, R. (2004) Quantum theory and the division of the world, *Mind and Matter* **2**, 53–66.
14. Cushing, J.T., and McMullin, E. (eds.) (1989) *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem*, Notre Dame University Press, Notre Dame (IN).
15. Bohm, D., and Hiley, B.J. (1993) *The Undivided Universe. An Ontological Interpretation of Quantum Theory*, Routledge, London.
16. Bohm, D. (1951) *Quantum Theory*, Dover, Mineola (N.Y.).
17. Heisenberg, W. (1958) *Physics and Philosophy: The Revolution in Modern Science*, Harper and Row, New York.
18. Albert, D. (1996) Elementary quantum metaphysics, in J. T. Cushing *et al.* (eds.), *Bohmian Mechanics and Quantum Theory: An Appraisal*, Kluwer Academic Publishers, Dordrecht, pp. 277–284.
19. Ghirardi, G.C., Rimini, A., and Weber, T. (1986) Unified dynamics for microscopic and macroscopic systems, *Physical Review D* **34**, 470–491.
20. Everett, H. (1957) Relative state formulation of quantum mechanics, *Review of Modern Physics* **29**, 454–462.
21. Rovelli, C. (1996) Relational quantum mechanics, *International Journal of Theoretical Physics* **35**, 1637–1678.
22. Rovelli, C., and Laudisa, F. (2002) Relational quantum mechanics, *Stanford Encyclopedia of Philosophy*, `plato.stanford.edu/entries/qm-relational/`.

CHAPTER III:

~QUANTUM~

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 293–316

REVERSING THE ARROW OF EXPLANATION IN THE RELATIONAL BLOCKWORLD: WHY TEMPORAL BECOMING, THE DYNAMICAL BRAIN AND THE EXTERNAL WORLD ARE ALL "IN THE MIND"

MARK STUCKEY[1] and MICHAEL SILBERSTEIN[2,3]
Departments of Physics[1] *and Philosophy,*[2] *Elizabethtown College*
Elizabethtown, PA 17022, U.S.A.
(stuckeym@etown.edu, silbermd@etown.edu)

MICHAEL CIFONE
[3]*Department of Philosophy, University of Maryland*
College Park, MD 20742, U.S.A.
(cifonemc@wam.umd.edu)

Abstract: We introduce the Relational Blockworld (RBW) as a paradigm for deflating the mysteries associated with quantum non-separability/non-locality and the measurement problem. We begin by describing how the relativity of simultaneity implies the blockworld, which has an explanatory potential subsuming both dynamical and relational explanations. It is then shown how the canonical commutation relations fundamental to non-relativistic quantum mechanics follow from the relativity of simultaneity. Therefore, quantum mechanics has at its disposal the full explanatory power of the blockworld. Quantum mechanics exploits this expanded explanatory capability since event distributions among detectors per the density matrix follow from spacetime relations (symmetry group) alone. Thus, the event distributions of non-relativistic quantum mechanics follow from a blockworld wherein spacetime relations are fundamental. Per RBW "quantum mysteries" are deflated and the implications for consciousness and the perception of temporal flow and absolute becoming are explored. We conclude that given RBW, consciousness is no less fundamental than any "physical" feature of the world such as brain states. Further, active consciousness is needed to explain the illusion that it is a dynamical world and consciousness in its most fundamental state is relational and non-local.

Keywords: Quantum Non-locality – Relational Blockworld – Fortuitousness – Consciousness – Absolute Becoming

1 Introduction

The *Relational Blockworld* (RBW) can be understood in two ways: (1) as a framework providing computational and metaphysical structures which can resolve most (if not all) of the tensions between non-relativistic quantum mechanics (QM) and special relativity (SR) and (2) as providing an interpretation of QM that deflates its conceptually problematic features, such as entanglement, non-locality, and quantum measurement. As an item of empirical metaphysics, RBW describes a reality in which the essence of SR (the relativity of simultaneity) and the essence of QM (non-commutivity, non-locality and non-separability) are both true of that reality. As an item of empirical science, RBW provides the computational formalism to model phenomena non-dynamically in an irreducibly relational fashion. The goal of the RBW program is to unify QM and SR in an empirically verifiable, non-dynamical account of reality.

In order to accommodate their essential features, QM and SR cannot both be afforded fundamental status in a unifying theory. Namely, there cannot be both definite classical events constituting a Minkowski manifold and physical observables that are non-commutative, non-separable and non-locally correlated. Per RBW, we can preserve the essence of both SR and QM if spacetime symmetries are considered fundamental, i.e., spatiotemporal relations are fundamental to relata. The conceptual price for this picture of reality — a radical spatiotemporal relationalism and a radically non-dynamical perspective — is dissonance with the way physics typically models reality. However, RBW is empirically compatible with both SR and QM, and affords a "middle way" out of the well-known conflict between them. In providing a spacetime basis for both SR and QM, RBW manages to capture the essential elements of our best spacetime theory and our best theory of matter, but gives up (i) the fundamentality of "trans-temporal objects," (ii) dynamical physical processes, (iii) the substance/property model of phenomena and (iv) time as a fundamental ingredient in physical explanations. Section 2 discusses in more detail how RBW resolves the tensions between QM and SR.

According to RBW, irreducible spatiotemporal relations in a blockworld explain physical phenomena (like the clicks in a measurement instrument, etc.), not transtemporal objects manifesting certain properties and interacting with other transtemporal objects. RBW explains by giving the geometric structure of spacetime symmetry relations — i.e., the global relational dependence of various regions of spacetime with each other. Geometry is fundamental in RBW; all other physical facts are manifestations, if you will, of the geometric structure of spacetime symmetries. RBW radically diverges from the way physics typically models reality, i.e., by presupposing trans-temporal objects, idealized as test particles with mass, under the governance of a class of dynamical laws and kinematical principles.

Consequently, the Hilbert space of QM, while *computationally* essential, is replaced *conceptually* with geometry in RBW. Thus Hilbert-space quantum mechanics, by which we mean the non-commutative structure of observables, entanglement and non-locality represented in the Hilbert space formalism, is *not* fundamental. Rather the *geometry*, uniquely determined by the spacetime symmetries basic to RBW, is fundamental. Not only does RBW advocate the view that spacetime geometry of Minkowski spacetime can satisfactorily explain, and even deflate, the so-called conceptual "mysteries" of QM, but RBW explains how QM *follows from the geometry* of a suitably chosen spacetime symmetry structure [1]. According to RBW the Hilbert space representation of physical observables, and the whole paradigm of state-space physics, are merely calculational tools — they are not metaphysically fundamental. The focus of Section 3 is to show how RBW deflates the various well known quantum mysteries.

In short, the three main tenets of RBW are: (1) the relativity of simultaneity (RoS) implies a BW view of reality, (2) QM is a *consequence of* a spacetime structure which respects RoS, (3) QM is a manifestation of the irreducibly relational symmetries of spacetime, and is not a dynamical theory of matter in motion, i.e., nothing is "quantized;" there are no "particles," "waves," etc., moving/acting in spacetime according to some dynamical equation of motion, such as Schrödinger's equation. The majority of the paper, Section 4, is devoted to drawing out the consequences of RBW for the experience of time, change and the status of consciousness. We conclude that consciousness is as fundamental in RBW as anything else, and that like everything else in RBW, it is fundamentally relational, non-separable and non-local. We also show why fundamental consciousness must be invoked in RBW to explain the persistent illusion of a dynamical world or "moving now." It is the dynamics of consciousness that explains the experience/illusion of a dynamical world and not the other way round.

2 RBW Resolves Tensions Between QM and SR

2.1 The relativity of simultaneity implies BW

The property of simultaneity is defined by a spacetime foliation into spacelike hypersurfaces. A spacelike hypersurface is a plane of simultaneity, i.e., what we refer to as "space" or "the universe" at an instant of time. According to SR, a collection of observers A at rest with respect to one another will foliate spacetime differently than another such collection of observers B in motion with respect to A. Further, there is no reason to grant preferred status to either foliation, so SR implies the *relativity of simultaneity.*

As a consequence of RoS, consider an observer Alice in A passing an observer Bob in B. Except for one another, Alice and Bob will disagree on who exists simultaneously with them at that instant of time (call it "today"); people at rest with respect to Alice will exist simultaneously with her "today," while those at rest with respect to Bob will exist simultaneously with him "today." According to SR, the people in Bob's plane of simultaneity will exist with people in Alice's past and future, and vice-versa. So, Bob and Alice exist together "today" and people in Bob's "today" exist together with people in Alice's "tomorrow" and "yesterday." Likewise, people in Alice's "today" exist together with people in Bob's "tomorrow" and "yesterday." If there is no empirical means of discrimination, then both Alice and Bob are justified in their designations of who exists with them "today," so their pasts and futures are as real as their presents. This interpretative consequence of the RoS is known as the *blockworld.*

Per the blockworld (BW), temporal as well as spatial location must be physically insignificant in some deep sense, and must be a matter of one's perspective rather than a property of the spacetime events themselves. The temporal and spatial locations of an event are unique to one's frame of reference in a more profound manner than implied by the intuitive Galilean coordinate transformations of Newtonian physics. As a consequence, *conscious beings themselves,* as observers in the spacetime of SR, also lack absolute spatiotemporal locations. Conscious observers do not carry an intrinsic "now" that is somehow mixed into the nature of their being to single out points along their worldlines in spacetime. If a "now" continually highlights different points along a particular worldline, then there exists movement with respect to another temporal dimension, i.e., some "meta-time". Meta-time invoked for the purpose of a moving "now" is empirically inconsequential otherwise, so in the interest of parsimony it is ignored by physics. Thus to imbue worldlines with "nowness," without invoking a superfluous meta-time, requires all points on all worldlines be equally endowed, thereby rendering the concept of "nowness" useless.

In summary, RoS says different space-like foliations of the spacetime manifold obtain and no space-like foliation is preferred, i.e., no observer-independent physical features of the spacetime manifold can be used to distinguish one foliation from the infinitely many other possible foliations. BW is the straightforward extrapolation of RoS to the co-reality of the past, future and present for all observers. Thus, the spirit of SR is the relativistic democracy afforded to all foliations of Minkowski spacetime and any theory purporting to be empirically equivalent to SR, while adding a preferred frame, violates this essential spirit and is rejected by BW. In this sense, BW accepts an *unmodified* SR, i.e., one true to the "principle" version of SR developed by Einstein, as opposed to the "constructive" version of SR Lorentz tried to develop before Einstein that presupposed a fixed background Newtonian spacetime along with an "aether" to explain the signature of the spacetime metric [2].

2.2 QM resides in a BW

Perhaps surprisingly, BW is germane to *non-relativistic* quantum mechanics. This follows from the work of Kaiser and Bohr & Ulfbeck who showed *the canonical commutation relations of QM follow from the relativity of simultaneity.* Kaiser writes [3],

> For had we begun with Newtonian spacetime, we would have the Galilean group instead of [the restricted Poincaré group]. Since Galilean boosts commute with spatial translations (time being absolute), the brackets between the corresponding generators vanish, hence no canonical commutation relations (CCR)! In the [$c \to \infty$ limit of the Poincaré algebra], *the CCR are a remnant of relativistic invariance where, due to the nonabsolute nature of simultaneity, spatial translations do not commute with pure Lorentz transformations.*

Bohr & Ulfbeck [4] realized that the "Galilean transformation in the weakly relativistic regime" is needed to construct a position operator for QM, and this transformation "includes the departure from simultaneity, which is part of relativistic invariance." Regarding the commutator of the "weakly relativistic boost" with a spatial translation they note, "The product of the coordinate transformations [a "weakly relativistic" boost and a spatial translation] taken in the opposite order are seen to differ by a time displacement. . . " It is precisely this "time displacement" which is responsible for RoS. They write [4],

> "For ourselves, an important point that had for long been an obstacle, was the realization that the position of a particle, which is a basic element of nonrelativistic quantum mechanics, requires the link between space and time of relativistic invariance."

Thus, the essence of QM — its canonical commutation relations — is the result of RoS and QM may be regarded as residing in a BW akin to that of Minkowski spacetime.

2.3 From a classical to a relational blockworld

QM predicts the existence of physical observables which are non-commutative, non-separable and which can manifest non-local correlations *at arbi-*

trary distances. QM manifestly contradicts our ordinary classical picture of reality, and as such isn't obviously compatible with what might be called the "classical" BW view provided *supra.* RoS is organic to QM as shown in the preceding section, but can BW, as an interpretation of RoS, accommodate QM?

Many philosophers, like Huw Price [5] and Gordon Fleming (with H. Bennett) [6], who are inclined to think about the theoretical problems between SR and QM, have proposed very novel theories which seemingly accommodate QM in a BW setting. Price takes issue with the temporal bias inherent in the common cause principle, which states that correlated experimental outcomes exist because of some common event in their past light cones and never the converse. Price proposes, rather, a *time-symmetric* QM in a BW setting. For Price, the arrow of time can point from past to future or future to past in order to explain the spacetime relationship between a common event in the past light cones of correlated experimental outcomes and those experimental outcomes. Unlike Price, Fleming advocates relativizing quantum mechanical properties like entanglement to hyperplanes of simultaneity in a Minkowski setting rather than trying to devise a time-symmetric interpretation of QM. Thus, at least in principle, Fleming's view preserves the spirit of BW by taking entanglement to be a *relation* between a physical system and some hyperplane and then being *democratic about all the families of hyperplanes* per RoS.

While perhaps only implicit in both Price and Fleming's proposals, spatiotemporal relationalism is made explicit in RBW wherein the salient geometric structure of BW is used to *explain*, rather than merely "house", QM. By doing so, RBW makes full use of the expanded explanatory potential of BW that is obtained via relationalism, and dynamical contrivances aren't required to accommodate QM phenomena. In fact, according to the relationalism of RBW, spatiotemporal relations exist independently of, and fundamental to, relata. This radical relationalism avoids the necessity of invoking classical, pseudo-classical or even quantum mechanically "entangled" entities with their own properties, changing over time, to explain fundamental physical processes. And, while other proposals merely render QM and SR compatible, RBW unifies them in that both emerge from the same basic geometric structure. In these respects, RBW is quite distinct from proposals common in the literature today that try to square QM and SR in a BW setting.

It is this relationalism which distinguishes RBW from BW in a classical setting such as SR, and allows for the explanation of quantum phenomena. In short, a classical BW becomes radically relational to accommodate certain features of QM. But this move is not made *merely* to accommodate quantum phenomena in a relativistic setting — we have quantum field theory for that. Rather, this move is made to deflate the "mysteries" of *non-relativistic* quantum mechanics *while maintaining harmony with SR.* And, the use of spatiotemporal relationalism is *entirely justified* by the formalism of QM.

That is, Bohr, Mottelson & Ulfbeck [7] have shown the density matrix can be obtained via the spatio-temporal symmetries of the experimental configuration (symmetry group) rendering concepts such as the Hamiltonian, mass and Planck's constant *ancillary.* This implies that detector clicks are not caused by impinging particles or collapsing waves that move through or occupy the space between the source(s) and detector(s). Bohr, Mottelson & Ulfbeck write [7], "Indeed, atoms and particles as things are phantasms (things imagined)." Bohr & Ulfbeck [8] call this the *Theory of Genuine Fortuitousness* and write [4],

> "It would appear, however, that the role of symmetry in relation to quantal physics has, so to speak, been turned upside down, and it is the purpose of the present article to show that quantal physics itself emerges when the coordinate transformations (the elements of spacetime symmetry) are recognized as the basic variables."

Now according to BW, as explained *supra*, RoS implies all spacetime events are equally real, whether they be labeled past, present or future relative to some observer. The reality of all events is "hidden" from beings "inside" the block, because they are relegated to a single perspective. The sense in which the totality of facts is hidden from the view of any one perspective in the BW gives rise to a "need," so to speak, for constructing dynamical explanations of, say, quantum phenomena. But in the block, "change" or "time" isn't a fundamental ingredient in the ultimate explanation of reality since nothing changes in a BW. By building upon BW, RBW employs a non-dynamical perspective, and dynamical explanations such as "genuine fortuitousness" are not necessary *at the fundamental level of reality.*

With this result, we have the physical motivation to reject the view that there are objects with intrinsic properties, or that there need be relata standing in the relations at the fundamental level of reality when explaining physical phenomena. Irreducible symmetry relations are all that exist at the fundamental level of reality. Consequently, RBW is radically relational and non-dynamical.

In conclusion, we understand that both the facts of SR and the facts of QM are facts about the same thing — spatiotemporal symmetries understood to be irreducible relations in a BW. This motivates RBW and reveals a deep unity between SR and QM. Consequently, in RBW we do not find a fundamental tension between SR and QM.

3 RBW Deflates "Quantum Mysteries"

RBW is a blockworld in which spatiotemporal relations are fundamental. A blockworld is a spacetime in which the future, past and present are equally real. Thus, presentism does not obtain in a BW and there is no uniquely "evolving universe" or "unfolding now." Every event that will happen or has happened just 'is' in a BW. In this sense, nothing about a BW can change, so the collapse (*qua* dynamical process) of the wave function must be a fundamentally epistemological fact about the state-space formalism *that does not directly capture the ontological facts of a relational blockworld.* That is, the wave-function *qua* state-space representation of QM is a calculational device, whereas the relational spacetime symmetries of an experimental arrangement, that give rise to quantum statistics, is the deeper ontological story of QM. Geometry is fundamental to Hilbert space, to use a slogan. Thus, BW eliminates the measurement problem trivially.

Quantum non-locality and non-separability are likewise handled trivially since RBW assumes spatiotemporal relations are fundamental in a BW. Correlations between space-like separated events that violate Bell's inequalities are of no concern as long as spatiotemporal relations in the experimental apparatus warrant the correlations. There is no need to satisfy the common cause principle, since non-local correlations are not about "particles" impinging on measuring devices. Rather, the non-local correlations derive from the spatiotemporal relations in the construct of the experiment. There are no influences, causal mechanisms, etc., because non-locality is a relational property that is precisely described by the spatial translations, rotations and reflections of any given experimental arrangement. Nothing happens in a relational blockworld, so there is nothing for such inherently dynamical processes and entities to do. One *can* invoke dynamical stories to account for quantum non-locality, but these stories will invariably be "error theories" in the sense that these dynamical stories do not express the deeper facts fundamental to a relational blockworld.

The conceptual trouble with quantum non-locality, quantum non-separability or entanglement is a consequence of our *seemingly* dynamical perspective 'within' a relational blockworld. The trouble is with us, not the world, so to speak. In trying to explain the *spatiotemporal* distribution of detector clicks as caused by or as determined by impinging particles (carrying with them their own properties), the standard account of QM in a spacetime setting assumes a Galilean *background* spacetime in which quantum states evolve. Since simultaneity is (in principle) absolute in Galilean spacetime, dynamical accounts of QM seem natural. If one is worried, though, about the tensions between QM and SR, then not all dynamical explanations will be so "natural." If SR is true and reality is like a blockworld, then quantum non-locality, non-separability, etc. better not violate RoS. Thus, nothing we say about quantum non-locality ought to allow us to send superluminal signals, for example. As well, if reality is like a BW, then nothing happens in the sense that nothing new "comes into being." Pre- and post-measurement facts are "already there" and don't come to be after a measurement "interaction." There is nothing ontologically unique about measurement events — they don't "change" anything. We can't think that a particle, in interaction with a measurement device, brings some fact into existence that wasn't already true. Particles don't "go" anywhere and don't "interact" with anything. Nothing "happens:" the past, present and future are equally real. Non-dynamical explanations must at least respect the reality of all spatiotemporal events.

RBW goes beyond mere non-dynamism when it comes to explaining quantum phenomena: *QM is a manifestation of the geometry of spacetime symmetries where simultaneity is relative.* Thus, RBW *does not assume* that QM is independent of Minkowski spacetime — rather QM is derivative from the (reduced) spacetime symmetries of Minkowski spacetime itself. Quantum facts are facts about the irreducible spatiotemporal relations of a given physical system, not facts about the behavior of particles, or the interactions of measurement devices and wave-functions, etc. There is no "collapse of the wave function" because there are no real quantum states — just "states" (if you will) of the *entire* spacetime configuration of a physical system *fixed at once.* Dynamical talk is simply a crude way of trying to describe global, *static*, spatiotemporal dependency relations between various regions of spacetime in a given experimental situation.

According to RBW, reality is fundamentally relational and non-dynamical, but *representable* dynamically. From the point of view of RBW, then, novel quantum phenomena such as non-separability are conceptually problematic only in the attempt to formulate a dynamical explanation for something that is irreducibly relational and non-dynamical. In fact, *all* phenomena are "non-separable" via the spatiotemporal holism of RBW. All of which has profound implications for the way we think about phenomenal consciousness and the way we explain our experiences of absolute change and temporal becoming.

4 Implications of RBW for the Experience of Time, Change and the Status of Consciousness

Given that in RBW temporal flow and absolute becoming are not external features of the world in their own right, there is no special "Now" moving from past to present, time does not flow or "go by," etc., then we must explain the experience of these things without recourse to these things as actual features of the world. That is, we must provide an explanation for the experience of absolute becoming and temporal flow in a relational blockworld in which presentism is false. What follows is just a short list of the phenomenological features of temporal experience (the various "psychological arrows of time") that must be explained in order to explain our experience of time and change (see Dainton [9] for a more detailed discussion):

1) Why, at any given moment, is our conscious awareness confined to such a small part of spacetime that we dub "the now?"
2) What gives some experiences, by definition those that feel real to us at any given moment, their feeling of presentness? Why do we experience some pains as memories and others as having the property of "nowness" or presentness?
3) Why are feelings of presentness and "realness" so inextricably connected? What explains the feeling that to be real is to be present, after all even memories only feel real when dragged into the present and conscious attention is focused upon them. It seems to be a transcendental truth that what separates real experience from, say, mere memories is "being appeared to presently."
4) What explains the experience that things change and that the experienced present is continually advancing into the future? Why do we feel that our lives unfold in the direction of the future-that time has a direction? For example, we can always tell whether a film is being run forward or backward, why is that? If time started going backwards globally, after a while, no doubt we would again feel that our lives were unfolding into the future.
5) The experience of the "phenomenal flow" of time, we experience time as passing even when there are no detectable changes in our environment.
6) The temporal coherence of our stream of consciousness or succession of

experiences such that each phase seems "phenomenally bonded" to its immediate predecessor and successor.
7) Why do we have detailed knowledge of (or greater epistemic access to) the "past" but not the "future"?
8) Why do we have such an asymmetry regarding attitudes, feelings, explanations and decision making about the "future" if "past" events are equally real? Why, for example, do I fear future pains but not past ones? Why do we generally explain later events (such as dying) with reference to earlier events (such as getting shot) and not the other way around?
9) What explains the phenomenology of the "specious present" — that experience comes in packets of meaningful duration (think of a melody or reading passages) say as opposed to durationless instants or spacetime points?

There are only so many logical possibilities open to us when it comes to explaining (or not) our experience of time and change:

1) Various asymmetries or features of internal mental (or neural) processes.
2) Various asymmetries or features of the external world.
3) Various asymmetries or features of both internal mental processes and the external world.
4) Neither internal mental processes nor the external world has the resources to explain our experience.

Of course there is no reason to believe that all of the preceding psychological arrows of time will be explained in exactly the same way. For example, the experienced asymmetry between past and future or the experience of change might be explained by asymmetries in the external world such as the thermodynamic arrow of time plus memory and the experience that irrespective of change time is always "flowing" might be explained by other mechanisms either in the world and/or in the brain.

That said there are a couple of misnomers here that need to be dispelled in order to make progress. First, that if the blockworld is true and contrary to presentism we do not directly apprehend the "moving now" or global metaphysical present, then we can only appeal to (1) above when it comes to explaining our experience of time and change, and thus explaining the experience of temporal flow and absolute change is much harder given blockworld. Second, that if presentism is true we can appeal to both mental processes and real asymmetries in the external world and therefore our experience of temporal flow and absolute becoming are no great mystery.

These claims are misnomers because (i) many external asymmetries (such as causal patterns) still exist even in a blockworld and can be called on by all to help explain experience, (ii) it is not clear how we would perceive a "moving now" even if it did exist and (iii) explaining the various psychological arrows of time turns out to be quite hard regardless of whether blockworld or presentism is true. As for (i) the following is a non-exhaustive list of external asymmetries that anyone, regardless of whether blockworld or presentism, is true, can appeal to in order to try and explain our experience of time and change (see Dainton [9] for a more detailed discussion):

1) Entropic asymmetry: the second law of thermodynamics states that entropy increases over time.
2) Causal asymmetry: some events are regarded as causes of other events and causes generally precede their effects.
3) Fork asymmetry: we often find later events that are correlated or caused by a single earlier event, for example everyone exposed to radiation gets sick at a later time. The inverse fork is much rarer.

As for (ii) while our perceptions appear to immediately inform us about the order and duration of events, we cannot apply any of the usual models of perception to explain this fact. The problem is that order, duration and other temporal "features" unlike, say, shape and color, are not "objects" or "properties" of perceptual states in any standard sense. To perceive the order and duration of events we have to be aware of the events themselves, whereas with color and shape we can focus on those features to the exclusion of other features of an event or entity. The point is that order, duration, the "moving now," etc., do not appear to be external features of events in the way that shape and color are, and therefore it is hard to explain our experience of them by appeal to the causal theory of perceptual knowledge as we do with say color experiences. Whereas we have identified areas of the brain responsible for perceiving and representing color and shape related physical phenomena, it is not clear that there is any part of the brain devoted to *perceiving and representing* an externally given "moving now." This leads some people to believe that the experience of the "moving now" is a projection of mind or brain rather than a perception, perhaps even a transcendental ground of experience as Kant would have it.

The point of (iii) is that regardless of blockworld or presentism, it is not yet clear to us what external and/or internal features account for our experience of temporal flow and absolute becoming. This much is clear, both blockworld and presentism can (and often do) appeal to many of the same external and internal features in order to explain our experience of time and change, and neither view has produced an answer leading to a scientific consensus — it is still a mystery. While blockworld, unlike presentism, cannot appeal to a special "moving now," the truth of presentism, etc., in order to explain the various psychological arrows of time, it is far from clear what extra explanatory mileage presentism gains from such an appeal. And again, the blockworld can also appeal to such external asymmetries as the causal (light-cone) structure given by Minkowski spacetime, the "radiative" asymmetry, the entropic asymmetry, etc. Blockworld can acknowledge that these and other external features of the world often contribute to the illusion of a "moving now" and absolute becoming. But as we shall see, such external features of the world are at best necessary conditions for our experience of time and change.

Indeed, just as there is an "explanatory gap" (and perhaps an ontological one) between brain processes and "phenomenal consciousness," so there is an explanatory gap between on the one hand time and change as conceived in the physics of blockworld and on the other the *experience* of temporal flow and absolute becoming. In fact the problem of explaining our conscious experience of time and change is in part a subset of the "hard problem of consciousness." Some might even argue that the experience of "nowness" slipping into the future is the very essence of phenomenal consciousness. And as we shall see, the hard problem becomes much harder in a blockworld and it takes on a certain ineluctable shape.

However, that said, even in a world dynamically conceived such as presentism there is a huge disconnect between the "flow" of physical processes (the external "arrows of time") and the subjective experience of temporal becoming. That is, there is no obvious isomorphism between physical processes and temporal experience (though some neuroscientists may hope to find some *in the brain*). In addition to showing us the disconnect on the one hand between time and change as experienced and the various external or physical arrows of time on the other, the following well-known examples also illustrate the necessity of normal brain function in "producing" our ordinary experience of temporal flow and absolute becoming:

The 0.5 second time lag in perception, the experienced present is actually of the recent past as there is a typical time-lag between initial stimulation and experience of 0.5 seconds. Obviously we are not aware of this time-lag. The more complicated an incoming stimulus, the longer it takes the brain to process.

Coherent and complex perceptual experiences involving multiple sensory modalities are formed from sensory stimuli that travel at different speeds, such as the speed of light, sound, smell, etc. Therefore each kind of sensory data that will ultimately form a particular coherent experience for the observer arrives at the brain for processing at different times. Furthermore, all of these different sensory signals are processed in different parts of the brain. The visual stimuli alone such as that pertaining to motion, color, distance, size, and "higher-level" processes such as facial recognition all get processed in different parts of the brain. But we do not, for example, experience the visual elements of an event before the auditory features even though light travels faster than sound. So how is it that people (with normal brains at least) experience perfectly synchronized and coherent events or conscious perceptions? The complete answer to this "binding problem" is unknown, but we do know that it involves the brain constantly "backdating," rearranging or reversing conscious perception in time. The brain backdates conscious perceptions to the time when the stimulus first entered the brain. Consciousness of events are backdated so that awareness seems to arise at the same time as the events actually take place. Part of this is explained by different processing times in the brain, for example, auditory signals are processed more quickly than visual ones.

However a differential in processing times for different stimuli is not the whole story. For example, Libet [10] discovered that if we directly stimulate the appropriate spot on the somatosensory cortex that is connected to the hand and then 150 milliseconds later we stimulate the hand itself, the subject reports the hand stimulus as coming first. This is very puzzling because the "real external" time to process both signals is the same. Somehow the brain flipped the order of events in conscious experience.

Another good example of the constructed nature of time perception is the brain mechanism of saccadic suppression. Why, given how rapid eye movements are, do we not feel motion induced nausea and experience the world as blurred? Part of the answer is saccadic suppression. This is a brain mechanism that interferes with vision during eye movements and blinks. Vision is at least in part shut down when your eye is in transition and thus we suffer neither nausea nor jerky images. The amount of *time* during the day in which vision is shut down is not trivial, "adding up all the little snippets of the running movie that constitutes daily life that are "lost" due to saccadic and blink suppression amounts to a staggering 60 to 90 minutes each day," Koch [11]. Why then do we not experience blank periods in our visual awareness everyday? Most neuroscientists believe that there must be some "trans-saccadic integration" brain mechanism that "fills in these intervals with a "fictive" movie, a composite of the image just before and just after the saccade," Koch [11].

If perception of temporal flow, the order of events, duration and other time-related features of experience are constructed and active projections of cognition, then intersubjective agreement under normal conditions plus individual local "nows" might help create the illusion of a shared "moving now" and absolute becoming "out there" in the external world. Of course there are many external contingencies that contribute to this intersubjective agreement such as the fact that the time scale of perception is short compared to the time scales upon which key features of the macroscopic environment change or vary, individuals are moving relative to one another at velocities small compared to c, the light travel time between individuals in an inertial frame in which they are nearly at rest is small compared to the time scales of perception, etc.

However normal *internal* or cognitive conditions are also necessary for ordinary time perception and they do not always obtain. We now have good evidence that there are one or more "clocks" in the brain. One such brain clock is a loop of dopamine-generated neural activity which flows between the substantia nigra in the base of the brain (where dopamine is produced), the basal ganglia, and the prefrontal cortex. Each "tick" of this clock is the same time it takes for the nerve signals to complete the loop. All neural events that occur within that time are experienced as a single moment. The average tick is about one-tenth of a second, but they do vary considerably. Many external events may occur within a particular cycle or tick of the brain clock, such as the flapping of an insect's wings, but they will be perceived as one event. If two flashes of light are presented to someone with less than a one-tenth of a second gap between them, they will be perceived as one flash only. If the two flashes are far enough apart so as to be in separate cycles or ticks of the brain clock, they will be perceived as such.

As a result of this data and more, some neuroscientists such as Koch [11] now believe that all perception, rather than being continuous, is actually discrete: "perception might well take place in discrete processing epochs, *perceptual moments, frames, or snapshots*. Your subjective life could be a ceaseless sequence of such frames." The suggestion here is that relative to each such snapshot the perception of sensory qualities such as color, depth and even motion would be constant. On this view motion is experienced not because of a change in position between two consecutive snapshots such as happens with film, but because motion is represented within a single snapshot by somehow being suggestive of movement. Imagine for example a still photograph of someone in a running posture. It is hypothesized that if conscious perception does take place in discrete moments that the perception of the *passage of time* might in part be a function of the rate at which snapshots occur. For example, the kind of "protracted duration" or slowing down of the passage of time experienced during accidents might result from more snapshots occurring per unit time and thus the same one-second interval will now be divided into more snapshots than normal resulting in the feeling that time is passing much more slowly. There is a rare alteration in time perception that sometimes happens to people with severe visual migraine dubbed "cinematographic vision" by Oliver Sacks (Koch [11]). When this occurs, time is experienced as discontinuous like a succession of stills with nothing in between in which the illusion of motion has been lost. Koch [11] hypothesizes that in such cases "the migraine may have temporarily inactivated the cortical motion areas," thus providing some first-person evidentiary support for the discrete theory of perception.

There are several well-known examples in which, due to brain damage, illness, trauma, shock, etc., the timing mechanisms in our brain are disrupted and produce radically altered states of consciousness. People with Parkinson's disease, in which the neurotransmitter dopamine is depleted, experience the passage of time differently. If you ask the average person to say "now" after they think a minute has passed, they will do so after about 40 seconds. The person with Parkinson's however will on average say "now" after about 60 seconds has passed. In one well-known case a 66-year old man found that he could not drive or watch TV because the cars and TV images seemed to be on "fast forward" and were zooming by him. When the "minute-test" was applied to him, he didn't say "now" until five minutes had passed. It was later discovered that the man had a growth in his prefrontal cortex. Catatonic patients who recover sometimes report their experience while catatonic as being like "stuck on pause," their memories of that time period suggest that time did not pass for them and there was no change in conscious states, though they were aware. We have all experienced alterations in our experience of temporal flow and duration during fever, accidents, etc.

The normal function of memory and its relationship to perception is also an important condition for our experience of the passage of time. One major reason we "sense" time passing is that our perceptions and memories combine in a particular sort of way over our entire life. At each moment of conscious awareness I have memories of previous moments from a few seconds back to many years back. This contributes significantly to the illusion that time passes, that absolute change occurs and it helps explain why I have the belief that time is really dynamically unfolding. When this memory mechanism is disrupted it causes extreme alterations in perceptions of time. For example, patients with Korsakoff syndrome cannot make new long term memories beyond those they had at the time of their brain damage and whatever enters their short term memory is forgotten in a couple of minutes or less. Such people do not experience time as passing as we do and in some extreme cases they do not believe they are aging until forced to view themselves in a mirror; they are horrified of course, but not for very long as they cannot retain the memory of what they saw. One very extreme example of amnesia is the case of Clive Wearing, "a gifted musician and scholar, he suffered a viral brain infection that almost killed him and destroyed parts of both temporal lobes. Clive consciously experiences *only* the present. He has no childhood, no past," (Koch [11]). Having different memories at different stages in our lives helps explain the illusion that times passes. The right kind of patterns of memory accumulation is an important part of the story about our sense that time passes.

Regardless of whether asymmetries of both internal mental processes and the external world are necessary to explain the illusion that time passes, there is no denying that our experience of the world and our introspective processes reveal a universe that has very ordered and unique patterns of organization that bespeak of unfolding dynamical processes along the temporal axis. After all, there would be no past, present and future at all if spacetime did not have timelike directions. There would be no approximate intersubjective "now" if we did not exist on timelike worldlines, but rather existed on spacelike worldlines. Of course the internal and external asymmetries are not completely orthogonal. No doubt there are features of the very same laws of physics that give rise to the external asymmetries that are also necessary for the very existence and functioning of the brain-mind.

The point is this, the distribution of events as experienced by us over the course of our lives and the various asymmetrical patterns in the world as seen from our perspective could all exist even in a blockworld. We have seen that even holding all external features of the world constant, people's temporal experience can be radically altered. We have seen that our experience of temporal flow and change is largely a cognitive construction, all of which raises doubts that anything like real dynamical processes in the external world are either necessary or sufficient to explain our experiences.

We have every reason to doubt that our experiences of time's passage and change are best explained by an objective global metaphysical property such as a "moving now."

So far so good, most of this is well-know to advocates of blockworld and most, therefore, are not too concerned by the argument from temporal experience against the static worldview. However there is a rub that no "blockworlder" that we are aware of has ever considered. We have learned that in order to explain our experience of time and change we are going to have to, at least in part, appeal to conscious brain processes whether it is a blockworld or not. Natural science such as cognitive neuroscience wants to explain *the very existence* of phenomenal conscious experience (such as the experience of a special "moving now"), by appealing to *dynamical* brain processes. This is evident just from the brain mechanisms alluded to in this paper, such as the mechanism of "temporal binding" that makes coherent experience possible, the brain's clock that produces the discrete frames of perception, the "processing time" of all sensory modalities, the saccadic suppression mechanism, etc. All these mechanisms and all the models of brain mechanisms in general are essentially dynamical in nature. In neuroscience, in every case such as cognition, perception, memory, etc., the attempted explanation of these functions appeals to the dynamics of cell assemblies, neuronal firing rates, etc. Explanation of specific conscious states and specific cognitive functions in cognitive neuroscience is always in terms of "underlying causal mechanisms" in the brain or the "neural correlate of consciousness or cognition," both of which are inherently diachronic and dynamic conceptions of explanation. Thus, the fundamental working assumption of cognitive neuroscience and much of philosophy of mind is that matter in general and brain processes in particular are more fundamental than consciousness, both ontologically and explanatorily.

So what's the rub? In the blockworld there is no absolute motion or change, no dynamical processes actually exist. The block universe "is", "was" and "always will be" as it "is". As Dainton [9] puts it: "Imagine that I am a God-like being who had decided to design and then create a logically consistent... block universe. Since the universe will be of the block-variety I will have to create it *as a whole*: the "beginning", "middle" and "end" will come into being together. Well, assuming that our universe is a static block, even if it never "came into being", it nonetheless exists (timelessly) as a coherent whole, containing a globally consistent spread of events." In a blockworld in which all events are equally real, any explanations proffered for any event (including those pertaining to conscious brain processes) that appeal to causal mechanisms/processes, non-linear dynamics, or more generally "becoming," "change," etc., must be error theories or merely compatibilist accounts of such processes. Certainly, as blockworlders have done since the beginning, we can cook up compatibilist versions of change, causation, becoming, etc., either by relativizing such notions to a frame of reference or by picking out certain invariant features in Minkowski spacetime, such as the light-cone structure, upon which to define these notions. But none of this changes the fact that all events in a blockworld are equally real and thus any talk about change, causation, becoming, etc., must be purely perspectival. All of which implies that brain "processes" do not literally cause (as in bring about or give rise to something that did not exist before) conscious "processes" and conscious processes are every bit as fundamental as brain processes. There is no *absolute sense* in which the better part of the universe's history unfolded without phenomenal consciousness and then conscious processes sprang into being and then became more sophisticated over time *as the result of* dynamically evolving brain processes.

Thus we find ourselves in the following dilemma: either explain phenomenal consciousness (or the illusion of such) by appealing to dynamical brain processes as we do in cognitive neuroscience, *or* explain the illusion of a dynamical world that appears to have temporal flow, change and becoming by appealing to the machinations of phenomenal conscious processes. At least when it comes to deciding which kind of explanation is more fundamental, we must choose one or the other option above — we cannot have both. Given blockworld, there is no absolute change, becoming, causation, etc, and therefore we must appeal to conscious experience (at least in part) to explain this illusion. And, given blockworld, we cannot *a la* cognitive neuroscience discharge consciousness as less fundamental or less explanatory than brain processes themselves. None of this suggests Cartesian dualism, but it does tell against physicalism as realistically conceived and it does speak for a kind of nondual or dual-aspect account of the relationship between mind and matter, as they are but two aspects or modes of a nondual blockworld. It is clear from all this that even in a classical blockworld (as opposed to RBW) there is an obvious sense in which the blockworld *qua* blockworld is a fundamental singular entity rather than something that can be decomposed or partitioned into discrete and autonomous parts in any absolute sense.

Anybody with standard dynamical physicalist intuitions about phenomenal consciousness should be asking themselves this question: forget about explaining the *character* of our experience such as temporal becoming and change, how can there be "beings" with conscious experiences *at all* in a static blockworld if nothing happens and all events and their various features (such as conscious states) are equally real? How can we explain phenomenal consciousness in a world in which evolutionary theory, molecular biology, cognitive neuroscience, etc., are merely heuristic devices in a static world? Assuming that conscious states are no exception to the block-nature of the world, what can a blockworlder say except "that's just the way this blockworld is, it's a brute fact that conscious beings exist and that particular conscious states bear whatever static correlations they do with particular brain states." If the physicalist finds this answer profoundly disturbing, then they have an internal conflict between our best physics and what they take to be our best explanations of consciousness and cognition from cognitive neuroscience.

There is one well-known physicist who tacitly at least acknowledges the inescapable brute nature of conscious states and their correlations with brain states in a static world, but nonetheless still tries to tell a story whereby brain states somehow determine, explain or are identical to conscious states. We have in mind Julian Barbour [12] who advocates what is arguably an even more radically static conception of the universe than our own RBW (see Barbour [12] for details). Barbour's interpretation of the Wheeler-Dewitt equation is that the universe is an N-dimensional configuration space wherein each point is a static three-space with one of infinitely many possible static configurations of matter-energy embedded in it. There is no temporal axis in Barbour's world. Barbour calls each of these points in configuration space a "Now." Each "Now" will of course have its conscious observers such that "any human experience is determined by that human's neurological state at a particular Now. A person will have different experiences at different Nows. Some of these will include representations of others, integrated in such a way as to be experienced as having happened earlier. Others will be integrated in such a way as to be experienced as perceived motion," (Healey [13]). In spite of his radically timeless universe, Barbour [12] says things that make him sound like a crude kind of mind/brain identity theorist when explaining, for example, the experience or illusion of motion:

> Could all motion be a similar deception? Suppose we could freeze the atoms in our brains at some instant. We might be watching gymnastics. What would brain specialists find in the frozen pattern of the atoms? They will surely find that the

> pattern encodes the positions of the gymnasts at that instant. But it may also encode the positions of gymnasts at preceding instants... The brain in any instant always contains, as it were, several stills of a movie. They correspond to different positions of objects we think we see moving. The idea is that it is this collection of "stills", all present in any one instant, that stands in psychophysical parallel with the motion we actually see. The brain "plays the movie for us", rather as an orchestra plays the notes on the score... If we could preserve one of these brain patterns in aspic, it would be perpetually conscious of seeing the gymnasts in motion.

Barbour must realize of course that given his claim that "Nows" are fundamental elements of reality, then brain states are no more fundamental than or explanatory than conscious states. Brain states do not exist prior in time to conscious states, nor do they "give rise to them" or cause them. Barbour's insinuation that brain states explain by merely "coding for" or being "isomorphic to" the conscious state they correlate with would be considered crude neuroscience even in a dynamical world. But the claim is even less well-motivated in his timeless world in which there is at best a brute correlation between a particular conscious state and a particular brain state; there is really nothing more to say about such correlations in such a world. In his more cautious moments Barbour [12] appreciates that at best his view can support a kind of naturalized psychophysical parallelism:

> Nothing in the material world gives us any clue as to how parts of it (our brains) become conscious. However, there is increasing evidence that certain mental states and activities are correlated with certain physical states in different specific regions of the brain. This makes it natural to assume, as was done long ago, that there is psychophysical parallelism: conscious states somehow reflect physical states in the brain. Put in its crudest form, a brain scientist who knew the state of our brain would know our conscious state at that instant. The brain state allows us to reconstruct the conscious state, just as musical notes on paper can be transformed by an orchestra into music we can hear.

However, even in the preceding passage embracing psychophysical parallelism, Barbour cannot resist making the additional claim that particular brain states code for particular conscious states such that in principle a super-duper neuroscience could read off the latter from the former. But again, in Barbour's timeless world the correlation or parallelism between particular brain states and particular conscious states is just a static brute fact, neither kind of state "explains" the other in any way. If neuroscience really could read off conscious states from brain states in Barbour's timeless world, that would just mean that we discovered that, in a purely *a posteriori* fashion, it just so happens that certain conscious states are always correlated with certain brain states, say across all "Nows."

The point of all this, and what Barbour does not fully appreciate, is that whether it be his timeless universe or the blockworld, the best one can say about the relationship between a particular conscious state and a particular brain is that they are correlated or if you prefer, "parallel" to one another. And of course there is no reason to believe that the correlations between conscious states and brain states are one-to-one. But, at least in Barbour's timeless world or the classical blockworld, the neuroscientist can take comfort in the fact that these static correlations exist between an individual's particular conscious states and particular brain states. This means that discovering the various static neural correlates of any given conscious state is as far as neuroscience can go in explaining such states in a blockworld.

Everything we have said so far about consciousness and the mind/body problem applies to a classical blockworld, but you will recall that we are defending a *relational* blockworld. In the relational blockworld things are even worse for physicalism and its standard dynamical conception of explanation regarding the mind and brain. As we have seen, in a classical blockworld it is still true that an individual's conscious states though not "determined by" their brain states, are at least correlated with those brain states. In the classical blockworld an individual's conscious brain states constitute a unified trans-temporal object that is local and separable with respect to the rest of the world. Even though a classical blockworld must be taken as a whole that is "open" to many different foliations, it is nonetheless also decomposable into individual events including conscious brain events. But recall that in RBW there are no fundamental events, trans-temporal objects, things, etc. In RBW *all* phenomena are non-separable and non-local via the spatiotemporal holism of RBW, and that includes conscious brain processes. Unlike classical blockworld, in RBW one cannot even approximate the idea of the neural correlates of consciousness because such an explanatory schema presupposes that an individual's conscious brain states are separable and local with respect to the rest of the world, both of which will fail to obtain in RBW. In RBW not only do an individual's conscious states not "supervene" upon (are not determined by) their brain states, but they are irreducibly relational, non-local and non-separable in nature. In RBW brains are, after all, nothing but "emergent" phenomena from spacetime symmetries, they do not constitute autonomous systems anymore than measuring devices do in QM experimental set-ups. One must remember that RBW itself is not composed of anything, it is the one and only fundamental "entity" that there is, and it is not a thing, process or system.

All of this suggests that consciousness, like everything else in RBW, must also be irreducibly relational, non-local and non-separable. However there is no reason to believe that fundamental spacetime symmetries can account for conscious experience. This leads us to hypothesize that consciousness ("pure being"), which we believe in its most fundamental representation is responsible for, or identical with, the feeling of "nowness" or "presentness" that gives such experiences the "stamp of reality," should be modeled or represented via some other symmetry group. Like fundamental spacetime symmetries, fundamental "consciousness symmetries" are relational and non-local, and thus have no counterpart in the brain. Fundamental consciousness symmetries are no more a thing, object or process than spacetime symmetries are. Pursuing this analogy perhaps we could say that fundamental consciousness symmetries underlie individual conscious perspectives, perceptions, memories, and other such denumerable phenomenal states, in the same way that spacetime symmetries underlie the world of "dynamical" processes, physical events, and trans-temporal objects such as measuring devices, detectors and individual brain states.

In RBW it is the relational blockworld (spacetime symmetries), plus pure being (consciousness symmetries), plus some initial and boundary condition (a frame of reference or experimental configuration for example) that makes for individual experiential perspectives. Compare this with physicalism wherein the appropriate intrinsic, local and separable brain states, plus the appropriate distinct and local environmental context explain the existence of conscious "beings." In RBW, to be an individual is to be or occupy a conscious perspective in the relational blockworld. Individual existence is nothing more than the illusion of separateness. The relational blockworld is a seamless, nondual whole, individual existence is just the partitioning of the whole by the active mind. Thus, temporal becoming, the dynamical brain and the external world are all "in the Mind."

> From the highest point of view the world has no cause. Once you create for yourself a world in time and space, governed

by causality, you are bound to search for and find causes for everything. You put the question and impose an answer. Each moment contains the whole of the past and creates the whole of the future. In reality all is here and now and all is one. Multiplicity and diversity are in the mind. Everything is caused by all and affects all. The diversity is in you only. See yourself as you are and you will see the world as it is — a single block of reality, indivisible, indescribable. Your own creative power projects upon it a picture and all your questions refer to the picture. (Sri Nisargadatta Maharaj [14])

References

1. For this we rely on the work of Kaiser and Bohr, Ulfbeck & Mottelson as described and referenced in what follows.
2. *See* Lorentz's "Electromagnetic phenomena in a system moving with any velocity less than that of light" (1904) for example, reprinted in *The Principle of Relativity*, Dover, New York.
3. Kaiser, G. (1981) Phase-space approach to relativistic quantum mechanics. III. Quantization, relativity, localization and gauge freedom, *J. Math. Phys.* **22**, 705–714.
4. Bohr, A., and Ulfbeck, O. (1995) Primary manifestation of symmetry. Origin of quantal indeterminacy, *Rev. Mod. Phys.* **67**, 1–35.
5. Price, H. (1999) *Time's Arrow and Archimedes' Point: New Directions for the Physics of Time*, Oxford University Press, Oxford.
6. Fleming, G., and Bennett, H. (1989) Hyperplane dependence in relativistic quantum mechanics, *Found. Phys.* **19**, 231–267.
7. Bohr, A., Mottelson, B.R., and Ulfbeck, O. (2004) The principle underlying quantum mechanics, *Found. Phys.* **34**, 405–417.
8. Personal correspondence to W. M. Stuckey dated 22 Dec 2004.
9. Dainton, B. (2001) *Time and Space*, McGill–Queen's UP, Montreal.
10. Libet, B. (2004) *Mind Time: the Temporal Factor in Consciousness*, Harvard University Press, Cambridge (MA).
11. Koch, C. (2004) *The Quest for Consciousness: a Neurobiological Approach*, Roberts and Company Publishers, Englewood.
12. Barbour, J. (1999) *The End of Time: the Next Revolution in Physics*, Oxford University Press, Oxford.
13. Healey, R. (2002) Can physics coherently deny the reality of time, in C. Callender (ed.), *Time, Reality and Experience*, Cambridge University Press, Cambridge, pp. 293–316.
14. Sri Nisargadatta Maharaj (1973) *I Am That*, Acorn Press, Durham, p. 39.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 317–343

RECURRENT QUANTUM NEURAL NETWORKS: A PARADIGM FOR SUBJECTIVE COMPUTING MODEL

LAXMIDHAR BEHERA
Department of Electrical Engineering, Indian Institute of Technology
Kanpur 208 016, UP, India
(lbehera@iitk.ac.in)

Abstract: A complete scientific theory that can integrate material objects with mental objects is capable of heralding the next stage of scientific revolution. Mental qualities such as experienced smell or taste has yet to be quantified in scientific domain. This chapter is devoted to this idea of subjective computation where mental qualities can be quantified. Schroedinger wave equation has been used in a recurrent quantum neural network framework to solve problems such as stochastic filtering, system identification and adaptive control.

Keywords: Quantum Neural Networks – Subjective Computing Model

1 Introduction

Information processing in the brain is mediated by the dynamics of large, highly interconnected neuronal populations. The activity patterns exhibited by the brain are extremely rich; they include stochastic weakly correlated local firing, synchronized oscillations and bursts, as well as propagating waves of activity. Perception, emotion, *etc.* are supposed to be emergent properties of such a complex nonlinear neural circuit. Although revolution in computing power in the last century has reached a stage beyond our imagination, such super computing machines trail way behind when compared with human brain processing tasks such as pattern recognition and language understanding. The structure of natural intelligence is still a mystery for us and this mystery has to be unraveled if neural computation is to go to the next stage of revolution.

Natural biological systems starting from plants to human beings exhibit a variegated level of intelligence. It seems that intelligence is an attribute in all those species which possess consciousness. Can studies in consciousness help one to improve the understanding of intelligence better?

2 Intelligence — Something Still Mysterious

Real Intelligence is what inspires a normal thought process of a human. Artificial Intelligence is a property of machines which gives them the abil-

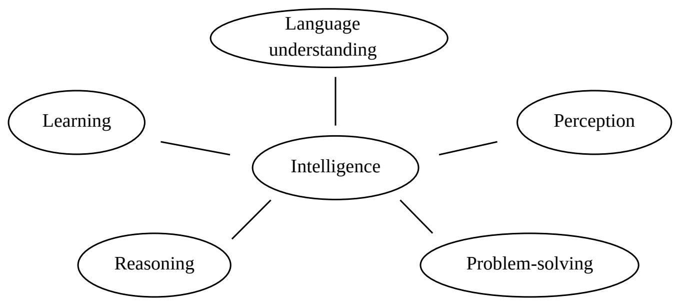


Figure 1. What is intelligence?

ity to mimic the human thought process. The foundational framework to intelligent computing lies in our proper understanding of mental processes. Though the term *intelligence* is still not completely defined, according to Turing it is a combination of five components as shown in Fig. 1. An intelligent system should have abilities to understand, perceive, reason, solve problems and, moreover, learn from past experiences. The systemic understanding of cognitive processes consists of the formulation and solution of three fundamental problems in the design of intelligent machines that 'intelligently' observe, predict and interact with the objects of the physical world. These problems are known as the system identification problem, the stochastic filtering problem, and the adaptive control problem.

3 Intelligent Computing: Some Challenges

How intelligent is an artificial machine? Consider a case of intelligent control system where such an artificial machine is employed as a controller. One can pose a following question:

- Can we construct a Control System that hypothesizes its own control law?

Let the same machine is put to use for a denoising application. Can one ask the following question?

- Can the machine estimate any signal embedded in a noise without assuming any signal or noise behavior?

Here are some examples from control systems:

1. Consider a second order non-linear system

$$\frac{d^2y}{dt^2} + h(y)\frac{dy}{dt} + g(y) = 0; \quad h(y) > 0.$$

To study the stability of the system around the origin $x_1 = y, x_2 = \dot{y}$, the generic form of the Lyapunov function is

$$V(x) = \int_0^{x_1} g(s)ds + \frac{1}{2}x_2^2.$$

Can we construct an intelligent machine that can hypothesize the above Lyaponov function?

2. A control engineer hypothesizes a control law. A generic structure of an optimal control law in a state-space configuration is as follows:

$$u^*(t) = -\frac{1}{A}B^T PAx(t).$$

The Question:

- How does the Control Engineer know that such a control law will help?

The Answer:

- The control engineer uses his experience, intuition and scientific upbringing to design a control given a specific dynamic system.

Can one allow an artificial machine to do everything from the scratch until a stable controller is designed as a control engineer would do?

Here another application is signal denoising. A signal can belong to one of the three types as shown in Fig. 2. Signal analysis can either be on a *case-by-case* basis or through a *generic model*. The Signal is often embedded in Noise, the nature of which has an important role in Signal Estimation. This noise can be Gaussian or non-Gaussian as shown in Fig. 3. Can a machine denoise a signal without any assumption about the signal type and noise type?

4 The Big Question

In spite of many ideal applications of neural computation in control, pattern recognition, image processing and speech synthesis, learning in neural computation is still far from being natural. All these methods make strong assumption about the space around. They cannot work in a generalized condition. It is still a long way to go before we can ask following questions:

- Can they hypothesize a theory?
- Can a Learning Theory prove a Theorem?
- Can it propose a theory similar to the special theory of relativity?

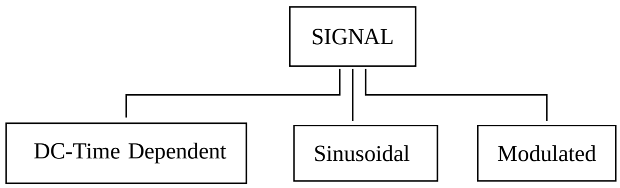


Figure 2. Various types of signal.

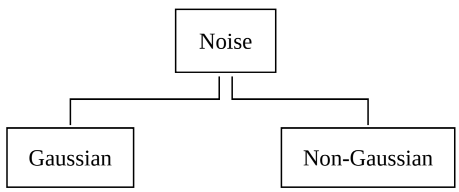


Figure 3. Broad classification of noise.

5 Naturalizing Intelligence in Neural Computation

Recently we have proposed a wave equation model of neural computation [1, 2, 3] that can easily model a probability density function in stochastic data. The prime motivation comes from the study of attributes of consciousness. As a conscious person, we always have a holistic experience although the biological body consists of many individual parts or agents. We identify that *collective response behavior* is a key feature in conscious beings.

The inspiration for our present work has been Bhagavata Sankhya philosophy as given in 26th chapter in 3rd Canto of Srimad Bhagavatam [4]. In this paradigm, the gross world is divided into five types: Earth, Water, Fire, Air and Ether. The element *Earth* carries smell, the element *Water* carries taste, the element *Fire* carries form, the element *Air* carries touch and the element *Ether* carries sound. All forms of experiences from smell to sound are unified and integrated in an element called Mind. The experience is conceptualized using another element, Intelligence. This hierarchy is shown in Fig. 4. The important information in this section is that although matter has its variegatedness from the gross world of experience to conceptual experience at the level of intelligence, the elements such as Mind

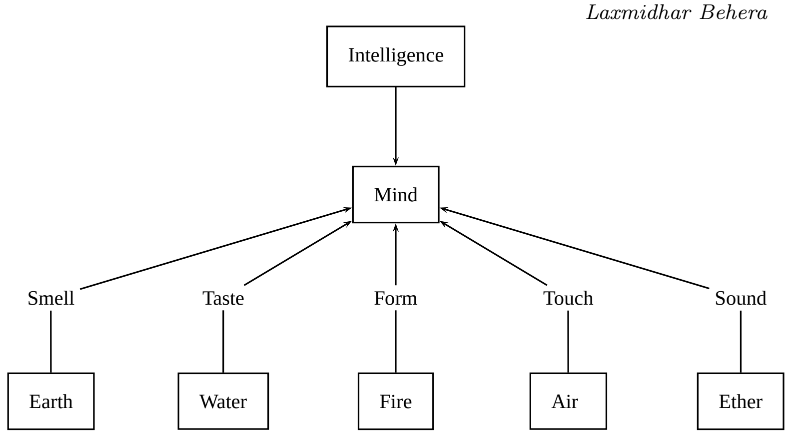


Figure 4. Bhagavata Sankhya Model of Structure of Matter.

and Intelligence are more like subjective while the Gross world of *Earth* to *Ether* is more like objective. The element sound connects the gross world to the subjective world.

One can see that the Bhagavata Sankhya model invokes collective or unified response ability of matter at the level of mind. We have used non-linear Schroedinger wave equation to model collective response behavior. It is shown that such a paradigm can naturally make a model more intelligent. This aspect has been demonstrated through an application — intelligent filtering — where complex signals are denoised without any *a priori* knowledge about the signal and noise as well, whereas the classical filtering methods such as a Kalman filter for DC signals, an FFT filter or a wavelet filter for sinusoids, make prior assumptions about the signal and noise. In essence, we claim that the consciousness-based model of matter may reveal nature in a more aesthetic manner.

6 Recurrent Quantum Neural Networks

In recurrent quantum neural networks(RQNN), we envision a new approach to cognitive modeling. The basic motivation is to develop models using minimal assumptions. To this end, we have shown [5] that an RQNN based stochastic filter can estimate a signal without making any assumption about the signal and the embedded noise. Interestingly, these RQNN models are quite different from the existing neural architectures [6, 7, 8, 9, 10, 11]. In RQNN, the unified response of a neural lattice is determined using the Schroedinger wave equation. Instead of synthesizing a neural network in terms of individual neuronal responses, the proposed model looks at the unified response of a neural lattice that accounts for the information processing using data from a certain type of sensory input.

For stochastic filtering applications, we make the hypothesis that the average behavior of a neural lattice that estimates a stochastic signal is a time varying probability density function which is mediated by a quantum process. We use the Schroedinger wave equation to track this *pdf* function since it is a well-known fact that the square of the modulus of the ψ function, the solution of this wave function, is also a *pdf* function. It will be explained in detail later in this paper that the Schroedinger wave equation becomes nonlinear when its potential field is excited by a feedback signal that is a function of ψ, the state of the quantum process. In essence, the proposed RQNN is quite different in spirit and objective from the QNN architecture available in the literature as these QNNs synthesize a neural lattice using individual neural responses. Thus we make a paradigm shift in understanding brain behavior by taking the complete neural lattice as a single quantum object. In this hypothesis, we make the assumption that there exists a quantum process in the brain that mediates the average response of the neurons in a specific lattice.

Further, we provide a scheme to develop quantum models of a damped harmonic oscillator. It is shown that any damped harmonic oscillator can be accurately modeled using the Schroedinger wave equation. The system parameters are learned on line using reinforcement type of learning scheme. Finally, an adaptive control scheme using RQNN has been implemented.

7 A Stochastic Filter Using RQNN

The architecture of the RQNN for filtering a one-dimensional signal embedded in noise is shown in Fig. 5. The signal $y(t)$ is the actual signal ($y_a(t)$) embedded in noise ($\mu(t)$), i.e. $y(t) = y_a(t) + \mu(t)$. The signal excites N neurons spatially located along the x-axis after being pre-processed by synapses. In the model the synapses are represented by time varying synaptic weights $K(x,t)$. The unified dynamics of the one-dimensional neural lattice consisting of N neurons is described by the Schroedinger wave equation of the form

$$i\hbar\frac{\partial\psi(x,t)}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\psi(x,t) + \zeta(U(x,t) + G(|\ \psi\ |^2))\psi(x,t), \qquad (1)$$

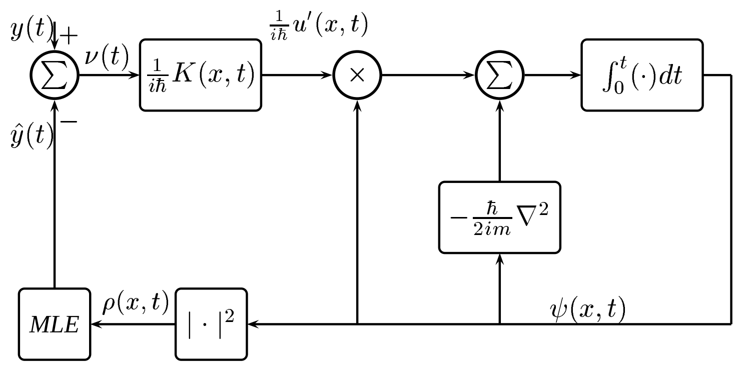


Figure 5. A stochastic filter using RQNN;MLE:maximum likelihood estimator.

where the symbols $i, \hbar, \psi(x,t)$ and ∇ have the usual meaning in the context. The potential field in Eq. (1) consists of two terms

$$U(x,t) = -K(x,t)y(t), \tag{2}$$

$$G(|\ \psi\ |^2) = K(x,t)\int xf(x,t)dx, \tag{3}$$

where

$$f(x,t) = |\ \psi(x,t)\ |^2\ . \tag{4}$$

Since the potential field term in Eq. (1) is a function of $\psi(x,t)$, the Schroedinger wave equation that describes the stochastic filter is nonlinear. In contrast to artificial neural networks studied in literature, in our model the neural lattice consisting of N neurons is described by the state $\psi(x,t)$ which is the solution of Eq. (1). Simultaneously, the model is recurrent as the dynamics consists of a feedback term $G(\ldots)$. When the estimate $\hat{y}(t)$ is the actual signal, then the signal that generates the potential field for the Schroedinger wave equation, $\hat{\nu}(t)$, is simply the noise that is embedded in the signal. If the statistical mean of the noise is zero, then this error correcting signal $\hat{\nu}(t)$ has a little effect on the movement of the wave packet. Precisely, it is the actual signal content in the input $y(t)$ that moves the wave packet along the desired direction which, in effect, achieves the goal of the stochastic filtering. It is expected that the synaptic weights evolve in such a manner so as to drive the ψ function to carry out the exact information of the *pdf* of the observed stochastic variable $y(t)$.

7.1 Learning and estimation

The nonlinear Schroedinger wave equation given by Eq. (1) exhibits a soliton property, i.e. the square of $\mid \psi(x,t) \mid$ is a wave packet which moves like a particle. The importance of this property is explained as follows. Let the stochastic variable $y(t)$ be described by a Gaussian probability density function $f(x,t)$ with mean κ and standard deviation σ. Let the initial state of Eq. (1) corresponds to a zero mean Gaussian probability density function $f'(x,t)$ with standard deviation σ'. As the dynamics evolves with on-line update of the synaptic weights $K(x,t)$, the probability density function $f'(x,t)$ should ideally move toward the *pdf*, $f(x)$, of the signal $y(t)$. Thus the filtering problem in this new framework can be seen as the ability of the nonlinear Schroedinger wave equation to produce a wave packet solution that glides along with the time varying *pdf* corresponding to the signal $y(t)$.

The synaptic weights $K(x,t)$ which represent an $N \times 1$ dimensional vector are updated using the Hebbian learning algorithm

$$\frac{\partial K(x,t)}{\partial t} = \beta \nu(t) f(x,t), \tag{5}$$

where $\nu(t) = y(t) - \hat{y}(t)$. $\hat{y}(t)$ is the filtered estimate of the actual signal $y_a(t)$. We compute the filtered estimate as the Maximum Likelihood Estimator *(MLE)*:

$$\hat{y}(t) = \int x f(x,t) dx. \tag{6}$$

In the stochastic filter model given by Dawes [12], the author used an inverse filter in the feedback. Using this model we could not move the wave packet and the author agreed to this finding in our personal correspondence. We will see later in this chapter that the wave packet moves in the required direction in our new model.

7.2 Simulation results

In this section we show some of the applications of RQNN. The stochastic filtering of amplitude modulated sine wave signal is shown in Figs. 6. The signals are embedded in $6dB$ and $20dB$ Gaussian noise respectively. The movements of wave packets are shown in Fig. 7. The same experimental simulation is repeated for an amplitude-modulated square wave signal and the results are shown in Fig. 8. It can be seen that the signal estimation is very accurate and the important observation is that the wave packets glide along the actual *pdf* of the stochastic signal being estimated.

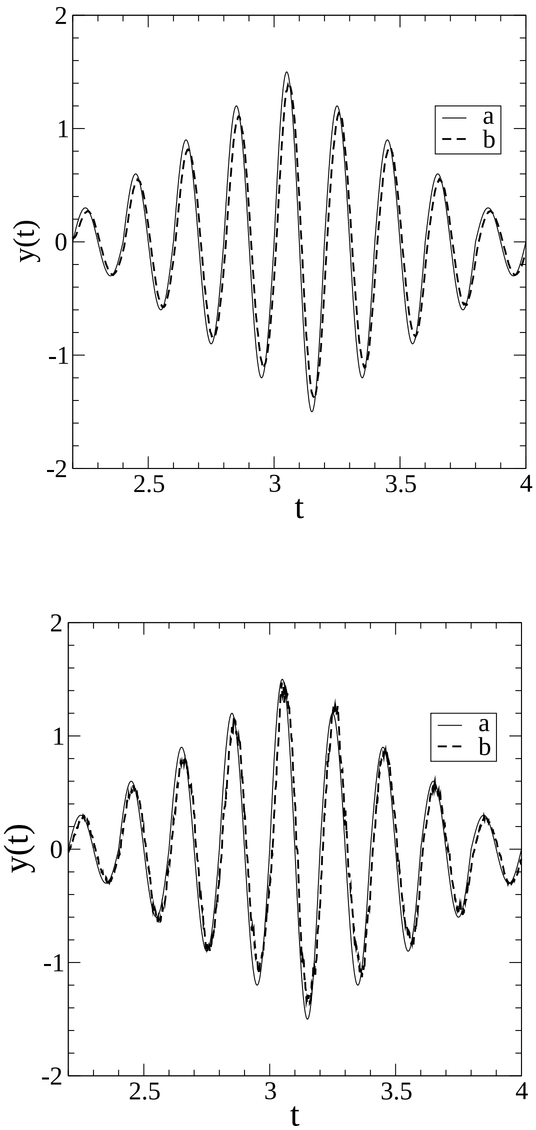


Figure 6. Tracking of the amplitude-modulated sinusoid signal embedded in: (*top*) 20dB Gaussian noise and (*bottom*) 6dB Gaussian noise; the signal 'a' represents the actual signal and signal 'b' represents the tracking by the RQNN.

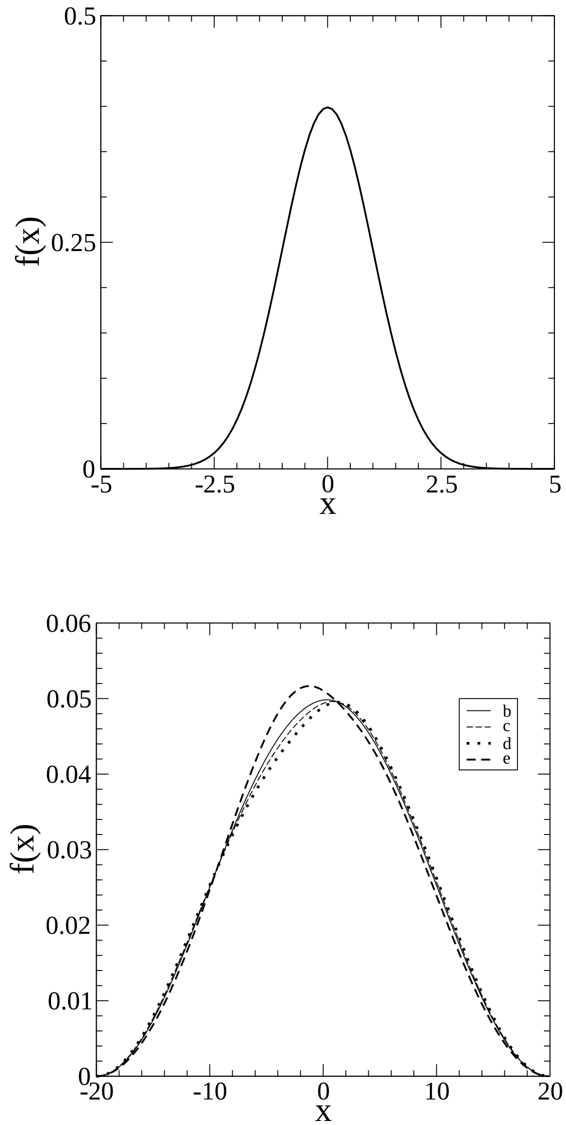
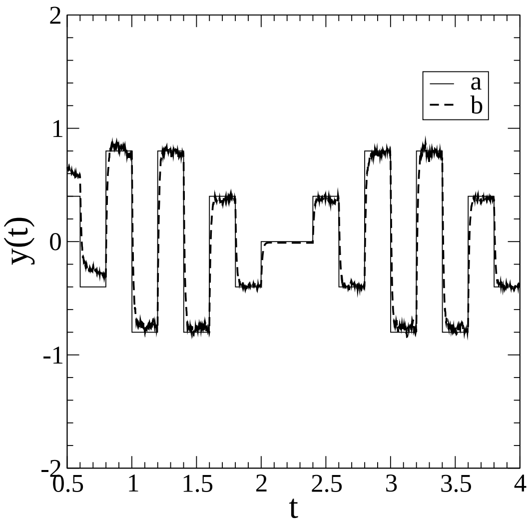


Figure 7. Movement of the wave-packets corresponding to Fig. 6, 20dB noise; (*top*) initial state of the Schroedinger wave equation; (*bottom*) snapshots of wave packets at four different instants are shown: the wave packet 'b' at $t = 2.25sec$, the wave packet 'c' at $t = 2.65sec$, the wave packet 'd' at $t = 3.05sec$ and the wave packet 'e' at $t = 3.15sec$.



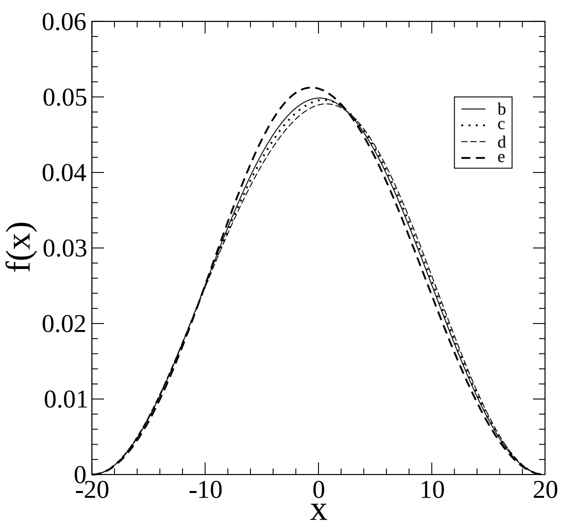


Figure 8. An amplitude-modulated square wave embedded in 20dB Gaussian noise (*top*). Tracking the signal: 'a' represents the actual signal and signal 'b' is the tracking by the RQNN (*bottom*). Snapshots of wave packets: the wave packet 'b' at $t = 2.1sec$, the wave packet 'c' at $t = 2.5sec$, the wave packet 'd' at $t = 2.9sec$ and the wave packet 'e' at $t = 3.1sec$.

8 Modeling of Damped Harmonic Oscillator

To solve any classical system with the help of the Schroedinger wave equation, it is required to obtain the quantum mechanical equivalent of the system model. A standard approach of quantization is to construct the Lagrangian of the system from its dynamical equations then obtain the corresponding Hamiltonian and use it in the Schroedinger wave equation. This approach is, however, not particularly suitable for dissipative systems because it has already been shown in the literature that the quantum representation obtained using this method does not perfectly describe the original dissipative system. So here we have taken an approach to obtain the quantum representation of the damped harmonic oscillator by incorporating nonlinear damping into the potential field of the Schroedinger equation. The general nonlinear Schroedinger wave equation for one dimension is

$$i\hbar\frac{\partial\psi(x,t)}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2\psi(x,t)}{\partial x^2} + U(x,\psi,t)\psi(x,t). \tag{7}$$

As the potential field itself is a function of ψ, the equation is nonlinear. Here the potential energy is the sum of two parts

$$U(x,\psi,t) = V(x,t) + \lambda Q(\psi). \tag{8}$$

If λ is zero then Eq. (7) becomes linear and if $V(x,t)$ is given by

$$V(x,t) = \frac{1}{2}\omega^2 x^2 - f(t)x, \tag{9}$$

then it corresponds to the original harmonic oscillator given by the dynamics

$$\frac{d^2x}{dt^2} + \omega^2 x = f(t). \tag{10}$$

The dynamic equation of the classical damped harmonic oscillator system is given by

$$\frac{d^2x}{dt^2} + 2\xi\omega\frac{dx}{dt} + \omega^2 x = f(t). \tag{11}$$

Then the potential field becomes a function of the wave function.

The properties of a nonlinear Schroedinger equation in which $Q(\psi)$ is given by $G(|\psi|^2)$, for some function G, are described in Bialynicki-Birula and Mycielski [13]. We consider an equation in which $Q(\psi)$ is a flux potential for ψ. For any given ψ

$$j_\psi(x,t) = \frac{1}{2i}[\psi^*(x,t)\nabla\psi(x,t) - \psi(x,t)\nabla\psi^*(x,t)] = Re(\psi^*\frac{1}{i}\nabla\psi) \tag{12}$$

is the probability current density associated with ψ where $Q(\psi)$ satisfies

$$j_\psi(x,t) = \nabla Q(\psi). \tag{13}$$

The coefficient λ determines the damping rate of the system. The potential energy U is calculated as

$$U(x,\psi,t) = \frac{1}{2}\omega^2 x^2 - f(t)x + \lambda \int_{-2}^{x} j_\psi(x,t)dx, \tag{14}$$

where $j_\psi(x,t)$ is given by Eq. (12). $\nabla\psi(x,t)$ is approximated as

$$\nabla\psi(x,t) = \frac{1}{2\triangle x}[\psi(x+\triangle x) - \psi(x-\triangle x)]. \tag{15}$$

The expectation of x is calculated as

$$\hat{x}(t) = \int_{-2}^{2} \psi^* x \psi dx. \tag{16}$$

8.1 Identification of system parameters

In the previous section we discussed how to model the damped harmonic oscillator in quantum domain. Next we shall see how we can learn the system parameters, that is the frequency and damping factor, starting from any initial value. The learning algorithm we used is based on the principle of Reinforcement learning. Steps of the algorithm is given below.

Step 1: Start from any initial values of ω and ξ, solve the NL Schroedinger equation; as the potential fields depend on ω and ξ, so the solution also does. Compute the error between the solution of this and the actual system response. Step 2: Move the parameters in any direction, i.e. either increase or decrease. Again compute the error. Step 3: Compare the current error with the previous one. If the error is increasing then move in the opposite direction, otherwise move in the same direction. Step 4: Check whether the error goes below a predefined value; if so, then stop.

The incremental value also depends upon the error. The higher the error, the higher is the incremental value.

8.2 Numerical integration technique of the Schroedinger wave equation

The integration technique used here is based on [14]. The nonlinear Schroedinger wave equation is — from the mathematical point of view — a partial differential equation in two variables: x and t. Eq. (7) is converted to the finite difference form by dividing the x-axis into N mesh points so that x and t are represented as

$$x_j = j\triangle x \quad t_n = n\triangle t, \tag{17}$$

where j varies from $-N/2$ to $+N/2$. The finite-difference form of Eq. (7) is approximately expressed as

$$\begin{aligned} i\frac{\psi(x, t+\triangle t) - \psi(x,t)}{\triangle t} &= \\ -\frac{\psi(x+\triangle x, t) - 2\psi(x,t) + \psi(x-\triangle x, t)}{2m\triangle x^2} &+ U(x)\psi(x,t). \end{aligned} \tag{18}$$

Here, we have assumed that $\hbar = 1$, $m = 1$. For convenience, we denote $\psi(x_j, t_n + \triangle t)$ as ${\psi_j}^{n+1}$, $\psi(x_j, t_n)$ as ${\psi_j}^n$ and $\psi(x_j - \triangle x, t_n)$ as ${\psi_{j-1}}^n$. In this notation, Eq. (18) reads

$${\psi_j}^{n+1} = {\psi_j}^n + i\triangle t\frac{{\psi_{j+1}}^n - 2{\psi_j}^n + {\psi_{j-1}}^n}{2\triangle x^2} - i\triangle t U_j {\psi_j}^n. \tag{19}$$

The attractive feature of the above equation is that it is explicit, i.e. it gives the wave function at time step $n+1$ directly in terms of the function at the earlier time n which permits a straightforward integration scheme. But it has an inherent drawback of being unstable. To see this, we can rewrite Eq. (19) with some minor modification in the approximation

$$\begin{aligned} {\psi_{j+1}}^{n+1} + (i\lambda_1 - 2\triangle x^2 U_j - 2){\psi_j}^{n+1} + {\psi_{j-1}}^{n+1} &= \\ -{\psi_{j+1}}^n + (i\lambda_1 + 2\triangle x^2 U_j + 2){\psi_j}^n + {\psi_{j-1}}^n&, \end{aligned} \tag{20}$$

where $\lambda_1 = \frac{2\triangle x^2}{\triangle t}$. This equation is stable and unitary, but implicit. Now, let us define

$${\Omega_j}^n = -{\psi_{j+1}}^n + (i\lambda_1 + 2\triangle x^2 U_j + 2){\psi_j}^n + {\psi_{j-1}}^n. \tag{21}$$

Eq. (20) thus becomes

$${\psi_{j+1}}^{n+1} + (i\lambda_1 - 2\triangle x^2 U_j - 2){\psi_j}^{n+1} + {\psi_{j-1}}^{n+1} = {\Omega_j}^n. \tag{22}$$

Now we can make the assumption that

$${\psi_{j+1}}^{n+1} = {e_j}^n {\psi_j}^{n+1} + {f_j}^n, \tag{23}$$

where ${e_j}^n$ and ${f_j}^n$ are two auxiliary equations. Substituting Eq. (23) into Eq. (22) we get,

$${\psi_j}^{n+1} = (2 + 2\triangle x^2 U_j - {e_j}^n - i\lambda_1)^{-1}[{\psi_{j-1}}^{n+1} + ({f_j}^n - {\Omega_j}^n)]. \tag{24}$$

This equation is identical with Eq. (23) except for the fact that here j is replaced by $j-1$. By comparing Eqs. (23) and (24) we get,

$$e_{j-1}{}^{n} = (2 + 2\triangle x^2 U_j - e_j{}^{n} - i\lambda_1)^{-1}, \tag{25}$$

$$f_{j-1}{}^{n} = e_{j-1}{}^{n}(f_j{}^{n} - \Omega_j{}^{n}). \tag{26}$$

Expressing $e_j{}^n$ and $f_j{}^n$ in terms of $e_{j-1}{}^n$ and $f_{j-1}{}^n$ we simply get,

$$e_j{}^{n} = 2 + 2\triangle x^2 U_j - i\lambda_1 - \frac{1}{e_{j-1}{}^{n}}, \tag{27}$$

$$f_j{}^{n} = \Omega_j{}^{n} + \frac{f_{j-1}{}^{n}}{e_{j-1}{}^{n}}. \tag{28}$$

It follows from Eq. (27) that $e_j{}^n$ is independent of time so we can write it simply as e_j. Eqs. (27) and (28) are recursive relations for e and f functions. To obtain the starting values, we can imagine our physical system is confined in a large one dimensional box on the walls of which the wave function ψ vanishes. Thus $\psi(\min x, t) = \psi(\max x, t) = 0$ for all t. Here we assume that the box extends from $\min x$ to $\max x$. Now, if $j = 0$ represents $x = \min x$ and $j = N$ represents $x = \max x$, then our boundary conditions become

$$\psi_0{}^{n} = \psi_N{}^{n} = 0 \text{ for all n.} \tag{29}$$

With the first of these conditions we can write for the case of $j = 1$: $\psi_2{}^{n+1} = (2+2\triangle x^2 U_j - i\lambda_1)\psi_1{}^{n+1} + \Omega_1{}^{n}$. By comparing this with Eq. (23),

$$e_1 = 2 + \triangle x^2 U_1 - i\lambda_1, \tag{30}$$

$$f_1{}^{n} = \Omega_1{}^{n}. \tag{31}$$

These starting values in conjunction with the two recursive Eqs. (27) and (28) provide a means for determining e_1, e_2,... and $f_1{}^n$, $f_2{}^n$,... for all n. From the second boundary condition with $j = N-1$ we have,

$$\psi_{N-1}{}^{n+1} = -\frac{f_{N-1}{}^{n}}{e_{N-1}}. \tag{32}$$

By inverting Eq. (23) we get

$$\psi_j{}^{n+1} = \frac{(\psi_{j+1}{}^{n+1} - f_j{}^{n})}{e_j{}^{n}}. \tag{33}$$

Now by combining Eqs. (32) and (33) we can determine $\psi_{N-1}{}^{n+1}$ which in turn provides $\psi_{N-2}{}^{n+1}$, $\psi_{N-3}{}^{n+1}$ down to $\psi_1{}^{n+1}$. Thus we are now with a procedure which gives $\psi_j{}^n$ for all j and all n with the knowledge of initial condition $\psi_j{}^0$ for all j.

8.3 Simulation results

8.3.1 Response of damped harmonic oscillator

We now compare the response of the classical damped harmonic oscillator with the response of the nonlinear Schroedinger equation obtained through the described numerical integration. The equation of the classical system is given by

$$\frac{d^2x}{dt^2} + 2\xi\omega\frac{dx}{dt} + \omega^2 x = f(t), \tag{34}$$

where ξ is the damping constant, ω is the natural frequency and $f(t)$ is the external input. The response of this system for $x(0) = 0.5$, $\xi = 0.1$, $\omega = 100$ and $f(t) = 0$ is obtained analytically and compared with the same obtained by solving Schroedinger wave equation. The equation was integrated for $N = 1000$, $\min x = -2$, $\max x = 2$, $\triangle x = 0.004$ and integration step size $\triangle t = 0.00005$. The initial state of the particle is represented using a stationary Gaussian wave packet centered at $x(0)$. The variance is chosen to be 0.08, which leads to a narrow wave packet.

Fig. 9 shows the expectation of x and actual x plotted against ωt for $\lambda = \frac{2\xi\omega}{\pi}$. The scaling factor of $\frac{0.75}{\pi}$ is empirically discovered in order to match the damping rates. Again, as the variance is changed the value of λ also needs to be changed slightly to adjust the damping rate. Further simulation reveals that if we add a zero mean Gaussian noise to the potential field of the wave equation as the input $f(t)$ the response remains unchanged as the zero mean noise does not affect the movement of the wave packet.

8.3.2 Parameters identification

Here we will show how first our learning algorithm can track the original system response without knowing the natural frequency of oscillation and damping factor. We started from different arbitrary values of ω and ξ like $40, 60, 90, 130, 170$ and $0.0395, 0.0605, 0.089, 0.1295, 0.1705$ respectively. Fig. 12 shows that error for the starting values of $\omega = 40$ and $\xi = 0.0395$ converges more rapidly compared to the starting values of $\omega = 170$ and $\xi = 0.1705$. Further simulation reveals that ω and ξ can be tracked starting from any arbitrary values with a variable learning rate.

i

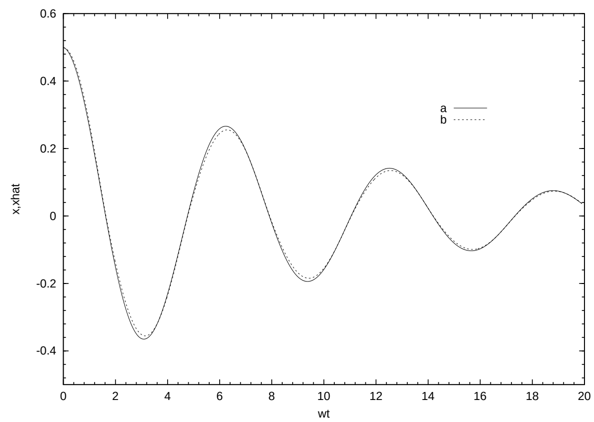


Figure 9. Response of the damped harmonic oscillator: a represents the classical one and b represents the one obtained using the nonlinear Schroedinger equation.

i

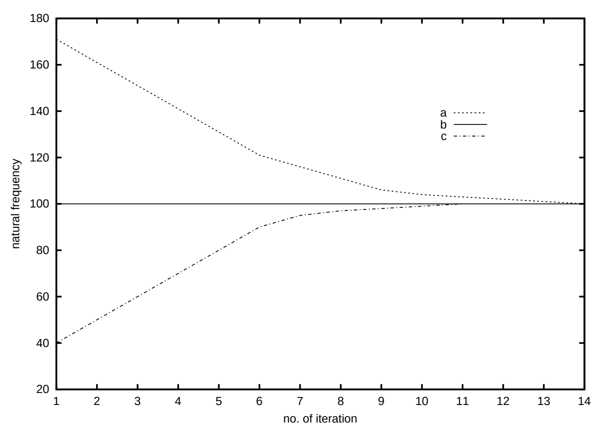


Figure 10. Tracking of ω starting from two arbitrary initial values: a shows the converging path for the starting value $\omega = 170$, c shows the same for $\omega = 40$ and b shows the actual ω.

i

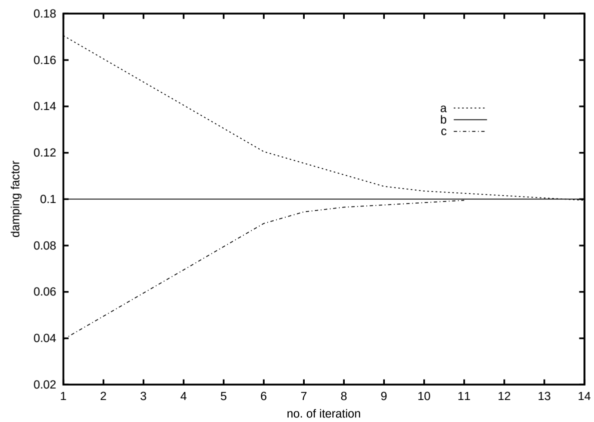


Figure 11. Tracking of ξ starting from two arbitrary initial values: a shows the converging path for the starting value $\xi = 0.0395$, c shows the same for $\xi = 0.1705$ and b shows the actual ξ.

i

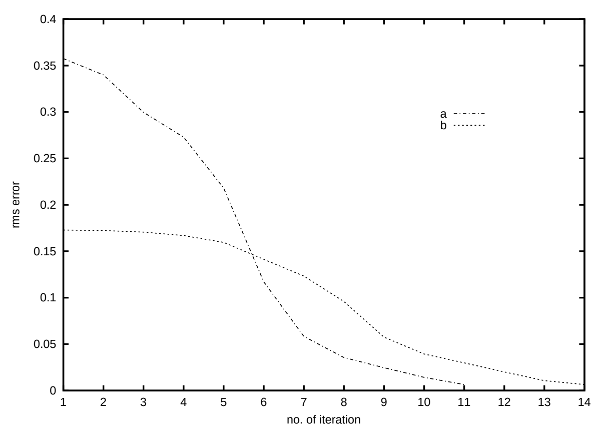


Figure 12. Converging path for the error: a shows the same for $\omega = 170$ and $\xi = 0.1705$ and b shows the same for $\omega = 40$ and $\xi = 0.0395$.

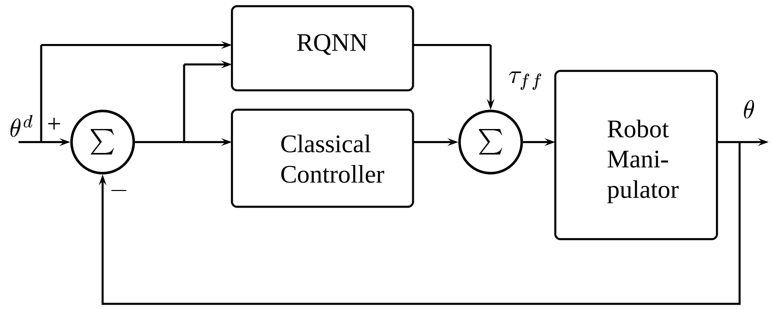


Figure 13. An Overall Block Diagram for the Adaptive Control Scheme.

9 Adaptive Control

The adaptive control scheme proposed in this chapter is shown in Fig. 13. The dynamical equation for a robot manipulator can be written as

$$m'l^2\frac{d^2\theta}{dt^2} + m'gl\cos\theta = \tau, \tag{35}$$

where m' is the mass and l is the length of the manipulator, θ is the angle with the vertical axis and τ is the external force. Our aim is to control θ according to some specified trajectory. We do not know exactly the actual values of m' and l, which means that there are uncertainties in the system parameters so that the control law should be adaptive to take account for the fact. The desired trajectory is given as

$$\theta^d = 0.5(1 - \cos\omega t). \tag{36}$$

Our control law is of the form

$$\tau = \tau_{ff} + \frac{d^2\theta^d}{dt^2} - k_p e - k_d\frac{de}{dt}, \tag{37}$$

where e is the error between the actual response and the desired response, k_p, k_d controller parameters, τ_{ff} is the output of the RQNN which gives the fine tuning of the control law. The input to the RQNN is θ^d. The potential field of the Schroedinger wave equation depends upon the input and the adaptation law. The above control law is always stable. The potential field of the Schroedinger wave equation in this case is given as

$$U(x,t) = \zeta K(x,t)(\theta^d - \tau^{ff}). \tag{38}$$

The error signal excites N neurons spatially located along the x-axis after being pre-processed by synapses. In the model the synapses are represented by time varying synaptic weights $K(x,t)$. Finally, τ^{ff} is computed as

$$\tau_{ff} = \int \psi^* x \psi dx, \tag{39}$$

where ψ is the solution of Eq. (1). The integration technique used here, is based on [14]. It is seen that instead of using original RQNN we can also use a QNN where there is no feedback of the estimated value obtained from the QNN. We will present our simulation results based on both RQNN and QNN.

9.1 Learning and estimation

The dynamics evolves with on-line update of the synaptic weights $K(x,t)$. The synaptic weights $K(x,t)$, which represent an $N \times 1$ dimensional vector, are updated using the Hebbian learning algorithm

$$\frac{\partial K(x,t)}{\partial t} = \beta e(t) f(x,t), \tag{40}$$

where $e(t) = \theta^d(t) - \theta(t)$ and $f(x,t) = \psi^* \psi$. We compute the estimate of τ_{ff}as the Maximum Likelihood Estimator *(MLE)*, i.e.

$$\tau_{ff}(t) = \int x f(x,t) dx. \tag{41}$$

As the potential field is a function of τ^{ff} here and τ^{ff} is a function of ψ itself, the Schroedinger equation acquires a nonlinear character.

9.2 Simulation results I

We now compare the desired response of the system with the actual one, which is obtained using the control law described in the previous section. The parameters values are chosen as $m = 0.01$, $\beta = 0.2$, $\zeta = 480$, $m' = 1$, $l = 1$ and $g = 10$. Fig. 14 shows that the capability of tracking the trajectory angular position θ for the controller with RQNN is much better than the one without RQNN. Fig. 15 shows the tracking of angular velocity $\dot{\theta}$ using RQNN.

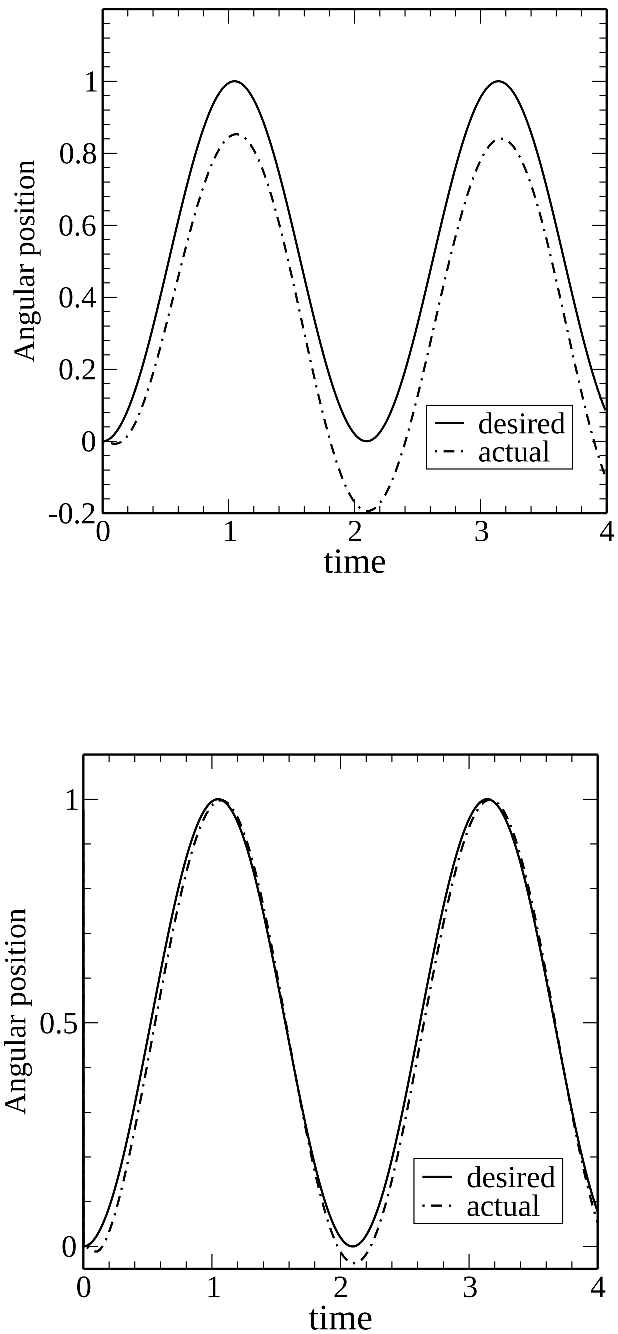


Figure 14. The desired and actual trajectories for the angular position θ of a robot manipulator: *top* — without RQNN, *bottom* — with RQNN.

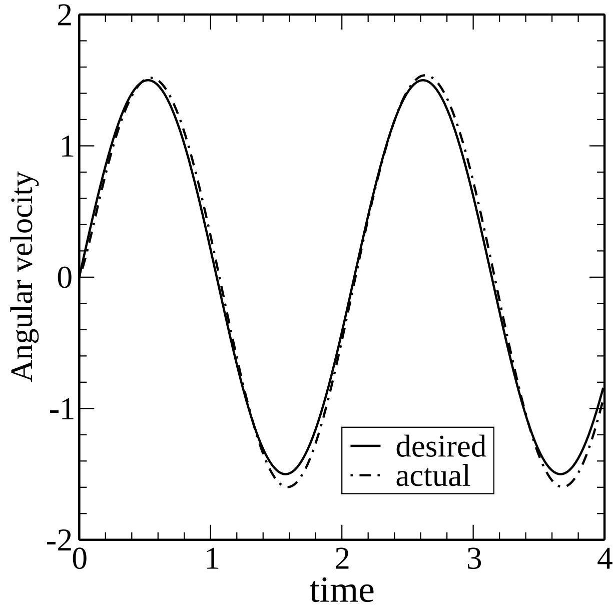


Figure 15. The desired and actual trajectories for the angular velocity $\dot{\theta}$ of a robot manipulator with RQNN.

Our simulation results reveal that the performance of the RQNN depends solely upon various parameters like β, ζ, m and these parameters are tuned heuristically to get a better performance. This tuning can be avoided if one uses a Gaussian kernel instead of using linear weights for the neurons. In such a case, the feedback loop in RQNN is omitted and the network can be termed as QNN. The potential function $V(x)$ is a function of θ^d and closed loop dynamics of QNN can be expressed in terms of the linear Schroedinger wave equation.

9.3 QNN with nonlinear Gaussian kernel

In a Gaussian kernel the nonlinear activation function is a Gaussian function. This function has a center randomly chosen between the upper and lower bound of the input. The potential function $V(x)$ is a nonlinear modulation of the input vector θ^d. Output of the i^{th} node can be written as

$$E_i = exp(-(\theta^d - c_i)^2/2\sigma^2), \tag{42}$$

where c_i is the center. For simplicity we can consider $\sigma = 1$. The architecture of the QNN is depicted in Fig. 16. The learning algorithm is defined

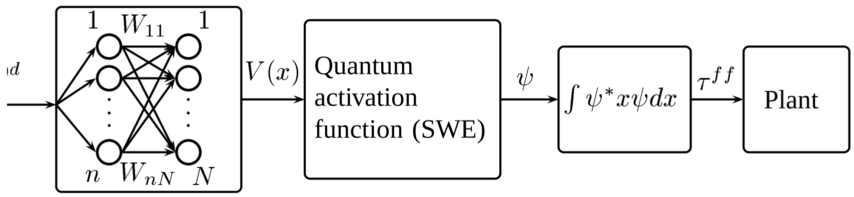


Figure 16. The QNN architecture with a Gaussian kernel.

as

$$\frac{\partial K(x,t)}{\partial t} = \beta E_i(t)[\dot{e}(t) + \gamma e(t)]. \tag{43}$$

The performance of this network is compared with that of a simple Radial Basis Function Network (RBFN). The above QNN performs well with a range of parameters.

9.4 Simulation results II

Simulation results obtained using a QNN with Gaussian kernel is presented in this section. The parameters are chosen as $\beta = 0.6$, $m = 0.7$, $\zeta = 300$, $\gamma = 1.5$. Fig. 17 shows desired and actual trajectories of the manipulator angle θ using QNN with a Gaussian kernel, whereas Fig. 18 shows the same using a simple RBF network. The variation in the square error for both the cases is shown in Fig. 19. The RMS error for the QNN is 0.03 and for the NN is 0.04, i.e. both compare well. In general, all adaptive control algorithms use the knowledge of e and $\dot{e}$ taken from the sensor and it is very often that the sensor adds some noise to them. Sensor noises may not be unbiased and thus may not have zero mean statistics. Simulation experiments are repeated while adding sensor noises. It is seen that if the noise has a zero mean statistics, then both QNN and RBFN model track the desired trajectory efficiently. However, if the noise has a non-zero mean statistics, then QNN performs efficiently while the performance of RBFN model degrades. Table 1 shows the performance of both the models in terms of the RMS error for various levels of noise. First two columns represent the mean of Gaussian noise added to the two variables e and $\dot{e}$. The third and fourth columns represent variance of Gaussian noise added to same variables. Whenever noise has non-zero mean statistics, QNN performs well while RBFN model degenerates in its performance.

Table 1. Performance comparison between RBFN and QNN.

Noise mean		Noise variance		RMS error	
e	$\dot{e}$	e	$\dot{e}$	RBFN	QNN
0.0	0.0	0.01	0.1	0.0388	0.0335
0.5	2.5	0.01	0.1	0.8170	0.1756
1.0	4.0	0.01	0.1	1.3506	0.1760
0.0	0.0	0.10	1.0	0.0389	0.0337
0.5	2.5	0.10	1.0	0.8172	0.1758
1.0	4.0	0.10	1.0	1.3509	0.1762

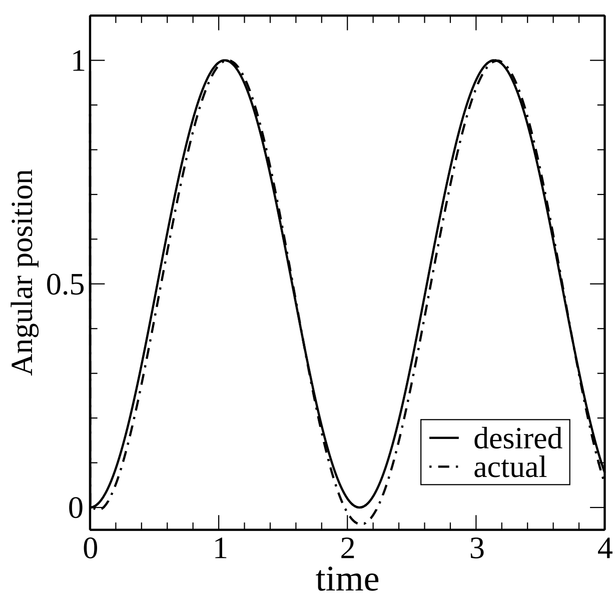


Figure 17. The desired and actual trajectories for the angular position θ of a robot manipulator using QNN with a Gaussian kernel.

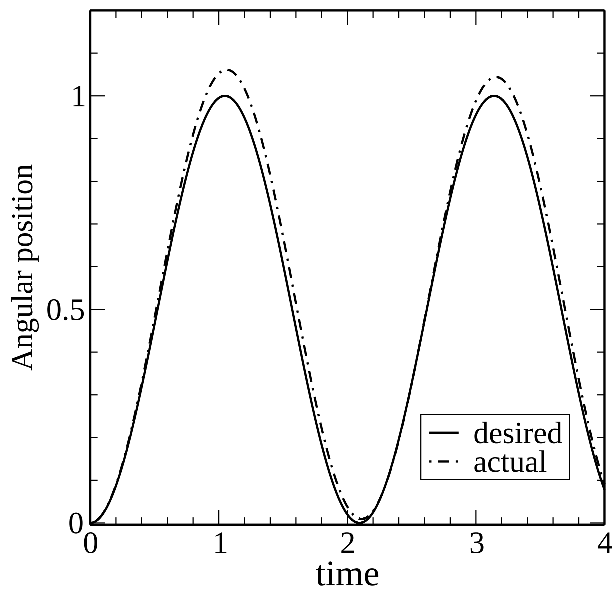


Figure 18. The desired and actual trajectories for the angular position θ of a robot manipulator using RBFN.

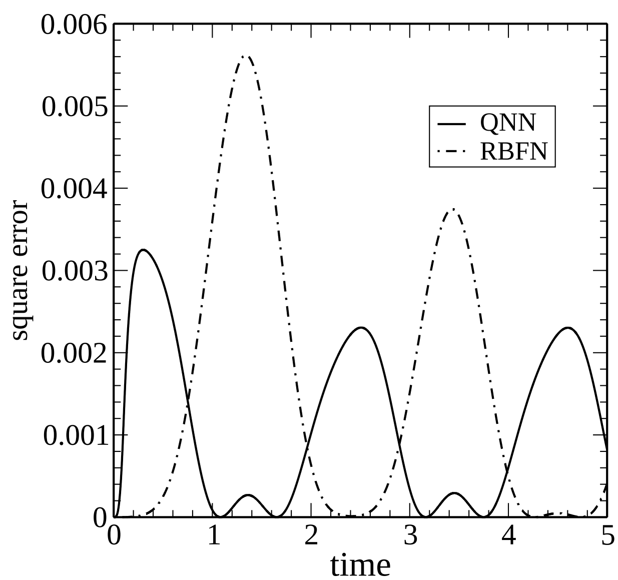


Figure 19. Square error with respect to time.

10 Conclusion

We have presented a recurrent quantum networks based novel approach to the subjective computation framework. In this approach, we can estimate a signal without making any *a priori* assumption about the signal as well as the embedded noise. A quantum mechanical model of a damped harmonic oscillator is also presented and verified through simulation results. Using reinforcement learning, the system parameters are also properly estimated.

QNN based adaptive control schemes have been proposed. The control schemes are implemented on a single link robot manipulator. The results are compared with a RBFN based adaptive control. It is observed that the performance of RBFN based adaptive controller degrades in the presence of sensor noise, while QNN based adaptive controllers are robust to the presence of sensor noise. The next step would be to consider a hybrid system where a QNN based adaptive controller is updated using a dissipative quantum model of uncertain nonlinear dynamical systems.

All our examples show that the subjective computational paradigm makes a system more intelligent.

References

1. Behera, L., and Sundaram, B. (2004) Stochastic filtering and speech enhancement using a recurrent quantum neural network, in M. Palaniswami, C. Chandra Sekhar, K. V. Ganesh and K. G. Muralidhar (eds.), *ICISIP-2004*, IEEE Press, pp. 165–170.
2. Behera, L., Kar, I., and Elitzur, A.C. (2005) A recurrent quantum neural network model to describe eye tracking of moving targets, *Foundations of Physics Letters*, accepted.
3. Behera, L., Kar, I., and Elitzur, A.C. (2005) Recurrent quantum neural network and its applications, in J. A. Tuszynski (eds.), *The Emerging Physics of Consciousness*, Springer–Verlag, Berlin–Heidelberg, to appear.
4. Bhaktivedanta Swami, A.C. (1974) *Srimad Bhagavatam*, BBT International.
5. Behera, L., Bharat, S., and Singhal, G. (2003) Speech enhancement using a recurrent quantum neural network, in B. Prasad (ed.), *IICAI-2003*, Springer-Verlag, Berlin–Heidelberg, pp. 43–56.
6. Cohen, M.A., and Grossberg, S. (1983) Absolute stability of global pattern formation and parallel memory storage by competitive neural networks, *IEEE Trans. SMC* **13**, 815–826.
7. Amari, S. (1983) Field theory of self-organizing neural nets, *IEEE Trans. SMC* **13**(5), 741–748.
8. Behera, L., Gopal, M., and Chaudhury, S. (1996) On adaptive control of a robot manipulator using inversion of its neural emulator, *IEEE Trans. Neural Networks* **7**(6), 1401–1414.

9. Behera, L., Chaudhury, S., and Gopa, M. (1998) Applications of self-organizing neural networks in robot tracking control, *IEE Proceedings Control Theory and Applications*, **145**(2), 134–140.
10. Amari, S. (1990) Mathematical foundations of neurocomputing, *Proc. IEEE* **78**, 1443–1463.
11. Amit, D.J. (1989) *Modeling of Brain Functions*, Cambridge University Press, Cambridge.
12. Dawes, R.L. (1992) Quantum neurodynamics: neural stochastic filtering with the Schroedinger equation, *IJCNN – Volume 1*, 133–140.
13. Bialynicki-Birula, I., and Mycielski, J. (1976) Nonlinear wave mechanics, *Annals of Physics* **100**, 62–93.
14. Goldberg, A., Schey, H.M., and Schwartz, J.L. (1967) Computer-generated motion pictures of one-dimensional quantum mechanical transmission and reflection phenomena, *American Journal of Physics* **35**(3), 177–186.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 345–354

QUANTUM MEASUREMENT ACT AS A SPEECH ACT

JEAN SCHNEIDER
Laboratoire de l'Univers et ses Théories, Observatoire de Paris–Meudon
Bat. 18, Pl. J. Janssen, F-92195 Paris–Meudon, France
(jean.schneider@obspm.fr)

Abstract: I show that the quantum measurement problem can be understood if the measurement is seen as a "speech act" in the sense of modern language theory. The reduction of the state vector is in this perspective an intersubjective — or, better, a-subjective — symbolic process. I then give some perspectives on applications to the "Mind–Body Problem".

Keywords: Quantum Measurement – Mind–Body Problem – Language

1 Introduction: "Realism" is an Idealism

Science, and, in particular, physics, is a perpetual fight against absolute basements and essences: space, simultaneity, heat as phlogistic, ether, properties of quantum objects. Relativity theory and quantum physics have shown all the benefits of the renouncement of essences such as ether and values of physical quantities. Such essences do not belong to experience and are only the fruit of imagination (more exactly they represent an abstraction constructed out of experience thanks to *a priori* concepts). In this sense, if by "realism" one means the belief that there is an essence behind experience, realism is an idealism. An "objective underlying reality" is only a word (expressing a desire of reality) and there is nothing behind or beyond it. Since the present meeting is also devoted to "the subjective", it is worthwhile to point out that the same phenomenological and constructivist approach holds also for the mental world and that, for instance, "the" mind (as an essence) has also to be renounced.

2 The Quantum Measurement

2.1 Reminder of the problem

Although the rules of quantum mechanics are well known, it is better, for clarity, to recall them. They rest on primitive notions such as "system", "state of a system", "observable" and can be summarized as follows:

- R1: Every system S is described by a Hilbert space $Hilb$.
- R2: Any state of the system is described by a $\psi \in Hilb$.
- R3: In absence of measurement, the system evolves according to the Schrödinger equation, $i\hbar\partial\psi/\partial t = H\psi$, where H is the Hamiltonian of the system.
- R4: A physical quantity (observable) is described by an operator A on $Hilb$.
- R5: The only possible outcomes of a measurement of the observable represented by A are the proper values a_i of A, with the corresponding proper vectors: $A\psi_i = a_i\psi_i$.
- R6: The result of the measurement of A on the system in a state ψ is random with a probability given by $p_i = |\langle\psi_i|\psi\rangle|^2$.
- R7: After the measurement the system is in the state ψ_i ("state vector collapse").

There is a kind of duality in these fundamental concepts and rules, since rules R1 − R3 deal with the description of the system, while rules R4 − R6 deal with observables which appear heterogeneous with respect to the system. In this sense, the observables do not belong to the system.

It is natural for a physicist to try to describe the measurement as an interaction between the system and the apparatus and therefore the latter as an other system, i.e., by a state vector ψ_A of $Hilb$. But then, when this approach is translated into the quantum formalism, a contradiction appears. Indeed, let ψ_{SA} be the vector describing the meta-system "system + apparatus" and H_{SA} the interaction operator system-apparatus. Then:

- from (R3), after the measurement, the meta-system is in the (unique and predictable) state $\psi_{SA}(t) = e^{-(i/\hbar)H_{SA}t}\psi_{SA}(0)$;
- from (R7), after the measurement, the system is, at random, in one of the states ψ_i.

The two final states are incompatible. That is the problem. The central question then is: "Why does the process of observation (giving rise to the state vector collapse, that is to a sudden transition between two states of the observed system) escape the normal evolution of the pair system +

observer described by the Schrödinger equation?". There is an even more radical question. The knowledge of the state $|\psi\rangle$ of the system is necessary to predict the possible outcomes of the observation. But it is not sufficient since, to describe the set of outcomes, we need to add a heterogeneous element, the operator associated with the observable which is measured. Why is this second level necessary? I shall call it the "question of the concept of observable".

2.2 Why "decoherence" does not solve the problem

Several solutions have been proposed during the past years. Some of them modify in a way or another the foundations of quantum mechanics: hidden variables, spontaneous localization, non linear Schrödinger equation, "many worlds" (in fact many observers) interpretation, *etc.*

A different solution, known as the decoherence theory, has been developed by Zeh, Zurek, Omnès and others without any change in the standard postulates [1,2]. It consists in pointing out that the interaction of the system with the environment diagonalizes very rapidly, with a very short characteristic time τ and in an irreversible manner, the density matrix of the meta-system formed by the system, the observer and the environment, thus leading to an apparent quasi-collapse of the state vector. This explanation has become popular since the occurence of decoherence has been experimentally demonstrated [3].

Unfortunately, the explanation based on decoherence is not satisfying for the following reasons. First, decoherence is a statistical notion based on the statistical matrix representing statistical ensembles of systems. But in a given experiment one does not deal with statistical ensembles but with an individual system (and an apparatus). In other words, the uniqueness of the result of a given experiment is not expressed by a diagonal matrix. In mathematical terms, decoherence leads to a diagonalized matrix, while in a single experiment all the diagonal elements of the matrix are all zero except one. In other words, the expression

$$\text{“}\rho = \begin{pmatrix} 1/2 & 0 \\ 0 & 1/2 \end{pmatrix}\text{”}$$

is not the same as

$$\text{“}\rho = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix} \quad \text{or} \quad \rho = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}\text{”}.$$

Supporters of decoherence often reply that quantum physics makes only statistical predictions. That statement is contradicted by predictions like "the measurement of any component of the spin of a photon in a single experiment will give an integer result". In addition, the very concept of "ensemble" presupposes that there are single individuals of the ensemble. If quantum theory only deals with statistical predictions, it is an incomplete theory since individual experiments escape it. A second problem with decohrence refers to the question of the concept of observable (Sec. 2.1). This question is, in fact, addressed to any attempt to describe the measurement as a system–apparatus interaction. If this interaction were a good model, it should be able to describe several aspects of a measurement with, as only primitive concepts, those of state vectors ψ_S, ψ_A of the system and the apparatus and the system–apparatus interaction Hamiltonian. Namely:

- What is the meaning of an "observable"?
- What means "the value" of an observable?
- Why is the outcome of an experiment random, while the interaction is deterministic?
- After the interaction why is the system exactly in one of the states $|a_i\rangle$?
- Why are the only possible outcomes one of the proper values of an operator A (that the model should construct)?

J. S. Bell was well aware of all these difficulties when he wrote his paper [4] where he proposed to replace observables by "beables".

2.3 What is really a measurement?

To be performed, a measurement needs two ingredients:

- an apparatus, object of perceptions and manipulations,
- (pre-existing) mathematical symbols to express the result.

There is indeed no measurement without (or before) the expression (in mathematical terms, for instance "$A = a_i$") of its result. This is not a philosophical point of view, it is an empirical fact. In this respect, $A = a_i$ *does not* reflect or translate a reality outside itself. It creates, by its own declaration, this reality. It *is* this (symbolic) reality. As a matter of fact, a symbol is its own actualization. It means that, as a mathematical symbol, the outcome of a measurement is not the (quantum) state of the screen of an apparatus and, thus, cannot be described by a state vector. In prequantal terms, a symbol, e.g., **1**, is differrent from its pixelized image and from its physical support, since the symbol **1** is required *a priori* before any pixelisation (Fig. 1). In terms of interaction, a measurement is thus not a physical interaction (i.e., described by a Hamiltonian) between two systems (described by state vectors), but an "interaction" between language (discourse) and a perception.

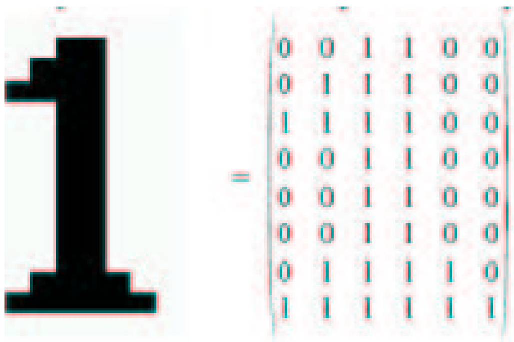


Figure 1. The pixelisation of the symbol "**1**" is different from the symbol itself.

These remarks lead in a natural way to the solution I proposed [5]: the measurement act is not a physical transition or phenomenon, but a purely *semantic* act, in the same line as the *speech acts*[a] well-known in the language theory. A speech act does not describe a situation independent of itself, it creates what at the same time it describes. The measurement act has more precisely the structure of a *declaration*. The question whether this process is of psychological nature or takes places in some mind is not relevant. A semantic process is exterior to any individual, it is existing only as shared by the community of locutors and in this sense is objective. It just takes place in a symbolic universe, the universe of discourse in which all physicists live. It is the universe studied by linguistics and semiotics. It has nothing to do with psychology. It is not the "consciousness" of the observer which operates the state vector collapse, as was proposed by London and Bauer [7]. It is the result of an impersonal, non psychological but empirically ascertainable, production of a *signifier* which exists only as shared by the community of physicists.[b] In other words, it is not a *passive* registration, it is an *active* semantic process. The subjectivity of one observer is to be replaced by the intersubjectivity of the discourse, with no psychological subject, where the impersonal semantic collapse of the state vector takes place. To express it in another way, the measurement act, as giving an attribute to a system, is an act of attribution, a declarative act. The judicial domain can help us for an analogy: a judgement does not register afterward

[a]For a general introduction to these notions, see [6].
[b]According to modern views, consciousness is, on the contrary, defined as being the crossrads of different *signifiers*.

a pre-existing reality, it does create it by its verdict. The judgement "guilty" creates, in the judicial universe, guilt. The result of that act is of course random and has a probability of occurence $|\langle a_i|\psi\rangle|^2$. This conception sheds a new light on causality in the quantum measurement: the result of a measurement act has no other cause than itself, it is its own cause. It is in this respect that there is no quantum causality.

The "classical" character of the measurement apparatus lies in the semantic nature of its description, not in its complex atomic structure (as could naturally, but erroneously, be inferred from the Ehrenfest theorem). A system is a measurement apparatus only insofar as it is described by a set of *signifiers*; otherwise it is nothing but a quantum system. As for the observer, it is most certainly decomposable in atoms, but it is an observer only as a support of semantems. In a measurement, the so-called interaction with the measuring apparatus (which would be described by a Hamiltonian) is an encounter, an interaction if one may say so, between the observed system and the universe of discourse. Because this encounter is not describable by a Hamiltonian, the measurement process escapes the Schrödinger equation. It was N. Bohr [8] who was among the first authors pointing out the role of language in the measurement. But for him language was just a collection of words, the vocabulary of classical physics. Here the point of view is different: what is important is not so much the *content*, but the *auto-productive* nature of a *signifier* and it is this auto-production which gives rise to the state vector collapse.

The idea that a measurement does not result from an interaction between a system and an apparatus has been also recently been expressed by Ulfbeck and Bohr [9]. For these authors, quantum physics does only deal with clicks of an apparatus. But they do not address the essential question: "What is a click?". For instance, when a click is recorded in a movie, what is the real click? The click or the movie of the click? The present paper explicitly claims that the objective (intersubjective) click is the declaration: "There is/was a click".

We can now apply this constructivist approach to the notion of subject and to the Mind–Body problem.

3 Mind–Body

3.1 General principles

We have seen that a measurement is the (random) emergence of a symbol detached from (the appearance of) an apparatus. If the symbol is mathematical, it is a scientific (physical) measurement.

But there can be "pre-scientific" measurements when the symbol is vague or fuzzy, such as a colour, sound, smell, *etc.* There is then (at least up to now) no mathematical representation of these vague symbols by hermitian operators. But they do nevertheless exist (i.e., are experienced) as symbols. All these vague symbols are not systems and have no state vector.

A first application of vague symbols in the context of quantum physics is the answer they provide to an argument often opposed (in particular by J. S. Bell) to the point of view defended here that the state vector collapse is operated by an observer. The argument is formulated in ironic terms: "Only physicists having their PhD can operate a state vector collapse". In other words, observations or experiments made without the support of elaborated mathematics would not exist. The notion of a vague symbol provides an answer: every experience, whatever its vagueness, is legitimated at its own level. It is a scientific measurement when it is expressed in scientific symbols.

Vague symbols lead to a more general notion of symbol, introduced progressively along all the XXth century by semiotics (the science of symbols). Indeed, words and mathematical symbols are special types of symbols. Symbols are what Cassirer calls symbolic forms. They are, like Kantian concepts, *a priori* symbols. They belong to an unlimited variety of registers: acoustic, graphical, gestual, conceptual, judicial, institutional, esthetical, emotional, affective, ethical, *etc.* They are all structured as declarations designating what they construct. To be less elliptic, this structure means that in a first step, as a declarative gesture, they produce themselves and in a second (timeless) step they present themselves as designating from the outside, as an objective reality, what they have just created.[c] To illustrate this approach by a concrete example, the symbol "a" is, in a first time, just a given letter which, in second time, designates the notion of "symbol a". It represents a kind of self-distanciation of symbols.

As mentioned in the introduction, no genuine "consciuosness" nor "subject" is needed. They are not genuine instances, they are constructed objects out of two primitive instances: subject-less sensations and (declarative) symbols. This construction, also called symbolization, detaches a symbolic object from the sensation. To be more precise, there is a primitive instance, the so called "object-relation" (equivalent to a sensation) which is a complex made of a relation and its "to be" object, entangled

[c]This process leads to the notion of "afterwardness", a non-linear notion of time, described by J. Lacan in his work (*passim*).

together. At this point, it is not relevant to ask if the object-relation is one or two instances, since the concept of number does not apply: we are in the realm of a "proto-arithmetic" [5]. More exactly, symbolization creates attributes and an object is in a second step the synthesis of different attributes.

3.2 Tentative quantum modelling of the Mind–Body relation

To address this question, Mind and Body have first to be defined and characterized in the framework of the concepts presented here [10].

"The" mind, or the subject, as things are bad primitive concepts. They have to be replaced by a-subjective symbols, i.e., symbols by their own, source-less. In the present view, the "subjective" is then a particular object: an object constructed out of ethical symbolic forms.[d]

The physical body is *not* the source of sensations. As a physiological object, it is an abstraction constructed by a bio-physical theoretization out of primitive and source-less sensations.

In other words, the primitive concepts are no more Mind and Body, but sensations and symbols out of which Mind and Body are constructed abstract objects. In particular, the body is an abstract synthesis of physiological attributes resulting from symbolization.

In quantum theory, symbolic attributes (i.e., values of observables) emerge randomly and are cause-less. By extending the notion of symbol as in Sec. 3.1, there are two types of bodies created by symbolization out of sensations:

- the physical, or physiological body, i.e., the bio-physical description of the body created by the conceptualization of physics;
- the emotional body created by emotional symbols (words of pain, joy, anxiety, *etc.*)

Emotional symbols are genuine, not constructible from physiological instances. This conception is generalizable to non-verbal symptoms (I refer here to the psycho-analytical conception of symptoms as symbols).

Take, for instance, as physiological observables skin colour, cardiac rhythm, blood pressure. The emotional observables are, for instance, an exchange of words (with or without an emotional content with an interlocutor). A complete discussion should include unconscious aspects, always

[d]The processes by which the subjective is constructed are very complex, they involve parental and social discourses, words like "I" which precede the subject, identification, *etc.*; strictly speaking, the sentence "I speak" means something like "The word "I" speaks". That is why the traditional subjective is in reality a-subjective.

emotional, of symbols. The two types of observables do not "commute", they are complementary in the quantum mechanical sense: it means that an individual cannot at the same time be subject to a physiological observation and have emotional relationships. It is interesting to note that C. Bohr (father of N. Bohr, a biologist) wrote:

> "An organism cannot at the same time be subject to a chemical analysis and be declared as living."

We then can have a succession of non-commutative events to describe how an emotion can make a face blushing: white skin $\longrightarrow$ expression of emotion $\longrightarrow$ pink skin. It is similar to the quantum measuremets of non-commutative components of ths spin: $S_X = +1/2 \longrightarrow S_Z = +1/2 \longrightarrow S_X = -1/2$. We thus have a simplified scheme for a quantum modelling of the undeterministic evolution of the body.

4 Perspectives

The main stream in current cognitive sciences is to seek a "naturalization" of consciousness. It is an attempt to treat Mind and Consciousness as objects (however immaterial they are). An essential prediction of the present approach is that these attempts of naturalization will certainly improve our knowledge of the physical brain, but not of the mind.

Secondly, many authors attempt to reconstruct, essentially thanks to decoherence, the classical world out of the quantum level. In the present approach, it is the classical world which precedes the quantum level: the latter is constructed from the behavior of macroscopic apparatuses.

With the concept of afterwardness briefly discussed in Sec. 3.1 (and formalized in [5]) it becomes possible to reformulate the notion of consistent history (see, e.g., [2]) and the transform it into a notion of "afterward history" [11].

References

1. Zurek, W. (1982) Environment–induced superselection rules, *Phys. Rev. D* **26**, 1862–1880.
2. Omnès, R. (1994) *The Interpretation of Quantum Mechanics*, Princeton University Press, Princeton (NJ).
3. Davidovich, L., Brune, M., Raimond, J.M., and Haroche, S. (1996) Mesoscopic quantum coherences in cavity QED: preparation and decoherence monitoring schemes, *Phys. Rev. A* **53**, 1295–1309.

4. Bell, J.S. (1990) Against measurement, *Physics World* **8**, 33–40.
5. Schneider, J. (1994) The now, relativity theory and quantum mechanics, in M. Bitbol and E. Ruhnau (eds.), *Time, Now and Quantum Mechanics*, Editions Frontières, Gif–sur–Yvette.
6. Austin, J. (1962) *How To Do Things With Words?*, Oxford University Press, Oxford.
7. London, F., and Bauer, E. (1983) The theory of observation in quantum mechanics, in J. A. Wheeler and W. Zurek (eds.), *Quantum Theory and Measurement*, Princeton University Press, Princeton (NJ), pp. 217–259.
8. Bohr, N. (1983) Discussions with Einstein on epistemological problems of atomic physics, in J. A. Wheeler and W. Zurek (eds.), *Quantum Theory and Measurement*, Princeton University Press, Princeton (NJ), pp. 9–49.
9. Ulfbeck, O., and Bohr, A. (2001) Genuine fortuitousness. Where did that click come from?, *Found. Phys.* **31**(5), 757–774.
10. Schneider, J. (1997). Time and the Mind–Body problem: a quantum perspective, *American Imago* **54**(3), 307–322.
11. Schneider, J. (2000) La nature n'a pas de passé ni d'origine, *Topique* **73**, 37–53.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 355–365

SELF-REFERENCE IN QUANTUM MEASUREMENT

SAMUEL MARCOVITCH
Physics Department, Tel-Aviv University, P.O. Box 39040
Tel-Aviv 69978, Israel
(shmuelma@post.tau.ac.il)

Abstract: Quantum measurement does not necessarily entail the involvement of human consciousness. However, the fact that people implicate consciousness only in quantum measurement phenomena is not accidental. In classical physics we could remain with "objective reality" description. It is suggested that a yet-unknown element of self-reference in quantum measurement causes the collapse of the wave function. Proposed is a new way of addressing physics and quantum theory as a whole based on Model Theory considerations. In this way a methodological analogy is constructed between the interpretations of Peano Arithmetic (PA) and physics. The interpretational shift PA receives when added with the negation of Gödel's Theorem as an axiom is similar to the interpretational shift classical physics formalism receives when added with a law indicating that the zero-state does not equal zero.

Keywords: Self-Reference – Gödel's Theorem – Quantum Theory – Non-Standard Arithmetic

1 Introduction

It will be claimed that all physical theories are in-principle incomplete. A "theory of everything" cannot be formulated (a formal proof will be given elsewhere). The term "incompleteness" applied on physical theories does not mean non-deterministic, due to quantum probabilities, nor insolvability, due to certain conditions on the mathematical equations. It means that Nature is strong enough in the sense that for every formalized theory it is possible to find a physical system which has no description in it; for example, a wave function whose eigenvalues and eigenstates are in principle not derivable. In order to do so, an interdisciplinary approach to major branches in science such as physics and mathematics is applied using model theory considerations. It is claimed that a number of basic characteristics of these branches of science have similar "behavior" based on the appearance of self-reference.

The paper is built as follows. In Section two, a short presentation of a major breakthrough in mathematics — Gödel's Theorem and its derivatives – is given. In Section three, Quantum Theory is revisited both formally and in interpretational way. Dealing with the interpretations of Quantum Theory special attention will be given to Penrose's attitude [1]. In Section four, a comparison between the extension of PA through Non-Standard Arithmetic and the extension of a physical theory through the formalism of Quantum Theory is given. In this part, a connection between Gödel's Theorem and Quantum Physics is proposed. In Section five, the collapse of the wave function is reinterpreted through the methodology proposed in this letter. It is claimed that the collapse may be derived, instead of exteriorly postulated, through the suggested methodology.

2 Gödel's Theorem and Model Theory

An intuitive and brief outline of a number of basic elements for the construction of Gödel's theorem is given (for a rigorous construction, see [2, 3]).

Gödel's Theorem was phrased in the Natural Number axiomatic system (NN) or, equivalently, in PA. This system contains the regular axioms of logic, excluding the negation assumption in which, if A is to be proved, its negation is assumed, which then leads to contradiction, concluding that A is correct. One of the most significant parts of Gödel's Theorem was defining a code, a code for each character or symbol in the language describing the natural numbers, where the code itself is a string of natural numbers. Thus, just as computer text files in the DOS format have ASCII codes, so mathematical propositions, theorems and proofs have their codes.

There are unique kinds of propositions whose codes will be called "open codes". In such propositions, there exists a free variable, a variable which is mentioned within the proposition, yet the proposition does not relate to it. For example, $X + 3 = 5$ is an open code. It may be closed by setting a number instead of the free variable, as in $7+3 = 5$, which is a closed falsity proposition, yet grammatically valid. It may also be closed by adding a quantifier to the free variable: $\exists X|X + 3 = 5$. An open code cannot be a legitimate theorem.

Gödel's Theorem is constructed from the following two basic elements. First define the open code P (P for Proof). $P(x, y)$ is a mathematical proposition, but it may be treated as a computer program [3]. P has two variables: a code of a proof x and a code of a proposition y. P checks whether x is a valid proof for y. P wouldn't be too difficult to program since only formal proofs are discussed. Therefore, P should check that each line of the inserted proof x is correctly inferred from the axioms or from previous lines. Eventually, the proof should end with the desired proposition y. P is an open code since it is general. It doesn't apply to only a specific proposition, or a proof, but to any grammatically valid proofs and propositions. Gödel formulated P mathematically [2].

The second basic element from which Gödel's Theorem is constructed is the open code $Q(x, y, z)$ (Q for Quinn). In this element the precious value of self-reference appears. Q has three variables: an open code x, a code of a number y and a closed code z. Like P, Q can also be thought of as a computer program. Q checks whether closing x by setting the open variable by the number coded by y indeed gives z. For example, assume that x is the code of $3 + X = 5$, y is the code of the number 2 and z is the code of $3+2 = 5$. Then Q's output is TRUE, otherwise FALSE. In Gödel's Theorem, a modified version of Q is used, which will be called AQ. AQ is exactly the same as Q, just endowed with an extra condition that y is the same as $/x$, where "/" is the action of taking the number which is the code of the proposition. This way, instead of having three variables, AQ has only two variables and checks if closing the open code x by setting the number $/x$ instead of the free variable yields z. In the previous example, if the code of $3 + X = 5$ is 167, then AQ-ing $3 + X = 5$ is setting 167 instead of x: $3 + 167 = 5$.

Before introducing Gödel's Theorem let's examine its generating proposition, also referred to as Gödel's "uncle":

$$u = \{\neg\exists x \exists y | P(x, y) \cap AQ(z, y)\}. \tag{1}$$

As previously seen, Godel's "uncle" is an open code, since z has no referring. Therefore it is certainly not a theorem. u may be closed by setting $/u$ instead of the free variable z. Doing so is actually AQ-ing Gödel's "uncle", which is Gödel's Theorem:

$$G_T = \{\neg\exists x \exists y | P(x, y) \cap AQ(/u, y)\}. \tag{2}$$

G_T is a number, a code — the AQ-ing of u. Therefore the right part of the proposition is true: there exists a number y which is the code of AQ-ing Gödel's "uncle". y is actually the code of Gödel's Theorem itself. If the whole proposition is to be true, then there should not be a number x which is the code of the proof for y, meaning, if G_T is to be true, then it should not have a formal proof. Gödel's Theorem may literally be stated as:

Theorem 1: There is no proof for a proposition that is AQ-ing: "There is no proof for a proposition that is AQ-ing z".

For the sake of convenience, this may also be loosely read as: There is no proof for: "there is no proof". These literal representations of Gödel's Theorem have a unique structure which includes two identical parts, one outside the inverted commas and the other inside. This is the literal meaning of AQ-ing. Gödel's Theorem implies the incompleteness of NN. It may also be generalized to axiomatic systems with an infinite number of axioms:

Theorem 2: In any axiomatic consistent system that is at least as strong as NN (meaning it includes arithmetic of substitution and multiplication, and the notion of natural number), and in which for any proposition it is possible to determine whether it is an axiom or not, there are correct propositions that are improvable.

The proof of Gödel's Theorem: Assume G_T is incorrect. Therefore, there is a proof for: "there is no proof". But, if there is a proof for: "there is no proof", then "there is no proof" is correct. Therefore, "there is no proof" indeed has no proof, which is a statement equal to G_T, leading to contradiction ($\neg G_T$ was assumed). However, if it has just been concluded that G_T is correct, then this process of concluding itself is a proof, which can be seen as another contradiction (therefore, not only $\neg G_T$ but also G_T is incorrect, as in the "Liar from Zeno Paradox"). However, the above is not a formal proof. A postulate outside the axiomatic system, the negation assumption, was used.□

Another manipulation may be done with Gödel's Theorem: insert it as an axiom into NN. Can the incompleteness phenomenon be overcome then? In such a case it will be possible to phrase G_T', which is once again improvable. In addition, $\neg G_T$ may be inserted as an axiom into NN. Doing so is equivalent to the negation assumption, in which case it will not be possible to phrase G_T'. However, inserting $\neg G_T$ as an axiom into NN keeps the axiomatic system consistent. Yet, then there is a number which is a code for the proof of G_T, but it is not 1, 2, 3,.... No natural number may be the code for the proof of G_T.

Inserting $\neg G_T$ as an axiom into NN gives birth to a new kind of arithmetic which is called non-standard arithmetic. In non-standard arithmetic the super-natural (or hyper-natural) numbers appear. The first one is the code for the proof of G_T. Supernatural numbers are greater than any natural number. It was found that a convenient way to represent these numbers is through three integer indexation (for example $I = [4, -5, 6]$). It is possible to define several indexations. In some, the substitution of $I1$ with $I2$ has formalization. In others, the multiplication of $I1$ with $I2$ has formalization. However, it was also found that there is no indexation in which there is formalization for both substitution and multiplication. This concludes that the insertion of $\neg G_T$ as an axiom weakened the arithmetic of NN. Herein hides the quantum linkage. Substitution and multiplication of supernatural numbers have complementary relations. The field of non-standard arithmetic is studied as a branch of Model Theory. Model Theory is a theory about theories (for a thorough description, see [4, 5]).

3 Quantum Theory Revisited

Several remarks on Penrose's attitude shall be mentioned, followed by revisiting a number of basic concepts in quantum theory. We shall conclude this section with a suggestion on the formalization of self-reference in physics.

3.1 Several remarks on Penrose's attitude

The use of Gödel's Theorem alongside quantum theory might seem familiar, as Penrose's book [1] comprises two parts: one devoted to Gödel's Theorem and the other to Quantum Theory (QT). Penrose claims that whole reality is scientifically describable (including the human brain). Furthermore, people understand that Gödel's Theorem is correct — they can "step outside the system". However, there is no formal description to the understanding of Gödel's Theorem. Therefore, genuine AI can never be programmed. In addition, the understanding of Gödel's Theorem has also physical implications for the brain. Therefore, a phenomenon in which the wave function has no formal description is yet to be found. Not only is determinism no more valid because of quantum probabilistic behavior, but the probabilities themselves may be totally unknown, as in the case of the human brain system. Penrose treats this phenomenon as quantum resonance. Here, however, a stronger hypothesis will be added. Gödel's Theorem is not only the principal theoretical source for special quantum behavior in the brain. It also leads to QT itself and to the incompleteness of physics.

Proposed is a model-theoretical isomorphism between NN "before and after" its extension by the negation of Gödel's Theorem and Physics' formalization "before and after" its extension by QT.

3.2 Formalism

As a directing philosophy it may be said that QT and Gödel's Theorem are both self-relating and have limiting theorems. However, several formalistic remarks on QT will preliminary be added:

First, in contrast to classical formalization, quantum formalization may be described by Creation and Annihilation Operators (or second quantization). These non-unitary operators are the essence of the quantum world. If they were used in the classical formalization, their action on states would always yield zero. One of the building blocks of QT is Creation and Annihilation Operators with non-zero eigenvalues.

Second, physical quantities in classical physics are numbers, or scalars, both before and after a measurement. Therefore they commute and no uncertainty principle, or complementary relations, appear. In quantum theory, however, physical quantities do not always commute. Therefore, it may be said that quantum theory changed or weakened the arithmetic of physical quantities.

Third, an additional difference between the classic and the quantum is the existence of the vacuum state ($|0\rangle$). There are two different kinds of "nothing" in QT: the classical nothing which equals zero (0) and the zero-state ($|0\rangle$). They are not the same. Measurable results can appear due to the difference, especially when applying them on the measuring device: "measuring nothing" is a zero-state, whereas "no measuring" is zero.

Fourth, a quantum system with finite boundary conditions is quantized, having a discrete spectrum. This is a possible starting point for having natural, or even supernatural, numbers in the quantum world.

However, where is the self-reference in quantum theory? It is well known that Euclidean Geometry, which was the single and true description of space for centuries, was replaced by Minkowski and Riemann Geometries as implied by relativity. According to the proposed analogy QT should cause a similar revolution to NN. Certainly, there is no problem with NN. However, the behavior of the quantum world analyzed in NN's domain requires adding a new axiom to the system.

In the traditional Copenhagen interpretation the measured and measuring systems are separated. The collapse is taken as exterior to the system. Here a different attitude will be taken. There is a single system that has a measuring subsystem and a measured subsystem. Such a system is self-referring; self-referring since one part of it is set to explore another part of itself. It is difficult to avoid this. Actually, all experimental physics deals with self-referring systems. No experiment is done without measuring.

One may ask, so how is this different from classical physics? Experiments were/are also conducted there. It is the quantum entanglement between the measured and the measuring that added this self-twist in the quantum world. In the classical world we could leave the detector out of the system. Therefore a more accurate definition of the system is: everything that is entangled with the measured quantity. Now, when the measurement is interior and not exterior, is there still the problematic non-unitary collapse? I believe that the collapse still happens and should not be postulated *ad hoc*; instead, it can be methodologically derived. However, it should be reinterpreted, and its reinterpretation is given in Sec. 5.

Gödel's Theorem may be examined in both its formal self-referring perspective and its meaning perspective. Is there a formal self-referring item in QT? First, recall that Gödel's Theorem is not an axiom. It is a mathematical derivation, which may be expressed as

$$0 = P(|0\rangle), \tag{3}$$

where 0 stands for *there–is–no–proof* , P represents *proving* and $|0\rangle$ — the AQ-ing of *there–is–no–proof* or, more briefly, *"there–is–no–proof"*. This is a self-referential proposition. The physical analogue to the mathematical derivation should be the result

$$0 = M(|0\rangle), \tag{4}$$

where 0 stands for *there–is–no–measurement*, M for *measuring* and $|0\rangle$ represents the AQ-ing of *there–is–no–measurement*, or *"there–is–no–measurement"*, which is indeed an appropriate description of the zero-state. Once again, a self-referential proposition has been produced. In the meaning perspective Gödel's Theorem inserted a new kind of dimension into mathematics: provable or improvable. Analogously, due to superposition, quantum theory also inserted a new dimension into physics, a dimension which is not binary and may be called "the amount of being in a certain state".

However, we have started with adding an axiom to the system, which is (model theoretically) analogous to adding a new physical law, not deriving a result. The quantum law to be added is a negative self-referring one,

$$0 \neq M(|0\rangle), \tag{5}$$

i.e. *there–is–a–measurement* that *measures "there–is–no–measurement"* (the zero-state). This new physical law is analogous to adding a new axiom into NN, namely the negation of Gödel's Theorem,

$$0 \neq P(|0\rangle). \tag{6}$$

Therefore, in the meaning perspective, the interpretation is different from the just mentioned one. Eventually, people understand that Gödel's Theorem is correct. They use and believe in the negation assumption. Assuming the negation of Gödel's Theorem prevents a(n uneasy) situation in which a proposition has no actual or formal value. In such a case there are no undecidable propositions. All theorems have actual or formal values. Analogously, even though superposition is real, it is potentially real, since no actual superposition can be observed in measurement. Eventually, even though Gödel's theorem is relevant in physics, physics has to "exterminate" it or assume its negation, since the observed physical quantity is single. Assuming that measuring the vacuum state does not equal not–measuring implies that there is no actual or observed superposition, deriving the collapse of the wave function! Therefore, it is proposed that the non-unitary collapse should not be exteriorly postulated but intrinsically derived from this methodology.

4 Comparing the Extension of PA through Non-Standard Arithmetic and the Extension of Physics through the Formalism of Quantum Theory

The comparison is illustrated from two perspectives: formalism and meaning. It should be mentioned that at the moment it is not clear if the suggested analogies are pure coincidence or if there is a more profound meaning beneath them. The first item is in the meaning perspective and is general for both theories "before" and "after" their extensions:

- Measurement predictability vs. proof derivability (meaning).

Before the introduction of QT into physics and Gödel's Theorem into mathematics, both the theories were believed to maintain:

- Determinism vs. complete mathematical systems — all theorems are provable (meaning).
- All physical quantities are commutable scalars vs. strong mathematical systems, in which substitution and multiplication are simultaneously defined and there is the notion of natural number (formalism).
- A derivation of Gödel's Theorem implies that a mathematical system which is both strong and complete is inconsistent, analogously to the well known findings that classical physics is incorrect (meaning).
- Physical systems are local in space and time vs. no infinite numbers (formalism).

We shall now add the negating self-referring items: $0 \neq M(|0\rangle)$ into physics and $0 \neq P(|0\rangle)$ $(\neg G_T)$ into mathematics.

- A physical state, law or result is analogous to a code, a formal description, in contrast to the real system or the real outcome (formalism).
- Inserting $\neg G_T$ as an axiom into NN vs. inserting new physical law: "zero is not the zero-state", applied on the measuring device (formalism).
- $|0\rangle$ vs I. Inserting $\neg G_T$ as an axiom into NN gives birth to supernatural numbers. The first, I, is the code for the proof of Gödel's Theorem $P(|0\rangle)$. I is analogous to the new measurement in quantum theory — the measurement of the zero state $M(|0\rangle)$ (formalism).
- Eigenstates: $a^n|0\rangle, (a\dagger)^n|0\rangle$ vs. $I+I+\ldots, I*I*\ldots$. The supernatural numbers are generated by substitution or multiplication operating on I, as the eigenstates of the wave function are generated by creation or annihilation operators operating on the vacuum state (formalism).
- Creation and annihilation operators operating on the vacuum state are like substitution and multiplication operating on supernatural numbers, all obey complementary relations, therefore weakening the arithmetic of the system (formalism).
- Superposition of states, the essence of the quantum world is analogous to Gödel's Theorem (meaning).
- Inserting $\neg G_T$ as an axiom into NN derives methodologically in physics that the observed outcome is single, or interior collapse (meaning).
- Non-locality in space and time appears analogously to the appearance of a new kind of infinity in the naturals, as the supernatural numbers are greater than any natural number (meaning).
- Indeterminism vs Improvability (meaning).

A possible test for the proposed analogies may be based on validating the "blank fields", as the comparison may reveal fields that are not yet filled in both physics and mathematics.

- Having no formalization to the non-unitary collapse derives having no formalization to G_T', when $\neg G_T$ is an axiom (a possible new derivation in mathematics).
- A specific example of incompleteness in physics is a system that has no formal description. Such a system is considered to be one in which there is no clear distinction between the measuring and the measured subsystems. The mathematical analog would be a specific mathematical improvable proposition with a similar ambiguity.

- In certain quantum systems, such as spin–half systems, $a\dagger$ operating on the upper-state yields zero, as if there was a conjugate vacuum state. It would be interesting to find out whether in supernatural arithmetic there is also a conjugate number to the first supernatural number (as in complex numbers $i^5 = i$).

5 Reinterpreting the Collapse

Let's assume there is an electron, isolated from the environment, which is in superposition of spin up and spin down states. It may be said that from the point of view of the electron, it "doesn't know" in which state it is. Analogously, from the point of view of inside the axiomatic system Gödel's Theorem is undecidable. Now suppose that there is a Stern–Gerlach (SG) device, also isolated from the environment that measures the spin of this electron. The familiar description of the collapse problem is whether the electron is now collapsed to a single eigenstate or the whole system is now in superposition. This question hasn't been answered yet.

Assuming that there is no theoretical scale limit to quantum interference, we should treat the isolated system as an entangled whole. Therefore, also the SG is in superposition of measuring up and measuring down. In the discussed methodology, it may be said that the SG (the self referring item of the system), is "stepping outside" the electron, analogously to stepping outside the axiomatic system, deriving that Gödel's Theorem is correct (decidable). Thus, from the point of view of the SG the electron is collapsed. Yet, then the SG itself is in superposition of measuring up and collapsed up electron plus measuring down and collapsed down electron (entanglement):

$$|SG\uparrow, e\uparrow\rangle + |SG\downarrow, e\downarrow\rangle. \tag{7}$$

We could now add another isolated device that measures the SG. Once again, the SG wave function collapses, but the measuring device stays in superposition. It may be claimed, however, that the collapse problem is actually not resolved here, since in the end a human-being is observing the measured result, and according to this methodology, he/she should become in a superposition state, each observing a collapsed wave function. Yet, it was previously claimed that if there is no distinction between the measuring and the measured, then the wave function has no formalization. In the case of a human-being entangled to the system, it is probably not so certain that there is a valid distinction between the measuring and the measured. Furthermore, in such a case the wave function of the whole universe cannot be formally treated.

6 Conclusion

The collapse problem in quantum theory has been puzzling the mind of many scholars for years. An uneasy feeling that it is connected somehow to human consciousness is not accidental, though it is not a necessity. In this letter, a connection between the self-referential objects in mathematics (Gödel's Theorem) and in quantum formalization (zero-state) is proposed. These self-referential objects have the feature of limiting the structures in which they appear (undecidability, non-determinism). Extending this connection also to the self-referential objects in us — the "self," "I" (or consciousness), gives rise to similar formally unsolvable questions (a psychophysical problem). This connection is what causes us to feel that our ability to understand Gödel Theorem differentiates us from the machine, and that we are the cause for the collapse of the wave function. These assertions are practically improvable, but can serve as connecting guidelines to a structural equivalence in all areas of human perception. There are and will always be things we cannot formalize.

Acknowledgement

I would like to thank Dr. Avshalom Elitzur for fascinating discussions.

References

1. Penrose, R. (1994) *Shadows of the Mind: A Search for the Missing Science of Consciousness*, Oxford University Press, Oxford.
2. Gödel, K. (1931) On formally undecidable propositions of *Principia Mathematica* and related systems, Monatshefte für Mathematik und Physik **38**, 173–198.
3. Hofstadter, D.R. (1979) *Gödel , Escher, Bach: An Eternal Golden Braid*, Basic Books, New York (NY).
4. Hodges, W. (1997) *Shorter Model Theory*, Cambridge University Press, Cambridge.
5. Robinson, A. (1966) *Non-Standard Analysis*, North-Holland, Amsterdam.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 367–388

A CONCEPTUAL INTRODUCTION TO NELSON'S MECHANICS

GUIDO BACCIAGALUPPI
Institut d'Histoire et de Philosophie des Sciences et des Techniques, 13 rue du Four
75006 Paris, France
(guidob@univ-paris1.fr)

Abstract: Nelson's programme for a stochastic mechanics aims to derive the wave function and the Schrödinger equation from natural conditions on a diffusion process in configuration space. If successful, this programme has some potential advantages, which are briefly sketched, over the better-known deterministic pilot-wave theory of de Broglie and Bohm. The essential points of Nelson's strategy are then reviewed, with particular emphasis on conceptual issues relating to the role of time symmetry. The main problem in Nelson's approach is the lack of strict equivalence between the coupled Madelung equations and the Schrödinger equation. After a brief discussion, the paper concludes with a sketch of two possible strategies for trying to overcome this problem.

Keywords: Stochastic Mechanics – De Broglie-Bohm Theory – Time Symmetry

1 Introduction

Within the foundations of quantum mechanics, Nelson's stochastic mechanics [1,2] is generally less well-known than other approaches, and is often presented as a stochastic variant of de Broglie's [3] and Bohm's [4] pilot-wave theory. It is true that the two theories have striking similarities; in particular, in both theories the motions (in configuration space) are described using a velocity field of the form $\frac{1}{m}\nabla S$. This is the deterministic velocity field for a particle in de Broglie–Bohm theory, and the current velocity of the diffusion process in Nelson's theory. Nevertheless, there is a crucial conceptual difference between de Broglie–Bohm theory or its stochastic variants and Nelson's approach as it was originally conceived: in de Broglie–Bohm theory the function S is assumed from the start to be the phase of Schrödinger's wave function, which obeys the Schrödinger equation. Instead, Nelson's original aim was to assume only that the particles obey a diffusion process in the configuration space and to *derive* a wave function and the Schrödinger equation by imposing natural conditions on the diffusion. Nelson's original approach, in apparently not assuming the wave function to be part of the ontology of the theory, is thus highly unusual (as compared not only to de Broglie–Bohm but also to spontaneous collapse theories and especially to Everett), and in this respect might provide an interesting comparison to the otherwise very different approaches that seek to understand the quantum state in purely epistemic terms, including entanglement and other supposedly typical quantum features (Spekkens [5]), and that derive or seek to derive quantum mechanics from simple, usually information-theoretic, principles (for example Hardy [6] and Fuchs [7]).

In Section 2 we shall focus on this special feature of Nelson's approach and spell out in more detail the potential advantages of Nelson's original approach over de Broglie–Bohm theory (and its stochastic variants).

The main section of this paper, Section 3, is devoted to reviewing the approach itself in some detail. We shall try to isolate various issues of conceptual interest, in particular the role of time symmetry, which is not immediately intuitive in the context of stochastic processes. Indeed, the idea of irreducible indeterminism (and by extension that of probability) is often thought of in terms of an 'open future' and a 'fixed past', and transition probabilities are thought of as law-like in the forward direction of time but as merely epistemic in the backward direction. (For an explicit articulation of this position, see Arntzenius [8].) One can equally well, however, have a picture that does not privilege one direction of time, namely a picture of individual trajectories with the evolution along them subject to stochastic laws in both directions of time. Nelson uses such a picture, since (as we shall see) he takes it that the external forces acting on a system constrain in a law-like way both the forward and the backward transition probabilities of the process. (For a related discussion in the context of decoherent histories, see Bacciagaluppi [9]. I also hope to give a fuller philosophical discussion of time symmetry in stochastic processes, both in general and with specific reference to Nelson's theory, in further publications.)

In Section 4 we then turn to the question of whether Nelson's approach, as stated so far, achieves its aim. As a matter of fact, it is rather well-known that it has not been entirely successful. The reason for this (as was detailed in print by Wallstrom [10]), is the lack of strict equivalence between the Schrödinger equation and the Madelung equations, seen as coupled equations for two abstract functions R and S. We assess the achievements of Nelson's programme in the light of these considerations.

In Section 5 we return to the comparison between Nelson's approach, as characterised in Section 4, and the Nelson-type variants of de Broglie–Bohm theory mentioned above. We conclude with some speculations on how it might still be possible, despite the known difficulties, to complete Nelson's original programme.[a]

2 Comparison with Pilot-wave Theory

The pilot-wave theory of de Broglie and Bohm is one of the better-known and best-understood approaches to the foundations of quantum mechanics. It is also one of the oldest. The mature version of de Broglie's theory was presented in October 1927 at the Fifth Solvay Congress [3]. The theory presented there is a new dynamics for systems of n particles (described in configuration space), where the motion of the i-th particle is determined by a velocity field of the form $\frac{1}{m_i}\nabla_i S(\mathbf{x}_1, \ldots, \mathbf{x}_n)$, S being the phase of the Schrödinger wave function. (S is defined in units of $\hbar$, that is, $\psi = Re^{iS/\hbar}$. One finds also the convention $\psi = Re^{iS}$, in which case the velocity field has the form $\frac{\hbar}{m}\nabla S$.)

At least as regards particle detections, it is clear that the theory can easily predict both interference and diffraction phenomena. Indeed, around the nodes of the modulus R of the wave function, the phase S will behave very irregularly, so one can at least qualitatively expect that the particles will be driven away from regions of configuration space where R is small. (Using second-order concepts, this corresponds to a large additional 'quantum potential' around the nodes.) Therefore, for instance, interference bands in the two-slit experiment should appear. And, indeed, it was the qualitative prediction of electron diffraction and its experimental detection that established the significance of de Broglie's matter waves even before the detailed theory of 1927 was worked out. Also quantitatively, as de Broglie remarks, the velocity field preserves the form of the particle distribution if at any time this is given by R^2.

Although de Broglie's paper and the related discussions include various applications, the measurement theory for quantum observables other than functions of position was worked out in general only when Bohm rediscovered and revived the theory a quarter of a century later [4]. Indeed, it ought to be puzzling at first how such a theory of particles in motion could have even qualitatively anything to do, for instance, with incompatible

[a] I wish to record my special thanks to Shelly Goldstein for long and fruitful discussions of the main topics of this paper, in particular the kinematics of time reversal, the comparison with pilot-wave theory, and the work by Davidson.

observables, with the projection postulate and with the rest of the full phenomenology of quantum mechanics. In modern terminology, what Bohm showed in general is that in situations such as measurements, the wave function of the *total* system decoheres in such a way that the non-interfering components are in fact separated in configuration space by regions with very small R (very large quantum potential), so that the representative point of the system is effectively trapped inside one of the components. This component alone (barring 'conspiratorial' reinterference) will be relevant at later times for the dynamics of the system, so that the particles behave as if the wave function had collapsed. Assuming that the behaviour of the particles comprising the apparatus is macroscopically different depending on which component is effectively guiding the (total) system, one can perform a selection of a corresponding sub-ensemble from an ensemble of (object) systems. Also quantitatively, if the original distribution is given by R^2, the particles comprising the sub-ensemble will be distributed according to the usual quantum mechanical Born rule (see [11] for a detailed discussion of this point). It is further straightforward to see that in the case of two (maximally) entangled particles, decoherence induced by a measurement on one of the particles forces the other particle and the relevant apparatus to produce the correlated outcome. Less than perfect correlations are quantitatively reproduced given an initial R^2 distribution.

At the individual level, de Broglie–Bohm theory is a new particle mechanics. At the statistical level, for (time-dependent) *equilibrium* ensembles, it reproduces the statistical predictions of quantum mechanics, and the analogy with the statistical mechanical underpinning of thermodynamics can be pursued in great detail. The theory is explicitly non-local and recovers in this way the quantum mechanical violations of the Bell inequalities. The theory can be easily modified to include spin, and various generalisations aiming to cover QED and other field theories have been proposed. For fuller details, apart from the original papers mentioned above, the following textbook treatments are recommended: Holland [12], Bohm and Hiley [13], Dürr [14] and the forthcoming one by Valentini [15].

In Nelson's theory, as mentioned earlier, the current velocity for the distribution in configuration space is equal to the de Broglie–Bohm velocity. This means that although the particle trajectories in Nelson's theory in general will not be the same as in de Broglie–Bohm theory, the most probable trajectories will oscillate randomly around the typical trajectories of de Broglie–Bohm theory. In terms of recovering the predictions of quantum mechanics, and essentially of all the aspects just mentioned, Nelson's theory will thus share the features of de Broglie–Bohm theory. Often one is interested only in this aspect, and one can formulate Nelson-type theories that preserve the quantum distribution as defined by the Schrödinger wave, assumed as given, and one can study these as stochastic variants of de Broglie–Bohm (the present author is no exception [16,17]).

While such theories may have some advantages over de Broglie–Bohm theory (specifically in justifying quantum equilibrium and the notion of typicality), Nelson's original approach enjoys a series of further and more important potential advantages, which we shall now spell out in somewhat more detail. It should be emphasised, however, that the following is not meant to be an exhaustive discussion and does not pretend to do justice to the critical positions that are only very briefly sketched. It should also be emphasised that, by common consensus, the situation as regards non-locality is the same in Nelson as it is in de Broglie–Bohm (irrespective of the approach to Nelson chosen). Indeed, it appears that Nelson himself would have hoped that his theory should be fundamentally local, and that he abandoned it because of its non-local features [2]. The question of locality and non-locality, in particular of at what stage and how the non-locality is implemented, of course deserves a detailed discussion, but will not be considered in this paper. (I am well aware that this makes it a rather incomplete introduction to the subject.)

A first group of criticisms of de Broglie–Bohm theory relates to (supposed) difficulties with equilibrium, and consists of the two rather opposite views that: (a) it is difficult to justify why particles in laboratory ensembles should be distributed according to R^2; and (b) since particles in such ensembles are always distributed according to R^2, individual trajectories are unobservable. It should be clear that in a stochastic theory such as Nelson's (or stochastic variants of de Broglie–Bohm), equilibrium is to be expected, while at the same time one will have ever so small but well-defined fluctuations.

The second group of criticisms focuses on the tension between the configuration-space perspective and the Hilbert-space perspective. As such it is a rather heterogeneous group, comprising: (a) the idea that de Broglie–Bohm theory breaks the symmetry of the Hilbert space (that is, that configurations play an unjustified privileged role in the theory); (b) objections to the fact that waves act on particles but are not acted back upon; (c) the curious status of 'empty waves', that is, of those components of the wave function that no longer contribute to guiding the particles after the relevant separation in configuration space due to decoherence; (d) the detailed arguments, recently put in print by Brown and Wallace [18], for the conceptual redundancy of particle positions and the pilot-wave picture if one admits the possibility of an Everett interpretation (this I take to be a serious criticism of de Broglie–Bohm).

It is plausible that Nelson's theory would not suffer from any of these criticisms if the Hilbert-space concepts are all derived concepts. Specifically (and briefly): problem (a) would disappear because the configuration space is in fact fundamental; (b) because there would only *appear* to be waves acting on particles; similarly for (c); and (d) would disappear because the Everett interpretation is no longer motivated if the wave function is not fundamental. (If one holds functionalist views in philosophy of mind, however, even the existence of the decohering wave function as a derived feature will allow for a many-minds version of the Everett interpretation.)

Notice also that one can use configuration-space trajectories to formulate conditions that rule out parastatistics for indistinguishable particles [17,19]. This is a case in which symmetry considerations at the level of the configuration space can play a non-trivial role.

Thirdly, it should be clear, even from the few remarks above, that the phenomenon of decoherence is crucial in order for de Broglie–Bohm theory to reproduce the phenomenology of the collapse of the wave function, and in fact of the whole 'classical regime' of quantum mechanics in the sense of the theory of decoherence. However, it appears to be merely a contingent fact that decoherence tends to produce separation of wave-function components in configuration space. If decoherence produced separation of components in momentum space, or if the pilot-wave kinematics and dynamics were defined with respect to momentum space, there would be no such distinguished regime in the theory, nor any effective collapse. While decoherence undoubtedly 'breaks the symmetry' of the Hilbert space, it does so purely contingently, and there appears to be no explanation why this matches the fundamental choice of configuration space in pilot-wave theory.

In the non-relativistic particle case this coincidence is not so immediately striking, maybe because historically both de Broglie's guidance equation and Schrödinger's wave equation derived their respective forms from the optico-mechanical analogy (as spelled out, respectively, in de Broglie's thesis [20] and in Schrödinger's second paper on quantisation [21]). In the field-theory case, however, it is not obvious what the 'correct' configuration space of a pilot-wave theory should be, and it is striking that if a configuration space is chosen that does not match up with decoherence, the right phenomenology will not emerge. A further, methodological, disadvantage is that it appears that pilot-wave theory has to feed on the results of decoherence for any successful generalisation to field theories. (These criticisms are essentially due to Saunders [22].)

On the other hand, at least in the point-particle case, if Nelson's derivation is successful, the form of the quantum Hamiltonian is actually derived from the form of the particle dynamics (as will be seen explicitly in Section 3). The connection between decoherence and configurations is therefore immediate. Insofar as it appears that de Broglie–Bohm theory can be generalised to encompass the known field theories (see for instance Valentini [15,23]), and if these generalisations should indeed manage in conjunction with decoherence to recover the correct phenomenology, one can speculate that analogous Nelson-type theories might be able to explain also in the general case the otherwise mysterious connection between the choice of the configuration space and the form of the decoherence Hamiltonian.

A final, independent motivation for a renewed interest in Nelson's research programme has been provided by its use in the completely different context of quantum gravity, in a recent paper by Markopoulou and Smolin [24]. Here, the idea that the wave function is indeed a derived concept is again of crucial importance.

3 Nelson's Strategy

We now turn to the description and analysis of Nelson's strategy. In the main, we shall follow Nelson's original paper [1]. We have mentioned above that Nelson's theory is defined in terms of a diffusion process in the configuration space of the system. More precisely, Nelson suggests considering a stochastic differential equation of the following form:

$$d\mathbf{x}(t) = \mathbf{b}(\mathbf{x}(t), t)dt + d\mathbf{w}(t). \tag{1}$$

The vector $\mathbf{b}(\mathbf{x}(t), t)$ is called the mean (forward) velocity (see also (33) below). $\mathbf{w}(t)$ is a Wiener process; the $d\mathbf{w}(t)$ are Gaussian with mean 0, independent of the $d\mathbf{x}(s)$ for $s \leq t$, and

$$E_t[dw_i(t)dw_j(t)] = 2\nu\delta_{ij}dt, \tag{2}$$

$\nu > 0$ being the diffusion coefficient and E_t denoting the expectation value at time t. For simplicity (and since we are not discussing non-locality) we can specialise to the case of a single particle, but the formalism and derivation are quite general.

Formally, (1) is the same equation as in the Einstein–Smoluchowski theory of Brownian motion. Nelson, however, emphasises that the context is different: the Einstein–Smoluchowski theory describes macroscopic Brownian motion in a fluid in the limit of infinite friction, while Nelson postulates the equation for elementary particles in the vacuum. The corresponding Fokker–Planck equation for the distributions has the form

$$\frac{\partial\rho}{\partial t} = -\mathrm{div}(\mathbf{b}\rho) + \nu\Delta\rho. \tag{3}$$

Nelson's aim is to impose natural constraints on the diffusion process such that (1) takes the form

$$d\mathbf{x} = \left(\frac{1}{m}\nabla S + \nu\frac{\nabla R^2}{R^2}\right) dt + d\mathbf{w} \tag{4}$$

(possibly, as will be discussed in more detail below, up to additional terms in $\mathbf{b}$ that will not contribute to the divergence in (6)), where the functions S and R satisfy the so-called Hamilton–Jacobi–Madelung equation,

$$\frac{\partial S}{\partial t} = -\frac{1}{2m}(\nabla S)^2 - V + \frac{\hbar^2}{2m}\frac{\Delta R}{R}. \tag{5}$$

If one inserts $\rho = R^2$ into the Fokker–Planck equation (3), with $\mathbf{b}$ defined as in (4), one obtains

$$\frac{\partial R^2}{\partial t} = -\mathrm{div}\left(\frac{1}{m}(\nabla S)R^2\right). \tag{6}$$

Equation (6) has the form of the usual quantum mechanical continuity equation. Equations (5) and (6) are called the Madelung equations and can be standardly derived from the Schrödinger equation setting $\psi = Re^{iS/\hbar}$. If one can find natural conditions on (1) such that (5) and (6) hold, this may suggest that it is (1) that is fundamental, the Schrödinger equation being only a convenient mathematical way of writing (5) and (6). Of course the problem can be trivialised by imposing as condition precisely that the current velocity be given through the gradient of the Schrödinger wave function, or some such *ad hoc* condition. A non-trivial solution to the problem should not make reference to the Schrödinger wave and equation in the formulation of the relevant conditions.

We shall see below, mainly in Section 3.2, how Nelson proposes to do this. At first sight, however, this strategy appears conceptually puzzling. It appears that the distribution R^2 itself contributes to determining the particle trajectories via (4). But how can an individual trajectory be affected by the distribution of other particles in an ensemble? This, however, is a red herring. Take a stochastic differential equation of the form (1) and consider *any* solution ρ of the corresponding Fokker–Planck equation (3). At least formally, one can always associate with ρ a so-called *osmotic velocity*

$$\mathbf{u}_\rho := \nu \frac{\nabla \rho}{\rho}, \tag{7}$$

and we can define a corresponding *current velocity*,

$$\mathbf{v}_\rho := \mathbf{b} - \mathbf{u}_\rho, \tag{8}$$

so that

$$d\mathbf{x} = \left(\mathbf{v}_\rho + \nu \frac{\nabla \rho}{\rho} \right) dt + d\mathbf{w}. \tag{9}$$

The Fokker–Planck equation for this ρ then reduces to a continuity equation:

$$\begin{aligned} \frac{\partial \rho}{\partial t} &= -\mathrm{div} \left[\left(\mathbf{v}_\rho + \nu \frac{\nabla \rho}{\rho} \right) \rho \right] + \nu \Delta \rho = \\ &= -\mathrm{div}(\mathbf{v}_\rho \rho), \end{aligned} \tag{10}$$

so that $\mathbf{v}_\rho$ is indeed the current velocity corresponding to the distribution ρ. If $\mathbf{u}_\rho$ and $\mathbf{v}_\rho$ are not too singular, the corresponding stochastic differential equation has indeed well-defined solutions (see also the related discussion by Carlen [25]). This choice of representation, in which some distribution enters explicitly, does not affect the time evolution of an individual particle as given by (1): one could as well use a different solution ρ' of (3) and write

$$d\mathbf{x} = \left(\mathbf{v}_{\rho'} + \nu \frac{\nabla \rho'}{\rho'} \right) dt + d\mathbf{w}. \tag{11}$$

We see that reference to some specific distribution can be thought of as defining a convenient way of writing the mean velocity $\mathbf{b}$. As we shall presently see, however, the choice of the distribution ρ is connected to the choice of a *time reversal* of equation (1).

3.1 Time reversal of diffusion processes

Take again the stochastic differential equation (1):

$$d\mathbf{x} = \mathbf{b}dt + d\mathbf{w}. \tag{12}$$

Such an equation essentially describes only the forward transition probabilities of a stochastic process (in the sense of a measure over all possible trajectories), and the process is in general underdetermined by equation (1). Indeed, suppose an arbitrary Markov process is defined on a time interval $[t_1, t_2]$. Given all the forward transition probabilities from a time s to a time $t > s$ for any $s, t \in [t_1, t_2]$, one can define as many processes as one has possible initial distributions at time t_1. Therefore, the backward transition probabilities that one can obtain for a process (by conditionalising on future states) are also underdetermined. As opposed to a deterministic equation, (1) has no well-defined time reversal, and specifying such a time-reversal will amount to a further condition on the process.[b]

A time reversal of (1) will be a diffusion with the same diffusion coefficient ν (since the size of the fluctuations does not depend on the time direction), that is, it will have the form

$$d\mathbf{x} = \mathbf{b}' d(-t) + d\mathbf{w}_*, \tag{13}$$

with some suitable mean velocity $\mathbf{b}'$, and where the $d\mathbf{w}_*(t)$ are again Gaussian with mean 0, and with

$$E_t\left[dw_{*i}(t)dw_{*j}(t)\right] = 2\nu\delta_{ij}dt, \tag{14}$$

but now the $d\mathbf{w}_*(t)$ are independent of the $d\mathbf{x}(s)$ for $s \geq t$. The Fokker–Planck equation corresponding to (13) is

$$\frac{\partial\rho}{\partial(-t)} = -\mathrm{div}(\mathbf{b}'\rho) + \nu\Delta\rho. \tag{15}$$

Now let us choose a representation (9) of (1):

$$d\mathbf{x} = \left(\mathbf{v}_\rho + \nu\frac{\nabla\rho}{\rho}\right) dt + d\mathbf{w}. \tag{16}$$

The time reversal of (16) will have the form (13), as mentioned, but more specifically, since $\rho(t)$ is manifestly invariant under time reversal, it will take the form

$$d\mathbf{x} = \left(\mathbf{v}'_\rho + \nu\frac{\nabla\rho}{\rho}\right) d(-t) + d\mathbf{w}_*, \tag{17}$$

[b]Notice that if one considers the process to be defined on $]-\infty, +\infty[$, and if one invokes the asymptotic properties of such processes, then the convergence of the distribution in both directions of time will generally enforce a unique distribution ρ and therefore a unique time reversal. Since however ρ and $\mathbf{b}$, though related, are still unspecified, the rest of our discussion in Section 3.2 will apply. We choose our mode of presentation because it is closer to Nelson's own and because it is more self-contained.

with a suitable current velocity $\mathbf{v}'_\rho$. But now, analogously to (10), ρ will satisfy also the continuity equation

$$\frac{\partial\rho}{\partial(-t)} = -\mathrm{div}(\mathbf{v}'_\rho\rho). \tag{18}$$

If (18) is meant to be the time reversal of (10), then we should further set

$$\mathbf{v}'_\rho = -\mathbf{v}_\rho, \tag{19}$$

that is, we have uniquely fixed $\mathbf{b}'$.

One generally defines $\mathbf{b}_* := -\mathbf{b}'$ and writes

$$d\mathbf{x} = \mathbf{b}_* dt + d\mathbf{w}_* \tag{20}$$

rather than (13). The corresponding Fokker–Planck equation (15) becomes

$$\frac{\partial\rho}{\partial t} = -\mathrm{div}(\mathbf{b}_*\rho) - \nu_*\Delta\rho \tag{21}$$

(the so-called backward Fokker–Planck equation).

We see that there is indeed a one-to-one correspondence between the choice of a solution ρ to the Fokker–Planck equation in the representation (9) of (1) and the choice of a time reversal for (1).

Now, if we make such a choice and write down the pair of stochastic differential equations

$$d\mathbf{x} = \left(\mathbf{v}_\rho + \nu\frac{\nabla\rho}{\rho}\right) dt + d\mathbf{w} \tag{22}$$

and

$$d\mathbf{x} = \left(\mathbf{v}_\rho - \nu\frac{\nabla\rho}{\rho}\right) dt + d\mathbf{w}_*, \tag{23}$$

this fixes ρ uniquely as the single-time distribution of the process, even if we take the process to be defined only on an interval $[t_1, t_2]$. The intuitive reason is that any distribution has to get closer to ρ in both directions of time, but then it has to be ρ for all times. (In the following, we shall drop the index ρ from $\mathbf{v}_\rho$ and $\mathbf{u}_\rho$.) Since the process is Markov, this also fixes uniquely the entire process. The equations (22) and (23) thus fix the process uniquely, while it is underdetermined if only one of the two equations is given.

Lest one be worried by the fact that the process is entirely fixed, let us emphasise again that a stochastic process is defined as a probability measure over a space of trajectories. Which trajectory is actually realised is a contingent matter, and so is the actual single-time distribution in any collection of sub-systems. Therefore, fixing the distribution at the level of the process does not fix the distribution in any actual such collection; rather, if one will, it is just a reflection of the fact that transitions along trajectories are governed in both directions of time by stochastic differential equations. What is fixed are the *probabilities* for distributions of sub-systems, and an actual distribution of sub-systems that is far from 'equilibrium' can be interpreted as a fluctuation, which is most likely both to evolve towards equilibrium in the time direction we label 'future' and to have evolved from equilibrium in the time direction we label 'past'.

3.2 Dynamical time symmetry and derivation of the Madelung equations

The framework for the derivation of the Madelung equations is now in place. Nelson takes the pair of equations

$$d\mathbf{x} = (\mathbf{v} + \mathbf{u})dt + d\mathbf{w}, \qquad d\mathbf{x} = (\mathbf{v} - \mathbf{u})dt + d\mathbf{w}_*, \tag{24}$$

where $\mathbf{u}$ is expressible as $\nu \dfrac{\nabla\rho}{\rho}$ in terms of the common distribution of the two evolutions.

Thus far, (24) is merely a kinematical representation of a diffusion process in time-reversible notation: $\mathbf{v}$ and $\mathbf{u}$ (or ρ) are quite arbitrary, if coupled through the continuity equation

$$\frac{\partial\rho}{\partial t} = -\mathrm{div}(\mathbf{v}\rho). \tag{25}$$

The question of whether the process is time-symmetric is a dynamical question. We need to determine the process by some further dynamical law that together with (25) will fix $\mathbf{v}$ and $\mathbf{u}$ (or equivalently, $\mathbf{b}$ and $\mathbf{b}_*$). One can both imagine laws that will do this in a time-symmetric way (for instance, $\mathbf{v} = \dfrac{1}{m}\nabla S$ and $\mathbf{u} = \dfrac{\hbar}{2m}\dfrac{\nabla R^2}{R^2}$, where $\psi = Re^{iS/\hbar}$ satisfies a time-symmetric equation such as the Schrödinger equation), and laws that will do it in a time-asymmetric way ($\mathbf{v}$ and $\mathbf{u}$ the same as above, but ψ satisfies some time-asymmetric equation, as are some non-linear variants of the Schrödinger equation; compare for instance [26]). Nelson's aim is to recover the time-symmetric Schrödinger equation, so he will essentially seek to impose constraints on $\mathbf{v}$ and $\mathbf{u}$ in the form of a time-symmetric dynamical law (which however should not make reference to Schrödinger's equation in its formulation!).

Before discussing that, however, let us consider in more detail the continuity equation (25). This will turn into an equation of the same form as the usual quantum continuity equation if we define $R^2 := \rho$ and impose

$$\mathbf{v} = \frac{1}{m}\nabla S + \tilde{\mathbf{v}}, \tag{26}$$

where $\tilde{\mathbf{v}}$ is a term satisfying

$$\mathrm{div}(\tilde{\mathbf{v}}R^2) = 0. \tag{27}$$

That is, $\tilde{\mathbf{v}}$ does not contribute to the divergence. This can be expressed equivalently also as

$$\tilde{\mathbf{v}} = \frac{\mathrm{rot}(\mathbf{t})}{R^2}, \tag{28}$$

for some function $\mathbf{t}$, or, using $\mathbf{u} = \nu\frac{\nabla\rho}{\rho}$, as

$$\mathrm{div}(\tilde{\mathbf{v}}) + \frac{1}{\nu}\tilde{\mathbf{v}} \cdot \mathbf{u} = 0. \tag{29}$$

(The treatment of such additional terms is somewhat different in Nelson's original approach and in Nelson-type pilot-wave theories; see below, Section 5. Notice also that Guerra and Morato [27] use a variational principle to define the dynamics of Nelson's theory. This approach would appear to justify setting $\mathbf{v}$ equal to a gradient, thus excluding the extra term $\tilde{\mathbf{v}}$ altogether.) Under these constraints then,

$$\frac{\partial R^2}{\partial t} = -\mathrm{div}\left(\frac{1}{m}\nabla S R^2\right), \tag{30}$$

as desired.

Given the definition of R and the condition (26), we return to the question of whether we can impose a dynamical law that will fix $\mathbf{v}$ and $\mathbf{u}$ such that S and R now obey also the Hamilton–Jacobi–Madelung equation (5). At this point, Nelson considers the so-called forward and backward stochastic derivatives of the process, which he defines, respectively, as

$$D\mathbf{x}(t) = \lim_{\varepsilon\to 0^+} E_t\left[\frac{\mathbf{x}(t+\varepsilon) - \mathbf{x}(t)}{\varepsilon}\right] \tag{31}$$

and

$$D_*\mathbf{x}(t) = \lim_{\varepsilon\to 0^+} E_t\left[\frac{\mathbf{x}(t-\varepsilon) - \mathbf{x}(t)}{-\varepsilon}\right]. \tag{32}$$

Here, again, E_t is the expectation value at time t. The definition of $D\mathbf{x}(t)$ involves the forward transition probabilities from time t to times $t+\varepsilon$, while the definition of $D_*\mathbf{x}(t)$ involves the backward transition probabilities from time t to times $t-\varepsilon$. One sees easily that

$$D\mathbf{x}(t) = \mathbf{b}(\mathbf{x}(t), t) \qquad \text{and} \qquad D_*\mathbf{x}(t) = \mathbf{b}_*(\mathbf{x}(t), t) \tag{33}$$

(thus justifying the terminology of mean velocities). Also, if $\nu = 0$ and therefore $\mathbf{u} = 0$, both $D\mathbf{x}(t)$ and $D_*\mathbf{x}(t)$ equal $\mathbf{v}$, and the stochastic derivatives reduce to the usual derivative.

Nelson points out that applying D or D_* to an arbitrary function $f(\mathbf{x}(t), t)$, one obtains

$$Df = \left[\frac{\partial}{\partial t} + \mathbf{b}\cdot\nabla + \nu\Delta\right] f \tag{34}$$

and

$$D_*f = \left[\frac{\partial}{\partial t} + \mathbf{b}_*\cdot\nabla - \nu\Delta\right] f. \tag{35}$$

He introduces the quantity $\mathbf{a} := \frac{1}{2}\left(DD_* + D_*Dx\right)\mathbf{x}$, which he calls the second stochastic derivative of $\mathbf{x}$ (or mean acceleration). One can easily calculate the quantity $\mathbf{a}$ by applying (34) and (35) to the components of $\mathbf{b}_*$ and $\mathbf{b}$. This yields

$$\begin{aligned} \mathbf{a} &= \frac{1}{2}\left[\frac{\partial}{\partial t} + \mathbf{b}\cdot\nabla + \nu\Delta\right]\mathbf{b}_* + \frac{1}{2}\left[\frac{\partial}{\partial t} + \mathbf{b}_*\cdot\nabla + \nu\Delta\right]\mathbf{b} = \\ &= \frac{1}{2}\frac{\partial}{\partial t}(\mathbf{b}+\mathbf{b}_*) + \frac{1}{2}(\mathbf{b}\cdot\nabla)\mathbf{b}_* + \frac{1}{2}(\mathbf{b}_*\cdot\nabla)\mathbf{b} - \frac{1}{2}\nu\Delta(\mathbf{b}-\mathbf{b}_*) \end{aligned} \tag{36}$$

(understood componentwise), or, using $\mathbf{b} = \mathbf{v}+\mathbf{u}$ and $\mathbf{b}_* = \mathbf{v}-\mathbf{u}$,

$$\begin{aligned} \mathbf{a} &= \frac{\partial\mathbf{v}}{\partial t} + \frac{1}{2}[(\mathbf{v}+\mathbf{u})\cdot\nabla](\mathbf{v}-\mathbf{u}) + \frac{1}{2}[(\mathbf{v}-\mathbf{u})\cdot\nabla](\mathbf{v}+\mathbf{u}) - \nu\Delta\mathbf{u} = \\ &= \frac{\partial\mathbf{v}}{\partial t} + (\mathbf{v}\cdot\nabla)\mathbf{v} - (\mathbf{u}\cdot\nabla)\mathbf{u} - \nu\Delta\mathbf{u}. \end{aligned} \tag{37}$$

Let us provisionally ignore the term $\tilde{\mathbf{v}}$ in (26) and insert $\mathbf{v} = \frac{1}{m}\nabla S$ and $\mathbf{u} = \nu\frac{\nabla\rho}{\rho} = \nu\nabla\ln\rho$ into (37), yielding

$$\mathbf{a} = \frac{1}{m}\nabla\frac{\partial S}{\partial t} + \frac{1}{m^2}(\nabla S\cdot\nabla)\nabla S - \nu^2(\nabla\ln\rho\cdot\nabla)\nabla\ln\rho - \nu^2\Delta\nabla\ln\rho. \tag{38}$$

One can use the fact that

$$(\nabla S \cdot \nabla)\nabla S = \frac{1}{2}\nabla(\nabla S)^2, \tag{39}$$

and similarly that

$$\begin{aligned}(\nabla \ln \rho \cdot \nabla)\nabla \ln \rho + \Delta\nabla \ln \rho &= \frac{1}{2}\nabla(\nabla \ln \rho)^2 + \nabla\Delta \ln \rho = \\ &= 2\nabla\left[\frac{(\nabla R)^2}{R^2} + \Delta \ln R\right] \end{aligned} \tag{40}$$

(where one also uses $\ln \rho = 2 \ln R$). Since

$$\Delta \ln R = \frac{R\Delta R - (\nabla R)^2}{R^2}, \tag{41}$$

(40) becomes

$$(\nabla \ln \rho \cdot \nabla)\nabla \ln \rho + \Delta\nabla \ln \rho = 2\nabla\frac{\Delta R}{R}, \tag{42}$$

and (38) simplifies to

$$m\mathbf{a} = \nabla\left[\frac{\partial S}{\partial t} + \frac{1}{2m}(\nabla S)^2 - 2m\nu^2\frac{\Delta R}{R}\right]. \tag{43}$$

In order to obtain the Hamilton–Jacobi–Madelung equation we can therefore impose

$$\nu = \frac{\hbar}{2m} \tag{44}$$

and

$$m\mathbf{a} = -\nabla V, \tag{45}$$

where V is the external potential. (The integration constant from (43) will induce only an irrelevant global gauge transformation.)

If we set $\mathbf{v} = \frac{1}{m}\nabla S + \tilde{\mathbf{v}}$, we obtain some additional terms in (38), which we must set equal to zero. Explicitly, we have to impose

$$\frac{\partial \tilde{\mathbf{v}}}{\partial t} + (\tilde{\mathbf{v}} \cdot \nabla)\frac{1}{m}\nabla S + (\frac{1}{m}\nabla \mathbf{S} \cdot \nabla)\tilde{\mathbf{v}} + (\tilde{\mathbf{v}} \cdot \nabla)\tilde{\mathbf{v}} = 0. \tag{46}$$

The crucial condition on the process that allows Nelson to recover the Madelung equations (apart from the assumption that $\mathbf{v}$ is essentially a gradient) is (45): a law-like statement (indeed, a stochastic analogue of Newton's second law!) that is entirely time-symmetric and involves both the forward and the backward transition probabilities of the process in an essential way.

Postulating (45) is very suggestive, of course, but it is not peculiar to Nelson's theory. As he points out, (45) holds in the Ornstein–Uhlenbeck theory of Brownian motion, and his theory thus combines the kinematics of the Einstein–Smoluchowski theory with the dynamics of the Ornstein–Uhlenbeck theory.

Notice also that while choosing (45) as the crucial condition on $\mathbf{b}$ and $\mathbf{b}_*$ yields precisely the Hamilton–Jacobi–Madelung equation, just about any condition would yield an equation coupling $\mathbf{v}$ and $\mathbf{u}$ in a non-trivial way. One especially interesting condition is $mD\mathbf{b} = -\nabla V$ (which does not involve mixing forward and backward transition probabilities). One easily shows that in this case

$$mD\mathbf{b} = mD_*\mathbf{b}_* = m\frac{1}{2}(D\mathbf{b} + D_*\mathbf{b}_*) = -\nabla V. \tag{47}$$

This yields

$$\frac{\partial S}{\partial t} = -\frac{1}{2m}(\nabla S)2 - V - 2m\nu 2\frac{\Delta R}{R}. \tag{48}$$

For $\nu = \dfrac{\hbar}{2m}$, this is exactly the Hamilton–Jacobi–Madelung equation, except for the sign of the quantum potential, and it corresponds to a non-linear and non-linearisable wave equation. Notice, however, that by taking a real linear combination of conditions (45) and (47) of the form

$$\alpha m\frac{1}{2}(D\mathbf{b}_* + D_*\mathbf{b}) + \beta m\frac{1}{2}(D\mathbf{b} + D_*\mathbf{b}_*) = -\nabla V, \tag{49}$$

with $\alpha + \beta = 1$ and $\alpha - \beta > 0$, one can again obtain the Hamilton–Jacobi–Madelung equation by imposing

$$\nu = \frac{1}{\sqrt{\alpha - \beta}}\frac{\hbar}{2m}. \tag{50}$$

The diffusion coefficient ν can therefore take any positive value for an appropriate choice of α and β. Such a result was first derived by Davidson [28].

4 Inequivalence of the Madelung Equations and the Schrödinger Equation

The conditions to be imposed on the system of stochastic differential equations (24) in order to relate them to the Madelung equations, as we have seen, are that $m\mathbf{a} = -\nabla V$ and that $\mathbf{b} + \mathbf{b}_*$ should be a gradient (or a slightly more general expression where the additional term satisfies some supplementary conditions). It is, however, not the case that the Madelung equations for two functions S and R imply the Schrödinger equation for the corresponding function $\psi = Re^{iS/\hbar}$ (although the converse is true). This, as was emphasised by Wallstrom [10], requires a supplementary condition on S, in fact one that appears rather *ad hoc*.

The problem is that $\mathbf{v} = \frac{1}{m}\nabla S$ defines $\mathbf{v}$ locally as the gradient of a function, but does not specify whether S is a single-valued or multi-valued function. The equivalence of the Madelung equations and the Schrödinger equation, however, depends extremely sensitively on the multi-valuedness properties of S. Indeed, both the assumption of single-valuedness and that of multi-valuedness (without further constraints) are problematic.

If S is assumed to be single-valued, then one can derive a Schrödinger equation from the Madelung equations, but this case does not capture the full generality of the Schrödinger equation, namely it does not include wave functions with angular momentum, for which S is indeed multi-valued. If instead one allows S to have an arbitrary multi-valued behaviour, then, as Wallstrom shows by example, there are solutions of the Madelung equations that do not correspond to *any* solution of the relevant Schrödinger equation.

The dilemma is between allowing too few or too many solutions of the Madelung equations than those necessary to recover all and only solutions of the Schrödinger equation. In order to do so, one has to assume that S is generally multi-valued, but that the difference in value acquired along a closed curve is restricted to an integer multiple of the Planck constant h. Obviously, this means assuming from the start that S is the phase of a complex function.

As Wallstrom puts it, in order to derive the Schrödinger equation from the Madelung equations, one has to impose a quantisation condition just like the Bohr–Sommerfeld condition of the old quantum theory. More neutrally, one could say that, *given* the non-trivial assumption that the current velocity of the process is given by some 'phase waves', Nelson shows there are natural conditions under which the complex function defining the waves obeys a Schrödinger equation and the distribution of the particles is given by the squared amplitude of this complex function.

This may not quite be Nelson's original aim, but it is a striking and non-trivial result. To illustrate just how striking it is one might resort to a historical fable. One could imagine that de Broglie had a yet younger brother, Édouard, who, starting from his brother's ideas on phase waves determining particle motions, connected them with ideas about Brownian motion and arrived to the Schrödinger equation a couple of years ahead of its actual discovery.

5 Conclusion

In Section 1, we mentioned that Nelson's stochastic mechanics is often presented as a theory in which one assumes the Schrödinger wave and Schrödinger equation as given. In these theories one constructs certain diffusion processes in such a way that the (asymptotic) distribution of the process is always given by R^2. In the previous section, we have suggested that Nelson's own approach to his theory can rather be seen as one in which one assumes that the phase of a complex function (defined on configuration space) describes the current velocity of a diffusion process, and one formulates conditions directly on the process that turn out to imply that this complex function obeys the Schrödinger equation. Some of the differences between the two approaches are worth spelling out in more detail.

If one assumes that the complex function ψ obeys the Schrödinger equation, then one can define $\mathbf{v}$ and $\mathbf{u}$ directly in terms of S and R under fewer constraints. In particular, while in Nelson's approach the diffusion coefficient ν is equal to $\frac{\hbar}{2m}$, in the alternative approach it can be arbitrary. This is not an essential difference, however, since, as mentioned, Davidson [28] has shown that it is possible to have Nelson-style derivations of the Madelung equations using diffusion coefficients other than $\frac{\hbar}{2m}$. Another constraint that no longer applies is the supplementary condition (46) on the additional velocity term $\tilde{\mathbf{v}}$.

More importantly, the Nelson-type pilot-wave theories need not assume the time-reversed equation (23) as an equation of the theory, nor the associated unique distribution ρ as the distribution for the particles. This line is taken explicitly for instance by Bohm and Hiley [13]. Therefore, such stochastic variants of de Broglie–Bohm theory are not committed to considering the time reversed transitions as law-like (and they often omit them entirely from the presentation). For large times, both approaches to the theory will agree that there is a well-defined probability measure over the positions (namely the asymptotic distribution R^2). For early times, however, before the forward transitions have driven the distribution close to the asymptotic one, the stochastic variants of de Broglie–Bohm theory are not committed to any particular particle distribution. Of course one can use the R^2-measure to define which trajectories should be considered as typical also for early times. This, however, should not be interpreted as a law of nature about the distributions to be expected in the world. Rather, it has to be argued for independently, as in the case of deterministic theories such as classical statistical mechanics or de Broglie–Bohm theory itself.

An approach that takes the Schödinger wave and equation as given, of course, is open to any of the criticisms listed in Section 2 as applying to de Broglie–Bohm theory (insofar as one accepts them, and with the qualified exception of the criticisms relating to equilibrium). The approach in which one assumes the existence of phase waves without assuming the Schrödinger equation, however, falls short of Nelson's original aim, and does not seem to fare much better. Indeed, if one assumes the existence of some phase waves and therefore the corresponding complex waves, and shows that these waves obey the Schrödinger equation, then in terms of ontological commitment this approach is just as problematic.

In order to make a difference to the interpretational debate in the sense sketched in Section 2, Nelson's approach would have to be developed truly along the lines of Nelson's original aim. I wish to conclude this paper by sketching two speculative strategies that might lead to meeting Wallstrom's criticism, and which I believe are both new.

The first strategy relies on the idea that by varying the potential V, one should be able to eliminate those nodes of R around which S accumulates terms other than hn. More precisely, by varying V, one wishes to make the complement of the nodal set of R simply connected in a neighbourhood of a certain time t. I expect this should be possible in the case of the Schrödinger equation (the only ineliminable nodes ought to be those dictated by antisymmetrisation of fermion wavefunctions, but the complement set of these nodes is simply connected if space has at least three dimensions), and may be true of the Madelung equations. In this case, one could allow S to be multi-valued, but it would have to be single-valued in a neighbourhood of t, so that equivalence with the Schrödinger equation is ensured in that neighbourhood. Equivalence then follows for all times, even for those when S might become multi-valued: the multi-valuedness will be automatically restricted to that obtainable when a Schrödinger wave acquires a multi-valued phase, as when one imparts angular momentum to a system.

According to this strategy, one would allow S to be multi-valued but discount the 'non-Schrödinger' solutions of the Madelung equations on the grounds that they are not globally well-defined in time if V is time-dependent. Of course, even if the mathematical argument is correct, one could dispute that the actual potential function has anything to do with the potentials one uses for the argument, or that it is at all time-dependent. Indeed, if one considers the total system, there are no external potentials, only interactions, which are arguably time-independent functions of position.

The second possible strategy focuses directly on the total system and on the other horn of the dilemma, that is, on the assumption that S is single-valued. It is clear that if one assumes the actual S for the total system to be single-valued, then a Schrödinger equation for the total system will follow from the Madelung equations; but then the motions of *all* particles in the system will be well-defined, irrespective of whether there are subsystems appearing to have wave functions with multi-valued phases (in the sense of the effectively collapsed wave functions mentioned in Section 2). One could thus impose the condition that S for the total system be single-valued. Instead of being an *ad hoc* quantisation, this condition would turn out to have the simple physical meaning that the angular momentum of the universe is zero.

This second strategy could be developed further. The otherwise contingent fact that S is single-valued for the universe could plausibly be given a theoretical justification in a relational variant of the theory. It is well-known that zero angular momentum for the universe is a typical prediction of relational ('Machian') theories of motion, and that such theories can be canonically constructed from non-relational ones if the latter have a variational formulation in configuration space (such as the classical Maupertuis principle). This is done by substituting the so-called intrinsic differential in the variation integral (which measures the intrinsic distance between configurations rather than the distance with respect to a metric on an independent space). This technique was originally introduced by Barbour and Bertotti [29] for the case of classical mechanics. Since Nelson's theory has such a variational formulation (the Guerra–Morato formulation [27], which further appears to justify the form of $\mathbf{v}$), it should be possible to give a relational version of Nelson's theory. If the above intuition is correct, this version would not suffer from Wallstrom's criticism. Finally, such a theory would also provide the first Machian formulation of standard quantum mechanics.

Acknowledgements

As mentioned above, I particularly wish to thank Shelly Goldstein for his time and enthusiasm in discussing matters relating to this paper. I would also like to thank Nico Giulini, Jerry Goldin, Gerard Milburn, Carlo Rovelli, Simon Saunders, the audience in Bielefeld and audiences in Sydney and Paris. I have written this paper while holding a research contract with CNRS.

References

1. Nelson, E. (1966) Derivation of the Schrödinger equation from Newtonian mechanics, *Phys. Rev.* **150**, 1079–1085.
2. Nelson, E. (1985) *Quantum Fluctuations*, Princeton University Press, Princeton.
3. de Broglie, L. (1928), La nouvelle dynamique des quanta, in H. A. Lorentz (ed.), *Électrons et Photons. Rapports et Discussions du Cinquième Conseil de Physique Solvay*, Gauthier–Villars, Paris, pp. 105–132.
4. Bohm, D. (1952) A suggested interpretation of the quantum theory in terms of 'hidden' variables, I and II, *Phys. Rev.* **85**, 166–179 and 180–193.
5. Spekkens, R. (2004) In defense of the epistemic view of quantum states: A toy theory, preprint `quant-ph/0401052`.
6. Hardy, L. (2001) Quantum theory from five reasonable axioms, preprint `quant-ph/0101012`.
7. Fuchs, C. (2002) Quantum mechanics as quantum information (and only a little more), in A. Khrennikov (ed.), *Quantum Theory: Reconsideration of Foundations*, Växjö University Press, Växjö, pp. 463–543; also preprint `quant-ph/0205039`.
8. Arntzenius, F. (1995) Indeterminism and the direction of time, *Topoi* **14**, 67–81.
9. Bacciagaluppi, G. (2005) The arrow of time and decoherent histories, *Stud. Hist. Phil. Mod. Phys.*, accepted.
10. Wallstrom, T. (1994) Inequivalence between the Schrödinger equation and the Madelung hydrodynamic equations, *Phys. Rev.* **A 49**, 1613–1617.
11. Dürr, D., Goldstein, S., and Zanghì, N. (1992) Quantum equilibrium and the origin of absolute uncertainty, *J. Stat. Phys.* **67**, 843–907.
12. Holland, P. (1993) *The Quantum Theory of Motion*, Cambridge University Press, Cambridge.
13. Bohm, D., and Hiley, B.J. (1993) *The Undivided Universe: An Ontological Interpretation of Quantum Theory*, Routledge, London.
14. Dürr, D. (2001) *Bohmsche Mechanik als Grundlage der Quantemechanik*, Springer, Berlin.
15. Valentini, A. (2005) *Pilot-Wave Theory*, Cambridge University Press, Cambridge, in preparation.
16. Bacciagaluppi, G. (1999) Nelsonian mechanics revisited, *Found. Phys. Lett.* **12**, 1–16; also preprint `quant-ph/9811040`.

17. Bacciagaluppi, G. (2003) Derivation of the symmetry postulates for identical particles from pilot-wave theories, preprint `quant-ph/0302099`.
18. Brown, H., and Wallace, D. (2004) Solving the measurement problem: de Broglie–Bohm loses out to Everett, *Found. Phys. – Special Issue in Honour of James T. Cushing*, submitted; also preprint `quant-ph/0403094`.
19. Dürr, D., Goldstein, S., Taylor, J., Tumulka, R., and Zanghì, N. (2005) Bosons, fermions, and the topology of configuration space in Bohmian mechanics, in preparation.
20. de Broglie, L. (1924) *Recherches sur la Théorie des Quanta*, Ph.D. Thesis, University of Paris.
21. Schrödinger, E. (1926) Quantisierung als Eigenwertproblem (zweite Mitteilung), *Annalen der Physik* **79**, 489–527.
22. Saunders, S. (1999) The 'beables' of relativistic pilot-wave theory, in J. Butterfield and C. Pagonis (eds.), *From Physics to Philosophy*, Cambridge University Press, Cambridge, pp. 71–89.
23. Valentini, A. (1996) Pilot-wave theory of fields, gravitation and cosmology, in J. T. Cushing, A. Fine and S. Goldstein (eds.), *Bohmian Mechanics and Quantum Theory: An Appraisal. Boston Studies in the Philosophy of Science*, Vol. 184, Kluwer, Dordrecht, pp. 45–66.
24. Markopoulou, F., and Smolin, L. (2004) Quantum theory from quantum gravity, *Phys. Rev.* **D 70**, 124029 (10 pp.); also preprint `gr-qc/0311059`.
25. Carlen, E. (1984) Conservative diffusions, *Comm. Math. Phys.* **94**, 293–315.
26. Doebner, H.-D. , and Goldin, G.A. (1996) Introducing nonlinear gauge transformations in a family of nonlinear Schrödinger equations, *Phys. Rev.* **A 54**, 3764–3771.
27. Guerra, F., and Morato, L. (1983) Quantization of dynamical systems and stochastic control theory, *Phys. Rev.* **D 27**, 1774–1786.
28. Davidson, M. (1979) A generalization of the Fényes–Nelson stochastic model of quantum mechanics, *Lett. Math. Phys.* **3**, 271–277.
29. Barbour, J., and Bertotti, B. (1982) Mach's principle and the structure of dynamical theories, *Proc. Roy. Soc. London* **A 382**, 295–306.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 389–407

TO QUANTUM MECHANICS THROUGH PROJECTION OF CLASSICAL STATISTICAL MECHANICS ON PRESPACE

ANDREI KHRENNIKOV
International Center for Mathematical Modeling in Physics, Engineering and Cognitive Science MSI, Växjö University
Växjö, S-35195, Sweden
(Andrei.Khrennikov@msi.vxu.se)

Abstract: We show that in opposite to a common opinion quantum mechanics can be represented as projection of classical statistical model on prequantum space — prespace. All distinguishing features of the quantum probabilistic model (interference of probabilities, Born's rule, complex probabilistic amplitudes, Hilbert state space, representation of observables by operators) are present in a latent form in the classical Kolmogorov probability model. However, classical model should be considered as a contextual model (in the sense that all probabilities are determined by contexts – complexes of physical conditions). Moreover, the prequantum→quantum map is well defined only for two fundamental physical variables (in quantum mechanics these are position and momentum). Quantum mechanics is a projection of classical statistical model through these two "reference observables". Similarly, ordinary classical statistical mechanics on physical phase space is a projection of classical statistical mechanics on prespace. We also introduce a mental prespace and consider its quantum-like representation. Mental prespace describes subconsciousness and its quantum-like representation gives a model of consciousness.

Keywords: Prespace – Contextual Probability – Interference of Probabilities

1 Introduction

Since the first days of creation of quantum mechanics, physicists, mathematicians and philosophers are involved in stormy debates on the possibility to create a classical prequantum statistical model, see for example [1–5] (and recent publications [6–9]). Here "classical statistical" has the meaning of a realistic model in that physical variables can be considered as objective properties and probabilities can be described by the classical (Kolmogorov) measure-thoretic model. There is a rather common opinion that it is impossible to construct such a prequantum model. Such an opinion is a consequence of Bohr's belief that quantum mechanics is a *complete theory.* Therefore it is in principle impossible to create a deeper description of physical reality. In particular, there is a rather common belief that quantum randomness is irreducible, see e.g. von Neumann [2] (in the opposite to classical randomness which is reducible in the sense that it can be reduced to ensemble randomness of objective properties). There is a huge activity in proving various mathematical "NO-GO" theorems (e.g. von Neumann, Kochen-Specker, Bell,...). Many people think that with the aid of such mathematical exercises it is possible to prove completeness of quantum mechanics. As was pointed out in the preface to the conference proceedings [9], such an approach cannot be justified, because we do not know the *correspondence rules* between prequantum and quantum models (since we do not have yet any prequantum realistic statistical model). J. von Neumann presented in his book [2] the list of his beliefs about features of such a prequantum→quantum map J. Later this list was strongly criticized by many authors (including J. Bell). In particular, there was criticized the assumption on one-to-one correspondence between the set of classical prequantum physical variables V and the set of quantum observables O. There was also pointed out that von Neumann assumption that $J(a+b) = J(a) + J(b)$ for any two physical variables (so without the assumption that observables $J(a)$ and $J(b)$ can be measured simultaneously) is unphysical. Then different authors proposed their own lists of beliefs about features of the map J which (as they think) are natural. These lists (including Bell's list) were again critisized. Such a "NO-GO" activity and its critique can be continued as long as we want.

In [10–14] I proposed to start the activity in the opposite direction. Instead of looking for lists of assumptions on the prequantum→quantum map J which would imply a new "NO-GO" theorem, it seems to be more natural to try to find such lists of features of J which would give the possibility to create a natural prequantum model. My solution of this problem is very close to ideas of L. De Broglie [5] and D. Bohm [3] who thought that not all physical variables have "equal rights." They thought that the position variable plays a special role. This is a fundamental physical variable and the corresponding observable is also fundamental, see De Broglie's book [5] which points out that all measurements in physics could be (at least in principle) reduced to position measurements. I also think so.

In [10–14] there was shown that quantum mechanics can be considered as an image of a prequantum classical statistical model if the list of features of the correspondence map J contains just one postulate:

Postulate RO. (Reference Observables) *There exist two fundamental physical observables $J(a)$ and $J(b)$ which correspond to prequantum physical variables a and b. We call them reference observables.*

Here "to correspond" has the following physical meaning. Values of observables $J(a)$ and $J(b)$ coincide with values of variables a and b and hence, for any complex of physical conditions C (physical context), probabilities also coincide.[a]

This is a good occasion to discuss relation with Bohmian mechanics. It is clear that we are very sympathetic to ideas of De Broglie and Bohm, since they were also looking for a realistic prequantum model. However, our approaches are very different both physically and mathematically. The crucial point is that in Bohmian mechanics only one variable — position — is realistic. The momentum is not! In our model not only position, but also the conjugate variable — momentum — is realistic. Another crucial point is that Bohm's prequantum model is based on the ordinary physical space. Here prequantum space coincides with the space of ordinary classical mechanics. In our model this is not the case. Our prequantum space — prespace — is essentially larger than the ordinary classical space. Both quantum space (complex Hilbert space) and ordinary classical space (three-dimensional real space) are projections of prespace. Moreover, prespace contains a domain which cannot be projected to classical phase space, nor quantum Hilbert space, but to so called hyperbolic Hilbert space, see Sect. 11. Of course, our approach based on the postulate RO differs strongly from dreams of those who wanted the direct classical reduction of quantum mechanics, but nevertheless we opened the door to deeper floors of nature.

2 Prespace

Denote the set of fundamental parameters of nature (if you like hidden variables) by symbol Ω. We call it *prespace.* Denote by $V(\Omega)$ the set of physical variables. In a mathematical model $V(\Omega)$ is realized as some class of functions $d : \Omega \to \mathbf{R}$, where $\mathbf{R}$ is the set of real numbers. We develop the most general abstract approach. We do not make any assumption on algebraic or topological structure of prespace. We will not study dynamics of parameters $\omega = \omega(t)$ in Ω; for our general probabilistic considerations we need not pay attention to algebraic and topological features of prespace. In principle, Ω might be a manifold of a huge (may be even infinite) number of dimensions; it need not be a manifold over the field of real numbers, it might be a non-Archimedean (e.g. p-adic) manifold, cf. [13].

[a] The reader may pay attention that De Broglie and Bohm discussed one fundamental observable and we discuss two. However, the presence of time always gives us the possibility to introduce the conjugate variable and observable. For example, quantum mechanics is an image of a realist statistical prequantum model created with aid of two fundamental variables: position and momentum.

It is supposed that prespace is endowed with the structure of the Kolmogorov probability space: $(\Omega, F, \mathbf{P})$. Here F is a σ-algebra of subsets of Ω and $\mathbf{P}$ is a probability measure on F. Typically elements of F are interpreted as *events*, for example, in the conventional Kolmogorov model. We propose *contextual interpretation* of the Kolmogorov probability space. By a *physical context* we understand a complex of physical conditions, e.g. experimental conditions (but we do not assume that any context can be realized experimentally; contexts belong to *ontic models*, see [6]). Contexts are represented by elements of F. So we use the set-theoretic description of complexes of physical conditions. In principle, we can choose the set of random variables (measurable functions) as the set physical variables $V(\Omega)$.

In the conventional model the conditional probability is mathematically defined by the Bayes formula: $\mathbf{P}(A/C) = \mathbf{P}(AC)/\mathbf{P}(C), \mathbf{P}(C) \neq 0$. In our model we do not have events, we consider contextual probability:

$$\mathbf{P}(d = x/C) = P(\omega \in C : d(\omega) = x)/P(C).$$

This is the probability that the variable d is equal to x under the complex of physical conditions C. There is nothing astonishing in such a contextual interpretation of the Kolmogorov model. It is very natural from the physical viewpoint.

We gave the description of ontic model of physical reality: reality as it is. We are now going to consider epistemic ("observational") models of reality, see [6] for details. There are two well-known epistemic models:

a). Ordinary classical mechanics on the physical phase space $\mathbf{R}^3 \times \mathbf{R}^3$.

b). Quantum mechanics on the complex Hilbert space H.

We emphasize that a classical model on prespace Ω should not be identified with the ordinary classical model on $\mathbf{R}^3 \times \mathbf{R}^3$. These are two different levels of descriprion of nature. In fact, the ordinary classical model on $\mathbf{R}^3 \times \mathbf{R}^3$ (as well as the quantum model) is epistemic for our ontic prespace model, see Sect. 12.

We now suppose that Postulate RO holds for the correspondence between prequantum classical statistical model and quantum statistical model. Denote such reference physical variables a and b; they belong to the space $V(\Omega)$. We show, see [10–14] for mathematical details, how one can construct a projection of the contextual Kolmogorov model to the complex Hilbert space.

3 Interference of Classical Probabilities

Let $a = a_1, ..., a_n$ and $b = b_1, ..., b_n$ be discrete random variables and let $C \in F$. Then the classical *formula of total probability* holds:

$$\mathbf{P}(b = b_i/C) = \sum_n \mathbf{P}(a = a_n/C)\mathbf{P}(b = b_i/a = a_n, C).$$

This formula is well-know in statistics. This is the basic formula of Bayesian analysis.

Let a, b be two random variables. They are said to be *supplementary* if

$$\mathbf{P}(b = x, a = y) \neq 0$$

for all their values x and y. We invented a new term "supplementary". In principle, it would be natural to use the term "complementarity". Unfortunately, this term was already reserved by N. Bohr who used it to express *mutual exclusivity.* In our case physical variables a and b are not mutually exclusive, they are well-defined for any $\omega \in \Omega$. Sometimes in quantum mechanics there is used term "incompatible". Incompatibility is impossibility of simultaneous measurement. Such a notion is totally meaningless inside the ontic model.

We shall consider the case of *supplementary dichotomous random variables* $a = a_1, a_2, b = b_1, b_2$. We set $Y = \{a_1, a_2\}, X = \{b_1, b_2\}$ ("spectra" of random variables a and b). We set

$$C_y = \{\omega \in \Omega : a(\omega) = y\}, y \in Y.$$

These sets represent contexts corresponding to selections with respect to fixed values $a = y$. By Postulate RO we can identify reference varaiables a and b with corresponding observables. Therefore the contexts represented by sets C_y are experimentally realizable. In [10–14] it was proved the following interference formula of total probability:

$$\mathbf{P}(b = x/C) = \sum_{j=1}^{2} \mathbf{P}(a = a_j/C)\mathbf{P}(b = x/a = a_j)$$

$$+2\lambda(b = x/a, C)\sqrt{\prod_{j=1}^{2} \mathbf{P}(a = a_j/C)\mathbf{P}(b = x/a = a_j)},$$

where

$$\lambda(b = x/a, C) = \frac{\mathbf{P}(b = x/C) - \sum_{j=1}^{2} \mathbf{P}(b = x/a = a_j)\mathbf{P}(a = a_j/C)}{2\sqrt{\prod_{j=1}^{2} \mathbf{P}(a = a_j/C)\mathbf{P}(b = x/a = a_j)}}. \quad (1)$$

In fact, this formula is just a representation of the probability $\mathbf{P}(b = x/C)$ in a special way. The $\lambda(x/a, C)$ were called the *coefficients of supplementarity.*

Suppose that for every $x \in X$, $|\lambda(b = x/a, C)| \leq 1$. In this case we can introduce new statistical parameters $\theta(b = x/a, C) \in [0, 2\pi]$ and represent the coefficients of statistical disturbance in the trigonometric form: $\lambda(b = x/a, C) = \cos\theta(b = x/a, C)$. Parameters $\theta(b = x/a, C)$ are called *probabilistic phases* ("angles of supplemetarity"). We remark that, in general, there is no geometry behind these phases. By using the trigonometric representation of the coefficients λ we obtain the well-known *formula of interference of probabilities* which is typically derived by using the Hilbert space formalism.

If both coefficients λ are larger than one, we can represent them as $\lambda(b = x/a, C) = \pm\cosh\theta(b = x/a, C)$ and obtain the formula of hyperbolic interference of probabilities; there can also be found models with the mixed hyper-trigonometric behavior, see [10–15].

4 Representation of "Trignometric Contexts" by Complex Probability Amplitudes

We recall that we consider the case of supplementary dichotomous random variables $a = a_1, a_2, b = b_1, b_2$. This pair of variables will be fixed. We call such variables **reference variables.** For each pair a, b of reference variables we construct a representation of the contextual Kolmogorov model in the Hilbert space ("quantum-like representation"). We start with the probabilistic representation of trigonometric contexts:

$$C^{\text{tr}} = \{C : |\lambda(x/a, C)| \leq 1, x \in X\}.$$

Of course, the system C^{tr} depends on the choice of a pair of reference observables, $C^{\text{tr}} \equiv C^{\text{tr}}_{b/a}$. We set

$$p^a_C(y) = \mathbf{P}(a = y/C), p^b_C(x) = \mathbf{P}(b = x/C), p(x/y) = \mathbf{P}(b = x/a = y),$$

$x \in X, y \in Y$. Let context $C \in C^{\text{tr}}$. The interference formula of total probability can be written in the following form:

$$p^b_c(x) = \sum_{y \in Y} p^a_C(y)p(x/y) + 2\cos\theta_C(x)\sqrt{\Pi_{y \in Y} p^a_C(y)p(x/y)},$$

where $\theta_C(x) = \theta(b = x/a, C) = \pm\arccos\lambda(b = x/a, C), x \in X$. By using the elementary formula:

$$D = A + B + 2\sqrt{AB}\cos\theta = |\sqrt{A} + e^{i\theta}\sqrt{B}|^2,$$

for $A, B > 0, \theta \in [0, 2\pi]$, we can represent the probability $p_C^b(x)$ as the square of the complex amplitude (Born's rule):

$$p_C^b(x) = |\varphi_C(x)|^2, \tag{2}$$

where a complex probability amplitude is defined by

$$\psi(x) \equiv \varphi_C(x) = \sqrt{p_C^a(a_1)p(x/a_1)} + e^{i\theta_C(x)}\sqrt{p_C^a(a_2)p(x/a_2)}\,. \tag{3}$$

We denote the space of functions: $\psi : X \to \mathbf{C}$ by the symbol $\Phi = \Phi(X, \mathbf{C})$. Since $X = \{b_1, b_2\}$, the Φ is the two-dimensional complex linear space. By using the representation (3) we construct the map $J^{b/a} : C^{\mathrm{tr}} \to \Phi(X, \mathbf{C})$ which maps contexts (complexes of, e.g., physical conditions) into complex amplitudes. The representation (2) of probability is nothing other than the famous **Born rule.** The complex amplitude $\psi_C(x)$ can be called a **wave function** of the complex of physical conditions (context) C or a (pure) *state.* We set $e_x^b(\cdot) = \delta(x - \cdot)$. The Born rule for complex amplitudes (2) can be rewritten in the following form:

$$p_C^b(x) = |(\psi_C, e_x^b)|^2, \tag{4}$$

where the scalar product in the space $\Phi(X, C)$ is defined by the standard formula:

$$(\psi_1, \psi_2) = \sum_{x \in X} \psi_1(x)\bar{\psi}_2(x). \tag{5}$$

The system of functions $\{e_x^b\}_{x \in X}$ is an orthonormal basis in the Hilbert space $H = (\Phi, (\cdot, \cdot))$. By using the Hilbert space representation of the Born rule we obtain the Hilbert space representation of the expectation of the (Kolmogorovian) random variable b:

$$E(b/C) = \sum_{x \in X} x|\psi_C(x)|^2 = \sum_{x \in X} x(\psi_C, e_x^b)\overline{(\psi_C, e_x^b)} = (\hat{b}\psi_C, \psi_C),$$

where the (self-adjoint) operator $\hat{b} : H \to H$ is determined by its eigenvectors: $\hat{b}e_x^b = xe_x^b, x \in X$. This is the multiplication operator in the space of complex functions $\Phi(X, \mathbf{C}) : \hat{b}\psi(x) = x\psi(x)$. It is natural to represent this random variable (in the Hilbert space model) by the operator $\hat{b}$. We would like to have Born's rule not only for the b-variable, but also for the a-variable:

$$p_C^a(y) = |(\psi_C, e_y^a)|^2, \quad y \in Y.$$

How can we define the basis $\{e_y^a\}$ corresponding to the a-observable? Such a basis can be found starting with interference of probabilities. We set $u_j^a = \sqrt{p_C^a(a_j)},\ p_{ij} = p(b_j/a_i),\ u_{ij} = \sqrt{p_{ij}},\ \theta_j = \theta_C(b_j)$. We have:

$$\psi = u_1^a e_1^a + u_2^a e_2^a, \tag{6}$$

where

$$e_1^a = (u_{11},\ \ u_{12}),\ \ e_2^a = (e^{i\theta_1} u_{21},\ \ e^{i\theta_2} u_{22}). \tag{7}$$

We consider the *matrix of transition probabilities* $\mathbf{P}^{b/a} = (p_{ij})$. It is always a *stochastic matrix:* $p_{i1} + p_{i2} = 1, i = 1, 2$. We remind that a matrix is called *double stochastic* if it is stochastic and, moreover, $p_{1j} + p_{2j} = 1, j = 1, 2$. The system $\{e_i^a\}$ is an orthonormal basis iff the matrix $\mathbf{P}^{b/a}$ is double stochastic and probabilistic phases satisfy the constraint: $\theta_2 - \theta_1 = \pi \bmod 2\pi$, see [10–15].

It will be always supposed that the $\mathbf{P}^{b/a}$ is double stochastic. In this case the a-observable is represented by the operator $\hat{a}$ which is diagonal (with eigenvalues a_i) in the basis $\{e_i^a\}$. The Kolmogorovian conditional average of the random variable a coincides with the quantum Hilbert space average:

$$E(a/C) = \sum_{y \in Y} y p_C^a(y) = (\hat{a}\psi_C, \psi_C),\ C \in C^{\mathrm{tr}}.$$

We remark that operators $\hat{a}$ and $\hat{b}$ representing the reference observables $J(a)$ and $J(b)$ do not commute, see [14] (this is a consequence of supplementarity of reference variables a and b).

5 Quantum-like Behaviour of Mind

5.1 Cognitive and social contexts

We consider examples of cognitive contexts:

1). C can be some selection procedure which is used to select a special group S_C of people or animals. Such a context is represented by this group S_C (so this is an ensemble of cognitive systems). For example, we select a group $S_{\text{prof.math.}}$ of professors of mathematics (and then ask questions a or (and) b or give corresponding tasks). We can select a group of people of some age. We can select a group of people having a "special mental state": for example, people in love or hungry people (and then ask questions or give tasks).

2). C can be a collection of paintings, C_{painting}, (e.g. the collection of Hermitage in Sankt-Peterburg) and people interact with C_{painting} by looking at pictures (and then they are asked questions about this collection).

3). C can be, for example, "context of classical music", $C_{\text{cl.mus.}}$, and people interact with $C_{\text{cl.mus.}}$ by listening in to this music. In principle, we need not use an ensemble of different people. It can be one person whom we ask questions each time after he has listened in to CD (or radio) with classical music. In the latter case we should use not an ensemble, but frequency (von Mises) definition of probability.

The last example is an important illustration why from the beginning we prefer to start with the general contextualist ideology and only after we consider the possibility to represent contexts by ensembles of systems. A cognitive context should not be identified with an ensemble of cognitive systems representing this context. For us $C_{\text{cl.mus.}}$ is by itself an element of reality.[b]

5.2 Observables

We describe mental interference experiment.

Let $b = x_1, x_2$ and $a = y_1, y_2$ be two dichotomous mental observables: x_1='yes', x_2='no', y_1='yes', y_2='no'. Observables can be two different questions or two different types of cognitive tasks. We use these two fixed reference observables for probabilistic representation of cognitive contextual reality given by C. [c]

5.3 Quantum-like structure of experimental mental data

We perform observations of a under the complex of cognitive conditions C :

$$p^b(x) = \frac{\text{the number of results } b = x}{\text{the total number of observations}}, \quad x \in X.$$

So $p^b(x)$ is the probability to get the result x for observation of the b under the complex of cognitive conditions C. In the same way we find probabilities $p^a(y)$ for the a-observation under the same cognitive context C. [d]

[b] We can also consider *social contexts.* For example, social classes: proletariat-context, bourgeois-context; or war-context, revolution-context, context of economic depression, poverty-context and so on. Thus our model can be used in social and political sciences (and even in history). We can try to find quantum-like statistical data in these sciences.

[c] Of course, by choosing another set of reference observables in general we shall obtain another representation of cognitive contextual reality. Can we find two fundamental mental observables? It is a very hard question. In physics everything is clear: the position and momentum give us the fundamental pair of reference observables. Which mental observables can be chosen as mental analogues of the position and momentum?

[d] Probabilities can be ensemble probabilities or they can be time averages for measurements over one concrete person (e.g., each time after listening in to classical music). Measurements can be even *self-measurements.* For example, I can ask myself questions a or b each time when I fall in love. These should be "hard questions" (incompatible

We suppose there can be created cognitive contexts C_y corresponding to selections with respect to fixed values of the a-observable. The context C_y (for fixed $y \in Y$) can be characterized in the following way. By measuring the a-observable under the cognitive context C_y we shall obtain the answer $a = y$ with probability one. We perform now the b-measurements under cognitive contexts C_y for $y = y_1, y_2$, and find the probabilities:

$$p(x/y) = \frac{\text{the number of the result } b = x \text{ under context } C_y}{\text{the total number of observations under context } C_y},$$

$x \in X, y \in Y$. For example, by using the ensemble approach to probability we have that the probability $p(x_1/y_2)$ is obtained as the frequency of the answer $b = x_1 =$ "*yes*" in the ensemble of cognitive system that have already answered $a = y_2 =$ "*no*". Thus we first select a subensemble of cognitive systems who replies "*no*" to the a-question: $C_{a=no}$. Then we ask systems belonging to $C_{a=no}$ the b-question.[e]

In the quantum-like statistical test for a cognitive context C we calculate the coefficient of supplementarity $\lambda(b = x/a, C)$, see (1). An empirical situation with $\lambda(b = x/a, C) \neq 0$ would yield evidence for quantum-like behaviour of cognitive systems. In this case, starting with (experimentally calculated) coefficient of supplementarity $\lambda(b = x/a, C)$ we can proceed either to the conventional Hilbert space formalism (if this coefficient is bounded by 1) or to the hyperbolic Hilbert space formalism (if this coefficient is larger than 1).

Complex or hyperbolic probability amplitude $\psi = \psi_C$ representing a cognitive context C we call *mental wave function.* This is nothing else than a special mathematical encoding of probabilistic information about this context which can be obtained with the aid of mental reference observables a and b.

---

questions). By giving, e.g., the answer $a =$ "*yes*", I should make some important decision. It will play an important role when I shall answer to the subsequent question b and vice versa.

[e]It is assumed (and this is a very natural assumption) that a cognitive system is "responsible for her (his) answers." Suppose that a system τ has answered $a = y_2 =$ "*no*". If we ask τ again the same question a we shall get the same answer $a = y_2 =$ "*no*". This is nothing else than the mental form of the von Neumann projection postulate: the second measurement of the same observable, performed immediately after the first one, will yield the same value of the observable.

6 Quantum-like Representation of Functioning of Neuronal Structures

We emphasize that the quantum-like representation is created through a projection of underlying mental realistic model to the complex Hilbert space. Such a projection induces a huge loss of information about the underlying mental model. Thus the quantum-like model gives a very rough image of the realistic model.

Let us consider two coupled neural networks N_1 and N_2. We assume that they are strictly hierarchic in the sense that there are "grandmother" neurons n_1 and n_2 in networks N_1 and N_2, respectively.[f] The integral network $N = N_1 + N_2$ interacts with contexts C which are given by input signals into both networks. For example, contexts $\mathcal{C} = \{C\}$ can be visual images and the integral network N recognizes those images (e.g. N_1 is responsible for countors and N_2 for colors). We use so called frequency-domain approach, see e.g. [16], and assume that cognitive information is presented by frequencies of firing of neurons. Consider two reference observables a, b where $a = 1 : n_1$ firing, and $a = 0 : n_1-$nonfiring, and $b = 1 : n_2-$firing, and $b = 0 : n_2-$nonfiring. Our quantum-like formalism gives the possibility to represent each context C (e.g., an image C) by a complex probability amplitude ψ_C. Here probabilities $\mathbf{P}(b = x/C), \mathbf{P}(a = y/C)$ are defined as frequencies. Such an amplitude can be reconstructed on the basis of measurements on grandmother neurons n_1 and n_2. Of course, ψ_C gives only a projection of the neuronal image of the context C. The complete neuronal image is given by frequencies of firing of all neurons in the network N and the QL-image ψ_C is based only on frequencies of firings of grandmother neurons. However, we could not exclude that cognition (and consciousness) is really based on such a QL-projecting of neronal states, see Sect. 7.

7 Quantum-like Consciousness

The brain is a huge information system which contains millions of minds. It could not "recognize" (or "feel") all those minds at each instant of time t.[g] Our fundamental hypothesis is that the brain is able to create the QL-

[f] The model of cognition based on grandmother neurons was dominating in the 60s–80s. Later it was strongly criticized, but was not totally rejected. In the modified approach there are considered grandmother neuronal groups, instead of single neurons.

[g] It may be more natural to consider mental (or psychological) time and not physical time, see e.g. [13,15]. There is experimental evidence that: a) cognition is not based on the continuous time processes (a moment in mental time correlates with $\Delta \approx 100ms$ of physical time); b) different psychological functions operate on different scales of physical time. In [13,15] mental time was described in terms of p-adic hierarchic trees.

representations of minds. At each instant of time t the brain creates the QL-representation of its mental context C based on two supplementary mental (self-)observables a and b. Here $a = (a_1, ..., a_n)$ and $b = (b_1, ..., b_n)$ can be very long vectors of non-supplementary dichotomous observables. The (self-)reference observables can be chosen (by the brain) in different ways at different instances of time. Such a change of the reference observables is known in cognitive sciences as a *change of representation.*

A mental context C in the $b/a-$representation is described by the mental wave function ψ_C. We can speculate that the brain has the ability to feel this mental field as a distribution on the space X. This distribution is given by the norm-squared of the mental wave function: $|\psi_C(x)|^2$. This mental QL-wave contributes into the deterministic dynamics of minds, e.g. by inducing a Bohmian quantum potential, see e.g. [13,15].

In such a model it might be supposed that the state of our consciousness is represented by the mental wave function ψ_C. By using Freud's terminology we can say that one has classical *subconsciousness* and quantum-like consciousness, cf. [13,15]. QL-consciousness is represented by the mental wave function ψ_C. The crucial point is that in this model consciousness is created through neglecting an essential volume of information contained in subconsciousness. Of course, this is not just a random loss of information. Information is selected through the algorithm presented in Sect. 4: context C is projected onto ψ_C.

The (classical) mental state of subconsciousness evolves with time $C \to C(t)$. This dynamics induces dynamics of the mental wave function $\psi(t) = \psi_{C(t)}$ in the complex Hilbert space, see [13] for the mathematical details.

Postulate QLR. *The brain is able to create the QL-representation of mental contexts, $C \to \psi_C$ (by using the algorithm based on the formula of total probability with interference, see Sect. 4).*

8 Brain as Quantum-like Computer

We can speculate that the ability of the brain to create the QL-representation of mental contexts, see Postulate QLR, induces functioning of the brain as a quantum-like computer.

Postulate QLC. *The brain performs computation-thinking by using algorithms of quantum computing in the complex Hilbert space of mental QL-states.*

We emphasize that in our approach the brain is not a quantum computer, but a QL-computer. On the one hand, a QL-computer works totally in accordance with mathematical theory of quantum computations (so by using quantum algorithms). On the other hand, it is not based on superposition of individual mental states. The complex amplitude ψ_C representing a mental context C is a special probabilistic representation of information states of the huge neuronal ensemble. In particular, the brain is a *macroscopic* QL-computer. Thus the QL-parallelism (in the opposite to conventional quantum parallelism) has a natural realistic base. This is real parallelism in working of millions of neurons. The crucial point is the way in which this classical parallelism is projected onto dynamics of QL-states. The QL-brain is able to solve NP-problems. But there is nothing mysterious in this ability: exponentially increasing number of operations is performed through involving an exponentially increasing number of neurons.

We pay attention that by coupling QL-parallelism to working of neurons we started to present a particular ontic model for QL-computations. We shall discuss it in more detail. Observables a and b are self-observations of brain. They can be represented as functions of the internal state of brain ω. Here ω is a parameter of huge dimension describing states of all neurons in brain: $\omega = (\omega_1, \omega_2, ..., \omega_N) : a = a(\omega), b = b(\omega)$. The brain is not interested in concrete values of the reference observables at fixed instances of time. The brain finds the contextual probability distributions $p_C^b(x)$ and $p_C^a(y)$ and creates the mental QL-state $\psi_C(x)$, see algorithm in Sect. 4. Then it works with $\psi_C(x)$ by using algorithms of quantum computing. The crucial problem is to find mechanism of calculating of contextual probabilities. We think that they are frequency probabilities which are created in the brain in the following way.

There are two scales of time: a) internal scale; b) QL-scale. The internal scale is finer than the QL-scale. Each instant of QL-time t corresponds to an interval Δ of internal time τ. We might identify the QL-time with mental (psychological) time and the internal time with physical time. During the interval Δ of internal time the brain collects statistical data for self-observations of a and b.

Thus the internal state ω of the brain evolves as $\omega = \omega(\tau, \omega_0)$. At each instance of internal time τ there are performed nondisturbative self-measurements of a and b. These are realistic measurements: the brain gets values $a(\omega(\tau, \omega_0))$, $b(\omega(\tau, \omega_0))$. By finding frequencies of realization of fixed values for $a(\omega(\tau, \omega_0))$ and $b(\omega(\tau, \omega_0))$ the brain obtains the frequency probabilities $p_C^a(x)$ and $p_C^b(y)$. These probabilities are related to the instant of QL-time time t corresponding to the interval of internal time $\Delta : p_C^b(t, x)$ and $p_C^a(t, y)$.

For example, a and b can be measurements over different domains of brain. It is supposed that the brain can "feel" probabilities (frequencies) $p_C^b(x)$ and $p_C^a(y)$, but it is not able to "feel" the simultaneous probability distribution $p_C(x, y) = P(b = x, a = y/C)$. This is not the problem of mathematical existence of such a distribution.[h] This is the problem of integration of statistics of observations from different domains of the brain. By using the QL-representation based only on probabilities $p_C^b(x)$ and $p_C^a(y)$ the brain could escape integration of information about *individual self-observations* of variables a and b related to spatially separated domains of brain. The brain does not need to couple these domains at each instant of internal time τ. It couples them only once in the interval Δ through the contextual probabilities $p_C^b(x)$ and $p_C^a(y)$. This induces the huge saving of time.

9 Evolution of Mental Wave Function

The mental wave function $\psi(t)$ evolves in the complex Hilbert space (space of probability amplitudes, see Sect. 4). The straightforward generalization of quantum mechanics would imply the *linear* Schrödinger equation:

$$i\frac{d\psi(t)}{dt} = \hat{\mathcal{H}}\psi(t), \quad \psi(0) = \psi_0, \tag{8}$$

where $\hat{\mathcal{H}} : H \to H$ is a self-adjoint operator in the Hilbert space H of mental QL-states. However, the Växjö model [13] predicts a broader spectrum of evolutions in the Hilbert space (induced by evolutions of contexts). We cannot go deeper into the mathematical details and only remark that, in general, the contextual dynamics $C \to C(t)$ can induce *nonlinear* evolutions in H :

$$i\frac{d\psi(t)}{dt} = \hat{\mathcal{H}}(\psi(t)), \quad \psi(0) = \psi_0, \tag{9}$$

where $\hat{\mathcal{H}} : H \to H$ is a nonlinear map. It is important to point out that even the nonlinear dynamics in the Hilbert state space induced by a contextual dynamics is *unitary:* $(\psi(t), \psi(t)) = (\psi(0), \psi(0))$.

In principle,

there are no a priori reasons to assume that the mental quantum-like dynamics should always be linear!

It might be that nonlinearity of the Hilbert space dynamics is the distinguishing feature of cognitive systems. However, at the present time this

[h] We recall that, since we consider only two realistic observables, there is no direct contradiction with Bell's inequality.

is just a speculation. Therefore it would be interesting to consider a linear mental quantum-like dynamics.[i] For example, let us consider a quantum-like Hamiltonian:

$$\hat{\mathcal{H}} \equiv \mathcal{H}(\hat{a}, \hat{b}) = \frac{\hat{b}^2}{2} + V(\hat{a}), \tag{10}$$

where $V : X \to \mathbf{R}$ is a "mental potential" (e.g. a polynomial), cf. [15,17]. We call $\hat{\mathcal{H}}$ the operator of *mental energy.* Denote by ψ_j stationary mental QL-states: $\hat{\mathcal{H}}\psi_j = \mu_j\psi_j$. Then any mental QL-state ψ can be represented as a superposition of stationary states:

$$\psi = k_1\psi_1 + k_2\psi_2, \quad k_j \in \mathbf{C}, \; |k_1|^2 + |k_2|^2 = 1. \tag{11}$$

One might speculate that the brain has the ability to feel superpositions (11) of stationary mental QL-states. In such a case superposition would be an element of mental reality. However, this does not seem to be the case. Suppose that ψ_1 corresponds to zero mental energy, $\mu_1 = 0$. For example, such a QL-state can be interpreted as the state of depression. Let $\mu_2 >> 0$. For example, such a QL-state can be interpreted as the state of excitement. My internal mental experience tells that I do not have a feeling of superposition of states of depression and high excitement. If I am not in one of those stationary states, then I am just in a new special mental QL-state ψ and I have the feeling of this ψ and not superposition.[j] Thus it seems that the expansion (11) is just a purely mathematical feature of the model.

10 Noninjectivity of Correspondence Between Classical Subconsciousness and Quantum-like Consciousness

We use here the interpretation proposed in the previous section and keep in mind that the map $J^{a/b} : \mathcal{C}^{\mathrm{tr}} \to \Phi(X, \mathbf{C})$, see Sect. 4, is not one-to-one. Thus it can be that a few different contexts $C, C', \ldots$ are represented by the same mental QL-state ψ. Suppose now that this is a stationary state — an eigenstate of the operator of mental energy. We pay attention that in general the corresponding mental context is not uniquely determined. QL-stationarity of a state ψ_j can be based on a rather complex dynamics of context, $C_j(t)$, in subconsciousness.

[i] In any event linear dynamics can be considered as an approximation of nonlinear dynamics.

[j] We exclude abnormal behavior such as a manic-depressive syndrome.

11 Hyperbolic Hilbert Space Projection of the Classical Probabilistic Model

We study here the model with the *hyperbolic interference.* We set $C^{\rm hyp} = \{C : |\lambda(x/a,c)| \geq 1, x \in X\}$. We call elements of $C^{\rm hyp}$ hyperbolic contexts.

11.1 Hyperbolic algebra

Instead of the field complex numbers $\mathbf{C}$, we shall use so called **hyperbolic numbers,** namely the two-dimensional Clifford algebra, $\mathbf{G}$. We call this algebra *hyperbolic algebra.* Denote by the symbol j the generator of the algebra $\mathbf{G}$ of hyperbolic numbers: $j^2 = 1$. The algebra $\mathbf{G}$ is the two dimensional real algebra with basis $e_0 = 1$ and $e_1 = j$. Elements of $\mathbf{G}$ have the form $z = x + jy,\ x, y \in \mathbf{R}$. We have $z_1 + z_2 = (x_1 + x_2) + j(y_1 + y_2)$ and $z_1 z_2 = (x_1 x_2 + y_1 y_2) + j(x_1 y_2 + x_2 y_1)$. This algebra is commutative. It is not a field — not every element has the inverse one.

We introduce an involution in $\mathbf{G}$ by setting $\bar{z} = x - jy$ and set $|z|^2 = z\bar{z} = x^2 - y^2$. We remark that $|z| = \sqrt{x^2 - y^2}$ **is not well defined** for an arbitrary $z \in \mathbf{G}$. We set $\mathbf{G}_+ = \{z \in \mathbf{G} : |z|^2 \geq 0\}$. We remark that $\mathbf{G}_+$ is a multiplicative semigroup as it follows from the equation $|z_1 z_2|^2 = |z_1|^2 |z_2|^2$. Thus, for $z_1, z_2 \in \mathbf{G}_+$, we have that $|z_1 z_2|$ is well defined and $|z_1 z_2| = |z_1||z_2|$. We define a hyperbolic exponential function by using a hyperbolic analogue of the Euler's formula:

$$e^{j\theta} = \cosh\theta + j\sinh\theta,\ \theta \in \mathbf{R}.$$

We remark that

$$e^{j\theta_1} e^{j\theta_2} = e^{j(\theta_1 + \theta_2)},\quad \overline{e^{j\theta}} = e^{-j\theta},\quad |e^{j\theta}|^2 = \cosh^2\theta - \sinh^2\theta = 1.$$

11.2 Hyperbolic probability amplitude, hyperbolic Born's rule

The interference formula of total probability can be written in the following form:

$$p_C^b(x) = \sum_{y \in Y} p_C^a(y) p(x/y) \pm 2\cosh\theta_C(x) \sqrt{\Pi_{y \in Y} p_C^a(y) p(x/y)}\ , \qquad (12)$$

where $\theta_C(x) = \theta(x/a, C) = \pm \mathrm{arccosh}|\lambda(\mathrm{x/a, C})|,\ \mathrm{x} \in \mathrm{X}, \mathrm{C} \in C^{\rm hyp}$. By using the elementary formula

$$D = A + B \pm 2AB\cosh\theta = |\sqrt{A} \pm e^{j\theta}\sqrt{B}|^2,$$

for $A, B > 0$, we can represent the probability $p_C^b(x)$ as the square of the hyperbolic amplitude $p_C^b(x) = |\psi_C(x)|^2$, where

$$\psi(x) \equiv \psi_C(x) = \sqrt{p_C^a(a_1) p(x/a_1)} + \epsilon_C(x) e^{j\theta_C(x)} \sqrt{p_C^a(a_2) p(x/a_2)}\ . \quad (13)$$

Here $\epsilon_C(x) = \text{sign } \lambda(x/a, C)$. Thus we have a *hyperbolic generalization of Born's rule* for the b-variable.

12 Växjö Model of Physical and Mental Realities

We constructed projections of special classes of contexts, C^{tr} and C^{hyp}, to complex and hyperbolic Hilbert spaces. We pay attention that in general $C^{\text{tr}} \cup C^{\text{hyp}} \neq F$. There exist contexts which could not be projected to the complex or hyperbolic Hilbert space. Quantum mechanics is not complete; moreover, even both quantum models (complex and hyperbolic) do not give the complete image of prespace reality. How could we complete our picture of prespace? We should be able to find a new fundamental physical variable u and take also its conjugate variable v such that they induce realistic observables $J(u)$ and $J(v)$. It is supposed that these observables are nonreducible to the position and momentum observables. Since in general $C^{\text{tr}}_{b/a} \neq C^{\text{tr}}_{u/v}$ and $C^{\text{hyp}}_{b/a} \neq C^{\text{hyp}}_{u/v}$, we get in the complex and hyperbolic Hilbert spaces images of new prespace contexts (by using the maps $J^{u/v} : C^{\text{tr}}_{u/v} \to H$ and $J^{u/v} : C^{\text{hyp}}_{u/v} \to H^{\text{hyp}}$). However, it might be that human beings could not even in principle observe physical variables nonreducible to position.

We also make remark about the von Neumann "NO-GO" theorem [2]. Our model does not contradict to von Neumann's conclusion that there are no *dispersion-free quantum states.* Of course, the Kolmogorov model on prespace contains dispersion-free contexts for the reference observables (e.g. the position and momentum). In particular, the Heisenberg uncertainty relations are violated for them. But such contexts do not belong to the class of trigonometric contexts C^{tr}. Therefore they do not have images in the complex Hilbert space of quantum states. For example, a single point context $C_\omega = \{\omega\}$ is dispersion-free, but does not belong to C^{tr}.

In our approach classicality is a joint feature of a context and reference observables. It is meaningless to speak about classical observables without relation to a context. A prespace context C can be called classical with respect to an observational model with reference observables a and b if in this model it is possible to find the joint probability distribution $p_C(x, y) = \mathbf{P}(b = x, a = y)$. Denote the set of classical contexts by the symbol C^{class}. We pay attention that there is a crucial difference between definitions of trigonometric and hyperbolic contexs and classical contexts. First two classes are defined in internally prespace terms (in the ontic model); the third class cannot be defined in the ontic model. Another important point is that we speak about the possibility "to find" and not (as many authors) about the purely mathematical existence of the joint probability distribution. In our model it always exists, but in general the observational model does not give us the possibility to find it.

Let us introduce the classical phase space corresponding to the reference observables: $Z = X \times Y$ (e.g. position–momentum space). Denote the set of probabilistic measures on the phase space by $M(Z)$. It is natural to represent classical contexts by elements of $M(Z) : J^{b,a}_{\text{class}} : C^{\text{class}} \to M(Z),\ C \to p_C$. This is our interpretation of the classical statistical mechanics (considered as an epistemologic model) as the image of the set of classical contexts in prespace. We emphasize that even classical projection induces an enormous loss of information about contexts. In particular, each point $z = (x, y) \in Z$ which can be represented by the Dirac δ-measure is, in fact, the image of the huge domain in the prespace, namely $W_z = \{\omega \in \Omega : b(\omega) = x, a(\omega) = y\}$. Stationarity in the classical phase space is the image of very compex motions in the prespace (the same is valid for stationarity in the quantum state space).

The same model can be used for the mental reality. As it was already remarked, here we have the problem of the choice of fundamental mental variables — analogues of position and momentum. It might be that there are no such fixed-for-ever observables and the brain can easily change a representation of mental reality.

Finally, we make a short remark about time. Time is classical in both quantum and classical epistemologic models in the following sense. It is assumed that beside the fundamental variable b and its conjugate a there is a well-defined time variable $T : \Omega \to \mathbf{R}$. It is also possible to represent it by the realistic time-observable. Let context $C \in C^{\text{class}}$. Then it is assumed that there is a well-defined joint probability distribution $p_C(t; x, y) = \mathbf{P}(T = t, b = x, a = y)$. It evolves according to the Liouville equation. Let now context $C \in C^{\text{tr}}$. It is assumed that for any reference observable there is defined a joint probability distribution with the time-observable: $p_C(t; x) = \mathbf{P}(T = t, b = x)$ and $p_C(t; y) = \mathbf{P}(T = t, a = y)$. These probability distributions determine (under some assumptions) the complex probability amplitude $\psi_C(t, x)$ which evolves (under some assumptions) according to the Schrödinger equation. In prespace there is no time! Time is created through a special realistic observable on the prespace. Finally, we remark that each instant of time t corresponds to a huge domain in the prespace, namely to $W_t = \{\omega \in \Omega : T(\omega) = t\}$.

References

1. Dirac, P.A.M. (1930) *The Principles of Quantum Mechanics,* Oxford University Press, Oxford.
2. Neumann, J. von (1955) *Mathematical Foundations of Quantum Mechanics,* Princeton University Press, Princeton (N.J.).
3. Bohm, D. (1951) *Quantum Theory,* Prentice-Hall, Englewood Cliffs (N.J.).
4. Lande, A. (1955) *Foundations of Quantum Theory,* Yale University Press, Yale.
5. Broglie, L. de (1964) *The Current Interpretation of Wave Mechanics: A Critical Study*, Elsevier, Amsterdam–London–New York.
6. Atmanspacher, H., Bishop, R. C., and Amann, A. (2001) Extrinsic and intrinsic irreversibility in probabilistic dynamical laws, in A. Yu. Khrennikov (ed.), *Foundations of Probability and Physics,* Ser. *Q. Prob. White Noise Anal.* **13**, WSP, Singapore, pp. 50–70.
7. Khrennikov, A.Yu. (ed.), (2001) *Foundations of Probability and Physics,* Ser. *Q. Prob. White Noise Anal.* **13**, WSP, Singapore.
8. Khrennikov, A.Yu. (ed.), (2002) *Quantum Theory: Reconsideration of Foundations,* Ser. *Math. Modeling* **2**, Växjö University Press, Växjö.
9. Khrennikov, A.Yu. (ed.), (2005) *Foundations of Probability and Physics – 3,* American Institute of Physics, Ser. *Conference Proceedings* **750**.
10. Khrennikov, A.Yu. (2001) Linear representations of probabilistic transformations induced by context transitions, *J. Phys. A: Math. Gen.* **34**, 9965–9981.
11. Khrennikov, A.Yu. (2002) Quantum statistics via perturbation effects of preparation procedures, *Il Nuovo Cimento* **B117**, 267–281.
12. Khrennikov, A.Yu. (2002) Ensemble fluctuations and the origin of quantum probabilistic rule, *J. Math. Phys.* **43**, 789–802.
13. Khrennikov, A.Yu. (2004) *Information Dynamics in Cognitive, Psychological and Anomalous Phenomena*, Ser. *Fundamental Theories of Physics*, Kluwer, Dordrecht.
14. Khrennikov, A.Yu. (2004) Contextual approach to quantum mechanics and the theory of the fundamental prespace, *J. Math. Phys.* **45**, 902–921.
15. Khrennikov, A.Yu. (2000) Classical and quantum mechanics on p-adic trees of ideas, *BioSystems* **56**, 95–120.
16. Hoppensteadt, F.C. (1997) *An Introduction to the Mathematics of Neurons: Modeling in the Frequency Domain,* Cambridge University Press, New York.
17. Khrennikov, A.Yu. (2003) Quantum-like formalism for cognitive measurements, *Biosystems* **70**, 211–233.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 409–426

ABSTRACT ALGEBRA, PROJECTIVE GEOMETRY AND TIME ENCODING OF QUANTUM INFORMATION

MICHEL PLANAT
FEMTO-ST, University of Franche-Comté, 32 Avenue de l'Observatoire
25044, Besançon, France
(planat@lpmo.edu)

METOD SANIGA
Astronomical Institute, Slovak Academy of Sciences
SK-05960 Tatranská Lomnica, Slovak Republic
(msaniga@astro.sk)

Abstract: Algebraic geometrical concepts are playing an increasing role in quantum applications such as coding, cryptography, tomography and computing. We point out here the prominent role played by Galois fields viewed as cyclotomic extensions of the integers modulo a prime characteristic p. They can be used to generate efficient cyclic encoding, for transmitting secrete quantum keys, for quantum state recovery and for error correction in quantum computing. Finite projective planes and their generalization are the geometric counterpart to cyclotomic concepts, their coordinatization involves Galois fields, and they have been used repetitively for enciphering and coding. Finally, the characters over Galois fields are fundamental for generating complete sets of mutually unbiased bases, a generic concept of quantum information processing and quantum entanglement. Gauss sums over Galois fields ensure minimum uncertainty under such protocols. Some Galois rings which are cyclotomic extensions of the integers modulo 4 are also becoming fashionable for their role in time encoding and mutual unbiasedness.

Keywords: Time – Codes – Quantum Information – Galois Fields – Finite Geometry

1 Introduction

Many objects of our today life would not have been designed without the revolution of knowledge undertaken one century ago: quantum mechanics. But many philosophers, as well as scientists, are still not satisfied with its abstract interpretation of the physical world. The operational formalism of quantum mechanics can answer almost every question about the observable quantities, but we would like to know more about the quantum machine. We had time and space in the old continuous machinery of the nineteenth century physics; where do they reside now? According to the Heisenberg indeterminacy principle, there are gaps in our time description of quantum processes that we cannot fill: accuracy in the isolation of time events means a lack of knowledge of their energy. The same for position in space of a particle which is complementary to the momentum. Some scholars are convinced that we, as humans, are partly responsible for tiny impacts such a particle may suffer during an experiment. The loose of realism would be inherent to the realm of quantum mechanics.

Let us point out that more knowledge about quantum processes may be obtained thanks to quantum information theory — the recent marriage of quantum mechanics and information theory. In the last decade new concepts with quantum bits (qubits), such as qu-cryptography, qu-teleportation, qu-cloning, qu-computing and qu-money have been implemented [1]. They have grown upon a big stone erected in 1935: the EPR paradox about the entanglement of quantum states. Qubit entanglement (and its generalization to qudits, i.e. many-level quantum states) is the main resource of the newly emerged quantum information technology.

The goal of this paper is to revisit some of the objects of quantum information theory using finite algebraic geometrical concepts such as finite fields (also known as Galois fields), and to give them a geometrical setting. In doing so, a kind of discrete space-time emerges, time being connected to algebraic ideals and space to finite geometries. The notion of a character maps elements of the Galois fields to the quantum states of interest.

2 Time and Its Relation to Ideals

2.1 Ideals and the residue class ring

Let us start our quest of the nature of time in the algebraic world. Our objects are elements of a finite set which is a ring, $\mathcal{R}$, i.e. the set endowed with two operations "+" and "·". The ring is a group with respect to addition; the product of two elements is in $\mathcal{R}$ and it is both associative and distributive with respect to addition. One needs the concept of an ideal $\mathcal{I}$ in $\mathcal{R}$, denoted $\mathcal{I} \lhd \mathcal{R}$, which is a subset of $\mathcal{R}$ such that $\forall a \in \mathcal{I}$, $\forall r \in \mathcal{R}$ one has both $ar \in \mathcal{I}$ and $ra \in \mathcal{I}$. In other words, with the concept of an ideal one pins each element of $\mathcal{R}$ into the subset $\mathcal{I}$; and with the concept of a principal ideal $\mathcal{I} = (a)$, a single element a generates the whole ideal. For a commutative ring $\mathcal{R}$ with an identity the definition is: $(a) = a\mathcal{R} = \{ar,\ r \in \mathcal{R}\}$. A familiar example is the ring of integers $\mathcal{R} = \mathcal{Z} = \{\cdots, -2, -1, 0, +1, +2, \cdots\}$. The principal ideal generated by the number $a = 3$ in $\mathcal{Z}$ is $(a) = \{\cdots, -6, -3, 0, 3, 6, \cdots\}$.

The next important object is the concept of a residue class of a modulo $\mathcal{I}$, which consists of all elements $[a] = \{a + c, \ \forall c \in \mathcal{I}\}$ and is useful to partition the ring into disjoint classes (or cosets). The set of classes has the property to be a ring, called the residue class ring and denoted $\mathcal{R}/\mathcal{I}$. For the integers $\mathcal{Z}$ modulo the ideal (3), one gets the three classes $[0] = 0 + (3)$, $[1] = 1 + (3)$ and $[2] = 2 + (3)$, and the residue class ring is $\mathcal{Z}/(3) = F_3$, where F_3 is the unique field with 3 elements. It is known that for a prime number p, $Z/(p) = \mathcal{Z}_p = F_p$, where $\mathcal{Z}_p$ is the set of integers modulo p and F_p the field with p elements. But, for example, $Z/(4)$ is not a field since $2.2 = 4 = 0$ and thus 2 divides 0.

2.2 Polynomial rings, Galois fields and their representations

Let us now consider a ring $\mathcal{R}[x]$ of polynomials with coefficients in $\mathcal{R}$

$$\mathcal{R}[x] = \{a_0 + a_1 x + \cdots + a_n x^n\}, \quad a_i \in \mathcal{R}. \tag{1}$$

One says that $g \in \mathcal{R}[x]$ is irreducible if it cannot be factored in $\mathcal{R}$; e.g. $x^2 - 2 \in \mathcal{Q}[x]$ is irreducible in the field $\mathcal{Q}$ of rational numbers, but $x^2 - 2 = (x + \sqrt{2})(x - \sqrt{2})$ over the real numbers $\Re$. There is an important theorem that for any polynomial $g \in \mathcal{R}[x]$, the residue class ring $\mathcal{R}[x]/(g)$ is a field if and only if (iff) g is irreducible over $\mathcal{R}$ [2]. For example for $\mathcal{R} = F_2 = \{0, 1\}$, the field with two elements, and since $g = x^2 + x + 1$ is irreducible over F_2, then $F_4 = F_2[x]/(g)$ is the Galois field with 4 elements $[0] = (g), [1], [x]$ and $[x+1]$. For example $[x]+[x+1] = x+(g)+x+1+(g) = 2x+1+(g)+(g) = 1 + (g) = [1]$. Similarly $[x][x] = (x + (g))(x + (g)) = x^2 + (g)(2x + 1) = x^2 + (g) = x^2 - (x^2 + x + 1) + (g) = -(x+1) + (g) = (x+1) + (g) = [x+1]$.

It can be shown that a Galois field with q elements exists iff $q = p^m$, a power of a prime number p. Actually, there are several representations of Galois fields. The first one is as a polynomial as in (1). The second one consists of identifying the Galois field F_q, with $q = p^m$, to the vector space F_p^m build from the coefficients of the polynomial. The third one uses the property that $F_q^* = F_q - \{0\}$ is a multiplicative cyclic group. One needs the concept of a primitive polynomial. A (monic) primitive polynomial, of degree m, in the ring $F_q[x]$ is irreducible over F_q and has a root $\alpha \in F_{q^m}$ that generates the multiplicative group of F_{q^m}. A polynomial $g \in F_q[x]$ of degree m is primitive iff $g(0) \neq 0$ and divides $x^r - 1$, with $r = q^m - 1$.

For example, F_8 can be build from $\mathcal{R} = F_2$ and $g = x^3 + x + 1$ which is primitive over F_2. One gets $F_8 = F_2[x]/(g) = \{0, 1, \alpha, \alpha^2, \alpha^3 = 1 + \alpha, \alpha^4 = \alpha + \alpha^2, \alpha^5 = 1 + \alpha + \alpha^2, \alpha^6 = 1 + \alpha^2\}$, see Table 1.

Table 1. Representations of the elements of the Galois field $GF(8)$.

as powers of α	as polynomials	as 3-tuples in $\mathcal{Z}_2^3$
0	0	$(0,0,0)$
1	1	$(0,0,1)$
α	α	$(0,1,0)$
α^2	α^2	$(1,0,0)$
α^3	$1+\alpha$	$(0,1,1)$
α^4	$\alpha+\alpha^2$	$(1,1,0)$
α^5	$1+\alpha+\alpha^2$	$(1,1,1)$
α^6	$1+\alpha^2$	$(1,0,1)$

2.3 Cyclic codes as ideals

In one of our recent papers arithmetical functions were considered relevant models of time evolution [3]. For instance, the function $a(n)$ defined as 1 if $n = p^m$, p a prime number, and 0 otherwise, was found to play an important role in the study of phase fluctuations in an oscillator. Three generic functions are met in elementary analytical number theory. One is the Mangoldt function, closely related to the above defined $a(n)$ function. The second is the Euler (totient) function $\phi(n)$, which counts the number of irreducible fractions l/n, $\gcd(l,n) = 1$. If one knows the decomposition $n = \prod_i p_i^{m_i}$ as a product of prime powers, then $\phi(n) = n\prod_i(1-1/p_i)$. The third one, the Möbius function, codes the distribution of primes as $\mu(1) = 0$, $\mu(n) = 0$ if n contains a square and $(-1)^k$ if n is the product of k distinct prime numbers. The last two functions still appear in the theory of cyclic codes, as it will be illustrated below.

In Sect. 2.2 we defined Galois fields as the residue class ring over a ground field F_p of characteristic p, generated by a polynomial $g(x)$ irreducible over F_p. One can generalize this view by considering F_q, $q = p^n$, as the ground field and by defining an ideal (g) from a polynomial g which is irreducible over the polynomial field $F_q[x] \equiv F_q^n$. This definition encompasses all linear cyclic codes. A linear code is any vector subspace of F_q^n, and it is cyclic if one goes from one line to the other of the generating matrix by a shift of its elements.

All cyclic codes are constructed by all the divisors g in $F_q[x]$ of the polynomial $x^n - 1$. The divisors are $g = Q_d$, the so-called d^{th} cyclotomic polynomials, their degree is $\phi(d)$ and they are defined as

$$Q_d = \prod_{d|n}(x^d - 1)^{\mu(n/d)}. \tag{2}$$

The Mangoldt function [3] is a way of encoding the primes.[a] In the new context of cyclic codes, the cyclotomic polynomial also encodes the irregularity of primes. There exists a "zeta" function and a "Riemann hypothesis" for F_q; the latter was proved by Weil in 1948 [4].

Let us describe a linear $[n, k]$ code from its generator matrix. We use the polynomial

$$g = g_0 + g_1 x + \cdots + g_m x^m \ \in F_q[x] = F_q^n, \ \ g|(x^n - 1), \ \ \deg(g) = m < n. \quad (3)$$

The generator matrix is as follows

$$\begin{bmatrix} g_0 & g_1 & \cdots & g_m & 0 & \cdots & 0 \\ 0 & g_0 & \cdots & g_{m-1} & g_m & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & g_0 & g_1 & \cdots & g_m \end{bmatrix} = \begin{bmatrix} g \\ xg \\ \cdots \\ x^{k-1} g \end{bmatrix}. \quad (4)$$

As an example, we mention the binary Hamming code of length $n = 7$, which is obtained from $g = x^3 + x + 1$ of coefficients over F_2 and contains 4 elements which are the lines of the following generating matrix

$$\begin{bmatrix} 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 1 \end{bmatrix}. \quad (5)$$

The index n plays the role of time and the code is thus a 2-valued time encoded by the cyclotomic polynomial (2).

3 Quantum States and Their Relation to Additive Characters

3.1 The additive characters

A character $\kappa(g)$ over an abelian group G is a (continuous) map from G to the field of complex numbers $\mathcal{C}$ that is of modulus 1, i.e. such that $|\kappa(g)| = 1$, $g \in G$. Since there are two operations "+" and "·" in the field F_q, one can define two kinds of characters. Multiplicative characters $\psi_k(n) = \exp(\frac{2i\pi nk}{q})$, $k = 0, \ldots, q-1$, are well known since they constitute the basis for the ordinary discrete Fourier transform. But additive characters introduced below are the ones which are useful to relate to quantum

[a]The Mangoldt function, $\Lambda(n)$, plays a prominent role in the (still unsolved) Riemann hypothesis. $\Lambda(n)$ equals $\ln(p)$ if $n = p^m$ and 0 otherwise. Its average value oscillates around 1 and the error term explicitly relies on the pole at $s = 1$ of the Riemann zeta function $\zeta(s) = \sum_{\Re(s)>1} n^{-s}$, $\Re(s) > 1$, on the trivial zeros at $s = -2l$, $l > 0$, of the extended zeta function $\xi(s) = \pi^{-s/2}\Gamma(s/2)\zeta(s)$, $\Gamma(s)$ being the Gamma function, and on the Riemann zeros presumably all located on the critical axis $\Re(s) = 1/2$.

information. One first defines a map from the extended field F_q, $q{=}p^m$, to the ground field F_p which is called the trace function

$$tr(x) = x + x^p + \cdots + x^{p^{m-1}} \in F_p, \quad \forall\, x \in F_q. \tag{6}$$

In addition to its property of mapping an element of F_q into F_p, the trace function has the following properties: $tr(x+y) = tr(x) + tr(y),\ x, y \in F_q$; $tr(ax) = a\ tr(x),\ x \in F_q,\ a \in F_p$; $tr(a) = ma,\ a \in F_p$; and $tr(x^q) = tr(x),\ x \in F_q$. Using (6), an additive character over F_q is defined as

$$\kappa(x) = \omega_p^{tr(x)}, \quad \omega_p = \exp\left(\frac{2i\pi}{p}\right), \quad x \in F_q. \tag{7}$$

It satisfies the following relation: $\kappa(x+y) = \kappa(x)\kappa(y),\ x, y \in F_q$.

3.2 Quantum states: qubits and qudits

Well before the development of quantum information theory physicists developed an efficient formalism for working out quantum states. This formalism was born (with Dirac) in the context of the second quantization of a harmonic oscillator. The language of kets $|u\rangle$ and bras $\langle u|$, for u an element of a Hilbert space $\mathcal{H}$, a vector space over the complex numbers $\mathcal{C}$ equipped with a complex-valued inner product $\mathcal{H} \times \mathcal{H} \to \mathcal{C}$, is still in use today.

Physically, a qubit is an element of a Hilbert space of dimension 2, $\mathcal{H}_2$; it can represent a spin 1/2, a two-level atomic system, a two-polarisation state, *etc.* The most general form of a qubit $|\psi\rangle$ is

$$|\psi\rangle = a|0\rangle + b|1\rangle, \quad |a|^2 + |b|^2 = 1 \quad a, b \in \mathcal{C}. \tag{8}$$

In the computational frame of a qubit base $B_0 = (|0\rangle, |1\rangle)$, we have $|0\rangle = (1, 0)$ and $|1\rangle = (0, 1)$. The geometry of the qubit is the Bloch sphere [5], with the qubit $|0\rangle$ at the north pole and the qubit $|1\rangle$ at the south one. In what follows we will be interested in qudits, quantum states in a generic, q-dimensional Hilbert space $\mathcal{H}_q$ defined as $|\psi\rangle = \sum_{k=0}^{q-1} a_k|k\rangle$, $\sum_k |a_k|^2 = 1$, $a_k \in \mathcal{C}$, although recently the particular cases of q=2, 4 and 8 received a lot of attention due to their intimate link to Hopf fibrations (see, e.g. [6]).

Another important concept for quantum measurements has recently emerged, the one of a complete set of mutually unbiased bases (MUBs). Besides the concept of an additive character of the Galois field F_q, MUBs reveal a connection between F_q and the structure of Hilbert space $\mathcal{H}_q$. Orthogonal bases of a Hilbert space $\mathcal{H}_q$ of finite dimension q are mutually unbiased if inner products between all possible pairs of vectors of distinct bases equal $1/\sqrt{q}$. They are also said to be maximally non-commutative in the sense that a measurement over one basis leaves one completely uncertain as to the outcome of a measurement performed over a basis unbiased to the first. For q=2, the eigenvectors of ordinary Pauli spin matrices provide the best-known example.

With a complete set of $q+1$ mutually unbiased measurements one can ascertain the density matrix of an ensemble of unknown quantum q-states, so that a natural question emerges as which mathematics may provide the construction. It is known that in dimension $q = p^m$ the complete sets of mutually unbiased bases (MUBs) result from Fourier analysis over the Galois field F_q (p odd) [7] or a Galois ring R_{4^m}(p even) [8].

Constructions of MUBs in odd characteristic[b] are related to the character sums with polynomial arguments $f(x)$, called Weil sums,

$$\sum_{x \in F_q} \kappa(f(x)). \tag{9}$$

In particular (see theorem 5.38 in [2]), for a polynomial $f(x) \in F_q[x]$ of degree $d \geq 1$, with $\gcd(d,q) = 1$, one gets $|\sum_{x \in F_q} \kappa(f(x))| \leq (d-1)q^{1/2}$. The complete sets of MUBs are obtained as [8, 9]

$$|\theta_b^a\rangle = \frac{1}{\sqrt{q}} \sum_{n \in F_q} \psi_k(n) \kappa(an^2 + bn)|n\rangle, \quad a, b \in F_q, \tag{10}$$

with $\psi_k(n)$ and $\kappa(x)$ defined in Sect. 3.1. Eq. (10) defines a set of q bases (with index a) of q vectors (with index b). Using Weil sums (9) it is easily shown that for q odd the bases are orthogonal and mutually unbiased to each other and to the computational base $\{|0\rangle, |1\rangle, \cdots, |q-1\rangle\}$ as well.

3.3 Mutually unbiased bases as quantum phase states

Dirac was the first to attempt a definition of a phase operator by means of an operator amplitude and phase decomposition. In this description the number operator N and the phase operator Θ are canonically conjugate such that $[N, \Theta] = i$, where [ ] are the commutator brackets, and this equation leads to a number–phase uncertainty relation $\delta N \delta\phi \geq 1/2$. Quantum phase states reaching the bound are coherent, or squeezed states. But there is a big problem in defining such a Hermitian quantum phase operator [10] using the familiar Fock states of the quantized electromagnetic field.

[b] Fourier analysis and MUBs in even characteristic are studied in Sect. 6.

One way to circumvent the problem is the use of a discrete Hilbert space $\mathcal{H}_q$. It was shown [11] that states (10) obtained from a trivial character $\kappa_0 = 1$ are eigenstates of the Hermitian phase operator

$$\Theta = \sum_{k \in \mathcal{Z}_q} \theta_k |\theta_k\rangle\langle\theta_k|, \tag{11}$$

with eigenvalues $\theta_k = \theta_0 + \frac{2\pi k}{q}$, θ_0 being an arbitrary initial phase. More generally, the MUB states are eigenstates of a "Galois" quantum phase operator [9]

$$\Theta_{\text{Gal}} = \sum_{b \in F_q} \theta_b |\theta_b^a\rangle\langle\theta_b^a|, \quad a, b \in F_q, \tag{12}$$

with eigenvalues $\theta_b = \frac{2\pi b}{q}$. The operator can be made more explicit when combined with Eq. (10),

$$\Theta_{\text{Gal}} = \frac{2\pi}{q^2} \sum_{m,n \in F_q} \psi_k(n-m)\omega_p^{tr[a(n^2-m^2)]} S(n,m)|n\rangle\langle m|, \tag{13}$$

with $S(n,m) = \sum_{b \in F_q} b\omega_p^{tr[b(n-m)]}$. The diagonal matrix elements feature the sums $S(n,n) = q(q-1)/2$, while for the non-diagonal ones one gets $S(m,n) = \frac{q}{1-\omega_p^{tr(m-n)}}$.

4 Phase Fluctuations: From Ramanujan to Gauss Sums

In the previous work [12], the near classical regime of a phase-locked oscillator has been studied and its phase fluctuations have been related to the irregularity of the distribution of prime numbers. A quantum model of phase-locking was derived based on operator (11) with an additional assumption that only elements $|\theta'_k\rangle$ with k coprime to q were taken into account. As a result, the quantum phase-locking operator

$$\Theta_{\text{lock}} = \sum_k \theta'_k |\theta'_k\rangle\langle\theta'_k| \tag{14}$$

can be evaluated explicitly as

$$\Theta_{\text{lock}} = \frac{1}{q} \sum_{n,l} c_q(n-l)|n\rangle\langle l|, \tag{15}$$

where n, l range from 0 to $\phi(q)$, $\phi(q)$ being the Euler totient function. The coefficients in the last equation are the so-called Ramanujan sums,

$$c_q(n) = \sum_{\gcd(p,q)=1} \exp\left(2i\pi \frac{p}{q} n\right) = \frac{\mu(q_1)\phi(q)}{\phi(q_1)}, \quad q_1 = q/\gcd(q,n), \tag{16}$$

where $\mu(q)$ stands for the above-introduced Möbius function.

For the evaluation of phase variability of states we considered a pure phase state of the form [12]

$$|f\rangle = \sum_{n \in \mathcal{Z}_q} u_n |n\rangle, \quad u_n = \frac{1}{\sqrt{q}} \exp(in\beta), \tag{17}$$

where β is a real parameter, and we computed the phase expectation value $\langle \Theta_{\text{lock}} \rangle = \sum_k \theta'_k |\langle \theta'_k | f \rangle|^2$ which reads

$$\langle \Theta_{\text{lock}} \rangle = \frac{\pi}{q^2} \sum_{n,l} c_q(l-n) \exp(i\beta(n-l)). \tag{18}$$

For $\beta = 1$ it was found that $\langle \Theta_{\text{lock}} \rangle$ has more pronounced peaks at those values of q which are precisely powers of a prime number, and it can be approximated by the normalized Mangoldt function $\pi \Lambda(q)/\ln q$. For $\beta = 0$ the expectation value of $\langle \Theta_{\text{lock}} \rangle$ is much lower. The parameter β can be used to minimize the phase uncertainty well below the classical value [12]. Related phase fluctuations, reflecting properties of the distribution of prime numbers, were obtained in the frame of a quantum statistical mechanics of shift and clock operators. This algebra was also found relevant as a model of time perception [13].

Finally, the phase fluctuations arising from the quantum phase states in MUBs are found to be related to Gaussian sums of the form

$$G(\psi, \kappa) = \sum_{x \in F_q^*} \psi(x)\kappa(x). \tag{19}$$

Using the notation ψ_0 for a trivial multiplicative character, $\psi = 1$, and κ_0 for a trivial additive character, $\kappa = 1$, Gaussian sums (19) satisfy $G(\psi_0, \kappa_0) = q - 1$; $G(\psi_0, \kappa) = -1$; $G(\psi, \kappa_0) = 0$ and $|G(\psi, \kappa)| = q^{1/2}$ for nontrivial characters κ and ψ. We need, however, a more general expression

$$G(\psi, \kappa) = \sum_{x \in F_q} \psi(f(x))\kappa(g(x)), \tag{20}$$

where $f, g \in F_q[x]$, which is found to be of the order of magnitude $\sqrt{q}$ ([2], p. 249). As a matter of fact, the two factors in the expression for the probability distribution $\langle \Theta_{\text{Gal}} \rangle = \sum_{b \in F_q} \theta_b |\langle \theta_b | f \rangle|^2$ have absolute values bounded by the absolute value of generalized Gauss sums (20), so that $|\langle \theta_b | f \rangle|^2 \leq \frac{1}{q}$ as it can be expected for an arbitrary phase factor. To be more rigorous, the phase expectation value can be expressed as

$$\langle \Theta_{\text{Gal}} \rangle = \frac{2\pi}{q^3} \sum_{m,n \in F_q} \psi_k(m-n) \exp[i(n-m)\beta] \omega_p^{tr[a(m^2-n^2)]} S(m,n), \quad (21)$$

where $S(m,n)$ was defined in Sect. 3.3. All the q diagonal terms $m = n$ in $\langle \Theta_{\text{Gal}} \rangle$ contribute an order of magnitude $\frac{2\pi}{q^3} q S(n,n) \simeq \pi$. The contribution of off-diagonal terms and possible cancellation of phase oscillations in the phase expectation value and in phase variance are discussed in [9].

5 Mutual Unbiasedness and Maximal Entanglement

As we have shown, there is a founding link between irreducible polynomials over a ground field F_p and complete sets of mutually unbiased bases arising from the Fourier transform over a lifted field F_q, $q = p^m$. On the other hand, the physical concept of entanglement over a Hilbert space $\mathcal{H}_q$ evokes irreducibility. Roughly speaking, entangled states in $\mathcal{H}_q$ cannot be factored into tensorial products of states in Hilbert spaces of lower dimension. We will now show that there is an intrinsic relation between MUBs and maximal entanglement.

We are all familiar with the Bell states

$$(|\mathcal{B}_{0,0}\rangle, |\mathcal{B}_{0,1}\rangle) = \tfrac{1}{\sqrt{2}}(|00\rangle + |11\rangle, |00\rangle - |11\rangle),$$
$$(|\mathcal{B}_{1,0}\rangle, |\mathcal{B}_{1,1}\rangle) = \tfrac{1}{\sqrt{2}}(|01\rangle + |10\rangle, |01\rangle - |10\rangle),$$

where a compact notation $|00\rangle = |0\rangle \odot |0\rangle$, $|01\rangle = |0\rangle \odot |1\rangle$, *etc.* is employed for the tensorial products. These states are both orthonormal and maximally entangled, such that $trace_2 |\mathcal{B}_{h,k}\rangle\langle\mathcal{B}_{h,k}| = \frac{1}{2} I_2$, where $trace_2$ is the partial trace over the second qubit [5]. One can define more generalized Bell states using the multiplicative Fourier transform [11] applied to the tensorial products of two qudits [9], viz.

$$|\mathcal{B}_{h,k}\rangle = \frac{1}{\sqrt{q}} \sum_{n=0}^{q-1} \omega_q^{kn} |n, n+h\rangle. \quad (22)$$

These states are both orthonormal, $\langle \mathcal{B}_{h,k} | \mathcal{B}_{h',k'} \rangle = \delta_{hh'} \delta_{kk'}$, and maximally entangled, $trace_2 |\mathcal{B}_{h,k}\rangle\langle\mathcal{B}_{h,k}| = \frac{1}{q} I_q$.

For odd characteristic, we can also define a more general class of maximally entangled states, using the Fourier transform over F_q and Eq. (10), as follows

$$|\mathcal{B}_{h,b}^a\rangle = \frac{1}{\sqrt{q}} \sum_{n=0}^{q-1} \omega_p^{tr[(an+b)n]} |n, n+h\rangle. \quad (23)$$

A list of the generalized Bell states of qutrits for the base $a = 0$ can be found in [14] , the work that relies on a coherent state formulation of entanglement. In general, for q a power of a prime, starting from (23) one obtains q^2 bases of q maximally entangled states. Each set of the q bases (with h fixed) has the property of mutual unbiasedness.

6 Mutually Unbiased Bases in Even Characteristic

6.1 Construction of the Galois rings of characteristic four

The Weil sums (9), which have been proved useful in construction of MUBs in odd characteristic, are not useful for $p = 2$ since in this case the degree d of the polynomial $f(x)$ is such that $\gcd(d, q) = 2$ — the characteristic of the relevant Galois fields. An elegant method for constructing complete sets of MUBs of m-qubits was found in [8]. It makes use of algebraic objects in the context of quaternary codes [22], the so-called Galois rings R_{4^m}. In contrast to the Galois fields where the ground alphabet has p elements in the field $F_p = \mathcal{Z}_p$, the ring R_{4^m} takes its ground alphabet in $\mathcal{Z}_4$. To construct this ring one uses the ideal class (h), where h is a (monic) basic irreducible polynomial of degree m such that its restriction to $\bar{h}(x) = h(x) \bmod 2$ is irreducible over $\mathcal{Z}_2$. The Galois ring R_{4^m} is the residue class ring $\mathcal{Z}_4[x]/(h)$ and has cardinality 4^m.

We also need the concept of a primitive polynomial. To this end, we recall that a (monic) primitive polynomial, of degree m, in the ring $F_q[x]$ is irreducible over F_q and has a root $\alpha \in F_{q^m}$ that generates the multiplicative group of F_{q^m}. A polynomial $f \in F_q[x]$ of degree m is primitive iff $f(0) \neq 0$ and divides $x^r - 1$, where $r = q^m - 1$. Similarly for Galois rings R_{4^m}, if $\bar{h}[x]$ is a primitive polynomial of degree m in $\mathcal{Z}_2[x]$, then there is a unique basic primitive polynomial $h(x)$ of degree m in $\mathcal{Z}_4[x]$ (it divides $x^r - 1$, with $r = 2^m - 1$). It can be found as follows [9]. Let $\bar{h}(x) = e(x) - d(x)$, where $e(x)$ contains only even powers and $d(x)$ only odd powers; then $h(x^2) = \pm(e^2(x) - d^2(x))$. For $m = 2$, 3 and 4 one takes $\bar{h}(x) = x^2 + x + 1$, $\bar{h}(x) = x^3 + x + 1$ and $\bar{h}(x) = x^4 + x + 1$ and gets $h(x) = x^2 + x + 1$, $x^3 + 2x^2 + x - 1$ and $x^4 + 2x^2 - x + 1$, respectively.

Any non zero element of F_{p^m} can be expressed in terms of a single primitive element. This is no longer true in R_{4^m}, which contains zero divisors. But in the latter case there exists a nonzero element ξ of order $2^m - 1$ which is a root of the basic primitive polynomial $h(x)$. Any element $y \in R_{4^m}$ can be uniquely determined in the form $y = a + 2b$, where a and b belong to the so-called Teichmüller set $\mathcal{T}_m = (0, 1, \xi, \cdots, \xi^{2^m-2})$. Moreover, one finds that $a = y^{2^m}$. We can also define the generalized trace to the base ring $\mathcal{Z}_4$ as the map

$$\widetilde{\mathrm{tr}}(y) = \sum_{k=0}^{m-1} \sigma^k(y), \tag{24}$$

where $\sigma(y)$ is the so-called Frobenius automorphism, obeying the rule

$$\sigma(a + 2b) = a^2 + 2b^2. \tag{25}$$

In R_{4^m} the additive characters acquire the form

$$\tilde{\kappa}(x) = \omega_4^{\widetilde{\mathrm{tr}}(x)} = i^{\widetilde{\mathrm{tr}}(x)}. \tag{26}$$

6.2 Exponential sums over R_{4^m}

The Weil sums (9) are replaced by the following exponential sums [8]

$$\Gamma(y) = \sum_{u \in \mathcal{T}_m} \tilde{\kappa}(yu), \quad y \in R_{4^m}, \tag{27}$$

which satisfy

$$|\Gamma(y)| = \begin{cases} 0 & \text{if } y \in 2\mathcal{T}_m,\ y \neq 0, \\ 2^m & \text{if } y = 0, \\ \sqrt{2^m} & \text{otherwise.} \end{cases} \tag{28}$$

Gauss sums for Galois rings were constructed in [23] and are of the form

$$G_y(\tilde{\psi}, \tilde{\kappa}) = \sum_{x \in R_{4^m}} \tilde{\psi}(x)\tilde{\kappa}(yx), \quad y \in R_{4^m}, \tag{29}$$

where the multiplicative character $\tilde{\psi}(x)$ can be made explicit. Using the notation $\tilde{\psi}_0$ for a trivial multiplicative character and $\tilde{\kappa}_0$ for a trivial additive character, we get $G(\tilde{\psi}_0, \tilde{\kappa}_0) = 4^m$, $G(\tilde{\psi}, \tilde{\kappa}_0) = 0$ and $|G(\tilde{\psi}, \tilde{\kappa})| \leq 2^m$.

6.3 Mutually unbiased bases of m-qubits

It was mentioned in the previous section that each element y of the ring R_{4^m} can be decomposed as $y = a + 2b$, with a and b belonging to the Teichmüller set $\mathcal{T}_m$. Employing this fact in the character function $\tilde{\kappa}$, one obtains

$$|\theta_b^a\rangle = \frac{1}{\sqrt{2^m}} \sum_{n \in \mathcal{T}_m} \tilde{\psi}_k(n)\tilde{\kappa}[(a + 2b)n]|n\rangle, \quad a, b \in \mathcal{T}_m. \tag{30}$$

This defines a set of 2^m bases (with index a) of 2^m vectors (with index b). Using Eq. (27), it is easy to show that the bases are orthogonal and mutually unbiased to each other and to the computational base. (For the explicit derivation of the bases, see [9].)

Quantum phase states of m-qubits (30) derive from a "Galois ring" quantum phase operator as in Eq. (12), and calculations similar to those in Sect. 3.3 can be performed, since the trace operator defined by Eq. (24) obeys the rules similar to those of the field trace operator, Eq. (6). In analogy to the case of qudits in dimension p^m, p an odd prime, the phase properties for sets of m-qubits rely substantially on Eq. (29). As before, the calculations are tedious, but they can successfully be accomplished in specific cases.

7 Quantum Geometry From Projective Planes

We have related complete sets of MUBs in dimension p^m, p odd, to additive characters over a Galois field. Complete sets of MUBs offer an intriguing geometrical interpretation, being related to discrete phase spaces [15], finite projective planes [16, 17], convex polytopes [18], and complex projective 2-designs [19]. The last-mentioned paper also points out an interesting link to symmetric informationally complete positive operator measures (SIC-POVMs) [20] and to Latin squares [21]. We focus here on the relation of MUBs to finite geometries and projective planes.

7.1 Mutually unbiased bases and projective planes

A remarkable link between mutually unbiased measurements and finite projective geometry has recently been noticed [16]. Let us find the minimum number of different measurements we need to determine uniquely the state of an ensemble of identical q-state particles. The density matrix of such an ensemble, being Hermitean and of unit trace, is specified by $(2q^2/2)-1 = q^2-1$ real parameters. When one performs a non-degenerate orthogonal measurement on each of many copies of such a system one eventually obtains $q-1$ real numbers (the probabilities of all but one of the q possible outcomes). The minimum number of different measurements needed to determine the state uniquely is thus $(q^2-1)/(q-1) = q+1$ [7, 15].

It is striking that the identical expression can be found within the context of finite projective geometry. A finite projective plane is an incidence structure consisting of points and lines such that any two points lie on just one line, any two lines pass through just one point, and there exist four points, no three of them on a line [24]. From these properties it readily follows that for any finite projective plane there exists an integer q with the

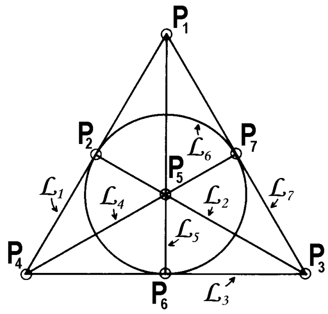


Figure 1. The Fano plane; small circles (denoted as $P_1,\ldots,P_7$) represent its points, while line-segments ($\mathcal{L}_1,\ldots,\mathcal{L}_5$ and $\mathcal{L}_7$) and a circle ($\mathcal{L}_6$) stand for its lines.

properties that any line contains exactly $q+1$ points, any point is the meet of exactly $q+1$ lines, and the number of points is the same as the number of lines, namely q^2+q+1. This integer q is called the order of the projective plane. The most striking issue here is that the order of known finite projective planes is a power of prime. The question of which other integers occur as orders of finite projective planes remains one of the most challenging problems of contemporary mathematics. The only "no-go" theorem known so far in this respect is the Bruck-Ryser theorem [24] saying that there is no projective plane of order q if $q-1$ or $q-2$ is divisible by 4 and q is not the sum of two squares. Out of the first few non-prime-power numbers, this theorem rules out finite projective planes of order 6, 14, 21, 22, 30 and 33. Moreover, using massive computer calculations, it was proved that there is no projective plane of order ten. It is surmised that the order of any projective plane is a power of a prime.

It is conjectured [16] that the question of the existence of a set of $q+1$ mutually unbiased bases in a q-dimensional Hilbert space if q differs from a power of a prime number is identical with the problem of whether there exist projective planes whose order q is not a power of a prime number.

The smallest projective plane, also called the Fano plane (see Fig. 1), is obviously the $q=2$ one; it contains 7 points and 7 lines, any line contains 3 points and each point is on 3 lines. It may be viewed as a 3-dimensional vector space over the field $GF(2)$, each point being a triple (g_1,g_2,g_3), excluding the (0,0,0) one, where $g_i \in GF(2)=\{0,1\}$ [24]. The points of this plane can also be represented in terms of the non-zero elements of the Galois field $G=GF(2^3)$, see the last column of Table 1.

7.2 Cyclic codes and projective spaces

As shown in Sect. 2.3, a linear code C is a subspace of F_q^n, $q = p^m$. And a cyclic code is an ideal (g) in the polynomial field $F_q[x] \equiv F_q^n$ attached to a polynomial g irreducible over F_q. One defines the Hamming distance [2] between x and y in F_q^n as the number of coordinates in which x and y differ. The minimum distance of a code is an important concept which characterizes its efficiency for error correcting; it is defined as

$$d = d_{min}(C) = \min_{\substack{u,v \in C \\ u \neq v}} d(u,v). \tag{31}$$

A linear code corrects up to $[\frac{d-1}{2}]$ and detect up to $d-1$ errors. It can be shown that for a linear $[n,k]$ code, the following bound holds

$$d \leq n - k + 1 = d_{\max}. \tag{32}$$

A minimum distance code (or a maximum distance separable, MDS code) is such that $d = d_{\max}$ and it is usually referred to as a $[n,k,d]$ code (or $[n, n-r, r+1]$ code). The binary Hamming $[7,4]$ code introduced in Sect. 2.3 thus corrects up to 1 and detect up to 3 errors. It is the MDS $[7,4,4]$ code.

There exists an intimate link between this code and the Fano plane, which can be inferred as follows. Let us take its seven codewords 1 to 7 by cyclic extending of matrix (5), viz.

$$\begin{bmatrix} 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 0 & 1 \\ 1 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 1 \\ 1 & 0 & 1 & 0 & 0 & 0 & 1 \end{bmatrix}. \tag{33}$$

The above matrix is nothing but the incidence matrix of the Fano plane, obtained as follows: if P_j is the jth point and $\mathcal{L}_i$ represents the ith line of the Fano plane, the elements of the matrix are

$$a_{ij} = \begin{cases} 1 & \text{if } P_j \in \mathcal{L}_i, \\ 0 & \text{otherwise.} \end{cases} \tag{34}$$

The link between good codes and projective geometry has recently received considerable attention [24]. Let us define a vector space V of dimension $\delta + 1 \geq 3$ over F_q. Then a projective geometry $P(V)$ can be defined as follows. The points of $P(V)$ are its 1-dimensional subspaces, the lines its 2-dimensional subspaces and the incidence structure in $P(V)$ is the set-theoretical containment. The geometry $P(V)$ is the projective space coordinatized by the Galois field F_q. This δ-dimensional projective space $P(V)$ over F_q is usually denoted as $PG(\delta, q)$.

Next, a set of points in $P = PG(\delta, q)$ is called an arc if any $\delta + 1$ of its points form a basis of P. An arc having n points is called an n-arc. In a projective plane $PG(2, q)$ an n-arc is a set of n points no three of which are collinear. If each point of an n-arc is exactly on one tangent, the arc is called an oval. The maximum value of n for an n-arc is

$$m(2,q) = \begin{cases} q+1 & \text{when } q \text{ is odd,} \\ q+2 & \text{when } q \text{ is even.} \end{cases} \tag{35}$$

The meaning of Eq. (35) is as follows. If q is odd, then arcs with a maximum number of points are ovals. If q is even then, each oval can be uniquely extended to a $(q + 2)$-arc, which is called a hyperoval. The possible correspondence between ovals and complete set of MUBs is discussed in [17].

There is a one to one correspondence between the generator matrix of $[n, n-r]$ MDS codes and n-arcs in $PG(r-1, q)$ ([25], p. 73). The construction of good codes with a prescribed minimum distance can be rephrased as follows. One is given the minimum distance d and r. Determine the greatest length of the code, $\max_{d-1}(r, q)$.

The simplest case is $d = 3$ for which $\max_2(r, q)$ is the maximum possible number of points in $PG(r - 1, q)$ such that two of them are independent: this is, obviously, the total number of points in $PG(r - 1, q)$, and thus

$$\max_2(r,q) = q^{r-1} + \cdots + q + 1. \tag{36}$$

In particular, we have $\max_2(r, 2) = 2^r - 1$, which corresponds to the Hamming $[n, n - r]$ code. The case $d = 4$ is less trivial. Only partial results are known:

$$\max_3(r,2) = 2^{r-1}, \tag{37}$$

$$\max_3(3,q) = \begin{cases} q+1 & \text{when } q \text{ is odd,} \\ q+2 & \text{when } q \text{ is even,} \end{cases} \tag{38}$$

and

$$\max_3(4,q) = q^2 + 1. \tag{39}$$

Putting $r = 3$ in Eq. (37) one gets the case of the $[7, 4, 4]$ code considered above. The geometry of Eq. (38) answers to ovals (q odd) and hyperovals (q even) of $PG(2, q)$, that of Eq. (39) to ovoids[c] of $PG(3, q)$.

[c] An ovoid is a nonempty set $\mathcal{O}$ of points of $PG(d, q)$ such that no three points of $\mathcal{O}$ are

8 Conclusion

Let us briefly summarize basic ideas developed in the paper. At the algebraic level, there exists a polynomial field F_q^n defined over a "base" field F_q, with $q = p^m$ and p a prime. The cyclic encoding (in "time" n) comes from (cyclotomic) laws of partitioning F_q^n. At the geometrical level, a projective space can always be partioned into subsets (called spreads). For example, $PG(3, q)$ is partioned into subsets of q^2+1 mutually skew (i.e. pairwise disjoint) lines. These may well form ovoids, which "give rise" to $MDS-$codes. Similarly, there is a partitioning of a projective plane $PG(2, q)$ into sets of $q+1$ lines. These may well be (the tangents of) ovals, which are conjectured to reproduce properties of the sets of mutually unbiased bases. Here, we play with a two-dimensional "quantum space-time." The vectorial projective space, $PG(\delta, q)$, is thus a promising playground for tackling both the measurement and coding problems in quantum mechanics. Yet, there exist more general kinds of finite (projective) geometries, e.g. (non-)Desarguesian projective planes defined over quasi-/near-fields, the latter obeying less stringent rules than fields [26]. These are, we believe, candidates for addressing another intriguing quantum effects like partial entanglement and decoherence.

Acknowledgement

M.S. would like to acknowledge the support received from a 2004 SSHN Physics Fellowship (#411867G/P392152B).

References

1. Bouwmeester, D., Ekert, A.K., and Zeilinger, A. (eds.) (2000) *The Physics of Quantum Information*, Springer Verlag, Berlin.
2. Lidl, R., and Niederreiter, H. (1983) *Finite Fields*, Addison-Wesley, Reading (Mass.).
3. Planat, M. (2001) $1/f$ noise, the measurement of time and number theory, *Fluct. Noise Lett.* **1**, R65–R79.
4. Roquette, P. (2003) The Riemann hypothesis in characteristic p, its origin and development, preprint available at http://www.rzuser.uni-heidelberg.de/~ci3/.
5. Nielsen, M.A., and Chuang, I. (2000) *Quantum Computation and Quantum Information*, Cambridge University Press, Cambridge.
6. Bernevig, B.A., and Chen, H.D. (2003) Geometry of the 3-qubit state, entanglement and division algebras, *J. Phys. A: Math. Gen.* **36**, 8325–8339.
7. Wootters, W.K., and Fields, B.D. (1989) Optimal state-determination by mutually unbiased measurements, *Ann. of Phys.* **191**, 363–381.

collinear and for each point $Q \in \mathcal{O}$ the tangents through Q span the whole hyperplane.

8. Klappenecker, A., and Rötteler, M. (2004) Constructions of mutually unbiased bases, *Lecture Notes in Computer Science* **2948**, 137–144; preprint `quant-ph/0309120`.
9. Planat, M., and Rosu, H. (2005) Quantum phase uncertainty in mutually unbiased measurements and Gauss sums, SPIE Proceedings, *Fluctuations and Noise* **5842**, pp. 183–193; preprint `quant-ph/0502167`.
10. Lynch, R. (1995) The quantum phase, a critical review, *Physics Reports* **256**, 367–436.
11. Pegg, D.T., and Barnett, S.M. (1989) Phase properties of the quantized single-mode electromagnetic field, *Phys. Rev. A* **15**, 1665–1675.
12. Planat, M., and Rosu, H. (2003) Cyclotomy and Ramanujan sums in quantum phase-locking, *Phys. Lett. A* **315**, 1–5.
13. Planat, M. (2004) On the cyclotomic quantum algebra of time perception, *NeuroQuantology* **2**(4), 292–308.
14. Fujii, K. (2001) A relation between coherent states and generalized Bell states, preprint `quant-ph/0105077`.
15. Gibbons, K.S., Hoffman, M.J., and Wootters, W.K. (2004) Discrete phase space based on finite fields, *Phys. Rev. A* **70**, 062101–062123; preprint `quant-ph/0401155`.
16. Saniga, M., Planat, M., and Rosu, H. (2004) Mutually unbiased bases and finite projective planes, *J. Opt. B: Quantum Semiclass. Opt.* **6**, L19–L20; preprint `math-ph/0403057`.
17. Saniga, M., and Planat, M. (2005) Viewing sets of mutually unbiased bases as arcs in finite projective planes, *Chaos, Solitons & Fractals* **26**(5), 1267–1270; preprint `quant-ph/0409184`.
18. Bengtsson, I., and Ericsson, A. (2004) Mutually unbiased bases and the complementarity polytope, preprint `quant-ph/0410120`.
19. Klappenecker, A., and Rötteler, M. (2005) Mutually unbiased bases are complex projective 2-designs, preprint `quant-ph/0502031`.
20. Grassl, M. (2004) On SIC-POVMs and MUBs in dimension six, preprint `quant-ph/0406175`.
21. Wocjan, P., and Beth, T. (2004) New construction of mutually unbiased bases in square dimensions, preprint `quant-ph/0407081`.
22. Wan, Z.-X. (1997) *Quaternary Codes*, World Scientific, Singapore.
23. Yunchang, Oh, and Heung-Joon, Oh (2001) Gauss sums over Galois rings of characteristic 4, *Kangweon-Kyungki Math. Jour.* **9**, 1–7.
24. Beutelspacher, A., and Rosenbaum, U. (1998) *Projective Geometry: From Foundations to Applications*, Cambridge University Press, Cambridge.
25. Hirschfeld, J.W.P. (1998) *Projective Geometries Over Finite Fields*, Oxford Science Publications, Oxford.
26. Hughes, D.R., and Piper, F.C. (1973) *Projective Planes*, Springer, New York.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 427–438

ON THE SUBJECTIVE NATURE OF RELATIVE FREQUENCIES: COMBINING SPECIAL RELATIVITY AND QUANTUM MECHANICS

THOMAS MARLOW
School of Mathematical Sciences, University of Nottingham
Nottingham NG7 2RD, U.K.
(pmxtm@nottingham.ac.uk)

Abstract: During this talk we argued that the peaceful coexistence between special relativity and quantum mechanics can be considered a misnomer. We argue that, given a collapse hypothesis, the Heisenberg picture, and subjective probabilities, one can reason within quantum mechanics in a way that is completely consistent with special relativity. We corroborate this thesis by discussing Bell-like arguments.

Keywords: Peaceful Coexistence – Probability – Bell-like Theorems

1 Motivation

In the literature Special Relativity (SR) and Standard Quantum Theory (SQT) are normally considered to be in some kind of 'peaceful coexistence'. This term was introduced by Shimony [1] because although, it seems, SQT cannot be used to transmit signals at faster than the speed of light there seems to be some form of nonlocality involved when dealing with entangled subsystems at spacelike separation. Thus the spirit of SR is not *seen* to be disobeyed, but still most of us are uncomfortable with the coexistence of quantum nonlocality and SR. The coexistence between SR and SQT is said to be 'peaceful' because we cannot *use* SQT to explicitly disobey SR. The aim of this talk was to try and illustrate an interpretation of SQT which might show SQT and SR to be more compatible than standard peaceful coexistence.

2 On the Compatibility of SR and SQT

We shall use an interpretation of SQT which has the following assumptions (which will be explained and justified in the text):

- The Heisenberg picture.
- A simultaneous-in-each-frame collapse hypothesis.
- Subjective probabilities.

The above three assumptions can be used to ensure that predicted probabilities are explicitly Lorentz invariant and that the reasoning involved in using them is completely consistent with SR [2].

We specifically assume the Heisenberg picture as we cannot see any way to make probabilities Lorentz invariant using the Schrödinger picture. In the Schrödinger picture the self-adjoint operators $\hat{A}$ that represent measurements in SQT are usually independent of time (unless, of course, there exists *explicit* time-dependence of, say, the Hamiltonian operator but here we shall only be considering implicit time dependence). Thus, the set of post-measurement states $\{|a_i\rangle\}$ in the Schrödinger picture are also usually independent of time. Here, i parameterises the eigenstates of the operator $\hat{A}$. When we calculate probabilities in SQT we take an inner product between two post-measurement states—preparations also occur via measurement. If these post-measurement states are independent of the time at which the relevent measurement was made then there is no way we can Lorentz transform these states and still give them the meaning we assign to them in the Schrödinger picture.

In the Heisenberg picture the self-adjoint operators $\hat{A}(t_1 - t_0)$ explicitly depend upon the time t_1 at which the measurement was made and the time t_0 at which the last fiducial measurement (or preparation) was made. Thus the set of possible post-measurement states $\{|a_i(t_1 - t_0)\rangle\}$ is explicitly dependent upon t_1 and t_0. Thus, when we calculate inner products of post-measurement states, each post-measurement state has the possibility of being Lorentz transformed. If we assume that the Poincaré group forms a symmetry on the relevant Hilbert space then Lorentz transformations of states occur via unitary transformations [3]. Thus, in the Heisenberg picture, the inner products that we use to calculate probabilities in SQT can be made explicitly Lorentz covariant.

We assume a simultaneous-in-each-frame collapse hypothesis so that, when discussing standard EPRB experiments in the Heisenberg picture, we can invoke passively Lorentz invariant probabilities for entangled subsystems. Take for example a standard EPRB set-up with the following initial spin-state:

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|x_+\rangle_a \otimes |x_-\rangle_b - |x_-\rangle_a \otimes |x_+\rangle_b). \tag{1}$$

This initial spin-state represents an ensemble of two entangled electrons, prepared at a source S_0 at time t_0, which are each sent to one of two observers O_a and O_b. Lets say that, in the frame Σ in which (1) is defined, O_a's measurement occurs at time $t_1 < t_2$ and O_b's at t_2. We are of course assuming that O_a and O_b are happy in mutually defining the x- and z-directions of their spin measurements. We can now discuss the probability that O_b, having measured the spin in the z-direction, receives the result '$z+$' (the spin of subsystem b is measured to be in the +ve z-direction) given that O_a made a measurement of the x-spin of subsystem a and received the result '$x+$'.

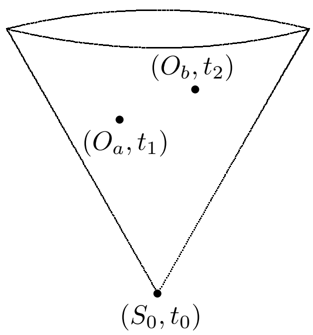


Figure 1. Frame Σ, where $t_1 < t_2$.

Using the Heisenberg picture and our simultaneous-in-each-frames collapse hypothesis, we can work out that this probability is, in frame Σ:

$$|\langle z_+(t_2 - t_1)|x_-(t_1 - t_0)\rangle|^2. \tag{2}$$

We drop the subsystem subscripts as we are only discussing states in O_b's subsystem. We find (2) by the following reasoning: if O_a measured x-spin and received the result '$x+$' then the state, in the Heisenberg picture, we use to represent that result is $|x_+(t_1 - t_0)\rangle$. By the total antisymmetry property of the initial state (1), and by our simultaneous-in-each-frame collapse hypothesis, we infer that the collapse must occur at t_1 leaving O_b's subsystem in the state $|x_-(t_1 - t_0)\rangle$. If O_b makes a z-spin measurement and receives the result '$z+$' then, given that at time t_1 the state of his subsystem was $|x_-(t_1 - t_0)\rangle$, we infer that the probability of his '$z+$' result is given by (2).

We can now discuss a different frame Σ' where two observers O'_a and O'_b measure the x'-spin and the z'-spin respectively. O'_a makes his measurement at t'_1, and O'_b makes his at t'_2. Here, all mentioned quantities are related to the quantities in frame Σ by Lorentz transformations. Lorentz transformations of states occur by unitary operators:

$$|x'_-(t'_1 - t'_0)\rangle = \hat{U}(\Lambda, d)|x_-(t_1 - t_0)\rangle. \tag{3}$$

Here, Λ is a Lorentz transformation and d is a translation parameter. Using this property of state transformations the Lorentz invariance of these probabilities becomes trivial due to the trace property of the inner product:

$$|\langle z'_+(t'_2 - t'_1)|x'_-(t'_1 - t'_0)\rangle|^2 = |\langle z_+(t_2 - t_1)|\hat{U}^\dagger \hat{U}|x_-(t_1 - t_0)\rangle|^2. \tag{4}$$

Thus, by the fact that we have invoked the Heisenberg picture we know that, as long as the Poincaré group forms a symmetry on the relevent Hilbert space, probabilities will be passively Lorentz invariant.

Note that O'_a and O'_b measure x'-spin and z'-spin rather than x-spin and z-spin. This is a gnomic allusion to the fact that the Lorentz transformed set of post-measurement states might logically also depend upon the position at which the measurement occurred as well as the time at which it was made—Lorentz transformations explicitly involve spatial transformations as well as temporal ones. Hence we are required to use fields in relativistic quantum mechanics; by requiring that probabilities are passively Lorentz invariant the sets of post-measurement states $\{|a_i(x^\mu)\rangle : \mu = 0, 1, 2, 3\}$ in the Heisenberg picture must be dependent upon space as well as time.

We have thus shown that, when discussing measurements on entangled subsystems, all probabilities of events in one spacetime region conditional upon events in the spacelike separated region can be made passively Lorentz invariant. This is a particularly subjective way to interpret probabilities as they are always conditional upon other results. We have not yet excluded the possibility of using a more objective notion of probability.

If one wants to try and invoke a probability that isn't conditional upon an event at spacelike separation one comes across a fundamental problem. We will illustrate this using the relative frequency interpretation of probability. By proving that relative frequencies are not well-defined at a single trial we will discard the propensity interpretation of relative frequency [4]. The only other interpretation of probability, other than particularly exotic interpretations, is Bayesian probability which is naturally subjective [5], and thus we will have shown that probabilities must be subjective (*i.e.* defined with respect to conditional events and information).

Relative frequencies are defined with respect to ensembles of counterfactually well-defined worlds. In each trial within an ensemble certain events happened. Other than these events, which can be different in different trials, we assume that the counterfactual worlds which define each trial in the ensemble are otherwise the same—we invoke 'identical' experiments. If we simply count the proportion of times the event occurred we can call this the relative frequency of that event with respect to the ensemble invoked.

If this ensemble consists of trials of two subexperiments that exist at spacelike separation we come across a problem, namely the fact that neither observer knows with what frequency the other chooses to make measurements. If we are to invoke an ensemble that represents a set of well-defined counterfactually distinct worlds we must know what proportion of times to include each counterfactually distinct world in the ensemble. If one measurement is chosen more often by an observer then we must weigh this set of counterfactually distinct worlds somehow, this involves knowing the prior-frequency with which measurements occur in the ensemble. It is clear that if one observer makes one measurement way more often than another measurement, this could effect the relative frequency of an event at spacelike separation simply by the fact that we are including different proportions of each counterfactually distinct world in our ensemble. This is a property of the ensemble which is not well-defined at each single trial, but is rather a global property of the whole ensemble. If we fix the prior-frequencies of measurements, or if we fix the measurements of each of the two spacelike separated observers to be constant, we have defined an ensemble that is explicitly dependent upon the prior-frequencies of measurements that are spacelike separated from each other. Thus, in order to even invoke the ensembles we use to calculate relative frequencies, we have to invoke properties of those ensembles that are not well-defined locally at a single trial. Thus we reject the possibility of assigning relative frequencies as properties at single trials, and thus we reject the propensity interpretation of relative frequency. Ensembles are not wholly defined by properties that are well-defined in small spacetime regions so we cannot strictly *prove* anything about causality between spacelike separated observers by invoking them.

We can, however, discuss signals between a large number of simultaneously occurring 'identical' experiments where the measurement parameter of one observer O_a is fixed while the measurement parameter of the other O_b is fixed to be either one value, $b = 1$, in all trials or another value,

$b = 2$, in all trials. We may possibly be able to infer the frequency of the result A of O_a's measurement a conditional upon each possible measurement parameter of O_b *i.e.* we might be able to work out $\nu(A|b = 1)$ and $\nu(A|b = 2)$. If these two relative frequencies have different limiting values, we could discuss signals being sent to O_a by O_b. If O_b chooses $b = 1$ in all trials then O_a would receive a different relative frequency to that he would have received if O_b had chosen $b = 2$ in all trials. But in SQT we have no-signalling theorems [1] which prove that these two relative frequencies must have the same limiting value ensuring that such signals cannot be sent.

We have shown here that the very definition of relative frequencies depends upon a notion of prior-frequency (which in turn is not well-defined at a single trial). This is rather analogous to the Bayesian notion of prior-probability and it is ironic that frequentists often argue against the Bayesian viewpoint with claims of circularity when a similar claim can be made for relative frequencies. Causal relations between events cannot be proved using relative frequencies because they are not well-defined in small spacetime regions at a single trial. Bayesian probabilities are, at least sometimes, well-defined at a single trial but it is also not natural to define them locally since they are always conditional upon the prior-information observers have of the whole set-up being discussed. Causality simply cannot be discussed using subjective notions of probability and signals cannot be discussed in SQT because the relevant probabilities have the same value.

Note that, due to the dependence of limiting frequencies of events upon the prior-frequencies of other events, it is impossible to not-distinguish between these other events without significant ambiguity. This is a fundamental problem with the use of relative frequencies—the limiting process is itself ambiguous for non-distinguished events (if they were distinguished what prior-frequency would they occur with?).

In order to show that there is no conflict between SR and SQT when using the reasoning we used to find (2), we need to prove that this reasoning does not depend upon the Lorentz frame we use. Obviously if we use a frame Σ'' such that O''_b is seen to make his measurement before O''_a makes hers, then we are having to invoke a collapse in frame Σ'' that occurs in the future of O''_b's measurement. Since we are discussing probabilities that are considered subjective we have no problem with this future collapse. In the relative frequency interpretation, for example, in Σ'' we simply post-select an ensemble whereas in frame Σ we pre-select an ensemble. Conditional information is conditional information, regardless of whether it is about the future (as defined with respect to one frame) or the past (as defined with respect to another frame).

Thus, if we interpret SQT using the Heisenberg picture, a simultaneous-in-each-frame collapse hypothesis and subjective probabilities, we do not get *any* conflict with SR. All probabilities that are well-defined can also be Lorentz invariant.

3 Why Peaceful Coexistence?

Strictly speaking we have not yet proved that peaceful coexistence might be a misnomer because we have not yet discussed Bell's inequalities [6] which is where the usual peaceful conflict with SR is invoked. No-signalling theorems prove that nothing in SQT can be *used* to send signals at faster than the speed of light, but Bell's inequalities seem to show that there is some kind of implicit nonlocality involved in SQT, and this is considered in conflict with the spirit of SR.

We shall argue here that Bell's inequalities do not strictly prove any conflict with SR and thus we shall maintain the possibility that peaceful coexistence is a misnomer. For a longer, more in-depth, argument see Marlow [7]. We have shown that one cannot use probabilities to prove anything about causality *per se* but, like Bell, we can argue that certain locally-causal theories must obey certain probabilistic assumptions. These probabilistic assumptions can then be used to prove that these locally-causal theories cannot be used to emulate the correlations between entangled subsystems in SQT.

Let us again discuss two spacelike separated observers O_a and O_b who make measurements on entangled subsystems. O_a choses measurement parameter a and receives result A and O_b measures b and receives result B. The probabilistic assumption that Bell implicitly invokes is:

$$P(AB|ab\lambda) = P(A|a\lambda)P(B|b\lambda), \tag{5}$$

where λ represents hidden variables. Jarrett [8] showed that this factorisation assumption can be split up into two logically distinct assumptions which, when taken together, imply Eq. (5). These two assumptions are, as named by Shimony [1], parameter independence and outcome independence. Shimony showed that SQT itself obeys parameter independence, namely:

$$P(A|abI) = P(A|aI). \tag{6}$$

Here, I represents all other known information we have about the set-up. This means that, in SQT, the probabilities of events A in one spacetime region do not depend on the parameters b chosen in measuring an entangled subsystem elsewhere. But SQT does not obey outcome independence, namely:

$$P(A|BabI) \neq P(A|abI). \tag{7}$$

Thus, Bell's theorem proves that no parameter independent hidden variable theory that is also outcome independent can be used to emulate the correlations we get in SQT. The possibility remains to try and find a locally-causal, yet outcome dependent, theory which can emulate SQT.

There exist very simple experiments which use locally-causal mechanisms but which do not obey outcome independence [9]. An example of such an experiment consists of taking an urn which is half-full of blue balls and half-full of red balls. This urn is split into two half-urns which each contain half the total number of balls in the original urn. The selection process which chooses which balls to put in which half-urn is independent of the colour of the balls. Thus if we take one ball out of a half-urn and note that it is a red ball it is clear that, due to the finite number of balls, the probability of another observer taking a red-ball from the other half-urn is diminished. This result is true regardless of the possible spacelike separation between the half-urns. Everyone must surely agree that all mechanisms involved here are locally-causal and yet it is an outcome dependent experiment. Nor would anyone claim that the reality of the balls we use is in doubt.

Thus outcome dependence does not *necessarily* prove anything about nonlocal causality. The colour of each ball, or the contents of each half-urn, is not a hidden (but ignored) variable *per se*, but rather it is unknown variable. We quantify how unknown it is by a probability. If the half-urns were transparent then in order to complete an equivalent experiment we would have to blind-fold the observers. If the observers could see the colours of the balls then it would be an *inequivalent* experiment with more known variables; it would *not* be an equivalent experiment with 'unhidden' variables. One cannot know unknown variables. Unknown variables are not hidden-but-ignored variables—one cannot know them, in order to ignore them, without changing the nature of the experiment.

Bell implicitly assumes outcome independence for his class of locally-causal theories because he restricts his attention to locally-causal theories that are wholly defined using local hidden variables. In order to strictly prove Bell's theorem for such theories one would have to have a notion of probability that is well defined in small spacetime regions and at a single trial. Nor is it clear that one should restrict one's attention to such hidden variable theories when there exist very simple locally-causal experiments which disobey outcome independence (in such a way that the 'reality' of all unknown variables is not in doubt). The only element of reality that is in doubt is the reality of a notion of probability that is well-defined in small spacetime regions. We can thus doubt that Bell's argument proves anything about causal nonlocality in SQT. In a similar way we can doubt the EPR analysis [10]. We corroborate Bohr's gnomic position on the matter [11].

A similar refutation of Bell's arguments, framed specifically within the von Mises interpretation of relative frequency, is given by Khrennikov [12].

4 Other Bell-like Arguments

If we cannot strictly invoke nonlocal causal relations using probabilistic assumptions of the ilk of Bell's, then is there any other way we can invoke such relations? In the literature there are some attempts to prove Bell-like conflicts between SQT and SR without using probabilistic assumptions. Such attempts are naturally confined to showing that a conflict exists for individual events. For example, the programme started by Stapp [13] discusses a variation of Hardy's paradox [14] which attempts to prove that a conflict between SR and SQT exists given plausible assumptions about the nature of backward-in-time influences and the free choices of observers. Shimony [15], however, has recently cogently criticised this programme. His criticism lies in Stapp's use of counterfactual reasoning. It seems that in order to prove such a Bell-like theorem one has to use counterfactual statements which are not well-defined in small spacetime regions. It is not yet clear whether such criticism blocks all such Bell-like theorems.

As physicists, we trust SR and we trust SQT [16]. There are inherent ambiguities in the notions of 'probabilities' and 'counterfactuals' we use, such that neither can be considered well-defined in small spacetime regions. Thus, no necessary causal nonlocality in SQT has yet been proved. In this discussion we have shown that there are ways to reason with probabilities in SQT that is consistent with SR (in the sense that they can be made passively Lorentz invariant). Perhaps SQT and SR are completely compatible, and such a possibility needs to be investigated.

5 Other Collapse Hypotheses

During this discussion we have specifically assumed a simultaneous-in-each-frame collapse hypothesis which necessarily requires an epistemic interpretation of quantum states. There exists the possibility of invoking a Lorentz covariant collapse hypothesis [17] if one wishes to promote a more objective interpretation of quantum states.

Also, it is not yet clear how, or if we should, include multiple collapses into this programme.

By invoking a collapse hypothesis we have not discussed many-world interpretations or their ilk, although these interpretations involve *effective* collapses which could be amenable to such a discussion as above.

6 On Endophysics and Subjectivity

Simply put, in the whole history of science there is *no* notion of probability that is well-defined objectively in small spacetime regions. SQT is a theory about our probabilistic predictions. Therefore we must interpret SQT subjectively or outline a notion of probability that is better defined objectively. Thus, what has been called the endophysical perspective is the *only* way we have at present to reason about SQT.

But is there any reason why we shouldn't discuss SQT from such an endophysical perspective? Hardy [18] has shown that if you accept that the whole premise of SQT is to formulate a theory of probabilistic predictions, one can derive SQT from simple plausible postulates. If one accepts that probabilities are to be interpreted subjectively—the only interpretation we have—then one does not have any problem with notions of wavefunction collapse—observers must predict something. They don't cause any given probabilistic prediction to come true, but if it does come true then they are obliged to use this knowledge to make further probabilistic predictions.

Recently Caticha [19] has shown that even such a 'physical' concept as entropy can be derived in a particularly Bayesian way. One can derive entropy formulae simply as a way to assign preference as a real number with certain plausible consistency conditions. To the present author, this shows the power of thinking in such a way—one can outline the assumptions *we* make when we invoke such concepts as 'entropy' and 'probability'. As Mana [20] explains, 'entropy' and 'probability' are not "experimentally observed regularities," but rather they are concepts which follow mathematically from assumptions *we* make. One can never measure 'entropy' or 'probability', one can only apply (correctly or incorrectly) these concepts to the measurements we make. 'Entropy' and 'probability' are forms of reasoning we *use*, not things that are. We must work out *why* and *how* we use these concepts. Assuming that they are objective properties of things does not help us in this enterprise as it only gives us the opportunity to accept them without thinking about why we use them in the way we do. This is the essence of the Bayesian programme and why such subjective notions are incredibly relevant to the sciences (*c.f.* [21]). We must not forget the 'I' in Murakami's koan-like quote [22]:

> More often than not I've observed that convenient approximations bring you closest to comprehending the true nature of things.

Without protagonists there is no meaning, and we would all agree that 'probability' must mean something. Without narrative, there can be no denouement.

7 Conclusion

We can reason using quantum probabilities in a way that seems completely consistent with SR as long as one uses a specific interpretation of SQT, namely one that invokes a simultaneous-in-each-frame collapse hypothesis, the Heisenberg picture, and subjective probabilities. We have not shown that this is the only example of such an interpretation. We corroborate this thesis—that SR and SQT are wholly probabilistically compatible—by discussing Bell-like theorems and showing that the probabilistic or counterfactual assumptions used are, in part, unwarranted due to ambiguities related to the strict localisation of these concepts in small spacetime regions.

Acknowledgments

I would like to thank EPSRC for funding this work. My warmest thanks are given to Guido Bacciagaluppi for a discussion after my talk which helped make this polemic significantly clearer in its perspective. Similarly to George Jaroszkiewicz for useful comments on an initial draft. Also, I would like to acknowledge the paper which inspired me to work in this area, namely [23], although it is not directly referenced in this work.

References

1. Shimony, A. (1986) Events and processes in the quantum world, in R. Penrose and C.J. Isham (eds.), *Quantum Concepts in Space and Time*, Clanderon Press, Oxford, pp. 182–203.
2. Marlow, T. (2005) On the probabilistic compatibility of special relativity and quantum mechanics, *Found. Phys. Lett.*, submitted; preprint `quant-ph/0501131`.

3. Weinberg, S. (1995) *The Quantum Theory of Fields, Vol. 1*, Cambridge University Press, Cambridge.
4. Popper, K.P. (1982) *Quantum Theory and the Schism in Physics*, Hutchinson and Co., London.
5. Jaynes, E.T. (2003) *Probability Theory: The Logic of Science*, Cambridge University Press, Cambridge.
6. Bell, J.S. (1987) *Speakable and Unspeakable in Quantum Mechanics*, Cambridge University Press, Cambridge.
7. Marlow, T. (2005) Bayesian Bell inequalities, *Annals Phys.*, submitted.
8. Jarrett, J.P. (1984) On the physical significance of the locality conditions in the Bell arguments, *Noûs* **18**, 569–589.
9. Jaynes, E.T. (1989) Clearing up mysteries—the original goal, in J. Skilling (ed.), *Maximum Entropy and Bayesian Methods*, Kluwer Academic, Dordrecht, pp. 1–27.
10. Einstein, A., Podolsky, B., and Rosen, N. (1935) Can quantum-mechanical description of physical reality be considered complete?, *Phys. Rev.* **47**, 777–780.
11. Bohr, N. (1935) Can quantum mechanical description of physical reality be considered complete?, *Phys. Rev.* **48**, 696–702.
12. Khrennikov, A. (2002) Frequency analysis of the EPR-Bell argumentation, *Found. Phys.* **32**, 1159–1174.
13. Stapp, H.P. (2004) A Bell-type theorem without hidden variables, *Am. J. Phys.* **72**, 30–33.
14. Hardy, L. (1992) Quantum mechanics, local realistic theories, and Lorentz invariant realistic theories, *Phys. Rev. Lett.* **68**, 2981–2984.
15. Shimony, A. (2004) An analysis of Stapp's "A Bell-type theorem without hidden variables"; preprint `quant-ph/0404121`.
16. Rovelli, C. (2001) Quantum spacetime: What do we know?, in C. Callender and N. Huggett (eds.), *Physics Meets Philosophy at the Planck Scale*, Cambridge University Press, Cambridge, pp. 101–122; preprint `gr-qc/9903045`.
17. Hellwig, K.E., and Kraus, K. (1970) Formal description of measurements in local quantum field theory, *Phys. Rev. D* **1**, 566–571.
18. Hardy, L. (2001) Quantum theory from five reasonable axioms, preprint `quant-ph/0101012 v4`.
19. Caticha, A. (2003) Relative entropy and inductive inference, preprint `physics/0311093`.
20. Mana, P.G.L. (2004) Consistency of the Shannon entropy in quantum experiments, *Phys. Rev. A* **69**, 062108; preprint `quant-ph/0302049 v5`.
21. Bouratinos, E. (2005) A new conceptual framework for physics, *this volume*.
22. Murakami, H. (2003) *Hard-boiled Wonderland and the End of the World*, Vintage Books, New York.
23. Anastopoulos, C. (2004) On the relation between quantum mechanical probabilities and event frequencies, *Annals Phys.* **313**, 368–382; preprint `quant-ph/0403207`.

CHAPTER IV:

∼THE SUBJECTIVE∼

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 441–462

OBSERVING REALITY ON DIFFERENT TIME SCALES

ALEXEY ALYUSHIN
Philosophical Faculty, Moscow M.V. Lomonosov State University
1st Humanities Building, Room 1136, 1 Vorobyovy Gory, Moscow 119899, Russia
(aturo@mail.ru)

Abstract: In the first part of the paper, I examine cases of acceleration of perception and cognition and provide my explanation of the mechanism of the effect. The explanation rests on the conception of neuronal temporal frames, or windows of simultaneity. Frames have different standard durations and yield to stretching and compressing. I suggest it to be the cause of the effect, as well as the ground for differences in perceptive time scales of living beings. In the second part, I apply the conception of temporal frames to model observation in the extended time scales that reach far beyond the temporal perceptive niche of individual living beings. Duration of a frame is taken as the basic parameter setting a particular time scale. By substituting a different frame duration, we set a hypothetical time scale and emulate observing reality in a wider or a narrower angle of embracing events in time. I discuss the status of observer in its relation to objective reality, and examine how reality does change its appearance when observed in different time scales.

Keywords: Time Scales – Altered States of Consciousness – Quantum – Bergson

1 Introduction

The initial impulse to this study was given by my fascination with the question: how would reality look like, if to view it through a different time magnifier (*Zeitlupe*), than we humans are used to? How would the picture of the Universe transfigure, if to imagine that we ("somebody" as a virtual observer) observe it on such speed scales that, let us say, the Earth rotating around the Sun would appear like a sling spin-up gradually turning into a smeared circle?

The same kind of fascination has guided H. G. Wells in writing his short story *The New Accelerator* (originally published in 1905). An inventor and his friend have taken the drug that extremely accelerated all processes in their organisms. And the usual surroundings have drastically changed to them. A bee was sliding down the air with wings flapping slowly and at the speed of an exceptionally languid snail. Frozen people in the park stood erect: strange, silent, hung unstably in mid-stride, promenading upon the grass. Nothing but a sort of faint patter was to be heard: analyzed sounds, disarticulated vibration of the park band's music. Friction of the air was so strong that the experimenters' trousers were going brown and nearly burst into flames. "We had lived half an hour while the band had played, perhaps, two bars. But the effect it had upon us was that the whole world had stopped for our convenient inspection." [1]

Speed-up of human perception and cognition or the feeling of a faster flow of subjective events is the really observed phenomenon. Several factors can cause it, among them are: 1) stress, 2) influence of drugs, 3) mental disease or brain impairment, 4) pre-mortal state, 5) accelerative forces produced by rotation in a centrifuge or lift-off of a spaceship, 6) intended training of the ability to discern small intervals of time, 7) sensory deprivation.

Acceleration of perception and cognition is the most typical of all other known effects of altered subjective temporality, like deceleration, time standing still, time going back, etc. In the next section, I will examine two of the named factors: stress and the influence of drugs. I will also overview data on the speed of visual perception with some animals, as compared to humans.

2 The Conception of Temporal Frames as a Tool to Explain Acceleration of Perception and Cognition and the Diversity of Perceptive Time Scales of Living Beings

2.1 Acceleration of perception and cognition under stress and the influence of drugs

Many records of real life experience show that in extreme situations and under great threat, perception and bodily reactions of a person may proceed quicker.

This is the evidence of a Soviet radio operator, E. Krenkel, who was famous for his winterings on the North Pole in the 1930s, and who also experienced flying dirigibles at those times. In his memoirs, he tells that once during the nighttime the dirigible steerage got impaired and the airship went out of control and rushed right in the direction of a church tower. At the last instant, he grasped to lay down on a loosened steering rope with all his body weight and thus to shift a steerage a little bit:

> "With inconceivable quickness, I managed to see in this weakened rope one of very few chances to land safely. As always in such moments, when mind works incredibly fast, time seems

> to get stretched somehow, helping to chose and to realize the most suitable decision." [2] (English translation from Russian here and below by A. A.)

In their book on perception of space and time in outer space, Soviet astronauts A.A. Leonov and V.I. Lebedev mention the evidence of Soviet test pilot M.L. Gallai. During one of the test flights of Lavotchkin-5 plane, the engine got on fire and fire and smoke started to penetrate the cabin. Further I cite Gallai's story by the Leonov and Lebedev book:

> "As always in desperate situations, the scale of time wavered and shifted from its place, and went on running on a strange "double" count. Every second acquired an ability to extend unlimitedly — becoming as long as is demanded: so many things one manages to do in such circumstances. It seemed as if the flow of time nearly stopped."[3]

Most of the psychoactive drugs, whatever varieties in their influence might be, are similar in making the pace of the external time less perceptible and significant. The outer time seems to freeze or to become indifferent, while the intensity of inner sensations rises.

Actually, nearly every second report on the use of psychedelics on the *Erowid Experience Vault* website contains notes on slowing down of the outer time at the expense of intensifying the flow of subjective events. So, I will mention just two classical reports here.

C. Castaneda described an experience of taking "magic mushrooms", with their active substance psylocibine. The experience showed that perception under this drug accelerates. His teacher in this practice, a Mexican sorcerer, told him: "The warms, the birds, the trees, all of them can tell us unimaginable things if only one could have the speed to grasp their message. The smoke can give us that grasping speed."[4] ("The smoke" is dry powdered mushrooms they smoked — A. A.)

Polish writer and painter S. Witkiewicz has documented his experiment with taking the mescaline-containing peyote extract. For twelve hours, the bright visual hallucinations like three-dimensional ornaments, fantastic monsters, faces and silhouettes of familiar or unfamiliar persons were in constant rapid kaleidoscopic change. In the primary unedited report which he managed to dictate to his wife or to write down himself almost all the time the drug was working, he stated:

> "The speed is horrifying. It seemed as if hours (days?) have gone — but it is only a quarter of an hour that passed". A

> little further: "I switch off the lamp and decide to take no more notes. I cannot. Ages are gone, but my watches show only seven minutes past half-past one." [5]

Drawing on the primary report of 1928, the more comprehensive essay was published in 1932 under the working title "*Narcotics*". He wrote in the essay:

> "... Later, I became certain of how delusive estimation of duration of the peyote-induced visions is. I have called it in my "peyote language" — "the swelling of time" [6]. ... "Above all, there is this truly devilish refinement of details of the visions. The peyote reality looks like ours, if viewed through a microscope — in a sense of "sharpness" and "exactness" of its finishing." [7]

Thus, as far as we can interpret Witkiewicz, the shift to the accelerated time scale is accompanied by the transition to the finer spatial scale. The swelling of time, as he describes it, looks not as an increase of speed as such, but rather as deeping inside of a second, and microscopic peering into a millimeter.

2.2 Time scales of visual perception of some other living beings

The German zoologist J. von Uexküll, known for his conception of *Lebenswelt*, described two experiments on identifying the duration of an elementary act of visual perception with fish and snails. The first experiment, in Uexküll's own words, consisted in the following. The fighting fish were trained

> "to snap toward their food if a gray disc was rotated behind it. On the other hand, if a disc with black and white sectors was turned slowly, it acted as a "warning sign", for in this case the fish received a light shock when they approached their food. After such training, if the rotation speed of the black and white disk was gradually increased, the avoiding reactions became more uncertain at a certain speed, and soon thereafter they shifted to the opposite. This did not happen until the black sectors followed each other within 1/50 of a second. At this speed the black-and-white signal had become gray. This proves conclusively that in the world of these fish, which feed on fast-moving prey, all motor processes — as in the case of slow-motion photography — appear at a reduced speed." [8, pp. 30–31]

In the second experiment,

> "A vineyard snail is placed on a rubber ball which, carried by water, slides under it without friction. The snail's shell is held in place by a bracket. Thus the snail, unhampered in its crawling movements, remains in the same place. If a small stick is then moved up to its foot, the snail will climb up on it. If the snail is given one to three taps with the stick each second, it will turn away, but if four or more taps are administered per second, it will begin to climb onto the stick. In the snail's world a rod that oscillates four times per second has become stationary. We may infer from this that the snail's receptor time moves at a tempo of three to four moments per second." [9]

A researcher of the bee's perception and behavior, K. von Frisch, wrote:

> "A motion picture for bees would have to have a ten-fold greater frequency of succession of pictures to prevent the image from flickering. The deficient power of spatial resolution of their eyes is compensated for by a high resolving power in time. . . " [10]

So, we have the following spread in values of the visual perception speed among these sample species. 0.01 sec is the duration of an elementary act of visual perception of bee, 0.02 sec — of a fish from the described experiment, 0.25 sec — of snail. 0.1 sec is suggested to be the normal average duration of an elementary act of visual perception with humans.

Thus, the span of the visual perception speeds of the very fast and the very slow of the living beings among mentioned is twenty five-fold. A human is somewhere in the middle of the interval.

Creatures at the opposite sides within these bounds can perceive and interact with physical surroundings differently, living in their own specific temporal *Lebenswelt*.

Thus, if we take the "champions" from the fast and the slow sides: bee and snail, then the bridge stick from the experiment, moving four times per second, will seem, as strange as it may be, stationary for both, but on the opposite grounds. For snail, because the stick moves too fast and melts into a single gray strip. For bee — because it moves too slowly. A bee, having had picked a moment, would have fairly managed to fly through between phases of the bridge stick moving back and forth.

So, the door, looking and actually being open for the fastest species, looks and actually is walled-up for the slowest one. The Wells' "accelerator effect" comes into force.

2.3 Neuronal temporal frame

The key idea underlying my further examination is that incoming perceptive data in brain is processed in the discrete mode. There is a flow of discrete perceptive frames, or "shots", with a specific standard duration of a frame.

It was H. Bergson who has first envisaged the existence of such a mechanism:

> "We take snapshots, as it were, of the passing reality. [...] Perception, intellection, language so proceed in general. Whether we would think becoming, or express it, or even perceive it, we hardly do anything else than set going a kind of cinematograph inside us. We may therefore sum up what we have been saying in the conclusion that the mechanism of our ordinary knowledge is of a cinematographical kind." [11]

When Uexküll later mentioned the "elementary acts of visual perception", and von Frisch the "succession of pictures", they both meant actually the same.

F. J. Varela showed on experimental basis in the end of 1980s and the beginning of 1990s that there is a real neurophysiological structure, which corresponds to the elementary act of visual perception. He called it frame.

According to Varela, frame is formed by spatially distributed, but temporally synchronized constellation of a large number of neurons. Frame is a structure, formed by synchronicity in time, not by localization in space. "The neuronal synchronization hypothesis postulates that it is the precise coincidence of the firing of the cells that brings about unity in mental-cognitive experience." [12, p. 275]

The alpha rhythm in human brain (8–13 Hz) can be identified with the flow of the visual perception frames. Thus, the time span of about 0.1 sec roughly corresponds to the normal duration of each visual frame.

In some sense, a neurophysiological frame resembles the movie frame. It is discrete, and nothing happens within it, in terms of the whole process; everything happens only in the sequence of frames.

Although Varela has based his conception only on experiments with visual perception, he asserted that the temporal frames conception is applicable to other modes of perception and to cognitive activity, including thinking. "For every cognitive act, there is a singular, specific cell assembly that underlies its emergence and operation. ... Cognitive act from perceptuo-motor behavior to human reasoning." [13]

Going to even further generalization, I would suggest that discreteness is essential and inalienable property of cognitive process as such.

The discerning ability of hearing is about ten times finer than of vision: 0.01 sec instead of 0.1 sec. The fineness of hearing is determined by the brain's need to compute time disparities of signals coming from two ears in order to spatially localize the source of sound.

E. Ruhnau and E. Pöppel explained the mechanism through which correlation and integration of streams of visual and auditory information is accomplished. The explanation rests on their conception of atemporal zones, or windows of simultaneity [14], similar to Varela's conception of frame as a "perceptive time quantum". Squared within the same window of simultaneity, the visual and the auditory signals "come to terms" with each other on detecting where and how far the observed object actually is, notwithstanding the substantial dissimilarity in timing of the incoming light and sound signals. The value of each integrative window of simultaneity duration Ruhnau and Pöppel give is 0.03 sec.

2.4 Explaining the speed-up and the slow-down effects: compressing and stretching of frames

I believe that the temporal frames conception can explain neurophysiological mechanism by which normal speed of perception is maintained and adjusted, and how deviations from the normal speed occur.

My central explanative thesis is that the speed-up perception corresponds to a shorter duration of each frame, and thus to a speedier flow of perceptive frames. The shorter each frame duration, the finer the perceptive temporal grain, the better external signals close to each other are discerned and quicker reacted to. The longer the frame duration — the coarser the discerning ability for close signals, the slower reaction. The duration of a frame, characteristic to particular animal species, is a stable value only in average, as a mean norm. A frame is not stiff in its duration, and can get adjusted to features of the perceivable. A piece of evidence for that is the photic driving effect in electroencephalography. Stimulation by repetitive light flashes with a frequency in the range from 5 to 30 per second causes rhythmical activity of the same frequency in the back areas of the brain, responsible for vision. That means that the brain tries to adjust its discerning ability to the incoming stimulus. "...Drugs that shorten or lengthen subjective time may exert their influence either by speeding or slowing a pacemaker or by altering the number of mental and external events that are registered" — W. J. Friedman suggested [15, p. 303].

Given that the very existence of a central pacemaker, allegedly determining the temporal profile of all perceptive processes in brain, is doubtful, the second variant of explanation seems to be true for me.

In terms of the temporal frames conception, when the frame duration gets two times shorter, there are twice as many frames managing to sequence each other in the brain within a second. Thus, the density of the frame flow doubles. What rises is the absolute volume of the incoming subjective information. It is this overflow that is commonly described as acceleration of subjective time, and, respectively, deceleration of the outer time.

"The proportions of time and of being are completely upset by the multitude and intensity of the sensations and ideas. It is as if one lived several lives in the space of an hour." [16] Baudelaire wrote on the use of hashish, conveying exactly the impression of not a quicker time race as such, rather of the risen density of events happening in mind.

G.K. Aghajanian has proved in his experiments on rats in the 1980s that any kind of sensory stimulation: sight, sound, smell, taste, or tactile sensation, speeds up the firing of neurons of locus coeruleus — which is a funneling mechanism in the brain that integrates all sensory inputs — and that the accelerated firing is greatly enhanced by treating the animals with LSD or mescaline [17].

Thus, the combining of two experimental findings: Aghajanian's, that firing gets accelerated under the influence of certain psychoactive substances, and Varela's, that firing of certain groups of neurons happens simultaneously, due to what neurons are constellated into frames — supports very logically the assertion that what is known as accelerated perception results from the accelerated frames change.

Here is the evidence of a personal LSD experience, involving visual frames.

> "I was also noticing some slight tracers in moving objects. I had a really brightly colored rubber ball, and when I threw it in the air and caught it again it left a definite trail. On a personal note, these tracers were not the streaks of bright light I expected them to be. The ball left transparent, picture-perfect images of itself in the air where it had just been. These took a second or two to fade and were really interesting to observe." [18]

In terms of the temporal frames conception, the explanation for the vision might be this. Under the LSD influence, the duration of the visual perception frame might have shortened from the normal 0.1 sec to, say, 0.05 sec. If the ball falls within a lapse of 0.2 sec., the normally functioning brain manages to take only 2 snapshots of it, while the drug-treated brain takes already 4 snapshots or more. Taking more snapshots within the same lapse of time may lead to going under the threshold of the movie-type alloying of content of separate frames in our brain into a smoothly changing visual image. The visual shooting mechanism starts to catch the bigger number of fixed images out of the total event of the ball falling down. And so the trajectory of falling, used to be seen as blurred, is viewed now as a row of separate pictures. This is what the person in the case did observe, as one could suggest.

2.5 The moiré mechanism hypothesis

If to assume the existence of two or more flows of frames in brain, it is logical to suggest that flows would somehow interact with each other and get matched in some configuration. It is relevant here to recall the moiré effect. The moiré effect is produced by superposing of two or more geometrical periodical structures, launching them into move in relation to each other, and obtaining some new running or stiff pattern out of this superposition in move [19].

The moiré mechanism, as I suggest, might bring us closer to understanding of general mechanisms of perception and cognition and of the brain functioning.

When explicating my temporal frames conception, I left aside one very important point. In order to notice the difference in contents of the two frames, consequently replacing one another, the third overlapping frame is required, which filling is right to be the difference of those two. Thus, an outer observer is needed in our scheme of frames flow.

If, in addition to two flows that induce and "strike" a pattern out of their reciprocal sliding one along the other, a third flow is introduced, then we get a minimal, though principally sufficient set for producing and perceiving images. A moir pattern induced by launching the two flows and their reciprocal collation in move is an autonomous structure — autonomous in a sense that it is not contained in either of them, it "hangs" in between, being presented with those two for reading off by the third flow-observer. Although with change or stop of one of the two primary flows, the pattern also changes or vanishes.

We may go further and suggest that the third flow not only reads off a picture but also maintains it — as an integrated and stable, although, in a sense, a phantom image. The image, in its turn, as our suggestion may implicate even further, would be able to steer the flows for the sake of its self-sustaining. If a speed or contents of the subordinate flows deflect, the self-sustained image-attractor of the third flow might be able to "remind" them of a due course and return them to a required dynamics.

The next step in applying the moiré model might consist in assuming of a multitude of moiré patterns interacting with each other in a complex way in the brain as wave structures, and in aligning each of them to a particular cognitive structure or mental unit.

So the own language of the brain may be geometry of interacting wave structures of the moiré origin.

If we compare the moiré model with the known holographic model of brain functioning, the first will look advantageous for introducing dynamics. The holographic model is mostly static, dealing with distribution of wave interferences in space, whereas the moiré model stresses the temporal aspect of interaction of wave structures. As a matter of fact, it also deals with interferences, but in their temporal dynamics. Therefore, the holographic model and the moiré model could productively accompany each other.

3 The Conception of Temporal Frames as a Tool to Model Hypothetical Observation in Extended Time Scales

3.1 Setting a time scale

The plot of this paper was conceived under the impact of H. Bergson's conception of duration of different tensions, as I would call it. I consider worth citing two important excerpts from his *Matter and Memory* (originally published in 1896).

> "The duration lived by our consciousness is a duration with its own determined rhythm, a duration very different from the time of the physicist, which can store up, in a given interval, as great a number of phenomena as we please. [...] We must distinguish here between our own duration and time in general. In our duration, — the duration, which our consciousness perceives, — a given interval can only contain a limited number of phenomena of which we are aware. Do we conceive that this content can increase...?" [20]

> "In reality there is no rhythm of duration; it is possible to imagine many different rhythms which, slower or faster, measure the degree of tension or relaxation of different kinds of conscious-

> ness, and thereby fix their respective places in the scale of being. To conceive of durations of different tensions is perhaps both difficult and strange to our mind. [...] And would not the whole of history be contained in a very short time for a consciousness at a higher degree of tension than our own, which should watch the development of humanity while contracting it, so to speak, into the great phases of its evolution? In short, then, to perceive consists in condensing enormous periods of an infinitely diluted existence into a few more differentiated moments of an intenser life, and in thus summing up a very long history. To perceive means to immobilize." [21]

There are two main duration values to be mentioned when speaking of the time scale of perception and cognition. (a) The speed of frame sequence and (b) the overall interval within which the process of perception and cognition lasts.

By referring to a certain standard duration of a neuronal perceptive frame of a living being, we set its perceptive time scale. We set a scale not by just mentioning the whole interval within which perceptive activity or some natural process last, but by setting the duration of perceptive frame or a certain discrete time lapse that determine the speed of scrolling through this whole interval.

In the same way, in terms of our modeling, by setting a certain hypothetical duration of temporal frame, we set a certain temporal scale of hypothetical observation, and introduce a hypothetical, or virtual observer, referred to the duration and the scale.

Out of the whole presumably multiple set of auxiliary neuroframes' flows in a creature's brain, we have to single out the one corresponding to the ability to sequentially fix positions of the moving external objects. The basic time scale-setting value is the number of "shots" of external objects one's brain makes within a certain time measure unit. This, in turn, is determined by the speed of bodily movements of a living being, and, eventually, by its "way of life" and of ways to get food.

The time scale is, however, only one of the parameters shaping the entire *Lebenswelt* of an individual living being. The other parameters include the concrete set of sensory modalities, the relative importance and active spectrum of each modality, the body size and the space niche a living being inhabits, predominant physical forces shaping the body structure and the locomotion scheme, etc.

3.2 Biological species as tentative subjects of perception and cognition

When commonly speaking of possessing the features of life, and of perception and cognition, it is naturally implied that their subject is an individual species, like a human or a wolf. This restricting presumption is likely to be false. In the realm of life on the Earth, we, as individuals, are surrounded by a multitude of entities within our physical bodies and outside them, or, rather, "in between them", that seem to have their own vitality.

It would be groundless to say that our individual brains are the only place where the data on the outer world gets reflected and processed, nor even that this place is the focal one in terms of the whole life and cognition pyramid.

> "The cognitive mechanism of genome is not able to give due to quick changes of the outer world. For, it cannot "know" about the success of some of its experiments before at least one generation goes through its life circle. That's why the genome in its behavior can make adjustments to only those conditions of the outer world, which are retained with statistically sufficient permanency for the longer period of time". [22] (English translation from German by A. A.)

Lorenz did neither resolutely defend the idea of the reality of species as cognitive subjects nor denied it, as it is seen from his quotes for "know".

I take this idea somewhat more for real and would like to go further with some of its implications. One can see that genetic evolution of species, likewise to a neuronal perceptive process of an individual, is accomplished in a discrete way. There is no genetic change within a generation, only between generations, with a single generation (roughly twenty years with humans) being a frame in a general genetic flow.

For species as tentative alternative observers (not just virtual observers, because I admit the possibility of them being real), we have to introduce the alternative space or field of events, in which only those events happen, which are "visible", or "perceivable", to species.

If we take the twenty-year-long frame as a minimal perceptive unit, or a grain of discerning, then, from the species point of view, no single animal or single plant, no seasons' change, etc. would be perceived. All events happening on those less extensive time scales would fall under the species' perceptive quantum level and be smeared into some homogenous background. Instead, what would exist and move in its picture of reality, i.e. appear as fields of events, are only areals of confronting species, or biomass clusters covering the Earth, expanding and squeezing, emerging and disappearing. This is the *Lebenswelt* species do inhabit.

3.3 Observation and the inherent temporal structure of reality

The starting point for me is that reality does exist by itself, i.e. independently of existence or non-existence of an observer within it.

Outside an observer, or irrespective of its viewpoint, reality is an all-containing entity. Any observer can perceive reality only in a certain temporal scale of observation, characteristic to its bodily action and perception. A certain temporal scale of observation corresponds to a certain temporal contour of the objective reality. This, and only this contour of reality, or, in other words, reality in this very contour, as discerned out of all its contours, is presented to an observer in response to its educing "appeal". In one temporal scale of observation you see reality in one contour, in another temporal scale you see reality in another contour. With a different temporal scale of observation you have a different ontological picture of reality.

If no particular temporal scale of observation is set, no reality at all may happen to be seen. One sees the empty reality, or the reality in an "unoptioned" mode. An explanative illustration could be found in computer practice. When you want to open a file, some file extensions and directories are prompted. But if you choose no extension or directory, the list of files may seem empty, as if none of them existed.

But is reality cut into temporal contours in itself? Are there distinguished spectral lines on the overall temporal range of the Universe, which correspond to these contours?

The answer I propose is that not any arbitrary position of a knob on a temporal wave band receiver will give a meaningful picture, but only those corresponding to certain "stations", i.e. objective temporally ordered layers of reality. There are gaps between those discrete layers in the hierarchical all-encompassing micro-macro dimension of the Universe, on which matter clusters itself in ordered form. There are rooms of "nothingness", periodically interrupted by islands of self-referentially compounded "something".

How these stratified and temporally coherent conjunctions of matter occur? I assert that only those material entities would belong to a certain objective temporal structure and be involved in a temporal contour, which are influencing and determining each other, i.e. which mutually interact. By their interaction, a certain self-sustained and self-referential material framework is formed, with its inherent order and shared temporality.

Shared temporality is only one of the set of factors making a material system and the hierarchical level of reality it exists on conjunct and coherent from within. Two other factors are physical forces predominant in ordering matter on this level and giving material systems their steady shape, and the spatial dimensions, within which those physical forces remain active and the characteristic speed of interaction lets the distant parts of the system act as a conjunct whole.

This is the very general answer to the question of how a temporally ordered structure "coagulates" from within. The question now is how it detaches and distinguishes itself from the total manifold of hierarchical layers and objective temporal contours?

I will try to explain it with the same idea of observation that I am explicating in the paper. We may metaphorically assume that the ability of material entities to interact can be viewed upon as the ability to "feel" and to respond to the signals of another material entity. In a sense, material entities by their interacting do "notice" and "observe" each other, and in this way mutually confirm each other's existence and the "membership" in some common ordered structure.

I have said that an observer selects, or discerns from reality as a whole a contour that corresponds to, or falls within the limits of, its own temporal scale of perception and bodily action. So we had a situation of an observer interacting with the reality. If we take now a situation of a material entity interacting with a material entity, we can follow the same line of argumentation. Namely, that a material entity selects from the total multitude of material entities those and only those, which it is able to interact with. So, material entities, mutually cutting themselves out of the total mass of irrelevant physical tissue, behave as "observers" to each other.

3.4 The zoom "now"

We have assumed the arbitrariness of singling out a moment of "now". "Now" might be presented as a circle on the time arrow with a variable diameter, zooming to a sharper or a wider focus. If we place ourselves in the center of this circle, it might seem that its boundaries are spread equally back and forward in time. Thus, by widening a circle of "now" and embracing therein the wider scope of events, we seem to be able to "creep" into the past and into the future. We get a kind of a "zoom time machine": just suppose that the "now" lap is not a second, not a day, and not a year, but forty years — why, actually, not? And your grandmother does still exist "now".

For extended entities with a larger frame, our future seems to be given already as their present. So, it looks as if by tuning to "the vibes" of these entities and stepping into their wider frame of "now", one can draw information on our own future. This is what seems to give natural explanation to all kinds of the foreteller phenomena.

More traditional view implies that the future objectively doesn't exist at all, hence the future blackout frontier is absolute for entities of any frame duration. Frames may stretch whatever far into the past, but none of them outstrip others for any fraction of a second into the future.

I am not going to exclude the possibility that for more extended entities our future is given as their present, and so basically one can look into the future by attaching oneself somehow to these entities. There are at least two problems here, though.

We can abstractly assume someone's being able to enter the temporal worlds the more extended entities inhabit. But, firstly, the ones entering won't be let smuggle their normal this-world bodies and consciousnesses. Having had found yourself in the world where life processes are cut into no less than, say, forty years quanta, you would have to undergo some weird transformation of your body. Your body, rather, particles it consists of, will get smeared all over the locations you were and are going to be present for twenty years back and twenty years forth from the moment having had been current in the world you left; you will find yourself abiding all over those places simultaneously.

You will have to dismiss your consciousness, too, which works within, at the largest, 1/1000 sec to 10 sec framing range. Secondly, you will hardly procure information concerning yourself anyway. You've got into the reign where there is, undoubtedly, some information turnover, but the smallest coin of its currency is molded for being relevant to living on this very level. You will neither join the currency turnover, nor take its coins back and make sense of unintelligible signs on it. The more extended frame contains no accessible information for you; it is information in just a different register, although your life should be compressed somewhere there too.

Any single object of the real life can be viewed in a multitude of hierarchical levels and temporal scales. Thus, one and the same person shares the whole manifold of social temporalities, from the shorter phases up to being involved into historical temporal profiles, as its proper scales. The "spot" acts of social behavior acquire (or spread up to) their different meanings within frameworks of a narrower or a wider range, often in an unforeseen way for the person himself.

3.5 Interface of adjoining time levels

I will attempt to infer some clues on what might constitute the reality's own temporal grid of events and grain of temporal discernability. I am going to show that, contrary to absoluteness of Planck values, values of grid and grain are relative and depend on interrelation of levels. Vanishingly small for one level, the same absolute value might be infinitively large for another level.

I would go even further, and suggest that the conception of quantum character of reality, which is used to be attributed to one distinguished type or level of the physical reality, can be made relative and be attributed to specific interrelation of a higher level to the lower in any batch of adjoining levels within their total hierarchy. I would suggest that when looking from one's own level at the phenomena of the lower emergent level, any observer sees them as quantum phenomena.

Speaking of scale, we have to distinguish a scale from which we observe, and a scale of what is observed. Observing reality in a different scale, mentioned in the paper's title, would mean both: trying to put foot as our observational standpoint into a scale improper to humans, and also dealing with layers of reality alien to our *Lebenswelt*. In the later case, again, we either deliberately retain our observational standpoint within the human scale and look at aliens with our own eyes, or try to identify ourselves with aliens and look at them with their eyes.

Suppose we have three levels of reality, with cyclically recurring processes of their specific nature on each of the levels. We place ourselves at the middle level and look horizontally, then up and down.

What we see on our own level, that is, in the proper scale of observation, are events. We see reality on our level as events. Events are distinguished and meaningful fragments of change by some parameter. Annual seasons are events, day and night follows on are events, and change of a hare's zigzag running direction is event. Our body motion and cognition share temporality with the field of events, for we are able to experience changes proceeding on this very temporality scale; we depend on these changes and can influence or utilize their course.

Events proceeding on the higher level are represented to us as states, or qualities. Although on their proper scale they are events. Actually, we are witnessing one and the same lasting event, having had begun to unfold itself as a change long ago, and being yet far from finishing the initiated phase. We are inside the event, it's frozen for us, and there is no meaningful or perceivable change for us. A season is a state for a butterfly, but an event for a species it belongs to. The view of the sky is frozen for us, although on its proper level the tissue of astral locomotions constitutes the field of events.

Events proceeding on the lower level are also represented to us as states, or qualities, being themselves events. But they are states not as a single event having begun to unfold, but as a statistical mass of events having had multiply folded and unfolded within a single phase of event of our scale and a frame of our perception. The statistical mass of events smears into a common background with the events' partition undistinguishable to us. Hydrodynamics of a water flow is a field of events on its proper scale, the Brownian motion of particles within the flow is a statistical quality from the point of view of this first scale, collision of single molecules is again an event on its proper scale, and so on.

I want to stress that going under the discernability threshold, that is, quantum level in its relative sense, is not only the matter of observation, but of material interaction. The distinction of events as events is not absolute and is not conditioned by a level itself, rather, by the levels which are boundary to it from below and from above. By "abstaining" from interaction with improper, higher or lower, material units, the unit designates, "settles down" its own field of interaction and of events. In this way it calibrates its proper grain of events and the thresholds under and over which events become states.

When an event ceases being represented in an interaction as event and starts being represented as a formational ingredient of a state or quality, it goes under the quantum threshold. When it continues to fluctuate between both, it is a transitional zone.

Bergson imagined how in the course of our transition to a lower scale the quality of red color would dissociate and turn into oscillations as a set of repetitive events, having no sign of redness in them already.

> "If we could stretch out this duration, that is to say, live it at a slower rhythm, should we not, as the rhythm slowed down, see these colors pale and lengthen into successive impressions, still colored, no doubt, but nearer and nearer to coincidence with pure vibrations? In cases where the rhythm of the movement is slow enough to tally with the habits of our consciousness, — as in the case of the deep notes of the musical scale, for instance, — do we not feel that the quality perceived analyses itself into repeated and successive vibrations, bound together by an inner continuity?" [23]

Viewing one and the same reality, since we admit its wholeness and unity as an all-containing reservoir, in different temporal scales makes certain objective features of reality educe, the others veil. But the fact that we do see the physical shell of the event from the lower level doesn't guarantee that we understand the essence and meaning it is loaded with in a larger framework.

We may try to search for features of life taking the Universe as a putative living body. If there are some processes of biological nature on the level of stars, galaxies and their clusters, they should be of an extremely slow timing of at least million years for each elementary act of interaction. We shall have to introduce an extremely large hypothetical interval and frame duration.

Suppose we managed to deduce with computer simulation some projections of the past and the future trajectories of stars and galaxies, basing on their shifts observed within about the last 300 years. The main problem still remains: how do we identify these imaginative lines with biologically loaded interactions? To emulate trajectories of movements of astral objects (clashes, spiral spinning, etc.) even in their proper temporal scale, that is, as they actively move "on themselves", does not mean to find what essence or objective meaning stands behind these visual physical transformations.

3.6 How may the Universe look like on its proper time scale?

Let's imagine that we are placed outside the Solar system and observe the Earth rotation around the Sun with a sequence of frames of five-year duration each. In objective terms, this would correspond to an assumption that five years is the minimal discernable grain of events.

What follows is that the earthly ball disappears from our picture of reality. We don't see any balls at all in their spherical shape any more, and are not able do see them. The shape in which we now start to see the whole Sun-Earth bundle in its motion, is a sequence of discrete fragments of their interwoven trajectories, each fragment constituting a five convolutions corkscrew body of the Earth with the slightly curved (due to its own rotation with a sleeve of the Galaxy and other processions) axis body of the Sun. The Earth's and the Sun's former strictly localized spherical solid or gas bodies become spread within their five-year lines of motion; they are here and there, at the beginning and at the end of the line, simultaneously.

My substitution of the five-year frame and of the corresponding grain of discretion is quite arbitrary here and is used only for illustration. In fact, the time quantum for intergalactic interactions should be of the order of ten millions of light years, if we take the time for a light signal to run from one side of the galaxy to the other side and back as the minimal sewing act in keeping the physical body together.

When speaking of a "proper celestial scale", I make a very strong simplification for the sake of juxtaposing of all "celestial" altogether to the proper human scale. In reality, there is no single proper celestial scale, but the whole manifold of them, each inherent to hierarchical layers of stars, galaxies, intergalactic clusters, etc., many orders of magnitude distant one from another.

In any case, why should we think that celestial bodies interact with their "peers" on their proper scale of motion as spherical, localized and slow moving objects, so as they are presented to us in the sky? Our temporal scale of seeing them as "billiard-balls" might be inadequate to their proper motion and the way of interaction, and, in fact, obscuring.

Wouldn't it be logical to imply from the said above that the basic units entering the process of interaction on the proper celestial scale are not balls, but fragments of their trajectories? Or trajectories as wholes, if we depart from the minimal grain level and take a look at the celestial physical tissue in a wider range. For, only in the physical appearance of trajectories, assigned by the extended temporal grain of discernability, not of balls, are celestial objects recognizable and "interactable" to each other. If one wishes to retain the corpuscular view on the matter, he can say that it's the discrete fragments of trajectories, not discrete bodies, that we take as corpuscles.

Now, what are trajectories, drawn by periodically rotating and onward moving objects? Aren't they oscillation structures, which means, waves? If to agree with that, the inference comes that the whole celestial tissue in its proper time scale does exist in form of wave structures and general wave field. What would be predominant for formation and activity of celestial objects, are wave interactions, resonances, interferences, etc, not classical mechanical and gravitational interactions. It's the features of their motion as waves, developed on the extended time scale, that determine their shape and orbits as classical mechanical objects, presented on the scale we see them.

In the wave-particle duality, the wave side should be related to an extended time scale on which an object is represented, the particle side — to a shorter-frame scale of representation of this very object. The confusion arises when we make no distinction of the scales. We run against the paradox having presumed both representations to be the phenomena of one and the same scale. Wave-likeness is an image of an object shaped at and conveyed to us from one temporal layer of reality, the particle image — from another layer. Both may overlap, producing the puzzling double contour of an object.

It's not because of their large size and mass in the absolute values that the wave side of the celestial objects' motion never gets an overt expression, according to Louis de Broglie formula of the matter wave; it is because we have to look for this expression on a different time scale, where it's always there. That would also imply that for each level we might have its own objective Planck-type values of the quanta bottom line of energy, length, and time.

Having hypothetically assumed trajectory to be a basic interactive unit, I have to call my assumption in question. How would you interact with a trajectory? In any case, you will have to interact with the plotter drawing a trajectory, that is, the ball itself. If you think you touched the "whole trajectory" as a single unified object, poking your "cosmic finger" into it, you have actually touched the ball, which is somewhere on the trajectory, not everywhere. Can one fragment of an object's trajectory interact or be resonative to other fragments of the same trajectory, somehow solidifying it as an extended chain whole within some even larger frame? Can an object's trajectory overlap and interweave with the tail of another object, having had flown through the same space location some time before? For, if duration of an opened frame still lasts, both objects should be recognized as embraced by the same frame and being present in their shared location.

In a word, the whole set of typically quantum puzzles comes into force. We have departed from the common-sense view on the Universe as an aggregate of solid bodies — "balls" as classical mechanical gravitational objects, or liquid "drops", freely falling in space and thus attaining their spherical form. We've passed by the intermediate stage of presenting the stellar matter as a statistical liquid-like medium with its whirls and turbulences. By applying the more extended temporal frame or grain, we have shifted to its tentative wave representation.

Now, by applying even greater temporal frame or grain, we can come again, on a higher level, to its appearance as a mechanical solid bodies' medium. We can even get such attributes of a mechanical medium as "cosmic" sound, produced by mechanical vibrations of its particles. What would constitute those particles in cosmic space in the real terms? They might be clusters of galaxies, as definitely detached and roughly equally spread over the space clods of matter. How does it come out?

Let's introduce a vast multitude of particles, a number of them being captured by a frame. Temporal, spatial, and quantitative spreads of a frame are coherent, since the larger number of particles is included, the vaster space is embraced, and the longer the travel time of a standard signal from side to side is.

With every step of a frame enlargement, particles get more and more densely crowded within a single frame, until the frame's content proceeds to act rather as a medium, able to transfer mechanical vibrations.

It was us for whom the quality of sound appeared as the emergent one out of our consequent probes in enlarging frame; meanwhile, this quality did exist at and was innate to the level we eventually attained. On particular levels of organization of matter and within a particular magnitude of framing, sound is always there to be heard.

The hearer arises where there is something to be heard. On the level where matter is presented as a medium to conduct a signal liable for being perceived, a perceiving subject is likely to arise. This may explain why the terrestrial living beings inhabit more or less neighboring space and time niches. This could also tell us in which domains of organization of matter can we look for the entities of life and cognition of a cosmic scale. Yet, how could we communicate with those whose single frame of perception would be longer than the total life span humankind is doomed to?

References

1. Wells, H.G. (1966) The New Accelerator, in *The Complete Short Stories of H. G. Wells*, Ernst Benn, London, p. 940.
2. Krenkel, E. (1970) Moi pozyvnie — RAEM, *Novy Mir* **11**, 164 (in Russian).
3. Leonov, A.A., and Lebedev, V.I. (1971) *Psichologitcheskie Osobennosti Dejatelnosti Kosmonavtov*, Nauka, Moscow, p. 143 (in Russian).
4. Castaneda, C. (2003) *A Separate Reality: Further Conversations with Don Juan*, Penguin Books, London, p. 232.
5. Witkiewicz, S.I. (2003) *Narkotiki (Esse); Edinstvenniy Vychod (Roman)*, Vachazar and Ripol Classik, Moscow, pp. 185–186 (in Russian; translated from Polish).
6. *Ibid.*, p. 134.
7. *Ibid.*, p. 136.
8. Uexküll, J.B. von (1975) A Stroll through the worlds of animals and men: a picture book of invisible worlds, in C. Schiller (ed.), *Instinctive Behavior*, International Universities Press, New York, pp. 5–80.
9. *Ibid.*, pp. 30–31.
10. Frisch, K. von (1967) *The Dance Language and Orientation of Bees*, Belknap Press of Harvard University Press, Cambridge (MA), pp. 480–481.
11. Bergson, H. (1913) *Creative Evolution*, Henry Holt, New York, p. 306.

12. Varela, F.J. (1999), The specious present. A neurophenomenology of time consciousness, in J. Petitot, F. J. Varela, B. Pachoud, and J.-M. Roy (eds.), *Naturalizing Phenomenology: Issues in Contemporary Phenomenology and Cognitive Science*, Stanford University Press, Stanford, pp. 266–314.
13. *Ibid.*, pp. 274–275.
14. Ruhnau, E., and Pöppel, E. (1991) Adirectional temporal zones in quantum physics and brain physiology, *Int. J. Theor. Physics* **30**(8), 1083–1090; Pöppel, E. (1997) The brain's way to create "nowness", in H. Atmanspacher and E. Ruhnau (eds.), *Time, Temporality, Now: Experiencing Time and Concepts of Time in an Interdisciplinary Perspective*, Springer, Berlin, pp. 107–117.
15. Friedman, W.J. (2000) Time in psychology, in P. Baert (ed.), *Time in Contemporary Intellectual Thought*, Elsevier, Amsterdam, pp. 295–314.
16. Baudelaire, Ch. (1926) *Prose and Poetry*, A. and Ch. Boni, New York, p. 257.
17. Baumgarten, H.G., and Gothert, M. (eds.) (1997) *Serotoninergic Neurons and Five-HT Receptors in the CNS*, Springer, Berlin–New York.
18. Comprehending my immediate field of vision, anonymous report (16.09.2001) posted at the Erowid Experience Vaults: LSD, `http://www.erowid.org/experiences/exp.php?-ID=9696`.
19. Amidror, I. (2000) *The Theory of the Moiré Phenomenon*, Kluwer Academic Publishers, Dordtrect–Boston–London; Oster, G. (1965) Moiré patterns and visual hallucinations, *Psychodelic Review* **7**, 33–40; Shanon, B. (2002) Ayahuasca visualisations: a structural typology, *J. Consc. Studies* **9**(2), 3–30.
20. Bergson, H. (1978) *Matter and Memory*, Humanities Press, London, pp. 272–273.
21. *Ibidem.*, p. 275.
22. Lorenz, K. (1973) *Die Rückseite des Spiegels: Versuch einer Naturgeschichte menschlichen Erkennens*, Piper Verlag, München–Zürich, p. 67.
23. Bergson, H. (1978) *Op. cit.*, pp. 268–269.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 463–485

PHENOMENAL CONSCIOUSNESS AND THE ALLOCENTRIC-EGOCENTRIC INTERFACE

PETE MANDIK
Department of Philosophy, William Paterson University, 300 Pompton Road
Wayne, New Jersey 07470, U.S.A.
(mandikp@wpunj.edu)

Abstract: I propose and defend the Allocentric-Egocentric Interface Theory of Consciousness. Mental processes form a hierarchy of mental representations with maximally egocentric (self-centered) representations at the bottom and maximally allocentric (other-centered) representations at the top. Phenomenally conscious states are states that are relatively intermediate in this hierarchy. More specifically, conscious states are hybrid states that involve the reciprocal interaction between relatively allocentric and relatively egocentric representations. Thus a conscious state is composed of a pair of representations interacting at the Allocentric-Egocentric Interface. What a person is conscious of is determined by what the contributing allocentric and egocentric representations are representations of. The phenomenal character of conscious states is identical to the representational content of the reciprocally interacting egocentric and allocentric representations.

Keywords: Consciousness – Qualia – Representation – Philosophy – Neuroscience

1 Introduction

The purpose of this chapter is to sketch in a relatively small amount of space a relatively comprehensive theory of phenomenal consciousness, one that is both empirically warranted and philosophically productive. A theory of phenomenal consciousness must do two things: it must explain what makes a mental state a conscious mental state (as opposed to an unconscious mental state) and it must explain what it is for a conscious mental state to have phenomenal character, that is, the property of the state in virtue of which there is something it is like to be in that state.

The theory I shall sketch is what I shall call "The Allocentric-Egocentric Interface Theory of Consciousness" or "the AEI theory" for short. In brief, the theory posits that mental processes form a hierarchy of mental representations with maximally egocentric (self-centered) representations at the bottom and maximally allocentric (other-centered) representations at the top. Part of what it means to be higher or lower in the hierarchy is to be further from or closer to the sensory and motor periphery of the nervous system. Focusing on the processing of sensory information, we can trace the path of information from relatively egocentric representations of the stimulus in sensation through stages of processing that increasingly abstract away from egocentric information and represent things in memory in an allocentric way. Further, we can note top-down effects from relatively allocentric representations high up in the hierarchy to egocentric representations lower in the hierarchy. I hypothesize that phenomenally conscious mental states are to be identified with states that are relatively intermediate in this hierarchy. More specifically, conscious states are hybrid states that involve the reciprocal interaction between relatively allocentric and relatively egocentric states: a conscious state is composed of a pair of representations interacting at the Allocentric-Egocentric Interface. Unconscious mental states are states that are either too high up or too low down in the hierarchy or are not engaged in the requisite reciprocal interactions. What a person is conscious of is determined by what the contributing allocentric and egocentric representations are representations of. The phenomenal character of these states is identical to the representational content of the reciprocally interacting egocentric and allocentric representations.

That, at least, is the theory in brief. The remainder of the paper will spell things out in a bit more detail. It is organized as follows. First I say a few more things about the way philosophers think of phenomenal consciousness and how this might relate to empirical work on consciousness. Then I dive into the exposition of AEI with an emphasis on empirical evidence for the theory. Finally I discuss philosophical ramifications of the theory.

2 Philosophy and Phenomenal Consciousness

The phrase "phenomenal consciousness" involves a philosophical technical use of "consciousness" and it is best introduced by first noting some less technical uses of "consciousness" and the related term "conscious."

The philosopher David Rosenthal has made some observations about different uses of the word "conscious" that are useful for gaining an understanding of what consciousness is supposed to be [1,2]. The first way in which uses of the word "conscious" may be distinguished is in terms of a distinction between the things that may be said to be conscious. The first sort of thing that we may say is conscious is a person or a creature. A person or non-human creature that is awake and responsive is said to be conscious in this sense of the word "conscious" and Rosenthal labels this "creature consciousness". A second sort of thing that we may say is conscious is a mental state of a person or a non-human creature. Many of us are familiar with the Freudian idea that some of our beliefs and desires are conscious while others are unconscious, and since the state of a creature is a very different sort of thing from the creature itself, the sense in which a state is conscious ("state consciousness") is a very different sense of the word "conscious" than is the sense in which a creature is conscious ("creature consciousness"). Rosenthal further distinguishes the notions of creature consciousness and state consciousness in terms of the relative difficulty that theorists have had in understanding these types of consciousness. According to Rosenthal, being creature conscious amounts to no more than being awake and having mental states whereas state consciousness requires the satisfaction of additional criteria that distinguish conscious mental states from unconscious mental states [1].

A second kind of distinction that Rosenthal draws among uses of the word "conscious" distinguishes transitive from intransitive uses of the word [2]. The word conscious is used transitively when we speak of someone being conscious of something as when I am conscious of a buzzing insect that is pestering me. Intransitive uses of the word "conscious" are silent about whether the thing that is conscious is thereby conscious of something. Thus, both creature consciousness and state consciousness are instances of intransitive consciousness. We thus have on our hands at least three kinds of consciousness: creature consciousness, state consciousness, and transitive consciousness, the second and third of which will be especially important to the current discussion. Various theorists disagree as the ultimate natures of these three kinds of consciousness. In particular, they disagree as to how these three kinds might be explained in terms of one another.

I will briefly indicate a couple of positions to give a flavor of the issues. Rosenthal advocates an explanation of state consciousness in terms of transitive consciousness and an explanation of transitive consciousness in terms of mental representation. According to Rosenthal, a person is transitively conscious of x just in case they have a mental representation of x. Further, Rosenthal embraces as pre-theoretically intuitive the transitivity thesis whereby a person has a conscious mental state only if they are transitively conscious of that state [1]. It follows from these two points, then, that a person has a conscious state only if that person has a mental representation of that state.

In contrast, theorists such as Dretske [3] and Tye [4,5] deny the transitivity thesis and instead embrace the transparency thesis whereby when one has a conscious state all one is conscious of is what the state is a representation of. A conscious state, according to Dretske, is a state in virtue of which one is conscious of something [3]. Thus, if one is conscious of a buzzing insect, one is thereby in a conscious state and need not additionally be conscious of that state. In spite of his disagreement with Rosenthal about state consciousness, he agrees that transitive consciousness is to be defined in terms of representation: being transitively conscious of x involves mentally representing x.

Note that the above discussion of creature consciousness, state consciousness, and transitive consciousness made no explicit mention phenomenal consciousness. The above points about state, creature, and transitive consciousness can all be made by calling our attention to the various ways in which people use the word "conscious" in non-technical discourse. The same cannot be said of so-called phenomenal consciousness. The term "phenomenal consciousness" is not only a technical term, but often those who introduce it into technical discourse give little indication as to how it involves a common sense use of the word "conscious." Indeed, when people use the term "phenomenal consciousness" they are not much interested in a kind of consciousness distinct from the three already mentioned. They are interested instead in certain properties that conscious states allegedly have. These properties are referred to interchangeably as "phenomenal properties," "phenomenal character," or "qualia." Two key theorists who discuss phenomenal consciousness and qualia are Block [6] and Chalmers [7]. Block characterizes phenomenal consciousness (P-consciousness) as follows.

> P-consciousness is experience. P-conscious properties are experiential ones. P-conscious states are experiential, that is, a state is P-conscious if it has experiential properties. The totality of the experiential properties of a state are "what it is like" to have it. Moving from synonyms to examples, we have P-conscious states when we see, hear, smell, taste, and have pains. P-conscious properties include the experiential properties of sensations, feelings, and perceptions, but I would also include thoughts, wants, and emotions. (p. 230)

Chalmers writes that

> a mental state is conscious if it has a qualitative feel — an associated quality of experience. These qualitative feels are also

> known as phenomenal properties, or qualia for short. The problem of explaining these phenomenal properties is just the problem of explaining consciousness. This is the really hard part of the mind-body problem. (p. 4)

Additionally, Chalmers writes that

> what it means for a state to be phenomenal is for it to feel a certain way. ...in general, a phenomenal feature of mind is characterized by what it is like for a subject to have that feature... (p. 12)

It is clear that the kind of consciousness that both Block and Chalmers are interested in is state consciousness, for all of their examples of consciousness are examples of conscious states. And what they find interesting about conscious states is, as Chalmers puts it, their "phenomenal properties, or qualia for short."

What, then are qualia? This is of course a vexed issue, but we can nonetheless characterize some agreement among those who are fond of asserting their existence. Qualia are alleged to be (1) intrinsic properties of conscious states that (2) account for "what it is like" for the subject to be in that state and are (3) directly and fully knowable only by that subject. To further characterize qualia, we can start with (2) and work our way out to (3) and then (1). When I have a conscious mental state, e.g. a conscious perception of a red rose, there is presumably something it is like for me to be in that state, and for all I know, when you have a conscious perception of a red rose, what it is like for you is quite different from what it is like for me. For all I know what it is like for you to see red things is like what it is like for me to see green things, and vice versa. And, while you can tell me a bit about what it is like for you there's a lot that you know that I can't have access too. It is in this way that the characterization of "what it is like"-ness goes hand and hand with the claim that this whatever-it-is is only directly and fully knowable by the subject who has it. The allegedly intrinsic nature of qualia is hypothesized to explain why what it is like to be in a mental state is only directly and fully knowable by the subject of the state. The thought here is that if something is defined by relations it enters into, then we can describe it fully by describing the relations it enters into. Thus if there is something that we cannot describe fully by describing the relations it enters into then it is not defined by relations it enters into.

Many philosophers have correctly raised the question of whether there really are such properties as qualia, that is, whether there really are properties that satisfy all three conditions. One of the most questionable aspects of qualia concerns whether they are intrinsic. One can question whether there really are any properties that are intrinsic. Or one can grant that some properties are intrinsic, but question whether intrinsic properties are consistent with being the sorts of properties that account for what it is like to have a mental state or the sorts of states that account for whether they are directly and fully knowable by the subject. One sort of consideration against regarding qualia as intrinsic is that if qualia are definable in terms of being directly knowable by the subject, then that makes them extrinsic or relational after all, since qualia would be definable in terms relations to the subject and the various parts of the person in virtue of which the person has any knowledge at all.

Given the highly questionable status of the allegedly intrinsic nature of qualia, I will proceed with the following minimal account of qualia: qualia (phenomenal characteristics) are the properties of mental states in virtue of which there is something it is like to have them. This characterization thus leaves open whether such properties are intrinsic or fully and directly knowable only by the subjects of the mental states that have them. It is worth noting that in the characterizations of phenomenal consciousness from the quotations from Block and Chalmers given above, qualia were characterized solely in terms of this minimal characterization, that is, no explicit mention was made of qualia being either intrinsic or knowable fully and directly only by their possessors. On the account of consciousness I advocate below, qualia will not turn out to be intrinsic for they will turn out to be representational contents and representational contents are widely and correctly regarded as relational. Regarding the question of whether they are directly and fully knowable only by the subject, I address that question at length elsewhere and will thus devote no additional space to it here [8].

3 Neuroscientific Applications of the Concepts of Consciousness

Let us leave these philosophical remarks aside for a moment and turn to discuss how one might apply these concepts of consciousness in empirical settings. Two useful kinds of cases to look at in this regard involve blindsight and motion induced blindness. I begin with blindsight.

We can roughly characterize blindsight as a condition following certain sorts of brain damage wherein subjects report a loss of consciousness in spite of the retention of visual ability. One source of difficulty in characterizing blindsight in a clear and uncontroversial way is that there are few if any clear and uncontroversial ways of characterizing the relevant notions of consciousness and visual ability. Another source of difficulty is that, even when one is able to fix interpretations for "consciousness" and "visual ability" the data concerning blindsight shows neither a total loss of consciousness nor a total retention of visual ability. Many philosophers who delight in the superior chemical purity of thought experiments over real experiments have taken to discussing the conceptual possibility of the imaginary condition superblindsight wherein both loss of consciousness and retention of visual ability are total. I propose that in this case, if not in general, we should reject fake chemical purity as being as good as none whatsoever and thus seek to gain as much clarity as possible by examining real phenomena.

We can summarize blindsight in terms of the following questions: What are the lesions involved? What is the measure of retention of visual ability? The lesions involved are to primary visual cortex (area V1). In an early study of blindsight subjects were better than chance at moving their eyes to the location of a flash of light in a region of the visual field wherein they had reported not being able to see flashes of light [9]. Subsequent studies investigated the sorts of stimuli that blindsight subjects could respond to in spite of reporting no visual awareness, including stimuli characterized in terms of features such as wavelength [10,11] and motion [12]. Additional studies examined the way in which the presence or absence of consciousness could be indicated as in, for example, having the subject indicate by pressing one of two keys "whether he had any experience whatever, no matter how slight or effervescent" [13].

There are several natural suggestions of how to apply the concepts of consciousness from the previous section to the case of blindsight. The retention of visual abilities indicates that certain kinds of visual information are represented in the nervous system and that these representational states can guide certain behaviors. However, it seems clear that these representational states are not conscious states. Thus, first and foremost, the kind of consciousness that blindsight subjects seem to lack with respect to vision is state consciousness. Regarding the question of transitive consciousness, note that theorists that regard representation as sufficient for transitive consciousness will attribute transitive consciousness of items in the "blind" regions of the subjects' visual fields. However, if we take subjects' reports at face value, it seems that they lack transitive consciousness since they report not being conscious of the items in question.

One problem with blindsight is that the majority of the readers of the present paper are not themselves blindsight subjects and insofar as introspection is an important source of information regarding the adequacy of theories of consciousness, the reader may find some of the remarks about blindsight difficult to evaluate. It will thus be helpful to look at empirical work on consciousness that the reader may have an easier time relating to.

Experiments concerning the phenomenon of motion induced blindness are very useful in this regard [14]. One way of eliciting the phenomenon of motion induced blindness is by having normally sighted subjects look at a computer screen that has a triangular pattern of three bright yellow dots on a black background. Moving "behind" the yellow dots is a pattern of blue dots. As subjects stare at the screen, fixating on the midpoint between the three dots, they report that one or more of the dots disappear. I've seen the effect several times myself and it is quite salient (readers are encouraged to search the internet for "motion induced blindness" and see for themselves). The yellow dots are not really disappearing from the screen although it looks as if they do. Further, there is evidence that the brain continues to represent the presence of the yellow dots and the "disappearance" is due to the representations changing from being conscious representations to being unconscious representations as opposed to being due to retinal suppression, sensory masking, or adaptation. Some of the evidence that the yellow dots are still represented in the brain includes the fact that the effect can be influenced by transcranial magnetic stimulation to parietal cortex (a relatively late stage of visual processing in the brain). Other evidence is that motion induced blindness is sensitive to object grouping so that, for example, when the stimuli are, instead of the three yellow dots, a pair of partially overlapping circles, one yellow and one pink, sometimes an entire circle will disappear leaving the other behind even though some of their contours are very close in the visual field. The brain mechanisms thought to mediate such object groupings are relatively late in the visual processing hierarchy. Thus, information concerning the yellow dots is represented at many levels of processing prior to consciousness.

To relate motion induced blindness to the kinds of consciousness described above, there are several compelling and plausible ways of describing the changes in consciousness. First, I think it is clear to anyone who has experienced the phenomenon that at one moment you are conscious of a yellow dot and then at another moment you are not. Since the consciousness in question here is "consciousness of" this is to describe the case in terms of transitive consciousness. Second, the combination of first-person introspective evidence and third-person empirical evidence indicates that in the course of a motion induced blindness experiment there is, under some conditions, a conscious mental state and, under other conditions, an unconscious mental state. When it is obvious to subjects that they are in a state of perceiving the yellow dots this is a conscious state. When the dots disappear, even though there is a brain state that represents the yellow dots, it is not a conscious state. (It is accurate to regard this neural state as a mental state insofar as it is accurate to regard it as an unconscious perception of the yellow dots). Since phenomenal character attaches to states that are conscious, and phenomenal character is the property in virtue of which there is something it is like to be in that state, we are in a position to investigate what the properties are of that state that are relevant for determining what it is like for that person. More can be said later, but for now we can note that what it is like for that person is that it is like seeing a yellow dot appear and disappear. This suggests that at least part of what it is like to be in that state is determined by its representational content: the state represents the presence of a yellow dot. Returning to the question of what makes the state in question a conscious state, we can note one important similarity between various competing theories of state consciousness: namely that they explain state consciousness in terms relations between relatively low level states like sensations and relatively high level states like conceptual thoughts. So, for advocates of the transparency thesis (like Tye) what makes the representation of the yellow dot a conscious representation is that it is poised to interact with higher level conceptual states like beliefs and desires [4,5]. Many advocates of the transitivity thesis, like Rosenthal, will require that what makes the representation of the yellow dot conscious is not merely that it is poised to interact with higher level conceptual states, but further, that those conceptual states must be about — that is, representations of — the low level representation of the yellow dot [1,2].

I propose that these theorists are correct in trying to explain state consciousness in terms of interactions between high-level and low-level states. However, I want to argue ultimately that neither the transitivity thesis nor the transparency thesis is true. I favor a different account of the relative contributions of the various levels to state consciousness. In the remainder of the discussion, I will be primarily interested in visual consciousness, though I do intend the theory to apply to consciousness generally.

When we look at visual processing, we can characterize levels in a hierarchy of information processing. More specifically, we can characterize the levels in terms of how much the information has been processed, where the information is being processed, and what the nature of the processing is.

The questions of how much and where can be answered simultaneously by tracing the flow of visual information from the earliest stages of processing in the eyes through to the latest stages of visual processing in the cerebral cortex. More specifically, we can trace the flow of information from retinal ganglia through the optic nerve to the subcortical structures of the lateral geniculate nucleus. Next information is sent to the first stages of cortical processing in occipital cortex in the primary visual area (area V1). Later stages of cortical processing involve sending information along two branching paths [15]. The first is the dorsal stream that sends information from occipital cortex to posterior parietal cortex. The second is the ventral stream that sends information from occipital cortex to inferotemporal cortex. Still later areas of processing involve areas in frontal cortex [16] as well as in the hippocampus [15]. It is worth noting that the flow of information is not strictly feed forward from sensory input to the highest levels of brain processing but also includes many instances of feedback or back-projections of information being sent back from higher levels to lower levels [17].

The "where" and "how much" questions do not exhaust all there is to say about visual processing: there remains the question of what the nature of the processing is. I propose that one fruitful general way of understanding what is happening to visual information as it progresses through the levels of the processing hierarchy is that what begins as a relatively egocentric (self-centered) representation of visual information becomes increasingly abstracted and increasingly allocentric (other-centered) in the higher levels. We are to find the most egocentric visual representations in the lateral geniculate nucleus and also in the primary visual areas in occipital cortex. The most allocentric representations are found in frontal areas and hippocampus. Intermediate areas of cortical visual processing contain representations that are intermediate between being egocentric and allocentric. To get a clearer grasp of the proposal that visual processing can be characterized in terms of egocentric to allocentric transformations of represented information, it will be helpful to consider a more detailed discussion of egocentric and allocentric representations.

4 Egocentric Representations and Allocentric Representations

A useful starting place in characterizing egocentric representation is the notion of a receptive field. A good initial definition of "receptive field" is "area in which stimulation leads to response of a particular sensory neuron" [18]. Retinal ganglion cells and neurons in the lateral geniculate nucleus have circular fields with either an excitatory center and an inhibitory surround or an inhibitory center and an excitatory surround. The locations of these fields are defined relative to retinal locations, that is, a particular cell in, e.g., lateral geniculate nucleus, is most responsive to a visual stimulus falling on a specific retinal location. The firing of such a cell is thus said to represent the location of a stimulus in a region of retinocentric space [19].

Retinocentric representations are the lowest level representations in a hierarchy from the most egocentric representations to the most allocentric. The progression of information up the hierarchy progressively abstracts away from the particularities of the maximally egocentric representations as in transformations from retinocentric to head-centered and body-centered representations. Such transformations involve neurons in area 7a of posterior parietal cortex. These neurons exhibit different responses depending in part on whether eye-position is fixed. When eye position is fixed, these neurons exhibit retinocentric receptive fields. However, when eye position is not fixed, stimulus of a given retinal region results in a neural response that varies linearly with eye position. Under these later conditions then, these neurons have a linear gain field defined over eye position. Response in normal conditions, then, is a product of retinal stimulus location and eye position resulting in a neuron tuned to a particular location in head-centered space [20].

The egocentric representations described above involve sensitivity to a spatial location relative to some part of the organism or the organism as a whole. However, egocentricity is not limited only to the responses of sensory neurons, but can be defined for motor neurons as well. For example, reach plans for arms are encoded in eye-centered coordinates [21].

There is more to our mental lives than can be accounted for by egocentric representations. Many of our thoughts have a detached or objective character that abstracts away from peculiarities about us. For instance, my knowledge that Pi is an irrational number is not in any obvious way about me, regardless of how irrational I might be. Similarly, my grasp of the fact that neutrons and protons are more massive than electrons is not particularly a fact about me, in spite of the fact that much of my mass and volume is determined by neutrons, protons, and electrons.

Our capability to have detached, objective mental states is grounded in our allocentric representations. Allocentric representations have been postulated to exist in frontal areas as well as in hippocampus. I here focus on research concerning the neural basis of allocentric hippocampal representations. The classic studies in these areas concern the spatial navigational capabilities of rats, especially comparisons of performance of rats with and without lesions in hippocampus. One representative class of experiments concerns the performance of such rats in the Morris water maze. The Morris water maze consists of a container filled with water rendered opaque by the addition of milk powder. In typical conditions, rats swim in the water to goal locations consisting of platforms submerged deep enough to not be visible to the rats, but shallow enough to offer a place to rest and breathe without having to tread water. In one such study the water maze was set up such that rats had to swim to a platform rendered visible during training trials, but occluded by opaque water during testing trials. Orientation cues consisted of varied visual stimuli positioned around the maze. Intact and hippocampal damaged rats were trained to swim to the platform from a given start location. Test trials involved two general kinds of condition: one in which the starting position was the same as in the training trials and one with novel starting positions. In trials where starting positions were the same in test as in training, both intact and hippocampal damaged rats were able to swim to the platform. However, in trials where starting positions in the test differed from the training start positions, intact rats out performed hippocampal damaged rats. Hippocampal damaged rats took much longer to reach the platform, and in some cases never found the platform [22].

Results such as these have led to the hypothesis that the hippocampus functions in spatial navigation by supporting a cognitive map involving allocentric representations of the spatial layout of the creature's environment. Allocentric representations are implicated since the rats' navigational ability does not seemed to be tied to any particular point of view on or orientation within the environment.

One especially prominent proposal concerning how allocentric representations in the hippocampus underwrite successful navigation is the slope-centroid system [23,24]. The basic idea behind the slope-centroid system is that of a polar coordinate system based on the distribution of objects in the animal's environment. The centroid is the point at the center of the collection of objects in the environment. The slope is a line running through the longest axis of the collection of objects. Orientation within the environment is encoded in terms of angles relative to the slope. Position within the environment is encoded in terms of a vector defined by distance from centroid and angle relative to slope. Movements would be encoded in terms of vectors encoding direction and distance. As the animal moves around in the environment, the vector encoding movement is added to the vector for the current location resulting in a vector encoding the location expected at the end of the movement. Upon arrival at a goal location, comparison of sensory inputs to the representation of expected location results in a capability for mismatch detection allowing for continual correction and updating of the memory of the environmental layout.

There are thus three major representational components of the slope-centroid system: the representation of place, the representation of heading, and the representation of speed. The hippocampal implementations of these representational capacities are postulated to be the following. Place representations are thought to be implemented by pyramidal cell activity, with highest level of activity in a pyramidal cell corresponding to the animal's current location, irrespective of the animals heading. Representation of heading is thought to be implemented by activity in cells in nearby brain regions with activity corresponding to the direction the animal is facing irrespective of the animals location within the environment [25]. The representation of speed is thought to be implemented by the frequency of sinusoidal oscillations of the hippocampal EEG called the "theta pattern" [24].

5 Locating Consciousness in the Allocentric-Egocentric Hierarchy

It is reasonable to ask where in the processing stream conscious states arise. I turn now to considerations that we should regard conscious states as residing neither at the highest most allocentric levels nor at the lowest most egocentric levels. Instead, visual consciousness resides at an intermediate level. We can arrive at this conclusion by first noting that neither fully allocentric representations nor fully egocentric representations are ever conscious states.

Purely egocentric representations are not sufficient for conscious states. Egocentric representations count among the most basic and primitive forms of representations. For example, the kinds of spatial representations that arguably underwrite taxes (movement toward or away from a stimulus) in organisms as simple as the nematode worm *C. Elegans* (a creature with a nervous system of only 302 neurons) represent spatial distances and directions in egocentric terms [26,27]. While such creatures are complex enough to support egocentric representations, few theorists would regard them as complex enough to support phenomenal consciousness.

Another consideration against thinking that egocentric representations are alone sufficient for conscious states comes from the case of Milner and Goodale's patient DF, a victim of carbon monoxide poisoning that resulted in bilateral lesions to lateral occipital cortex. DF's lesions gave rise to visual form agnosia, a condition in which DF reports being unable to see objects, especially aspects of objects concerning their shape or form. In brief, patient DF seems not to be visually conscious of the form of objects. Nonetheless, it can be demonstrated that in spite of this lack of visual consciousness she is able to make use of certain unconscious representations of visual information about the form of objects in order to guide her actions. One demonstration of DF's condition is her performance on a task in which she had to put a card into a slot that could be variously oriented. For a given orientation of the slot, DF was able to orient the card correctly and post into the slot. DF's performance on this task was about as good as normal subjects. However, when asked to not put the card into the slot but instead to merely report on the orientation of the slot by holding the card in a comparable orientation, DF's performance was quite poor compared to normal subjects. The aspect of DF's performance that is relevant for our purposes is that while DF was not conscious of the orientation of the slot, her successful performance on the task indicates that her nervous system had unconscious egocentric representations of the slot. That she was able to correctly post the card into the slot demonstrates not only that she had representations of the orientation of the slot, but also that the orientation was represented relative to her hand and was thus egocentric [15].

One final consideration against regarding consciousness as purely egocentric involves making note of how frequently conceptual knowledge can affect what it is like to have various conscious experiences. For example, a pattern of black splotches on a white page can suddenly resolve as an image of a dog for someone who has a concept of a dog. The concept of a dog and the conceptual knowledge of what dogs are involve allocentric representations. The categorical knowledge that dogs are furry need not encode any information about the current relations of any dogs to oneself. Nonetheless, the way in which conceptual knowledge can be brought to bear on perceptual experience shows that concisions experience is not solely a matter of egocentric representation.

Just as consciousness is not solely egocentric, neither is it solely allocentric. One consideration in favor of this view is that visual consciousness is perspectival in the sense of embodying a pictorial perspective. The different features that characterize perspective in paintings and photographs also characterize a key feature of visual consciousness. For example, the visual perception of a row of three houses, like a picture, contains information about the locations and distances relative to the viewer in a way that the purely allocentric thought that there are three houses does not [8].

Another reason for believing that purely allocentric representations are insufficient for phenomenal consciousness comes when we realize that many propositional attitudes lack phenomenal character. Consider, for example, one's belief that Pi is an irrational number. It is implausible to suppose that this thought has any particular phenomenal character associated with it. As Jackendoff suggests, any apparent phenomenal character of the thought actually is the phenomenal character of associated sensory imagery, not of the thought itself [28]. And leaving the question of phenomenal character to the side momentarily, we can note that one can have a belief without it being a conscious belief. For example, the reader may have believed for many years that π is an irrational number, but this fact was probably not in the forefront of the reader's consciousness until this paragraph. Thus one can have allocentric representations (in this case, representations of π and irrationality) without those representations thereby being conscious. This is not to say that allocentric contents can never enter into consciousness. Indeed, the point of the above discussion concerning the influence that conceptual knowledge of dogs can have on visual perceptions of dogs was to demonstrate that allocentric contents do enter into conscious experience. The point here is that conscious experience is never solely allocentric.

Since conscious experience is never solely allocentric or solely egocentric, it is never to be found at either end of the allocentric-egocentric hierarchy. This lends plausibility to the hypothesis that conscious states are to be identified with representations at an intermediate level of the processing hierarchy. Additional evidence comes from research on the neural correlates of consciousness in binocular rivalry. In binocular rivalry research, human and animal subjects are presented with contradictory stimuli to their eyes, such as horizontal stripes to the left eye and vertical stripes to the right eye. While two stimuli are presented, both stimuli do not enter into the conscious percept but instead compete in the following way. At one moment the subject will see only the vertical stripes and at another moment the subject will see only the horizontal stripes. Neuroscientific investigations look for which neural activations seem most closely associated with the conscious percept. Monkeys can be trained to indicate which of the two stimuli they are aware of at any given time and single cell recordings can indicate whether activation in a cell is correlated with the conscious percept. Logothetis [29] found that among monkey cortex cells associated with the conscious percept, 90% were in inferotemporal cortex whereas only 40% were in extrastriate cortex (regions of cortex adjacent to area V1).

6 The Allocentric-Egocentric Interface Theory of Phenomenal Consciousness: Empirical Evidence

According to the AEI theory, not only are conscious states to be identified with representations at the intermediate level of the egocentric to allocentric processing hierarchy, they are, more specifically, to be identified with representations for which there is a mutual influence between egocentric and allocentric representations. That is, conscious states are hybrid representations in which there is both-bottom up influence of egocentric representations on allocentric representations and top-down influence of allocentric representations on egocentric representations.

Evidence for the reciprocal interaction between egocentric and allocentric representations comes from multiple sources. Already noted was the way in which conceptual knowledge can influence the nature of a perceptual experience. Additional evidence comes from studies of the relative contributions of low and high levels of the processing hierarchy conducted by Pascual-Leone & Walsh [17]. They applied precisely timed pulses of trans-cranial magnetic stimulation to different regions of visual cortex so as to test which areas seemed necessary for a conscious percept. In particular they looked at the relative contributions of area V1 and the relatively higher-level adjacent area known as MT or V5. Activity in neither area was alone sufficient for a conscious percept (a perception, in this case, of a moving stimulus). The conscious percept arose only when information was allowed to feedback from MT to V1.

We can relate the allocentric-egocentric interface proposal to the phenomenon of motion induced blindness. As already mentioned above, parietal areas-relatively intermediate in the processing hierarchy-are implicated in the phenomenon. Especially noteworthy are the contributions of relatively allocentric representations to the phenomenon. Bonneh and Cooperman [30] investigated what frames of reference seemed most implicated in the motion induced blindness and found that head-centered and object-centered mechanisms are involved in the disappearance effect.

Another promising line of evidence concerning the role of higher-level processes concerns the processes implicated in the kinds of learning that seem to involve consciousness. For example, there is evidence from fear conditioning studies that trace learning but not delay learning depends on consciousness. In the trace learning, there is a time gap between the conditioned stimulus and the unconditioned stimulus and in delay learning the two stimuli overlap. Additionally, it has been suggested that trace but not delay learning depends critically on hippocampus and certain prefrontal structures [31].

The question arises of whether Milner and Goodale's dual systems theory of vision is inconsistent with the AEI theory of consciousness. One way of seeing a tension between the two accounts involves reading Milner and Goodale's view as the hypothesis that consciousness arises only in ventral stream processes and never in dorsal stream processes whereas the AEI theory allows that consciousness (at least sometimes) involves parietal processing. Two main points need to be made to ward off any threat that might be posed by Milner and Goodale's account. First we need to see that parietal areas do indeed sometimes get implicated in conscious states. The second point is to give an account of what distinguishes the occasions in which parietal processing affects consciousness and when it does not. Regarding the first point, it has already been noted that motion induced blindness may be modulated by transcranial magnetic stimulation of parietal areas. Further, parietal activity is implicated in conscious motor imagery [32,33]. Regarding the distinction between conscious and unconscious parietal activity, the distinction can be drawn as follows: direct projections from parietal areas to pre-motor areas do not result in conscious states, whereas projections from parietal areas to pre-motor areas via prefrontal cortex do give rise to conscious states [34]. This fits nicely with the Allocentric-Egocentric Interface theory given the role frontal cortex plays as a high-level area of visual processing implicated as a locus of allocentric representations.

7 Philosophical Implications of the Theory

In this section I turn to spell out some of the philosophical implications of the Allocentric-Egocentric Interface theory of phenomenal consciousness. It will be useful to first relate the empirical theory to the philosophically motivated terminology described in the second section of this chapter. Recall that the basic gist of the theory at hand is an account of state consciousness. A conscious state is comprised of two mutually interacting representations (via feed-forward and feed-back connections), one of which is relatively more allocentric and the other more egocentric. With respect to the question of transitive consciousness, the question of what a person is thereby conscious of in virtue of having a conscious state is that they will be conscious of whatever the allocentric and egocentric representations involved are representations of. What one is conscious of is always the content of both egocentric and allocentric representations. Regarding the question of phenomenal character, the account that emerges is that phenomenal character is identical to the representational contents of the implicated representations. Further details concerning these issues will come to light in the following discussion of how the AEI theory compares to some of its main philosophical competitors. I turn now to discuss comparisons between AEI and, on the one hand, the First-Order Representational theories of consciousness favored by proponents of the transparency thesis and, on the other hand, Higher-Order Representational theories favored by proponents of the transitivity thesis.

First-order representational theories of consciousness attempt to explain consciousness in terms of first-order representations, that is, representations that, whatever they represent, do not represent other representations. Higher-order representations are representations of representations. A representation of a first-order representation is a second-order representation and a representation of one of these is a third-order representation and so on. First-order representationalists are especially fond of the transparency thesis that when one has a conscious experience, all that one is conscious of is what the experience is an experience of. First-order representationalists presuppose the transparency thesis as intuitively obvious and utilize it to justify their claim that conscious states have only first-order representational content and that phenomenal character is identical to the representational content of these first order states. If the transparency thesis turns out to be false then first-order representationalism turns out to be false for the following reason. If one were able to be conscious of something other than what an experience is an experience of (like vehicular properties of the state itself) then what it is like to be in a conscious state (a conscious state's phenomenal character) is something other than the just the first-order representational content of that state. Phenomenal character would thus include either the vehicular properties of experiences or the representational contents of the higher-order states in virtue of which one is conscious of the experiences.

The entering wedge of a case against the transparency thesis begins by noting the way that allocentric representational content, especially conceptual content, can influence what it is like to have a particular experience. So, for example, what it is like to look at a ladybug and conceive of it as an example of *Hippodamia convergens* is, intuitively, quite different from what it would be like to conceive of it as one's reincarnated great-great-grandmother. This in and of itself is not a threat to the transparency thesis, since representations of ladybugs, *Hippodamia convergens*, reincarnation, and great-great-grandmothers need not be anything other than first-order representations. However, the possibility that conceptual content can enter into what it is like to have an experience opens up the possibility that higher-order conceptual content can enter into what it is like to have an experience.

To spell out the possibility just described it will be helpful to spell out some of the conditions sufficient for violating the transparency thesis. First-order representationalists read the transparency thesis as saying that when an experience is conscious one can only be conscious of what the experience is an experience of and thus one cannot be conscious of the experience itself. The question arises, of course, of what it means to be conscious of the experience itself and here the answer is best understood if we grasp the distinction between representational contents and representational vehicles. We can illustrate the distinction in terms of an analogy concerning non-mental representations. The English sentence "an orange cat is on a red mat" has as its representational content an orange cat's being on a red mat. Vehicular properties of the sentence would include what font and ink color it is printed in. Event though the sentence represents an orange thing being on a red thing, the sentence itself — the representational vehicle — need not be printed in either red or orange ink. Returning to the topic of mental/neural representations, consider that a conscious experience can have as its content an orange cat being three feet away while the experience itself — the representational vehicle — is a state of the nervous system and is thus neither orange nor three feet away (nor is it a cat). Returning to the transparency thesis with the content/vehicle distinction in hand we can see that part of what it is denying in denying that we are conscious of experiences themselves is that it is denying that we are conscious of vehicular properties (on the assumption, of course that the vehicular properties of a representation just are whatever properties it has other than its content). However, if we combine the suggestion that conceptual contents enter into the phenomenal character of experience with the suggestion that some of our concepts can be concepts of certain vehicular properties, the suggestion presents itself that we can indeed be aware of properties of experiences themselves. Thus, following Churchland's suggestion of the possibility of the direct introspection of brain states [35], if a person had the conceptual knowledge that consciously perceiving motion involved reciprocally influencing activity in areas V1 and MT, and acquired the skill of being able to automatically and without conscious inference apply that conceptual knowledge to experience, then that person would be able to be conscious of the vehicular properties of that experience. One consequence of this view that concerns phenomenal character is that when brain states are directly introspected it is not the vehicular properties of experiences that contribute to phenomenal character but instead the representational content of the introspective states (which, of course, represent vehicular properties) that contribute to phenomenal character.

The above remarks spell out the falsity the transparency thesis in terms of the fact that when we have conscious states we are sometimes able to be conscious of the states themselves. This, however, is not to endorse the transitivity thesis that requires that we are always conscious of our conscious states. Indeed, I believe the transitivity thesis to be false. The Allocentric-Egocentric Interface theory is an empirically warranted theory which is logically consistent with the falsity of the transitivity thesis. Further, there are philosophical reasons for being suspicious of the transitivity thesis.

First off, according to advocates of the transitivity thesis it is supposed to be intuitively obvious that it is a requirement on having a conscious state that one is conscious of that state [1,36]. If the transitivity thesis is true it should be obviously incorrect to say of a state that is was conscious before any one was conscious of it. However, if we consider a particular example, it seems that the transitivity thesis is not obviously correct (which is not, of course, to say that it is obviously incorrect). Consider, for example, how one might describe what happens in motion induced blindness experiments when the yellow dots pop into and out of consciousness. It seems equally plausible to say either (1) that first the perception of the yellow dot becomes conscious and then you become conscious of your perception of the yellow dot or (2) the perception of the yellow dot becomes conscious only if you also become conscious of your perception of the yellow dot. If the transitivity thesis were pre-theoretically obvious, then option (1) would be obviously incorrect and (2) would be obviously correct. However, since neither (1) nor (2) seem obviously correct (or obviously incorrect), the transitivity thesis is not pre-theoretically obvious.

A second consideration that casts suspicion on the transitivity thesis concerns how easily we can explain whatever plausibility it has without granting its truth. We can grant that the transitivity thesis may seem plausible to very many people but explain this as being due to the fact that counterexamples would not be accessible from the first-person point of view. If we ask a person to evaluate whether the transparency thesis is true, they will call to mind all of the conscious states of which they have been conscious. But this can not constitute conclusive proof that conscious states are necessarily states that their possessor is conscious of. Consider the following analogy. Every tree that we have ever been aware of is, by definition, a tree that we have been aware of. But this is not due to the definition of being a tree, but only due to the definition of being aware of it. The fact that every tree that we are aware of is a tree of which we have been aware cannot constitute proof that trees are essentially the objects of awareness or that no tree can exist without our being aware of it. By analogy we should not conclude from our being conscious of all of our conscious states that we have been aware of from the first-person point of view that all conscious states are *necessarily* states that we are conscious of. We should instead view our first-person access to conscious states as a way of picking out a kind of state that we can further investigate utilizing third-person methods. The description "states we are conscious of ourselves as having" thus may be more profitably viewed as a contingent reference fixer of "conscious state" that leaves open the possibility that it is not part of the essence of conscious states that we are conscious of them. Instead, the essence of conscious states is that they are hybrid representations that exist in the allocentric-egocentric interface.

Acknowledgements

This work was supported in part by grants from The National Endowment of the Humanities and The James S. McDonnell Foundation's Project for Philosophy and the Neurosciences. I am grateful to audiences of versions of this material at the University of Quebec in Montreal; the Heron Island, Australia meeting of the McDonnell Project of Philosophy and Neuroscience; the City University of New York Graduate Center Cognitive Science Symposium and Discussion Group; the William Paterson University Department of Psychology; and the ZiF conference on Endophysics, Time, Quantum and the Subjective. I am especially grateful for feedback from the following individuals: Ralph Abrams, Kathleen Akins, Omid Bayati, Ned Block, Mike Collins, Luc Faucher, Thomas Hogan, Doug Meehan, Rachelle Nashner, Anatoly Nichvoloda, David Rosenthal, Alex Vereschagin, and Josh Weisberg.

References

1. Rosenthal, D. (1993) Thinking that one thinks, in M. Davies and G. Humphreys (eds.), *Consciousness*, Basil Blackwell, Oxford, pp. 197–223.
2. Rosenthal, D. (1993) State consciousness and transitive consciousness, *Consciousness and Cognition* **2**(4), 355–363.
3. Dretske, F. (1995) *Naturalizing the Mind*, MIT Press, Cambridge (MA).

4. Tye, M. (1995) *Ten Problems of Consciousness: A Representational Theory of the Phenomenal Mind*, MIT Press, Cambridge (MA).
5. Tye, M. (2000) *Consciousness, Color, and Content*, MIT Press, Cambridge (MA).
6. Block, N. (1995) On a confusion about a function of consciousness, *Behavioral and Brain Sciences* **18**(2), 227–288.
7. Chalmers, D. (1996) *The Conscious Mind*, Oxford University Press, New York.
8. Mandik, P. (2001) Mental representation and the subjectivity of consciousness, *Philosophical Psychology* **14**(2), 179–202.
9. Pöppel, E., Held, R., and Frost, D. (1973) Residual visual functions after brain wounds involving the central visual pathways in man, *Nature* **243**, 295–296.
10. Stoerig, P., and Cowey, A. (1989) Wavelength sensitivity in blindsight, *Nature* **342**, 916–918.
11. Stoerig, P., and Cowey, A. (1992) Wavelength discrimination in blindsight, *Brain* **115**, 425–444.
12. Weiskrantz, L. (1995) Blindsight: not an island unto itself, *Curr. Directions Psychol. Sci.* **4**, 146–151.
13. Weiskrantz, L. (1996) Blindsight revisited, *Curr. Opin. Neurobiol.* **6**(2), 215–220.
14. Bonneh, Y., Cooperman, A., and Sagi, D. (2001) Motion induced blindness in normal observers, *Nature* **411**(6839), 798–801.
15. Milner, A., and Goodale, M. (1995) *The Visual Brain in Action*, Oxford University Press, New York.
16. Olson, C., Gettner, S., and Tremblay, L. (1999) Representation of allocentric space in the monkey frontal lobe, in N. Burgess, K. Jeffery, and J. O'Keefe (eds.), *The Hippocampal and Parietal Foundations of Spatial Cognition*, Oxford University Press, New York, pp. 359–380.
17. Pascual-Leone, A., and Walsh, V. (2001) Fast backprojections from the motion to the primary visual area necessary for visual awareness, *Science* **292**, 510–512.
18. Levine, M., and Shefner, J. (1991) *Fundamentals of Sensation and Serception* (2nd edition), Brooks/Cole, Pacific Grove (CA).
19. Hubel, D., and Wiesel, T. (2001) Brain mechanisms of vision, in W. Bechtel, P. Mandik, J. Mundale and R. Stufflebeam (eds.), *Philosophy and the Neurosciences: A Reader*, Basil Blackwell, Oxford, pp. 179–198.
20. Andersen, R. (1995) Coordinate transformations and motor planning in posterior parietal cortex, in M. Gazzaniga (ed.), *The Cognitive Neurosciences*, MIT Press, Cambridge (MA), pp. 519–532.
21. Batista, A., Buneo, C., Snyder, L., and Andersen, R. (1999) Reach plans in eye-centered coordinates, *Science* **285**, 257–260.
22. Eichenbaum, H., Stewart, C., and Morris, R. (1990) Hippocampal representation in spatial learning, *Journal of Neuroscience* **10**, 331–339.

23. O'Keefe, J. (1993) Kant and the sea-horse: an essay in the neurophilosophy of space, in N. Eilan, R. McCarthy and B. Brewer (eds.), *Spatial Representation: Problems in Philosophy and Psychology*, Blackewell, Oxford, pp. 43–64.
24. O'Keefe, J. (1994) Cognitive maps, time and causality, *Proceedings of the British Academy* **83**, 35–45.
25. Taube, J., Muller, R., and Ranck, J. (1990) Head direction cells recorded from the postsubiculum in freely moving rats. Description and qualitative analysis, *Journal of Neurosciences* **10**, 420–435.
26. Mandik, P. (2002) Synthetic neuroethology, *Metaphilosophy* **33**(1/2), 11–29.
27. Mandik, P. (2003) Varieties of representation in evolved and embodied neural networks, *Biology and Philosophy* **18**(1), 95–130.
28. Jackendoff, R. (1987) *Consciousness and the Computational Mind*, MIT Press, Cambridge (MA).
29. Logothetis, N. (1999) Vision: a window on consciousness, *Sci. Am.* **281**, 69–75.
30. Bonneh, Y., and Cooperman, A. (2003) Motion induced blindness is affected by head-centered and object-centered mechanisms, *Journal of Vision* **3**(9), 221.
31. Carter, R., Hofstotter, C., Tsuchiya, N., and Koch, C. (2003) Working memory and fear conditioning, *Proc. Natl. Acad. Sci.* **100**(3), 1399–1404.
32. Decety, J., Perani, D., Jeannerod, M., Bettinardi, V., Tadary, B., Woods, B., and Mazziotta, J. (1994) Mapping motor representations with PET, *Nature* **371**, 600–602.
33. Grafton, S., Arbib, M., Fadiga, L., and Rizzolatti, G. (1996) Localization of grasp representations in humans by PET: 2. Observation compared with imagination, *Experimental Brain Research* **112**, 103–111.
34. Boussaoud, D., di Pellegrino, G., and Wise, S., (1996) Frontal lobe mechanisms subserving vision-for-action versus vision-for-perception, *Behav. Brain. Res.* **72**, 1–15.
35. Churchland, P. (1979) *Scientific Realism and the Plasticity of Mind*, Cambridge University Press, Cambridge.
36. Lycan, W. (1995) *Consciousness and Experience*, MIT Press, Cambridge (MA).

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 487–506

INTUITION: WHAT SCIENCE SAYS (SO FAR) ABOUT HOW AND WHY INTUITION WORKS

PAUL BERNSTEIN
Educational Services, 8 Ferry Street
Chelsea, Massachusetts 02150, U.S.A.
(pbernste@earthlink.net)

Abstract: Intuition is defined for the purposes of this analysis as: the appearance in the mind of accurate information about the external world, which can be shown to have come not through the five senses, nor through a rearrangement of stored memory contents. Forms of intuition obeying this definition have been explored scientifically under such labels as telepathy, precognition, presentiment, and remote viewing. This paper summarizes those scientific findings, and presents a few theories which have been hypothesized to explain them. Those theories are largely based in theoretical physics, including quantum non-locality, holography, and complex space-time. Related biological theories are also cited, which propose to explain how information might move from the subatomic level up into waking consciousness, for example through DNA structures or neuronal microtubules.

Keywords: Telepathy – Precognition – Quantum – Hologram – Space-time

1 Introduction

Probably all of us can recall occasions when we've had a strong 'hunch' or intimation about some person or event. Most often it came as a quick 'flash' of information — perhaps about a person's trustworthiness, or about an impending event's danger or success. This morsel of information was not a conclusion we'd arrived at after lengthy, rational cogitation, assessing evidence we'd gathered deliberately over a long period of time. Nevertheless, the 'flash' turned out to be true — which, ironically, may then have engendered a conflict of feelings within us.

For on the one hand, we were pleased to find ourselves 'right' about the person or the future event. But on the other hand, we may have felt troubled, because we didn't know how we'd gotten that accurate information, and therefore we weren't sure how to summon up the ability again in the future or even, whether to trust it. Consequently, we may have decided to dismiss the episode as a chance coincidence, and decided that it did not really constitute a reliable way to acquire accurate information.

But what if science were to study such occasions of 'hunches', monitoring them under controlled laboratory conditions, counting the number of accurate and inaccurate 'flashes'? Would the results equal chance — thereby demonstrating that indeed, such occasions of accuracy are merely coincidence? Or would the experiments reveal that persons experience such accuracy at rates significantly greater or less than chance? And if they occur more often than chance, could the scientific method help us learn how and why they occur?

2 Findings

For at least 100 years, scientists have in fact been studying forms of intuition under controlled, laboratory conditions [1]. By 'intuition', for the purposes of scientific study, we mean:

> the appearance of accurate information in the mind of an individual,
> concerning events, persons or locales outside that individual,
> which can be shown to have come not through the five senses,
> nor through a rearrangement of the individual's stored memory contents.

This definition is faithful both to our common subjective experience of intuition and to our scientific need for 'operationalizing' a phenomenon in order to subject it to controlled research [2].[a]

In practice, this definition includes three types of intuition that scientists have tried to study:

(i) information which we gain from another *person* (informally called 'telepathy')
(ii) information which we gain about another *place or object* (sometimes called 'remote viewing' or 'clairvoyance')
(iii) information which we gain about *the future* (which for scientific purposes is divided into 'precognition' [thoughts] and 'presentiment' [feelings]).

The next three sections review the research that has been attempted in each of these areas (and has been published in the English language).

[a]Broader than this definition is the common usage of 'intuition' to mean realizations that *do come from stored memory contents* — as when an artist or scientist at first gives up consciously trying to solve a particular creative problem and then a day or two later, thinks of a solution while doing something else — taking a walk, a shower, or in a dream. That is a process of *creativity*, and is worthy of scientific study in its own right. But it is distinct from the acquisition of information that exists originally outside the individual's mind, such as items perceived through forms of intuition known as precognition or remote viewing.

2.1 Research on 'telepathy' (person-to-person transmission)

Beginning in 1927, Prof. Joseph Rhine conducted laboratory experiments at Duke University in North Carolina (USA), in which one person would select a card from a well-shuffled deck and would mentally concentrate on its image while another person some distance away would note down the image that appeared in his or her mind. Rhine and his colleagues used a set of 25 cards designed especially for this purpose. Each card contained a simple symbol: circle, square, star, etc. In a series of experiments spreading over the following 13 years, they accomplished almost one million trials. Twenty-seven of those 33 studies produced statistically significant results; that is, the 'receiver' or 'guesser' correctly identified the card being viewed by the 'sender' at rates greater than chance. Colleagues at other institutions began to replicate Rhine's procedure, and 61% of those other laboratories' replication experiments also yielded statistically significant results — whereas only 5% would have been expected by chance [3].

A different laboratory method for testing person-to-person transmission was created by Dr. Charles Tart working at the Massachusetts Institute of Technology (USA) in 1963. Instead of asking a 'receiver' to record an image appearing in his mind while a 'sender' gazed at a card, Tart measured the *bodily reactions* of the receiver when a stimulus was applied to the body of the sender. (Let us recall that the root meaning of tele-pathy is '*feeling* [pathos] at a distance [tele]'). The two individuals were located in separate rooms. To ascertain the receivers' bodily responses, Tart monitored their brain waves, finger pulse blood volume, and skin electrical conductance, and found that the first two, brain waves and peripheral blood volume, changed significantly when the stimulus was engaged at or near the sender (Table 1) [4]. (The table's caption reports the statistical significance of each physiological indicator's data: the smaller the p value [the probability that the data would have occurred by mere chance], the greater the possible causal link).

Changes in a person's peripheral blood volume and galvanic skin response are indicators of the human 'fight-or-flight' response, a coordinated activity of our autonomic nervous system. And changes in brain wave patterns indicate significant, even if subconscious, mental activity. Combined, these measures potentially offer researchers an opportunity to track reactions of the human organism to particular events, even if such reactions never emerge into conscious portions of the mind.

Table 1. Body-to-body telepathy trials [4]. The distribution of Finger Pulse Volume (FPV; $p < 0.01$, two-tailed), Galvanic Skin Response (GSR; $p < 0.1$, two-tailed), and EEG Complexity (i.e., sums of ranks for Wilcoxon matched-pair signed-ranks tests; $p < 0.01$, two-tailed (*), and $p < 0.05$, two-tailed(**). 'S' and 'NS' stand for 'Stimulus' and 'No Stimulus', respectively. 'NPC' stands for 'Number of Paired Comparisons'.

Distribution of FPV, GSR, and EEG Responses							
Type of Trial	FPV		GSR		EEG Complexity		
	S	NS	S	NS	S	NS	NPC
Shock	35	25	60	57	21,508.5	14,808.5	269*
Nonshock	47	12	77	49	19,756.5	14,434.5	261**

A larger study utilizing this strategy was conducted by Drs. Marilyn Schlitz (Institute of Noetic Sciences) and William Braude (Institute of Transpersonal Psychology, both in California). These researchers analyzed 19 laboratory experiments conducted in Edinburgh, Scotland and California between 1979 and 1996 in which professional 'healers' had directed their thoughts toward individual volunteers located in separate rooms, at time intervals dictated by a randomized scheduling device. In between those 'sending' intervals, the healers rested, allowing their thoughts to move onto other matters. The recipients' skin conductance was measured. A total of 105 senders and 317 recipients were observed, and in most cases, the bodies of the recipients registered a change at the moment when the senders' thoughts were being focused on them. When the senders rested, the recipients' physiologies likewise returned to the more normal, quieter state. The statistical significance of these changes was quite high: $p = .000054$, and the single-mean T-test reported a success rate of 37%, compared to only 5% had these correlations been occurring by chance [5].

During the same two decades, in parallel with such mind-to-body studies, a large number of mind-to-mind experiments were conducted. Forty studies, comprising 2,549 sessions by 10 different research teams used the 'Ganzfeld' procedure, which isolates receivers from auditory and visual stimuli by covering their ears with earphones through which white noise is played, and by covering their eyes with white cups onto which soft red light shines. This is done to decrease the usual stimuli that enter a person's brain, so that the individual might more readily notice any non-sensory information available. To test whether mind-to-mind information might somehow be conveyed by a form of electromagnetic radiation (like radio waves), the researchers enclosed the recipients within steel walls and Faraday screening. Each sender was shown one of four pictures, either on a card or a video screen, at randomized intervals; and each recipient wrote down what came into her or his mind. Despite the steel and copper shielding, the receivers' overall accuracy rate was 33.2%, which exceeded the chance rate of 25% — which elementary statistics predicts should occur by chance only once in 1015 attempts (Fig. 1) [6].[b]

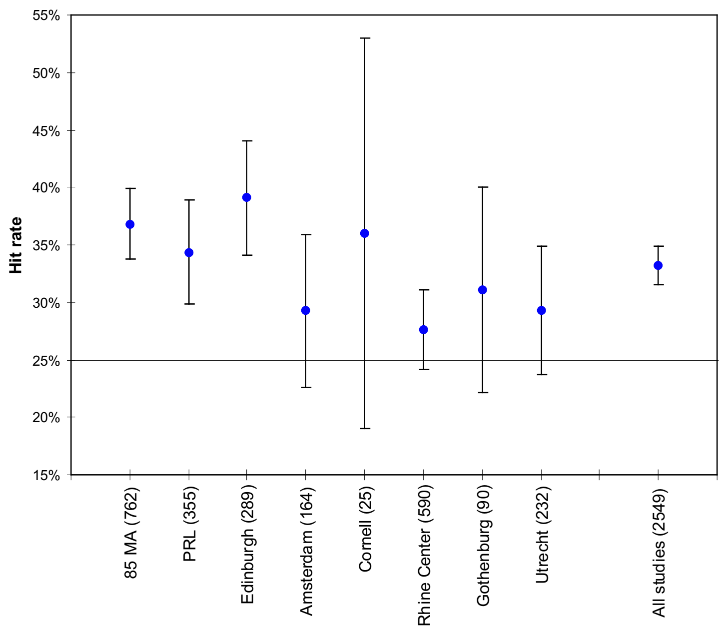


Figure 1. Telepathy experiments using the Ganzfeld technique [6].

2.2 *Research on 'remote viewing' (person perceiving a place or object)*

As he was with telepathy, Prof. Joseph Rhine was one of the first researchers to rigorously investigate remote viewing (which he called 'extra-sensory perception') — that is, the appearance in a person's mind of accurate information about a location or object out of range of his five senses. In these

[b]In response to the objection that such high statistics might have been caused by unsuccessful studies having been withheld from publication, a calculation was made of that thesis, which revealed that 15 studies would have had to have been conducted and hidden for every one of the published studies, in order to be the sole cause of the published studies' combined success rate [6, p. 80].

experiments, there is no human 'sender' of information, only a receiver and a 'target' object selected at random so its identity is also unknown at the time to the experimenter. Rhine used the same symbol cards he had devised for his telepathy experiments, but concealed them within opaque, sealed envelopes, in later trials also placing those sealed envelopes behind an opaque screen, and in still later experiments putting the sealed envelopes into different rooms and buildings from where the perceivers were situated. All told, Rhine and his colleagues conducted 34 such studies between 1934 and 1939, amounting to 792,000 trials [3].

Because there were five possible images in each trial, pure chance would have led to a success rate of 20%, but Rhine's subjects were correct 21.52% of the time. Most of his subjects were average university student volunteers, not persons who claimed to be 'gifted clairvoyants'. So of particular interest to science is a more recent series of experiments that searched for and found individuals who repeatedly manifested higher rates of success. This series was conducted between 1973 and 1988, funded initially in secret by the US Central Intelligence Agency at the Stanford Research Institute in Palo Alto, California. The experimental procedure was to place into a sealed envelope a photograph or the geographical coordinates (longitude and latitude) of a particular locale, and to ask the percipient to describe what he or she saw at that locale. Percipients were allowed to describe the location not only verbally but also graphically, that is by drawing on paper the scene they perceived in their mind's eye. Independent judges were then shown a set of photographs, some of which showed the actual site (depicting its landscape, buildings, etc.) and others which showed other locales. The judges were not told which photographs were the correct ones, but were asked to match the percipient's description and drawings to one of the photographs. Over 9,700 trials were conducted, and the probability that their high accuracy rate could have occurred by chance is estimated by elementary statistics to be only one in 1011 attempts [7,8].

2.3 Research on 'precognition' and 'presentiment' (person perceiving the future)

Perhaps the form of intuition most familiar in the life of the average person is a hunch about *the future*: we feel, suspect, or have a premonition, that something will 'turn out bad', or that, against all likelihood, some effort will be successful. Can this, too, be studied scientifically, under controlled laboratory conditions?

Scientists have been trying to do so at least since 1935, and by 1989 309 studies had been published in English that could be subjected to a collective assessment. Dr. Charles Honorton (Psychophysical Research Laboratories, Princeton, New Jersey) and his colleague Diane Ferrari analyzed that collection. In all the experiments, the subjects had been asked to predict a target (symbol cards in the 1930s, computer-displayed numbers by the 1980s) that would be selected in the future by a randomized process. The time interval tested in these experiments between the subject's prediction and the future generation of each target varied from less than one second to a full year. In total, nearly two million such trials were performed under strict laboratory conditions by more than 50,000 subjects, in experiments conducted by 62 different researchers. The overall accuracy of the predictions made by the experimental subjects had the probability of occurring by chance, according to elementary statistics, of only one in 1025 attempts [9].[c]

Besides making *conscious predictions* about the future, humans have been observed to experience sometimes-difficult-to-articulate *feelings* about the future. Indeed, this is commonly how most of us experience a 'hunch' — as a feeling, often in the 'gut', rather than as a clear image or thought in our conscious mind ('head'). Scientists use the term *presentiment* for such feelings, from the Latin words 'sentir' (to feel) and 'pre-' (before) — that is, to feel an event before it occurs. In the 1990s, this form of intuition was subjected to laboratory investigation, in particular by Dutch psychologist Dick Bierman at the University of Amsterdam and by American researcher Dr. Dean Radin at the University of Nevada. Both investigators monitored the usual physiological indicators of their subjects' emotions — heart rate, skin conductance, and peripheral blood volume — while computers randomly displayed pictures of two types: calm, pleasant scenes of nature and happy people; or disturbing, violent or erotically stimulating scenes. As Fig. 2 shows, the subjects' bodies reacted differently *before* they saw each type of image, not only *after* their eyes took in the image [10].

In subsequent research, Dr. Bierman observed the internal brain activity of his subjects (using functional magnetic resonance imaging) when they were shown each type of picture, and again he found distinct differences *before* the violent-emotional pictures were shown, in comparison to

[c] In response to the objection that such high statistics might have been caused by unsuccessful studies being withheld from publication, that thesis was calculated statistically: 14,268 negative studies would have had to have been conducted and hidden in order to be the sole reason for these positive results [9].

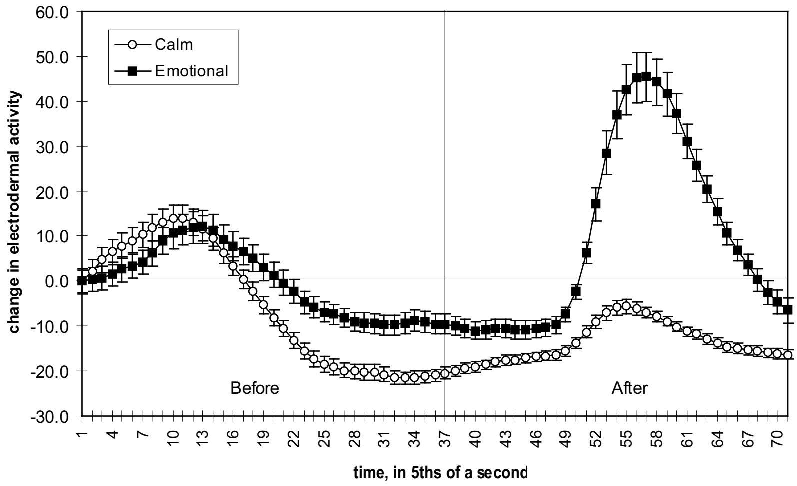


Figure 2. Presentiment experiment, showing differences in subjects' physiology before, not only after, emotional (violent or erotic) images were displayed, as compared to calm images [10].

the calm pictures. In particular, brain regions near the amygdala (where we process certain strong emotions, including fear and sexual drive) exhibited activation before the violent and erotic pictures were shown, but not before the pleasant and calm pictures [11].

3 Theories

When one considers together these findings about presentiment, precognition, remote viewing and telepathy, at least four generalities emerge, which, therefore, any theory seeking to explain intuition would have to account for:

- From remote viewing experiments, during which some perceivers were separated by thousands of miles from their targets, one observes that the human ability to acquire information intuitively *does not decrease with distance.*
- From presentiment and precognition experiments, it appears that intuition is *not limited by the normal causal relations of time* (since the cause of the perceivers' knowledge or emotions took place only after their response was measured).

- From the shielding of recipients by Faraday cages and steel walls during telepathy experiments, it seems fairly certain that *electromagnetism cannot be the 'carrier wave'* for intuitive information traveling between persons.
- The skill of intuition appears to be more developed in some persons than in others, and can vary over time, so it therefore may be an inherent skill, like athletic or musical ability.

During the past one hundred years of research, many theories have been proposed to explain how intuitive information transfer might be possible. Very often, those theories — as typically occurs in the development of any science — 'borrow' a mechanism better understood in another area of science to try to explain the phenomenon at hand. For example, in the 1930s a theory was put forward that telepathy was 'mental radio' [12], building upon the recent discovery that radio waves could be modified to carry information over long distances.[d]

In our day, theorists have borrowed models from quantum physics, special relativity, and holography (the science of holograms) in their attempt to explain the characteristics of intuition observed in the laboratory data. For example, because of intuition's apparent independence of distance, theorists have explored the quantum phenomenon of entangled non-locality. And because of intuition's independence of forward-only time, they have delved into elaborations of Einstein & Minkowski's space-time model. In an attempt to account for intuition's access to information about seemingly any location, theory-builders have explored the holographic principle, by which information about the whole can be contained in any of its minute parts.

The remainder of this article examines those theories, organized into the three categories we used when considering the empirical studies:

(i) intuition between one person and another — or, using mathematical symbols, when A acquires information concerning B:

$$A \leftarrow B$$

(ii) intuition that involves A acquiring information about a place or locale (L):

$$A \leftarrow L$$

[d]Since that time, as we've already mentioned, the use of Faraday caging has shown that electromagnetic signals, including radio waves, cannot be the main carrier of intuitive information.

(iii) intuition whereby A acquires information now (at time T_1) about the future (time T_2):

$$A_{T_1} \leftarrow X_{T_2}$$

None of these theories yet claims to have been proven. Rather, they are based on some empirical work already done, and they point to the kinds of empirical investigations that might fruitfully be undertaken in the near-term future.

3.1 One theory component: Receiving from another person [$A \leftarrow B$]

In order to account for the effect 'healers' were observed to have on their target subjects (as in the experiments of Schlitz & Braude [5] described in Sec. 2.1) and to account for other forms of mind-to-body and mind-to-mind transmission, Professor William Tiller of Stanford University's Department of Materials Science and Engineering (Palo Alto, California) has extended the particle-wave duality discovered by modern physics into a larger theory that posits two types of sub-space in our universe:

(i) a 'coarse, *particulate*' subspace, in which electric charge plays a key role, and
(ii) a 'fine, information *wave*' subspace, in which magnetic force plays a key role [13].

The first subspace is our familiar world of physical matter, which science describes mathematically by using distance and time coordinates. Dr. Tiller calls this familiar realm Direct (or 'D') subspace. The other, which he calls Reciprocal or R-subspace, is a portion of the realm described by quantum physics as the 'vacuum', from which particles continually emerge and into which particles continually disappear (although Tiller cautions that R-subspace is only the 'coarsest' level of the vacuum, not its entire domain).

Electromagnetism (e.g., light, heat, cosmic rays, etc.) plays a central role in both subspaces, but with inverse characteristics: whereas *electricity* can exist in our D-subspace as a monopole (that is, a negative electric charge can exist on a particle without that particle also having to contain a corresponding positive electric charge), a *magnetic* monopole (that is, a 'north' magnetic pole existing on a particle without a corresponding 'south' magnetic pole) can not. This results in the fact that we observe electric *currents* (flows of particles carrying solely negative electric charges) in our daily world, but we don't observe magnetic currents (which would be flows of solely north-charged, or solely south-charged, units). However, in

R-space, magnetic currents and monopoles do exist, hypothesizes Tiller, building on the physics and mathematics of Harmuth [14] and Barrett [15] who resolved long-standing problems inherent in Maxwell's equations of electromagnetism by introducing into those equations *magnetic current density*, and by building on the work of Seiberg & Witten [16] who found that key singularities in quantum field theory also could be eliminated by the introduction of magnetic monopoles. The relevance to intuition enters at this point: just as information is transmitted over long distances in our familiar D-subspace on carrier waves of electromagnetism (radio, visible light, etc.) at the speed of light (the velocity c), in Reciprocal subspace, information can be transmitted at much higher speeds, up to c^2, on carrier waves of magneto-electrism [13]. Human intention and emotion, Tiller has observed in the laboratory [17], can modulate such magnetic waves traveling through R-space, which then, one proposes, could be received and decoded by another human to correctly report what had been in the mind of the 'sender'.

But how could human intention, emotion, and other characteristics of mind cross from our familiar domain into the hardly-ever-measured domain where magnetic currents might be traveling? While R-space, like the rest of the vacuum of which it is one part, is normally chaotic (entropic), its chaos/entropy seems to be reduced (i.e., its symmetry apparently increases) in the vicinity of human individuals when those individuals move themselves into more coherent (e.g., meditative) states [18,19]. Once in that more symmetric state (estimated as being greater than the U(1) and significantly towards the SU(2) Gauge symmetry level [20,48]), magnetic waves can be propagated into R-space by the human mind, modulated by (and therefore carrying) the information-content of the sender's mind, as detailed by the precise Fourier transform equations[e] which the human brain has been empirically observed to use to encode its visual — and perhaps other — experiences [21–23]. In this way, the image in the mind of the sender is encoded into magnetic wave-forms that spread out from that person at great speed.

To illustrate the considerable power which humans possess to propagate such electromagnetic (and theoretically, magnetoelectric) waves, Tiller cites the laboratory measurements taken by Dr. Elmer Green and his colleagues at the Menninger Clinic (then in Topeka, now in Houston, USA). That team found healers' output of electrostatic charges to be fully 103 times

[e]The Fourier transform is a mathematical representation of images in terms of frequency, magnitude, phase, and orientation, rather than mapping the images as bits or pixels.

greater than the average person's galvanic skin response, 105 times greater than the average electrocardiogram (heart) voltage, and 106 times greater than the average electroencephalogram (brain) voltage [24]. To this Tiller adds empirical evidence which implies that parts of the human anatomy may function at the SU(2) level of Gauge symmetry [25], the coherence level he predicates as enabling the generation of magnetic carrier waves.

When the mind of a second person, the 'receiver', is impinged upon by such encoded magnetic waves, it responds instinctively to apply the Fourier transform that it uses for many forms of perception, thereby decoding the waveform and hence becoming aware of the image that resided in the sender's mind. The telepathic transmission is thereby accomplished.

3.2 A second theory component: Perceiving other locales [A ← L]

The same Fourier transform equation has also made possible the industrial creation of holograms: 3-dimensional projections from 2-dimensionally-stored data. Dr. Edgar Mitchell (Institute of Noetic Sciences, USA) and Dr. Peter Marcer (British Computer Society, UK) combine this efficient information-storage capacity of the hologram with the observed phenomenon of quantum non-locality to propose a theory of how an individual can perceive objects or locations at great distances, even when there is no 'sending' human mind at that location to encode the image onto putative magnetic waves [26,27].

Marcer points out that any wave field (be it acoustic, electromagnetic, quantum mechanical, or other) that impinges upon a physical object, has parts of its amplitude and phase altered because of that impact [28]. This occurs not only because a portion of the wave gets reflected back from the surface of the object, but also because portions of the wave get *absorbed* by the object. Thirdly, as a result of that absorption, the object may be energized to emit a wave back outward, at least part of which may travel towards the source of the first wave. All three of these facts result in a communication of information returning to the source of the initial wave which conveys directly, through the spectral Fourier transform of holography, attributes of the object that was impinged, including its shape, color, temperature, substance, etc.

Citing Walter Schempp's elucidation of the successful focusing of such quantum level information into meaningful images as achieved by devices that perform Magnetic Resonance Imaging (MRI) [29], Mitchell points out that the information conveyed by a returning wave (in particular its particles' spin numbers and their polarization [26, p. 300]), inevitably reveal the object's internal and microscopic, not merely its external and macroscopic, features. In cooperation with Schempp, Marcer developed a model of how the human neuron may process such quantum-level information [30], and also how the assembly of neurons we call the brain might bring that information into useful awareness [31].

In their models, Marcer and Schempp emphasize that the human neural system can retrieve quantum-holographic information from an external object only because it establishes a 'phase conjugate adaptive resonance' with that object [27, pp. 158–160]. By this they mean that the neural system combines the incoming wave with its own wavelets optimized to reconstruct the interference pattern that initially established information into the wave field when it interacted with the external object. Marcer and Mitchell postulate that this human-generated resonant frequency also functions as an *outgoing* wave (which is experienced subjectively by the individual as 'paying attention to', attending to, the external object). As evidence that human attention can be a physically consequential force when directed externally, Mitchell cites laboratory data from thousands of trials, at first pioneered by Helmut Schmidt at Boeing Laboratories and then developed further by Drs. Robert Jahn and Brenda Dunne at Princeton University, in which focused human attention apparently altered the behavior of random-event mechanisms, both material and electronic [32,33].

When brought together, all this may explain remote viewing, as follows:

(a) An individual calms his normal, thinking mind and directs his mental attention towards a particular location (not visible to his eyes).
(b) That act allows the individual's neural system to establish a phase conjugate adaptive resonance with the quantum-mechanical level of objects at the distant location.
(c) So long as that vibratory resonance is maintained, the individual's neural structures can apprehend holographic information available through quantum entanglement.
(d) The holographic information is converted by the brain through a Fourier transform process into visual imagery and other sensations.
(e) The individual sketches and/or verbalizes the imagery and sensations, thereby giving to other persons a report on the scene at the remote location.

Unlike the model of Tiller and Dibble described in Section 3.1, this model does not invoke magnetic waves as the means of transmission from the source to the receiver's mind. Instead, it insists on quantum-nonlocality as the basis for the remote viewer's connection to the distant location. Nevertheless, both models are happy to incorporate the known use by the brain of Fourier transforms, in their explanation of its processing of (the remote) perceptions.

3.3 A third theory component: Perceiving other times [$A_{T_1} \leftarrow X_{T_2}$]

Probably the toughest job in theory-proposing with regard to the laboratory data reported in Sec. 2, is the challenge of explaining the cause-and-effect dynamics that could lead to precognition and presentiment. Frankly, what could account for a person's body or mind correctly knowing what a randomized computer process will be generating in the future?

Not shrinking from this challenge, Dr. Elizabeth Rauscher and physicist Russell Targ (Bay Research Institute, California) have offered an extension of relativity theory's Einstein-Minkowski 4-dimensional space-time into eight dimensions, in order to explain such events [34]. They conceive of the four additional dimensions as counterparts to the four traditional ones, so they have mapped out three additional space dimensions and one additional time dimension.

Mathematically, these four new dimensions they designate by multiplying the original dimensions (x, y, z and t) by the square root of -1 (conventionally symbolized as the coefficient i). This has the consequence that between any two points in the 8-dimensional space-time universe[f] there is always a path that has zero units of separation. In near-layman's language, *non-locality* is thereby demonstrated to be true of *time*, not just of space. So any two points in time can become adjacent: for instance, something that will happen in the future we can be aware of now. And that is what the laboratory experiments on presentiment and precognition seem to confront us with.

Rauscher and Targ's eight-dimensional space-time metric does not violate any of the equations of Maxwell, Einstein, or Schrödinger. Indeed, one might appreciate the Transactional Interpretation of quantum mechanics [35,36] as *requiring* the kind of attention to connections between the 'future' and the present which Rauscher and Targ have explicated. As the

[f] The authors point out that eight is the *minimal* number of dimensions required, if nonlocality — demonstrated empirically by Aspect and Gisin — is to be consistent with the Poincaré and Lorentz invariances.

Polish theoretical physicist Bialynicki-Birula insists:

> The very structure of all quantum theories suggests... that *two copies of space-time*, rather than one, are the proper arena for all quantum processes.... Every set of equations and formulae in quantum theory, from which all the transition amplitudes are determined, may always be written in two equivalent forms, differing by *complex conjugation*. We obtain one set from the other *by reversing the sign of the imaginary unit i*. [37]

So for physics' own needs, not just for accommodating the data on human intuition, it would seem necessary to adopt 8-dimensional complex space-time into fundamental theory.

3.4 A fourth theory component: Registering the perceptions into waking consciousness [the 'biology of intuition']

Already, some of the theories we examined in Secs. 3.1–3.3 included hypotheses about how the human neural system might decode and make available to the conscious mind the information that was acquired during intuitive experiences like telepathy and remote viewing. For example, more than one theory included the Fourier transform process, by which the human neural system has been empirically observed to encode 3-dimensional experience into easily stored and retrieved holographic markers [21–23]. As a completion to this article, we mention five physiological components that have been identified as possibly participating in the pathway of intuitively-acquired information, from the boundary of the receiver's body into that person's conscious awareness.

3.4.1 Meridian points and channels

Recalling the Tiller-Dibble model of information traveling from one mind to another on superluminal magnetic waves (Sec. 3.1), such waves could only be detected, according to that theory, by portions of the receiving human body that could develop an SU(2) level of Gauge symmetry or coherence. Tiller has identified the acupuncture meridian system as one such portion of the human body [25]; and empirical measurements of the skin locations traditionally identified by Chinese medicine as acupuncture points do indeed reveal an electrical conductance 20 to 40 times greater than all other regions of the human skin [38]. These locations, then, could logically be where magnetoelectric waves might most easily enter the body, to be decoded subsequently, perhaps, by other biological structures.

3.4.2 DNA as transducer

As chief nominee to be one of those other structures, some investigators have proposed the DNA molecule that is present in the nucleus of every cell. Those authors point out that DNA's characteristic double-helix structure makes it intriguingly apt to participate in information transfers:

(i) The molecule's longitudinal configuration might allow it to function as a *blade antenna* in response to incoming electrical waves;
(ii) simultaneously, the molecule's circular shape (when viewed on-end) might allow it to function as a *ring antenna* in response to incoming magnetic waves. (So far, (i) and (ii) are speculations [39]).
(iii) Some empirical evidence indicates that the DNA molecule can, in effect, 'store' information impinging on it from electromagnetic waves by vibrating as a solitonic wave, and then can release that same information, carried on its own generated, coherent light [40].
(iv) The 90% of the DNA molecule which does not contain genes for protein synthesis exhibits the mathematical characteristics of language (syntax, grammar, etc.), suggesting to some investigators that information might also be stored and transferred at that level [41].

3.4.3 Neuronal microtubules

Alternatively, if intuitive information does not arrive on superluminal magnetic waves as Tiller and Dibble have proposed, but is instead apprehended through quantum-hologram phase resonance as Mitchell, Marcer, and Schempp have proposed (Sec. 3.2), then the transduction may occur as British mathematical physicist Roger Penrose and American anesthesiologist Stuart Hameroff have suggested: nerve cells contain microscopic structures, called 'microtubules', which can respond consistently to changes at the quantum level [42]. The particular neuron experiencing those changes can then communicate its response through 4-nanometer-sized gap junctions to adjacent neurons, thereby amplifying the original quantum event to a many-neuron synchronized discharge and sending that on to areas of the brain involved in conscious awareness.[g]

[g]Hameroff and Penrose have responded to colleagues' objections that the brain is too 'wet, warm, and noisy' to permit coherent utilization of quantum events as information carriers, by directing critics' attention to the finely-tuned cycle by which actin gels emerge and effectively shield the critical microtubule regions from thermal decoherence.

3.4.4 Cranial processing

Once the neuronal microtubules, DNA, or other transducing structures have converted the magnetically or quantum carried information into conventional neural impulses, those signals can travel to the brain for processing. Empirical measurements gathered by Dr. Rollin McCraty and his colleagues at the HeartMath Institute in California reveal the brain's frontal lobes to play an active part in this neural journey of intuitive information [43][h] — as did previous research conducted by neuroscientists Norman Don and Charles Warren [44,45].

Experientially, people sometimes report that intuitive information first emerges into their awareness as a vague *sensation*, then becomes a partially-focused *image*, and finally (if ever) becomes specific enough to be put into *words* [46,47]. This movement from sensation or image into words has been correlated with brain processes proceeding from the right hemisphere into the left (via the corpus callosum). Significantly, once the information has traveled into the left hemisphere, we also frequently experience our critical, judgmental faculty (which also seems to be coordinated primarily by the left hemisphere) raising doubts about the validity of the image or sensation. An assessing dialogue then ensues, at the end of which we either decide to accept the image/sensation (or at least to report it to others while maintaining our own skepticism), or to reject the information — especially if we feel uncomfortable being unable to fit it into our pre-existing expectations, or our worldview.

3.4.5 Also the heart

Between the neurons of the body and the lobes of the brain, significant activity takes place in the heart's neural system during at least some forms of intuitive perception-processing. Dr. McCraty and his colleagues observed consistent changes in heart rhythms *prior* to changes in the brain's frontal lobes, in persons exhibiting receipt of presentiment intuition [43]. Subsequently, EEGs indicated that the heart's changes were being signaled to the brain, which suggests that the heart could function either as a perceiver or a transducer of intuitively-acquired information for the brain. Research continues in order to clarify the apparently complex relationship between the heart, brain, and intuitive processing.

[h]Men differ from women in this respect, involving not only their frontal lobes but also portions of their occipital, temporal, and to a lesser extent parietal lobes in the processing of intuitively-acquired information [43, p. 330].

4 Conclusion

Although the scientific study of intuition has not yet migrated into the mainstream of academic psychology, many decades of empirical work would seem to have earned its investigators the right to assert that several forms of intuition have been confirmed as real phenomena, and are widespread among the populace. As for developing a theory to explain the findings, mechanisms from fields quite outside the conventional models of academic psychology would seem to be necessary, if one wishes to establish a precise chain of cause-and-effect steps in the occurrence of intuitive perception and intuitive communication. The field of physics presently appears to offer the most fertile explanatory hypotheses, partly because of its experience of grappling with the phenomena of information transfer and time, and also because of its familiarity with using mathematics to map realities that our more culturally-limited verbal apparatus recoils from.

Acknowledgement

I am very grateful to Dr. Metod Saniga for inviting me to participate in the interdisciplinary symposium for which this article was written.

References

1. Radin, D. (1997) *The Conscious Universe*, HarperEdge, San Francisco, pp. 65, 93.
2. Babbie, E. (1975) *The Practice of Social Research*, Wadsworth, Belmont (CA), pp. 82–83.
3. Rhine, J., *et al.* (1966) *ESP After Sixty Years*, B. Humphries, Boston, pp. 95–105.
4. Tart, C. (1963) Physiological correlates of psi cognition, *International Journal of Parapsychology* **5**, 375–386.
5. Schlitz, M., and Braude, W. (1997) Distant intentionality and healing: Assessing the evidence, *Alternative Therapies* **3**, 62–73.
6. Radin, D. (1997) *Op. cit.*, pp. 87–88.
7. Puthoff, H. (1996) CIA-initiated remote viewing program at Stanford Research Institute, *Journal of Scientific Exploration* **10**, 63–76
8. May, E. *et al.* (1988) *Review of the Psychoenergetic Research Conducted at SRI International 1973–1988*, SRI International, Palo Alto (CA).
9. Honorton, C., and Ferrari, D. (1989) Future-telling: A meta-analysis of forced-choice precognition experiments, 1935–1987, *Journal of Parapsychology* **53**, 281–308.
10. Bierman, D., and Radin, D. (1997) Anomalous anticipatory response on randomized future conditions, *Perceptual and Motor Skills* **84**, 689–90.
11. Bierman, D., and Scholte, H.S. (2002) An fMRI brain imaging study of presentiment, *Journal of the International Society of Life Information Science* **20**, 380–388.

12. Sinclair, U. (1930) *Mental Radio*, Upton Sinclair, Pasadena (CA).
13. Tiller, W. (1999) Towards a predictive model of subtle domain connections to the physical domain aspect of reality: Origins of wave-particle duality, electric-magnetic monopoles and the mirror principle, *Journal of Scientific Exploration* **13**, 41–67.
14. Harmuth, H. (1986) Correction of Maxwell's equations for signals I, *IEEE Transactions on Electromagnetic Compatibility* **28**, 250.
15. Barrett, T. (1988) Comments on the Harmuth Ansatz: Use of a magnetic current density in the calculation of the propagation velocity of signals by amended Maxwell theory, *IEEE Transactions on Electromagnetic Compatibility* **30**, 419.
16. Seiberg, N., and Witten, E. (1994) Electro-magnetic duality, monopole condensation, and confinement in N=2 supersymmetric Yang-Mills theory, *Nuclear Physics B* **426**, 19–52.
17. Tiller, W., and Dibble, W. (2004) Towards general experimentation and discovery in 'conditioned' laboratory spaces — Part III: A theoretical interpretation of non-local information entanglement, preprint `www.tillerfoundation.com/PaysonTheoryIII.pdf`.
18. Tiller, W., and Dibble, W. (2001) New experimental data revealing an unexpected dimension to materials science, *Materials Research Innovations* **5**, 21–34.
19. Dibble, W., and Tiller, W. (1999) Electronic device-mediated pH changes in water, *Journal of Scientific Exploration* **13**, 175 (Appendix A).
20. Tiller, W., and Dibble, W. (2002) Anomalous temperature oscillation behavior near a 'source' in a 'conditioned' space — Part II: A bi-conformal base-space theoretical interpretation, preprint `www.tillerfoundation.com/AnomalouspartII.pdf`.
21. De Valois, R. and De Valois, K. (1990) *Spatial Vision*, Oxford University Press, New York.
22. Pribram, K. (1991) *Brain and Perception: Holonomy and Structure in Figural Processing*, Lawrence Erlbaum Assoc., Hillsdale (NJ).
23. Pribram, K. (2004) Consciousness reassessed, *Mind and Matter* **2**, 7–35.
24. Green, E., *et al.* (1991) Anomalous electrostatic phenomena in exceptional subjects, *Subtle Energies and Energy Medicine* **2**, 69.
25. Tiller, W. (2004) Subtle energies and their roles in bioelectromagnetic phenomena, in P. Rosch (ed.), *Bioelectromagnetic Medicine*, Dekker, New York, pp. 159–192.
26. Mitchell, E. (2000) Nature's mind: The quantum hologram, *International Journal of Computing Anticipatory Systems* **7**, 295–312.
27. Marcer, P., and Mitchell, E. (2001) What is consciousness?, in P. van Loocke (ed.), *The Physical Nature of Consciousness*, John Benjamins, Amsterdam–Philadelphia, pp. 145–174.
28. Marcer, P. (2004) Status of the mission, Cybernetic Machine Specialist Group, British Computer Society, preprint `www.bcs.org.uk/siggroup/cyber/status.htm`.

29. Schempp, W. (1992) Quantum holography and neurocomputer architectures, *Journal of Mathematical Imaging and Vision* **2**, 109–164.
30. Marcer, P., and Schempp, W. (1997) Model of the neuron working by quantum holography, *Informatica* **21**, 519–534.
31. Marcer, P., and Schempp, W. (1998) The brain as a conscious system, *International Journal of General Systems* **27**, 231–248.
32. Schmidt, H. (1970) Mental influence on random events, *New Scientist and Science Journal* **50**, 757–8.
33. Jahn, R., and Dunne, B. (1987) *Margins of Reality: The Role of Consciousness in the Physical World*, Harcourt Brace Jovanovich, New York.
34. Rauscher, E., and Targ, R. (2001) The speed of thought: Investigation of a complex space-time metric to describe psychic phenomena, *J. Sci. Explor.* **15**, 331–354.
35. Cramer, J. (1986) The transactional interpretation of quantum mechanics, *Reviews of Modern Physics* **58**, 647–688.
36. Price, H. (1996) *Time's Arrow & Archimedes' Point: New Directions for the Physics of Time*, Oxford University Press, Oxford–New York.
37. Bialynicki–Birula, I. (1986) Transition amplitudes versus transition probabilities and a reduplication of space-time, in R. Penrose and C. Isham (eds.), *Quantum Concepts in Space and Time*, Clarendon Press, Oxford, p. 226.
38. Reichmanis, M., *et al.* (1975) Electrical correlates of acupuncture points, *IEEE Transactions on Biomedical Engineering* **22**, 533–536.
39. Fosar, G., and Bludorf, F. (2004) The biological chip in our cells, preprint `www.fosar-bludorf.com/archiv/biochip_eng.htm`.
40. Gariaev, P., *et al.* (2000) The DNA-wave biocomputer, *Fourth International Conference on Computing Anticipatory Systems*, Institute of Mathematics, University of Liege, Belgium.
41. Mantegna, R., *et al.* (1994) Linguistic features of non-coding DNA sequences, *Physical Review Letters* **73**, 3169–3172.
42. Hameroff, S. (2000) Biological feasibility of quantum approaches to consciousness, in P. van Loocke (ed.), *The Physical Nature of Consciousness*, Amsterdam–Philadelphia, John Benjamins, pp. 1–61.
43. McCraty, R., *et al.* (2004) Electrophysiological evidence of intuition — Part 2: A system-wide process?, *Journal of Alternative & Complementary Medicine* **10**, 325–336.
44. Don, N., *et al.* (1998) Event-related brain potential (ERP) indicators of unconscious psi, *Journal of Parapsychology* **62**, 127–145.
45. Warren, C., *et al.* (1992) Event-related brain potential changes in a psi task, *Journal of Parapsychology* **56**, 1–30.
46. Welling, H. (2005) The intuitive process: The case of psychotherapy, *Journal of Psychotherapy Integration* **15**, 19–47.
47. Puthoff, H., and Targ, R. (1976) A perceptual channel for information transfer over kilometer distances, *Proceedings of the IEEE* **64**, 345–346.
48. Aitchison, I., and Hey, A. (1989) *Gauge Theories in Particle Physics*, Institute of Physics Publishing, Bristol–Philadelphia, pp. 249–280.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 507–530

OUT-OF-BODY, OUT-OF-TIME. ABNORMAL UNITY OF BODY AND SELF IN SPACE AND TIME

SHAHAR ARZY,[1,2,3] THEODOR LANDIS[3] and OLAF BLANKE[1,3a]

[1]*Lab. of Cognitive Neuroscience, École Polytechnique Fédérale de Lausanne (EPFL) 1015 Lausanne, Switzerland*

[2]*Dept. of Neurology, Hadassah Hebrew University Hospital, Jerusalem, Israel*

[3]*Department of Neurology, University Hospital, Geneva, Switzerland (shahar.arzy@hcuge.ch, olaf.blanke@epfl.ch)*

Abstract: Under normal conditions, human subjects experience the self within the limits of the physical body and the limits of the present time. This unified experience of the self in space and time has been challenged by philosophers and physicists. The spatial unity between self and body has also been challenged by a well defined group of experiences called "autoscopic phenomena" (AP), during which subjects have the impression of seeing a second own body in extrapersonal space. Yet, with respect to the three main forms of AP — autoscopic hallucination, heautoscopy, and out-of-body experience — previous studies have concentrated on describing the spatial unity between self and body while neglecting to analyze the temporal unity of self and body. Here we describe several AP-cases with an altered experience of age or time for one's own body or self. In some AP-cases the second own body was seen as being younger or older than the subject's actual body. We show that the second own body is experienced as if "coming from another time" although the observing self is experienced in the present time. Other AP-subjects reported a feeling of timelessness of the observing self without any age difference between the subjects' actual and illusory body. We argue that these differences in age or time suggest that the temporal experience of one's own body and self is altered in these subjects. Collectively, these data suggest that AP may be associated not only with abnormal sensations with respect to spatial unity, but also with respect to temporal unity. Moreover, we found that out-of-body experiences were associated with feelings of timelessness and no age differences between self and body and that autoscopic hallucinations and heautoscopy were associated with age differences between self and body but not with feelings of timelessness. We conjecture that out-of-body experiences are characterized by disembodiment not only in space but also in time. For autoscopic hallucinations and heautoscopy our findings suggest that the spatial displacement between self and body (without disembodiment) is accompanied by a temporal displacement of the body to a different time period than the present. We discuss these abnormal experiences of the bodily self in time and space and propose their potential functional and anatomical mechanisms.

Keywords: Autoscopic Phenomena – Out-of-Body Experience – Out-of-Time Experience – Temporo-Parietal Junction

[a]Corresponding author.

1 Introduction

The self as an entity distinct from other human conspecifics may be described as an enduring and spatial entity (i.e. the feeling that one is the same person across time and space) to which certain mental events and actions are ascribed (i.e. the feeling of agency; being author of one's own thoughts and actions) and which is distinct from the environment [1]. Moreover, humans experience themselves to be located in a specific moment ("the present moment") and in a specific place ("the present place") [2]. Bermudez [3,4] suggested to define such a fundamental behaviour [5] in space and time as "non-conceptual", proposing that the behaving agent does not possess the concepts required to be aware of the contents of space and time.[a]

The many concepts of "self" have been influenced by theology, philosophy and psychology [6–9], but also by clinical observations from neurology and psychiatry [1,10–13]. Thus, several clinical conditions have been described during which the spatial or temporal self location is disturbed. With respect to spatial self location, experiences occurring in microgravity such as the inversion illusion during space missions or during the low gravity phase of parabolic flights (an spatial disorientation illusion in which pilots at least temporarily feel as though they are inverted relative to the earth; this illusion can be caused either by gravitoinertial forces or by visual factors; [14–16]) and the room tilt illusion (a transient tilt perception of the extrapersonal visual space on its side or upside down, with respect to a stable observer might be mentioned. Both experiences have also been reported in neurological and otological patients [17–19]). When referring to disturbances of temporal self location, authors have mentioned conditions such as delusional misidentification syndromes (DMS), which include among other reduplifications the reduplification of oneself in time [20,21]. Another clinical condition during which temporal self location is disturbed are spontaneous confabulations (i.e. acting on the basis of previous habits rather than currently relevant memories). These patients have been reported to produce confabulations about themselves that are composed of elements of past true events, present actions and future imaginations [22,23]. Especially relevant to our present investigation about spatial and temporal self processing is the group of clinical phenomena of autoscopic phenomena (AP). AP are generally defined as illusory visual experiences during which the subject has the impression of seeing a second own body in extraper-

[a] Such subject-effected mental states are found in non-linguistic behavior and subpersonal computational constructions (like the Chomskyan approach to syntax) [3].

sonal space associated with varying degrees of separation of the self from the body. [10,13,24,25]. Thus, it has been argued that AP challenge our notions about the experienced spatial unity of self and body, localization of the self, as well as agency [8,26]. Interestingly, in some of these cases it has been reported that the autoscopic body (i.e. one's reduplificated body that is seen during the AP) is experienced as having a different age than the observing subject. Other AP-subjects have also reported a feeling of "timelessness" or changes in the experience of time. Thus, AP seem to challenge common conceptions of our experience of self location not only in space as commonly thought and analyzed, but also in time. The present review analyzes how body and self during AP are experienced with respect to temporal characteristics.

2 Autoscopic Phenomena — Illusions of Body and Self in Space and Time

During most AP a fundamental component of the self is isolated, as the self is not experienced as residing within the limits of one's body. Therefore it has been argued that AP present a valuable advantage to the study of the self [13,27–29]. Nevertheless, during the last century studies of AP are still rare in the neurological and scientific literature [10,13,30–35].

Three distinct forms of autoscopic phenomena have been defined (Fig. 1): (1) Autoscopic hallucination (AH): the experience of seeing a "double" of oneself in extrapersonal space viewed from the own physical body, i.e. in an AH the subject feels his "self" or center of awareness within the physical body [10,13,34]. (2) Out-of-body experience (OBE): the experience or feeling that the center of awareness is located outside of the physical body. The subjects experience seeing their body and the world from an elevated extrapersonal location that differs from their habitual position. Their perceptions are thus organized in such a way as to be consistent with this elevated visuo-spatial perspective [13,32,33]. (3) Heautoscopy (HAS): an intermediate form between AH and OBE. During HAS the subject also sees his double in extrapersonal space, but it may be difficult for the subject to decide whether he is disembodied or not or whether the self is localized in the physical or the double's body. In addition, subjects may experience the world from two simultaneous or alternating visuo-spatial perspectives: the habitual physical visuo-spatial perspective and an additional extracorporal perspective [13,35]. Despite of the association of AP with a wide range of neurological diseases such as epilepsy, migraine, neoplasm, infarction, and infection [33,34], they have also been reported in the general population, in

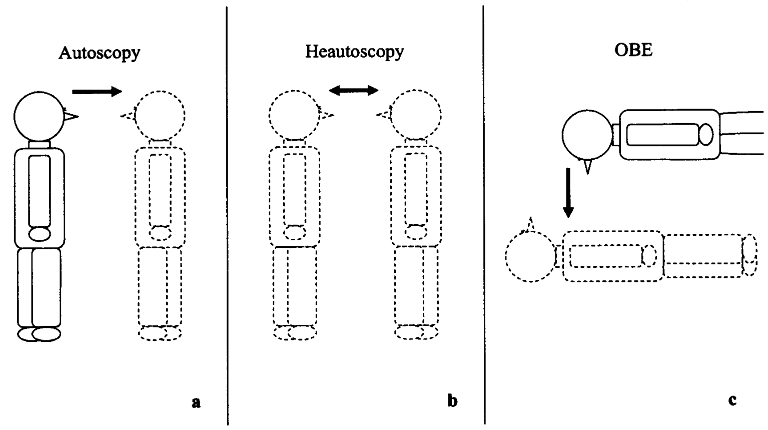


Figure 1. *Phenomenology of Autoscopic Phenomena (AP). a) Autoscopic hallucination (AH)*: experience of seeing one's body in extracoporeal space (as a double) without disembodiment (experiencing the self as localized outside one's physical body boundaries). The double (right figure) is seen from the habitual egocentric visuo-spatial perspective (left figure). *b) Heautoscopy (HAS)*: intermediate form between autoscopic hallucination and OBE; the subject experiences to see his body and the world in an alternating (or simultaneous) fashion from an extracorporeal and his bodily visuo-spatial perspective; often it is difficult for the subject to decide whether the self is localized in the double or in one's own body. *c) Out-of-Body Experience (OBE)*: During an OBE the subject appears to "see" himself (bottom figure) and the world from a location above his physical body (extracorporeal location and visuo-spatial perspective; top figure). The self is localized outside one's physical body (disembodiment). The directions of the subject's visuo-spatial perspective during the AP is indicated by the arrows. Solid line represents the subject's point of view, dash line represents the "double".

approximately 10%, where they occur only once or twice in a lifetime [27].

The above classification refers to AP by systematically describing the experienced position of one's body and self in spatial terms. Yet, one could not only analyze *e e* the subject experiences the double (or autoscopic body) to be localized (i.e. in a different location in extrapersonal space with respect to the experiencing subject), but also *e* in time the subject experiences the double to be localized (i.e. is the double experienced as being younger or older than the subject; is the double localized in the present or not). In fact, there have been reports that the autoscopic body looks older or younger than the actual body of the subject during the AP and subjects have described these doubles to "come" from the past (younger double) or from the future (older double). Other subjects have not reported age-differences between autoscopic and physical body, but rather feelings of timelessness during the AP. As age-differences between autoscopic and physical body and feelings of timelessness in subjects with AP have not been systematically analyzed we decided to carry out such an analysis in the present study.

3 Neuro-Phenomenology

This chapter describes 20 cases of APs from the literature with abnormalities in the experience of time with respect to the patient's body and self. We quote and summarize the description of each subject and classify the experience with regard to spatial and temporal body and self location. Our analysis includes AP-cases from neurology and psychiatry, as well as healthy subjects.

3.1 Sivadon ([36], observation no. 1; HAS, AH)

A 50 year-old patient with influenza. In his first autoscopic experience he reports:

> He became "two men: one who is walking and another who is lying on his bed and watches the other man". He knew himself perfectly and was not surprised. Some days afterwards he had another experience: "I saw in front of me *a* [illegible], *a* [illegible], nevertheless without strength, trying to get dressed, putting on his clothes with uncoordinated movements. And slowly I recognized myself in this silhouette, I recognized my hair and my face".[b]

In the second event this patient saw a young man in front of him. He did not recognize this young man immediately as he himself. He noticed the "painful" behaviour of his double, and characterized it as "half-sleeping". We classified this experience as AH since the autoscopic body appears in front of the subject, with no depersonalization [10], and no disembodiment or floating as in OBE. The first experience of the patient was classified as heautoscopy, since he had experienced himself simultaneously as "two men".

3.2 Lhermitte ([37]; AH)

> A middle-aged man recovering from a severe myocardial infarct. Several days after the infarct the patient revealed a dream which

[b]Cases 3.1 – 3.4 have been translated by the authors.

> he saw himself walking effortlessly. Suddenly he found himself in the presence of a person who turned his back on him, but he immediately recognized him, since this person was he himself; *e e d e e e e e de* , with worn-out clothes and an uncertain gait. “I said to myself, counting my disease, ‘like you here become old and handicap on the doorstep to the grave you are going to finish miserably’”.

The patient emphasizes the old age of his double, which he interprets as a clue to his destiny, caused by the disease. It is not clear if this experience occurred during dreaming, as a hypnagogic or hypopompic hallucination or during wakefulness. However, the description is of AH as the patient sees his double from the original body’s point of view, with no disembodiment or depersonalization. Despite of the age difference and the back-view, the patient immediately recognizes the double as himself.

3.3 Hécaen and Ajuriaguerra ([31], observation no. 78; AH)

A 45 years old man with post traumatic stress disorder, without known brain damage or physiopathology. He describes his autoscopic experience:

> “I am sitting at a table, and I have beside me or in front of me, another self [moi-même], who sits down and actually speaks to me, this is my double, I have the impression to see him materializing before me, in general this double speaks to me to tell me that I have messed up my life, and he calls me “you”, he sits in the chair in front of my desk [. . .] I had the impression of seeing myself in a mirror, he thought like I did, but criticized me heavily, I have the impression that this is somebody else who knows me well, it is not me in front of me, but physically it is the same [. . .] *e a e a e ce e e a , e ee e a e , e a e* At this moment I had the impression to be in a situation like if I was in an unreal play [. . .] In these moments I believed the reality of the double”.

The double is explicitly described as being younger than the patient. The double is speaking to the subject, and his younger voice is the first clue for the patient concerning the age differences between the autoscopic and physical body. Despite the immediate recognition, internally the subject feels strange to the personality of the double. We classified this experience as AH, since the “double” is described as “separated” from the body and there is only a weak affinity between the physical and autoscopic body. Also there is no description of depersonalization or disembodiment. The patient refers to mirror reflections to describe his experience of the autoscopic body, as has also been employed by other patients with AH (i.e. [38–40]). The subject is sitting in his chair, and so is the double.

3.4 Schmidt ([41]; AH)

> A woman of 35 years old, epileptic. At the moment when she woke up from a seizure, the patient saw [. . .] in front of her somebody who looked exactly like herself "like she was completely , and charming" who ran away, laughing. She tried to catch her, but failed and fell down.

This short passage describes an appearance of a younger autoscopic body, who runs away from the physical body. The experience is of AH as the patient experiences neither depersonalization nor disembodiment and sees her double in front of her. The double is exactly like the patient but "completely young". The double is in standing position, running away from the patient. The patient is trying to run after her young double.

3.5 Green ([42]; 11 OBE-cases)

37.3% of Green's healthy OBE-subjects reported a change in their experience of the passage of time. This change was mostly described as if time did not exist or as if time passed more slowly or faster than usual. These abnormal experiences of time might overlap to a certain extent. Below we give the eleven cases that Green [42] has described.

> 1. "While I was out of my body there *a e a a*, but once I had regained myself I realized the experience had taken few seconds."
> 2. "I omitted to mention the actual time that this experience took. It could have been minutes or hours, *e e a e a e.*"
> 3. "I had *dea e.*"
> 4. "There was a sense of *e e e*."
> 5. "The sensation was of a *e a*."
> 6. "*T e ee a d*"
> 7. "*T e cea e e*"
> 8. "I did *ce e a a e e* at all: I think *a e e c e e e ded a e a e ce e*"

> 9. “I was climbing a hard new route when a big block that I was holding on to came off and I fell down 90’ [. . .] on that occasion I felt that I was watching from below and *e ee ed a e .* .”
> 10 “I *e a e e e* completely and feel afterwards that it has lasted hours but actually it is only a few minutes.”
> 11. “It all seemed to take long time but it could be one second or less, because *, , e eed ,* ”

Of the eleven subjects reported by Green, 63% (n=7) mention a feeling of “timelessness”, 18% (n=2) report an experience of slowing of time-passage, and 9% an experience of accelerated time (n=1). 9% (n=1) combine the two experiences with slowing of time following timelessness. Also note that in case 9, the experience of slowing of time was closely associated with disembodiment (“watching from below”). Thus the disturbance of the spatial and temporal unity between body and self were associated. No age differences were reported between autoscopic and physical bodies.

3.6 Moody ([43], case 1; OBE)

Moody claims that “almost everyone [of his subjects] remarks upon the timelessness of this out-of-body state [. . .] time was not really an element of their experience as it is in physical life”, as in the following report:

> I lost control of my car on a curve and the car left the road and went into the air [. . .] at that point *d e e e* and I lost my physical reality as far as my body is concerned — I lost touch with my body. My being or my self or my spirit, or whatever you would like to label it, I could sort of feel it rise out of me, out through my head. And it wasn’t anything that hurt, it was just sort of like a lifting and being above me [. . .] it seemed then as though time were standing still. At the first and the last of the accident, everything moved so fast, but this one particular time, sort of in between, as my being was suspended above me and the car was going over the embankment, it seemed that it took the car a long time to get there, and in that time I really wasn’t to be involved with the car or the accident or my own body. . .

This description includes two characteristic elements of OBEs, disembodiment and elevated visuo-spatial perspective, but not explicit mentioning of autoscopy. The feeling of timelessness, described in the beginning of the experience, becomes in the continuation a feeling of tremendous slowness of the passage of time or fastness of the march of events. Also note that the experience of timelessness closely associated with disembodiment. Paraphrasing the patient we could say that he lost touch with his body and time. No age differences were reported between autoscopic and physical body.

3.7 Moody ([43], case 2; OBE)

> When I came out of my physical body it was like I did come out of my body and go into something else [...] I can't describe it. I was more fascinated with everything around me, seeing my own body there [...] and all this seemed to go so quickly. *T e a ea . a e e e* — and yet it was. *T , ee , a e a e . , e . d..*

The subject describes all three elements of an OBE, extracorporal visuo-spatial perspective, disembodiment, and autoscopy. With respect to time, we see again the combination of timelessness ("time wasn't really an element") with the fastening of the events' passage or slowing of time as here. Again the subject notes that spatial and temporal characteristics between self and body interact by stating that "things seem to go faster after you get out of your body". No age differences were reported between autoscopic and physical body.

3.8 Devinsky et al. ([24], case 9; AH)

> A 32 years old man had simple and complex partial seizures followed by generalized tonoclonic seizures since the age of 8 years. After initial control of 8 years the seizures recurred at age 16 years. The first episode of autoscopy had occurred at this time. The patient described the episode, saying "suddenly, I saw myself about five feet in front of me. My double was mowing the lawn, which is what I should have been doing." He has subsequently experienced autoscopy 15 times. His double is always a transparent, full figure that is slightly smaller than life size. It often *ea d e e c , a e a e* and doesn't share the patient thoughts or emotions. The double is engaged in *a ac . a e a e ee e d e d ,*, and he says, "that guy is my guilty conscience".

Unlike most of Devinsky *e a* 's patients, who mentioned seeing their double in the same clothing they wear at the event, here the clothing is different. The difference in the clothing is a clue to the different age of the patient and his double.[c] We suggest that the age of the autoscopic body might rather be slightly older than the physical body as the patient experiences the double carrying out activities that the patient feels he should be doing (in the future). The patient relates his guilty conscience as the cause of the double's appearance. The episode described here is classified as AH, as the patient describes seeing a double in front of him, while there is neither disembodiment, nor depersonalization.

3.9 Blackmore ([44]; OBE)

OBEs may also be part of Near-Death-Experiences (NDEs) [43,44]. Next to OBEs, NDEs may also be characterized by a feeling of joy and peacefulness, the experience of passing through a tunnel, seeing of a light, a review of the person's life, and the return to life after the NDE. In addition, there might be an experience of timelessness. Blackmore describes 3 OBE-cases with such an experience of timelessness.

> 1. "I had an NDE type experience complete with the tunnel and light, out-of-body travels, expansion and contraction of size, *e e e* , a mystical experience and the decision to return..." (p. 43)

Another NDE subjects report:

> 2. "It was like *e*."
> 3. "I found myself in a space, in a period of time I would say, where all space and *e a e a ed*"[d]

With respect to timelessness Blackmore summarizes: "There can be a strange sense of timelessness in which everything happens very fast although time is not passing, or a sense that there is not even any order to time any more". Here, the first two cases describe their temporal experience as timeless. The third case describes experiencing a fast passage of the events. No age differences were reported between autoscopic and physical bodies.

---

[c] Double's clothing helped identifying OTE experience in other reports; see case 3.10 below; [32,34].

[d] It is not mentioned if these latter two had also OBEs, thus were not included in the statistics as different cases.

3.10 Blanke et al. ([13], patient 5; HAS)

This patient, 43 year-old male, was known for familial hemiplegic migraine. Associated neurological symptoms were noticed since he was 19 years old. During his hospitalization he presented a complex partial seizure that was associated with AP:

> The patient sits while a nurse is inserting a venous catheter to his arm. Suddenly he has the feeling that “it is all finished now. She will kill me”. This was associated with a feeling of backward rotation of his body (accompanied with nausea and trembling). He had the feeling of seeing the world from two points of view: the original one and the rotated one. Towards the end of the rotation he suddenly noticed a presence of a person behind the nurse. Immediately he identified him as himself: “ *e* [illegible] *ed* [illegible] *e* [illegible] *e* [illegible] *e* [illegible] *ea* [illegible], *e*. He was not dressed as I was. He hadn’t the catheter, glasses and watch”. He perceived the double as a real body in the extrapersonal space who comes to help him, and was deeply relived by his appearance. The double asked the original body “what am I supposed to do?” His response was: “help me get away from here; these people want to kill me!” then, a nurse and a doctor ran towards the patient. Here the double became active, and have been fighting with the doctor. Finally, the patient noticed a big black woman coming from behind, and physically inclines the chair backwards. He lost contact with his double and was put in bed by the medical staff.

The appearance of the double from the past is suggested by his looks, his clothing, his behavior and the absence of the catheter and watch of the patient. The double comes from the past, looks as in the past, but acts in the current situation . The patient’s experience is HAS as he sees the world simultaneously from two points of view. The double is active and fighting. A feeling of trembling accompanies the experience, and a sense of relief. There is a dialogue between the double and the “I”, or, at least, there is a mental communication which is perceived as a speech.

4 Discussion

We have analyzed 20 cases of APs in whom the temporal location of body or self was abnormal. 25% of cases (n=5) were classified as AH, 5% (n=1) were classified as HAS and the majority (70%; n=14) as OBE (Tab. 1). Our findings show that the unitary experience of self and body during AP is not only abnormal with respect to unity in space (self is localized in the body under normal conditions) but also (in the analyzed cases) with respect to unity in time (self is localized in the present under normal conditions). In addition, we found systematic differences in the temporal disunity between AH/HAS as compared to OBEs. In the following we will discuss that AP not only challenge the unified experience of the self in time, but that they also allow to formulate more precise research hypotheses about the functional and neural mechanisms that participate in the construction of "self" across time.

All analyzed OBE-subjects had a feeling of timelessness or changes in the experience of time such as acceleration or slowing of time without any age differences between autoscopic and physical body. The disembodied subject (or self) during an OBE thus seems to experience seeing the own body from a "timeless" location or a location that is "out-of time". Accordingly, we have named this phenomenon "out-of-time experience" (OTE). Interestingly, this suggests that in phenomenological terms the spatial coordinates of the self (with respect to the body) and the temporal aspects of the self (with respect to the present) share important characteristics. Namely, the experience of being outside one's body is associated with the experience of being "outside" the present. This suggests that experience of the self in space and time might share functional and neural mechanisms, and temporal self mechanisms are influenced by spatial self mechanisms (or vice versa; see below).

With respect to AH/HAS the analyzed cases did not experience timelessness but experienced their physical body at the present moment. Yet, during AH/HAS the autoscopic body was either experienced as older than the physical body ("as if coming from the future"; 33.3%), or as younger ("as if coming from the past"; 66.6%). Based on these data we suggest that the self in AH/HAS is experienced as being in the present and that the double (or autoscopic body) is experienced as being displaced into the future (older autoscopic body) or the past (younger autoscopic body). Again, this suggests that in phenomenological terms the spatial and temporal aspects of the self share important characteristics. Namely, whereas the self is experienced as being embodied and as being in the present, the (autoscopic) body is experienced as being in extrapersonal space and as coming from past or future.

In the following we try to account for the disturbed experience of temporal aspects of self and body in AP with respect to the cognitive and neural

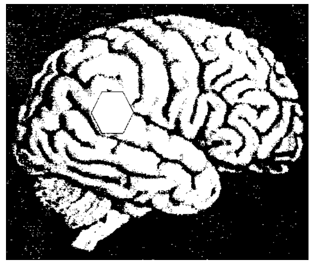


Figure 2. *Temporo-parietal Junction.* This brain region is supposed to be responsible to the integration of multisensory inputs and to self-processing, thus to creation of fundamental mental contents as agency, self-other distinction and self-location in time and space. Disturbance of the activity in this region may lead to AP, sometimes accompanied with OTE.

mechanism that have previously been described for AP. Yet, before proposing a model for disturbed experience of self and body in AP with respect to temporal aspects, we quickly resume what is known about it with respect to spatial characteristics. Studies suggest that in AP the integration of multisensory information of one's body (such as visual, tactile, proprioceptive, and vestibular information) has failed [10,13,29]. Such a failure might lead to the experience of seeing one's body in a position that does not coincide with its felt position as proposed for the effected body part in supernumerary phantom limbs [11,45]. It was further hypothesized that there are several brain areas, and especially the temporo-parietal junction (TPJ) [13,26,29], that are responsible for the integration of the above mentioned multisensory information as well as self-processing data. When this area is disturbed either by pathology or by mental imagery this might facilitate the occurrence of AP [25,29]. Several neuropsychological and neuroimaging studies corroborate the important role of the TPJ (Fig. 2) and other cortical areas along the intraparietal sulcus in combining these tactile, proprioceptive, and visual information in a coordinated reference frame [46], in body perception [47–49], and in mental imagery with respect to one's own body [25,50,51]. The TPJ has also been involved in cognitive functions that are closely linked to self processing and AP: egocentric visuo-spatial perspective taking, agency and self-other distinction (the capacity by which one distinguishes between oneself and other particulars) [52]. Furthermore, the TPJ is the classical lesion site in patients with visuo-spatial neglect [12], a clinical condition, which has been shown to disturb the patient's egocentric spatial relationship with extrapersonal space and visuo-spatial perspective taking [53]. Neuroimaging studies in healthy observers have also revealed activation of the TPJ during egocentric visuo-spatial perspective changes [54,55]. Although many other cortical areas have been shown to play a role in self-processing, the reviewed neuroimaging data on body and self-processing as well as the clinical data on APs suggest that the TPJ is a key neural locus for self processing that is involved in multisensory body-related information processing as well as in processing of phenomenonological and cognitive aspects of the self. Thus, disturbance or lesion in this area might evoke AP [13,25,29]. Collectively, these studies have therefore shown a strong link of the TPJ for processing with respect to spatial self location. Yet, the TPJ has also been shown to play a central role also in time-processing [56–58]. In the following we will briefly review what is known about the TPJ with respect to temporal processing. We will then try to apply these findings to processing with respect to temporal self location.

The parietal part of the TPJ (the inferior parietal lobule: IPL) has been shown to be involved in a number of different time estimation tasks. Thus, lesions in this area and the prefrontal cortex have been shown to be critical for time discrimination and estimation deficits of several seconds [59,60]. The IPL was also found to be activated in sensorimotor synchronization tasks (of several seconds) [61,62], in time estimation tasks (of several seconds) [63–65] and in temporal discrimination (of milliseconds) [66–70], rhythm discrimination [71,72] and time counting (of hundreds milliseconds) [73]. Rubia and Smith [58] linked the involvement of IPL in time management to its role in attentional processing. However, as time-processing is an integral part of self-processing [56], we here speculate that the IPL (and TPJ) is one of the modules recruited for the integration of temporal self-processing. Thus, the TPJ is involved in immediate time management, i.e. seconds and hundreds of milliseconds, and especially in time-estimation and time-discrimination tasks and not (or less) in other time-processing aspects which are not connected to self-processing (like motor timing, pure time synchronisation or long time estimation) [58–60].

Despite this involvement of the TPJ in time-processing, these short time judgement of periods cannot easily be linked to the abnormal time-processing observed during AP that were experienced as spanning longer time periods and timelessness. Yet, this link might be provided by other studies that have investigated longer time periods as in autobiographical memory. Thus, the TPJ has been found to be activated in memory retrieval studies that use either PET [74–76], fMRI [77] or EEG [78], as a part of an autobiographical memory network that is composed by different structures in the frontal and temporal cortex as well as the hippocampus [74,79]. The right TPJ has also been shown to be involved in autobiographical episodic memory retrieval [74,77]. Interestingly, using PET during memory retrieval, Maguire and Mummery [80] differentiated between self-relevant (personal) memories with a specific time-location (personal/time; autobiographical events), self-relevant memories without time-location (personal/non-time; autobiographical facts), non-self-relevant memories with time-location (non-personal/time; public events) and non-self-relevant memories without time-location (non-personal/non-time; general knowledge).[e] Different activations were found for the different types of memories. Most interesting with respect to the present considerations, the TPJ activation showed a differential response to personal memories (personal) but did not discriminate between autobiographical events and facts (time and non-time), i.e. the TPJ was activated during personal memories independent of whether there was a time locus or not. In contrast, the medial frontal cortex, the hippocampus, and the temporal pole showed enhanced activity for stimuli that were personally relevant and had a specific locus in time (personal/time).[f]

In addition to the implication of the TPJ in AP, temporal processes and autobiographical memory, there are other neurological conditions that might help understanding the temporal disunity in AP,[g] such as spontaneous confabulations and delusional misidentification syndromes (DMS). Confabulations have been defined as false memories occurring in clear consciousness in association with an organically derived amnesia [81]. Spontaneous confabulations act on the basis of previous habits rather than currently relevant memories. Thus, past true events and imaginations about the future interfere with the experienced present ("now") [22,23]. For instance, a 58-year-old neurological patient was convinced that she had to feed her baby, who was over 30 years old at the time [23,82]. It was suggested that the anterior limbic system provides a reality monitoring mechanism which selects memories of current relevance by suppressing (inactivating) currently irrelevant memories. Lesion in this area might thus cause involvement of irrelevant earlier (past) or imagined later (future) memories during

[e]Personal/time vs. personal/non-time reminds the differentiation between episodic autobiographical memory (conscious recollection of a temporally and spatially specific events from one's personal past) and semantic autobiographical memory, which is time independent [89,90].

[f]Maguire and Mummery [80] remark that the preference of the TPJ to personal memories irrespective of temporal context has not been explored previously, but clearly requires further investigation.

[g]For a psychoanalytical explanation of AP in space and time see Rank [91].

the current processing of events [22,23]. DMS are a group of delusional disorders that involve a belief that the identity of a person, object or place has been changed or altered. Briefly, DMS include the syndrome of Capgras (the belief that (usually) a close relative or spouse has been replaced by an identical-looking impostor), the syndrome of Fregoli (the belief that various people that the believer has met are actually the same person in different disguises), the syndrome of intermetamorphosis (the belief that people in the environment switch identities with each other while maintaining the same appearance), the syndrome of subjective and inanimate doubles (AP or multiple duplications of oneself), and the syndrome of reduplicative paramnesias (the belief that a familiar event or place has been duplicated) [20,21,83,84]. Moreover, the different subtypes of DMS might co-appear [20,21,85]. Thus, although most authors think that reduplification of events concerns only the event and not the self [20,84], the above reports and the co-appearance of subtypes in DMS suggest that DMS might combine AP with delusions of temporal-reduplication or event reduplification (i.e. age-difference between original body and autoscopic body). With respect to the anatomy of DMS, clinical and experimental evidence suggests that multifocal brain damage is necessary. Thus, right-posterior brain damage has been reported leading to deficits in visuo-spatial orientation and visual recognition. Also, the frequently associated bilateral frontal lobe pathology might be responsible for the patient's inability to correct the reduplicative phenomenon in the face of otherwise adequate mnemonic function, thus avoids correction by former knowledge and compensation mechanisms [21,83]. The above reviewed phenomena of AP, spontaneous confabulations, and DMS demonstrate that our immediate experience of being temporally located in the present moment, in a specific "now", passing forward with time in an irreversible process depends on a variety of functions and brain areas. We suggest that the breakdown of the "now" in AP can be systematically examined leading to the description of some of the underlying functional and neural mechanisms of temporal self location.

5 Conclusion

In summary, our non-conceptual experience of self location inside our body and "inside" the present moment might be abnormal in various neurological conditions such as DMS, spontaneous confabulations and AP. The later are divided into AH/HAS, during which subjects experience seeing an autoscopic body from their habitual and embodied perspective, and OBEs, during which subjects appear to see the autoscopic body from a disembodied perspective. Our analysis showed that the abnormal spatial location of body and self during AP is sometimes accompanied by an abnormal temporal disunity of body and self.

Our analysis showed that OBE-subjects frequently report a sensation of "timelessness" as if seeing the passage of time from an outer point-of-view. We named this experience "Out-of-Time Experience" or OTE. We suggest that the spatial coordinates of the self (with respect to the body) and temporal aspects of the self (with respect to the present) share important characteristics because the experience of being outside of one's body (OBE) was found to be associated with the experience of being outside of the present moment (OTE). This suggests that the experience of the self in space and time might share functional mechanisms at the TPJ and other areas.

With respect to AH/HAS we did not encounter OTEs. Rather, the subjects reported being in the present moment, but experienced the autoscopic body as older or younger than the physical body. This suggests a differently disturbed self location in AH/HAS. Here, the double (or autoscopic body) is sometimes experienced as being displaced into the future (older autoscopic body) or the past (younger autoscopic body) showing again (as in OBE/OTE) that the spatial coordinates of the self and temporal aspects of the self share important functional mechanisms at the TPJ. Thus, the self is experienced as being embodied and in the present, whereas the autoscopic body is experienced as being in extrapersonal space and as coming from past or future.

The implication of the TPJ and especially the IPL (1) in time estimation and discrimination, (2) its involvement in autobiographical memory (independent of the autobiographical event's locus in time), (3) together with its central role in spatial self location and AP suggests that these abnormal experiences of the body and self in time might also be due to interference with the TPJ. The implication of many other brain areas and especially the prefrontal cortex in autobiographical memory, DMS, and spontaneous confabulations demonstrates that location of the self in time and space is not only processed at the TPJ, but in a largely distributed network. Whereas the implication of the different parts of the network certainly depend on the task or action the subject is performing, the reviewed clinical and neuroimaging data suggest that the TPJ plays a key role in spatial and temporal self location. We hope that the reviewed data will lead to further inquiries about how the brain generates our everyday experience of being placed in our body at the present moment.

References

1. Kircher, T.T., Brammer, M., Bullmore, E., Simmons, A., Bartels, M., and David, A.S. (2002) The neural correlates of intentional and incidental self processing, *Neuropsychologia* **40**, 683–692.
2. Stern, D. (2004) *The Present Moment in Psychotherapy and Everyday Life*, William Morrow & Company, New York.
3. Bermudez, J.L. (1995) Nonconceptual content: from perceptual experience to subpersonal computational states, *Mind and Language* **10**, 333–369.
4. Bermudez, J.L. (1998) *The Paradox of Self-Consciousness*, MIT, Cambridge.
5. Brewer, B. (1992) Self-location and agency, *Mind* **401**, 17–34.
6. Neisser, U. (1988) The five kinds of self-knowledge, *Phil. Psychol.* **1**, 35–59.
7. Gallagher, S. (2000) Philosophical conceptions of the self: implications for cognitive science, *Trends Cogn. Sci.* **4**, 14–21.
8. Metzinger, T. (2003) *Being No One. The Self-Model Theory of Subjectivity*, Bradford Books, Cambridge.
9. Metzinger, T. (2005) The pre-scientific concept of a "soul". A neurophenomenological hypothesis about its origin, in M. Peschl (ed.), *Auf der Suche nach dem Konzept/Substrat der Seele. Ein Versuch aus der Perspektive der Cognitive (Neuro-)Science*, Königshausen und Neumann, Würzburg, in press.
10. Brugger, P., Regard, M., and Landis, T. (1997) Illusory reduplication of one's own body: phenomenology and classification of autoscopic phenomena, *Cogn. Neuropsychiatry* **2**, 19–38.
11. Ramachandran, V.S. and Hirstein, W. (1998) The perception of phantom limbs, *Brain* **121**, 1603–1630.
12. Halligan, P.W., Fink, G.R., Marshall, J.C., and Vallar, G. (2003) Spatial cognition. Evidence from visual neglect, *Trends Cogn. Sci.* **7**, 125–133.
13. Blanke, O., Landis, T., Spinelli, L., and Seeck, M. (2004) Out-of-body experience and autoscopy of neurological origin, *Brain* **127**, 243–258.
14. Lackner, J.R. (1992) Sense of body position in parabolic flight, *Ann. N.Y. Acad. Sci.* **656**, 329–339.
15. Mittelstaedt, H. and Glassauer, S. (1993) Illusions of verticality in weightlessness, *Clin. Investig.* **71**, 732–739.
16. Previc, F.H., Varner, D.C., and Gillingham, K.K. (1992) Visual scene effects on the somatogravic illusion, *Aviat. Space. Environ. Med.* **63**, 1060–1064.
17. Solms, M., Kaplan-Solms, K., Saling, M., and Miller, P. (1988) Inverted vision after frontal lobe disease, *Cortex* **24**, 499–509.
18. Tiliket, C., Ventre-Dominey, J., Vighetto, A., and Grochowicki, M. (1996) Room tilt illusion. A central otolith dysfunction, *Arch. Neurol.* **53**, 1259–1264.
19. Malis, D.D. and Guyot, J.P. (2003) Room tilt illusion as a manifestation of peripheral vestibular disorders, *Ann. Otol. Rhinol. Laryngol.* **112**, 600–605.
20. Weinstein, E.A. (1994) The classification of delusional misidentification syndromes, *Psychopathology* **27**, 130–135.
21. Ellis, H.D., Luaute, J.P., and Retterstol, N. (1994) Delusional misidentification syndromes, *Psychopathology* **27**, 117–120.
22. Schnider, A. (2000) Spontaneous confabulations, disorientation, and the processing of 'now', *Neuropsychologia* **38**, 175–185.

23. Schnider, A. (2001) Spontaneous confabulation, reality monitoring, and the limbic system — a review, *Brain Res. Rev.* **36**, 150–160.
24. Devinsky, O., Feldmann, E., Burrowes, K., and Bromeld, E. (1989) Autoscopic phenomena with seizures, *Arch. Neuro.* **46**, 1080–1088.
25. Blanke, O. (2004) Out of body experiences and their neural basis, *BMJ* **329**, 1414–1415.
26. Blanke, O., Mohr, C., Michel, C.M., Pascual-Leone, A., Brugger, P., Seeck, M., Landis, T., and Thut, G. (2005) Linking out-of-body experience and self processing to mental own-body imagery at the temporoparietal junction, *J. Neurosci.* **25**, 550–557.
27. Blackmore, S.J. (1982) *Beyond the Body. An Investigation of Out-of-Body Experiences*, Heinemann, London.
28. Irwin, H.J. (1985) *Flight of Mind. A Psychological Study of the Out-of-Body Experience*, Scarecrow Press, Metuchen (NJ).
29. Blanke, O. and Arzy, S. (2005), Out-of body experiences due to disturbed self processing at the right temporo-parietal junction, *Neuroscientist* **11**, 16–24.
30. Menninger-Lerchenthal, E. (1935) *Das Truggebilde der eigenen Gestalt*, Karger, Berlin.
31. Hécaen, H. and Ajuriaguerra, J. (1952) L'heautoscopie, in H. Hécaen and J. Ajuriaguerra (eds.), *Meconnaissances et Hallucinations Corporelles*, Masson, Paris, pp. 310–343.
32. Lukianowicz, N. (1958) Autoscopic phenomena, *Arch. Neurol.* **80**, 199–220.
33. Grüsser, O.-J. and Landis, T. (1991) The splitting of 'I' and 'me'. Heautoscopy and related phenomena, in O.-J. Grüsser and T. Landis (eds.), *Visual Agnosias and Other Disturbances of Visual Perception and Cognition*, MacMillan, Amsterdam, pp. 297–303.
34. Dening, T.R. and Berrios, G.E. (1994) Autoscopic phenomena, *Br. J. Psychiatry* **165**, 808–817.
35. Brugger, P., Agosti, R., Regard, M., Wieser, H.G., and Landis, T. (1994) Heautoscopy, epilepsy, and suicide, *J. Neurol. Neurosurg. Psychiatry* **57**, 838–839.
36. Sivadon, P. (1937) Phénomènes autoscopiques au cours de la grippe, *Annales Médicine Psychologie* **2**, 215–220.
37. Lhermitte, J. (1951) Les phénomènes heautoscopiques, les hallucinations speculaires, in J. Lhermitte (ed.), *Les Hallucinations. Clinique et Physiopathologie*, G. Doin, Paris, pp. 124–168.
38. Féré, C. (1891) Note sur les hallucinations autoscopiques ou spéculaires et sur les hallucinations altruistes, *C. R. Séanc Sociale Biologie* **3**, 451–453.
39. Sollier, P.A. (1903), *Les Phénomènes d'Autoscopie*, Félix Alcan, Paris.
40. Brugger, P. (2002), Reactive mirrors. Perspective taking in autoscopic phenomena, *Cogn. Neuropsychiatry* **7**, 179–194.
41. Schmidt, B. (1948), L'heautoscopie, *Chaiers de Psychyatrie* **2**, 21–26.
42. Green, C.E. (1968) *Out-of-Body Experiences*, Hamish Hamilton, London.
43. Moody, R. (1975) *Life After Life*, Bantam, New York.
44. Blackmore, S. (1993) *Dying to Live: Near-Death Experiences*, Prometheus Books, Buffalo.

45. Ramachandran, V.S. and Blakeslee, S. (1998) *Phantoms in the Brain*, William Morrow & Company, New York.
46. Calvert, G.A., Campbell, R., and Brammer, M.J. (2000) Evidence from functional magnetic resonance imaging of crossmodal binding in the human heteromodal cortex, *Curr. Biol.* **10**, 649–657.
47. Bonda, E., Petrides, M., Frey, S. and Evans, A. (1995) Neural correlates of mental transformations of the body-in-space, *Proc. Natl. Acad. Sci. USA* **92**, 11180–11184.
48. Downing, P.E., Jiang, Y., Shuman, M., and Kanwisher, N. (2001) A cortical area selective for visual processing of the human body, *Science* **293**, 2470–2473.
49. Astafiev, S.V., Stanley, C.M., Shulman, G.L., and Corbetta, M. (2004) Extrastriate body area in human occipital cortex responds to the performance of motor actions, *Nat. Neurosci.* **7**, 542–548.
50. Zacks, J.M., Rypma, B., Gabrieli, J., Tversky, B., and Glover, G. (1999) Imagined transformations of bodies. An fMRI study, *Neuropsychologia* **37**, 1029–1040.
51. Zacks, J.M., Ollinger, J.M., Sheridan, M.A., and Tversky, B. (2002) A parametric study of mental spatial transformations of bodies, *Neuroimage* **16**, 857–872.
52. Decety, J. and Sommerville, J.A. (2003) Shared representations between self and other: a social cognitive neuroscience view, *Trends Cogn. Sci.* **7**, 527–533.
53. Farrell, M.J. and Robertson, I.H. (2000) The automatic updating of egocentric spatial relationships and its impairment due to right posterior cortical lesions, *Neuropsychologia* **38**, 585–595.
54. Maguire, E.A., Burgess, N., Donnett, J.G., Frackowiak, R.S., Frith, C.D., and O'Keefe, J. (1998) Knowing where and getting there: a human navigation network, *Science* **280**, 921–924.
55. Ruby, P. and Decety, J. (2001) Effect of subjective perspective taking during simulation of action: a PET investigation of agency, *Nat. Neurosci.* **4**, 546–550.
56. Nobre, A.C. and O'Reilly, J., (2004) Time is of the essence, *Trends Cogn. Sci.* **8**, 387–389.
57. Mauk, M.D. and Buonomano, D.V. (2004) The neural basis of temporal processing, *Annu. Rev. Neurosci.* **27**, 307–340.
58. Rubia, K. and Smith, A. (2004) The neural correlates of cognitive time management: a review, *Acta Neurobiol. Exp.* **64**, 329–340.
59. Harrington, D.L., Haaland, K.Y., and Knight, R.T. (1998) Cortical networks underlying mechanisms of time perception, *J. Neurosci.* **18**, 1085–1095.
60. Kagerer, F.A., Wittman, M., Szelag, E., and von Steinbchel, N. (2002) Cortical involvement in temporal reproduction: evidence for differential roles of the hemispheres, *Neuropsychologia* **40**, 357–366.
61. Lejeune, H., Maquet, P., Pouthas, P., Bonnet, M., Casini, L., Macar, F., Vidal, F., Ferrara, A., and Timsit-Berthier, M. (1997) Brain activation correlates of synchronization: a PET study, *Neurosci. Lett.* **235**, 21–24.

62. Rubia, K., Overmeyer, S., Taylor, E., Brammer, M., Williams, S., Simmons, A., Andrew, C., and Bullmore, E. (2000) Functional frontalisation with age: mapping neurodevelopmental trajectories with fMRI, *Neurosci. Biobehav. Rev.* **24**, 13–19.
63. Macar, F., Lejeune, H., Bonnet, M., Ferrara, A., Pouthas, V., Vidal, F., and Maquet, P. (2002) Activation of the supplementary motor area and of attentional networks during temporal processing, *Exp. Brain Res.* **142**, 475–485.
64. Lewis, P.A. and Miall, R.C. (2002) Brain activity during non-automatic motor production of discrete multi-second intervals, *Neuroreport* **13**, 1731–1735.
65. Basso, G., Nichelli, P., Wharton, C.M., Peterson, M., and Grafman, J. (2003) Distributed neural systems for temporal production: a functional MRI study, *Brain Res. Bull.* **59**, 405–411.
66. Maquet, P., *et al.* (1996) Brain activation induced by estimation of duration: a PET study, *Neuroimage* **3**, 119–126.
67. Pedersen, C.B., Mirz, F., Ovesen, T., Ishizu, K., Johannsen, P., Madsen, S., and Gjedde, A. (2000) Cortical centres underlying auditory temporal processing in humans: a PET study, *Audiology* **39**, 30–37.
68. Rao, S.M., Mayer, A.R., and Harrington, D.L. (2001) The evolution of brain activation during temporal processing, *Nat. Neurosci.* **4**, 317–323.
69. Belin, P., *et al.* (2002) The neuroanatomical substrate of sound duration discrimination, *Neuropsychologia* **40**, 1956–1964.
70. Nenadic, I., Gaser, C., Volz, H-P., Rammsayer, T., Hager, F., and Sauer, H. (2003) Processing of temporal information and the basal ganglia: new evidence from fMRI, *Exp. Brain Res.* **148**, 238–246.
71. Schubotz, R.I., Friederici, A.D., and von Cramon, Y.D. (2000) Time perception and motor timing: a common cortical and subcortical basis revealed by fMRI, *Neuroimage* **11**, 1–12.
72. Numminen, J., Schurmann, M., Hiltunen, J., Joensuu, R., Jousmaki, V., Koskinen, S.K., Salmelin, R., and Hari R. (2004) Cortical activation during a spatiotemporal tactile comparison task, *Neuroimage* **22**, 815–821.
73. Ortuno, F., Ojeda, N., Arbizu, J., Lopez, P., Marti-Climent, J.M., Penuelas, I., and Cervera, S. (2002) Sustained attention in a counting task: normal performance and functional neuroanatomy, *Neuroimage* **17**, 411–420.
74. Fink, G.R., Markowitsch, H.J., Reinkemeier, M., Bruckbauer, T., Kessler, J., and Heiss, W.D. (1996) Cerebral representation of one's own past: neural networks involved in autobiographical memory, *J. Neurosci.* **16**, 4275–4282.
75. Cabeza, R., Mangels, J., Nyberg, L., Habib, R., Houle, S., McIntosh, A.R., and Tulving, E. (1997) Brain regions differentially involved in remembering what and when: a PET study, *Neuron* **19**, 863–870.
76. Piolino, P., Giffard-Quillon, G., Desgranges, B., Chetelat, G., Baron, J.C., and Eustache, F. (2004) Re-experiencing old memories via hippocampus: a PET study of autobiographical memory, *Neuroimage* **22**, 1371–1383.
77. Levine, B., Turner, G.R., Tisserand, D., Hevenor, S.J., Graham, S.J., and McIntosh, A.R. (2004) The functional neuroanatomy of episodic and semantic autobiographical remembering: a prospective functional MRI study, *J. Cogn. Neurosci.* **16**, 1633–1646.

78. Wilding, E.L. and Rugg, M.D. (1996) An event-related potential study of recognition memory with and without retrieval of source, *Brain* **119**, 889–905.
79. Lee, A.C., Robbins, T.W., Graham, K.S., and Owen, A.M. (2001) "Pray or Prey?" dissociation of semantic memory retrieval from episodic memory processes using positron emission tomography and a novel homophone task, *Neuroimage* **16**, 724–735.
80. Maguire, E.A. and Mummery, C.J. (1999) Differential modulation of a common memory retrieval network revealed by positron emission tomography, *Hippocampus* **9**, 54–61.
81. Berlyne, N. (1972) Confabulation, *Br. J. Psychiatry* **120**, 31–39.
82. Schnider, A., von Daniken, C., and Gutbrod, K. (1996) The mechanisms of spontaneous and provoked confabulations, *Brain* **119**, 1365–1375.
83. Benson, D.F., Gardner, H., and Meadows, J.C. (1976) Reduplicative paramnesia, *Neurology* **26**, 147–151.
84. Voros, V., Tenyi, T., Simon, M., and Trixler, M. (2003) 'Clonal pluralization of the self': a new form of delusional misidentification syndrome, *Psychopathology* **36**, 46–48.
85. Sno, H.N. (1994) A continuum of misidentification symptoms, *Psychopathology* **27**, 144–147.
86. Tsuruta, S. (1994) Age-delusion: age-misidentification of chronic schizophrenic patients, *Seishin Shinkeigaku Zasshi* **96**, 755–773.
87. Rotenberg, M. (1983) *Dialogue with Deviance: the Hassidic Ethic and the Theory of Social Contraction*, University Press of America, Philadelphia.
88. Rotenberg, M. (1987) *Re-Biographing and Deviance: Psychotherapeutic Narrativism and the Midrash*, Prager Publications, New York.
89. Tulving, E. and Markowitsch, H.J. (1998) Episodic and declarative memory: Role of the hippocampus, *Hippocampus* **8**, 198–204.
90. Levine, B. (2004) Autobiographical memory and the self in time: brain lesion effects, functional neuroanatomy, and lifespan development, *Brain Cogn.* **55**, 54–68.
91. Rank, O. (1925) *Der Doppelganger: Eine psychoanalytische Studie*, Internationaler Psychoanalytischer Verlag, Leipzig.

Appendix A: Therapeutic Considerations

Tsuruta [86] noticed that schizophrenic patients who believe to be in a different age than their chronological one might get an advantage from the phenomenon, as "believing in their subjective age seems to allow them to reunify or rewrite their own past history and gain some hope for the future". The psychotherapeutic method of hermeneutic re-biography uses similar conditions. The method tries to repair the past by re-reading the patient's history from a different temporal point of view, and then to shape the future accordingly [87,88]. However, how is the therapeutic-migrating through rereading of past failure possible without changing facts or events? And how can one write a script of one's future realistically? Rotenberg suggests that "we must realize that we can understand the possibility of dialogue between one's past "I" and one's future "I" only in terms of the balance between the finite rational-material and the infinite mystic-spiritual conceptions of life that prevail in particular cultures" [88, p. 180]. The reviewed data suggest that the neurocognitive phenomena of AP facilitate such changes in temporal self location.

In AP one may see his double in the past or in the future, under positive or negative circumstances. Thus, case 10 of the current study faces his younger double, who helps him to get back his force and fight his unwilled position (past, positive). Case 3 hears from his younger double that the temporary reading of his life is a failure (past, negative). The dialogue with the past double may lead to a new reading of the self biography. Case 2 sees his imagined future double broken and ill (future, negative). The manifestation of such a future should lead the subject to change his way of life. On the other hand, Case 8's double is coming from the future, showing the subject a possible, recommended future (future, positive). Thus, AP with age-difference between the original body and the autoscopic body claim for open future and past and suggest alternative probable outcomes, thus assist re-biographing mental states.

Table A.1. *Phenomenological findings of Autoscopic Phenomena and time-experience.* (AP = Autoscopic Phenomena; HAS = HeAutoScopy; AH = Autoscopic Hallucination; OBE = Out-of-Body Experience; DP = Depersonalization; DE = Disembodiment; n.r. = not reported)

Subj. #	Ref.	AP	DP	DE	Time of Double	Action	Speech	Subject's Position	Double's Position	Gender	Weak	Fear	Surprise	Vestib. Manifest.
1	[36]	AH HAS	±	–	past	n.r.	–	n.r.supine	standing	m	double	n.r.	–	±
2	[37]	AH	–	–	future	walking	+	standing	standing	m	+	n.r.	n.r.	n.r.
3	[31]	AH	–	±	past	–	+	sitting	sitting	m	n.r.	n.r.	n.r.	n.r.
4	[41]	AH	–	–	past	running, laughing	n.r	–	standing	f	n.r.	n.r.	n.r.	n.r.
5	[42] (11 subj's)	OBE	+	+	timeless	–	–	n.r.	n.r	n.r.	n.r.	n.r.	n.r.	+
6	[43; C1]	OBE	+	+	timeless	–	–	n.r.	n.r	n.r.	n.r.	n.r.	n.r.	+
7	[43; C2]	OBE	+	+	timeless	–	–	n.r.	n.r	n.r.	n.r.	n.r.	n.r.	+
8	[24]	AH	–	–	near future	moving the lawn	–	n.r.	standing	m	n.r.	n.r.	+	n.r.
9	[44]	OBE	n.r.	n.r.	timeless	–	–	n.r.	n.r	n.r.	n.r.	n.r.	n.r.	+
10	[13]	HAS	+	–	past	fighting	+	sitting	standing	m	+	+	+	+

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 531–546

THE MIND IN PHYSICS

JOHN SANFEY
Alvaston Medical Centre, 14 Boulton Lane
Alvaston, Derby, DE24 0GE, U.K.
(johnsanfey@mac.com)

Abstract: It can be proven that physical theory always contains some abstract mechanism whose function is equivalent to the unique role played by the human mind during the empirical manifestation of reality. The importance of this hypothesis, known as the Conservation of Now-ness, or CON hypothesis, is that it defines a formal relationship between the subjective phenomenon of conscious experience and physics, allowing us to reformulate the hard problem into a solvable form, and to develop an endophysics paradigm and program of research.

Keywords: Consciousness – Time – Continuum – Complementarity

1 Introduction

> *There is... no great advance without a double mystery... two clues that can be played off against each other to yield the answer. Fortunate are we to have before us two such mighty mysteries as time and existence — each linked with two other great questions, the quantum and the continuum.* J.A. Wheeler [1].

The Conservation of Now-ness, or *CON hypothesis*, is the idea that all objective representations, including formal physical theory, contain some conceptual device that is functionally equivalent to the apparatus of perception [2,3]. At the last endophysics workshop in Tatranská Lomnica (Slovakia), I tentatively presented the argument for this hypothesis. Here, I go further, and claim the argument to be a proof. If correct, the hypothesis shows that the so-called 'hard problem' of explaining subjective experience, can be solved, establishing the basis of a formal mind-matter relationship. I shall summarise the argument again in concise form, then present the case for a model of subject-object complementarity that seems to arise naturally from the hypothesis, discussing its potential value as an axiomatic basis for a new endophysics paradigm. On the way, I explore Wheeler's suggestion that four great mysteries, or two double mysteries, of time, existence, the continuum and the quantum, might be linked. In fact, they are strongly linked in the reasoning used to prove the CON hypothesis. Lastly, I shall speculate on the structure of the brain that would create the form of consciousness implied by the CON hypothesis. This latter step is important to demonstrate that the hypothesis does indeed open the door to a full-blown explanation of consciousness.

I apologise in advance for the speculative nature of much of the discussion that follows the proof for the CON hypothesis. The hypothesis is a new idea that has not yet been discussed in the literature. It remains uncertain how useful it will prove to be: being true does not guarantee importance. However, given that the hypothesis appears to be true, there are certain deductions that seem to follow, and I welcome the opportunity to present them, albeit in a somewhat crude form.

1.1 Background: the mind-body problem

The CON hypothesis came about in the search for a solution to the so-called 'hard problem', the problem of explaining why the subjective phenomenon of consciousness accompanies physical processes in the brain, when those physical processes should have sufficient explanatory power on their own, since the universe is causally closed. In his presentation, Avshalom Elitzur did a good job of explaining the severity of the problem. It is possible to imagine that the whole world, including human brains and behaviour, could be explained down to the last detail in terms of physical cause and effect, without any explanation of why someone must experience an inner sense of being [4]. The phenomenon of experiencing appears not only to be *ontologically distinct* from the physical world of cause and effect, but also superfluous to it: once we have a full description of the world in terms of cause and effect, nothing further can be added physically, by the fact that someone is having subjective experience. It is conceivable that *zombies* could exist that are identical to us, but without any sense of 'what it is like to be' [5]. Even the empirical discovery of some new phenomenon such as *radical emergence* for example, would not be sufficient to explain the subjective, qualitative sense of being, sometimes known as *qualia*. Radical emergence is the idea that certain physical properties, with their own, new causal powers, only come into existence with increasing complexity of a system. No examples of radical emergence have ever empirically been found to exist, but even if they were, the hard problem would remain unsolved, because a physical system with radically emergent properties should be able to function just the same by cause and effect, without an inner sense of being. The hard problem, in this deepest, metaphysical form, can only be solved by an explanation of why the phenomenon of being is necessary. In a similar way, *panpsychism* is not a satisfactory solution to the hard problem either. Panpsychism is the idea that qualia are fundamental properties of matter like charge or spin. The very concept is an ugly one: qualia are tagged on to some otherwise self-sufficient physical process, without any physical purpose except to account for the phenomenon of experience. Panpsychism neither explains the purpose of qualia, nor how they could cause physical change without disregarding the laws of physics. Small wonder then, that so many researchers dismiss the hard problem as metaphysical and impossible. The CON hypothesis however, provides a new, elegant and simple solution to the hard problem. Qualitative experience only appears to be excluded from the world of cause and effect; but is already part of it, mistaken for something else.

1.2 The CON hypothesis

First and foremost, the CON hypothesis proves that the hard problem, as currently formulated, is ill conceived, impossible to solve and yes, metaphysical. But by making the necessary re-adjustment, allowed by the CON hypothesis, it ceases to be impossible, but eminently solvable in principle. I use the word 'proves' quite deliberately, because the argument for the hypothesis can be made by deduction from a set of statements comprising *everything that is empirically certain. Empiricism* is the view that experience through the senses is the only source of knowledge. Historically, empiricism rose to prominence in the seventeenth century with the British and Irish philosophers Locke, Berkeley and Hume. It became clear that there could in principle, never be any proof that the whole of reality is not some illusion of the mind of an experiencer. Science is the process of inter-subjective agreement on what we experience. Consequently it is impossible in principle, to resolve the idealism-realism debate, i.e. the question of whether everything is really mind-stuff or matter-stuff. Most of us choose to believe that persistent patterns we experience, which seem to be independent of our wishes, should be thought of as existing independently of mind; we agree by convention to call this 'matter'. On the other hand, the brute fact that experience is taking place is something of which we can be absolutely certain. It is interesting to note that Descartes' famous statement 'cogito, ergo sum' (I think, therefore I am), can be seen as having two distinct but related meanings. It can be seen as either an equation or a statement [6]:

in the former, the words 'I think', simply state the self-evident, *a priori* certainty that consciousness exists, while in the latter, 'I think' means the capacity to reason and doubt. Both meanings are empirically certain: experience is indeed occurring, and secondly, we can doubt. It is important to note that both these meanings should be seen as empirically certain. The fact that we can doubt, and therefore hypothesize, can be shown by a simple thought experiment. Imagine being taken aside by god and given the complete set of all possible knowledge, including the inside story of how the universe was created out of nothing. God smiles and says; 'now, you know everything'. It is obviously possible to doubt the truth of this statement. Of course, we might be completely over-awed, but we all know at least one awkward customer who would express a certain scepticism. This argument, aimed at the intuitive level, seems to evoke Gödel's incompleteness theorem, which Penrose used in a more formal way to argue that consciousness could not have a computational basis [7]. Even with complete knowledge, there is uncertainty, and where there is uncertainty, there is the possibility of hidden variables.

Taking the two interpretations of 'cogito' into account, that consciousness just is, and that consciousness exists because we question, and taking seriously the lesson of empiricism in terms of the idealism-realism stalemate, I propose that the following four statements encompass the whole domain of empirical certainty:

(a) Something is happening:
(b) Whatever that something is, it is changing:
(c) Within this change, are patterns that vary at different rates:
(d) We can speculate:

Everything else is uncertain.

Next, in order to examine the relationship between the phenomenon of experiencing and matter, while remaining within the domain of empirical certainty, we need to make two assumptions. The first, is that the principle of cause and effect is true, such that when A causes B, then A is in the past of B. Secondly, in describing the relationship between a conscious mind and the world it observes, we assume that the observed is separated from the mind by space-time. Given these two assumptions, and without straying from the domain of empirical certainty, we can now deduce the CON hypothesis as follows:

(i) Physical reality is changing continuously from A to B such that A causes B, or vice-versa, and is in the past of B.

(ii) Any duration of time, even an infinitesimal one, that is external to the mind of the observer, can only be experienced such that the beginning of the duration, is re-created by the mechanism of consciousness
(iii) If matter exists it must occupy a volume of space-time
(iv) And consequently occupies duration of time
(v) Given (ii) and (iv), matter occupies duration of time in a manner determined by the mechanism of human consciousness

The Conservation of Now-ness hypothesis, or CON hypothesis can be stated thus: *any empirical phenomenon, external to the mind of the observer, employs the living mechanism of consciousness to occupy duration of time. The subsequent, theoretical representation of something separated from the observer by space-time, requires some conceptual device that performs this same function of human consciousness.* It seems proven that the human mind is already part of physics; the hard problem can be solved in principle, after a little re-alignment, and we have the basis of an endophysics paradigm in which mind and matter are formally related. For the rest of this paper, I shall depart somewhat from proof and certainty, and begin to speculate on the possible nature of that relationship between the subjective phenomenon of experiencing, and the world of physics.

2 Implications of the Hypothesis; Part I: Wheeler's Four Mysteries

2.1 Time and existence

> *Explain time? Not without explaining existence. Explain existence? Not without explaining time.* J.A. Wheeler [1].

Human consciousness already operates in every corner of physics, but in disguise. We already have 'endo-physics', to use the term coined by Finkelstein and Rossler when they called for the incorporation of subjectivity into physics [8,9]. This does not imply that the whole practice of modern physics is wrong. Rather, the CON hypothesis makes the ontological statement that the actual 'glue' joining the beginning and end of an experienced duration, is human consciousness, and that any strategy allowing the past, and the future it causes, to be represented together in physical theory is not a fact about the external world but describes that part of the experience of phenomena, caused by consciousness. Calculus is a good example of such a strategy; invented to overcome problems arising from continuous change. A continuum implies that durations are infinitely divisible into smaller and smaller durations but never reach a point. In calculus, infinitesimal durations are conceived as approaching a limit, enabling them to be treated epistemically as finite points while retaining properties defined by duration. The CON hypothesis is that this technique describes a task, equivalent to the role played by the human mind in the empirical manifestation of reality.

The word 'exist' means to persist through some duration of time. Traditionally, we humans have largely agreed that there is some 'stuff' called matter, which we assume to be out there occupying space-time, persisting. The CON hypothesis however, proves that this is not so, indeed, this very way of thinking is shown to be false. Matter occupies duration because of a process: the process of consciousness. And not just energetic process either. There is no way to imagine or model existence without invoking something new, because energetic process simply requires the principle of cause and effect of *A then B*, not *A and B*. In order to exist, we require both the beginning and the end of duration. This already gives us the crude beginnings of a governing principle of existence, which can be stated as: *the beginning of a duration of time must influence the end of the duration in some way that is different from, and in addition to, its past role in causal history.* We can see that we must introduce some new process to explain the duration of existence. I shall return to that later.

I said that this was the 'crude beginnings' of a principle. The word 'crude' does not imply that the principle may be false but rather, that the CON hypothesis gives us the opportunity to adjust our concepts of space, time and energy. As I wrote in the last endophysics volume [3], none of these concepts have any meaning except as part of a whole that includes the hypothetical predictive machinery of the human mind. I agree with Jaroszkiewicz, who writes in this volume [10], that it is a mistake to think of time outside the context of process. On the other hand, the CON hypothesis tells us that when we consider the world objectively, outside the context of immediate experience, that world contains an abstract reflection of the process of experiencing. Provided we understand the manner of that reflection, it is okay to use a geometric notion of time knowing that it is a conceptual projection, provided it is useful to do so. The CON hypothesis just opens our eyes a little to the difference between the ontological nature of time as an experience of process, and its various, arbitrary epistemic projections.

I shall return to this question later. Before doing so, it is necessary to point out that the fact of *some* relationship between time and existence holds true *only if there is a scientific explanation of consciousness.*

If consciousness were to have a more metaphysical explanation, such as panpsychism or Cartesian mind-spirit interaction, then, there would be no intimate relationship between time and existence. The philosopher David Chalmers, for instance, has provided an explanation of consciousness in which awareness does not occupy duration of time at all [4]. He proposes that subjective awareness could be an intrinsic property of A or B, without requiring the duration of change, represented by $A \rightarrow B$. His theory is *pan-proto-psychist*, which is the idea that the building blocks of qualitative awareness, *qualia* for short, are a fundamental property of matter like charge or spin. The Penrose–Hameroff model of consciousness, which they call Orchestrated Objective Reduction or Orch OR, is also panpsychist [11], and so is the Relational Block World model of Stuckey *et al.*, presented in this volume [12]. In the Penrose–Hameroff model every gravitational collapse of the wave function is an occasion of awareness, whereas in the RBW model, "*fundamental 'consciousness symmetries' are relational and non-local, and thus have no counterpart in the brain*".

Panpsychism is certainly logically possible, but it is not a comprehensive solution to the mind-matter problem. As I argued above, in the introduction, it does not allow consciousness to have a causal effect in the world. To any scientist, it should only be a solution of last resort. The CON hypothesis on the other hand, shows that it is possible to identify the precise properties of consciousness in relation to the invariance we experience, i.e. the physical world. Having thus been identified, it becomes possible in principle, to predict the sort of physical machinery that will have conscious inner experience. To do so, we shall need to flesh out some more conceptual implications of the hypothesis.

We have yet to state the precise form of the relationship between time and existence, but we have proven that there is one, and that it is intimate. More light can be shed on the nature of the relationship by examining the other of Wheeler's double mysteries.

2.2 The continuum and the bit

> *Adopt rigor, or adopt the continuum? These ways of speaking should not be counted as contradictory, but as complementary.*
> J.A. Wheeler [1].

The argument for the CON hypothesis was based on the premise that change is continuous, but what if that were untrue? Would its claim to be an axiomatic, fundamental principle, be proven false? Curiously perhaps, the answer is no. Furthermore, in showing why, we discover more about the form of the relationship between the phenomenon of being and the physical world.

It is certainly true that in current physical theory, both classical and quantum, change is regarded as being continuous. In relativity theory, time and space form a continuum such that, when the space co-ordinates of something are unchanging, its time co-ordinates are changing continuously, and vice-versa. Of course, in block universe models, the past and future are represented together as part of a static whole, but the fact remains that for any point within the block world, its space-time coordinates are changing continuously. In quantum theory, when an object is at rest, its momentum cannot be zero, or any other known quantity, since this would violate the uncertainty principle. Despite the presence of bit-like or discrete packets of quantities, quantum theory always uses the concept of an external time continuum. According to physical theory therefore, the statement that change from $A \rightarrow B$ is continuous, with A in the past of B, or vice-versa, does indeed hold true.

What if this was wrong, and change actually occurred in little jumps? Surprisingly, this would make no difference to the CON hypothesis, because change is also intrinsic to the concept of awareness, irrespective of whether or how the world is changing. To see why this is so, go back a step and suppose that the physical world is indeed changing continuously but that the observer has no awareness of the past whatsoever; such that when A is in the past of B, there is no awareness of A, no matter how brief the duration. If physical change were continuous, then no duration would be brief enough to allow A and B to occupy the same 'point' in time; one would always be in the past of the other. In these circumstances, external events would have the same impact on awareness as it would on empty space: it would leave no trace whatsoever, and awareness would not occur. So, without change and memory of the immediate past, awareness would be the same as that experienced by nothingness through which something passed without leaving a trace; which is equal to non-awareness, unless we are willing to believe that empty space is conscious in some extremely panpsychist sense. Awareness cannot occur without a record of change, something that is true whether change occurs in bit-like jumps, or continuously. Even if the physical world were unchanging, we could only be aware of it if consciousness were a changing process. Now consider what this would mean if the physical world were changing in bits.

Having established that change is necessary for awareness to occur, suppose that the physical world were changing in bit-like jumps of A to B, as opposed to a continuum. Each bit occurs against the backdrop of changing awareness, and consequently, each experienced bit has at least two phases of change in terms of its context, so, if physical change were bit-like, it would nevertheless be indistinguishable from a continuum, because the smallest bit of which we can be aware, is further divisible, at least in terms of the background context of awareness. Once something is always further divisible, we have a continuum.

We can see that when reality is analysed in terms of an observer-observed relationship, in the context of empirical certainty, there will always be a continuum. Furthermore, it appears that the representation of reality can always be made in two ontologically opposite but epistemically equivalent ways. At the last endophysics conference, I argued that the well-known theory of gauge/string duality is a specific example of this wider generalisation of representational duality, arising from the CON hypothesis. Gauge/string duality is the idea that string theory, in which strings are the fundamental entities, and quantum chromo-dynamics (QCD), in which field characteristics are fundamental, are actually two ways of describing the same thing. This reflects the more general rule that can be stated as follows: *any representation of the objective world can be made in two ontologically opposite, but epistemically equivalent forms, depending on whether a continuum of change is attributed to the observer (including its abstract, CON equivalent), or to the observed*. Reality is either, a continuous flow of bits against an abstract background, or a continuum of change in which the bits are abstract entities. The first statement is quantum-like, against some abstract background continuum; the second is classical with an intrinsic continuum and block universe, in which the concept of static bits (A_M and B) is abstract. The question of whether fundamental reality exists in bits or a continuum is unanswerable; the question is meaningless without the mind of a thinker.

There is one further hypothesis that can be inferred from this sort of crude analysis of the so-called 'four empirical certainties'. When this hypothesis of ontological duality is re-combined with the CON hypothesis, we come upon a model of subject-object complementarity, which offers an apparently credible basis for a new endophysics paradigm.

3 Implications Part II: The Mind-Matter Relationship

3.1 Subject-object complementarity: An endophysics paradigm

The 'hard problem' was the question of why consciousness accompanies certain physical processes, when any physical processes should be sufficient to explain physical effects in a causally closed world. This can now be seen as an incorrect formulation, because consciousness is always a part of physical process, in abstract form. The hard problem was impossible to solve because the world of matter excluded the phenomenon of consciousness. Now however, since every description of matter must incorporate some reflection of mind, the problem has been transformed. Of course, metaphysical questions remain; where does reality come from, for instance? But the question of why consciousness exists can be answered in terms of the behaviour of matter. All we have to do is find the correct way to describe the relationship. Once again, some broad principles that seem to govern the relationship, suggest themselves. In a later section, I shall speculate on how the human brain might instantiate these principles, to produce consciousness.

First, let us look again at the crude governing principle that arose earlier. *The beginning of a duration of time must influence the end of the duration in some way that is different from, and in addition to, it's past role in causal history.* We can go deeper by further examination of the four statements of empirical certainty in the context of both the CON hypothesis and the further hypothesis of representational duality. Recall that without panpsychism or mind-spirit dualism, consciousness must be considered a dynamic process. Somehow this dynamic process must occur outside the causally closed world in which energetic process is entirely sufficient to explain effects, yet must also be part of the physical world. We also know from the CON hypothesis that energetic process is not sufficient for physicalism, which must include mind in its abstract form as the techniques and paradigms of a particular theory. In physics, these techniques, paradigms, boundary conditions, laws etc act as a fixed informational framework that all help to determine *the form* of particular energetic processes. In consciousness however, the dynamics are opposite. The four certainties tell us that the existence of an independent physical world is something we infer from the experience of consistency against a background of change. Here, in subjective experience, it is the informational, unconscious background that is active in relation to persistent features of the external world. There is an complementarity between the phenomenon of subjective experience and physics. Let us look at this more closely.

The mechanism of consciousness can be seen as the hypothetical modelling of persistent patterns in the causal flux we receive from the physical world. The experienced duration of $A \to B$ requires that A is a lingering memory or model of A, call it A_M. The representation A_M is hypothetical in the sense that it is proposed by the brain to be an effective model of something in the immediate past. The brain might have chosen A_X or A_Y to represent A, but if these proved less useful than A_M, then biological natural selection would eliminate them. Either the neural firing patterns representing A_X or A_Y would not be reinforced by repeated use, or perhaps the owners of such brains might step off a cliff thinking it was a pothole and subsequently fail to reproduce. This idea owes much to Karl Popper's description of biological structure as being theoretical in nature, subject to falsification by a hostile environment [13]. We shall see later, that there is no need to invent some magical new force of nature to explain this process of modelling; it can have a physical basis, but more of that later.

Thus there is an *ontological complementarity* between the concepts of subjective and objective views of reality. The idea of complementarity was first introduced by Neils Bohr in 1927 when he claimed that Heisenberg's uncertainty principle was a specific instance of a more fundamental principle in which the complete classical description of microscopic phenomena requires knowledge of two complementary but mutually exclusive quantities such that measuring one destroys information about the other [14]. In the model of subject-object complementarity I am proposing, which might be called *CON Complementarity*, all the elements present in one perspective are also present in the other, but whereas causal dynamics are active and real in the objective perspective, they become the relatively fixed, relational framework in the subjective phenomenon of being. Similarly, where the process of hypothesis is active and real in subjectivity, it forms the relational, abstract framework in physicalism; it becomes the 'stuff' known as matter.

CON Complementarity is summarized by the proposition that the following two statements are equally true:

(a) Empirical reality is the action of energetic process in relation to a conceptual framework of predictive knowledge (objective)
(b) Empirical reality is the action of hypothesis in relation to consistency in energetic dynamics (subjective)

Statement (a) describes the exo-physical paradigm, but with the inclusion of consciousness represented in the framework of knowledge. Statement (b) describes the subjective phenomenon of experiencing reality. This is seen as the action of knowledge in the brain giving form to energetic processes, to become the phenomenon of experiencing physical reality. In each statement, there is a relatively fixed, representation: however, any notion of stasis is an illusion, rather the opposite of block-world models. That which appears to be fixed and relational in one statement, is actually dynamic. The knowledge framework of physical theory might appear to be relatively fixed, but at a glance can be seen to be dynamic on certain timescales, for example, during the change from Newtonian to Relativistic mechanics. Within the empirical certainty of experience, the two perspectives are superimposed: we can look at reality objectively as well as experience it qualitatively. In this model, time being an abstraction of change, is duplicate. There are two time dimensions that are independent of each other [3], one that is abstracted from the process of predictive hypothesis, and the other, from energetic change.

This model does not pretend that duality is an illusion. After all, duality is one of our empirical certainties. Part of the phenomenal world has so far, always behaved independently of the phenomenon of experiencing. It seems appropriate therefore, to seek the most productive way to model duality, rather than pretend it did not exist. CON complementarity replaces the frustrating mind-matter duality and its associated hard problem, with an integrated complementarity. 'Integrated', because the new model of empirical reality includes the act of hypothesis entailed in perception, within the concept of physical process. 'Integrated' also, because this is the same as saying that the model of empirical reality includes causal history within the concept of perceptual modelling. Both statements are opposite sides of the one coin, the former is the physicalist perspective and the latter, subjective. The model allows us to inter-convert the concepts of physicalism and subjective experience, such that everything present in one is also present in the other, but those elements that are fixed and conceptual in one, become dynamic, active and real in the other. Where hypothetical modelling is dynamic and real during qualitative experience, it becomes the abstract reference framework in physicalism. Consider the classic example of a red rose. The rose can be seen objectively in terms of its causal history, in relation to our knowledge of causality, and other physical laws. The qualia of smelling a rose on the other hand, is the movement of knowledge in relation to consistent patterns in the rose's causal history. The more the brain can access and focus unconscious knowledge, the more intense the experience.

3.2 Mind-matter relationship: The brain

Having started with a metaphysical hard problem, we now have a physical task. Armed with the admittedly crude concept of CON complementarity it becomes possible to design physical systems that would provide consciousness. The real difficulty is to explain how the process of hypothetical modelling can have a physical basis. CON complementarity implies that consciousness is correlated with the degree to which knowledge is active across the brain, a principle that has much in common with Baars global workspace theory [15]. The real difficulty however, is explaining how it could also act independently across the brain. Nowhere in the physical world can information embedded in material, act independently of that material. The simple solution to this dilemma is duplication. If a process of causal change were duplicated onto a different physical system, which itself had access to the organism's store of knowledge and memory, it would mean that the replicated knowledge, although physically caused, could act independently of the original.

Surprisingly perhaps, there is a feasible way that such a process of continuous duplication could take place in the brain. Biological knowledge is hard-wired in the pattern of neural connections in the brain. Each time a neuron fires, an electric charge is delivered down its axon, leading to the release of hormone at a connecting synapse with other neurons. Every synaptic discharge reinforces the inter-neural connection; neurons that 'fire together, wire together' [16]. Electromagnetic (EM) field theories of consciousness postulate that consciousness is instantiated in the EM field associated with firing neurons, and various such theories have been proposed [17,18]. It is important to note that EM theories of consciousness do not contradict the neural doctrine that consciousness be correlated with neural activity, since the shape of a particular EM field is determined by which neurons are firing at the time, something in turn determined by which neural connections have evolved over time. There is evidence that synchronous firing of neurons is associated with consciousness [19,20,21]. Such synchronous firing patterns produce correlated EM fields, which have some rather special properties. Every point in these correlated fields contains information about the shape of the whole field at that moment. CON complementarity predicts that these macroscopic correlated fields should replicate onto something with a different physical basis and access to huge memory, which in turn, can then interact with the original. As it happens, this is physically possible. Macroscopic correlated EM fields could interact with multiple microscopic quantum fields. Interaction of this kind is specifically predicted within quantum field theory (QFT). When applied to warm systems interacting with an external environment (open systems), QFT predicts a massive, indeed infinite memory, because an infinite number of distinct, zero energy, vacuum or ground states are possible [22]. Furthermore, for such open systems, QFT specifically predicts there should be two fields that mirror each other, known as a 'tilde' system. It is possible then, that patterns of synchronous neural firing could be stored inside the firing neurons, possibly in ordered water associated with dendritic microtubules. It is also possible that the multiple memories of previous firing patterns, stored within neurons, could influence current macroscopic firing behaviour, thereby causing consciousness as defined by CON complementarity. This proposal could also work under the Hameroff-Penrose model of consciousness, which they call the Orchestrated Objective Reduction model (Orch OR) [11], but only if they simplified their ontology, such that different space-time geometries represented the memory ground states of previous neural firing patterns, rather than being a code for platonic truth. This vision of the mind-body relationship, predicted by CON complementarity is empirically falsifiable in principle; a task best left to others.

4 Conclusion

It appears proven that the physical world cannot be understood without taking into account the particular effects of the phenomenon of consciousness. Which also proves that the hard problem can be solved in principle, at least in terms of physical theory, if not in terms of the metaphysical question 'why does anything exist'? It is no longer conceivable or logical, that zombie creatures could exist that are physically identical to us, but lacking subjective experience: because the CON hypothesis gives us a governing principle of consciousness, which makes it impossible for a creature without consciousness to be physically identical to a creature that is conscious. The governing principle of consciousness is a little crude at present, but it can, in principle, be refined into something more precise. At present, it can be stated qualitatively that to exist, is to create duration by modelling the immediate past, such that the model can influence the present in two ways; firstly in terms of its causal history, and secondly in terms of its symbolic meaning.

Empirical reality is the fusion of two processes, one of which is energetic change as conventionally understood in physical theory, and the other is prediction and hypothesis, which must be considered to be an additional, virtual dimension in physical theory. In physical theory, the predictive power of hypothetical knowledge is the relatively fixed framework of the background paradigms and theory in question. However, when that process of hypothesis is dynamic in relation to consistency in causal history, we are describing subjective experience. The experience of redness for example, is the action of biological hypothesis, including that which is hard-wired in our eyes and visual pathways, in relation to recognised patterns of energetic process. Thus, instead of the previous duality between mind and matter, we now have an integrated complementarity of two perspectives, the subjective and the objective: CON complementarity.

Having defined consciousness in physical terms, it becomes possible to produce plausible models of how the brain might cause consciousness. This is important philosophically, because a true solution to the hard problem should allow consciousness to a unique place in nature, and yet be reducible to micro-physics in terms of its own causation; a position known as *non-reductive physicalism* [23]. The particular model I suggested may eventually be proven false, but the important point is that such models become possible in principle, which is evidence that the hard problem is no longer metaphysical; no longer 'hard' but easy, albeit in a rather difficult sort of way.

I had hoped to say more on the implications of this approach for our picture of physical reality, but unfortunately I can add little more to my comments in the last endophysics workshop [3]. Certainly space-time cannot be considered primary. In this, I agree with Jaroszkiewicz [10], furthermore, his emphasis in this volume on Bayesian probability is fully in keeping with the approach here in which hypothesis is always part of empirical reality, both subjective, where it is dynamic, and objective, where it is not. Space-time is outside the four empirical certainties, and is therefore part hypothesis. Consequently it is subject to the principle that it can be represented in two ontologically opposite but epistemically equivalents ways.

The most important lesson of the CON hypothesis is that it is indeed possible to incorporate the subjective mind into physics, where it belongs, but only when we come to grips with the true nature of uncertainty.

References

1. Wheeler, J.A. (1986) Hermann Weyl and the unity of knowledge, *American Scientist* **74**(4), 366–375.
2. Sanfey, J.J. (2000) The physics of meaning, in R. Ascott (ed.), *Art, Technology and Consciousness: Mind @ Large*, Intellect, Bristol.
3. Sanfey, J.J. (2003) Reality, and those who perceive it, in R. Buccheri, M. Saniga and W. M. Stuckey (eds.), *The Nature of Time: Geometry, Physics, and Perception* (NATO ARW), Kluwer Academic Press, Dordrecht–Boston–London, pp. 105–113.
4. Chalmers, D.J. (1996) *The Conscious Mind*, Oxford University Press, Oxford.

5. Nagel, T. (1974) What is it like to be a bat?, *Philosophical Review* **83**, 435–450.
6. Schwanauer, F. (2005) personal communication.
7. Penrose, R. (1989) *The Emperor's New Mind*, Oxford University Press, Oxford.
8. Rossler, O.E. (1985) Classical quantization: Two possible approaches, in G. Casati (ed.), *Chaotic Behaviour in Quantum Systems*, Plenum, New York, pp. 345–351.
9. Buccheri, R. (2003) The intelligibility of nature, the endophysical paradigm, and the relationship between physical and psychological time, in R. Buccheri, M. Saniga and W. M. Stuckey (eds.), *The Nature of Time: Geometry, Physics, and Perception* (NATO ARW), Kluwer Academic Press, Dordrecht–Boston–London, pp. 403–416.
10. Jaroszkiewicz, G. (2005) The entropy of the future, *this volume*.
11. Hameroff, S., and Penrose, R. (1996) Conscious events as orchestrated space-time selections, *J. Consc. Studies* **3**, 36–53.
12. Stuckey, W.M., Silberstein, M., and Cifone, M. (2005) Reversing the arrow of explanation in the relational blockworld: Why temporal becoming, the dynamical brain and the external world are all "in the mind", *this volume*.
13. Popper, K. (1972) *Objective Knowledge: An Evolutionary Approach*, Oxford University Press, Oxford.
14. Bohr, N. (1927) The quantum postulate and the recent developments of atomic theory, *Atti del Congresso dei Fisici*, Como, 11–20 Settembre, Zanicelli, Bologna.
15. Baars, B.J. (1997) *In the Theater of Consciousness: The Workspace of the Mind*, Oxford University Press, New York; Bergson, H. (1896/1911) *Matter and Memory* (translated by N. Paul and W. Palmer), Allen and Unwin, London.
16. Stent, G.S. (1973) A physiological mechanism for Hebb's postulate of learning, *Proc. Natl. Acad. Sci. USA* **70**, 997–1001.
17. Pockett, S. (2000) *The Nature of Consciousness: A Hypothesis*, N.E. Writer's Club Press, Lincoln.
18. McFadden, J. (2002) Synchronous firing and its influence on the brain's electromagnetic field: Evidence for an electromagnetic theory of consciousness, *J. Consc. Studies* **9**(4), 23–50.
19. Singer, W. (1993) Synchronisation of cortical activity and its putative role in information processing and learning, *Ann. Rev. Physiol.* **55**, 349–374.
20. Varela, F. (1995) Resonant cell assemblies: A new approach to cognitive functioning and neural synchrony, *Biol. Research* **28**, 81–95.
21. Lutz, A., Lachaux, J.P., Martinerie, J., and Varela, F.J. (2002) Guiding the study of brain dynamics by using first-person data: Synchrony patterns correlate with ongoing conscious states during a simple visual task, *Proc. Natl. Acad. Sci. U. S. A.* 10.1073/pnas.032658199v1.
22. Vitiello, G. (1995) Dissipation and memory in the quantum brain model, *International Journal of Modern Physics* **9**, 973–989.
23. Van Gulick, R. (2001) Reduction, emergence and other recent options on the mind/body problem, *J. Consc. Studies* **8**, 1–34.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 547–566

ENCOUNTERING COMPLEXITY: IN NEED FOR A SELF-REFLECTING (PRE)EPISTEMOLOGY

VASILEIOS BASIOS
Interdisciplinary Centre for Nonlinear Phenomena and Complex Systems
C.P. 231, Université Libre de Bruxelles, Brussels, B-1050, Belgium
(vbasios@ulb.ac.be)

Abstract: We have recently started to understand that fundamental aspects of complex systems such as emergence, the measurement problem, inherent uncertainty, complex causality in connection with unpredictable determinism, time-irreversibility and non-locality all highlight the observer's participatory role in determining their workings. In addition, the principle of 'limited universality' in complex systems, which prompts us to 'search for the appropriate level of description in which unification and universality can be expected', looks like a version of Bohr's 'complementarity principle'. It is more or less certain that the different levels of description possible of a complex whole — actually partial objectifications — are projected on to and even redefine its constituent parts. Thus it is interesting that these fundamental complexity issues don't just bear a formal resemblance to, but reveal a profound connection with, quantum mechanics. Indeed, they point to a common origin on a deeper level of description.

Keywords: Selforganization – Complexity – Objectification – Pre-Epistemology

"Mais quand une règle est fort composée,
ce qui luy est conforme, passe pour irrégulier"
(But when a rule is extremely complex,
that which conforms to it passes for random)
Leibniz, Discours de Métaphysique, VI, 1686

1 Introduction

The main thesis of this presentation is that Complex Systems afford many and distinct levels of descriptions, dynamical, structural, geometrical or topological, metric or probabilistic, or even a hybrid interplay of the above. Moreover, especially for 'real-life' complex systems, any observation will necessarily be partial, incomplete and always depending on the observer's choices due to incompressible initial conditions and/or approximate parameter estimation. This points to the fact that no single set of mathematical or other formalism — as we know them — is or could be capable of both a complete and consistent description of a complex whole.

Therefore a new double-edged approach is called for. A concertated approach which, on the one hand, would synthesize and unify, at different levels, using different tools and descriptions. And, on the other hand, being able to discriminate among several given aspects of the facts under scrutiny, and how these facts were acquired based upon the specifics of sets of objects and relations which provided these facts.

In short, we are fast reaching the point where we need to concern ourselves not only with the study of nature, but with the nature of that study. Being aware of the limits of our descriptions we can describe the limits of our awareness. That, as a consequence, will set the search of a 'Science towards the Limits' as William James called the scientific endeavour which is capable of reflecting not only upon its abstractions — a discourse that epistemology provides — but also reflecting upon its fundamental objectifications — that is one step beyond considering a pre-epistemology able to provide such a discourse.

2 What is Complexity that We Should Be Mindful of?

Looking into Webster's dictionary the word 'complexity' is defined as 'the quality or state of being complex' and in the entry 'complex' we see that it means:

> Main Entry: (1) complex, Function: noun, Etymology: Late Latin complexus totality, from Latin, embrace, from complecti, Date: 1643, (1) : a *whole* made up of complicated or *interrelated* parts.

Self-referential as this definition might seem places the emphasis on 'whole' and 'interrelated parts'. As we came to understand, something complicated is not necessarily complex although a complex system could be complicated. The terms 'whole' and 'interrelated parts' are emerging as fundamental notions upon which the nonlinear relations among constituent parts rely and as such are identified. This has been the case mainly in physical sciences but it is not necessarily restricted to only there.

Indeed, this connection between complexity studies and nonlinear science brings forth a deeper understanding across the divide of subjective and objective narration in fields as diverse as physics, chemistry, biology, cognitive and consciousness studies, and even sociology and economics.

In complex system studies one is confronted with nonlinear relations which give rise, usually, to a great number of states. This multitude of states most of the times signifies many levels of ongoing processes of different time, and space, scales. The signature of complexity is the presence of multistationarity and/or chaotic regimes of motion.

All these aspects unavoidably lead to the breaking of symmetries both in the spatial (pattern formation) and the time (irreversibility) domain.

It is, now, well understood that these emergent patterns and rhythms are due to 'nonlocal' — in the sense that the correlation lengths of the patterns and rhythms emerging are orders of magnitude larger than the correlation lengths of their constituent parts — as well as an associated limited horizon of predictability due to strong sensitive dependence on initial conditions and parameters, which is the *sine qua non* of chaotic motion.

Of course complexity of form and structure is not a new or alien concept in the field of scientific investigations. Intricate patterns and forms, structures with great beauty and delicate design have captured the attention and admiration of scientific thinking since the dawn of time. A classic reference remains D'Arcy's 'On Growth and Form' [1]. Recently, the studies of structural complexity in relation to information processes, from physicochemical and biological systems, to man-made networks such as electricity's power-grid, the 'World Wide Web' and the internet, various social groups, *etc.*, have made an impact on the scientific literature and created lively discussions (see, for example, [2, 3] for an introduction, specialized references can also be found therein).

Nevertheless, aside from the structural aspects of complexity the dynamical basis of it has been a path-breaking area of research during the sixties and onwards. Owing to the early, seminal, contributions of Hermann Haken, Ilya Prigogine, Brian Goodwin, their co-workers, and many others, the role of nonlinear relations and fluctuations to self-organization, synergetics, pattern formation, irreversibility and, in general, to what now tends to be called 'emergence' has been ellucidated. For an overview of their work, one might consult [4, 5, 6].

These pioneering contributions go well beyond qualitative descriptions, analogies and metaphors. They address fundamental issues such as the interplay of structure, function and fluctuations; they invoke a non-classical — sometimes circular — causality (since the parts collectively determine the macroscopic order parameters and the macroscopic order parameters determine the behavior of the collective of the parts) and they offer a new apprehension of the fact that determinism does not necessarily imply predictability (a corollary due to sensitive dependence on initial conditions and parameters).

Through the analytical tools of theoretical physics and mathematics unexpected relations between topological and geometrical aspects (structure), dynamical laws (function) and stochastic processes (fluctuations) were discovered in complex systems.

3 The Complex and the Quantum: Classical Objects Misbehaving

A curious thing about Complexity as the hailed 'third revolution in physics' is that it did not happen as a paradigm shift over unaccommodated data and unexplained facts. Definitely it is not the brainchild of a single investigator, like Relativity, and has not been followed by explosions threatening mankind, like Quantum Mechanics. Although its technological and conceptual advances are being harvested by the most wide array of disciplines possible in science, it constitutes a community of ideas and workers with a quite well defined area of studies and a fertile laboratory of new concepts characterized by a noted interdisciplinary nature and an intrinsic multitude of approaches.

Probably it was a spectacular and rapid advance of Quantum Mechanics and Relativity that attracted attention away from the developments of nonlinear science in the turn of the previous century. Indeed, it is commonly believed that classical determinism had to be revised after the advent of the uncertainty principle and the ever present, fundamental in nature, 'quantum jumps'. But this statement, although commonly accepted, is far from right. As John C. Sommerer put it in [7]:

> To cast the situation as a mystery, classical determinism was widely believed to have been murdered (maybe even tortured to death) by quantum mechanics. However, determinism was actually dead already, having been diagnosed with a terminal disease 10 years earlier by Poincaré. Having participated in a very late autopsy, I would like to describe some of the findings.

What Poincaré diagnosed was that classical systems with a given degree of complexity, due to the nonlinear interactions present among their parts, give rise to very complicated motion. Today, we have arrived at calling this kind of motion, that he first encountered, 'chaotic'. In the case of Poincaré the system at hand was the celebrated 'three body problem' within the setting of classical Newtonian gravity. Poincaré's investigations triggered another famous mathematician of these days, Hadamard, to study a more general setting. Hadamard was — probably — the first to articulate what we now call 'sensitive dependence on initial conditions' or 'the butterfly effect', the hallmark of chaos. Indeed, it was in the year 1898, almost twenty years before the dawn of quantum mechanics, when Jacques Hadamard published his work on the motion of particles in surfaces with negative curvature. In the course of this work he showed that this motion is everywhere unstable [8]. Hadamard utilized a simple description of all the possible sequences, induced by the motion on the geodesics of surfaces with negative curvature. His idea was to project the motion onto partitions upon the surfaces in the regions that takes place and examine all possible trajectories of the visiting particle. By constructing a finite set of forbidden pairs of 'symbols' associated with each region of the partitioned surface, he showed subsequently that the possible sequences are *exactly* the ones which do not contain these forbidden pairs. Actually he was the first to intoduce a new and powerfull tool that now we call *'symbolic dynamics'* with fundamental notions central to (discrete) probability and what later will be identified as *information theory.*

This work, although quite mathematical for the physicists of his time, proved to be rather fertile and was later taken up by Birkoff and von Neumann in their work on ergodic hypothesis, published in the early 1910's. Further decisive progress came, again, from the work of Poincaré. He was concerned with problems of instability and integrability of dynamical systems. As a famous mathematician and philosopher of his time, he increased his fame even more by winning the prize of 2500 kroner put forth by King Oscar II of Sweden and Norway. The contest consisted of several questions, one of them formulated by Weierstrass and concerning 'our understanding of the solar system': Three bodies, Sun, Moon, Earth, attract each other by Newton's law for gravitation. Could one find a solution in a closed form or in form of a converging series? Poincaré won, although his celebrated result is a negative one: he managed to show that this motion does not have any conserved quantity and thus is non-integrable.[a] Poincaré's work opened up an area of research that enabled us to deepen our understanding of the solar system as the competition, set by the king, demanded. It also enabled us to deal with a wide class of systems with unstable motions. Poincaré based

[a]Actually what Poincaré showed is that the Bernoulli technique of finding a conserved quantity cannot yield any conserved quantity analytic in the momenta and positions of the bodies. Curiously enough, a Finnish mathematician named Sundman was later able to find a series of the type Weierstrass asked. But Sundman's technique is useless for any calculation, even though it is constructive, so it remains undeservingly forgotten.

his methods on geometry and he provided us with a wealth of techniques and concepts widely used in chaotic dynamics. He is thus considered as the founding father of the theory of Nonlinear Dynamical Systems.

The work of Birkoff, Poincaré and others was almost equaled by Lyapunov and his celebrated 'Russian School' in dynamical systems. Later on, Adronov in his work on nonlinear oscillators formalized and deepened the understanding of the particular class of planar dynamical systems and prepared the ground for the interpretation of the experimental results of Lord Rayleight III, laid out in his famous treatise 'Theory of Sound', as well as those of van der Pol and Duffing on forced oscillators with friction. These latter works were later taken up by Lady Mary Lucy Cartwright and J.E. Littlewood. While Adronov was 'leading his group' in Russia, in the other parts of Europe this area of study was almost halted. The theory of Relativity and Quantum Mechanics were drawing almost all the attention.

Yet, although the period 1910–1950 was stagnant for nonlinear dynamics some results were paving the way for the future renaissance of the field, which happened in the mid sixties. In a series of papers starting in 1921, Marston Morse had given a scheme of enumeration of the orbits of the class of systems considered by Hadamard. This body of work motivated the studies of Artin, Heldund and Hopf cumulating in proving that the motion of a ball on a surface of constant negative curvature was ergodic. One of the first physicists who realized the importance of these results was Krylov, arguing that a physical billiard *is* a system with negative curvature along the lines of collision. Later, Sinai showed that a physical billiard can be ergodic (the well studied 'Sinai billiards').

After more than a century of development, today, we come to appreciate a 'billiard' — or a *pinball*, in modern terms — as a prototype system for chaos [9]. Fig. 1 is an illustration of the complexity of such a *seemingly* simple system. Complexity, in describing the sequence of the trajectory of a test-particle visiting each disk here, enters through the nonlinear relationship (the curved surfaces of the disks) between its parts (the disks). It is this aspect that makes the dynamics of such systems chaotic. If it were that the reflecting surfaces were flat, i.e. rectangular boxes instead of disks, the system would be *complicated* but not *complex*, the parts would have uniquely define the whole as their linear superposition; whereas in complex systems the whole is more that its parts due to the intricate, nonlinear, interrelations between parts and whole that. Thus one attributes emerging properties to such systems.

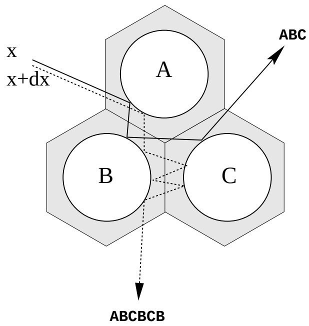


Figure 1. Motion of a test particle in 'pinball' serves as a simple, representative and very descriptive model for chaotic/complex systems. Chaos arises due to complexity because of the strong nonlinear relations among its parts.

4 The Fallen Doctrine of Classical Determinism

The link between deterministic causality and stability of classical systems did not escape these early days the penetrating genius of James Clark Maxwell. Reflecting upon the roots of causality, he has written (quoted in [10]):

> It is a metaphysical doctrine that from the same antecedents follow the same consequents. No one can gainsay this. But it is not of much use in a world like this, in which the same antecedents never again concur, and nothing ever happens twice...
> The physical axiom which has a somewhat similar aspect [with this doctrine] is 'That from like antecedents follow like consequents'.

What chaos and complexity studies have revealed is that our classical notion which expects determinism to imply predictability is a long held fantasy stemming from the Newtonian/Laplacian paradigm. As a matter of fact, it is more than a false fantasy, it is a persistent fallacy in scientific and philosophical thought for over three hundred years. Laplace's all-knowing daemon, the god of reductionism, is symbolized in one of Laplace's most famous proclamations:

> ... if we can imagine a consciousness great enough to know the exact locations and velocities of all the objects in the universe at the present instant, as well as all forces, then there could be no secrets for this consciousness. It could calculate anything about past or future from the laws of cause and effect.

A relevant discussion about the Newtonian/Laplacian doctrine and modern developments of chaos theory can be found in [11], (pp. 9–14). This prevailed as a paradigmatic bias only to start coming to its natural end by Werner Heisenberg's proclamation of his uncertainty principle. What is of interest here regarding this principle is that it talks, at a different level, for complex systems as well. Let us follow Heisenberg's line of thinking; he states that [11]:

> In the strict formulation of the causality — 'When we know the present precisely, we can calculate the future' — it is not the final clause, but rather the premise, that is false. We cannot know the present in all its deterministic details. Therefore, all perception is a selection from an abundance of possibilities and a limitation of future possibilities.

This is true for the, ontologically probabilistic, quantum mechanics. But is it not true when we encounter complex, or chaotic, dynamics? Even if we think of them as ontologically deterministic, could we ever hope to know in perfect detail and exactly their precise initial conditions? If we ascribe to the fact that initial conditions are represented by the continuum of real numbers, can we pin down with infinite precision real numbers since almost all of them are irrationals and impose the need for infinite amount of information? Definitely in the mind of the Laplacian god of reductionistic mechanism that could be true but in any act of projection, such as measuring or specifying initial conditions, that we pure humans have to go through, we necessarily loose certainty and end up with probabilities. We must stress, once more, that the above is unavoidable even if the laws are deterministic and our theories at hand — providing these laws — impeccably correct.

Definitely the vivid discussions over causality, determinism and Quantum Mechanics — and Relativity, to certain extent — covered what chaos and complexity studies were whispering until the sixties and seventies. With the appearance of fractals, self-organization, emergent pattern-forming systems and the realization that seemingly simple, deterministic yet non-linear, dynamical systems — which are, by the way, fully transparent to rigorous mathematical investigations — give rise to chaos, we now have entered a new frontier in sciences.

We have chosen to follow a certain line of historical developments of this field which have not been narrated as often as the one we learn from the recent rediscovery of chaos and complexity. Of course it is not an exhaustive account. The aim of this presentation is not to give historical details but to help, hopefully, in revealing aspects of complexity studies that are instructive of what kind of issues and ideas inform about the new way of thinking.

The lessons we are learning from this new era are numerous and still being born. One of these that we shall focus on is that we must be fully conscious with what objects we are preoccupied. The multitude of available states of complex systems and their inter-relations make possible different levels of description of a complex whole. These levels of descriptions, our own partial objectifications, are projected on to, and even redefine, its constituent parts.

5 Probabilistic Conceptions of Chaos and Complexity

Prediction is difficult, especially for the future
Niels Bohr

Let us see now, in a very general setting, what kind of 'simple', deterministic, nonlinear dynamical systems can tell us about the distinction between determinism and predictability. What this brings to the concept of causality and how it gives rise to a probabilistic way of approaching complex systems which resembles at certain aspects the Schrödinger picture of quantum mechanics.

A common, yet historically important, example of such systems is what is known as the logistic map. A time-discrete dynamical system which can be found in any other standard textbook of nonlinear science (for a detailed account, see [11]; for an introduction into its probabilistic approach, see [5, 9]) describes a wide array of diverse phenomena in population biology, electrical circuits, birth-and-death processes, even lasers and information processing. It is a one-dimensional system characterized by a state variable, say x, which takes continuous values within an interval, say $[0, 1]$, which is updated in a discrete fashion each discrete time step, t. The updating follows the simple deterministic rule $x(t + 1) = \mu x(t)(1 - x(t))$, where μ is a real-valued parameter. By changing its parameter we observe a tremendous repertoire of qualitatively different dynamical behaviors: from stable periodic via quasi-periodic to chaotic. For $\mu = 4$ we are in the region of what is called 'fully developed chaos' with its *sine-qua-non* sensitive dependence on initial conditions. A typical trajectory, the motion from a single starting point to its iterates, then would look *as if* it were random. The left-hand side of Fig. 2 shows exactly this evolution. This 'erratic' motion cannot be repeated, as a whole, by any other starting point no matter how close they are. It is nevertheless fully determined in 'theory' although not determinable due to the fundamental inability to explicitly express any typical initial condition (i.e. an irrational number) in full accuracy.

Turning now from this point-like 'topological' description of trajectories to a probabilistic treatment, we see a different picture emerging. If we now set as observables not each point but the statistics of each typical trajectory, we observe that they all have the same histogram. Each one of the erratic trajectories now produces the same statistical distribution over very large time intervals (infinite in the theoretical treatment, sufficiently large in practice). They all visit the available phase-space according to the so-called invariant measure of the iteration rule (or 'mapping'), as depicted in the middle of Fig. 2. To complete this probabilistic description one starts over

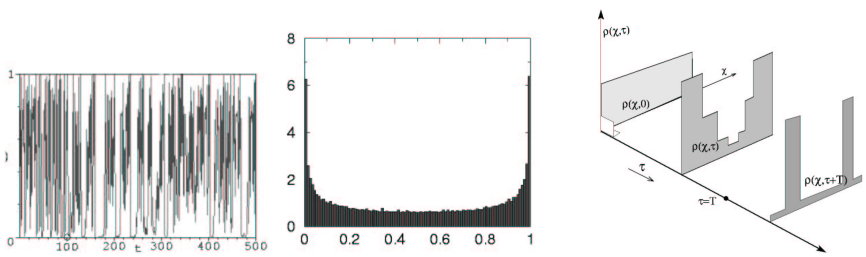


Figure 2. A typical trajectory, i.e. a point-like description, of a chaotic system (on the left) is unstable and erratic. A statistical treatment (i.e. its probability density in the center) reveals that ensembles of trajectories, i.e. a probabilistic description, follow a stable evolution (on the right).

again considering now from the beginning not one point, but a collective, or ensemble, of them (technically, of course, this is a merit of our system being ergodic). This ensemble now takes whole new meaning and interpretation. It signifies the probability to start from any point, or the initial density of state. This, or any other, (smooth) probability density will eventually take a *predictable*, stable route towards the invariant probability density after a sufficiently long time. This is sketched on the right-hand side of Fig. 2, for an initial ensemble with equiprobable starting points.

These two different, yet connected, pictures are based on different assumptions of what is an observable fact in each setting. Their evolution operators are different. The point-wise evolution operator and its erratic, unstable, unpredictable, outcome versus the operator which evolves the ensembles with its resulting smooth, stable and predictable evolution. We gained predictability for the collective but we lost the individual fate. We lost certainty of each sharp outcome and we gained accurate prediction of the probabilities of repeated outcomes.

6 A Glance at Irreversibility

In the above picture where probability densities evolve[b] deterministically and all initial probabilities tend to the invariant probability density we can say that the system looses 'memory' of its initial conditions in the course of its evolution. Thus the evolution is characterized as irreversible. Coming from the future backwards we do not really know where we started, all initial settings seem equally plausible.

This is a kind of chaotic system which reflects basic aspects of the 'problem of irreversibility'. That is, the demand for a consistent description of macroscopic irreversibility in terms of reversible microscopic dynamics. All theories of physics at work, classical dynamics, Electro-Magnetism, Relativity, Quantum Mechanics, start from reversible laws. Time in these theories can go back and forth and we cannot distinguish past from future. The measurement problem (either by the collapse of the wave function in Quantum Mechanics or by the projection onto any coarse grained set of observables, in classical complex/chaotic) and the field theories of Thermodynamics and Diffusion though paint a totally different picture. Heat flows always from the hot to the cold, salt dissolves in water, for any irreversible process like these to extract an opposite behavior we have to pay the price in energy. The only law that goes against all other laws is the celebrated 'Second Law of Thermodynamics' which defines an arrow of time. Irreversibility is one of the long standing problems in statistical mechanics, actually it turns out to be its own 'Holy Grail', so far. Refraining from this long and cumbersome subject, we shall mention only that an up-to-date discusion about irreversibility and its relation to the underlying chaotic dynamics can be found in [12] (with one of the most detailed list of publications on the subject).

Nevertheless, we must also mention that the evolution operators appearing in this context of complex system studies admit a treatment which bears important similarities to the operator algebras of quantum mechanics, especially to the Dirac picture of quantum mechanics based on the duality between states and observables; along with all the interesting prob-

[b] The operator evolving these probability densities for such discrete systems is called the Perron–Frobenius operator (its dual being the Koopman operator) and is related to the Liouvilian operator of statistical mechanics.

lems of convergence and non-commutativity. The role of non-commutative algebras underlying the fundamental connection of unpredictability and complex causality in the framework of another picture of quantum mechanics, that of Heisenberg, and the 'trajectory based' picture of quantum mechanics, i.e. the original approach by Bohm and Hiley, is elaborated in [13]. There, new perspectives on 'Active Information' and its relation to Shannon's Entropy are outlined with envisioned far reaching implications for both complex and quantum system studies in the future. Finally, we shall mention an even more controvertial and daring line of approach undertaken by Edwin Thompson Jaynes [23] and recently re-emerging. Jaynes became a quite notorious figure among his peers in the late 1950s when he published (against the advice of referees) his ideas about the generalization of the second law for far beyond equilibrium systems. Quoting from his obituary published in *Physics Today*:

> [Edwin Jaynes] insisted that some of the thorniest conceptual problems faced in physics, notably in statistical physics and quantum theory, arise from a mistaken identification of probabilities as physical quantities rather than as representations of the available information on a system — a confusion between what is ontological and what is epistemological...

Something even more puzzling about the Second Law's time arrow is that all other arrows of time point to the same direction, what we call 'the future': biological aging, the fact that in radiation we observe no converging electromagnetic waves, in the Quantum realm where a wave function once collapsed stays that way, in the Neutral-Kaon disintegration recent experiments on CP-violation where the observed rates rule out reversed time, in probability theory where once a possibility is realized cannot be undone (what is known as 'Heads and tails don't merge'), in gravity where we observe one way collapse (so far we know about black holes but of no white holes). Add to these time-arrows the cosmological arrow of time and the subjective or psychological arrow of time, (where normally we can't remember the future, see the contribution of Metod Saniga in this issue [22]). In all and all we observe that total entropy does not decrease. Most probably all these arrows of time are somehow connected, yet how and why still remains elusive. It is one of the biggest questions on the foundation of physics, which unavoidably touches upon epistemological issues; it would be resolved though at a deeper level if we could probe our pre-epistemological assumptions and our basic doctrines of what time really *is*.

7 Then, Who Will Observe the Observers?

We have seen that as a general outline of the evolution of a complex system, we usually say that it is drawn to its attractor(s) which can be 'strange attractors' and/or 'fractal' or 'multifractal' ones as the common knowledge assimilated over the last decades points out.

Nowhere else this fundamental role of fractal geometry in the dynamics of complex systems is so pronounced with respect to the unpredictability of deterministic systems as in the case of systems with riddled basin boundaries. Systems comprising more that one attractors naturally possess boundaries between the basins of these attractors. The basin of an attractor signifies the fact that if one sets initial conditions within the basin of each attractor the evolution of the system will bring the system, eventually, to each corresponding attractor. Interesting phenomena arise whenever the boundary itself is fractal. A structural fractal geometry in phase-space adds to the dynamic fractal geometry of time evolution very counter-intuitive situations. No matter how accurately we pin-down any initial condition on the fractal basin boundary, we can never tell on which attractor we are going to end up. The unavoidable, slightest uncertainty in our approximation of the initial conditions will set us off in a totally different course of evolution landing in an indeterminable final place (within any attractor) after a given time.

To make things even more interesting, there is a quite generic class of systems, possessing more than one attractor, for which class of systems their whole phase space is a boundary! To be distinguished from the systems with merely fractal basin boundaries they are called systems with *riddled* basin boundaries (for a detailed discussion with specific examples and illustrations, see [7] and references therein). The route towards systems with riddled basin boundaries starting from systems with simple basin boundaries via the change of their parameters is known as 'Blown-out Bifurcation', a novel kind of bifurcation discovered in the early nineties due to these studies on nonlinear science. Such a complexity explosion renders any slight disturbance, fluctuation, fuzziness or approximation amenable to absolute unpredictability.

Again, a deep analogy persists with quantum mechanics related to the celebrated complementarity principle. Observation in both classical and quantum measurements share the common feature of the projection or collapse of any mixed or 'entangled' initial state onto one among a limited set of the system's final states. These are the eigenstates for quantum mechanical systems or the attractors for classical systems. Certain fundamental connections between, on the one side, the two-slit delayed experiment and, on the other side, the nonlinear dynamics of classical systems possessing coexisting attractors separated by smooth or fractal boundaries have been proposed quite recently in [14]. In particular, the quantum two-slit delayed experiment was studied in the above reference. It has been well known that in the delayed double slit experiment, the possibility to alter the initial disposition of the state vector and induce it to switch from one final state to another by altering the geometry of the setting has been realized experimentally and has been described theoretically. Such a switching was recognized to exist, also, in an analogous nonlinear classical system with two coexisting point attractors separated by a fractal basin boundary [14]. The classical analogue of the two-slit delayed experiment demonstrates indeed similar features through the switching of its unique, control parameter. Along with the authors of [14] we cannot but stress the fact that the above work draws an *analogy* between the measurement problem as elucidated by the delayed two-slit quantum system and that of a classical, yet nonlinear, information processing system with fractal basin boundaries. A deep and far reaching, in concequences, analogy, yet still an analogy.

Nevertheless, let us allow ourselves to speculate along these lines. For systems where the measurement requires a relatively, or sufficiently, long interval of time, the parameters of the system might as well change over the period of observation. They might even change in such a way that the original collection, or ensemble, of each sample make it split into a number of given subsets according to the respective results of the measurements performed. Now, given the ubiquity of fractal or even riddled basin boundaries for nonlinear dynamical systems with high dimensionality of their phase-space (degrees of freedom), it is reasonable to assume that we end up with a situation where the act of probing to perform an observation alters the state of the system, even if this is a classical — but nonlinear, complex — dynamical system. Here because of the underlying logic and non-commutativity structure of quantum mechanical systems — although ontologically different from the classical setting — permits a fundamental similarity with classical — but complex/chaotic — systems to reveal itself.

8 The Complex and the Living

It is well known that many of the early workers on the foundation of quantum mechanics, like Pauli and Schrödinger, where preoccupied with the question 'what is life?'. Bohr was the first to point out that a generalized complementarity principle, which he proposed in the framework of quantum mechanics, could be at work for living systems. Indeed living systems are *the* most profound of complex dynamical systems. Everchanging in time yet keeping a distinct sense of wholeness and identity, dynamically adjusting, equipped with vast yet undermined information processes, they stand out in the far highest levels of the hierarchies of both structural *and* dynamic complexity. Complex systems, which are not living, could provide a stepping stone towards a renewed and deeper understanding and more rich meaning of the phenomenon of life as a scientific area of study. Provided, of course, that we could raise beyond the straightjackets of any pre-ordained paradigmatic thinking.

Revisiting Aristotle, although daring, may be helpful in this respect. Aristotle maintained that plants are animals compared with rocks, but rocks compared to animals. Something similar applies to complex systems and their emerging properties. Complex systems could be seen as 'alive' compared to machines, but machines compared to living systems. Moving from the logic attached to naive mechanistic thinking, which applies to *objects* towards the logic of living systems, which applies to *organisms*, one should not be surprised if one has to go through a logic embracing complementarity, self-reference and paradox, as the logic revealed by the quantum.[c]

The idea that complementarity could be useful not only in physics but in other areas as well, in particular in biology (see [18], p. 87), was not foreign not only to Bohr, but also to other early thinkers. As Walter Elsasser remarked as early as 1968 [16]:

> L. Brillouin has gathered a great many illustrative examples to show how in problems of classical physics any initial uncertainty increases with time. His work is clearly related to the fact that since the advent of quantum mechanics there have been the two schools of thought: those who tried to return to classical determinism and those who found in quantum theory a challenge for investigating all possible ramifications or generalizations of indeterminacy which may be part of physical description and prediction.

Brillouin's work belongs to the second category, so does Elsasser's who has had already investigated the implications of the generalized complemen-

[c]Recently, in the context of analytical philosophy certain extensions of standard logics to non-classical ones have been investigated and remarks on their relevance to physics have been discused in [15].

tarity principle in the field of statistical mechanics as well as in Biology [16].

When the modern thinking in biology is concerned, nowhere else, more urgently and more cleverly, such a radical change of view has been advocated than in the 'prophetic' work of Richard Strohman [19]. He anticipated, already in the mid-90's, the 'surprising results' of the genome project which came around circa 2001. Strohman, starting from the ideas of Goodwin [6] and others about the role of self-organization, nonlinearity and dynamic complexity in systems biology draws his argument on the profound implications of complex systems studies to epigenetic networks. His main point is to challenge the underlying naive reductionistic view of modern biology that 'everything is in the genes' by making clear that any further understanding of molecular biological systems has to rely 'not in the genes alone'.

He stresses the importance of the fact that the nonlinear interelations involved in gene expression necessitates a change of perspective influencing the whole area of investigations from an object-mediated view to that of a system wide unfolding dynamical process. After the 'surprises' coming with the conclusion of the genome initiative, where 'mainstream' biology was stunned to learn that humans have far less genes than expected in comparison to other simpler forms of life, we now realize that a gene is more of a functional unit acting as — and in relation to — a whole rather than an isolated object in the DNA.

As Strohman put it when he introduced a collection of state-of-the-art publications dedicated to the topic [20]:

> Human disease phenotype are controlled not only by genes but by lawful self-organizing networks that display system-wide dynamics. These networks range from metabolic pathways to signaling pathways that regulate hormone action. When perturbed, networks alter their output of matter and energy which, depending on the environmental context, can produce either a pathological or a normal phenotype. Study of the dynamics of these networks by approaches such as metabolic control analysis may provide new insights into the pathogenesis and treatment of complex diseases.

In the above quotation we would like to put emphasis on the concepts of self-organization, system-wide dynamics, and network structure. All of which rely upon the presence of non-linear interrelations within a complex whole. Here, the relevance to the studies of complexity and statistical mechanics has been made evidently clear from a plethora of recent advances after the seminal work on complex networks by Barabási and co-workers [21]. Although a deeper dynamical system's perspective is lacking from the investigations of 'life's complexity pyramid', the authors themselves and many others testify that such a necessary step has to be taken sooner or later. How this next step will be accomplished and where it will lead our concepts of complexity, entropy, information and life remains to be seen. Nevertheless, we can expect not only interesting breakthroughs but also some fundamental questioning of the logic underlying such investigations, like Elsasser was advocating, as well as the mode of thinking that underlies any logic implicated.

To return to Niels Bohr and his reflections upon epistemological levels, "no experience is definable without a logical frame. Any apparent disharmony [among observed phenomena or levels of phenomena] can be removed only by appropriately widening the conceptual framework ". In other words, those of Emilios Bouratinos [25], hinting at a pre-epistemological level: "... modern science is constantly broadening, deepening and differentiating the world image. But if the world image is being constantly enriched, so must our ways of knowing it... "

9 Pre-Epistemology: The Complex and the Subjective

There are powers and thoughts within us, that we know not till they rise
Through the stream of conscious action from where Self in secret lies
But where will and sense are silent, by the thoughts that come and go
We may trace the rocks and eddies in the hidden depths below

James Clerk Maxwell, quoted in [10]

The realization has been that structurally simple systems could give rise to a very complex dynamical behavior and classify as complex systems even if they are composed of few constituent parts. The challenge here is to find appropriate levels of description to express any underlying, hidden, universalities. Once we pass from one description to another the objects that define our systems inevitably change, i.e. from trajectories to probability densities. This redefinition of the objectification scheme required to construct a model of any complex system at hand is not a matter of choosing which is best. The situation here calls for a radically different thinking. We need to find a way of articulating the fact how *both* descriptions hold aspects of reality, i.e. both a point-like picture *and* a probabilistic view of evolution are real; moreover, such a nonlinear thinking extracts an answer for the limit up to which these partial objectifications can safely been taken as reflecting the system's realities.

The sciences of complexity and the whole field of complex systems' studies deny the domination of one single approach. They call for a creative interplay beyond and above paradigms, whatever any paradigmatic thinking brings as benefits it also brings limitations. Complexity forces us to reflect upon our objectifications. From whatever kind of thinking these objectifications might arise — reductionistic, holistic, mechanistic, probabilistic, dualistic or metaphysical mode of thought — any level of description reflects only a partial projection of the unified *reality* of a complex system.

One of the greatest twentieth century's mathematicians working on probability, B. O. Koopman, maintained that 'knowledge is possible, while certainty is not'! As he wrote in 1940 "both in its meaning and in the laws it obeys, probability derives directly from... intuition and is prior to objective experience" [24]. Intuition and subjectivity can now be rehabilitated theoretically, provided that they are practiced openly, knowingly and honestly (see [25]). John Searle, commenting on the 'inadequacy of objective understanding', calls for more of empiricism, but of a different order [26].

> If science is the name of the collection of objective and systematic truths we can state about the world... then the existence of subjectivity is an objective scientific fact, like any other... If the fact of subjectivity runs counter to a certain definition of 'science', it is the definition and not the fact that we have to abandon.

To what extent can we experience reality without being blinded by our preconceived ideas about it? How can we be free from our own projections if we deny their existence?

10 Outlook

The sciences dealing with complexity find themselves at a crossroads. According to some skeptics, the very notion of complexity is ambiguous. Furthermore, the skeptics believe that it has given rise to a very ambitious project. They insist that its basic concept is far too all-embracing, holistic and blurred to ever become the subject of a proper scientific investigation. Needless to add that similar skepticism had been leveled in the past against the study of Time and Space, Entropy and Information, Cognition and Consciousness. Skeptics in science frequently want to fit reality into their static vision of science. But the real challenge for investigators would be to fit their vision of science into the dynamics of reality. We shouldn't allow our concepts to fashion the picture of the world. Rather we should allow the essence of the world to fashion the nature of our concepts.

Scientific thinking today has reached a stage which doesn't compare with that of any other in its history. The feeling is that Complexity and Emergence, Time and Space, Entropy and Information, Cognition and Consciousness are presently at the frontier of fundamental research in the physical sciences. Despite that, they cannot be defined in exclusively objective quantitative terms. The reason is simple. These four areas constitute also the ultimate prerequisites for the observations carried out in their name.

In our times the very foundations of what we perceive as a properly established epistemological ethos have been cast in doubt. This calls for a radically new kind of science — one that can reflect on its own foundations. It also calls for a new kind of scientists. They don't only need to be cognizant of their limitations. They need to be cognizant of their objectifications. In addition, they need to be aware of the relative merits of different, complementary or even seemingly contradictory approaches.

Never before has the need for qualitative change in science been so obvious — and pressing. The importance of complexity studies lies in that it has made such a radical change not only possible, but imperative. It can only directly inform and inspire the struggle for introducing self-reflection into science.

Acknowledgments

I would like to thank Emilios Bouratinos, Rosolino Buccheri and Metod Saniga for inspiring discussions, sharing ideas and very fruitful comments.

REFERENCES

1. Thompson, D'Arcy Wentworth (1942) *On Growth and Form*, Cambridge University Press, Cambridge.
2. Barabási, A.-L. (2002) *Linked: The New Science of Networks*, Perseus Books Group, Cambridge (MA).
3. Strogatz, S. (2003) *Sync: The Emerging Science of Spontaneous Order*, Hyperion, New York.
4. Haken, H. (2004) *Synergetics: Introduction and Advanced Topics* (Reprinted Edition), Springer–Verlag, Berlin.
5. Nicolis, G., and Prigogine, I. (1989) *Exploring Complexity*, W. H. Freeman, New York; see also Nicolis, G., and Prigogine, I. (1977) *Self-Organization in Nonequilibrium Systems: From Dissipative Structures to Order Through Fluctuations*, John Wiley & Sons, New York.
6. Goodwin, B. (2001) *How the Leopard Changed Its Spots: The Evolution of*

Complexity, Princeton University Press, Princeton (NJ).
7. Sommerer, J.C. (1995) The end of classical determinism, *Johns Hopkins APL Technical Digest* **16**(4), 333–347.
8. Hadamard, J. (1898) Les surfaces a courbures opposées et leurs lignes geodesiques, *Journal de Mathematiques Pures et Appliqueé* **4**, 27–73.
9. Cvitanović, P., Artuso, R., Mainieri, R., Tanner, G., and Vattay, G. (2005) *Chaos: Classical and Quantum*, Niels Bohr Institute, Copenhagen, available on `ChaosBook.org`.
10. Mahon, B. (2003) *The Man Who Changed Everything: The Life of James Clerk Maxwell*, John Wiley & Sons, New York.
11. Peitgen, H.-O., Jurgens, H., and Saupe, D. (1992) *Chaos and Fractals: New Frontiers of Science*, Springer–Verlag, New York–Berlin.
12. Tasaki, S. (2004) On Prigogine's approaches to irreversibility: A case study by the Baker map, *Discrete Dynamics in Nature and Society* **1**, 251–272.
13. Hiley, B.J. (2002) From the Heisenberg picture to Bohm: a new perspective on active information and its relation to Shannon information, in A. Khrennikov (ed.), *Quantum Theory: Reconsideration of Foundations*, Växjö University Press, Växjö, pp. 141–162.
14. Nicolis, J.S., Nicolis, G., and Nicolis, C. (2001) Nonlinear dynamics and the two-slit delayed experiment, *Chaos, Solitons & Fractals* **12**, 407–416.
15. Da Costa, N.C.A., and Krause, D. (2004) Complementarity and paraconsistency, in S. Rahman, J. Symons, D. M. Gabbay and J. P. van Bendegem (eds.), *Logic, Epistemology, and the Unity of Science*, Springer–Verlag, Berlin.
16. Elsasser, W.M. (1937) On quantum measurements and the role of the uncertainty relations in statistical mechanics, *Physical Review* **52**(1), 987–999.
17. Elsasser, W.M. (1968) Theory of quantum-mechanical description, *Proceedings of the National Academy of Sciences (USA)* **59**(1), 738–744.
18. Jammer, M. (1974) *Philosophy of Quantum Mechanics*, John Wiley & Sons, New York.
19. Strohman, R. (1997) The coming Kuhnian revolution in biology, *Nature Biotechnology* **3**, 194–200.
20. Strohman, R. (2002) Maneuvering in the complex path from genotype to phenotype, *Science* **296**(5568), 701–703.
21. Oltvai, Z.N., and Barabási, A.-L. (2002) Life's complexity pyramid, *Science* **298**, 763–764; and also, among many, Albert, R., and Barabási, A.-L. (2002) Statistical mechanics of complex networks, *Reviews of Modern Physics* **74**, 47–97.
22. Saniga, M. (2005) A geometrical chart of altered temporality (and spatiality), *this volume.*
23. Jaynes, E.T., and Larry Bretthorst, G. (Editor) (2003) *Probability Theory: The Logic of Science: Principles and Elementary Applications – Volume 1*, Cambridge University Press, Cambridge.
24. Koopman, B.O. (1940) The axioms and algebra of intuitive probability, *Annals of Mathematics* **41**, 269–292.
25. Bouratinos, E. (2005) A new conceptual framework for physics, *this volume.*
26. Searle, J. (1991) *Minds, Brains and Science*, Penguin Books, London, p. 25.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 567–588

TIME WITHIN: THE PERCEPTUAL RIVALRY SWITCH AS A NEURAL CLOCK

JOHN D. PETTIGREW
Vision Touch and Hearing Research Centre, School of Biomedical Sciences
University of Queensland, Queensland 4072, Australia
(j.pettigrew@uq.edu.au)

JAN D. TILDEN
PO Box 172 Maleny, Queensland 4552, Australia
(dbletake@squirrel.com.au)

Abstract: Attention is drawn to weaknesses in the case for an external, physical basis for time's perceptual phenomena, raising the possibility of a Darwinian evolutionary explanation for the apparent flow, structure and arrow of time. We develop the hypothesis that, of all arrows of time identified by physicists and philosophers, the most fundamental is the psychological arrow. Based on findings of an on-going program of empirical research, we suggest a neural basis for time phenomena in the rhythmicity and plasticity of one of the brainstem dopaminergic nuclei, the venetral tegmental area (VTA). We examine links between neural time-keeping and perceptual rivalry and discuss evidence that rivalry is mediated by the VTA which functions as an ultradian oscillator. Further research is suggested, which could challenge or support the hypothesis of the VTA as an important neural time-keeper and the subjective basis of the asymmetric phenomena of time.

Keywords: Time Perception – Perceptual Rivalry – Neural Clock

1 The Phenomena of Time and their Objective Existence

At an international conference on the arrow of time in 1991, Julian Barbour, author of *The End of Time*, took a straw poll of scientists and philosophers to discover that a clear majority of those surveyed doubted whether time was required as a fundamental concept in any theory of the world [1]. Yet nobody would deny that time is one of the most basic aspects of our lived experience. If the cause of this experience is not to be found outside ourselves then we must look for it within. Taking as its starting point the notion that time may not be a fundamental physical fact, this paper explores some experimental findings to suggest a neural basis for the familiar phenomena of time — its apparent flow, its past/present/future structure, the arrow of time and, perhaps, time itself — in the rhythmicity and plasticity of the brainstem monoaminergic nuclei.

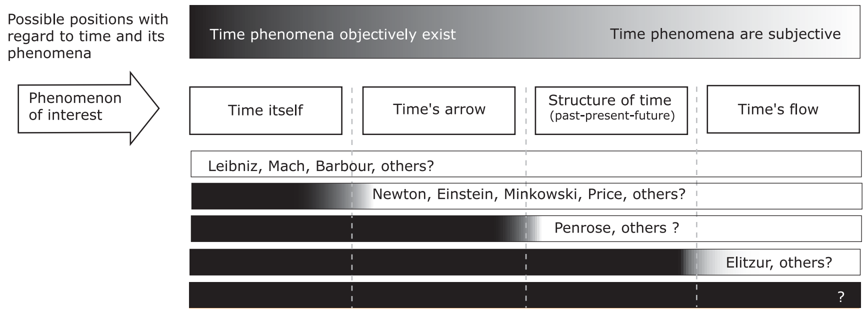


Figure 1. A summary of various positions taken by physicists and philosophers regarding time phenomena and their objective existence. Other ontological considerations not depicted complicate the picture, in particular, beliefs about mental causality.

Controversy rules within the world of physics about the objective nature of time. Some possible positions on this issue are summarised in Fig. 1. There is general agreement that time's flow must be a purely subjective phenomenon because trying to locate it in the external world leads to a paradox. If time flows then at what rate does it flow? One second per second? A thing cannot be defined in terms of itself. And while philosophers debate the meaning of "now" and whether it is all that exists (the "presentist" perspective) or yet another of time's illusions (the Parmenides position), within physics it is orthodox to regard the familiar past/present/future structure of time as subjective also.

A more vigorous controversy surrounds time's arrow. Penrose [2] has identified seven phenomena that suggest the arrow of time is real.[a] Penrose's seven arrows are:

- Total entropy does not decrease.
- The big bang appears to be irreversible.
- Radiation always propagates outwards.
- In quantum mechanics, the collapse of the wave function cannot be reversed — Schrödinger's cat is either dead or alive and cannot be returned to a state of superposition (or to use Penrose's analogy, heads and tails don't mix).
- There are black holes which destroy matter or information but to date no evidence has been found of white holes (or anti-black holes) which spew out matter or information.

[a]The original order in which Penrose listed his seven arrows has been changed here for the sake of the discussion that follows.

- Neutral K-mesons and their anti-particles behave asymmetrically with regard to the conservation of charge, parity and time (CPT).
- The psychological or subjective arrow of time dictates that we cannot remember the future.

We shall examine briefly each of these arrows:

1. Entropy increases: The increase in entropy we observe everywhere is, statistically speaking, a reversible phenomenon. The underlying molecular processes are time reversal invariant and, as Poincare demonstrated, decreases in entropy are inevitable over a very long period of time. However the timescale involved renders them extremely improbable and therefore we do not see them.

2. Big bang: The cosmological (big-bang) arrow of time is clearly related to the tendency for entropy to increase. What requires explanation is not the existence of this arrow but how the universe came to be in such a low entropy state around the time of the big bang, since low entropy states are equally as improbable in the past as in the future.

3. Outward radiation: The propagation of radiation can also be characterised statistically. At the quantum level, absorbers and emitters of radiation are indistinguishable. Macroscopically, what seems to be rare is a coherent absorber. However, since the arrow of time cannot be taken as a given while we are trying to prove it, there is a sense in which coherent macroscopic absorbers are just as common as coherent emitters — only in reverse time, as has been pointed out by Price [3]. What must be explained is why we live in a region of the universe with so many coherent sources of radiation. So the arrow of radiation can be seen as a variation of the thermodynamic arrow.

4. Irreversible collapse of the wave function: What of the quantum arrow? Much depends on how one interprets quantum mechanics. While interpretations involving the collapse of the wave function may imply an intrinsic arrow of time, no-collapse explanations are amenable to a similar statistical interpretation to the one applied above. The equation governing the evolution of the quantum state is time-reversal invariant. The apparent irreversibility of macroscopic systems comes from the extremely low probability of the conditions needed for such a reversal.

5. Absence of "white holes": The "no white holes" arrow seems less assailable. Until recently it was considered that information was annihilated by black-holes eventually to be spat out in the form of thermal radiation which has high entropy compared with what went in. In the 1970s, Steven Hawking had a well-publicised bet with John Preskill that this was the

case. Elitzur and Dolev [4] have pointed out that information-annihilating events in closed systems give rise to an intrinsic time-arrow regardless of initial conditions because information loss creates indeterminacy with respect to the future. So this arrow of time cannot be eliminated by appeal to statistical considerations.

At his presentation at the 17th International Conference on General Relativity and Gravitation, held in Dublin in July 2004, Hawking recanted his position that information was destroyed by black holes (and honoured his bet). While Elitzur maintains that, even if black holes were found to radiate information, the chances are what came out would not be exactly what went in, Hawking seems to be claiming he has solved the problem of future indeterminacy.

> The black hole only appears to form but later opens up and releases information about what fell in, so we can be sure of the past and we can predict the future.

If this turns out to be the case, black holes can no longer be taken to be time irreversible. Given black holes have been identified with certainty by astronomers only recently and given that both black holes and white holes emit energy, it may be premature to conclude that white holes do not exist.

6. K-meson decay: The decay of the neutral K-meson seems to be the only arrow of time to manifest itself at the microscopic level. Considering the diverse zoo of particles that are indifferent to the direction of time, one could ask — how much emphasis is it appropriate to place on the single example that appears to reveal time's arrow? Since K-meson decay is not a direct demonstration of time irreversibility, but instead an inference from the violations of CP-symmetry, this apparent arrow of time is not such a powerful argument that it could stand alone.

7. Psychological arrow: This leaves the psychological arrow of time. In all its manifestations, it is this compelling subjective arrow that prompts us to seek a basis for time asymmetry in the physical world. Is it possible that the psychological arrow is the most fundamental arrow of all?

Philosopher Le Poidevin examines three arrows of time in search of a fundamental arrow — the thermodynamic (accounting for three or four of the Penrose arrows), the psychological and the causal [5]. He explores each of these to see if it could serve as time's basic arrow, concluding that the causal arrow — the invariable precedence of causes over effects — is the best candidate.

However, in discussing the causal arrow, he does not quite manage to avoid the trap of introducing time by fiat. For example, if the causal arrow is to be basic, one would have to argue that the terms "before" and "after" were fully explained by the terms "cause" and "effect". In order for one thing to occur *before* the other, it would have to be (in some part) the *cause* of the other. Le Poidevin tries to get around the problem of earlier things that seem to have no possible causal connection with later ones by replacing the term "causally connected" with that of "causally *connectible*" however "connectibility" appears to imply the "before" condition that he is trying to explain. Price, among others, rejects the causal arrow as fundamental on precisely these grounds [3]. It is due to difficulties disentangling the causal arrow from the subjective arrow that physicists such as Penrose usually do not consider this to be an arrow in its own right.

On the other hand, Le Poidevin rejects the *psychological* arrow on the grounds that it, alone, does not explain how two subjects can agree about the order and direction of time. Such agreement is fundamental to daily life, for example, an ordinary conversation between two people requires concordance about the order and direction of events at very fine time scales [6].

Recent work by physicist, James Hartle (reported in [7]) demonstrates how, through the process of evolution, the passage and arrow of time can reside in the brain without necessarily reflecting any feature of objective reality.

> Our powerful sense that there is a "now" and that time "flows" from the past, through the present to the future, has survival value... it is the only plausible explanation, since none of these concepts actually appear in Einstein's special relativity, our most fundamental physical description of space and time.

Hartle believes it is information, and the way we process it, that accounts for the familiar phenomena of time. From this perspective, the imperatives for perceiving time the way we do, rather than some other way, are biological not physical. So on this basis, the fact that we can have conversations, or indeed coordinate our activities with those of other species, is a matter of "intersubjectivity" with regard to time rather than something fundamental to time itself.

Of course it could be argued that introducing evolution to account for the psychological arrow of time begs the question of the arrow's existence even more obviously than trying to make the causal arrow fundamental as Le Poidevin did. But time, stripped of appearances such as flow, past/present/future structure and arrow, would be a much more space-like dimension than what we normally perceive. From the Minkowskian perspective, time *is* a fourth space-like dimension and all evolution exists simultaneously as a complex four-dimensional superorganism. Indeed, it is a four dimensional tree of life with each individual organism in our familiar three-dimensional world representing a cross section taken somewhere in the tree. So although the word "evolution" involves change which implies the existence of time, if we think of it as being more like ecology in four-dimensions we are close to understanding how flow and arrow need not be fundamental and could simply be a product of the human (or biological) perspective.

2 Subjective Time as Fundamental

While the arguments presented above are far from conclusive as to the nature of time, a plausible case can be made that the phenomena of time, at least the asymmetric features such as the arrow and flow, are not part of objective reality. How else could they be explained? According to proponents of the anthropic principle we live in a universe finely tuned to the existence of life as we know it. This is because many physical constants (e.g. the fine-structure constant, the number of physical dimensions in the universe, the cosmological constant and many others), while theoretically free to vary, in fact have values that uniquely support carbon-based life. One answer to the mystery of why entropy is so improbably low in our part of the cosmos is based on this principle — if entropy were not so low we would not be here to ask questions about its magnitude.

Perhaps the anthropic principle could be turned on its head to yield the following proposition: While universes with other physical constants and properties may be conceivable, may be legitimately conjectured to exist or may indeed exist, this is the only universe we can *know* because it is the universe in which we evolved. Time's arrow, time's flow and possibly time itself may take the form they do because our physical nature does not support the detection of any other type of universe. For example, Atmanspacher *et al.* [8] have suggested that while non-causal and anti-causal neuronal interactions are theoretically possible, they do not give rise to stable neuronal assemblies and therefore, cannot support mental representations of sensory input. Thus mental representation is strongly linked with causality, producing a sense of time flowing in one direction only. Of course mental representation is also basic to knowledge, therefore, following Atmanspacher's logic, we would not be able to detect non-causal or anti-causal universes even if they existed under our very noses.

Based on this inversion of the anthropic principle as it is usually stated, *time and its phenomena are a product of biological evolution*, as Hartle suggests, and we should look for their origin in the brain.

3 Biological Time-Keeping

The conventional approach to studying biological time-keeping is to assume the existence of time, with its arrow, as an objective physical fact then to investigate the various ways nature has managed to capture time and put it to the service of living systems. The science of chronobiology took off in the mid 1950s when it was acknowledged that living organisms were not merely responding to external time cues, such as the day/night light cycle, but had internal mechanisms that continued to keep time even in the absence stimuli from the environment. Whatever our true relation to time, it is implicated in living systems across a variety of scales from microseconds to aeons. However our *consciousness* of time and its passage begins at the point at which we can distinguish time from space, which ranges between 10 and 100 milliseconds depending on the sensory modality. The phenomena of time consciousness include the specious present, the past/present/future structure, duration, time's apparent flow and the subjective arrow of time, all of which operate around 1 second.

While the existence of endogenous time-keeping is now taken for granted, what is still widely debated is the exact nature of its mechanisms. Are they central or distributed? Do the same structures account for timing at all scales? If not, how are the different timers co-ordinated? Where in the brain (or body) are they located? Is there a master "clock"? And what is the relationship between the mechanisms of time-keeping and our subjective sense of time?

In what follows, we explore results to date of an ongoing program of research undertaken by one of the authors (JDP), focusing on the relationship between perceptual rivalry and human timing keeping. Clock-like properties of the brain have been well described. These properties could account for many of the features of time that were enumerated above and could also lead to new explanations because of the details sometimes available about the clock-like behaviour of particular neurons.

4 Links Between Perceptual Rivalry and Duration Estimation

Two different lines of evidence implicate the dopaminergic neurons of the brainstem in the generation of clock-like behaviour. The first line is the work of Warren Meck, who has assembled a remarkable set of data on human timing that converges on these neurons. Neuropharmacology shows that drugs that slow the sense of time also have their strongest impact on increasing the firing rate of the dopamine neurons, with a corresponding, opposite effect on time perception of drugs that decrease the firing rate. Supporting this precise correspondence between the mode of action of a dopaminergic agonist or antagonist and sense of time, Meck used scanning studies to show activation during timing tasks in the dopaminergic nuclei, clusters of neurons rich in dopaminergic neurons that project diffusely to all parts of the brain, with a preponderance of terminals in the "thinking" part of the brain, the prefrontal cortex where the most complex cortical neurons are found. Meck also found individual variation in time estimates could be correlated with individual variation in the size of the nucleus concerned. In one study it was found that schizophrenics had much larger dopaminergic nuclei than normal. This was correlated with altered timing, such as reduced estimates of time duration (in production tasks) consistent with a clock that is running faster in schizophrenia.

Meck's proposal for a clock-like neural structure is exactly paralleled by work on the "rivalry oscillator". Perceptual rivalry is the oscillation of sensory experience that occurs in the face of an unchanging (if ambiguous) input. A strong case has been made for a mid-brain neural basis for these perceptual oscillations. A rivalry switch is proposed to activate homologous areas of each cerebral hemisphere alternately, by means of a bistable oscillator located in the ventral tegmental area of the basal ganglia, a crucial dopaminergic nucleus [9].

The roles of the brainstem modulatory nuclei, such as serotoninergic *raphe*, the dopaminergic ventral tegmental area (VTA) and noradrenergic *locus coeruleus*, have excited much speculation since their extraordinarily wide arborisations to all parts of the brain were demonstrated with fluorescence histochemistry [10]. Modern immunofluorescence has confirmed the diffuse, far-reaching nature of the connections and electron microscopic studies have shown, for example, that no synapse in the cortex is more than 50 micra away from a dopaminergic terminal. Such a diffuse system, originating from a few thousand neurons, has limited ability to convey specific information in the way that the visual system, for example, conveys a detailed visual image via millions of channels. The puzzle about the role of these nuclei was initially answered in a convincing way by Kety, who proposed that these diffuse systems evolved to detect situations of great survival value and to communicate that occurrence to the rest of the brain, which would take the appropriate steps, such as increasing its ability to store information [11]. In a crude analogy, we imagine being chased by a lion. The importance of the situation is recognized by increased activity in the catecholaminergic nuclei, with the result that its many targets would now be in an "up-regulated" state where synaptic plasticity mechanisms are enabled... a "now print" situation, to use the phrase coined by Jim Olds, the discoverer of the "pleasure center". The strong emotion (of fear in this case) would be an epiphenomenon of the altered state created by the release of the neuromodulator. Its targets, such as cortex, could now store information that might be useful in a similar encounter in the future. Although this system is not very focused and we might remember even seemingly irrelevant details, it is hard to tell in advance what details might be important for future survival. On the other hand, if one were lying safely in one's lair, well-fed and relaxed, it does not make sense to remember every detail on the ceiling of the lair. In that situation, the catecholaminergic nuclei are close to silent, shutting down completely in sleep.

In Kety's formulation, the key feature of the neuromodulatory system is that it signals the timing of the event of significance. It does not have the machinery to signal more complex aspects. When one records from these neurons they behave a little like novelty detectors, rapidly habituating for repeated events and peaking again when an expected event does not occur. In tissue culture they show rhythmic firing. Now their activity has been linked by caloric stimulation, fMRI and pharmacology to perceptual rivalry [12,13].

It was not previously thought that precise timing information could be derived from rivalry because there are significant sources of noise that disturb the oscillation, such as one's voluntary effort to switch the percept. But it has been shown that the rivalry switch rate is very steady if one uses a form of rivalry where familiarity cues cannot be used to cause a voluntary switch and if one takes care to maintain the stimulus conditions constant. Under these conditions there is an 83% test-retest reliability as well as significant individual variation. Furthermore, identical twin studies have shown that rivalry rhythms are highly heritable (see Fig. 2). These findings led to the hypothesis that the oscillator driving the seconds-long perceptual rivalry rhythms is an ultradian oscillator analogous to the suprachiasmic nucleus (SCN) which drives the 24-hour human, circadian rhythm [14]. The

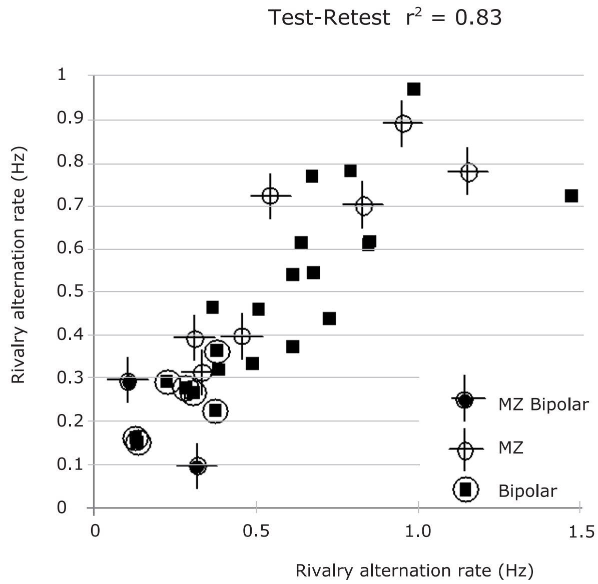


Figure 2. Stability of binocular rivalry rate: Despite the more than one order of magnitude inter-individual variation, intra-individual variation in rate is small, with 83% test-retest. Similar high concordance is seen when the rates of identical twins are compared with each other. Fraternal twins and siblings sharing 50% genes have very low concordance (unmeasurable in a sample of 200, data not shown). Slow rates are associated with mood disorder. This pattern of heritability is consistent with many genes. A similar rate and stability is found in the chemotaxis switch of bacteria which is based on around 1K genes. The high degree of stability of the rivalry timer suggest that it will also prove to be buffered by such a large number of gene products.

SCN has also been shown to be an interhemispheric oscillator [15].

Surprisingly, the individual variation in rivalry switch rate is correlated with individual variations in time perception that can be used to cross-link the timing of rivalry to the time perception studies of Meck. For example, schizophrenics have a high rivalry switch rate if they are not receiving anti-psychotic medications (whose action is to slow down the switch rate). This high switch rate is exactly on line with the observed shortening of their subjective duration of time, as well as the predicted high switch rate of an enlarged nucleus (larger neural networks have faster oscillations).

Finally, fMRI studies suggest that the rivalry switch is correlated with activation of the ventral tegmental area, (VTA) a dopaminergic nucleus on the ventral midline of the midbrain. This activation was observed in only two subjects out of nine, but it may be significant that these two

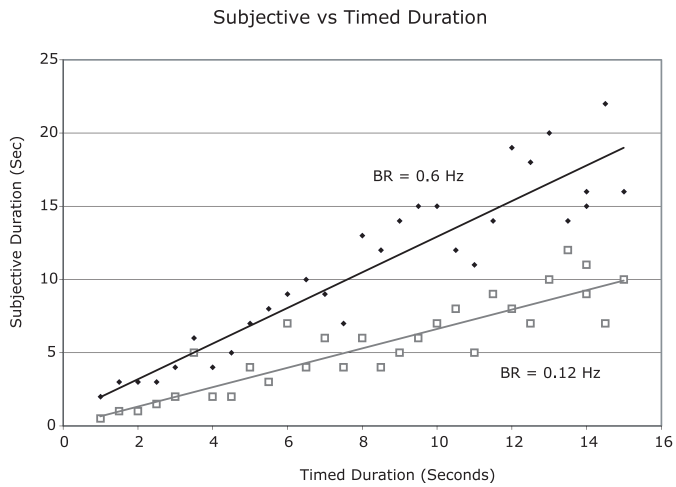


Figure 3. Estimated time duration in two individuals with different rivalry switch rates: The "fast switcher" also has a much steeper slope on the curve relating estimated duration vs. real duration. While this result conforms to the expectation that the rivalry switch reflects fundamental neural timing, there is a qualification — the time estimation task can dramatically alter rivalry rate, so it is not possible to use rivalry rates obtained under laboratory conditions (e.g. like those of Fig. 2) to make assumptions about rivalry rates during time estimations. It can be difficult for volunteers to measure rivalry and estimate duration at the same time, so more work is required to establish the relationship between rivalry rate and subjective time.

subjects were slow switchers. A slow rivalry switch could have facilitated the detection of the signal in a way that was not possible, due to limits of the measuring apparatus, when the switch was changing on a second by second basis, as in most of the volunteers. The possibility of confirming this hypothesis awaits the development of more sensitive tests.

A corollary of this link between the rivalry oscillator and Meck's clock-like mechanism should be a predictable relationship between rivalry switch rate and the individual's subjective perception of time. We tested this, with encouraging results but with a proviso. We did find that rivalry switch rate predicted the slope of the subjective passage of time, showing an inverse relationship between switch rate and duration estimate (in a reproduction task, see Fig. 3). However, it must be pointed out that the individual rivalry switch rate that emerged from the time perception test was sometimes quite different from the rivalry switch rate obtained in the lab where the same conditions have been used to measure it in thousands of volunteers. It is quite reasonable that the time perception task would change the rate of rivalry, particularly as we have shown in the lab that there is a strong input from working memory that slows down the rivalry switch, an observation backed by other studies of the effects of working memory on duration estimation. But this introduces a new complication that will take considerable work to define, since there is no way to calculate in advance just how the rivalry switch rate will change in the time perception experiment.

Other researchers' attempts to correlate clock-like behaviour with different brain areas using fMRI, focal lesion and pharmacological studies have yielded a variety of potential loci for time-keeping activity, including the various dopaminergic structures of the basal ganglia (*striatum*, *substantia nigra*, ventral tegmental area) [16–19]. The *cerebellum* has been implicated in clock-like behaviour and we note an intimate connection between midline cerebellar structures and the VTA. There is a quantitative link between the gain of the efference copy system, widely believed to originate in the *cerebellum*, and perceptual rivalry rate [20]. These observations link the time-keeping functions of the *cerebellum* to both rivalry and the VTA.

Several authors, including Meck have suggested a time-keeping process mediated by cortico-striatal loops with cortical areas responsible for the attentional and memory operations of time-keeping while more central clock functions, such as oscillatory input, are localised in one or other nucleus in the basal ganglia. Observed loci of cortical clock-like functions include the following: the SMA [18,21], the frontal and prefrontal cortices, particularly the right prefrontal cortex [17,18,21–23] and the right parietal cortex [19,24]. While Meck favours the *substantia nigra* as an oscillator, consistent with data from patients with Parkinson's disease who have deterioration of the dopaminergic cells of this nucleus along with well-documented deficits in temporal processing, note that the VTA is a midline extension of the *substantia nigra* that has similar dopaminergic neurons except that they are biochemically more robust and linked to the timing of motivational, rather than motor, events. The VTA also shows deterioration in Parkinsonian patients.

5 Perceptual Rivalry and Time's Flow

Other findings regarding perceptual rivalry and interhemispheric switching add to evidence for a complex link with time-keeping. A strong relationship has been found between rivalry rate and mood disorders such as endogenous depression and bipolar disorder [25]. Typically, people with these conditions are slow switchers. The link between mood disorders and faulty *circadian* clocks is well documented, supporting the hypothesis that an ultradian oscillator mediates perceptual rivalry [26–28]. Also well documented are alterations to the subjective passage of time associated with mood disorders [29]. Arguably, these altered time-percepts are paralleled by changes in rivalry rates, although this remains to be demonstrated.

More recently, a systematic relationship has been discovered between rivalry rates and meditation as practiced by Tibetan Buddhist monks, with different types of meditation (translated as "compassion", "emptiness" and "one-point" meditation) producing different patterns in the behaviour of the perceptual rivalry switch [30]. In addition, psychedelic drugs such as LSD and psilocybin, acting via serotoninergic receptors that powerfully link the activity of the midbrain *raphe* and VTA, produce both distortions in the perceptions of time's flow and reliable changes in perceptual rivalry rates. In fact, these studies are the first to demonstrate a consistent quantitative change as a result of a psychedelic, which infamously disorders perceptual reports. The studies also identified the receptors involved, by using antagonist drugs in combination with psilocybin (see Fig. 4). This showed that the receptor involved with the timing of rivalry rate is a 5HT 1a receptor, thereby focusing once more on the brainstem, where most of these receptors are found, and away from visual cortex, where they are not found but where much attention has been focused as a putative site for generating rivalry [13]. Apparently the dopaminergic inputs to cortex are responsible for the timing of the rivalry switch, while the cortex itself may be responsible for the details of the percepts that are being switched.

Interestingly, the very factors that have been shown to produce systematic variations in rivalry rates — drugs such as LSD and psilocybin, the psychoses (schizophrenia, bipolar disorder and endogenous depression) and meditation (which produces voluntary changes) — have all been associated with alterations to perception of time's flow, as studied and modeled by Saniga [31].

To summarise, perceptual rivalry with its proposed underlying midbrain oscillation can be linked with the phenomena of duration (and its estimation) and the subjective flow or passage of time. What of phenomena such as the specious present and time's apparent arrow?

6 Is Perceptual Ambiguity Resolved in the Specious Present?

Varela has made important contributions to the study of the first person perspective and was studying multistable perceptual phenomena just before his untimely death. He noted that:

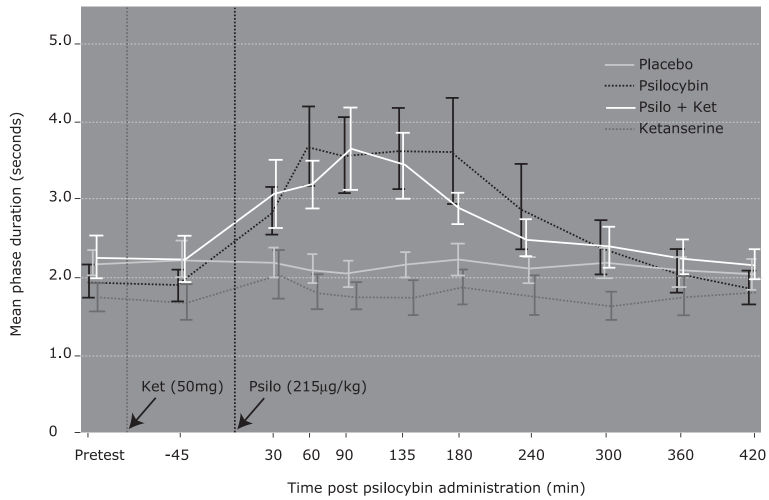


Figure 4. Effects upon rivalry rate of the 5HT 1a/2a agonist Psilocybin: Cognitive changes caused by psychedelics are notoriously variable, yet rivalry rate slowed in every subject tested (12 subjects, data not shown). The period of peak slowing corresponds to the maximal entheogenic experience for the subject, where time speeds up, the subject feels at one with the cosmos ("oceanic boundlessness") and there may be dissolution of ego boundaries. Ketanserine is a 5HT2a blocker, so the failure of ketanserine to change the effect of psilocybin shows that the effects of the slowing of the rivalry timer must be mediated by 5HT1a receptors, which are located largely in the brainstem raphe. There is a strong reciprocal interaction between raphe the dopaminergic VTA, so these data support the fMRI evidence that the rivalry timer is not located in cortex, but in the midbrain where Meck has also located the neural timer using independent evidence.

> [t]he gesture of reversal [in perceptual rivalry of a bistable figure] is accompanied by a "depth" in time, an incompressible duration that makes the transition perceptible as a sudden shift from one aspect to the other, and not as a progressive sequence of linear changes [32].

He goes on to grant that "this well known phenomenon is not common in ordinary life" but is that really the case? Many studies in perception have shown that the seamless logical world we perceive in space and time is the product of a brain actively processing ambiguous stimuli received via imperfect sense organs.

This is particularly well-illustrated by Motion-Induced-Blindness (MIB), an oscillatory perceptual phenomenon that was not linked at first to perceptual rivalry but which we now know, from divergent sources including neuropharmacology, is in the same class as the reversing cube studied by Varela [33,34]. This stimulus consists of three large, bright yellow dots, arranged in an equilateral triangle, on a field of small, moving, blue dots. When one of the yellow dots disappears, we have no knowledge of its continued presence. While there may be a very high cognitive level that understands that perhaps there should be a yellow dot in that position, to immediate perception there is no trace or indication of the yellow dot until it returns to consciousness in the next phase of the perceptual oscillation. Typically, a subject will believe that the dot is objectively gone — that it has been physically switched off. If there were a similar process taking place during everyday life, this example shows that we would not be aware of our "denial" (of the part of the world we were not perceiving in that phase of our perceptual oscillation). In the hurly burly of eye and head movements in daily life, it is unlikely that we would be able to recognize the fact that our brain was actively "denying" one of the viable perceptual alternatives, as we are able to do in the MIB demonstration, where the yellow dot's disappearance is so striking and laid out in such an orderly way that makes the disappearance more obvious than it would be in a complex world.

So there are two reasons why we may not be aware of perceptual oscillations in daily life. The first relates to the example just given where one phase of the oscillation is completely unconscious of its perceptual alternative. The second relates to the fact that the role of the oscillations may be to deal with ambiguity at the earliest level instead of waiting for its later resolution. The argument that can be mounted in favour of this viewpoint originates from the thesis that ambiguity is pervasive in the universe. This is not an uncommon view in physics, and suggests that the best strategy for handling ambiguity is to recognize it at the outset and install a mechanism to deal with it early in the process of evolution. The usual Western approach to ambiguity is assume that it can be circumvented ("See! I can put my finger on it and resolve the conflict immediately"). But if the ambiguity is unavoidable, as many certainly are, the appropriate strategy is to build in an oscillatory mechanism that prevents the brain from getting stuck in the "wrong" phase.

There are many examples of ambiguity that suggest this is a fundamental, unavoidable feature of the world with which perceptual oscillations have evolved to cope. Poincare, who provided an important spatial framework for Einstein's theory of relativity, also pointed out that the sum of all vision is inherently ambiguous because we must use a two-dimensional image in the eyeball to try to reconstruct the three-dimensional world. One of the authors (JDP) got a shock to realize, after reading Poincare, that his beloved stereopsis, with its extraordinary accuracy in pin-pointing the relative location of objects in space (e.g. having a discrimination of a paper's thickness at arm's length) was NOT VERIDICAL and could not therefore be used to guide one's arm to a target in depth without other sources of information! It was profoundly shocking to realize that the most accurate visual sense studied (normal human stereoacuity is 2 arc sec, vernier-like acuity) is at the same time incapable, by itself, of providing precise guidance to an absolute point in the 3-D world.

The general case that ambiguity is often inescapable has been presented by Purves, who is perhaps not as well respected amongst psychophysicists as he deserves to be. The problem here seems to be that the psychophysics community assumes that he is taking credit for original statements about ambiguity when these were made by many investigators previously. When asked about ambiguity, these psychophysicists will usually point out how it can be resolved, rather than accepting the fact that it may be irresolvable. Purves' originality therefore lies in his emphasis that ambiguity may have to be accepted as part of the world and that it may not always be possible to take the "Western" option to resolve it. If Purves' thesis is correct, then evolution may have incorporated this fact into oscillations which ensure that even the earliest sensory decisions do not get "stuck". Even bacteria oscillate between "go" and "stop" in a very precise way when trying to navigate a concentration gradient of attractant, with the precision of the oscillator essential to the success of the operation.

Examples that further highlight this issue include Patrick Hughes' paintings and visual optics. In Hughes' paintings, a three-dimensional physical object is rendered so the perspective cues lead to a depth impression that is opposite to the real depth. At a distance where stereo cues cannot dominate, the artwork will usually be seen in the depth suggested by the painting ("Reverspective"). The really surprising result occurs when one moves one's head and there is a "collision" between the inferences from movement parallax and the pre-exiting cues from perspective. Under these circumstances, most observers will cling to the pre-existing, mistaken impression set up by perspective and will see the painting physically distort as if it were made of stretchable rubber sheet! The effect is similar to what happens when one moves past a hollow mask of a face that is seen (falsely) as convex...the face appears to follow as if it can be physically distorted. In both these examples, we see that different cues from the physical world provide different conclusions about the same physical object, with the possibility that we may opt for the "wrong" set of cues. The Hughes painting example shows that the brain can cling to the "wrong hypothesis" rather than reject it when conflicting data arrive. While this may be considered a counter-example, where an oscillatory model breaks down and "sticks" to the wrong hypothesis, in fact it shows the validity of the argument that sensory oscillations may be fundamental... and the perception finally does switch, at a time that depends upon the individual timing of the perceptual oscillator.

The many foregoing examples serve to underline that, in reality, ambiguity in sensory input may be the rule rather than the exception. The duration taken to resolve the ambiguity, that incompressible "depth" in time noted by Varela, may correspond with the specious present. This may, in part, account for the slow passage of time in situations of novelty. Everyone is familiar with the elongation of time that accompanies a holiday taken in novel surroundings compared with the speed at which one's life flies by in the familiar context of daily life.

7 Time's Arrow and the Plasticity of the VTA

Finally, the unusual physiology of the putative time-consciousness nucleus could help make predictions about how time's arrow may arise, despite the primitive level of understanding of this part of the brain. First, it is one of the most plastic brain regions, with the highest level of NMDA receptors which underlie the synaptic modifications of learning and memory [35]. This property helps to explain the dramatic effects on time consciousness of the NMDA receptor blocker ketamine [36]. Further, the VTA is the only structure in the adult brain that expresses the embryonic morphogen, retinoic acid [37]. This embryonic characteristic emphasises the extreme plasticity of the VTA. It is a part of the brain that does not function well in slices, requiring the considerable inputs that it normally receives in the living intact brain. The VTA is also unique in that its dopaminergic neurons are resistant to the toxin MPTP, unlike almost identical dopaminergic neurons nearby in the *substantia nigra*. The basis of this resistance is higher levels of the enzyme superoxide dismutase, making the VTA the most resistant brain structure to oxidative stress and therefore arguably the most resistant to aging, a property that goes along with our proposal of its role as a time-keeper, which paradoxically should be immune to the degradations of time [38]. This may help explain the fact that we feel like the same person, with few fundamental changes, despite the accumulated changes of age.

The high level of plasticity is what one would expect of a brain structure underlying the arrow of time. Continuity of the sense of self requires that current experience be "grafted" onto the autobiographical sense of self in the form of accumulated life experiences. The extreme plasticity of VTA could mediate that process. The pulsatile, around one second, action of VTA could be understood as the integration time between events when the new episode of self is added.

An anecdote might help make this point concrete. A strange case of dementia occurred in a multi-lingual woman in an English hospital. Raised in Russia, but acquiring German as a second language, she finally moved to England around the time of World War II and acquired her third fluent language of English in early adulthood. In old age, as the dementia progressed, she first lost the ability to converse in English but her German and Russian were intact. In the next phase of her dementia, German disappeared but she could still converse adequately in Russian. Finally she was unable to converse in Russian. This striking example illustrates the operation of a modulatory structure like the VTA as well the arrow of time that it produces.

The action of dopamine released by the VTA is to place the brain, especially cortical structures, in an "up-regulated" state, with a high level of readiness to respond and store information, by virtue of mechanisms like NMDA receptors for example [39]. In Kety's formulation, discussed earlier, the widespread arborisations of the monoaminergic systems would be incapable of imparting any specific information about the nature of the sensory input. There are far too few neurons connected with too many parts of the brain to mediate specific information processing. But, as Kety suggested, they could supply information about timing, in the form of a statement that the current moment was of increased survival value. Since the VTA can compare the current sensory input with the cortical model that predicts what that input should be, any mismatch will lead to increased firing related to the significance of the current input. The emotion that one feels at the time when such systems discharge was felt by Kety to be an epiphenomenon related to this signal that was switching on memory and plasticity mechanisms in order to "imprint" sensory input. In the example of being chased by a lion, clearly it may have survival value to store information from any sensory channel of the chase (e.g. the size of that gap between rocks, the position of the lower branches on that tree). In contrast, if one is lying safely in one's lair after dinner, it does not make the same evolutionary sense to memorise all the fine details of cracks in the ceiling, and the calm parasympathetic feeling and the low VTA output (which goes to zero in sleep) all reflect a low level of plasticity.

Returning to the trilingual woman with dementia, we can understand the "temporal hierarchy" of her language structure in terms of the VTA's role in gating brain plasticity. Laying down all the traces for German during her childhood would have required that she integrate them to some extent with her pre-existing native language of Russian. Similarly, the modifiable synapses responsible for English would have been laid down in a separate later set of episodes that would have to go "on top of" the pre-existing structures for Russian and German, to which it would have had a more tenuous connection. This successive "layering" of language, as a result of separate plastic episodes, was finally revealed as the dementia peeled away more and more connections, with the first to be affected being the later, less well-integrated connections associated with English language. The surprising ordering of the three language substrates tends to emphasise just how strongly our brains reflect temporal phenomena and just how difficult it may be to escape these effects when we think about time.

8 Conclusion

In the introduction, we examined the possibility of a Darwinian evolutionary basis for the flow, structure and arrow of time. In particular, we developed the hypothesis that the most fundamental arrow of time was the psychological arrow. While two physical candidates — the "black hole" arrow and the apparently lopsided behaviour of the neutral k meson and its antiparticle — remain problematic at this stage, a possible fundamental role for the brain in producing the familiar phenomena of time is well worth investigating.

With this aim in mind, we explored the extent to which the rhythmicity, intrinsic plasticity and induction of cortical plasticity of the brainstem monoaminergic nuclei, in particular the dopaminergic ventral tegmental area (VTA), might account for various phenomena of time — its duration and flow, the specious present, the past/present/future structure and the subjective arrow of time. In contrast to the theoretical and philosophical considerations of the first section, discussion of the VTA and its clock-like properties was based on the convergence of Meck's identification of the dopaminergic brainstem system as the important second-to-second timekeeper, with an independent line of work on the timing of perceptual rivalry oscillations that seem to have the same neural substrate.

More sensitive fMRI studies are needed to confirm the link between perceptual rivalry and oscillatory behaviour of the VTA. The exact relationship between rivalry rate and duration estimation must be teased out in experiments that systematically account for the memory and attentional demands of the experimental tasks. The influence of mind-altering drugs, psychotic states and meditation on both rivalry rate and the so-called pathologies of time perception (such as time running fast or slow, all time seeming to be present at once or the order of events appearing to be altered in dramatic ways) need to be further explored, along with the relationships among these phenomena.

It should also be possible to test the hypothesis that the "duration" of the present is somehow linked with the behaviour of the rivalry oscillator and its part in sorting out the inherent ambiguities of perception. Finally, the potential role played by extreme plasticity of the VTA in the layering of present over past over more distant past to give time its arrow is worthy of further exploration.

We have drawn attention to weaknesses in the case for an external, physical basis of the arrow of time and suggest an internal alternative, a neural timer that can be tapped using perceptual rivalry switches. Rivalry switches occur at a frequency around 1 Hz and are relatively easy to record, even when the subject is hallucinating under the action of drugs. This makes it possible to explore internal time with fine grain during a wide variety of conditions when time measurements vary.

References

1. Barbour, J. (1999) *The End of Time*, Weidenfeld and Nicholson, London.
2. Penrose, R. (1979) Singularities and time-asymmetry, in S. W. Hawking and W. Israel (eds.), *General Relativity: An Einstein Centenary*, Cambridge University Press, Cambridge, pp. 581–638.
3. Price, H. (1996) *Time's Arrow and Archimedes' Point*, Oxford University Press, Oxford.
4. Elitzur, A.C., and Dolev, S. (2000) Blackhole evaporation entails an objective passage of time, preprint `quant-ph/0012081, v1`.
5. Le Poidevin, R. (2003) *Travels in Four Dimensions: The Enigmas of Space and Time*, Oxford University Press, Oxford.
6. Buonomano, D.V., and Karmarkar, U.R. (2002) How do we tell time?, *Neuroscientist* **8**(1), 42–51.
7. Chown, M. (2004) Clockwatchers, *New Scientist* **182**(2445), 34.
8. Atmanspacher, H., Filk, Th., and Scheingraber, H. (2005) The significance of causally coupled, stable neuronal assemblies for the psychological time arrow, *this volume*.

9. Pettigrew, J.D. (2001) Searching for the switch: neural bases for perceptual rivalry alternations, *Brain and Mind* **2**, 85–118.
10. Fuxe, K., and Jonnson, G. (1973) The histochemical fluorescence method for the demonstration of catecholamines. Theory, practice and application, *Journal of Histochemistry and Cytochemistry* **21**, 293–311.
11. Schildkraut, J.J., and Kety, S.S. (1967) Biogenic amines and emotion, *Science* **156**(771), 21–37.
12. Miller, S.M., Liu, G.B., Ngo, T.T., Hooper, G., Riek, S., Carson, R.G., and Pettigrew, J.D. (2000) Interhemispheric switching mediates perceptual rivalry, *Current Biology* **10**, 383–392.
13. Carter, O.L., Pettigrew, J.D., Hasler, F., Wallis, G.M., Liu, G.B., Hell, D., and Vollenweider, F.X. (2004) Modulating the rate and rhythmicity of perceptual rivalry alternations with the mixed 5-HT2A and 5-HT1A agonist psilocybin, *Neuropsychopharmacology* **30**, 1–9.
14. Pettigrew, J.D., and Carter, O.L. (2003) Perceptual rivalry as an ultradian oscillation, in D. Alais and R. Blake (eds.), *Recent Advances in Binocular Rivalry*, MIT Press, Boston, pp. 283–300.
15. de la Iglesia, H.O., Meyer, J., Carpino, A., Jr., and Schwartz, W.J. (2000) Antiphase oscillation of the left and right suprachiasmic nuclei, *Science* **290**, 799–801.
16. Meck, W.H., and Benson, A.M. (2002) Dissecting the brain's internal clock: how frontal-striatal circuitry keeps time and shifts attention, *Brain and Cognition* **48**(1), 195–211.
17. Harrington, D.L., and Haaland, K.Y. (1999) Neural underpinnings of temporal processing: a review of focal lesion, pharmacological, and functional imaging research, *Rev. Neuroscience* **10**(2), 91–116.
18. Coull, J.T., Vidal, F., Nazarian, B., and Macar, F. (2004) Functional anatomy of the attentional modulation of time estimation, *Science* **303**, 1506–1508.
19. Rao, S.M., Mayer, A.R., and Harrington, D.L. (2001) The evolution of brain activation during temporal processing, *Nature Neuroscience* **4**(3), 317–323.
20. Campbell, T.G., Ericksson, G., Wallis, G., Liu, G.B., and Pettigrew, J.D. (2003) Correlated individual variation of efference copy and perceptual rivalry timing. Program No. 550.1. 2003 Abstract Viewer/Itinerary Planner, Society for Neuroscience, Washington, DC.
21. Macar, F., Lejeune, H.F., Bonnet, M., Ferrara, A., Pouthas, V., Vidal, F., and Maquet, P. (2002) Activation of the supplementary motor area and of attentional networks during temporal processing, *Experimental Brain Research* **142**, 475-485.
22. Hinton, S.C., and Meck, W.H. (1997) The internal clocks of circadian and interval timing, *Endeavour* **21**, 82–87.
23. Lewis, P. (2002) Finding the timer, *Trends in Cognitive Sciences* **6**, 195–196.
24. Harrington, D.L., Haaland, K.Y., and Knight, R.T. (1999) Cortical networks underlying mechanisms of time perception, *J. of Neuroscience* **18**, 1085–1095.
25. Miller, S.M., Gynther, B.D., Heslop, K.R., Liu, G.B., Mitchell, P.B., Ngo, T.T., Pettigrew, J.D., and Geffen, L.B. (2003) Slow binocular rivalry in bipolar disorder, *Psychological Medicine* **33**, 683–692.

26. Rossenwasser, A.M., and Wirz-Justice, A. (1996) Circadian rhythms and depression: clinical and experimental models, in P. H. Redfern and B. Lemmer (eds.), *Handbook of Experimental Pharmacology: Physiology and Pharmacology of Biological Rhythms*, Springer, Berlin, pp. 457–486.
27. Goodwin, F.K., and Jameson, K.R. (1990) *Manic Depressive Illness*, Oxford University Press, Oxford.
28. Souetre, E., Salvati, E., and Belugou, J-L. (1989) Circadian rhythms in depression and recovery: evidence for blunted amplitude as a main chronobiological abnormality, *Psychiatry Research* **28**, 263–278.
29. Eisler, A.D. (2003) Human sense of time: biological, cognitive and cultural considerations, in R. Buccheri, M. Saniga, and W. M. Stuckey (eds.), *The Nature of Time: Geometry, Physics and Perception* (NATO ARW), Kluwer Academic Publishers, Dordrecht–Boston–London, pp. 5–18.
30. Carter, O.L., Callistemon, C., Presti, D.E., Liu, G.B., Ungerer, Y., and Pettigrew, J.D. (2005) Meditation alters perceptual rivalry in Tibetan Buddhist monks, *Current Biology*, in press.
31. Saniga, M. (2005) A geometrical chart of altered temporality (and spatiality), *this volume*.
32. Varela, F.J. (1999) The specious present: A neurophenomenology of time consciousness, in J. Petitot, F. J. Varela, B. Pachoud, and J.-M. Roy (eds.), *Naturalising Phenomenology: Issues in Contemporary Phenomenology and Cognitive Science*, Stanford University Press, Stanford (CA), pp. 266–314.
33. Carter, O.L., and Pettigrew, J.D. (2003) A common oscillator for perceptual rivalries?, *Perception* **32**, 295–305.
34. Funk, A., and Pettigrew, J.D. (2003) Does interhemispheric competition mediate motion-induced-blindness? A trans-cranial magnetic stimulation study, *Perception* **32**, 1328–1338.
35. Rodriguez, J.J., Doherty, M.D., and Pickel, V.M. (2000) N-methyl-D-aspartate (NMDA) receptors in the ventral tegmental area: subcellular distribution and colocalization with 5-hydroxytryptamine(2A) receptors, *Journal of Neuroscience Research* **60**(2), 202–211.
36. Moretti, R.J., Hassan, S.Z., Goodman, L.I., and Meltzer, H.Y. (1984) Comparison of ketamine and thiopental in healthy volunteers: effects on mental status, mood, and personality, *Anesthesia and Analgesia* **63**(12), 1087–1096.
37. Luo, T., Wagner, E., Grun, F., and Drager, U.C. (2004) Retinoic acid signaling in the brain marks formation of optic projections, maturation of the dorsal telencephalon, and function of limbic sites, *Journal of Comparative Neurology* **470**(3), 297–316.
38. Hung, H.C., and Lee, E.H. (1998) MPTP produces differential oxidative stress and antioxidative responses in the nigrostriatal and mesolimbic dopaminergic pathways, *Free Radical Biology Medicine* **24**(1), 76–84.
39. O'Donnell, P. (2003) Dopamine gating of forebrain neural ensembles, *European Journal of Neuroscience* **17**(3), 429–435.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 589–606

BECOMING AS A BRIDGE BETWEEN QUANTUM MECHANICS AND RELATIVITY

AVSHALOM C. ELITZUR
Unit of Interdisciplinary Studies, Bar-Ilan University
Ramat-Gan 52900, Israel
(avshalom.elitzur@weizmann.ac.il)

SHAHAR DOLEV
Edelstein Center for the History & Philosophy of Science, The Hebrew University
Jerusalem 91904, Israel
(shahardo@cc.huji.ac.il)

Abstract: Time's apparent "flow" is often dismissed in physical theory. We propose to take it as a real property of reality and show how the addition of this assumption to physics' prevailing postulate yields a new framework within which relativity and quantum theories are in harmony with one another.

1 Introduction

For more than a century since the advent of relativity theory and quantum mechanics, the two theories have made tremendous progress, yet the conflict between their principles has only become sharper. A more fundamental theory, within which the two theories would naturally fit in as special cases, is not yet at sight.

Unrelated to this stalemate, a much older debate goes on concerning the nature of time. Why does time, unlike space, appear to be "flowing"? And why are certain processes asymmetric in time, in contrast to their spatial symmetry?

We submit that addressing the latter issue may yield a new resolution to the former. In what follows we propose that time's apparent "flow" is real, and then proceed to show how this assumption might enable quantum mechanics and relativity theory to begin merging into a new theory.

This is a highly speculative work. We claim neither rigor nor certainty. It is after several years of working on specific problems that we feel that time is ripe for a more daring synthesis, even at the cost of being loose.

The structure of our theory is like that of any scientific theory. At the basis we introduce a few known principles of prevailing physical theories as postulates, plus one new assumption. In return we hope to derive *i*) conclusions already accepted as correct although not assumed, and, *ii*) testable predictions. Unfortunately, nothing like *ii*) has been yielded by our theory yet, to say nothing of confirmation, otherwise we would be singing it from all the roofs. Yet, because something like *i*) seems to have emerged from time to time along our search, we dare take it as a hint that we may be on the right track.

2 "Block Universe" or "Presentism"?

Mainstream physics' account of time is known as the "Block Universe." Rooted in the theory of relativity, it portrays the universe as a four-dimensional continuum in which all past, present and future events have the same degree of existence along time, just as different locations coexist along space. All three-dimensional objects are "slices" of four-dimensional world-lines, extending from past to future. An object's motion is a curvature on its world-line.

The rival model, "Presentism," tries to account for our perception of time by asserting that only present events are real. States merely appear and vanish, consecutively, "time" being just the sum of these changes. Referring to time as a dimension, so goes this view, is only a useful metaphor, and relativistic notions like "spacetime" and "world lines" are mere abstractions. Only the "Now" is real, and is the same everywhere. Of course, in order to avoid conflict with relativity (see [1]), Presentism must concede that this simultaneity can never be observed. This concession is not necessarily a disadvantage of the model, as unobservable elements of nature feature in many respectable theories.

Both models come with a price. The former dismisses our subjective sensation of time, while the latter gives up full conformance with relativity, yet both are self-consistent. It is only when trying to blend the two notions to match both subjectivity and relativity, that serious paradoxes ensue. For example, taking time to be the fourth dimension *together with* an objective "Now" is bound to imply a yet higher time dimension within which the "Now" is supposed to proceed. Only the two extremes in their pure form seem to be viable, the Block Universe being mainstream physics' choice while Presentism is opted by a minority.

The option we seek is different. We wish to preserve the essential elements of relativity theory, but we also want to take the "Now" as a key to a deeper layer of physical reality. And, of course, we hope to avoid the paradoxes that often follow such a double standard. We name the proposed model the Spacetime Dynamics theory, as it suggests that spacetime itself is subject to evolution.

Let us, then, first point out those essential elements of relativity theory that are likely to remain within any future theory. First is the notion of a four-dimensional spacetime. General relativity's interpretation of gravity as a curvature of spacetime is one of the theory's greatest achievements, well-supported by all experimental tests. Even some yet-unknown aspects of spacetime, such as its form in a black hole singularity or at the Planck scale, give valuable leads for future research. Similarly constructive is the notion of a world-line, portraying any object as a four-dimensional line extending from past to future. The world-line notion provides, *e.g.*, the best understanding of relativistic contraction (see [2]). At the micro level, Feynmann's diagrams, especially the idea of an anti-particle being a particle that moves backwards in time [3], testifies to the great heuristic potential of the 4-D spacetime. Two modern interpretations of QM, namely, Aharonov's [4] and Cramer's [5], elegantly invoke spacetime zigzags in order to account for some of the peculiarities of quantum phenomena (see [6]). All these are promising elements of the relativistic spacetime, which we intend to preserve within the Spacetime Dynamics theory.

It is with respect to two other assertions that the Block Universe model turns out to be very awkward:

1. There is no objective "Now" moving from one minute to another. Each event is "Now" for its observer. Similarly, "past" and "future" are relative terms just as, say, "East" and "West."

2. At any moment, future events are as real as present events and as fixed as past events. It is only because no information comes from the future (due to the second law of thermodynamics, which can be assumed even within the Block Universe framework) that future events seem not to exist.

These assertions have odd consequences. Every person, rather than being just one person undergoing many events, is supposed to be a series of equally-existing momentary persons, each residing in its moment. Every such a momentary self is a 3-D "slice" of the 4-D world-line, which in itself does not move or change. Every momentary self possesses memories of the previous ones, thereby having the illusion that he or she is one and the same person who has been through all past events. Whatever is going to happen in the future, even one's own actions, "already" exists, albeit unknown, together with the future selves, and cannot be changed or avoided, just like past events.[a]

This account is awkward not only in terms of ordinary experience but in the quantum context as well. In earlier publications we have presented three results that, although not disproving the Block Universe, seriously undermine it:

1. *"Hidden Variables Must Be Forever-hidden Variables."* Consider a photon at time t after being emitted from its source. Its wave function describes its position as a superposition, which will give its place ("collapse") to a definite position only upon measurement. Now quantum theory can only give probabilities for that future position. In order to assume that the future position is pre-determined already at t, one has to invoke hidden variables of some sort. However, elsewhere [2] we have given a very straightforward proof for the following. *In any theory within which relativity remains valid, quantum hidden variables must never be observed, since observing them is bound to produce violations of relativistic invariance.* Such invocation of something that must exist but never be observed — properties that even the 19^{th}-century ether was not claimed to have — places hidden variables in the realm of religion rather than science.[b] It is, therefore, the combined lesson of both QM and relativity that gives us an important hint: There are future events that can never be predicted by a present state. Would it not be reasonable, then, to doubt whether such future events exist in the first place?

2. *The Indeterminacy-Asymmetry Entailment.* If quantum theory indeed reveals a genuinely indeterminate element that takes part in any interaction, then, in any closed system, an arrow of time must eventually emerge, regardless of the system's initial conditions and concurring with the time arrow of the universe outside, from which the system is supposed to be shielded [8]. Hence, the Block Universe assertion

[a]This account, it should be stressed, is not just one possible interpretation of relativity theory but an inevitable part of it. This was Einstein's own view; see [7] for a detailed discussion.
[b]"For there shall no man see me, and live." — Exodus 33: 20.

"the future determines the present just like the past," is simply wrong. True, the question of determinism *vs.* indeterminism has not been decisively resolved yet, but given our above proof that "hidden variables must be forever-hidden variables," strong determinism is a metaphysical theory. Consequently, by the Indeterminacy-Asymmetry Entailment, an initial low-entropy state can causally bring about the final high-entropy state but *not vice versa*. This conclusion strongly undermines the Minkowskian picture of future events coexisting in time alongside with the present.

3. *Quantum Mutual Measurements Entailing Inconsistent Histories.* As odd as the famous quantum effects are known to be, e.g., single-particle interference and the EPR experiment, they yield self-consistent evolutions. We have shown, however, a few cases where even this consistency does not hold [9]. When the quantum measurement is delayed, such that one particle "measures" another particle before the macroscopic device completes the measurement, something intriguing occurs: The outcome is self-contradictory — a quantum version of the Liar Paradox [2]. These results further undermine the notion of a fixed spacetime within which all events maintain simple causal relations. Rather, it seems that quantum measurement can sometimes "rewrite" a process's history.

Something, then, seems to be flawed with the orthodox view of time as a mere dimension. Bearing in mind that the nature of time has an immediate bearing on many physical issues, it is reasonable to expect that a deeper theory of time will shed a new light on some other conundrums in the foundations of physics.

3 The Assumption: Becoming Is Real

The Spacetime Dynamics theory makes one new assumption:

The Assumption Of Becoming: What an observer perceives as "Now" is a special moment which marks the genuine creation of new events. World-lines objectively "grow" in the future direction. At any moment in time which an observer perceives as "Now," future events are not only unknown but *objectively inexistent*, to be created later as the "Now" advances.

Notice that the Block Universe is preserved as a special case in this model: Spacetime with its world lines exist in the past, but not in the future. Broad [10] and Sider [11] refers to this as the "Growing Block Universe."

In what follows, the new theory's postulates will be all the prevailing physical principles and effects, plus this new assumption. Let us follow their consequences.

4 Mach's Principle Extended: Spacetime Itself Unfolds with the Unfolding of New Events

Our first postulate is a simple principle due to Mach [12]:

Postulate A: Space and time are inconceivable in the absence of events.

The logical consequence of the Becoming Assumption and Postulate A is that we cannot conceive of new events being added to some empty spacetime in the future. Rather, spacetime itself must be "growing" in the future direction, alongside with the "growth" of the world-lines and the creation of new events. Hence,

Consequence 1: Any moment in time which an observer perceives as "Now" is simply the edge of time: *Nothing*, not even spacetime, exists beyond it.

While it is easy to illustrate spacetime with the familiar Minkowski diagram, our alternative model eludes graphic representation. We could draw a Minkowski diagram with an upper boundary representing the "Now", where all world-lines simply end, but that would be misleading: The empty surface above the "Now" would still have the diagram's spatial dimensions. It is simply impossible so portray the absence of space! But it is this very difficulty that should give us an insight into the reason why physical theory has been stagnating so long in this respect. Space, as Kant [13] has proven, underlies any possible though; we cannot think even the most abstract thought without implicitly assuming some underlying space. Bergson [14] has further shown that this problem besets modern physics' theorizing about time: We keep "spatializing" time. One should be aware of this inherent limitation of human thinking when seeking to transcend the present account of space and time.

5 Cosmology Extended: Spacetime Expands in the Time Direction Too

It cannot escape us that Consequences 1 has a strong affinity to mainstream cosmology's standard model:

Postulate B: Spacetime, ever since the Big Bang, keeps expanding.

But then, if the advancing "Now" is the edge of time beyond which no spacetime exists, then spacetime must be expanding in the time direction too. We move away from past events, perhaps, not unlike the way we move away from neighboring galaxies. The analogy is not perfect, nor should one try too hard to make it so,[c] but the idea of an expanding time seems to have a striking accord with the universe's spatial expansion.

Consequence 2: The universe's evolution involves the growth of both space and time. Alongside with the expansion of the spatial dimension, time expands too as the advancing "Now" creates more events together with their associated spacetime.

6 Infinity of Times Avoided

Cosmology gives us another valuable clue for dealing with an old problem. Most theorists avoided Becoming because it seemed to inevitably entail an endless series of higher and higher time parameters. For if the "Now" moves along time, than time itself constitutes merely a dimension for this movement, and an additional time must be assumed for this motion to occur. Cosmology, however, has dealt with a similar problem. The question "what happened before the Big Bang?" is routinely dismissed as meaningless by pointing out that "before" entails time and time itself was created in the Big Bang. Yet, several models invoked some "pregeometry" which existed "before" the Big Bang [16]. The validity of these speculations does not concern us here, but the basic idea is useful: The primordial geometry does not have to be the same as our present geometry, but of a more primitive kind, characterized by different axioms, and thus no infinite series of geometries is entailed.

[c] The main difference is that spacetime has no boundaries in the Big Bang theory while the "Now" assumed here constitutes a clear boundary. Still, the Big Bang itself is a boundary in time (Hawking's [15] attempt to eliminate it has not been generally accepted). Black holes constitute boundaries too. Moreover, it is not clear why boundaries should be considered a disadvantage for a theory.

Similarly for our case, there is no need to invoke a yet higher dimension for the development of spacetime, because this development can be of a more primitive kind. Recall that Presentism, the model rivaling the Block Universe, makes a self-consistent assertion: Time is nothing but change, "the fourth dimension" being merely a metaphor. Most physicists dismiss this option, and so do we, as it does not accord with relativity theory. But this reason does not apply for the dynamics of spacetime itself. If spacetime is subject to dynamics, such as growth in the future direction, there is no reason to assume that this dynamics is also subject to the laws of relativity. Velocities may be infinite, absolute simultaneity may hold, and therefore no higher dimension may have to be invoked. Bergson's [14] radical idea about pure change which transcends any dimensionality can therefore be neatly integrated with the relativistic spacetime, simply by assigning the former a more fundamental status:

Consequence 3: Change is more fundamental than space and time. Relativistic spacetime is subject to changes, such as the growth of its spatial and temporal dimensions. This is pure change, i.e., one state coming into existence after another, not subject to relativistic constraints, hence possessing no dimensionality whatsoever.

7 Relativity Dynamized: Interaction Precedes Spacetime

The Big Bang model has asserted what a few philosophers have earlier speculated: Space and time are not primary entities but derivatives of the unique event of creation. Our theory goes one step further to suggest that this creation of spacetime is continuous, thus affirming the naïve impression that every moment is a new creation.

Next, therefore, let us examine the relativistic principles governing spacetime within the new framework. Here, the Becoming Assumption seems to give these principles an appealing twist. Recall that for spacetime to be conceivable, there has to be not only a body, but two bodies at least, for it takes two bodies to distinguish between relative rest and motion [12]. Our next postulate is therefore taken from relativity:

Postulate C: There is no absolute motion or rest. All velocities are relative.

In fact, Mach went further to argue that all effects of inertia on a body — rest, motion and even acceleration — stem from the mere presence of matter in the universe. In other words, any kinematic state is due to some interaction. These arguments fit in naturally within the Spacetime Dynamics theory:

Consequence 4: The interaction between bodies precedes the advance of the "Now." First, bodies interact outside spacetime. Then, as the "Now" advances, a new spacetime zone is formed around the events created by this interaction, elongating the interacting bodies' world-lines and determining the spatiotemporal relations between them. Position, momentum and even acceleration are relative because they arise due to interactions prior to the formation of the spacetime within which they occur.

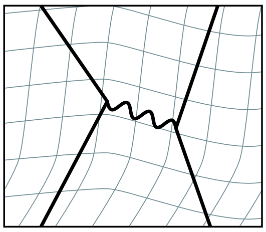


Figure 1. Block Universe model.

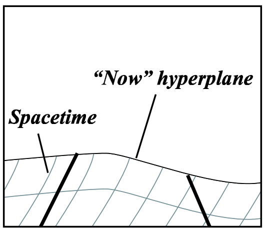


Figure 2. Initial state.

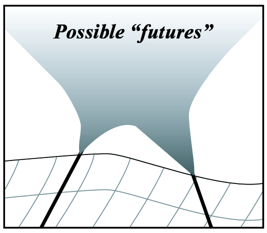


Figure 3. Interaction precedes spacetime.

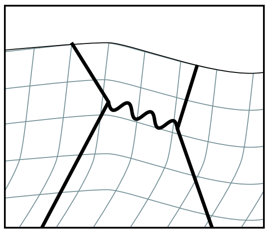


Figure 4. New spacetime region is created.

Figs. 1–4 portray this hypothesis, contrasting the Spacetime Dynamics theory with the Block Universe. Of course, no serious attempt is made to portray what occurs beyond spacetime or in the presumed pre-spacetime interaction.

Interestingly, the problem of nonlocality that besets Mach's principle is not a hindrance in the present framework. If the initial interactions take place outside spacetime, distances do not matter and the entire matter of the universe can affect any body. Rosen [17] proposed a similar hypothesis.

The relativistic c invariance,

Postulate D: The velocity of light is the same in all reference frames.

is amenable to a similar explanation. We recall that c is the velocity of all interactions mediated by zero mass bosons, *e.g.* electromagnetic and gravitational. Here again, the fact that a certain, privileged velocity is rendered by relativity as more basic than space and time, strikingly accords with our assumption that spacetime is not a primary ingredient of physical reality. Rather, perhaps,

Consequence 5: The spacetime of every reference frames is *formed* by the gravitational/electromagnetic interaction of that reference frame with its environment. These interactions, which occur in the pre-spacetime stage, determine the spatio-temporal distances between the events, such that the speed of light always appears the same.

We have thus elevated Mach's epistemological principle to an ontological hypothesis: It is not only in our thinking, but in reality, during Becoming, that *interaction precedes space, time, position and momentum.*

8 Quantum Mechanics and Relativity Intergrated: Macroscopic Superposition Enables the Pre-Spacetime Interaction

Dynamizing Mach's principle, turning it into a real component of Becoming, offers a deeper explanation not only to the principles of relativity theory but to quantum phenomena as well. "Superposition," the most fundamental ingredient of QM, denotes the coexistence of several mutually exclusive states, such as many positions of the same particle. Ever since the discovery of this state it kept posing two problems:

1. While superposition of microscopic objects has been demonstrated in numerous experiments, no macroscopic objects are observed superposed, even though quantum theory obliges the latter case just as well. A single particle can apparently traverse two slits at the same time, but a dead-plus-alive cat is never encountered.
2. Moreover, even the theoretical possibility of macroscopic superposition entails a serious problem within the framework of General Relativity. Suppose that a massive object is superposed. Then, not only its position within space, but the gravitational field associated with

it as well, must be superposed. Now since gravitation is defined by GR as a curvature of spacetime, an awkward situation emerges when this curvature is supposed to be superposed. While we can imagine a superposition of something within spacetime, it is hard to figure out within what can spacetime itself be in superposition.

Two major attempts were made so far to deal with this question:

1. The Many-Worlds interpretation asserts that the whole wave function of the Universe splits with every occurrence of superposition. Here too, many spacetimes are implicitly supposed to coexist within some undefined superspace.

2. Penrose's hypothesis [18] suggests that "collapse" occurs once the difference between two superposed states, in terms of spacetime curvature, exceeds that of one graviton.

Hypothesis (2) is bold and ingenious, but there is a more far-reaching possibility. If

Postulate E: Macroscopic superposition, though obliged by QM, is never observed,

then, perhaps,

Consequence 6: Macroscopic superposition occurs just as the microscopic one, but beyond the advancing "Now," where spacetime does not exist yet. All macroscopic phenomena have been genuinely superposed, but collapsed together with the progression of the "Now." Superposition does not evolve in empty spacetime. Rather, it marks the absence of spacetime in the future.

An interesting affinity now emerges, which perhaps is not coincidental: Many quantum physicists try to avoid the notion of "collapse," preferring hidden-variable interpretations of QM, because of the non-relativistic implications of this collapse and its time-asymmetry. The advancing "Now," of course, is also generally dismissed, for reasons discussed above. Yet collapse remains the simplest explanation for the difference between micro- and macroscopic phenomena, and the "Now" keeps being the most immediate feature of our experience. Perhaps, then, these two enigmatic phenomena are one and the same?

Consequence 7: "Collapse" marks the very advance of the "Now," by which several potential future outcomes of a certain state give place to one definite outcome in the present.

Once the more difficult phenomenon of macroscopic superposition has been addressed, the "ordinary" superposition, occurring at the microscopic scale, becomes much more natural. We know that

Postulate F: Most physical characteristics of macroscopic reality hold, at the microscopic scale, only statistically,

and

Postulate G: Many quantum oddities (e.g., the EPR and the delayed-choice experiments) can be interpreted as stemming from retro- active effects of the measurement backwards in time.

which pose the following restriction on Becoming:

Consequence 8: While the "Now" generally advances forward in time, at the quantum scale it might move also backwards. Limited spacetime segments, such as the superposed trajectories of a particle, are sometimes left "void" by the general Becoming, to be retroactively filled later by future interactions.

Our hypothesis is that microscopic superposition differs from the macroscopic one in that the former occurs within a spacetime already formed by the surrounding macroscopic bodies, previously collapsed with the advancing "Now" and leaving only a few causal chains incomplete. Measurement, that is, the interaction of the particle's wave function with other (unsuperposed) objects, fills these chains backwards. The famous time-symmetry of quantum interactions [19] may indicate that quantum evolution sometimes proceeds forward in the time of Becoming but backwards in the relativistic t. In other words, while the "Now" generally advances forward, it may sometimes "go back" in the $-t$ direction to fill some paths which have remained void.

Our hypothesis of a pre-spacetime stage preceding the formation of every instant is a dynamic version of Rosen's [17] notion of a deeper level of reality which is "fundamentally and predominantly nonspatial and nontemporal in character."

9 Time's Arrow Anchored: The Advancing "Now" Is the Master Asymmetry

Penrose [20], in a very bold move, conjectured that once a theory of quantum gravity is available, one cherished ideal of physics will be sacrificed, namely, time asymmetry. In other words, a tiny time-asymmetry may hide in the basic physical interactions. Although Penrose occasionally endorsed the Block Universe, his heresy accords much better with the notion of Becoming. The advancing "Now" is supposed, by definition, to move forward, hence is the best candidate to be the long sought-for "master asymmetry" from which all other time asymmetries (entropy, black hole formation, K-mesons T-violation, etc.) stem. Moreover, if future events genuinely do not exist at any "Now," quantum indeterminacy is also genuine rather than reflecting some unobservable hidden variables. Then, by the Indeterminacy-Asymmetry Entailment [8], entropy increase naturally follows.

Consequence 9: The advancing "Now" is the source of all time-asymmetries. Entropy increases already when different wave functions interact in advance of the "Now." The consequent formation of spacetime makes these interactions irreversible.

In this respect, at least, the Spacetime Dynamics theory has an undeniable advantage over the Block Universe. In the latter, time arrows like the thermodynamic entropy increase are merely assumed, as additions to the four-dimensional spacetime. They are obliged by everyday experience but with no justification in the theory itself (see [21]). In the Spacetime Dynamics theory, in contrast, indeterminism and entropy increase are necessary consequences of spacetime's nature.

10 Clues for Field Theory: Collapse of Macroscopic Superposition as the Source of Attraction/Repulsion Between Bodies

Let us reiterate our last steps. We speculated that relative positions and momenta of bodies, with all the resulting relativistic effects, are due to pre-spacetime interactions, after which, with the advance of the "Now," spacetime forms around the new events (Consequence 4). Then, in the context of quantum mechanics, we speculated that macroscopic superpositions also occur outside of spacetime, beyond the "Now" (Consequence

6). As Consequences 4 and 6 propose essentially the same thing, we may venture to conclude:

Consequence 10: The wave function of a macroscopic body creates a genuine superposition in the pre-spacetime state beyond the "Now." Several such wave functions, when interacting outside spacetime, exert "measurements" on one another, leading to mutual collapse and to relative positions and momenta. Relativistic effects are due to these mutual quantum measurements of macroscopic bodies during the pre-spacetime stage.

Next, another pair of postulates, one from QM and one from relativity, may integrate into a new consequence of the Spacetime Dynamics theory:

Postulate H: When a particles' position is measured and the particle is found not to reside at that point in space, the entire wave function is affected by this negative measurement and the likelihood for collapse increases elsewhere.

This is the familiar result known as "interaction-free measurement" [22]. It oddly renders the position of a particle a result of its being measured elsewhere and *not found* there. Apparently, this quantum mechanical peculiarity has nothing to do with the general relativistic principle

Postulate I: Spacetime is curved in the vicinity of mass.

But both phenomena might be unified by a single new definition of macroscopic collapse within the framework of the Spacetime Dynamics theory:

Consequence 11: When a macroscopic body is superposed at the pre-spacetime stage, its "collapse" gives rise not only to its position or momentum at some definite site and time. It also gives rise to all the empty sites in spacetime where the body *could* have been located.

Again, "position" gains an entirely new meaning by this formulation. Rather than a body being located in some empty space, both the body and its associated spacetime are created by the same wave function. But now, *changes* in relative positions, namely, *accelerations*, call for a new formulation:

Consequence 12: Attraction between bodies results from the special configuration of spacetime around the interacting bodies. There is, so to speak, "less space" between attracting bodies.

Having suggested that, it occurs to us that not only attraction but repulsion too can be given a new understanding in such a framework. Repulsion, however, occurs only in electromagnetism and not in gravity, and the long sought-for unification of the two realms is still far away. But perhaps the new reformulation, namely attraction/repulsion being due to special spacetime regions created by the wave functions around the interacting bodies, can give a hint towards this goal.

11 Summary and Apology

The omnivorous synthesis we proposed here originates from a twofold motivation. First, we find the Block Universe extremely odd. Second, many unresolved riddles in physics are obviously related to the nature of time, indicating that something essential is still missing in the relativistic account. Especially QM seems to keep telling us that the idea of a fixed, objectively existing future is obscure metaphysics. We therefore suggested adding Becoming to the existing postulates of theoretical physics.

Trying to preserve the essential features of both relativistic time and the idea of Becoming, we integrated them in a picture which ascribed pure change, without dimensionality, to spacetime itself, while relativity theory holds within that spacetime, thus becoming a special case of the Spacetime Dynamics theory. Applying Mach's principles, we concluded that Becoming involves not only the growth of world-lines but also the growth of spacetime itself in the future direction, in perhaps nontrivial resemblance with spacetime's spatial expansion in the Big Bang model. In other words, whereas present-day cosmology invokes one unique event of the creation of spacetime from nothing, we propose that at every instant, a new segment of spacetime is created, added to the universe's history.

Then, following Mach's principles and the principles of special relativity, we gave precedence to events over space and time, and precedence to relations over events. Consequently, we proposed that relative positions and momenta are formed in the pre-spacetime stage of every instant, ahead of the advancing "Now." Next, from the viewpoint of QM, addressing the apparent absence of macroscopic superpositions, we proposed that such states also exist in the pre-spacetime stage. Our next speculation, then, proposed a unification: It is the wave-functions of macroscopic objects that interact with one another beyond the "Now," so as to establish relative positions and momenta. Spacetime, according to this speculation, is formed only after the interactions. Applying Machian thinking even further, we suggested that the collapsing wave functions, upon measuring one another, create both the bodies and their associated spacetime. Thus, "position" and "momentum" gained an entirely new meaning. But then, perhaps even the phenomena of attraction and repulsion can get a new twist in this paradigm, by assuming that bodies created different configurations of spacetime between them so as to become closer or farther. From another perspective, that of thermodynamics, time's asymmetry, rather than being a fact-like feature of physical reality added "by hand" to the physical account of spacetime, became, together with indeterminism, part and parcel of it.

We anticipate the objections by which the Spacetime Dynamics theory may be dismissed, as we are painfully aware of them ourselves. At this stage the theory is vague, relying too much on intuitive guesses, lacking formal rigor and offering no testable predictions. If we venture to propose it nonetheless, it is in protest against the dearth of theorizing in current theoretical physics, dearth which we find, particularly in this centenary of the *Annus Mirabilis*, unacceptable. Physicists rarely dare to propose unconventional ideas nowadays, despite growing discontent with the prevailing models of spacetime, quantum, and the universe. It is time to move on. New hypotheses, even highly tentative, provide the best impetus for such a move.

Particularly odd in this respect is the impoverishment of the superstring models. While they reasonably seek to revise the account of spacetime for a better understanding of matter and energy, they rarely bother to address the "old" riddles of QM such as wave-particle duality, non-locality and macroscopic superposition. It is highly unlikely that a theory that ignores these riddles will ever come up with the long waited-for unification of relativity and quantum theories.

Even odder is superstring theories' muteness about the nature of time. In marked contrast with their lavishness concerning space — adding many hidden spatial dimensions — they leave time, with all its enigmatic features such as transience and asymmetry, as ill-understood as ever. We, in contrast, believe that even in the above sketchy account we were able to point out the enormous theoretical potential of the Becoming Assumption, as it so naturally provides a hidden time within which possible interactions can operate on the Minkowski-Einstein spacetime.

Cosmology, on the other hand, has been bolder, exploring many exotic features of the physical reality that might have existed prior to the Big Bang. "Pre-geometries," possessing primitive features that might lie beneath our familiar geometry, are being studied, and here superstring theories do yield important insights. Our modest contribution in this respect is the proposition that *the Big Bang is incessant.* Every new instant is a genuine creation *ex nihilo* of another segment of spacetime together with its events, just as the Big Bang is supposed to have been at the beginning of the universe. Let, then, all the speculations about the conditions that preceded the Big Bang be applied the unfolding of the next moment. Profound insights might emerge from such an attempt.

It is to the future, which we believe to be really undetermined, that we relegate the final judgment on this proposal.

References

1. Gödel, K. (1949) The debate over the block universe, in P. A. Schilpp (ed.), *Albert Einstein: Philosopher-Scientist*, The Library of Living Philosophers Inc., Evanston (IL), pp. 557–562.
2. Elitzur, A.C., and Dolev, S. (2005) Quantum phenomena within a new theory of time, in A. C. Elitzur, S. Dolev and N. Kolenda (eds.), *Quo Vadis Quantum Mechanics?*, Springer, New York, pp. 325–350.
3. Feynman, R. (1948) Space-time approach to non-relativistic quantum mechanics, *Rev. Mod. Phys.* **20**, 367–387.
4. Rohrlich, D., Aharonov, Y., Popescu, S., and Vaidman, L. (1995) Negative kinetic energy between past and future state vectors, *Ann. N. Y. Acad. Sci.* **755**, 394–404.
5. Cramer, J.G. (1986) The transactional interpretation of quantum mechanics, *Rev. Mod. Phys.* **58**, 647–688.
6. Elitzur, A.C. (1990) On some neglected thermodynamic peculiarities of quantum non-locality, *Found. Phys. Lett.* **3**, 525–541.
7. Davies, P.C.W. (1995) *About Time: Einstein's Unfinished Revolution*, Simon & Schuster, New York.
8. Elitzur, A.C., and Dolev, S. (1999) Black hole evaporation entails an objective passage of time, *Found. Phys. Lett.* **12**, 309–323.
9. Dolev, S., and Elitzur, A.C. (2000) Non-sequential behavior of the wave function, preprint `quant-ph/0012091`.
10. Broad, C.C. (1923) *Scientific Thought*, Hartourt, Brace and Co., New York.
11. Sider, T. (2001) *Four Dimensionalism*, Clarendon, Oxford.
12. Mach, E. (1960) *The Science of Mechanics*, Open Court, LaSalle (IL).
13. Kant, I. (1787/1966) *Critique of Pure Reason*, Anchor Doubleday, New York.
14. Bergson, H. (1911) *Creative Evolution*, Holt & Co., New York.
15. Hawking, S.W., and Penrose, R. (1996) *The Nature of Space and Time*, Princeton University Press, Princeton.
16. Patton, C.M., and Wheeler, J.A. (1975) Is physics legislated by cosmogony?, in C. J. Isham, R. Penrose and D. W. Sciama (eds.), *Quantum Gravity*, Clarendon Press, Oxford, pp. 538–605.
17. Rosen, J. (1994) Time, *c*, and nonlocality: A glimpse beneath the surface?, *Phys. Ess.* **7**, 335–339.

18. Penrose, R. (1979) Singularities and time-asymmetry, in S. W. Hawking and W. Israel (eds.), *General Relativity: An Einstein Centenary Survey*, Cambridge University Press, Cambridge, p. 581.
19. Aharonov, Y., Bergman, P.G., and Lebowitz, J.L. (1964) Time symmetry in the quantum process of measurement, *Phys. Rev.* **134**, 1410–1416.
20. Penrose, R. (1994) *Shadows of the Mind*, Oxford University Press, Oxford.
21. Price, H. (1996) *Time's Arrow and Archimedes' Point*, Oxford University Press, Oxford.
22. Elitzur, A.C., and Vaidman, L. (1993) Quantum mechanical interaction-free measurements, *Found. of Phys.* **23**, 987–997.

R. Buccheri et al. (eds.); Endophysics, Time, Quantum and the Subjective; 607–609

CLOSING ADDRESS

GEORGE JAROSZKIEWICZ
School of Mathematical Sciences, University of Nottingham
University Park, Nottingham NG7 2RD, U.K.
(george.jaroszkiewicz@nottingham.ac.uk)

Ladies and Gentlemen, Friends and Colleagues,

I have had the honour of being asked to close both the previous meeting in Tatranská Lomnica, Slovakia, in 2002 and now here at the Zentrum für interdisziplinäre Forchung der Universität Bielefeld (ZiF) in 2005. I am a bit worried. What significance does this have? Am I perceived somehow as having some special talent for ending meetings and thereby help to disperse friends?

I was fortunate to speak on the first day, because for the rest of the week I could relax and enjoy a real "out-of-body" experience, listening to all the fascinating talks that were to follow. And what could be more fascinating than the subject of time? Well, I have to say that in one respect, our meeting here was a complete failure. Time is still mysterious, I am sorry to say, but maybe that's not so bad, on second thoughts. It means we have not been deprived of the exciting possibility of meeting "old" and new friends at the next in what is now a successful series of workshops.

Let me remind you of the history of these meetings. Way back in 1996, Rosolino Buccheri from Palermo, Sicily and Metod Saniga from Tatranská Lomnica, Slovakia, found a mutual interest in time and consciousness and started a scientific collaboration in that area. Before long they decided to organize an international workshop on the subject, in which all relevant aspects of time and consciousness would be considered. That meeting was in Palermo in 1999, which I attended. There I met for the first time a group of extraordinary people involved with its organization and I am delighted to say we are still friends. The success of that meeting encouraged Lino and Metod to plan the second of these workshops, in Tatranská Lomnica, Slovakia in 2002. Now the third has been held here in the ZiF Institute in Bielefeld. All have been excellent. Where the next meeting will be has yet to be finalized, but I am sure some good colleagues will rise to the challenge and organize the fourth in what it is hoped will be a long term series of workshops in a truly fascinating subject full of significance to all people.

Looking back at the journey we have taken from Palermo, through Tatranská Lomnica and now to Bielefeld, it appears to me that there have been some subtle changes along the way. There have been fewer completely speculative talks, with more rigorous lines of thinking developed throughout the week with more focus on certain key areas such as the role of quantum mechanics and the structure of the brain. And of course, no one who was here this week will quickly forget the numerous amusing references to the concept of a "zombie", which featured in a number of talks. The plan of the meeting, which was structured into four interrelated sessions, was well drawn by the organising committee. I found myself interested in all sessions and this was the first conference I attended where I did not miss a single talk.

A remarkable feature of these meetings which I came to appreciate very much in Palermo, then in Tatranská Lomnica, and now here at ZiF, has been the contribution of the philosophers. Their function is like that of the man who stood behind a successful Roman general on his chariot during the general's triumph through the streets of Ancient Rome. A golden crown was held over the general's head and he was reminded constantly that he was, after all, mortal. By definition, philosophers cannot give scientists new scientific results, for then philosphers would be scientists themselves. What philosophers can do for scientists is to constantly remind them that humans have an amazing capacity to make serious conceptual mistakes. It would be no bad thing, perhaps, if all scientific conferences, particularly those on string theory, reserved a place of honour for a philosopher, charging them with the duty of reminding participants that they too are mortal and could be wrong in their fundamental assumptions. The timely address from Professor Emilios Bouratinos on this the last day serves as an important reminder to us of the dangers of blind objectification, of believing in the reality of our mathematical descriptions, without any regard to the complex processes of thought which led us to those descriptions. In the words of Professor Bouratinos, amended from Plato's *Republic,* "Scientists should become philosophers and philosophers scientists. Scientists need to learn more about how to think, thinkers need to learn more about how science operates."

Another remarkable feature of this meeting has been the active participation of a number of outstanding young people. I pay tribute to the excellence of their talks, which were at a very high level, and to the impressive way in which they were given.

The importance of such meetings cannot be overestimated. We go to them not only to advertise and sell our own wares, but to buy new ones. We meet old friends and reinforce existing collaborations; we make new friends and establish new collaborations. In order to do this, we rely on the generosity of sponsors and organizations such as ZiF. Without them, nothing could be done.

ZiF is a remarkable institution. Over many years it has followed an enlightened policy of inviting academics from all over the world to participate in interdisciplinary programmes such as ours in a friendly and comfortable setting. Many people including us have benefitted from this wise policy and long may it continue. Bielefeld has been our home and our University over this last week and we shall miss it and its people. It is a great pleasure to thank the Director and all staff of ZiF for being such excellent hosts. Everyone will want to thank the Catering Staff in particular for putting on such an excellent Conference Banquet.

I am sure all participants will wish me to extend our gratitude to our other chief sponsor, SkyEurope Airlines, for their invaluable contribution. Thank you SkyEurope for your help; it is greatly appreciated.

Of course, any meeting relies on the people who attend. Without them, there could be no meeting. So on behalf of the Organizers, I sincerely thank all you participants for making the effort to come here and for all your invaluable contributions. These Proceedings are an enduring testament to the quality of your efforts. Finally, let us never forget to thank all our friends and our family back home for covering for us during this time.

It is a pleasure to give special thanks to a number of key individuals, without whom this meeting would not have taken place. On behalf of all participants, I thank Metod Saniga, Rosolino Buccheri and Avshalom Elitzur for their very hard work in organizing this successful meeting. Last but not least, I thank Trixi Valentin, our tireless secretary here at ZiF, for keeping us so well-informed during the run up to the meeting, for making our travel to ZiF so trouble-free, and for her constant help during this week.

Time is information, information is time. We do not know at the time of writing where the next meeting will be held, but plans are under way. Let us make the effort to keep in touch and work hard to meet again in the not too distant future.