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ORIGINAL PAPER

Categorical Ontology of Levels and Emergent Complexity: An Introduction

Ion C. Baianu

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Abstract An overview of the following three related papers in this issue presents the Emergence of Highly Complex Systems such as living organisms, man, society and the human mind from the viewpoint of the current Ontological Theory of Levels. The ontology of spacetime structures in the Universe is discussed beginning with the quantum level; then, the striking emergence of the higher levels of reality is examined from a categorical—relational and logical viewpoint. The ontological problems and methodology aspects discussed in the first two papers are followed by a rigorous paper based on Category Theory, Algebraic Topology and Logic that provides a conceptual and mathematical basis for a Categorical Ontology Theory of Levels. The essential links and relationships between the following three papers of this issue are pointed out, and further possible developments are being considered.

Keywords A categorical ontology theory of levels ·
Non-Abelian algebraic topology of spacetime structures ·
Evolution, co–evolution, Rosetta groupoids and the emergence of *homo sapiens*, society and the human mind ·
Conceptual framework for a categorical ontology theory of levels ·
Biodynamics, variable topology and biogroupoids in relational biology ·
Non-linear network dynamics of functional genomes and /Lukasiewicz many-valued logic algebras ·
Quantum gravity, quantum logic, and non-Abelian approaches to quantized spacetime structures

I. C. Baianu (✉)
FSHN and NPRE Departments, AFC–NMR and NIR Microspectroscopy Facility, University of Illinois at Urbana–Champaign, Urbana, IL 61801, USA
e-mail: ibaianu@uiuc.edu

1 Introduction

We are exploring in this issue fundamental questions in the Ontological Theory of Levels (OTL) as recently re-structured by Poli (1998–2008), and Gnoli and Poli (2004). Such important questions span a wide range of reality, from the basic Space–Time Structure of the Universe to the Emergence of higher complexity levels in Life, Mind and Society. This is a largely unexplored field that poses novel ontological as well as methodological questions; such ontological investigations began perhaps in earnest with the work of Brentano (see for example Albertazzi 2005), and later by Alexander (1927), and also Hartmann (1935, 1952).

As the intended readers are both philosophers and scientists interested in Ontology—in part philosophy and also science—we do not lay claim to 'solve' any major ontological problem in the three following papers included in this issue, such as the question of existence of an essence for every ontological item, or indeed how highly complex systems, processes or 'items', in general, have come into existence. Neither do we aim to provide a complete (ontological) taxonomy of highly complex systems which would take far more space and time than available to us here, if it were at all possible to accomplish it rigorously. Furthermore, an ontology based strictly on object classification may also have little to offer from the point of view of its cognitive content in spite of its Aristotelian appeal.

Whereas solutions may not be soon forthcoming because basic ontological problems are both subtle and difficult, it seems possible to define the key problems and establish a conceptual framework for OTL. Ontology has acquired over time several meanings and has been approached in many different ways, however mostly connected to the concept of an '*objective existence*'; we shall consider here the noun 'existence' as a basic, or primitive, concept not definable in more fundamental terms. The attribute 'objective' will be assumed with the same meaning as in '*objective reality*', and reality is understood as whatever has an existence which can be rationally or empirically verified independently by human observers in a manner which is neither arbitrary nor counter-factual. Furthermore, the *meaningful classification of items* that belong to such an 'objective reality' is one of the major tasks of ontology.

We are enquiring if new and powerful, methodological tools may be brought to bear, and indeed further developed, with the hope of being able to help one understand the spacetime ontology and highly complex dynamics of 'natural systems' (such as various biosystems or organisms), the human brain, the mind and society. One is looking for a strong framework which is both precise and flexible, yet without being too narrow to prevent further ontological and theoretical developments. Beginning in antiquity with Aristotle and Plato, conceptual *categories* have served well the philosopher as well as special sciences; beginning with the middle of the last century, new categories have emerged in a tendency to unify mathematics (Ehresmann 1963–1984; Eilenberg and Mac Lane 1942, 1945; Grothendieck 1957, 1971; Grothendieck and Dieudonné 1960; Bourbaki 1960, 1961–1964, 1991; Brown 1967, 2004–2006). Universality of properties and objects then acquired new, precise meanings in the context of the mathematical theory of categories, functors and natural transformations (TC-FNT, Eilenberg and Mac Lane 1945; Grothendieck and Dieudonné 1960;

Grothendieck 1971; Cohen 1965; Freyd 1964; Mitchell 1965; Gabriel and Popescu 1964; Gablot 1971; Gabriel 1962; Gabriel and Zisman 1967; Popescu 1973; Mac Lane 1963, 2000; Gray 1965; Bucur and Deleanu 1968; May 1999; Samuel and Zariski 1967; Mac Lane and Moerdijk 1992). TC-FNT applications in Neurosciences and Biology have originated with the seminal papers by Rosen (1958a, b) and were anticipated by Rashevsky's papers on Topological and Relational Biology (Rashevsky 1954). These were subsequently developed in a series of papers extending the concepts of category and functor (Baianu 1987a, b); other recent applications focused on bionetworks and their ontology (Brown and Porter 2003; Brown et al. 2004; Baianu et al. 2004, 2006; Ehresmann and Vanbremeersch 2006; Healy and Caudell 2004, 2006). A monograph was also assembled in 1986 posing also some of the questions discussed here such as computability of biosystems, many-valued logics underlying genetic and neural networks, as well as possible medical applications of computers, multi-valued logics and categorical modelling (Baianu 1987a, b). In a subsequent paper on complex systems, Rosen (1987) also pointed out the impassable, numerical-computational barriers between simple, physical systems/machines and complex, living organisms. Elsasser (1981) also raised in an earlier paper the important question of the form or system logic suited for Biology, whereas Fleischacker (1988) addressed autopoiesis (Maturana and Varella 1980) in terms of its internal 'system logic'.

The 'methodological' ontology task of providing the 'right kind of tools' is indeed monumental in itself, if not daunting, and one may be surprised at first that it has not been seriously attempted before throughout ages. The reason may be that we are now at such a stage of development in philosophy and science that the required tools are beginning to emerge or are indeed in the process of being developed by the 'exact sciences', including logics, mathematics, physics, genetics, molecular biology, relational biology, etc. as a result of major trends towards unity in logics, mathematics, physics, biology and psychology. The challenges that one must face, we feel, are so great that one cannot accept on an a priori basis (e.g. Platonic, Aristotelian, Kantian, Wittgensteinian, etc.) any theses, axioms or even assumptions that may not be decidable 'rationally' (whatever that means). Such is one's choice in deciding to be rigorous especially when approaching highly complex dynamic problems upon whose solution the very existence of human society may now depend; this is because such highly complex problems cannot be 'reduced' in any conceivable manner to simpler ones.

In this issue we introduce a Formal Theory of Levels in a Categorical Ontology framework of Space and Time for Emergent Biosystems, Super-complex Dynamics, Evolution and Human Consciousness. Relational structures of organisms and the human mind can be then naturally represented in non-Abelian categories and Higher Dimensional Algebra. Here, we are in harmony with the theme and approach of the ontological theory of levels of reality (Poli 1998–2008) by considering categorical models of complex systems in terms of an evolutionary dynamic viewpoint. Our main descriptive mechanism involves the mathematical techniques of category theory which afford describing the characteristics and binding of levels, besides the links with other theories. Whereas Hartmann (1952) stratified levels in terms of the four frameworks: physical,'organic'/biological, mental and spiritual, we restrict mainly to the first three.

2 Categorical Ontology and Dynamics of Highly Complex Systems

In our first paper in this issue, the ascent of man and other organisms through adaptation, evolution and social co-evolution is viewed in categorical terms as variable algebraic—topological representations of evolving species. The unifying theme of a local-to-global approach to organismic development, evolution (Mayr 1970) and human consciousness leads to novel patterns of relations that emerge in super- and ultra- complex systems in terms of colimits of variable, topological biogroupoids, and more generally, as compositions of local procedures. Solutions to such local-to-global problems in highly complex systems with 'broken symmetry' may be found with the help of generalized van Kampen theorems in algebraic topology such as the Higher Homotopy van Kampen theorem (HHvKT). Primordial organism structures are predicted from the simplest Metabolic-Repair systems extended to self-replication through autocatalytic reactions. The intrinsic dynamic 'asymmetry' of genetic networks in organismic development and evolution is investigated in terms of categories of many-valued, Łukasiewicz-Moisil logic algebras (Georgescu 2006; Georgescu and Popescu 1968) and then compared with those obtained for (non-commutative) Quantum Logics. The claim is then defended that human consciousness is *unique* and should be viewed as an ultra-complex, global process of processes. Philosophical theories of the mind are approached from the theory of levels and ultra-complexity viewpoints which throw new light on previous representational hypotheses and proposed semantic models in cognitive science.

In our first paper, the human mind is represented for the first time as an *ultra–complex* '<system> of processes' based on, *but not necessarily reducible to*, the human brain's highly complex activities enabling and entailing the emergence of mind's own consciousness; thus, an attempt is made here to both define and represent in categorical ontology terms the human consciousness as an *emergent/global, ultra-complex process* of mental activities as distinct from—but correlated with—a multitude of integrated local super-complex processes that occur in the human brain. In accordance with replacing reductionism by appropriate complexity theories of the highly complex human mind and its supporting matter systems in the brain, one requires second order models consisting of a meta-model or *meta-theory*. A brief and only partial analogy as discussed in Atmanspacher and Jahn (2003) might be made with first-order engineering connecting hardware to software in AI systems; this partial analogy suffers, however, from severe, reductionist limitations. The *hard problem of consciousness* is:

> "How can one fully comprehend the emergence of *non-spatial* forms arising from one that is spatial (such as the brain) within the subjective manifold of human sensibility?"

The brain matter in itself appears to be *insentient* (as far as one can tell) and does not by itself explain causal, spatiotemporal events as agents of consciousness. Thus, over the last 25 years considerable attention has been paid to the question of whether or not mental processes have some physical content, and if not, how do they affect physical processes. Of course, the historically leading disciplines in this respect are philosophy and psychology, which were later joined by behavioral

science, cognitive science and neuroscience. Regarding the issue of complexity, this is quite evident: the brain is one of the most complex systems we know, but arguably not as complex as the mind (James 1890, 1958; Pickering and Skinner 1990; Harman 1981).

In another context of a simple, physical example, the expectation value of an observable defined in some limit $N \longrightarrow \infty$, which conceivably does not exist, can be however realized in the second order viewpoint by studying the mean-value of the considered observation as changing, in accord with functions up to finite N. In general, it is erroneous to employ first-order experiments as an attempt to validate second-order models (a psychological stumbling block when it comes to "thinking about thinking", again, cf the 'mereological fallacy', Bennett and Hacker 2003); whereas a level (**n – 1**)-theory may be deducible from a level **n**-theory, the converse is not true, in so far as, for instance, that a theory of neuronal assemblies cannot be used as the sole basis for the explanation of a given cognitive process. In this regard, the categorical methods we propose for ultra-complex processes or systems are suitably geared for the 'contraction principle' in going from level n down to level $(n - 1)$ and making the right predictions accordingly. The mind, or the mental level, then is a *meta–level* of reality, as it utilizes < representations > of representations, self-representation, and processes of processes… For example, the 'self' increases in complexity in confronting new challenges and implementing new tasks. But this categorical approach of access to level $n - 1$ from level n is a blueprint for studying complex processes that the usual 'self' often dispenses with. Many individuals can admirably perform their secular duties, enjoy their leisure etc. in society without any due regard to the concepts and functions of their corporal metabolism, neurophysiology, and cognitive mechanisms, etc., unless illness or some other disposition causes an alert to these functions. The situation for AI and 'conscious' machines is even more pronounced. Chalmers (1996) points out the examples of Hofstadter (1979)—it is not necessary to give a system access to its low-level components - and Winograd's program SHRDLU (1972) had no knowledge of the programming language in which it was written despite its capacity to assimilate the structure of a virtual world and make inferences about it.

Therefore, the *process-based approach* to universal ontology is essential for the understanding of the ontology of levels, hierarchy, complexity, anticipatory systems, Life, Consciousness and Universe(s). On the other hand, the opposite approach, based on objects, is perhaps useful only at the initial cognitive stages in experimental science, as the reductionist approach of 'cutting off' functional connectivities and relations, retaining the object pieces, and then attempting 'to put back together the pieces' does *not* work for complex, super-complex or ultra-complex systems. Psychologists and us would be thus horrified at the suggestion of 'taking a mind to pieces and attempting to put it back together afterwards'; not only it would not work, but it would also be *highly unethical*, and of course not legal.

Following a more detailed analysis, the claim is defended here that the human mind is more like a '*multiverse with a horizon, or horizons*' rather than merely a '*super-complex system with a finite boundary*'. Anticipatory systems and complex causality at the top levels of reality are also discussed in the context of the

ontological theory of levels with its complex/entangled/intertwined ramifications in psychology, sociology and ecology.

Brentano's position regarding *intentionality* of mental representations was clearly stated as making the distinction between the physical and mental realms. Other philosophers are less supportive of this view; a cogent presentation of various positions adopted by philosophers of the mind vis a vis mental representations was provided by Field (Chapt. 5 in Block 1981). Mental representations are often considered in psychology and cognitive sciences (including neocognitivism, cf. Dennett 1981) as fundamental; the concept has been therefore intensely debated by philosophers of psychology, as well as psychologists, and/or cognitive scientists (Baars 1988; Edelman 1989, 1992; Csikzentmihalyi 1990; Damasio 1994; Baars and Newman 1994; Chalmers 1996; Freeman 1999; Grossberg 1999; Andersen et al. 2000; Pribram 2000; Baars and Franklin 2003). It has been proposed by Field (1981) that organisms which are sufficiently complicated for the notions of belief and desire to be clearly applicable must also have **systems of internal representations (SIR)** in which **sentence-analogs** have significant grammatical structure. On this hypothesis, a belief involves a ***relation between organisms and sentence-analogs in a SIR*** for organisms of 'sufficient complexity'. From a functionalism standpoint that abstracts out the physical structure of particular organisms, the problem arises how psychological properties are realized by such organisms (Rashevsky 1954–1969; Rosen 1958a, b–1987); there are also the two related questions of how to define a *realization* of a psychological property, and how to define "what a psychological property itself is". Therefore, "*if you do not construe belief* ***relationally***, *you need a* ***physical realization*** *of the belief relation*" (p. 91 of Field 1981). Perhaps Field's proposal can be implemented along the Tarskian compositional semantics in a many-valued setting, such as the Łukasiewicz generalized topos (LGT), that was first introduced in Baianu et al. (2004, 2007) and may provide an adequate conceptual framework for such semantic interpretations, for example *with nuances specified by many truth values* instead of a single one!

In his widely-read books on Cybernetics and Society, Norbert Wiener (1950, also 1989 edn.) attempted in vain to reconcile mechanistic views and machine control concepts with the dynamics of modern society. He also advocated the representation of living organisms in terms of *variable* machines or variable automata (formally introduced in Baianu 1971b; Warner 1982). (The problem with representing life forms as variable automata is in essence the strictly deterministic character of the latter systems, as well as their simple dynamic character determined by the semigroup, or monoid,'purely' algebraic structure of any automaton's state space.) It remains to be seen if complexity theories will be able to fare better than Cybernetics in addressing '*the human use of human beings*' as Wiener has so aptly labelled the key problem of human societies, past and present.

One can only thus hope for a rigorous foundation of ontology of highly complex systems, and indeed philosophy of science, by employing the most suited tools to the task; it may also be that such tools that we consider might have value not only to the sciences of complexity and ontology but, more generally also, to all philosophers seriously interested in keeping on the rigorous side of the fence in their arguments. In the not too distant past, similar methodological and indeed

theoretical arguments may have been made for the theory of sets, rather promptly disposed of by Whitehead, Bertrand Russell and many others, followed in a different vein by Zermelo, Čech (1932), Carnap (1938), Tarski in 1960, Charles Ehresmann (1959–1984), Lawvere (1963, 1966), Löfgren (1968) and Alexander Grothendieck (1957–1971) to mention just several of the most prominent contributors, besides the 'anonymous Nicolas Bourbaki' (1961–1964, 1991), and also Wittgenstein. The latter two found fault with *set-like problems* in philosophers' language and they too had problems especially when language was used to carry on certain deep philosophical arguments; Wittgenstein himself used such arguments in his two published, monumental/philosophical treaties that he afterwards labelled as "non-sense". His point is well taken-there seems to be a long-standing, methodological problem in philosophy related to language, and perhaps to all other extensions or forms of 'languages' that are set-theoretical in their essence. Consistent with this standpoint, we use throughout this issue the attribute 'categorial' for philosophical-linguistic arguments only.

3 A Conceptual and Categorical Framework in the Ontology of Levels—The Rigors of Mathematics and Logic Algebras

On the other hand, the rigorous term '*categorical*' is here utilized only in conjunction with applications of concepts and results from the TC-FNT field of mathematics whose conceptual framework is concisely presented in the accompanying, third paper by Brown et al. (2007) in this issue along with current, fundamental concepts and results from Algebraic Topology, such as the van Kampen theorem (van Kampen 1933) and its generalizations (Brown 1967, 1987, 1988, 2004, 2006; Brown and Janelidze 1997; Bunge and Lack 2003; Brown et al. 2007, 2008), or the Galois theory and homotopy double groupoids (Brown 2002; Brown and Janelidze 2004). Therefore, the reader is not required here to have either a mathematical or physical background, although some background knowledge of biology, neurosciences, psychology and cognitive science may be either beneficial or essential, depending on the level of the argument.

The categorical techniques which we introduce provide a means of describing levels in both a linear and interwoven fashion thus leading to the necessary bill of fare: emergence, complexity and open non-equilibrium/irreversible systems. Furthermore, as shown by Baianu and Poli (2008), an effective approach to Philosophical Ontology is concerned with universal items assembled in categories of objects and relations, transformations and/or processes in general. Thus, Categorical Ontology is fundamentally dependent upon both space and time considerations. The formation, changes and indeed the evolution of the key concepts of space, time and spacetime are therefore considered first in the preceding paper.

Our viewpoint is that models constructed from category theory and higher dimensional algebra have potential applications towards creating a higher science of analogies which, in a descriptive sense, is capable of mapping imaginative subjectivity beyond conventional relations of complex systems. Of these, one may strongly consider a *generalized chronoidal-topos* notion that transcends the

concepts of spatial-temporal geometry by incorporating *non-commutative multi-valued logic*. Current trends in the fundamentally new areas of quantum-gravity theories appear to endorse taking such a direction. We aim further to discuss in the paper some prerequisite algebraic-topological and categorical ontology tools for this endeavor.

It is interesting that Abelian categorical ontology (ACO) is also acquiring several new meanings and practical usefulness in the recent literature related to computer-aided (ontic/ontologic) classification, as in the case of: neural network categorical ontology (Baianu 1972; Ehresmann and Vanbremeersch 2006; Healy and Caudell 2006), Genetic Ontology, Biological Ontology, Environmental representations by categories and functors (Levich and Solovy'ov. 1999), or highly complex societies.

4 Categorical Ontology of the SpaceTime and the Universe

In the second paper of this issue we introduce a novel, TC-FNT, quantum logics and higher-dimensional algebra approach to Quantum Gravity Space–Time Ontology. We also consider briefly how the space and time concepts evolved, resulting in the joint concept of an objective '*spacetime*' in the physical Relativity theory, in spite of the distinct, (human) perception of space and time dimensions. Then, we shall proceed to define the role(s) played by the space, time and space–time concepts in the broader context(s) of Categorical Ontology. A dynamic classification of systems at different levels of reality, is proposed beginning with the physical levels (including the fundamental quantum level) and continuing in an increasing order of complexity to the chemical/molecular levels, and then higher, towards the biological, psychological, societal and environmental levels. Indeed, it is the principal tenet in the theory of levels that "*there is a two-way interaction between social and mental systems that impinges upon the material realm for which the latter is the bearer of both"* (Poli 2001a, b).

Whereas Newton, Riemann, Einstein, Weyl, Hawking and Ellis (1973), Penrose (1994), Weinberg (1995–2000) and many other exceptionally creative theoreticians regarded physical space as represented by a *continuum*, there is an increasing number of proponents for a *discrete, 'quantized'* structure of space–time, since space itself is considered as discrete on the Planck scale (see, for example, Butterfield and Isham 1998, 1999, 2000–2002). Like most radical theories (Woit 2006), the latter view carries its own set of problems. The biggest problem arises from the fact that any discrete, 'point-set' (or discrete topology), view of physical space–time is not only in immediate conflict with Einstein's General Relativity representation of space–time as a *continuous Riemann* space, but it also conflicts with the fundamental impossibility of carrying out quantum measurements that would localize precisely either quantum events or masses at singular (in the sense of disconnected, or isolated), sharply defined, geometric points in space–time.

The evolution in our universe is thus seen to proceed from the level of 'elementary' quantum 'wave-particles', their interactions via quantized fields (photons, bosons, gluons, etc.), also including the quantum gravitation level, towards aggregates or categories of increasing complexity. In this sense, the

classical macroscopic systems are defined as 'simple' dynamical systems, computable recursively as numerical solutions of mathematical systems of either ordinary or partial differential equations. Underlying such mathematical systems is always the Boolean, or crysippian, logic, namely, the logic of sets, Venn diagrams, digital computers and perhaps automatic reflex movements/motor actions of animals.

It will also be shown in the second paper of this issue that any complete Categorical Ontology theory is *a fortiori non-Abelian*, and thus *recursively and numerically* non-computable, on account of both the quantum level (which is generally accepted as being non-commutative), and the top ontological level of the human mind—which also operates in a non-commutative manner, albeit with a different, *multi-valued* logic than Quantum Logic. To sum it up, the operating/operational logics at both the top and the fundamental levels are *non-commutative* (the 'invisible' actor (s) who—behind the visible scene—make(s) both the action and play possible!). At the fundamental level, spacetime events occur according to a quantum logic (QL), or *Q-logic*, whereas at the top level of human consciousness, a different, non-commutative Higher Dimensional Logic Algebra prevails akin to the many-valued (Łukasiewicz - Moisil, or LM) logics of genetic networks which were shown previously to exhibit non-linear, and also non-commutative/non-computable, biodynamics (Baianu 1977, 1987a, b, 2008; Baianu et al. 2008; Goodwin 1982, 1994; Edelman and Tononi 2000). Then we further consider spacetime ontology in the context of Astrophysics, and also our Universe's representations in terms of quantum algebraic topology and quantum gravity approaches founded upon TC-FNT, quantum logics, non-Abelian Algebraic Topology and Higher Dimensional Algebra; this approach is then integrated with the viewpoint of the Quantum Logics in a Generalized 'Topos'—a new concept that ties in closely Q-logics with many-valued, LM-logics and category theory.

The fundamental quantum level is generally accepted to be dynamically, or intrinsically *non-commutative*, in the sense of the *non-commutative quantum logic* and also in the sense of *non-commuting quantum operators* for the essential quantum observables such as position and momentum. Therefore, any 'complete' theory of levels, in the sense of incorporating the quantum level, is thus—*mutatis mutandis—non-Abelian*. Therefore, at this point, there are two basic choices in Categorical Ontology: either to include the quantum level and thus generate a non-Abelian Ontology founded upon the non-commutative quantum logic, or to exclude the 'fundamental' level and remain strictly Abelian, that is accepting only strict determinism/linear causality and a commutative logic for its foundation such as Boolean or Brouwer-intuitionistic logic. Furthermore, as the non-Abelian case is the more general one, from a strictly formal viewpoint, a non-Abelian Categorical Ontology is the preferred choice. Nevertheless, from the point of view of simplicity (see Occam's razor) or 'economy of thought', the *Abelian* form of Categorical Ontology may be often selected by reductionists, mathematicians or engineers, for example; the commutativity and/or symmetry present in the Abelian theory can be seen as quite attractive either from an esthetic viewpoint or from the standpoint of the rapid elaboration/development of Categorical Ontology. Regardless of the latter views, the paradigm-shift towards a *non-Abelian Categorical Ontology* has already started (Brown et al. 2008: '*Non-Abelian Algebraic Topology*'; Baianu et al. 2006:

NA-QAT). New areas of Categorical Ontology are likely to develop as a result of the recent paradigm shift towards non-Abelian theories. Such new areas would be related to recent developments in: non-Abelian Algebraic Topology, non-Abelian gauge theories of Quantum Gravity, non-Abelian Quantum Algebraic Topology and Noncommutative Geometry, that were briefly outlined in this issue in relation to spacetime ontology. A paradigm shift towards *non-commutative*, or non-Abelian, theories of highly complex dynamics is suggested to unfold now in physics, mathematics, life and cognitive sciences, thus leading to the realizations of higher dimensional algebras in neurosciences and psychology, as well as in human genomics, bioinformatics and interactomics.

Mathematical generalizations such as higher dimensional algebra are thus logical requirements of the unification between complex system and consciousness theories that would be leading towards a deeper understanding of man's own spacetime ontology, which is claimed here to be both *unique* and *universal*.

However, we are unable to consider in detail in this issue the broader, and very interesting implications of *objectivation* processes for human societies, cultures and civilizations. To what extent the tools of Categorical Ontology and Higher Dimensional Algebra are suitable for the latter three items remains thus an open question. Furthermore, the possible extensions of the approach outlined in this issue to investigating globally the *biosphere* (Wallace 2000) and also the

$$\textbf{Biosphere} \Longleftrightarrow \textbf{Environment interactions}$$

remain as a further object of study in need of developing a formal definition of the horizon concept, only briefly touched upon here.

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References

Albertazzi L (2005) Immanent realism—introduction to Franz Brentano. Springer, Dordrecht

Alexander S (1927) Space-time and deity, vols 1, 2. McMillan and Co. Ltd, London

Andersen PB, Emmeche C, Finnemann NO, Christiansen PV (2000) Downward causation. Minds, bodies and matter. Aarhus University Press, Aarhus, DK

Atmanspacher H, Jahn RG (2003) Problems of reproducibility in complex mind matter systems. J Sci Exploration 17(2):243–270

Baars B (1988) A cognitive theory of consciousness. Cambridge University Press

Baars B, Franklin S (2003) How conscious experience and working memory interact. Trends Cogn Sci 7:166–172

Baars B, Newman J (1994) A neurobiological interpretation of the global workspace theory of consciousness. In: Consciousness in philosophy and cognitive neuroscience. Erlbaum, Hildale NJ

Baianu IC (1970) Organismic supercategories: II. On multistable systems. Bull Math Biophys 32:539–561

Baianu IC (1971a) Organismic supercategories and qualitative dynamics of systems. Bull Math Biophys 33(3):339–354

Baianu IC (1971b) Categories, functors and quantum algebraic computations. In: Suppes P (ed) Proceedings of the fourth International congress logic-mathematics-philosophy of science. Bucharest

Baianu IC (1972) Energetic considerations in the interpretation of EEG—categories of neuronal network oscillators. Ann Univ Bucharest 21:61–67

Baianu IC (1973) Some algebraic properties of (M,R)-systems. Bull Math Biophys 35:213–217
Baianu IC, Marinescu M (1974) A functorial construction of (M,R)-Systems. Revue Roumaine de Mathematiques Pures et Appliquees 19:388–391
Baianu IC (1977) A logical model of genetic activities in Łukasiewicz algebras: the non-linear theory. Bull Math Biol 39:249–258
Baianu IC (1980a) Natural transformations of organismic structures. Bull Math Biol 42:431–446
Baianu IC (1980b) On partial order and disorder in biological systems. Lett Editor Bull Math Biophys 42:601–605
Baianu IC (1983) Natural transformation models in molecular biology. In: Denver CO (ed) Proceedings of the SIAM national meeting. Eprint: http://www.cogprints.org/3675/ http://www.cogprints.org/3675/0l/Naturaltransfmolbionu6.pdf
Baianu IC (1987a) Computer models and automata theory in biology and medicine. In: Witten M (ed) Mathematical models in medicine, vol 7. Pergamon Press, New York, pp 1513–1577. CERN Preprint No. EXT-2004-072: http://www.doe.cern.ch//archive/electronic/other/ext/ext-2004-072.pdf
Baianu IC (1987b) Molecular models of genetic and organismic structures. In: Proceedings of relational biology symposium. Argentina; CERN Preprint No. EXT-2004-067 http://www.doc.cern.ch/archive/electronic/other/ext/ext2004067/MolecularModels-ICB3.doc
Baianu IC (2006) Robert Rosen's work and complex systems biology. Axiomathes 16(1–2):25–34
Baianu IC (2007) Translational genomics and human cancer interactomics. Invited Review, submitted in November 2006 to Translational Oncogenomics
Baianu IC, Brown R, Glazebrook JF (2006) Quantum algebraic topology and field theories. http://www.ag.uiuc.edu/fs40l/QAT.pdf (manuscript in preparation)
Baianu IC, Brown R, Georgescu G, Glazebrook JF (2006) Complex nonlinear biodynamics in categories, higher dimensional algebra and Łukasiewicz–Moisil topos: transformations of neuronal, genetic and neoplastic networks. Axiomathes 16(1–2):65–122
Baianu IC, Glazebrook JF, Georgescu G (2004) Categories of quantum automata and N-valued Łukasiewicz algebras in relation to dynamic bionetworks, (M,R)-systems and their higher dimensional algebra, Abstract and Preprint of Report: http://www.ag.uiuc.edu/fs401/QAuto.pdf and http://www.medicalupapers.com/quantum+automata+math+categories+baianu/
Baianu IC, Glazebrook JF, Georgescu G, Brown R (2007) Non-abelian algebraic topology representations of quantum space-time in a generalized 'Topos' with a quantum N-valued logic classifier
Baianu IC, Marinescu M (1968) Organismic supercategories: towards a unitary theory of systems. Bull Math Biophys 30:148–159
Baianu IC, Poli R (2008) From simple to super- and ultra- complex systems: towards a non-abelian dynamics paradigm shift. In: Theory and applications of ontology, vol 2.
Bennett M, Hacker P (2003) Philosophical foundations of neuroscience. Blackwell Publishing, London
Block N (ed) (1981) Readings in philosophy of psychology, vol 2. Harvard University Press, Cambridge, Mass
Bourbaki N (1960) Éléments de mathématique. In: Théorie des ensembles. Hermann, Paris
Bourbaki N (1961 and 1964) Algèbre commutative. In: Èléments de mathématique, Chapts 1–6. Hermann, Paris
Bourbaki N (1991) General topology. In: Elements of mathematics, Chapts 1–6. Springer, Berlin
Brown R (1967) Groupoids and Van Kampen's theorem. Proc London Math Soc 17(3):385–401
Brown R (1987) From groups to groupoids: a brief survey. Bull London Math Soc 19:113–134
Brown R (1988) Topology: a geometric account of general topology, homotopy types and the fundamental groupoid. Ellis Horwood, Chichester, Prentice Hall, New York
Brown R (1996) Homotopy theory, and change of base for groupoids and multiple groupoids. Appl Categ Struct 4:175–193
Brown R (2002) Categorical structures for descent and Galois theory. Fields Institute, September 23–28
Brown R (2004) Crossed complexes and homotopy groupoids as noncommutative tools for higher dimensional local-to-global problems. In: Proceedings of the fields institute workshop on categorical structures for descent and Galois theory, Hopf algebras and semiabelian categories, vol 43. Fields Institue Communications, September 23–28, 2002, pp 101–130
Brown R (2006) Topology and groupoids. BookSurge LLC
Brown R, Glazebrook JF, Baianu IC (2007) A conceptual and categorical framework in the ontology of levels. Axiomathes 17 (this issue), doi: 10.1007/s10516-007-9010-3
Brown R, Higgins PJ, Sivera R (2008) Non-abelian algebraic topology. http://www.bangor.ac.uk/.mas010/nonab-a-t.html; http://www.bangor.ac.uk/mas010/nonab-t/partI010604.pdf (in preparation)

Brown R, Janelidze G (1997) Van Kampen theorems for categories of covering morphisms in lextensive categories. J Pure Appl Algebra 119:255–263, ISSN 0022-4049
Brown R, Janelidze G (2004) Galois theory and a new homotopy double groupoid of a map of spaces. Appl Categ Struct 12:63–80
Brown R, Paton R, Porter T (2004) Categorical language and hierarchical models for cell systems. In: Paton R, Bolouri H, Holcombe M, Parish JH, Tateson R (eds) Computation in cells and tissues—perspectives and tools of thought. Natural computing series, Springer-Verlag, pp 289–303
Brown R, Porter T (2003) Category theory and higher dimensional algebra: potential descriptive tools in neuroscience. In: Singh N (ed) Proceedings of the international conference on theoretical neurobiology. National Brain Research Centre, Conference Proceedings 1, pp 80–92
Buchsbaum DA (1955) Exact categories and duality. Trans Am Math Soc 80:1–34
Bucur I, Deleanu A (1968) Introduction to the theory of categories and functors. John Wiley and Sons, London
Bunge M, Lack S (2003) Van Kampen theorems for toposes. Advan Math 179:291–317
Butterfield J, Isham CJ (2001) Spacetime and the philosophical challenges of quantum gravity. In: Callender C, Hugget N (eds) Physics meets philosophy at the planck scale. Cambridge University Press, pp 33–89
Butterfield J, Isham CJ (1998, 1999, 2000–2002) A topos perspective on the Kochen–Specker theorem I–IV. Int J Theor Phys 37(11):2669–2733; 38(3):827–859; 39(6):1413–1436; 41(4):613–639
Carnap R (1938) The logical syntax of language. Harcourt Brace and Co., New York
Čech E (1932) Höherdimensionale homotopiegruppen. In: Verhandlungen des Internationalen Mathematiker-Kongresses Zurich, Band 2, p. 203
Chalmers DJ (1996) The conscious mind—in search of a fundamental theory. Oxford University Press
Changeux J-P (1985) Neuronal man—the biology of mind. Princeton University Press
Cohen PM (1965) Universal algebra. Harper and Row, New York
Csikzentmihalyi M (1990) The evolving self: a psychology for the third millenium. Harper & Row, New York
Damasio A (1994) Descartes' error: emotion, reason and the human brain. Avon Books, New York
Dennett DC (1981) A cure for the common code? In: Block N (ed) Readings in philosophy of psychology, vol 2. Harvard University Press, Cambridge, Mass, pp 21–37
Edelman G (1992) Brilliant air, brilliant fire—on the matter of the mind. Basic Books, New York
Edelman G (1989) The remembered present. Basic Books, New York
Edelman G, Tononi G (2000) A universe of consiousness. Basic Books, New York
Ehresmann C (1959) Catégories topologiques et catégories différentiables. Coll Géom Diff Glob (Bruxelles), Centre Belge Rech. Math., Louvain, pp 137–150
Ehresmann C (1963) Catégories doubles des quintettes: applications covariantes. CRAS Paris 256:1891–1894
Ehresmann C (1965) Catégories et structures. Dunod, Paris
Ehresmann C (1966) Trends toward unity in mathematics. Cahiers de Topologie et Geometrie Differentielle 8:1–7
Ehresmann C (1984) Oeuvres complètes et commentées: Amiens, 1980–1984. edited and commented by Andrée Ehresmann
Ehresmann AC, Vanbremeersch J-P (2006) The memory evolutive systems as a model of Rosen's organisms. Axiomathes 16(1–2):13–50
Eilenberg S, Mac Lane S (1942) Natural Isomorphisms in group theory. Am Math Soc 43:757–831
Eilenberg S, Mac Lane S (1945) The general theory of natural equivalences. Trans Am Math Soc 58:231–294
Elsasser MW (1981) A form of logic suited for biology. In: Rosen R (ed) Progress in theoretical biology, vol 6. Academic Press, New York, pp 23–62
Field HH (1981) Mental representation. In: Block N (ed) Readings in philosophy of psychology, vol 2. Harvard University Press, Cambridge, Mass, pp 64–77
Fleischaker G (1988) Autopoiesis: the status of its system logic. Biosystems 22(1):3749
Freeman WJ (1997) Nonlinear neurodynamics of intentionality. J Mind Behav 18:143–172
Freeman WJ (1999) Consciousnness, intentionality and causality. J Conscious Stud 11:143–172
Freyd P (1964) Abelian categories. Harper and Row, New York
Gablot R (1971) Sur deux classes de catégories de Grothendieck. Thesis, University de Lille
Gabriel P (1962) Des catégories abéliennes. Bull Soc Math France 90:323–448

Gabriel P, Popescu N (1964) Caractérisation des catégories abéliennes avec générateurs et limites inductives. CRAS Paris 258:4188–4191
Gabriel P, Zisman M (1967) Category of fractions and homotopy theory, Ergebnesse der math. Springer, Berlin
Georgescu G (2006) N-valued logics and Łukasiewicz—moisil Algebras. Axiomathes 16(1–2):123–136
Georgescu G, Popescu D (1968) On algebraic categories. Revue Roumaine de Mathematiques Pures et Appliquées 13:337–342
Gnoli C, Poli R (2004) Levels of reality and levels of representation. Knowl Organ 21(3):151–160
Goodwin BC (1982) Development and evolution. J Theor Biol 97:43–55
Goodwin BC (1994) How the leopard changed its spots: the evolution of complexity. Touchstone Publication, New York
Gray CW (1965) Sheaves with values in a category. Topology 3:1–18
Grossberg S (1999) The link between brain learning, attention and consciousness. Conscious Cogn 8:1–44
Grothendieck A (1957) Sur quelque point d-algébre homologique. Tohoku Math J 9:119–121
Grothendieck A (1971) Revêtements Étales et Groupe Fondamental (SGA1). In: Catégories fibrées et descente. Lecture notes in math. chapt VI, vol 224. Springer-Verlag, Berlin
Grothendieck A, Dieudonné J (1960) Eléments de geometrie algébrique. Publ Inst des Hautes Etudes de Science, vol 4, 228pp
Harman GH (1981) Language learning. In: Block N (ed) Readings in philosophy of psychology, vol 2. Harvard University Press, Cambridge, Mass, pp 38–44
Hartmann N (1935) Zur Grundlegung der Ontologie. W. de Gruyter, Berlin
Hartmann N (1952) The new ways of ontology. In: Systematische Philosophie, Chicago, pp 199–311
Hawking SW, Ellis GFR (1973) The large scale structure of space–time. Cambridge University Press, Cambridge, UK
Healy MJ, Caudell TP (2006) Ontologies and worlds in category theory: implications for neural systems. Axiomathes 16(1–2):165–214
Healy MJ, Caudell TP (2004) Neural networks, knowledge and cognition: amathematical semantic model based upon category theory. Technical report EECE-TR-04-20, Dept of Electrical and Computer Engineering, University of New Mexico
Hofstadter DR (1979) Gödel, Escher, Bach: an eternal Golden Braid. Basic Books, New York
James W (1958) In talks to teachers on psychology. Norton, New York
James W (1890) The principles of psychology. Henry Hold and Co., New York
Kosslyn SM (2007) On the evolution of human motivation: The role of social prosthetic systems. In Platek SM, et al (eds) Evolutionary cognitive neuroscience. MIT Press, Cambridge, MA
Lawvere FW (1966) The category of categories as a foundation for mathematics. In: Eilenberg S et al (eds) Proceedings of theConference in Categorical Algebra-La Jolla. Springer-Verlag, pp 1–20
Lawvere FW (1963) Functorial semantics of algebraic theories. Proc Natl Acad Sci USA, Math 50:869–872
Levich AP, Solovy'ov AV (1999) Category-functor modelling of natural systems. Cybern Syst 30(6):571–585
Löfgren L (1968) An axiomatic explanation of complete self-reproduction. Bull Math Biophys 30:317–348
Mac Lane S (1963) Homology. Springer, Berlin
Mac Lane S (2000) Categories for the working mathematician. Springer, New York
Mac Lane S, Moerdijk I (1992) Sheaves in geometry and logic. A first introduction in topos theory. Springer-Verlag, New York
Maturana HR, Varela FJ (1980) Autopoiesis and cognition—the realization of the living. Boston studies in the philosophy of science, vol 42. Reidel Pub Co., Dordrecht
May JP (1999) A concise course in algebraic topology. The University of Chicago Press, Chicago
Mayr E (1970) Populations, species, and evolution. Harvard University Press, Cambridge, MA
Mitchell B (1965) Theory of categories. Academic Press, London
Penrose R (1994) Shadows of the mind. Oxford University Press, Oxford
Pickering J, Skinner M (1990) From sentience to symbols. University of Toronto Press, Toronto
Poli R (1998) Levels. Axiomathes 9(1–2):197–211
Poli R (2001a) The basic problem of the theory of levels of reality. Axiomathes 12(3–4):261–283
Poli R (2001b) Alwis. Ontology for knowledge engineers. Ph.D. Thesis, Utrecht University
Poli R (2006a) Levels of reality and the psychological stratum. In: Revue Internationale de Philosophie, 61:2, pp 163–180

Poli R (2006b) Steps towards a synthetic methodology. In: Proceedings of the Conference in continuity and change: perspectives on science and religion. Metanexus Institute, Philadelphia, PA, June 2006, http://www.metanexus.net/conferences/pdf/conference2006/Poli.pdf
Poli R (2006c) First steps in experimental phenomenology. In: Loula A, Gudwin R (eds) Artificial cognition systems. Idea Grouping Publishing, Hersey, PA
Poli R (2008) Ontology: the categorical stance. In: Poli R (ed) Theory and applications of ontology, vol 1. Springer, Berlin (in press)
Popescu N (1967) La théorie générale de la décomposition. Rev Roum Math Pures et Appl 7:1365–1371
Popescu N (1973) Abelian categories with applications to rings and modules, 2nd edn. Academic Press, 1975: New York and London (English translation by Baianu IC)
Pribram KH (2000) Proposal for a quantum physical basis for selective learning. In: Farre (ed) Proceedings ECHO IV 1–4
Rashevsky N (1954) Topology and life: in search of general mathematical principles in biology and sociology. Bull Math Biophys 16:317–348
Rashevsky N (1967) Organismic sets and biological epimorphism. Bull Math Biophys 29:389–393
Rashevsky N (1968) Neurocybernetics as a particular case of general regulatory mechanisms in biological and social organisms. Concepts de l'Age de la Science 3:243–248
Rashevsky N (1969) Outline of a unified approach to physics, biology and sociology. Bull Math Biophys 31:159–198
Rosen R (1958a) A relational theory of biological systems. Bull Math Biophys 20:245–260
Rosen R (1958b) The representation of biological systems from the standpoint of the theory of categories. Bull Math Biophys 20:317–341
Rosen R (1985) Anticipatory systems. Pergamon Press, New York
Rosen R (1987) On complex systems. Eur J Operat Res 30:129–134
Samuel P, Zariski O (1957 and 1960) Commutative algebra, vols 1, 2. van Nostrand, New York
van Kampen EH (1933) On the connection between the fundamental groups of some related spaces. Am J Math 55:261–267
Wallace R (2007) Culture and inattentional blindness: a global workspace perspective. J Theor Biol 245:378–390
Warner M (1982) Representations of (M,R)-systems by categories of automata. Bull Math Biol 44:661–668
Weinberg S (1995–2000) The quantum theory of fields, vols 1–3. Cambridge University Press, Cambridge, UK
Wiener N (1950) The human use of human beings: cybernetics and society, 1989 edn. Free Association Books, London, pp 147–148
Woit P (2006) Not even wrong: the failure of string theory and the search for unity in physical laws. Jonathan Cape