

**CATEGORICAL ONTOLOGY OF COMPLEX SYSTEMS,
META-SYSTEMS AND LEVELS: THE EMERGENCE OF LIFE,
HUMAN CONSCIOUSNESS AND SOCIETY**

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ABSTRACT.

Relational structures of organisms and the human mind are naturally represented in terms of novel variable topology concepts, non-Abelian categories and Higher Dimensional Algebra—relatively new concepts that would be defined in this tutorial paper. A unifying theme of local-to-global approaches to organismic development, evolution and human consciousness leads to novel patterns of relations that emerge in super- and ultra- complex systems in terms of compositions of local procedures [1]. The claim is defended in this paper that human consciousness is *unique* and should be viewed as an ultra-complex, global process of processes, at a *meta-level* not sub-summed by, but compatible with, human brain dynamics [2]-[5]. The emergence of consciousness and its existence are considered to be dependent upon an extremely complex structural and functional unit with an asymmetric network topology and connectivities—the human brain. However, the appearance of human consciousness is shown to be critically dependent upon societal co-evolution, elaborate language-symbolic communication and ‘virtual’, higher dimensional, non-commutative processes involving separate space and time perceptions. Theories of the mind are approached from the theory of levels and ultra-complexity viewpoints that throw new light on previous semantic models in cognitive science. Anticipatory systems and complex causality at the top levels of reality are discussed in the context of psychology, sociology and ecology. A paradigm shift towards *non-commutative*, or more generally, non-Abelian theories of highly complex dynamics [6] 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. The presence of strange attractors in modern society dynamics gives rise to very serious concerns for the future of mankind and the continued persistence of a multi-stable Biosphere.

KEYWORDS: *Categorical Ontology of Super-Complex and Ultra-Complex System Dynamics, Higher Dimensional Algebra of Networks, Theoretical Biology and Variable Groupoids, Non-Abelian Quantum Algebraic Topology and Quantum Double Groupoids, Higher Homotopy-General van Kampen theorems*

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1. INTRODUCTION

Ontology has acquired over time several meanings, and it has also been approached in many different ways, however these are all connected to the concepts of an ‘*objective existence*’ and categories of items. We shall consider here the noun *existence* as a basic concept which cannot be defined in either simple or atomic terms, with the latter in the sense of Wittgenstein. Furthermore, generating *meaningful classifications of items* that belong to the objective reality is a major task of ontology. Without any doubt, however, the most interesting question by far is how human consciousness emerged subsequent only to the emergence of *H. sapiens*, his speech-syntactic language and an appropriately organized primitive society of humans. No doubt, the details of this highly complex process have been the subject of intense controversies over the last several centuries, which will continue as long as essential data remains either scarce or unattainable.

The authors aim at a concise presentation of novel methodologies for studying the difficult, as well as the controversial, ontological problem of Space and Time at different levels of objective reality defined here as Complex, Super-Complex and Ultra-Complex Dynamic Systems. These are biological organisms, societies, and more generally, systems that are not recursively-computable. Rigorous definitions of the logical and mathematical concepts employed here, as well as a step-by-step construction of our conceptual framework, were provided in a recent series of publications on categorical ontology of levels and complex systems dynamics (Baianu et al, 2007 a–c; Brown et al, 2007). The continuation of the very existence of human society may now depend on an improved understanding of highly complex systems and the mind, and how the global human society interacts with the rest of the biosphere and its natural environment. It is most likely that such tools that we shall suggest here 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. Following Kant’s critique of ‘pure’ reason and Wittgenstein’s critique of language misuse in philosophy, one needs also to critically examine the possibility of using general and universal, mathematical language and tools in formal approaches to ontology. Throughout this essay we shall use the attribute ‘*categorial*’ only for philosophical and linguistic arguments. On the other hand, we shall utilize the rigorous term ‘*categorical*’ only in conjunction with applications of concepts

and results from the more restrictive, but still general, mathematical *Theory of Categories, Functors and Natural Transformations* (TC-FNT). According to SPE (2006): “Category theory ... is a general mathematical **theory of structures and of systems of structures**. *Category theory is both an interesting object of philosophical study, and a potentially powerful formal tool for philosophical investigations of concepts such as space, system, and even truth... It has come to occupy a central position in contemporary mathematics and theoretical computer science, and is also applied to mathematical physics.*” Traditional, modern philosophy—considered as a search for improving knowledge and wisdom—does also aim at unity that might be obtained as suggested by Herbert Spencer in 1862 through a ‘*synthesis of syntheses*’; this could be perhaps iterated many times because each treatment is based upon a critical evaluation and provisional improvements of previous treatments or stages. One notes however that this methodological question is hotly debated by modern philosophers beginning, for example, by Descartes before Kant and Spencer; Descartes championed with a great deal of success the ‘*analytical*’ approach in which *all* available evidence is, in principle, examined critically and skeptically first both by the proposer of novel metaphysical claims and his, or her, readers. Descartes equated the ‘*synthetic*’ approach with the Euclidean ‘*geometric*’ (axiomatic) approach, and thus relegated synthesis to a secondary, perhaps less significant, role than that of critical *analysis* of scientific ‘*data*’ input, such as the laws, principles, axioms and theories of all specific sciences. Spinoza’s, Kant’s and Spencer’s styles might be considered to be synthetic by Descartes and all Cartesians, whereas Russell’s approach might also be considered to be analytical. Clearly and correctly, however, Descartes did not regard analysis (*A*) and synthesis (*S*) as exactly inverse to each other, such as $A \rightleftharpoons S$, and also not merely as ‘*bottom–up*’ and ‘*top–bottom*’ processes ($\downarrow\uparrow$). Interestingly, unlike Descartes’ discourse of the philosophical method, his treatise of philosophical principles comes closer to the synthetic approach in having definitions and deductive attempts, logical inferences, not unlike his ‘*synthetic*’ predecessors, albeit with completely different claims and perhaps a wider horizon. The reader may immediately note that if one, as proposed by Descartes, begins the presentation or method with an analysis *A*, followed by a synthesis *S*, and then reversed the presentation in a follow-up treatment by beginning with a synthesis *S** followed by an analysis *A** of the predictions made by *S** consistent, or analogous, with *A*, then obviously $AS \neq S^*A^*$ because we assumed that $A \simeq A^*$ and that $S \neq S^*$. Furthermore, if one

did not make any additional assumptions about analysis and synthesis, then $analysis \rightarrow synthesis \neq synthesis \rightarrow analysis$, or $AS \neq SA$, that is analysis and synthesis obviously ‘do not commute’; such a theory when expressed mathematically would be then called ‘non-Abelian’. This is also a good example of the meaning of the term non-Abelian in a philosophical, epistemological context.

2. THE THEORY OF LEVELS IN CATEGORIAL AND CATEGORICAL ONTOLOGY

This section outlines our novel methodology and approach to the ontological theory of levels, which is then applied in subsequent sections in a manner consistent with our recently published developments (Baianu et al 2007a,b,c; Brown et al 2007), and also with the papers by Poli (2008) and Baianu and Poli (2008), in this volume. Here, we are in harmony with the theme and approach of the ontological theory of levels of reality (Poli, 1998, 2001, 2008) by considering both philosophical–categorical aspects such as Kant’s relational and modal categories, as well as categorical–mathematical tools and models of complex systems in terms of a dynamic, evolutionary viewpoint.

We are then presenting a categorical ontology of highly complex systems, discussing the modalities and possible operational logics of living organisms, in general. Then, we consider briefly those integrated functions of the human brain that support the ultra-complex human mind and its important roles in societies. More specifically, we propose to combine a critical analysis of language with precisely defined, abstract categorical concepts from Algebraic Topology (Brown et al 2007a) and the general-mathematical Theory of Categories, Functors and Natural Transformations (Eilenberg and Mac Lane 1943, 1945; Mitchell, 1968; Popescu, 1973; Mac Lane and Moerdijk, 1992; Mac Lane 2000) into a categorical framework which is suitable for further ontological development, especially in the relational rather than modal ontology of complex spacetime structures. Basic concepts of Categorical Ontology are presented in this section, whereas formal definitions are relegated to one of our recent, detailed reports (Brown, Glazebrook and Baianu, 2007). On the one hand, philosophical categories according to Kant are: *quantity*, *quality*, *relation* and *modality*, and the most complex and far-reaching questions concern the relational and modality-related categories. On the other hand, mathematical categories are considered at present as the most general and universal structures in mathematics, consisting of related *abstract objects connected by arrows*. The

abstract objects in a category may, or may not, have a specified *structure*, but must all be of the same type or kind in any given category. The arrows (also called '*morphisms*') can represent relations, mappings/functions, operators, transformations, homeomorphisms, and so on, thus allowing great flexibility in applications, including those outside mathematics as in: Logics (Georgescu 2006), Computer Science, Life Sciences (Baianu and Marinescu, 1969; Baianu, 1987; Brown and Porter, 1999; Baianu et al, 2006a; Brown et al 2007a), Psychology and Sociology (Baianu et al, 2007a). The mathematical category also has a form of '*internal symmetry*', specified precisely as the *commutativity* of chains of morphism compositions that are uni-directional only, or as *naturality of diagrams* of morphisms; finally, any object A of an abstract category has an associated, unique, identity, 1_A , and therefore, one can replace all objects in abstract categories by the identity morphisms. (When all arrows are *invertible*, the special category thus obtained is called a '*groupoid*', and plays a fundamental role in the field of mathematics called Algebraic Topology).

The categorical viewpoint— as emphasized by William Lawvere, Charles Ehresmann and most mathematicians— is that the key concept and mathematical structure is that of *morphisms* that can be seen, for example, as abstract relations, mappings, functions, connections, interactions, transformations, and so on. Thus, one notes here how the philosophical category of '*relation*' is closely allied to the basic concept of morphism, or arrow, in an abstract category; the implicit tenet is that arrows are what counts. One can therefore express all essential properties, attributes, and structures by means of arrows that, in the most general case, can represent either philosophical '*relations*' or modalities, the question then remaining if philosophical—categorical properties need be subjected to the categorical restriction of *commutativity*. As there is no *a priori* reason in either nature or '*pure*' reasoning, including any form of Kantian '*transcendental logic*', that either relational or modal categories should in general have any symmetry properties, one cannot impose onto philosophy, and especially in ontology, all the strictures of category theory, and especially commutativity. Interestingly, the same critique and comment applies to Logics: only the simplest forms of Logics, the Boolean and intuitionistic, Heyting-Brouwer logic algebras are commutative, whereas the algebras of many-valued (MV) logics, such as Łukasiewicz logic are *non-commutative*, (or *non-Abelian*). These ideas about the non-Abelian character of general philosophical and logical theories, including general ontology approaches, will be considered next in further detail.

3. BASIC STRUCTURE OF CATEGORICAL ONTOLOGY AND THE THEORY OF LEVELS. EMERGENCE OF HIGHER LEVELS, META-LEVELS AND THEIR SUBLEVELS

With the provisos specified above, our proposed methodology and approach employs concepts and mathematical techniques from Category Theory which afford describing the characteristics and binding of ontological levels besides their links with other theories. Whereas Hartmann (1952) stratified levels in terms of the four frameworks: physical, ‘organic’/biological, mental and spiritual, we restrict here mainly to the first three. The categorical techniques which we introduce provide a powerful means for describing levels in both a linear and interwoven fashion, thus leading to the necessary bill of fare: emergence, complexity and open non-equilibrium, or irreversible systems. Furthermore, an effective approach to Philosophical Ontology is concerned with *universal items* assembled in categories of objects and relations, involving, in general, transformations and/or processes. Thus, Categorical Ontology is fundamentally dependent upon both space and time considerations. Therefore, one needs to consider first a dynamic classification of systems into different levels of reality, 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, 2001). Thus, any effective Categorical Ontology approach requires, or generates—in the constructive sense—a ‘**structure**’ or pattern rather than a discrete set of items. 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 that are computable recursively as numerical solutions of mathematical systems of either ordinary or partial differential equations. Underlying such mathematical systems is always the Boolean, or chrysippian, logic, namely, the logic of sets, Venn diagrams, digital computers and perhaps automatic reflex movements/motor actions of animals. The simple dynamical systems are always recursively computable (see for example, Suppes, 1995–2007), and in a certain specific sense, both degenerate and *non-generic*, consequently also

structurally unstable to small perturbations. The next higher order of systems is then exemplified by ‘systems with chaotic dynamics’ that are conventionally called ‘complex’ by physicists, computer scientists and modelers even though such physical, dynamical systems are still completely deterministic. It has been formally proven that such systems are *recursively non-computable* (see for example, Baianu, 1987 for a 2-page, rigorous mathematical proof and relevant references), and therefore they cannot be completely and correctly simulated by digital computers, even though some are often expressed mathematically in terms of iterated maps or algorithmic-style formulas. Higher level systems above the chaotic ones, that we shall call ‘*Super-Complex, Biological systems*’, are the living organisms, followed at still higher levels by the *ultra-complex ‘systems*’ of the human mind and human societies that will be discussed in the last section. The evolution to the highest order of complexity- the ultra-complex, meta-‘system’ of processes- the human mind- may have become possible, and indeed accelerated, only through human societal interactions and effective, elaborate/rational and symbolic communication through speech (rather than screech (as in the case of chimpanzees, gorillas, baboons, etc).

4. TOWARDS BIOLOGICAL PRINCIPLES AND THE EMERGENCE OF HIGHLY COMPLEX DYNAMICS THROUGH SYMMETRY BREAKING

Quantum symmetries occur not only on microphysical scales, but also macroscopically in certain, ‘special’ cases, such as liquid ^3He close to absolute zero and superconductors where *extended coherence* is possible for the superfluid, Cooper electron-pairs. Explaining such phenomena requires the consideration of *symmetry breaking* (Weinberg, 2003). Occasionally, symmetry breaking is also invoked as a ‘possible mechanism for human consciousness’ which also seems to involve some form of ‘global coherence’-over most of the brain; however, the existence of such a ‘*quantum coherence in the brain*’-at room temperature-as it would be precisely required/defined by QTs, is a most unlikely event. On the other hand, a *quantum symmetry breaking* in a neural network considered metaphorically as a Hopfield (‘spin-glass’) network might be conceivable close to physiological temperatures but for the lack of existence of any requisite (electron ?) spin lattice structure which is indeed an absolute requirement in such a spin-glass metaphor-if it is to be taken at all seriously!

Now comes the real, and very interesting part of the story: neuronal networks do form functional patterns and structures that possess partially ‘broken’, or more general symmetries than those described by quantum groups.

Such *extended symmetries* can be mathematically determined, or specified, by certain *groupoids*—that were previously called ‘*neuro-groupoids*’. Even more generally, genetic networks also exhibit extended symmetries represented for an organismal species by a *biogroupoid* structure, as previously defined and discussed by Baianu, Brown, Georgescu and Glazebrook (2006). Such biogroupoid structures can be experimentally validated, for example, at least partially through Functional Genomics observations and computer, bioinformatics processing (Baianu, 2007). We shall discuss further several such interesting groupoid structures in the following sections, and also how they have already been utilized in local-to-global procedures to construct ‘global’ solutions; such global solutions in quite complex (holonomy) cases can still be *unique* up to an isomorphism (*the Globalization Theorem*, as to be discussed in Brown, Glazebrook and Baianu, 2007). Last-but-not-least, *holonomy* may provide a global solution, or ‘explanation’ for ‘memory storage by ‘neuro-groupoids’. Uniqueness holonomy theorems might possibly ‘explain’ unique, persistent and resilient memories.

Towards Biological Postulates and Principles

Whereas the hierarchical theory of levels provides a powerful, systems approach through categorical ontology, the foundation of science involves *universal* models and theories pertaining to different levels of reality. It would seem natural to expect that theories aimed at different ontological levels of reality should have different principles. We are advocating the need for developing precise, but nevertheless ‘flexible’, concepts and novel mathematical representations suitable for understanding the emergence of the higher complexity levels of reality. Such theories are based on axioms, principles, postulates and laws operating on distinct levels of reality with a specific degree of complexity. Because of such distinctions, inter-level principles or laws are rare and over-simplified principles abound. Alternative approaches may be, however, possible based upon an improved ontological theory of levels. Interestingly, the founder of Relational Biology, Nicolas Rashevsky (1968) proposed that physical laws and principles can be expressed in terms of *mathematical functions*, or mappings, and are thus being predominantly expressed in a *numerical* form, whereas the laws and principles of biological organisms and societies need take a more general form in terms of quite general, or abstract—mathematical and logical relations which cannot always be expressed numerically; the latter are often qualitative, whereas the former are predominantly quantitative.

Rashevsky focused his Relational Biology/Society Organization papers on a search for more general relations in Biology and Sociology that are also compatible with the former. Furthermore, Rashevsky proposed two biological principles that add to Darwin's natural selection and the 'survival of the fittest principle', *the emergent relational structure that are defining the adaptive organism*:

1. The Principle of Optimal Design, and

2. The Principle of Relational Invariance (phrased by Rashevsky as "*Biological Epimorphism*").

In essence, the 'Principle of Optimal Design' defines the organization and structure of the 'fittest' organism which survives in the natural selection process of competition between species, in terms of an extremal criterion, similar to that of Maupertuis; the optimally 'designed' organism is that which acquires maximum functionality essential to survival of the successful species at the lowest 'cost' possible. The 'costs' are defined in the context of the environmental niche in terms of material, energy, genetic and organismic processes required to produce/entail the pre-requisite biological function(s) and their supporting anatomical structure(s) needed for competitive survival in the selected niche. Further details were presented by Robert Rosen in his short but significant book on optimality (1970).

The 'Principle of Biological Epimorphism' on the other hand states that the highly specialized biological functions of higher organisms can be mapped (through an epimorphism) onto those of the simpler organisms, and ultimately onto those of a (hypothetical) primordial organism (which was assumed to be unique up to an isomorphism or *selection-equivalence*). The latter proposition, as formulated by Rashevsky, is more akin to a postulate than a principle. However, it was then generalized and re-stated as the Postulate of Relational Invariance (Baianu, Brown, Georgescu and Glazebrook, 2006). Somewhat similarly, a dual principle and colimit construction was invoked for the ontogenetic development of organisms (Baianu, 1970).

An axiomatic system (ETAS) leading to higher dimensional algebras of organisms in supercategories has also been formulated (Baianu, 1970) which specifies both the logical and the mathematical (π -) structures required for complete self-reproduction and self-reference, self-awareness, etc., of living organisms. To date there is no higher dimensional algebra (HDA) axiomatics other than the ETAS proposed for complete self-reproduction in super-complex

systems, or for self-reference in ultra-complex ones. On the other hand, the preceding, simpler ETAC axiomatics, was proposed for the foundation of ‘all’ mathematics, including categories (Lawvere, 1966, 1968), but this seems to have occurred before the emergence of HDA.

5. CATEGORICAL REPRESENTATIONS OF THE ONTOLOGICAL THEORY OF LEVELS: FROM SIMPLE TO SUPER- AND ULTRA- COMPLEX DYNAMIC SYSTEMS. ABELIAN VS. NON-ABELIAN THEORIES

General system analysis seems to require formulating ontology by means of categorical concepts (Poli, 2007, TAO-1; Baianu and Poli, 2007). Furthermore, category theory appears as a natural framework for any general theory of transformations or dynamic processes, just as group theory provides the appropriate framework for classical dynamics and quantum systems with a finite number of degrees of freedom. Therefore, we have adopted a categorical approach as the starting point, meaning that we are looking for “*what is universal*” (in some domain, or in general), and that only for simple systems this involves *commutative* modelling diagrams and structures (as, for example, in Figure 1 of Rosen, 1987). Note that this ontological use of the word ‘*universal*’ is quite distinct from the mathematical use of ‘*universal property*’, which means that a property of a construction on particular objects is defined by its relation to *all* other objects (i.e., it is a *global* attribute), usually through constructing a morphism, since this is the only way, in an *abstract* category, for objects to be related. With the first (ontological) meaning, the most universal feature of reality is that it is *temporal*, i.e. it changes, it is subject to countless transformations, movements and alterations. In this select case of *universal temporality*, it seems that the two different meanings can be brought into superposition through appropriate formalization. Furthermore, *concrete* categories may also allow for the representation of ontological ‘universal items’ as in certain previous applications to categories of neural networks (Baianu, 1972; 1987; Baianu et al 2006, 2007a). For general categories, however, each object is a kind of a Skinnerian black box, whose only exposure is through input and output, i.e. the object is given by its *connectivity* through various morphisms, to other objects. For example, the dual of the category of sets still has objects but these have *no structure* (from the categorical viewpoint). Other types of category are important as expressing useful relationships on structures, for example *lax* categories, which have been used to express a general van Kampen theorem by Brown and Janelidze (1997). Thus, abstract

mathematical structures are developed to define *relationships*, to deduce and calculate, to exploit and define analogies, since *analogies are between relations* between things rather than between things themselves. A description of a new structure is in some sense a development of part of a *new language*; the notion of structure is also related to the notion of *analogy*. It is one of the triumphs of the mathematical theory of categories in the 20th century to make progress towards *unifying* mathematics through the finding of *analogies* between various behavior of structures across different areas of mathematics. This theme is further elaborated in the article by Brown and Porter (2002) which argue that many analogies in mathematics, and in many other areas, are *not* between objects themselves but *between the relations* between objects.

Categorical Logics of Processes and Structures: Universal Concepts and Properties.

The logic of classical events associated with either mechanical systems, mechanisms, universal Turing machines, automata, robots and digital computers is generally understood to be simple, *Boolean* logic. The same applies to Einstein's GR. It is only with the advent of quantum theories that quantum logics of events were introduced which are *non-commutative*, and therefore, also *non-Boolean*. Somewhat surprisingly, however, the connection between quantum logics (QL) and other *non-commutative* many-valued logics, such as the Łukasiewicz logic, has only been recently made (Dalla Chiara, 2004 and refs. cited therein; Baianu, 2004; Baianu et al., 2005;2006). Such considerations are also of potential interest for a wide range of complex systems, as well as quantum ones, as it has been pointed out previously (Baianu, 1977; 2004; Baianu et al, 2005;2006). Furthermore, both the concept of 'Topos' and that of variable category, can be further generalized by the involvement of *many-valued* logics, as for example in the case of 'Łukasiewicz-Moisil, or LM Topos' (Baianu et al., 2005). This is especially relevant for the development of *non-Abelian dynamics* of complex and super-complex systems; it may also be essential for understanding human consciousness (as it will be discussed in the context of Section 4).

Quantum Logics (QL), Logical Lattice Algebras (LLA) and Łukasiewicz Quantum Logic (LQL)

As pointed out by von Neumann and Birkhoff (1930), a logical foundation of quantum mechanics consistent with quantum algebra is essential for the

internal consistency of the theory. Such a non-traditional logic was initially formulated by von Neumann and Birkhoff (1932) and called ‘Quantum Logic’. Subsequent research on Quantum Logics (Chang, 1958; Genoutti, 1968; Dalla Chiara, 1968, 2004) resulted in several approaches that involve several types of non-distributive lattice (algebra) for n -valued quantum logics. Thus, modifications of the Łukasiewicz Logic Algebras that were introduced in the context of algebraic categories by Georgescu and Popescu (1968), followed by Georgescu and Vraciu (1970) with a characterization of LM-algebras, also recently being reviewed and expanded by Georgescu (2006), can provide an appropriate framework for representing quantum systems, or– in their unmodified form– for describing the activities of complex networks in categories of Łukasiewicz Logic Algebras (Baianu, 1977). There is a logical inconsistency between the quantum algebra and the Heyting logic algebra of a standard topos as a candidate for quantum logic (Baianu et al 2007b). Furthermore, quantum algebra and topological approaches that are ultimately based on set-theoretical concepts and differentiable spaces (manifolds) also encounter serious problems of internal inconsistency. There is a basic logical inconsistency between quantum logic—which is not Boolean—and the Boolean logic underlying all differentiable manifold approaches that rely on continuous spaces of points, or certain specialized sets of elements. A possible solution to such inconsistencies is the definition of a generalized ‘topos’-like concept, such as a *Quantum, Extended Topos* concept which is consistent with both Quantum Logic and Quantum Algebras (Alfsen and Schultz, 2003), being thus suitable as a framework for unifying quantum field theories and modelling in complex systems biology.

Łukasiewicz-Moisil (LM) Quantum Logic (LQL) and Algebras. Quantum Algebras (Majid, 1995, 2002) involve detailed studies of the properties and representations of Quantum State Spaces (QSS; see for example, Alfsen and Schultz, 2003). With all truth ‘nuances’ or assertions of the type $\langle\langle$ *system A* is excitable to the i -th level and *system B* is excitable to the j -th level $\rangle\rangle$ one can define a special type of lattice that subject to the axioms introduced by Georgescu and Vraciu (1970) becomes a n -valued *Łukasiewicz-Moisil, or LM, Algebra*. Further algebraic and logic details are provided in Georgescu (2006) and Baianu et al (2007b). In order to have the n -valued Łukasiewicz Logic Algebra represent correctly the observed behaviours of quantum systems (that involve a quantum system interactions with a measuring instrument –which is a macroscopic object) several of the LM-algebra axioms have to be significantly changed so that the resulting lattice becomes *non-distributive* and also (pos-

sibly) *non-associative* (Dalla Chiara, 2004). With an appropriately defined quantum logic of events one can proceed to define Hilbert and von Neumann/ C^* -algebras, etc, in order to be able to utilize the ‘standard’ procedures of quantum theories (precise definitions of these fundamental quantum algebraic concepts were presented in Baianu et al, 2007b). On the other hand, for classical systems, modelling with the unmodified Łukasiewicz Logic Algebra can also include both stochastic and fuzzy behaviours. For an example of such models the reader is referred to a previous publication (Baianu, 1977) modelling the activities of complex genetic networks from a classical standpoint. One can also define as in (Georgescu and Vraciu, 1970) the ‘centers’ of certain types of LM, n -valued Logic Algebras; then one has the following important theorem for such Centered Łukasiewicz n -Logic Algebras which actually defines an equivalence relation.

Theorem 0.1. The Adjointness Theorem (Georgescu and Vraciu, 1970).

There exists an Adjointness between the Category of Centered Łukasiewicz n -Logic Algebras, $\mathbf{CLuk-n}$, and the Category of Boolean Logic Algebras (\mathbf{BL}).

Remark 0.1. The natural equivalence logic classes defined by the adjointness relationships in the above Adjointness Theorem define a fundamental, ‘*logical groupoid*’ structure.

Remark 0.2. In order to adapt the standard Łukasiewicz Logic Algebra to the appropriate Quantum Łukasiewicz Logic Algebra, LQL , a few axioms of LM-algebra need modifications, such as $N(N(X)) = Y \neq X$ (instead of the restrictive identity $N(N(X)) = X$, whenever the context, or ‘measurement preparation’ interaction conditions for quantum systems are incompatible with the standard ‘negation’ operation N of the Łukasiewicz Logic Algebra; the latter remains however valid for the operation/ dynamics of classical or semi-classical systems, such as various complex networks with n -states (cf. Baianu, 1977). Further algebraic and conceptual details are provided in a rigorous review by Georgescu (2006), and also in the recently published reports by Baianu et al (2007b) and Brown et al. (2007).

Higher-Dimensional Logics and Łukasiewicz-Moisil (LM) Logic Algebroids. Higher-dimensional logics may be constructed in several ways. A direct approach is by employing higher-order categories of LM algebras, such as 2-categories, 3-categories, ..., n -categories of LM algebras. An alternative to constructing higher-dimensional logics in a geometric, or algebraic topology

sense is in terms of double categories (Brown et al., 2002) of LQL algebras. A third, and more direct possibility than the previous two, is the construction of higher-dimensional logics in terms of *LM-algebroids* rather than LM-algebras. The algebroid concept is understood in this context as defined by Brown and Mosa in 1997 (cited in Baianu, Glazebrook and Brown, 2009). A specific example of algebroid was previously introduced by Barry Mitchell as a '*ring with many objects*' instead of a single object. Thus, a *higher-dimensional logic algebroid* operates simultaneously with many LM-algebras in a consistent manner that does not lead to contradictions and antinomies among its many LM-algebraic objects. The required conditions or axioms needed to satisfy such a logical consistency criterion are subject to further investigation, and will be addressed in subsequent publications.

A Hierarchical, Formal Theory of Levels. Commutative and Non-Commutative Structures: Abelian Category Theory vs. Non-Abelian Theories.

Ontological classification based on items involves the organization of concepts, and indeed theories of knowledge, into a *hierarchy of categories of items at different levels of 'objective reality'*, as reconstructed by scientific minds through either a *bottom-up* (induction, synthesis, or abstraction) process, or through a *top-down* (deduction) process (Poli,2007), which proceeds from abstract concepts to their realizations in specific contexts of the 'real' world. Both modalities can be developed in a categorical framework. We discuss here only the bottom-up modality in Categorical Ontology.

One of the major goals of category theory is to see how the properties of a particular mathematical structure, say S , are reflected in the properties of the category $\text{Cat}(S)$ of all such structures and of morphisms between them. Thus, the first step in category theory is that a definition of a structure should come with a definition of a morphism of such structures. Usually, but not always, such a definition is obvious. The next step is to compare structures. This might be obtained by means of a *functor* $A : \text{Cat}(S) \longrightarrow \text{Cat}(T)$. Finally, we want to compare such functors $A, B : \text{Cat}(S) \longrightarrow \text{Cat}(T)$. This is done by means of a natural transformation $\eta : A \Rightarrow B$. Here η assigns to each object X of $\text{Cat}(S)$ a morphism $\eta(X) : A(X) \longrightarrow B(X)$ satisfying a commutativity condition for any morphism $a : X \longrightarrow Y$. In fact we can say that η assigns to each morphism a of $\text{Cat}(S)$ a commutative square of morphisms in $\text{Cat}(T)$ (as shown in Diagram 13.2 in the Brown, Glazebrook and Baianu (2007).). This notion of *natural*

transformation is at the heart of category theory. As Eilenberg-Mac Lane write: “*to define natural transformations one needs a definition of functor, and to define the latter one needs a definition of category*”. Also, the reader may have already noticed that 2-arrows become ‘3-objects’ in the meta-category, or ‘3-category’, of functors and natural transformations (Brown et al, 2007a).

One could formalize—for example as outlined in Baianu and Poli (2008, in this volume)—the hierarchy of multiple-level relations and structures that are present in biological, environmental and social systems in terms of the mathematical Theory of Categories, Functors and Natural Transformations (TC-FNT, see Brown, Glazebrook and Baianu, 2007). On the first level of such a hierarchy are the links between the system components represented as ‘*morphisms*’ of a structured category which are subject to several axioms/restrictions of Category Theory, such as *commutativity* and associativity conditions for morphisms, functors and natural transformations. Then, on the second level of the hierarchy one considers ‘*functors*’, or links, between such first level categories, that compare categories without ‘looking inside’ their objects/system components. On the third level, one compares, or links, functors using ‘*natural transformations*’ in a 3-category (meta-category) of functors and natural transformations. At this level, natural transformations not only compare functors but also look inside the first level objects (system components) thus ‘closing’ the structure and establishing ‘the universal links’ between items as an integration of both first and second level links between items. Note, however, that in general categories the objects have no ‘inside’, though they may do so for example in the case of ‘concrete’ categories.

From the point of view of mathematical modelling, the mathematical theory of categories models the dynamical nature of reality by representing temporal changes through either *variable* categories or through *toposes*. According to Mac Lane and Moerdijk (2004) certain variable categories can also be generated as a topos. For example, the category of sets can be considered as a topos whose only generator is just a single point. A variable category of varying sets might thus have just a generator set. However, a qualitative distinction *does exist* between organisms—considered as complex systems— and ‘simple’, inanimate dynamical systems, in terms of the modelling process and the type of predictive mathematical models or representations that they can have (Rosen, 1987, and also, previously, in Baianu, 1968 through 1987). A relevant example of applications to the natural sciences, e.g., neurosciences, would be the higher-dimensional algebra representation of processes of cogni-

tive processes of still more, linked sub-processes (Brown, 2004). Additional examples of the usefulness of such a categorical constructive approach to generating higher-level mathematical structures would be that of supergroups of groups of items, 2-groupoids, or double groupoids of items.

Symmetry, Commutativity and Abelian Structures.

The hierarchy constructed above, up to level 3, can be further extended to higher, n -levels, always in a consistent, natural manner, that is using commutative diagrams. Let us see therefore a few simple examples or specific instances of commutative properties. The type of global, natural hierarchy of items inspired by the mathematical TC-FNT has a kind of *internal symmetry* because at all levels, the link compositions are *natural*, that is, if $f : x \rightarrow y$ and $g : y \rightarrow z \implies h : x \rightarrow z$, then the composition of morphism g with f is given by another unique morphism $h = g \circ f$. This general property involving the equality of such link composition chains or diagrams comprising any number of sequential links between the same beginning and ending objects is called *commutativity* (see for example Samuel and Zarisky, 1957), and is often expressed as a *naturality condition for diagrams*. This key mathematical property also includes the mirror-like symmetry $x \star y = y \star x$; when x and y are operators and the symbol ' \star ' represents the operator multiplication. Then, the equality of $x \star y$ with $y \star x$ defines the statement that "the x and y operators *commute*"; in physical terms, this translates into a sharing of the same set of eigenvalues by the two commuting operators, thus leading to 'equivalent' numerical results i.e., up to a multiplication constant); furthermore, the observations X and Y corresponding, respectively, to these two operators would yield the same result if X is performed before Y in time, or if Y is performed first followed by X. This property, when present, is very convenient for both mathematical and physical applications (such as those encountered in quantum mechanics). However, not all quantum operators 'commute', and not all categorical diagrams or mathematical structures are, or need be, commutative. *Non-commutativity* may therefore appear as a result of 'breaking' the 'internal symmetry' represented by commutativity. As a physical analogy, this might be considered a kind of '*symmetry breaking*' which is thought to be responsible for our expanding Universe and CPT violation, as well as many other physical phenomena such as phase transitions and superconductivity (Weinberg, 2003).

On the one hand, when commutativity is global in a structure, as in an Abelian (or commutative) group, commutative groupoid, commutative ring,

etc., such a structure that is commutative throughout is usually called *Abelian*. However, in the case of category theory, this concept of Abelian structure has been extended to a special class of categories that have meta-properties formally similar to those of the category of commutative groups, $Ab-\mathbf{G}$; the necessary and sufficient conditions for such ‘Abelianness’ of categories other than that of Abelian groups were expressed as three axioms **Ab1** to **Ab3** and their duals (Freyd, 1964; see also the details in Baianu et al 2007b and Brown et al 2007). Among such mathematical structures, *Abelian* categories have particularly interesting applications to rings and modules (Popescu, 1973; Gabriel, 1962) in which commutative diagrams are essential. Commutative diagrams are also being widely used in Algebraic Topology (Brown, 2005; May, 1999). As one can see from both the earlier and more recent literature, Abelian categories have been studied in great detail, even though their study is far from complete. On the other hand, the more general case is the *non-commutative* one. Several intriguing, ‘non-commutative’ or non-Abelian, examples are provided by certain *asymmetric* drawings by Escher, such as his perpetuum water mill, or his 3D-evading, illusory castle with monks ‘climbing’ from one level to the next—at ‘same-height’ (that might be considered as a hint to paradoxes caused by the imposition of only one level of reality, similar to Abbott’s flat-land).

Abelian Meta-Theorems.

Freyd (1964) has an interesting section on **meta**-theorems in his book on Abelian categories. In essence all propositions, or mathematical truth statements of a specific mathematical form “**p**” that are valid for the category of Abelian groups are also valid in any extended Abelian category defined by axioms Ab1 to Ab3 and their duals. Other types of meta-theorems are also possible for super-categories of categories, and of course such meta-theorems are not restricted to Abelian structures.

Non-Abelian Theories and Spacetimes Ontology.

Any comprehensive Categorical Ontology theory is *a fortiori non-Abelian*, and thus recursively 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, 1987; Baianu, Brown, Georgescu and Glazebrook, 2006). 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 some prerequisite algebraic–topological and categorical ontology tools for this endeavor, again relegating all rigorous mathematical definitions to the Brown, Glazebrook and Baianu (2007). 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, 1987, Healy, 2006), Genetic Ontology, Biological Ontology, Environmental representations by categories and functors (Levich and Solovy'ov., 1999), or ultra-complex societies.

An example of a non-commutative structure relevant to Quantum Theory is that of the *Clifford algebra* of quantum observable operators (Dirac, 1962; see also Plymen and Robinson, 1994). Yet another- more recent and popular-example in the same QT context is that of C^* -algebras of (quantum) Hilbert spaces. Furthermore, the microscopic, or quantum, ‘first’ level of physical reality does *not* appear to be subject to the categorical naturality conditions of Abelian TC-FNT– the ‘standard’ mathematical theory of categories (functors and natural transformations). It would seem therefore that the commutative hierarchy discussed above is not sufficient for the purpose of a General, Categorical Ontology which considers all items, at all levels of reality, including those on the ‘first’, quantum level, which is non–commutative. On the other hand, the mathematical, Non-Abelian Algebraic Topology (Brown, Higgins and Sivera, 2007), the Non-Abelian Quantum Algebraic Topology (NA-QAT;

Baianu et al., 2005), and the physical, Non-Abelian Gauge theories (NAGT) may provide the ingredients for a proper foundation for Non-Abelian, hierarchical multi-level theories of a super-complex system dynamics in a General Categorical Ontology (GCO). Furthermore, it was recently pointed out (Baianu *et al.*, 2005, 2006) that the current and future development of both NA-QAT and of a quantum-based Complex Systems Biology, *a fortiori*, involve *non-commutative*, many-valued logics of quantum events, such as a modified Łukasiewicz–Moisil (LMQ) logic algebra (Baianu, Brown, Georgescu and Glazebrook, 2006), complete with a fully-developed, novel probability measure theory grounded in the LM-logic algebra (Georgescu, 2006b). Such recent developments point towards a paradigm shift in Categorical Ontology and to its extension to more general, *Non-Abelian theories*, well beyond the bounds of commutative structures/spaces and also free from the *logical* restrictions and limitations imposed by set theory.

Systems Classification in Ontology: Simple/Complex–Chaotic, Super–Complex and Ultra–Complex Systems viewed as Three Distinct Levels of Reality: Dynamic Analogy and Homology.

We introduce here a few basic definition of a general, dynamical system that may facilitate further developments of the theory of levels in categorical ontology. No claim is here made however to either universality or mathematical rigour.

Defining Dynamic Systems as Stable Spacetime Structures with Boundaries.

As defined in Baianu and Poli (2008), a system is a dynamical (whole) entity able to maintain its working conditions; the system definition is here spelt out in detail by the following, general definition, **D1**.

D1. A simple system is in general a bounded, but not necessarily closed, entity– here represented as a category of stable, interacting components with inputs and outputs from the system’s environment, or as a supercategory for a complex system consisting of subsystems, or components, with internal boundaries among such subsystems.

As proposed by Baianu and Poli (2008) in order to define a system one therefore needs specify the following data: (1) components or subsystems, (2) mutual interactions or links; (3) a separation of the selected system by some boundary which distinguishes the system from its environment, without

necessarily ‘closing’ the system to material exchange with its environment; (4) the specification of the system’s environment; (5a) the specification of the system’s categorical structure and dynamics; (5b) a supercategory will be required only when either the components or subsystems need be themselves considered as represented by a category, i.e. the system is in fact a super-system of (sub)systems, as it is the case of all emergent super-complex systems or organisms.

As discussed by Baianu and Poli (2008), “the most general and fundamental property of a system is the *inter-dependence* of parts/components/sub-systems or variables.” ; *inter-dependence* is the presence of a certain organizational order in the relationship among the components or subsystems which make up the system. It can be shown that such organizational order must either result in a stable attractor or else it should occupy a stable spacetime domain, which is generally expressed in *closed* systems by the concept of equilibrium. On the other hand, in non-equilibrium, open systems, one cannot have a static but only a *dynamic self-maintenance* in a ‘state-space region’ of the open system – which cannot degenerate to either an equilibrium state or a single attractor spacetime region. Thus, non-equilibrium, open systems that are capable of self-maintenance (seen as a form of autopoiesis) will also be generic, or structurally-stable: their arbitrary, small perturbation from a homeostatic maintenance regime does not result either in completely chaotic dynamics with a single attractor or the loss of their stability. It may however involve an ordered process of changes - a process that follows a determinate pattern rather than random variation relative to the starting point. Systems are usually conceived as ‘objects’, or things, rather than processes even though at the core of their definition there are dynamic laws of evolution. Spencer (1898) championed such evolutionary ideas/laws/principles not only in the biosphere but also in psychology and human societies. Furthermore, the usual meaning of ‘dynamic systems’ is associated with their treatments by a ‘system’ (array) of differential equations (either exact, ordinary or partial); note also that the latter case also includes ‘complex’ chaotic systems whose solutions cannot be obtained by recursive computation, for example with a digital computer or supercomputer.

Boundaries are especially relevant to *closed* systems, although they also exist in many open systems. According to Poli (2008): “they serve to distinguish what is internal to the system from what is external to it”, thus defining the fixed, overall structural topology of a closed system. By virtue of possessing boundaries, “a whole (entity) is something on the basis of which there is

an interior and an exterior...which enables a difference to be established between the whole closed system and environment.” (cf. Baianu and Poli, 2008). As proposed by Baianu and Poli (2008), an essential feature of boundaries in open systems is that they can be crossed by matter. The boundaries of closed systems, however, cannot be crossed by molecules or larger particles. On the contrary, a horizon is something that one cannot reach. In other words, a horizon is not a boundary. This difference between horizon and boundary appears to be useful in distinguishing between systems and their environment. Organisms, in general, are *open systems with variable topology* that incorporate both the valve and the selectively permeable membrane boundaries –albeit much more sophisticated and dynamic than the simple/fixed topology cellophane membrane–in order to maintain their stability and also control their internal structural order, or low microscopic entropy. The formal definition of this important concept of ‘*variable topology*’ was introduced in our recent paper (Baianu et al 2007a) in the context of the spacetime evolution of organisms, populations and species. Interestingly, for many multi-cellular organisms, including man, the overall morphological symmetry (but not the internal organizational topology) is retained from the beginning of ontogenetic development is externally bilateral–just one plane of mirror symmetry– from *Planaria* to humans. The presence of the head-to-tail asymmetry introduces increasingly marked differences among the various areas of the head, middle, or tail regions as the organism develops. There is however in man– as in other mammals– an internal bilateral asymmetry (e.g., only one heart on the left side), as well as a front to back, both external and internal anatomical asymmetry. In the case of the brain, however, only humans seem to have a significant bilateral, internal asymmetry between the two brain hemispheres that interestingly relates to the speech-related ‘centers’ (located in the majority of humans in the left brain hemisphere). The multiplicity of boundaries, and the dynamics that derive from it, generate interesting phenomena. Boundaries tend to reinforce each other, as in the case of dissipative structures formed through coupled chemical, chaotic reactions. According to Poli (2008), “*this somewhat astonishing regularity of nature has not been sufficiently emphasized in perception philosophy.*”

Simple, Complex and Super–Complex Dynamics: Closed vs. Open Systems.

In an early report (Baianu and Marinescu, 1968), the possibility of formu-

lating a Super-Categorical Unitary Theory of Systems (i.e., both simple and complex, etc.) was pointed out both in terms of organizational structure and dynamics. Furthermore, it was proposed that the formulation of any model or ‘simulation’ of a complex system— such as living organism or a society— involves generating a first-stage *logical model* (not-necessarily Boolean!), followed by a *mathematical* one, *complete with structure* (Baianu, 1970). Then, it was pointed out that such a modelling process involves a diagram containing the complex system, (**CS**) and its dynamics, a corresponding, initial logical model, **L**, ‘*encoding*’ the essential dynamic and/or structural properties of **CS**, and a detailed, structured mathematical model (**M**); this initial modelling diagram may or may not be commutative, and the modelling can be iterated through modifications of **L**, and/or **M**, until an acceptable agreement is achieved between the behaviour of the model and that of the natural, complex system (Baianu and Marinescu, 1968; Comoroshan and Baianu, 1969). Such an *iterative modelling* process may ultimately ‘converge’ to appropriate models of the complex system, and perhaps a best possible model could be attained as the categorical colimit of the directed family of diagrams generated through such a modelling process. The possible models **L**, or especially **M**, were not considered to be necessarily either numerical or recursively computable (e.g., with an algorithm or software program) by a digital computer (Baianu, 1971b, 1986-87). The mathematician John von Neumann regarded ‘complexity’ as a measurable property of natural systems below the threshold of which systems behave ‘simply’, but above which they evolve, reproduce, self-organize, etc. It was claimed that any ‘natural’ system fits this profile. But the classical assumption that natural systems are simple, or ‘mechanistic’, is too restrictive since ‘simple’ is applicable only to machines, closed physicochemical systems, computers, or any system that is recursively computable. Rosen (1987) proposed a major refinement of these ideas about complexity by a more exact classification between ‘simple’ and ‘complex’. Simple systems can be characterized through representations which admit maximal models, and can be therefore re-assimilated via a hierarchy of informational levels. Besides, the duality between dynamical systems and states is also a characteristic of such simple dynamical systems. Complex systems do not admit any maximal model. On the other hand, an *ultra-complex* system— as applied to psychological-sociological structures— can be described in terms of *variable categories* or structures, and thus cannot be reasonably represented by a fixed state space for its entire lifespan. Simulations by limiting dynamical approx-

imations lead to increasing system ‘errors’. Just as for simple systems, both *super-complex* and *ultra-complex* systems admit their own orders of causation, but the latter two types are different from the first–by inclusion rather than exclusion– of the mechanisms that control simple dynamical systems.

Commutative vs. Non-commutative Dynamic Modelling Diagrams.

Interestingly, Rosen (1987) also showed that complex dynamical systems, such as biological organisms, cannot be adequately modelled through a *commutative* modelling diagram– in the sense of digital computer simulation–whereas the simple (‘physical’/ engineering) dynamical systems can be thus numerically simulated. Furthermore, his modelling commutative diagram for a *simple dynamical system* included both the ‘encoding’ of the ‘real’ system \mathbf{N} in (\mathbf{M}) as well as the ‘decoding’ of (\mathbf{M}) back into \mathbf{N} :

$$\begin{array}{ccc}
 [SYSTEM] & \xrightarrow{\text{Encoding} \dots \leftrightarrow} & LOGICS \oplus MATHS. \\
 \delta \downarrow & & \downarrow \aleph_M \\
 SYSTEM & \xleftarrow{\text{Decoding} \leftrightarrow \dots} & [MATHS. \square MODEL]
 \end{array}$$

where δ is the real system dynamics and \aleph is an algorithm implementing the numerical computation of the mathematical model (\mathbf{M}) on a digital computer. Firstly, one notes the ominous absence of the *Logical Model*, \mathbf{L} , from Rosen’s diagram published in 1987. Secondly, one also notes the obvious presence of logical arguments and indeed (*non-Boolean*) ‘schemes’ related to the entailment of organismic models, such as \mathbf{MR} -systems, in the more recent books that were published last by Robert Rosen (1994, 2001, 2004). This will be further discussed in Section 4, with the full mathematical details provided in the paper by Brown, Glazebrook and Baianu (2007). Furthermore, Elsasser (1980) pointed out a fundamental, logical difference between physical systems and biosystems or organisms: whereas the former are readily represented by *homogeneous* logic classes, living organisms exhibit considerable variability and can only be represented by *heterogeneous* logic classes. One can readily represent homogeneous logic classes or endow them with ‘uniform’ mathematical structures, but heterogeneous ones are far more elusive and may admit a multiplicity of mathematical representations or possess variable structure. This logical criterion may thus be useful for further distinguishing simple systems from highly complex systems.

The importance of *Logic Algebras*, and indeed of *Categories of Logic Algebras*, is rarely discussed in modern Ontology even though categorical formulations of specific Ontology domains such as Biological Ontology and Neural Network Ontology are being extensively developed. For a recent review of such categories of logic algebras the reader is referred to the concise presentation by Georgescu (2006); their relevance to network biodynamics was also recently assessed (Baianu, 2004, Baianu and Prisecaru, 2005; Baianu et al, 2006).

Super-complex systems, such as those supporting neurophysiological activities, are explained only in terms of non-linear, rather than linear causality. In some way then, these systems are not normally considered as part of either traditional physics or the complex ‘chaotic’ systems physics that are known to be fully deterministic. However, super-complex (biological) systems have the potential to manifest novel and counter-intuitive behavior such as in the manifestation of ‘emergence’, development/morphogenesis and biological evolution. The precise meaning of supercomplex systems is formally defined here in Section 3.3.

Comparing Systems: Similarity Relations between Analogous or Adjoint Systems. Diagrams Linking Super- and Ultra- Complex/Meta-Levels. Classification as a Dynamic Analogy, Categorical Adjointness or Functional Homology.

Categorical comparisons of different types of systems in diagrams provide useful means for their classification and understanding the relations between them. From a global viewpoint, comparing categories of such different systems does reveal useful analogies, or similarities, between systems and also their universal properties. According to Rashevsky (1969), general relations between sets of biological organisms can be compared with those between societies, thus leading to more general principles pertaining to both. This can be considered as a further, practically useful elaboration of Spencer’s philosophical principle ideas in biology and sociology. When viewed from a formal perspective of Poli’s theory of levels (Baianu and Poli, 2008), the two levels of super- and ultra-complex systems are quite *distinct* in many of their defining properties, and therefore, categorical diagrams that ‘mix’ such distinct levels *do not commute*.

Considering dynamic similarity, Rosen (1968) introduced the concept of ‘*analogous*’ (classical) dynamical systems in terms of categorical, dynamic isomorphisms between their isomorphic state-spaces that commute with their transition (state) function, or dynamic laws. However, the extension of this

concept to either complex or super-complex systems has not yet been investigated, and may be similar in importance to the introduction of the Lorentz-Poincaré group of transformations for reference frames in Relativity theory. On the other hand, one is often looking for *relational invariance* or *similarity in functionality* between different organisms or between different stages of development during ontogeny—the development of an organism from a fertilized egg. In this context, the categorical concept of ‘*dynamically adjoint systems*’ was introduced in relation to the data obtained through nuclear transplant experiments (Baianu and Scripcariu, 1974). Thus, extending the latter concept to super- and ultra- complex systems, one has in general, that two complex or supercomplex systems with ‘state spaces’ being defined respectively as A and A^* , are dynamically adjoint if they can be represented naturally by the following (functorial) diagram:

$$\begin{array}{ccc}
 A & \xrightarrow{F} & A^* \\
 F' \downarrow & & \downarrow G \\
 A^* & \xrightarrow{G'} & A
 \end{array} \tag{0.1}$$

with $F \approx F'$ and $G \approx G'$ being isomorphic (that is, \approx representing natural equivalences between adjoint functors of the same kind, either left or right), and as above in diagram (2.5), the two diagonals are, respectively, the state-space transition functions $\Delta : A \rightarrow A$ and $\Delta^* : A^* \rightarrow A^*$ of the two adjoint dynamical systems. (It would also be interesting to investigate dynamic adjointness in the context of quantum dynamical systems and quantum automata, as defined in Baianu, 1971a).

A *left-adjoint* functor, such as the functor F in the above commutative diagram between categories representing state spaces of equivalent cell nuclei *preserves limits*, whereas the *right-adjoint* (or coadjoint) functor, such as G above, *preserves colimits*. (For precise definitions of adjoint functors the reader is referred to Brown, Galzebrook and Baianu, 2007, as well as to Popescu, 1973, Baianu and Scripcariu, 1974, and the initial paper by Kan, 1958).

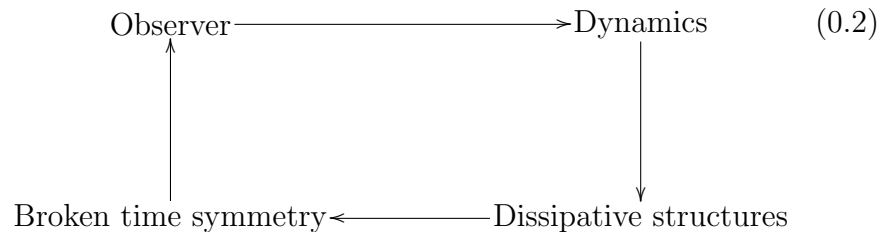
Thus, dynamical attractors and genericity of states are preserved for differentiating cells up to the blastula stage of organismic development. Subsequent stages of ontogenetic development can be considered only ‘weakly adjoint’ or partially analogous. Similar dynamic controls may operate for controlling di-

vision cycles in the cells of different organisms; therefore, such instances are also good example of the dynamic adjointness relation between cells of different organisms that may be very far apart phylogenetically, even on different ‘branches of the tree of life.’ A more elaborate dynamic concept of ‘homology’ between the genomes of different species during evolution was also proposed (Baianu, 1971a), suggesting that an entire phylogenetic series can be characterized by a topologically—rather than biologically—*homologous sequence* of genomes which preserves certain genes encoding *the essential* biological functions. A striking example was recently suggested involving the differentiation of the nervous system in the fruit fly and mice (and perhaps also man) which leads to the formation of the back, middle and front parts of the neural tube. A related, topological generalization of such a dynamic similarity between systems was previously introduced as *topological conjugacy* (Baianu, 1986-1987a; Baianu and Lin, 2004), which replaces recursive, digital simulation with symbolic, topological modelling for both super- and ultra- complex systems (Baianu and Lin., 2004; Baianu, 2004c; Baianu et al., 2004, 2006b). This approach stems logically from the introduction of topological/symbolic computation and topological computers (Baianu, 1971b), as well as their natural extensions to quantum nano-automata (Baianu, 2004a), quantum automata and quantum computers (Baianu, 1971a, and 1971b, respectively); the latter may allow us to make a ‘quantum leap’ in our understanding Life and the higher complexity levels in general. Such is also the relevance of Quantum Logics and LM-logic algebra to understand the immanent operational logics of the human brain and the associated mind meta-level. Quantum Logics concepts are introduced next that are also relevant to the fundamental, or ‘ultimate’, concept of spacetime, well-beyond our phenomenal reach, and thus in this specific sense, *transcendental* to our physical experience (perhaps vindicating the need for a Kantian-like *transcendental logic*, but from a quite different standpoint than that originally advanced by Kant in his critique of ‘pure’ reason; instead of being ‘mystical’- as Husserl might have said—the transcendental logic of quantized spacetime is very different from the Boolean logic of digital computers, as it is *quantum*, and thus non-commutative). A *Transcendental Ontology*, whereas with a definite Kantian ‘flavor’, would not be at all ‘mystical’ in Husserl’s sense, but would rely on ‘verifiable’ many-valued, non-commutative logics, and thus contrary to Kant’s original presupposition, as well as untouchable by Husserl’s critique. The fundamental nature of spacetime would be ‘provable’ and ‘verifiable’, but only to the extent allowed by Quantum Logics, not by an arbitrary (‘mystical’)

Kantian–transcendental logic or by impossible, direct phenomenal observations at the Planck scale.

Irreversibility in Open Systems: Time and Microentropy, Quantum Super-Operators.

A significant part of the scientific and philosophical work of Ilya Prigogine (see e.g. Prigogine, 1980) has been devoted to the dynamical meaning of phenomenal/physical *irreversibility* expressed in terms of the second law of thermodynamics. For systems with strong enough instability of motion the concept of phase space trajectories is no longer meaningful and the dynamical description has to be replaced by the motion of distribution functions on the phase space. The viewpoint is that quantum theory produces a more coherent type of motion than in the classical setting and the quantum effects induce correlations between neighbouring classical trajectories in phase space. Prigogine’s idea (1980) is to associate a macroscopic entropy (or Lyapounov function) with a microscopic entropy (quantum) super–operator M . A self-consistent scheme may be summarized in the following diagram (Prigogine, 1980):



for which ‘irreversibility’ occurs as the intermediary in the following sequence:

$$\text{Dynamics} \implies \text{Irreversibility} \implies \text{Dissipative structures}$$

This diagram sketches four major pieces from the puzzle of the emergence/origin of life on earth, without however coming very close to completing this puzzle; thus, Prigogine’s subtle concepts of microscopic time and micro–entropy super–operators may allow us to understand how life originated on earth several billion years ago, and also how organisms function and survive today. They also provide a partial answer to subtle quantum genetics and fundamental evolutionary dynamics questions asked by Schrödinger– one of the

great founders of quantum ‘wave mechanics’– in his widely read book “What is Life?” Other key answers to the latter’s question were recently provided by Robert Rosen (2000) in his popular book “Essays on Life Itself.”, unfortunately without any possibility of continuation or of reaching soon the ‘ultimate’ or complete answer. Schrödinger’s suggestion that living organisms “feed on ‘negative entropy’...” was at least in part formalized by Prigogine’s super-operators, such as M . This theory is in great need of further developments that he could not complete during his lifespan; such developments will apparently require a categorical and Higher Dimensional Algebraic, non-Abelian theory of irreversible thermodynamics, as well as a quantum-mechanical statistics of open systems that are capable of autopoiesis, e.g. living organisms.

Dynamic Emergence and Entailment of the Higher Complexity Levels.

We are considering here the question of how biological, psychological and social functions are entailed through *emergent* processes of increasing complexity in higher-dimensional spacetime structures that are essential to Life, Evolution of Species and Human Consciousness. Such emergent processes in the upper three levels of reality considered by Poli (2006b) have corresponding, defining levels of increasing dynamic complexity from biological to psychological and, finally, to the social level. It is therefore important to distinguish between the *emergent* processes of higher complexity and the underlying, component physicochemical processes. Chaotic dynamics are *not*, however, *emergent* systems because their existence does not require aggregation, or the presence of a level higher than molecular. We are here defending the claim that all ‘true’ dynamic complexity of higher order is *irreducible* to the dynamics of sub-processes—usually corresponding to a lower level of reality—and it is therefore a truly *emergent*, real phenomenon. In other words, **no emergence** \Rightarrow **no complexity** higher than that of physicochemical systems with chaos, whereas reductionists now attempt to reduce everything, from life to societies and ecology, to systems with just chaotic behaviour. The detailed nature of the higher level emergence will be further developed and treated in a more formal/precise manner in the following sections.

As explained above, there is an ongoing ambiguity and also inconsistency in the current use of the term ‘complex’, as in ‘complex dynamics and dynamical

systems’– which is employed by chaotic physics reports and textbooks with a very different meaning from the one customarily employed in Relational Biology (Rosen,1987; and also earlier, more general definitions proposed by Baianu (1968 through 1987). We propose, however, to retain the term ‘complexity’–in accord with the use adopted for the field of physicochemical chaotic dynamics demanded by modern physicists and chemists. Then, in order to avoid the recurring confusion that would occur between inanimate, chaotic or robotic, systems that are ‘complex’ and living organisms which are at a distinctly higher level of dynamic complexity, we propose to define the latter, higher complexity level of *biosystems* as ‘*supercomplex*’. Thus, we suggest that the *biological* complex systems–whose dynamics is quite distinct from that of *physical* ‘complex systems’– should be called ‘*supercomplex*’ (Baianu and Poli, 2007). (Elsasser also claimed that living organisms are ‘extremely complex’, as discussed in a recent report (Baianu, 2006)). For example, a collection of parts could be assembled through a categorical *colimit*, as it will be shown in a subsequent section (8). Note also that a categorical colimit is defined not just by its parts but also by the morphisms between the objects, which conforms with the naive view that an engine, say, is not just a collection of parts, but depends crucially on how they are put together, if it is to work!

Interestingly, the term ‘super-complex’ is already in use in the computer industry for high performance digital computer systems designed with a high-degree of parallel processing, whose level of complexity is, however, much lower than that of physicochemical chaotic systems that are called ‘complex’ by physicists. On the other hand, in the fields of structural and molecular biology, the term ‘super-complex’ recently designates certain very large super-aggregates of biopolymers that are functional within a cell. Thus, our proposed use of the term $\langle \textit{super-complex} \rangle$ is for the higher level of organization–that of the *whole, functional organism*, not for the first (physicochemical) level of reality–no matter how complicated, ‘chaotic’ or intricate it is at the molecular/atomic/quantum level. Therefore, in our proposed terminology, *the level of super-complex dynamics is the first emergent level*–which does correspond to the first emergent level of reality in the ontological theory of levels recently proposed by Poli (2006a,b). A more precise formulation and, indeed, resolution of such emergent complexity issues will be presented in the following sections. Our approach from the perspectives of spacetime ontology and dynamic complexity thus requires a reconsideration of the question how new levels of dynamic complexity arise at both the biological and psychological levels.

Furthermore, the close interdependence/two-way relations of the psychological and social levels of reality (Poli, 2006a) do require a consideration of the correlations between the dynamic complexities of human consciousness and human society. The *emergence* of one is ultimately determined by the other, in what might be expressed as *iterated feedback and/or feedforward loops*, though not restricted to the engineering meaning which is usually implied by these terms. Thus, *feedforward* loops should be understood here in the sense of *anticipatory* processes, that can, for example, lead in the future to the improvement of social interactions through deliberate, conscious human planning—or even more—to the prevention of the human, and other species, extinction. Further *inter-relations* among the different ontological levels of system complexity are discussed in Baianu and Poli (2007).

*Super-Complex System Dynamics in Living Organisms: Genericity,
Multi-Stability and Variable State Spaces.*

The important claim is here defended that above the level of ‘complex systems with chaos’ there is still present a higher, super-complexity level of living organisms—which are neither machines/simple dynamical systems nor are they mere ‘chaotically’—behaving systems, in the sense usually employed by the physical theory of ‘chaotic’ dynamics. These distinct levels, physical/chaotic and biological were represented as distinct objects in the non-commutative diagram of the previous section joined by causal links, running from simple to ‘chaotic–complex’ (physical) dynamics, then upwards linked to super-complex biodynamics, and still higher to the ultra-complex, meta-level of mental dynamic processes of processes. A further claim is defended that even though the higher levels are linked to—and indeed subsumed, or include—the lower ones in their distinct organization, they are not reducible in a physical or (bio) chemical sense to the lower dynamic level. *In esse*, the distinction between the existence of the higher, super– and ultra– complexity levels and the physical/chemical level of reality can only be made on the basis of their dynamics. Neither Life nor the Mind can be properly conceived as *static*/closed systems, or even as quasi–static structures, without either a time-dependence or associated, material (including energy) and microentropy/gradient-driven flows which are characteristic of *irreversible, open* systems. If the super-complex dynamics stops so does life. Somewhat similarly, but at a different, higher level of reality, the human mind’s ultra–complex existence emerges as a dynamic meta-process of processes, supported also by neural dynamics and life. Artificially

separating the mind from the human brain and life in an abstract–‘analytical’ sense, as in Cartesian Dualism, promotes a static view and an object–based approach that might be relevant, or just partially applicable only to *unconscious* human beings, such as in the case of a severe brain stroke, or even worse, in cases caused by permanent, irrecoverable human brain injuries to a ‘living–vegetable’ status in grave, major accidents.

We shall examine next in some detail how super-complex dynamics emerges in organisms from the *molecular and supra-molecular* levels that recently have already been claimed to exist by several experimental molecular biologists to be ‘super-complex’. As shown in previous reports (Baianu, 1973 through 2004; Baianu et al, 2006), multi-cellular organismic development, or ontogeny, can be represented as a directed system or family of dynamic state spaces corresponding to all stages of ontogenetic development of increasing dimensionality. The *colimit* of this *directed system* of ontogenetic stages/dynamic state spaces represents the *mature* stage of the organism (Baianu, 1970 through 2004; Baianu et al. 2006). This emergent process involved in ontogeny leads directly to *variable*, super-complex dynamics and *higher dimensional* state spaces. As an over-simplified, pictorial–but also formalizable–representation, let us consider a living cell as a topological ‘cell’ or simplex of a CW-complex. Then, as a multi-cellular organism develops a complete simplicial (CW) complex emerges as an over-simplified picture of the whole, mature organism. The higher dimensionality then emerges by considering each cell with its associated, *variable* dynamic state space (Baianu, 1970,1971a,b). As shown in previous reports (Baianu, 1970, 1980), the corresponding variable dynamic structure representing biological relations, functionalities and dynamic transitions is an organismic supercategory, or **OS**. The time-ordered sequence of CW-complexes of increasing dimensionality associated with the development of a multi-cellular organism provides a specific example of a *variable topology*. The ‘boundary conditions’ or constraints imposed by the environment on the organismic development will then lead to context-dependent variable topologies that are not strictly determined by the genome or developing genetic networks. Although ontogenetic development is usually structurally stable there exist teratogenic conditions or agents that can ‘de-stabilize’ the developing organism, thus leading to abnormal development. One also has the possibility of abnormal organismic, or brain, development caused by altered genomes, as for example in those cases of autism caused by the fragile-X chromosome syndrome. On the other hand, both single-cell and multi-cellular organisms can be represented

in terms of variable dynamic systems, such as generalized **(M,R)**- systems (Baianu, 1973; Baianu and Marinescu, 1974), including dynamic realizations of **(M,R)**- systems (Rosen,1971a,b).

Organisms Represented as Variable Dynamic Systems: Generic States and Dynamic System Genericity.

In actual fact, the super-complexity of the organism itself emerges through the generation of dynamic, variable structures which then also entail variable/flexible functions, homeostasis, autopoiesis, anticipation, and so on. In this context, it is interesting that Wiener (1950,1989) proposed the simulation of living organisms by variable machines/automata that did not exist in his time. The latter were subsequently formalized independently in two related reports (Baianu, 1971a,b).

The topologist René Thom 's metaphorical approach of Catastrophe Theory (1980) to biodynamics, provides some insights of *structural stability* and biodynamics *via* 'generic' states that when perturbed lead to other similarly stable states. When viewed from a categorical standpoint, organismic dynamics has been suggested to be characterized not only by homeostatic processes and steady state, but also by *multi-stability* (Baianu, 1970). The latter concept is clearly equivalent from a dynamic/topological standpoint to super-complex system genericity, and the presence of *multiple dynamic attractors* (Baianu, 1971) which were categorically represented as *commutative super-pushouts* (Baianu, 1970). The presence of generic states and regions in super-complex system dynamics is thus linked to the emergence of complexity through both structural stability and the *open* system attribute of any living organism that enable its persistence in time, in an accommodating niche, suitable for its competitive survival.

6. ULTRA-COMPLEX SYSTEMS: THE EMERGENCE OF THE UNIQUE
ULTRA-COMPLEXITY THROUGH CO-EVOLUTION OF THE HUMAN MIND
AND SOCIETY. ULTRA- COMPLEX MENTAL PROCESSES VIEWED AS
META-LEVEL DYNAMICS.

Higher still than the organismic level characterized by super-complex dynamics, there emerged perhaps even earlier than 400,000 years ago the *unique, ultra-complex* levels of human mind/consciousness and human society interactions, as it will be further discussed in the following sections. There is

now only one species known who is capable of rational, symbolic/abstract and creative thinking as part-and-parcel of consciousness—*Homo sapiens sapiens*—which seems to have descended from a common ancestor with *Homo ergaster*, and separated from the latter some 2.2 million years ago. However, the oldest fossils of *H. sapiens* found so far are just about 400,000 years old.

The following diagram summarizes the relationships/links between such different systems on different ontological levels of increasing complexity from the simple dynamics of physical systems to the ultra-complex, global dynamics of psychological processes, collectively known as ‘human consciousness’. With the emergence of the ultra-complex system of the human mind—based on the super-complex human organism—there is always an associated progression towards higher dimensional algebras from the lower dimensions of human neural network dynamics and the simple algebra of physical dynamics, as shown in the following, essentially *non-commutative* categorical ontology diagram. This is similar—but not isomorphic—to the higher dimensionality emergence that occurs during ontogenetic development of an organism, as discussed in the previous subsection.

$$\begin{array}{ccc}
 [SUPER - COMPLEX] & \xrightarrow{\text{(Higher Dim)}} & ULTRA - COMPLEX \\
 \Lambda \downarrow & & \downarrow \text{onto} \\
 COMPLEX & \xleftarrow{\text{(Generic Map)}} & [SIMPLE]
 \end{array}$$

Note that the above diagram is indeed not ‘natural’ for reasons related to the emergent higher dimensions of the super-complex (biological/organismic) and/or ultra-complex (psychological/neural network dynamic) levels in comparison with the low dimensions of either simple (physical/classical) or complex (chaotic) dynamic systems. It might be possible, at least in principle, to obtain commutativity by replacing the simple dynamical system in the diagram with a quantum system, or a quantum ‘automaton’ (Baianu,1971,1987); however, in this case the diagram still does not necessarily close between the quantum system and the complex system with chaos, because it would seem that *quantum systems are ‘fuzzy’*—not strictly deterministic— as complex ‘chaotic’ systems are. Furthermore, this categorical ontology diagram is neither recursively computable nor representable through a commutative algorithm of the kind proposed for Boolean neural networks (Healy and Caudell, 2006; for an

extensive review of network biodynamic modelling, ‘simulations’ and also non-computability issues for biological systems see Baianu, 1986 and references cited therein). Note also that the top layer of the diagram has generic states and generic regions, whereas the lower layer does not; the top layer lives, the bottom one does not.

Connectivity and Bionetwork Topology: Genetic Ontology and Interactomics Reconstruction.

One may place special emphasis on network topology and connectivity in Genetic Ontology and Categorical Biology since these concepts are becoming increasingly important in modern biology, as realized in rapidly unfolding areas such as post-Genomic Biology, *Proteomics* and *Interactomics* that aim at relating structure and protein-protein-biomolecule interactions to biological function. The categories of the biological/genetic/ecological/ levels may be seen as more ‘structured’ compared with those of the cognitive/mental levels (hinging on epiphenomenalism, interactive dualism, etc.) which may be seen as ‘less structured’, but not necessarily having less structural power owing to the increased abstraction in their design of representation. We are here somewhat in concert with Hartmann’s (1952) laws of autonomy.

7. THE EMERGENCE OF LIFE, HUMAN CONSCIOUSNESS AND SOCIETY

With an increasing level of complexity generated through billions of years of evolution in the beginning, followed by millions of years for the ascent of man, and perhaps 10,000 more years for human societies and their civilizations, there is an increasing degree of *genericity* for the dynamic states of the evolving systems (Thom, 1980; Rosen, 2001). If such genericity is sufficient for the survival of the relatively very young human civilization is arguably one of the most important human ontology questions. Evolutionary theories based only on historical evidence, and also without a dynamic foundation, cannot obviously answer the important question of **What is Life ?**

Emergence of Super-Complex Systems and Life. The ‘Primordial’ as the Simplest (M,R)- or Autopoietic- System.

In the preceding two sections we have already discussed from the categorical viewpoint several key systemic differences in terms of dynamics and modelling between living and inanimate systems.

Arguably, the most important attributes of Life are those related to the logics ‘immanent’ in those processes that are essential to Life. As an example, the logics and logic-algebras associated with functioning neuronal networks in the human brain—which are different from the multi-valued (Łukasiewicz–Moisil) logics (Georgescu, 2006) associated with functional genetic networks (Baianu, 1977, 1987; Baianu, Brown, Georgescu and Glazebrook, 2006) and self-reproduction (Lofgren, 1968; Baianu, 1970; 1987)—were shown to be different from the simple Boolean-crypsippian logic upon which machines and computers are built by humans. The former n-valued (LM) logics of functional neuronal or genetic networks are *non-commutative* ones, leading to *non-linear, super-complex* dynamics, whereas the simple logics of ‘physical’ dynamic systems and machines/automata are *commutative* (in the sense of involving a commutative lattice structure). Here, we find a fundamental, logical reason why living organisms are *non-commutative*, super-complex systems, whereas simple dynamical systems have *commutative modelling diagrams* that are based on *commutative Boolean* logic. We also have here the reason why a *commutative* Categorical Ontology of Neural networks leads to advanced robotics and AI, but has indeed little to do with the ‘*immanent logics*’ and functioning of the living brain, contrary to the proposition made by McCulloch and Pitts (1943).

The intrinsic variability of living systems, or biosystems, was previously recognized as *fuzziness* (Baianu and Marinescu, 1968) and some of its possible origins were suggested to be found in the partial structural disorder of biopolymers and biomembranes (Baianu, 1980). Yet other basic reasons for the presence of both dynamic and structural ‘*bio-fuzziness*’ is the ‘immanent’ LM-logic in biosystems, such as functional genetic networks, and possibly also the Q-logic of signalling pathways in living cells. There are, however, significant differences between Quantum Logic, which is also non-commutative, and the LM-Logics of Life processes. Whereas certain reductionists would attempt to reduce Life’s logics, or even human consciousness, to Quantum Logic (QL), the former are at least logically and algebraically *not reducible to QL*. Nonetheless, it may be possible to formulate QL through certain modifications of *non-commutative LM-logics* (Baianu, 2005; Baianu, Brown, Georgescu and Glazebrook, 2006).

Robert Rosen has taken up the challenge of representing organisms in terms of simple categorical models—his Metabolic-Repair, (\mathbf{M}, \mathbf{R}) -systems, or $(\mathbf{MR})_s$ (Rosen, 1958a,b). These two seminal papers were then followed by

a series of follow up reports with many interesting, biologically relevant results and consequences in spite of the simplicity of the MR, categorical set ‘structure’. Further extensions and generalizations of MR’s were subsequently explored by considering abstract categories with both algebraic and topological structures (Baianu and Marinescu, 1973; Baianu, 1974, 1980a, 1984, 1987). On the one hand, simple dynamical (physical) systems are often represented through groups of dynamic transformations. In GR, for example, these would be Lorentz–Poincare’ groups of spacetime transformations/reference frames. On the other hand, super-complex systems, or biosystems, emerging through self-organization and complex aggregation of simple dynamical ones, are therefore expected to be represented mathematically—at least on the next level of complexity—through an extension, or generalization of mathematical groups, such as, for example, *groupoids*. Whereas simple physical systems with linear causality have high symmetry, the super-complex (living) systems emerge with lower symmetries but higher dynamic and functional/relational complexity. As symmetries get ‘broken’ the complexity degree increases sharply. From groups that can be considered as very simple categories that have just one object and reversible/invertible endomorphisms, one moves through ‘symmetry breaking’ to the structurally more complex groupoids, that are categories with many objects but still with all morphisms invertible. Dynamically, this reflects the transition from degenerate dynamics with one, or a few stable, isolated states (‘degenerate’ ones) to dynamic state regions of many generic states that are metastable; this multi-stability of biodynamics is nicely captured by the many objects of the groupoid and is the key to the ‘flow of life’ occurring as multiple transitions between the multiple metastable states of the homeostatic, living system. More details of how the latter emerge through biomolecular reactions, such as catabolic/anabolic reactions, are presented in a related paper in these Proceedings.

The emergence of human consciousness as an ultra-complex process became possible through the development of the *bilaterally asymmetric* human brain, not just through a mere increase in size, but a basic change in brain architecture as well. Relationally, this is reflected in the transition to a higher dimensional structure, for example a double biogroupoid representing the bilaterally asymmetric human brain architecture. Therefore, we can consider various groupoids as some of the ‘simplest’ illustrations of the mathematical structures present in super-complex biological systems and classes thereof, such as *biogroupoids* (the groupoids featuring in bio–systems) and variable

biogroupoids to represent evolving biological species. Relevant are here also *crossed complexes* of variable groupoids and/or *multi-groupoids* as more complex representations of biosystems that follow the emergence of ultra-complex systems (the mind and human societies, for example) from super-complex dynamic systems (organisms).

Furthermore, simple dynamic systems, or general automata, have *canonically decomposable semigroup* state spaces (the Krone-Rhodes Decomposition Theorem). It is in this sense also that recursively computable systems are ‘simple’, whereas organisms are not. In contrast, super-complex systems do not have state spaces that are known to be canonically decomposable, or partitioned into functionally independent subcomponent spaces, that is within a living organism all organs are inter-dependent and integrated; one cannot generally find a subsystem or organ which retains organismic life—the full functionality of the whole organism. However, in some of the simpler organisms, for example in *Planaria*, regeneration of the whole organism is possible from several of its major parts.

Emergence of Organisms, Essential Organismic Functions and Life. The Primordial.

Organisms are thought of having all evolved from a simpler, ‘primordial’, proto-system or cell formed somehow three, or perhaps four, billion years ago. Such a system, if considered to be the simplest, must have been similar to a bacterium, though perhaps without a cell wall, and also perhaps with a much smaller, single chromosome containing very few RNA ‘genes’ (two or, most likely, four). A simple ‘metaphor’ of metabolic, self-repairing and self-reproducing models called (M,R)-systems, was introduced by Robert Rosen (1958 a,b). Such models can represent some of the organismic functions that are essential to life; these models have been extensively studied and they can be further extended or generalized in several interesting ways. An extended **MR** (Baianu, 1969; 1984) predicts, however, the primordial, PMR, equipped with a *ribozyme* (a telomerase-like, proto-enzyme), and this PMR is then also capable of ribozyme-catalyzed DNA synthesis, as represented by the following, possibly over-simplified diagram:

$$A \xrightarrow{f} B \xrightarrow{\Phi} \mathfrak{R}[A, B] \xrightarrow{\beta} \mathfrak{R}[B, \mathfrak{R}[A, B]] \xrightarrow{\gamma} \dots \longrightarrow \infty \dots \quad (0.3)$$

where the symbol \mathfrak{R} is the **MR** category representing the ‘primordial’ organism, PMR, and $\mathfrak{R}[A,B]$ is the class of morphisms (proto-enzymes) between

the metabolic input class A (substrates) and the metabolic output class B (metabolic products of proto-enzymes). The ribozyme γ is capable of both catalyzing and ‘reverse’ encoding its RNA template into the more stable DNA duplex, ∞ . Note that the primordial **MR**, or $PMR = \mathfrak{R}$, is an auto-catalytic, self-reproducing and autopoietic system; it can also be represented as an automaton (Warren, 1979). However, its ‘evolution’ is not entailed or enabled as yet; therefore, one needs define the primordial first as a variable biogroupoid or variable category, as discussed in further detail in a related paper in these *Proceedings*.

Biological Species. Evolving Species as Variable Biogroupoids

From an ontology viewpoint, the biological species can be defined as *a class of equivalent organisms from the point of view of sexual reproduction and/or functional genome*, or as a *biogroupoid* (Baianu, Brown, Georgescu and Glazebrook, 2006). The biogroupoid concept, can be readily extended to a more flexible concept, the *variable groupoid*, which can be then utilized in theoretical evolutionary studies, and through predictions, impact on empirical evolutionary studies, as well as possibly organismic taxonomy.

For a collection of *variable groupoids* we can firstly envisage a parametrized family of groupoids $\{G_\lambda\}$ with parameter λ (which may be a time parameter, although in general we do not insist on this). This is one basic and obvious way of seeing a variable groupoid structure. If λ belongs to a set M , then we may consider simply a projection $G \times M \rightarrow M$, which is an example of a trivial fibration. More generally, we could consider a *fibration of groupoids* $G \hookrightarrow Z \rightarrow M$ (Higgins and Mackenzie, 1990). However, we expect in several of the situations discussed in this paper (such as, for example, the metabolic groupoid introduced in the previous subsection) that the systems represented by the groupoid are interacting. Thus, besides systems modelled in terms of a *fibration of groupoids*, one needs to consider a multiple groupoid as defined as a set with a number of groupoid structures any distinct pair of which satisfy an *interchange law* which can be expressed as: each is a morphism for the other. Brown and Higgins (1981a) showed that certain *multiple groupoids* equipped with an extra structure called *connections* were equivalent to another structure called a *crossed complex* which had already occurred in homotopy theory. such as *double, or multiple groupoids* (Brown, 2004, 2005). An example that may involve multiple groupoids in the ultra-complex system of the human mind is

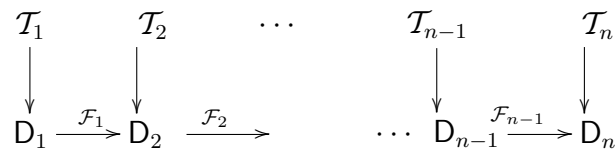
that of *synaesthesia*—the case of extreme communication processes between different types of ‘logics’ or different levels of ‘thoughts’/thought processes. The key point here is *communication*. Hearing has to communicate to sight/vision in some way; this seems to happen in the human brain in the audiovisual (neocortex) and in the Wernicke (W) integrating area in the left-side hemisphere of the brain, that also communicates with the speech centers or the Broca area, also in the left hemisphere. Because of this *dual-functional*, quasi-symmetry, or more precisely asymmetry of the human brain, it may be useful to represent all two-way communication/signalling pathways in the two brain hemispheres by a *double groupoid* as an over-simplified groupoid structure that may represent such quasi-symmetry of the two sides of the human brain. The brain’s overall *asymmetric* distribution of functions and neural network structure between the two brain hemispheres may therefore require a non-commutative, double-groupoid structure for its relational representation. The very common health problem caused by the senescence of the brain could be approached as a *local-to-global*, super-complex ageing process represented for example by the *patching* of a *topological double groupoid atlas* connecting up many local faulty dynamics in ‘small’ un-repairable regions of the brain neural network, caused for example by tangles, locally blocked arterioles and/or capillaries, and also low local oxygen or nutrient concentrations. The result, as correctly surmised by Rosen (1987), is a *global*, rather than local, senescence, super-complex dynamic process.

Developmental processes, and in general, ontogeny considered from a structural or anatomical viewpoint involves not only geometrical or topology-preserving transformations but more general/complex transformations of even more flexible structures such as variable groupoids. The natural generalizations of variable groupoids lead to ‘variable topology’ concepts that are further explained in a related paper in this *Conference Proceedings*.

Variable Topologies.

Let us recall the basic principle that a *topological space* consists of a set X and a ‘topology’ on X where the latter gives a precise but general sense to the intuitive ideas of ‘nearness’ and ‘continuity’. Thus the initial task is to axiomatize the notion of ‘neighborhood’ and then consider a topology in terms of open or of closed sets, a compact-open topology, and so on (see Brown, 2006). In any case, a topological space consists of a pair (X, \mathcal{T}) where \mathcal{T} is a topology on X . For instance, suppose an *open set topology* is given by the set \mathcal{U}

of prescribed open sets of X satisfying the usual axioms (Brown, 2006 Chapter 2). Now, to speak of a variable open-set topology one might conveniently take in this case a family of sets \mathcal{U}_λ of a *system of prescribed open sets*, where λ belongs to some indexing set Λ . The system of open sets may of course be based on a system of contained neighbourhoods of points where one system may have a different geometric property compared say to another system (a system of disc-like neighbourhoods compared with those of cylindrical-type). In general, we may speak of a topological space with a varying topology as a pair (X, \mathcal{T}_λ) where $\lambda \in \Lambda$. The idea of a varying topology has been introduced to describe possible topological distinctions in bio-molecular organisms through stages of development, evolution, neo-plasticity, etc. This is indicated schematically in the diagram below where we have an n -stage dynamic evolution (through complexity) of categories D_i where the vertical arrows denote the assignment of topologies \mathcal{T}_i to the class of objects of the D_i along with functors $\mathcal{F}_i : D_i \rightarrow D_{i+1}$, for $1 \leq i \leq n - 1$:



In this way a variable topology can be realized through such n -levels of complexity of the development of an organism. Another instance is when cell/network topologies are prescribed and in particular when one considers a categorical approach involving concepts such as *the free groupoid over a graph* (Brown, 2006). Thus a varying graph system clearly induces an accompanying system of variable groupoids. As suggested by Golubitsky and Stewart (2006), symmetry groupoids of various cell networks would appear relevant to the physiology of animal locomotion as one example.

*Lukasiewicz and LM-Logic Algebra of Genome Network Biodynamics.
 Quantum Genetics, Q-Logics and The Organismic LM-Topos.*

The representation of categories of genetic network biodynamics **GNETs** as subcategories of LM-Logic Algebras (**LMAs**) was recently reported (Baianu, Brown, Georgescu and Glazebrook, 2006) and several theorems were discussed in the context of morphogenetic development of organisms. The **GNET** section of the cited report was a review and extension of an earlier article on

the ‘immanent’ logic of genetic networks and their complex dynamics and non-linear properties (Baianu, 1977). Comparison of GNET universal properties relevant to *Genetic Ontology* can be thus carried out by colimit- and/or limit-preserving functors of GNETs that belong to adjoint functor pairs (Baianu and Scripcariu, 1974; Baianu, 1987; Baianu et al, 2006). Furthermore, evolutionary changes present in functional genomes can be represented by natural transformations of such universal-property preserving functors, thus pointing towards evolutionary patterns that are of importance to the emergence of increasing complexity through evolution; they can also lead to the emergence of the human organism. Missing from this approach, however, is a consideration of the important effects of social, human interactions in the formation of language, symbolism, rational thinking, cultural patterns, creativity, and so on... to full human consciousness.

The Organismic LM-Topos.

As reported previously (Baianu et al., 2006) it is possible to represent directly the actions of LM, many-valued logics of genetic network biodynamics in a categorical structure generated by selected LM-logics. The combined logico-mathematical structure thus obtained may have several operational and consistency advantages over the GNET-categorical approach of ‘sets with structure’. Such a structure was called an ‘LM-Topos’ and represents a significant, non-commutative logic extension of the standard Topos theory which is founded upon a commutative, intuitionist (Heyting-Brouwer) logic. The non-commutative logic LM-topos offers a more appropriate foundation for structures, relations and organismic or societal functions that are respectively super-complex or ultra-complex. This new concept of an LM-topos thus paves the way towards a Non-Abelian Ontology of highly complex spacetime structures as in organisms and societies.

Natural Transformations of Evolving Organismic Structures: Generalized (M,R)-Systems as Variable Groupoids

We have considered the important example of MR-Systems with *metabolic groupoid* structures (that is, *reversible enzyme reactions/metabolic functions-repair replication* groupoid structures), for the purpose of studying RNA, DNA, epigenomic and genomic functions. In this respect, the simplest MR-system can be represented as a *topological groupoid* with the open neighbourhood topology defined for the entire dynamical state space of the MR-system,

that is an open/generic- and thus, a structurally stable- system, as defined by the dynamic realizations of MR-systems (Rosen, 1971a,b). This requires a descriptive formalism in terms of *variable groupoids* following which the human MR-system would then arise as the *colimit* of its complete biological family tree expressible in terms of a family of many linked/connected groupoids; this variable biogroupoid representation proves also to be useful in studies of evolution.

Let us consider again the diagram corresponding to the simplest (\mathbf{M}, \mathbf{R}) -System realization of a Primordial Organism, PO. The RNA and/or DNA duplication and cell divisions would occur by extension to the right of the simplest MR-system, (f, Φ) , through the $\beta : H(A, B) \rightarrow H(B, H(A, B))$ and $\gamma : H(B, H(A, B)) \rightarrow H(H(A, B), H(B, H(A, B)))$ morphism. Note in this case, the 'closure' entailed by the functional mapping, γ , that physically represents the regeneration of the cell's *telomere* thus closing the DNA-loop at the end of the chromosome in eukaryotes. Thus γ represents the activity of a *reverse transcriptase*. Adding to this diagram an hTERT *promoter gene* – that may require to be activated in order to begin cell cycling–allows one to introduce simple models of carcinogenesis or cancer cells.

On the other hand, Rashevsky's hierarchical theory of organismic sets can also be constructed by employing mcv's with their observables and natural transformations as it was shown in a previous report (Baianu, 1980). *Thus, one obtains by means of natural transformations and the Yoneda-Grothendieck construction a unified, categorical-relational theory of organismic structures that encompasses those of organismic sets, biomolecular sets, as well as the general (\mathbf{M}, \mathbf{R}) -systems/autopoietic systems which takes explicitly into account both the molecular and quantum levels in terms of molecular class variables* (Baianu, 1980, 1984,1987).

Evolution as a Local-to- Global Problem: The Metaphor of Chains of Local Procedures. Bifurcations, Phylogeny and the 'Tree of Life'.

Darwin's theory of natural selection considers both specific and general biological functions such as adaptation, reproduction, heredity and survival, has been substantially modified and enriched over the last century. In part, this is due to more precise mathematical approaches to population genetics and molecular evolution which developed new solutions to the key problem of speciation (Bendall, 1982; Mayr and Provine, 1980; Pollard, 1984; Sober, 1984; Gregory, 1987). Modified evolutionary theories include neo-Darwinism,

the ‘punctuated evolution’ (Gould, 1977) and the ‘neutral theory of molecular evolution’ of Kimura (1983). The latter is particularly interesting as it reveals that evolutionary changes do occur much more frequently in unexpressed/silent regions of the genome, thus being ‘invisible’ phenotypically. Therefore, such frequent changes (‘silent mutations’) are uncorrelated with, or unaffected by, natural selection. For further progress in completing a logically valid and experimentally-based evolutionary theory, an improved understanding of speciation and species is required, as well as substantially more extensive, experimental/genomic data related to speciation than currently available. Furthermore, the ascent of man, is apparently not the result of only natural selection but also that of co-evolution through society interactions. Thus, simply put: the emergence of human speech and consciousness occurred both through selection and co-evolution, with the former not being all that ‘natural’ as society played a protective, as well as selective role from the very beginnings of hominid and hominid societies more than 2.2 million years ago. Somewhat surprisingly, the subject of *social selection* in human societies is rarely studied even though it may have played a crucial role in the emergence of *H. sapiens*, and occurs in every society that we know, without any exception.

Furthermore, there is a theory of levels, ontological question that has not yet been adequately addressed, although it has been identified: *at what level does evolution operate: species, organism or molecular (genetic)?* According to Darwin the answer seems to be the species. However, not everybody agrees because in Darwin’s time a valid theory of inherited characters was neither widely known nor accepted. Moreover, molecular evolution and concerted mutations are quite recent concepts whose full impact has not yet been realized. As Brian Goodwin (2002) puts it succinctly:

”Where has the organism disappeared in Darwin’s evolutionary theory?”

The answer in both Goodwin’s opinion, and also in ours, lies in the presence of key functional/relational patterns that emerged and were preserved in organisms throughout various stages over four billion years or so of evolution. The fundamental relations between organism, species and the speciation process itself do need to be directly addressed by any theory that claims to explain the evolution of species and organisms. Furthermore, an adequate consideration of the biomolecular levels and sub-levels involvement in speciation and evolution must also be present in any improved evolutionary theory. These fundamental questions were considered from the categorical ontology

viewpoint in a recent report (Baianu et al, 2007a). Thus, one needs to address the question of super-complex systems' evolution as a *local-to-global* problem instead of a topologically continuous process. We are then seeking solutions in terms of the novel categorical concepts that were sketched in the previous subsections and also exactly defined in recent reports (Brown et al, 2007a; Baianu et al, 2007a). Therefore, we consider here biological evolution by introducing the unifying metaphor of '*local procedures*' which may represent the formation of new species that branch out to generate still more evolving species. Because genetic mutations that lead to new species are discrete changes, we are therefore not considering evolution as a series of continuous changes—such as a continuous curve drawn analytically through points representing species—but heuristically as a *tree of 'chains of local procedures'* (Brown, 2006). Evolution may be alternatively thought of and analyzed as a *composition of local procedures*. Composition is a kind of combination and so it might be confused with a colimit, but they are substantially different concepts. Therefore, one may attempt to represent biological evolution as an evolutionary tree, or 'tree of life', with its branches completed through chains of local procedures (pictured in Figure 1 as overlapping circles) involving certain groupoids, previously defined as *variable topological biogroupoids* in Baianu et al, (2007a). The overlaps in this latter representation correspond to 'intermediate' species or classes/populations of organisms which are rapidly evolving under strong evolutionary pressure from their environment (including competing species, predators, etc., in their niche).

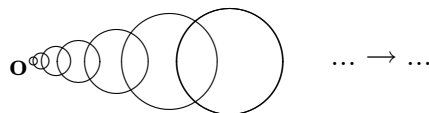


Figure 1: A pictorial representation of Biological Evolution as a composition of local procedures involving variable biogroupoids that represent biological speciation phenomena. COLPs may form the branches of the evolutionary tree, oriented in this diagram with the time arrow pointing to the right.

The notion of 'local procedure' is an interpretation of Ehresmann's formal definition of a *local admissible section* s for a groupoid G in which $X = \text{Ob}(G)$ is a topological space. Then s is a section of the source map $\alpha : G \rightarrow X$

such that the domain of s is open in X . If s, f are two such sections, their composition st is defined by $st(x) = s(\beta t(x)) \circ t(x)$ where \circ is the composition in G . The domain of st could also be empty. One may also put the additional condition that s is ‘admissible’, namely βs maps the open domain of s homeomorphically to the image of βs , which itself is open in X . Then an admissible local section is *invertible* with respect to the above composition. A tree-graph that contains only single-species biogroupoids at the ‘core’ of each ‘local procedure’ does define precisely an evolutionary branch without the need for subdivision because a species is an ‘indivisible’ entity from a breeding or reproductive viewpoint. Several different concepts in organismic dynamics, stability and variability ‘converge’ here on the metaphor of (chains of) ‘local procedures’ for evolving organisms and species. Such distinct representations are: the dynamic genericity of organismic states which lead to structural stability, the logical class heterogeneity of living organisms, and the inherent ‘bio-fuzziness’ of organisms (Baianu and Marinescu, 1968) in both their structure and function. These can also be considered as autopoietic models of the ‘structural variability’ exhibited by living systems (Maturana, 1980), imposed to the organisms through their couplings with a specific environmental niche, albeit without the mathematical precision provided by our categorical framework.

This novel, *dynamic* rather than historic/Darwinist intuition of evolution may be difficult to grasp at first as it involves several construction stages on different ontological levels: it begins with organisms (or possibly even with biomolecular categories), emerges to the level of populations/subspecies/species that evolved into classes of species, that had then further evolved, ...and so on. Finally, it reaches the point in time where the emergence of man’s, *Homo* family of species began to separate from other hominin/hominide families of species some 5 to 8 million years ago.

One concludes that evolutionary processes operate on several different levels/sublevels of reality, on different time scales; it is now generally accepted that speciation is also aided by geographical barriers or geological accidents. This highly complex, dynamic reality of the emerging higher levels of complexity is quite different from that in Darwin’s widely acclaimed “Origin of Species”, and it is also a much more powerful concept than Spencer’s vague evolutionary speculations in his several books on philosophical principles (1898). Furthermore, it also includes— but is not limited to— Goodwin’s excursions into contingent, ‘chaotic complexity’ (1994, 2000). The following subsection links

up our novel evolutionary model with other recently emerging, autopoiesis models, as well as their earlier, corresponding Rosen's **MR**-systems.

Autopoiesis Models: Species Survival and Extinctions through Space and Time.

The autopoietic model of Maturana (1987) claims to explain the persistence of living systems in time as the consequence of their structural coupling or *adaptation* as structure determined systems, and also because of their existence as *molecular* autopoietic systems with a 'closed' network structure. As part of the autopoietic explanation is the 'structural drift', presumably facilitating evolutionary changes and speciation. One notes that autopoietic systems may be therefore considered as dynamic realizations of Rosen's simple **MR**s. Similar arguments seem to be echoed more recently by Dawkins (2003) who claims to explain the remarkable persistence of biological organisms over geological timescales as the result of their intrinsic, (super-) complex, adaptive capabilities. The point is being often made that it is not the component atoms that are preserved in organisms (and indeed in 'living fossils' for geological periods of time), but the *structure-function relational pattern*, or indeed the associated organismic categories/ supercategories. This is a very important point: only the functional organismic structure or pattern persists as it is being conserved and transmitted from one generation to the next. Biomolecules turn-over in an organism, and not infrequently, but the *structure-function patterns/organismic categories remain unchanged/are conserved* over long periods of time through repeated repairs and replacements of the molecular parts that need repairing, as long as the organism lives. Such stable patterns of relations are, at least in principle, amenable to logical and mathematical representation without tearing apart the living system. Hence the relevance here, and indeed the great importance of the science of abstract structures and relations, i.e., Mathematics. In fact, looking at this remarkable persistence of certain gene subnetworks in time and space from the categorical ontology and Darwinian viewpoints, the *existence of live 'fossils'* (e.g., a coelacanth found alive in 1923 to have remained unchanged at great depths in the ocean as a species for 300 million years!) it is not so difficult to explain; one can attribute the rare examples of 'live fossils' to the lack of 'selection pressure in a very stable niche'. Thus, one sees in such exceptions the lack of any adaptation apart from those which have already occurred some 300 million years ago. This is by no means

the only long lived species: several species of marine, giant unicellular green algae with complex morphology from a family called the *Dasycladales* may have persisted as long as 600 million years (Goodwin, 1994), and so on. However, the situation of many other species that emerged through *super-complex adaptations*—such as the species of *Homo sapiens*—is quite the opposite, in the sense of marked, super-complex adaptive changes over much shorter time-scales than that of the exceptionally ‘lucky’ coelacanths. Clearly, some species, that were less adaptable, such as the Neanderthals or *Homo erectus*, became extinct.

The Emergence of *Homo sapiens* and Human Society

We are briefly considering here the tenuous evidence for the emergence of the *Homo sapiens* species— the Ascent of Man. The related question of the development of syntactically-structured speech through social *co-evolution* is also addressed in this section. Thus, the formation of the first human societies were apparently closely correlated with efficient communication through structured speech; on the other hand, the propagation, further development and indeed elaboration of speech was both made possible and sustained only through social interactions in the pre-historic human societies.

Biological Evolution of Hominins (Hominides.)

Studies of the difficult problem of the emergence of man have made considerable progress over the last 50 years with a series of several key hominide/hominin fossils being found, such as: *Australopithecines*, *Homo erectus*, and *Homo habilis* being found, preserved, studied and analyzed in substantial detail. *Hominini* is defined as the tribe of *Homininae* that only includes humans (*Homo*), chimpanzees (*Pan*), and their extinct ancestors. Members of this tribe are called *hominins* (cf. Hominidae or ‘hominids’). Humans, on the other hand are: of the Kingdom: Animal; Phylum: Chordate; Class: Mammal; Order: Primate;...

; Tribe: hominin. The Tribe hominini describes all the human/ human-line species that have ever evolved (including the extinct ones) which excludes the chimpanzees and gorillas. On the other hand, the corresponding, old terminology until 1980 was ‘hominides’, now hominoides. Among these, *Homo erectus* (and *H. ergaster*) were probably the first hominins to form a hunter gatherer society. Even though *H. erectus* used more sophisticated tools than the previous hominin species, the discovery of the Turkana boy in 1984 has

produced the very surprising evidence that despite the *H. erectus*'s human-like skull and general anatomy, it was disappointingly incapable of producing sounds of the complexity required for either, ancient (< 8,000 BC) or modern, elaborate speech. Therefore, it seems that *H. erectus* may not have topped the super-complexity threshold level towards the next level—that of human consciousness. Thus, *H. sapiens* stands up as the only remaining species which is *unique* in its vocal (speech) and mental (reasoning) abilities.

The Ascent of Man through Social Co-Evolution. The Evolution of the Human Brain. Emergence of Human Elaborate Speech and Consciousness

As stated above, there seems to be little doubt that a 'human-like' brain already was shaping up in *Homo erectus*, *ergastus*, or the Neanderthals but none of these preceding hominides are currently thought to have been able to speak, think, or have a consciousness of their own 'selves'. Following *Homo erectus*, however, some apparent and temporary slowing down of hominin biological evolution may have occurred over the next 2 million years or so for hominides other than *H. sapiens* which according to some anthropologists separated as a species from a common ancestor with *H. ergastus* about 2.2 million years ago.

Therefore, the human brain considered as a biological organ, or subsystem, must have evolved *before* the highly coherent conscious states of the ordered mind of low informational entropy that emerged later through social co-evolution. The human mind is therefore proposed here to be represented by an *ultra-complex* 'system of processes' based on, *but not necessarily reducible to*, the human brain's super-complex level of activities that both enable and entail the emergence of the human 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. It has been suggested (Arbib, 2003)—with some evidence from certain experiments—that mirror neurons may mediate the social interactions leading to coherent, rational and elaborate speech, that thereafter supports the emergence of consciousness. Thus, the emergence of symbolic language with syntax, and the whole social co-evolution and progression towards consciousness may have accelerated only through the *unique* appearance of *H. sapiens*. Other hominin species, such as for example the Neanderthals, did not seem to have been able to catch up with *H. sapiens* and did not evolve beyond very primitive,

small hunter-gatherer groups. Stronger evidence for the appearance of the coherent human speech comes only from the discoveries of the pre-historic Cro-Magnon man some 60,000 years ago. This leads one to assume that a very rapid 'transition' either occurred or began *from super- to ultra-complexity*, from biologically-based evolution to the societally-based 'co-evolution' of human consciousness but only after the birth of *H. sapiens* species. This relatively, very high rate of development through *societal-based 'co-evolution'* in comparison with the rather slow, preceding biological evolution is consistent with consciousness 'co-evolving' rapidly as the result of primitive societal interactions that have acted nevertheless as a powerful, and seemingly essential, 'driving force', 'catalyst' or stimulus. On the other hand, one may expect that the degree of complexity of human primitive societies which supported and promoted the emergence of human consciousness was also significantly higher than those of hominin bands characterized by what one might call individual *hominin 'quasi-consciousness'*. Passing the threshold towards human consciousness and awareness of the human self may have occurred –with any degree of certainty–only with the ascent of the *Cro-Magnon* man which is thought to belong to the modern species of *Homo sapiens sapiens*, (chromosomally descended from the Y haplogroup F/mt haplogroup N populations of the Middle East). This important transition seems to have taken place between 60,000 and 10,000 years ago through the formation of Cro-Magnon, human 'societies'–perhaps consisting of small bands of 25 individuals or so sharing their hunting, stone tools, wooden or stone weapons, a fire, the food, a cave, one large territory, and ultimately reaching human consensus.

After human consciousness fully emerged along with complex social interactions within pre-historic *H. sapiens* tribes, it is likely to have acted as a positive feedback on both the human individual and society development through multiple social interactions, thus leading to an ever increasing complexity of the already ultra-complex system of the first historic human societies appearing perhaps some 10,000 years ago. As in the case of the primordial, the question is raised if *H. sapiens* might have evolved in different places at different times, and is also answered in the negative, thus supporting uniqueness.

The claim is defended here that the emergence of ultra-complexity required the occurrence of '*symmetry breaking*' at several levels of underlying organization, thus leading to the unique *asymmetry* of the human brain–both functional and anatomical; such recurring symmetry breaking may also require a sharp complexity increase in our representations of mathematical-relational structure

of the human brain and also human consciousness. Arguably, such repeated symmetry breaking does result in *layered complexity dynamic patterns* (Baianu and Poli, 2008; Poli, 2006c) in the human mind that appear to be organized in a hierarchical manner. Thus, ‘conscious planes’ and the focus of attention in the human mind are linked to an emergent *context-dependent variable topology* of the human brain, which is most evident during the brain’s developmental stages guided by environmental stimuli such as human/social interactions; the earliest stages of a child’s brain development would be thus greatly influenced by its mother.

Memory and the Emergence of Consciousness

Although the precise nature of human memory is unknown one may hypothesize that it involves processes that induce and regulate, or control the formation of higher levels of memory accessible to consciousness from the culmination of those at lower stages that may not be accessible to the conscious mind. Just as chemical reactions and syntheses engage canonical functors to build up neural networks (Baianu 1972, 1987), and natural transformations between them can enable ‘continuous’ perceptions, the various neural dynamic super-network structures– at increasingly higher levels of complexity– may support the dynamic emergence of the *continuous, coherent and global ‘flow of human consciousness’* as a new, *ultra-complex level of the mind*–as clearly distinct from, but also linked to– the underlying human brain’s localized neurophysiological processes. Clearly, however, consciousness without memory is virtually impossible, but the reverse may not be necessarily true as even an individual neuron retains at least a transient ‘memory’ of the most recent history of its stimuli.

Local-to-Global Relations: A Higher Dimensional Algebra of Hierarchical Space/Time Models in Neurosciences. Higher-Order Relations (HORs) in Neurosciences and Mathematics.

The Greeks devised *the axiomatic method*, but thought of it in a different manner to that we do today. One can imagine that the way Euclid’s Geometry evolved was simply through the delivering of a course covering the established facts of the time. In delivering such a course, it is natural to formalize the starting points, and so arranging a sensible structure. These starting points came to be called *postulates, definitions and axioms*, and they were thought

to deal with real, or even ideal, objects, named points, lines, distance and so on. The modern view, initiated by the discovery of non-Euclidean geometry, is that the words points, lines, etc. should be taken as undefined terms, and that axioms give the *relations* between these. This allows the axioms to apply to many other instances, and has led to the power of modern geometry and algebra. Clarifying the meaning to be ascribed to ‘concept’, ‘percept’, ‘thought’, ‘emotion’, etc., and above all the *relations* between these words, is clearly a fundamental but time-consuming step. Although relations—in their turn—can be, and were, defined in terms of sets, their axiomatic/categorical introduction greatly expands their range of applicability well-beyond that of set-relations. Ultimately, one deals with *relations among relations* and relations of higher order. We are thus considering here the possibility of a novel higher-dimensional algebra approach to spacetime ontology and also to the dynamics of the human brain and the meta-level of the human mind. The human brain is perhaps one of the most complex systems—a part of the human organism which has evolved about two million years ago as a separate species from those of earlier *hominins/hominides*. Linked to this apparently unique evolutionary step—the evolution of the *H. sapiens* species—human consciousness emerged and co-evolved through *social* interactions, elaborate *speech, symbolic communication/language* somewhere between the last 2.2 million and 60,000 years ago. We shall thus consider in our essay the dynamic links between the biological, mental and social levels of reality. The most important claim defended here is that the *ultra-complex* process of processes (or meta-process) usually described as *human consciousness* is correlated with certain functions of fundamentally *asymmetric* structures in the human brain and their corresponding, recursively non-computable dynamics/psychological processes. These are *non-commutative* dynamic patterns of structure-function and can be therefore represented by a Higher Dimensional Algebra of neurons, neuronal (both intra- and inter-) signaling pathways, and especially high-level psychological processes viewed as *non-computable patterns* of linked-super-aggregate processes of processes,...,of still further sub-processes. Therefore, a local-to-global approach to Neural Dynamics and the human brain functions seems to be necessary based upon the essential dynamic relations that occur between the hierarchical layers of neural structures and functions in the brain; the emphasis here will be primarily on the human brain functions/biodynamics. We shall consider certain essential relations in Neurosciences and Mathematics as a potential starting point for a Categorical Ontology of Neurosciences. We conclude

here that contrary to previous philosophical and ontological thinking, *low-level* relations are quite *insufficient* to define or understand consciousness, which is intrinsically based on meta-level, **higher order relations (HORs)**, such as those involved in meta-processes of processes. Rather than being ‘immaterial’, the mind’s meta-level works through such HORs, thus subsuming the lower order relations and processes to do its bidding without any need for either ‘mystical’/‘spiritualistic’ pseudo-explanations or an equally baffling/inconceivable (human) mind-brain split with no physical connections between them. This extremely important theme will be further discussed in the remaining sections.

What is Consciousness?

The problem of how the human mind and brain are related/correlated with each other has indeed many facets, and it can be approached from many different starting points. Herbert Spencer (1898) simply ‘defined’ consciousness as a **relation** between a ‘subject’ and an ‘object’. Over the last twenty five 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. It would seem however that previously not all the ‘right’, or key, questions have been asked about human consciousness. We have seen in the previous subsection that the meta-level question can be answered in the context of consciousness by HORs; Spencer’s vague idea of a simpler, lower relation is insufficient here because of the general/fundamental asymmetry or distinction between ‘object’ and ‘subject’: an external object can often be defined in terms of simpler relations than those of the meta-level of the ‘subject’. On the other hand, when the human mind becomes itself the ‘object’ of study by the ‘subject’, both are characterized by (albeit different) *meta-level* relations, and one also needs to consider then the *next higher order relations* (NHORs) between such meta-level relations. (As in Category Theory, simple morphisms are insufficient; the ‘raison d’ être’ of mathematical categories are the *natural transformations*/functorial morphisms between functors, which as explained above are defined only on the second order meta-level, and thus involve NHORs.) Awareness, or self-consciousness, would then *a fortiori* involve such NHORs. Thus, both consciousness of others and the consciousness of one’s self involve such ultra-complex NHOR’s that are part and parcel of HDA; as we shall see later, the consciousness of others developed first through primitive human, social (tribal) interactions, followed by self-consciousness on the same ultra-complex level of reality. As we shall see, this view is consistent

with both recent philosophical psychology and with sociological enquiries into primitive *H. sapiens* tribes.

Historically, the leading disciplines concerned with the mind have been philosophy and psychology, later joined by behavioral science, cognitive science, logics, biomathematics, neuroscience and neural net computing. In addition, the physics of complex systems and quantum physics have produced stimulating discussions on the nature of consciousness. On the other hand, The study of neural networks and their relation to the operation of single neurons can profit a great deal from complex systems dynamic approaches. There is however no substantial, experimental evidence that quantum processes in the brain are *directly* correlated with any mental activity. One also has to pose here the related important question—as Deacon (1997) did: *why don't animals have language?* Some mammals, for example, show good evidence of intelligence in many other respects, yet fluent, symbolic language with meaning is altogether beyond their abilities. Parrots can learn only to repeat, but not generate meaningful, short sentences. Deacon also examined what it is unique about the human brain that makes it capable of symbolic speech with meaning. Unlike, Mumford (1958) however, Deacon seems to have missed the important point of the rhythmic dances and symbolic rituals in primitive human societies as the turning point for ordering and training the emerging human mind coupled to an orderly society in which reification has most likely played also the key role in the further co-evolution/advancement of the mind, the language and the human society. This latter, ‘magic’ triangle was not considered by Deacon; he only considered the human brain \rightleftharpoons language co-evolution, and did not seem to appreciate the role(s) played by the primitive human societies in the development of the unique human mind and consciousness.

Attempting to define consciousness runs into similar problems to those encountered in attempting to define Life; there is a long list of attributes of human consciousness from which one must decide which ones are the essential ones and which ones are derived from the primary attributes. Human consciousness is *unique*—it does not share its essential attributes with any other species on earth. It is also unique to each human being even though, in this case, certain ‘consensual’/essential attributes do exist, such as, for example, *reification*. We shall return to this concept later in this section.

William James (1958) in “Principles of Psychology” considered consciousness as “*the stream of thought*” that never returns to the same exact ‘state’. Both *continuity* and *irreversibility* are thus claimed as key, defining attributes

of consciousness. We note here that our earlier metaphor for evolution in terms of ‘chains of local (mathematical) procedures’ may be viewed from a different viewpoint in the context of human consciousness—that of chains of ‘local’ thought processes leading to global processes of processes..., thus emerging as a ‘higher dimensional’ stream of consciousness. Moreover, in the monistic—rather than dualist—view of ancient Taoism the individual flow of consciousness and the flow of all life are at every instant of time interpenetrating one another; then, Tao in motion is constantly *reversing* itself, with the result that consciousness is *cyclic*, so that everything is—at some point—without fail changing into its opposite. One can visualize this cyclic patterns of Tao as another realization of the Rosetta biogroupoids that we introduced earlier in a different context—relating the self of others to one’s own self. Furthermore, we can utilize our previous metaphor of ‘chains of local procedures’—which was depicted in Figure 1—to represent here the “flow of all life” (according to Tao for example) not only in biological evolution, but also in the case of the generic local processes involving sensation, perception, logical/‘active’ thinking and/or meditation that are part of the ‘stream of consciousness’ (as described above in dualist terms). There is a significant amount of empirical evidence from image persistence and complementary color tests in perception for the existence of such cyclic patterns as those invoked by Tao and pictorially represented by the Rosetta biogroupoids in Figure 2; this could also provide a precise representation of the ancient Chinese concept of “Wu-wei” —literally ‘inward quietness’—the perpetual changing of the stream of both consciousness and the unconscious into one another/each other. ‘Wu’, in this context, is just awareness with no conceptual thinking. Related teachings by Hui-neng can be interpreted as implying that *“consciousness of what is normally unconscious causes both the unconscious and consciousness to change/become something else than what they were before”*.

The important point made here is that there is a very wide spread of philosophical approaches, ranging from the Western duality to the ‘neutral monistic’ (Spencerian), and the Eastern (monistic) views of Consciousness and Life. On the other hand, neither the Western nor the Eastern approaches discussed here represent the only existing views of human consciousness, or even consciousness in general. The Western ‘science’ of consciousness is divided among several schools of thought: *cognitive psychology*—the mainstream of academic orientation, the *interpretive psychoanalytic tradition*, the ‘*humanistic*’ *movement*, and finally, the *trans-personal psychology* which focuses on practices

