Introduction: Understanding the Origins and Evolution of Living Organisms—The Necessity of Convergence Between Old and New Paradigms

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> For several decades now, the field of evolutionary biology has been envisioned as organized around a profound and fundamental divide: theories relying on strong selective factors and those appealing to weak ones only [...]. This Introduction calls for a new and more consistent paradigm that would make sense of the overall development of evolutionary biology, one based on a realignment of the alliance between all partners pursuing research in this area.
> —*Richard Delisle (2021).*

Abstract

Global warming, the Anthropocene concept (Hamilton C, Nat News 536(7616): 251, 2016), the sixth mass extinction (Ceballos et al., PNAS 114(30):E6089–E6096, 2017), and the rapid progress in astrobiology looking for primitive life forms are raising the awareness of the actors of society toward evolution as the prime reality without which neither the biodiversity nor our species would exist, and our civilizations survive. This discernment leads us to a better understanding of the processes at the origin of the organization of dynamic structures and their reproductive properties, from the smallest cellular unit to the most complex interactions within the organism and then between organisms for the same unit

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of time and space. This awareness also encourages us to discern, over very long geological and cosmic time scales, principles of self-organization of complex systems and generic laws of adaptation and complexification.

Keywords

Life · Evolution · Self-organization · Complexity · Emergence · Memory · Transdisciplinarity · Paradigms · Modeling · Epistemology · Basic and applied research

1.1 Introduction

The transformism formulated by Jean-Baptiste Lamarck in 1801 at the National Museum of Natural History, Paris, and the "natural selection" formulated by Charles Darwin in 1859 were the premises of a general systems theory (Bertalanffy 1968), necessary to understand the self-organized processes with the transmission of acquired characters, but they did not master the physical explanations for abiogenesis or the emergence of the cellular cycle, the beginning of life. Since then, the development of technics and methods of knowledge acquisition, as well as critical thinking, have made it possible to develop numerous models for the distinct levels of organization, thanks to physical, chemical, thermodynamics, and mathematics formulations, each one questioning the analytical processes creating order and stability, but also instabilities with innovative emergences, up to the level of reflexive consciousness and its creative abilities.

The sciences concerned with time (instant, duration, memory), energy (conservation, dissipation), form (mathematics, physical laws), and signals (information) had their precursors with Ernst Haeckel (1834–1919), Henri Bergson (1859–1941), D'Arcy Wentworth Thompson (1860–1948), Alexandre Oparin (1894–1980), John Haldane (1892–1964), Claude Shannon (1916–2001), René Thom (1923–2002), and Ilya Prigogine (1917–2003), among other remarkable theorists of the nineteenth and twentieth centuries. Their research has contributed to the development of new theories and paradigms, such as the deterministic Chaos theory with nonlinear dynamic systems, near or far from equilibrium in living phenomena: dissipative structures and geometric and dynamic fractals. Cybernetics in systems theory developed during the twentieth century and applied to robotics or nonliving natural phenomena help to distinguish the living properties from the artificial intelligence (AI) created by the human mind. AI is cut off from the irreversible processes of biological evolution, which have been going on for 4 billion years. Human biology and cognitive abilities emerge from this, with the trace of this evolution in each cell, that a robot even hybridized with a human cell will never have. A robot is the artificial product of mathematical knowledge and not an innovation of biological evolution. For this reason, a fundamental reflection is necessary to discuss self-organization not only in biological ontogeny, well-accepted, but also in evolutionary gametogenesis, which is much rarer and that raises difficulties at a conceptual level upstream of biological processes. Such difficulties are the processes of emergence, which become explicit with the origins of life.

Those scientific developments have been slowly integrated into the life sciences, to model the morphogenesis, the regulation of homeotic genes in the control of embryogenesis, the phylogenetic stability of ontogenetic geometric trajectories, the emergence processes, etc. The transdisciplinarity developed by Edgar Morin (Rigolot 2020) for half a century is a forthcoming method of the twenty-first century, allowing for the juxtaposition of such different fields of knowledge, in the acceptance of their differences and without mutual exclusion. The origins of life created the evolutionary properties of gametogenesis, and ontogeny and phylogeny are thus associated in recursive loops since phylogeny of gametes has created a great variety of ontogeny.

The volume divided into two parts does not claim to be exhaustive as the diversity of models varies according to the scales studied. Rather, it is meant to be representative of the immense scope of theoretical knowledge in need of attention, requiring a combination of open-mindedness, rigor, reflection, and the search for complementarity between explanatory models. These advances concern all scales of time and space in living systems, from complex molecular interactions and productions (memorized by transmission or innovative) to instinct, intuition, and memory until the self-reflexive consciousness.

The first part brings together chapters devoted to the modern relevance of nineteenth- and twentieth-century theories. The origins of life are analyzed since the abiotic phase with Georgy Levit and Uwe Hossfeld revisiting Ernst Haeckel (1834–1919) (Chap. 2). The authors recall that Charles Darwin never proposed a theory to understand the transition between an abiotic molecular environment and the formation of unicellulars necessary for the credibility of transformism. Ernst Haeckel postulated the spontaneous generations of monera, the precursor of Haldane-Oparin hypothesis, "we reconstruct Haeckel's theory of abiogenesis as a self-organization theory and demonstrate its importance as an early attempt to discuss the origin of life in the post-Darwinian era." In Chap. 3, Adam Scarfe develops the current influence of D'Arcy Thompson (1860–1948) calling in mind his Aristotelian and Kantian thinking patterns and his "physico-mathematical" approach of morphogenesis. The author refers to the Cambrian explosion under the angle of self-organized complex systems, referring to autopoiesis, teleology, and the hypothetical scenario of paleontologist Simon Conway Morris (1988) that "serves as a concrete example of how physico-geometrical factors entrain and/or present constraints that may canalize the behavioral selections of organisms."

Ilya Prigogine (1917–2003) has demonstrated the compatibility between the production of entropy and the spontaneous organization of a dynamical system. These are the dissipative structures far from thermodynamic equilibrium. Since then, the Brussels school of thermodynamics has multiplied the examples of physico-chemical mechanisms whose behaviors resemble those of a living being engaged in an irreversible growth, the time arrow of life fighting against disorganization and death. Nonliving dissipative structures show that physicochemical components can generate complex dynamic organizations ordered in their own space and according to their environment. In Chap. 4, Dilip Kondepudi, James Dixon, and Benjamin De Bari describe the remarkable formation of a worm-like structure capable of displacement. "We will see how some fundamental traits such as end-directed behavior, self-healing, and mutations, can be described in thermodynamic terms, as phenomena in self-organized non-equilibrium systems, called dissipative structures."

The step of life requires properties missing in crystals that of self-memorization. A self-organization could not reproduce itself without its own memorization and the level of energy allowing the emergence of both its complexity and stability. The conditions are at least that of concentration thresholds of "islets" of complexities and energetical and informative interactions in permanent search of equilibrium. Those "islets" were composed of molecules whose properties allowed them to be recognized by other molecules to reproduce their information content, such as RNA and DNA, able to form membranes, produce energy, and synthesize proteins. Abiogenesis is a growing interest thanks to the search for exoplanets and studies of ancient Martian lake deposits with analysis of algal-like biota. "Our morphological and morphometrical investigations (. . .) suggest the presence of remnants of complex algal-like biota, similar to terrestrial procaryotes and/or eukaryotes; possible microorganisms that, based on absolute dating criteria used by other scholars, lived on Mars about 2.12 ± 0.3 Ga ago" (Rizzo et al. 2021).

Understanding the dynamics of self-memorizations still has a long way to go, with the models of dissipative structures and basins of attraction and their attractors. The diversity of unicellulars and their chemical–energetic environments have favored the Cambrian explosion with the emergence of multicellular organisms. Chapter 5 addresses this new threshold in the evolution of life with Valeria Isaeva. The author follows the arrow of negentropic time by comparing the current cyanobacteria (colonial and filamentous prokaryotes) and the metazoans such as sea urchins and analyzes the physical properties (forces) that constrain the morphogenesis of an embryonic body plan (or archetype). The aim is a discussion to identify the correlations between genome and phenotype that determine the body plan, from the molecular scale to the organs, thanks to a multidisciplinary approach introducing forms, energy, and topology according to René Thom (1923–2002). Indeed "the central problem of topology is that of reconstructing the global from the local" (Papadopoulos 2020), Thom's mathematics allows a more precise explanation of self-constrained dynamical systems and the emergence of new body planes coherent on the different spatial and temporal scales of ontogeny.

The first part ends with Chap. 6 on questions raised by Henri Bergson (1859–1941) still relevant: Stephen Robbins comes back to *Creative Evolution* (1907–1911) and "a pivotal discussion, the extreme complexity of instinctual behavior" such as Hymenoptera, which "'knows' precisely the three locations of motor–neuron complexes at which to sting a cricket such that it is paralyzed." These observations require mechanisms of analysis and recognition of signals, therefore previous memories before finding innovative solutions: "Any theory of evolution, be it selection, self-assembly, or self-organization, is equally bound to address not only the origin problem of an organism's structure but the correlated functional problem of instinct." The problem extends to intuition and memory and requires a consensus on the nature of consciousness, understood as a network of exchanges of signals, correctly identified, and therefore previously learned, memorized, and transmitted. Such complex processes have recently been described in the unicellular *Physarum polycephalum* (Broussard et al. 2019).

The second part of the volume presents contemporary models dealing with self-organization. Werner Arber describes harmless intestinal bacteria showing that "biological evolution occurs in microorganisms by consecutive steps of genetic variation [which] can be attributed to a process of self-organization that contributes to the permanent creation of appropriate biological capacities" (Chap. 7). Understanding the evolution of organogenesis under conditions of instability requires the distinction between cybernetics and living organisms affected by unpredictable fluctuations of global equilibrium and the ability of self-reorganization since fertilization. In Chap. 8, Stuart Newman discusses the concept of self-organization since the teleological formulation by Immanuel Kant in "*Critic of Judgement*" (1790) making the distinction between self-organization of non-living systems, living beings (embryogenesis), and the evolutionary processes that changed embryonic development. The concept has progressively replaced the metaphor of genetic program encoded in the DNA inspired by cybernetics in the 1950s. The emergence of new embryogenesis is not the one of a genetic program that assumes knowledge of the end (the final stage).

Life and the evolution of living organisms are not programmed robots, and fluctuations are innovative parameters that cannot predict bifurcations, but the complexity of gametes still misunderstood allows the reorganization of the ontogenetic memory and its hereditary transmission. Andrei Granovitch is engaged in a critical analysis of the synthetic theory (Neo-Darwinian doctrine) in which the notion of a highly integrated metastable system is missing, underlying that concept varies according to the scale of observation and regarding different evolutionary problems, adaptation, or transformation. In this Chap. 9, the author proposes to remove the doubt by unifying the distinct levels in a dynamical and dissipative system or morphoprocess and "a change of the evolutionary paradigm" to an "extended evolutionary synthesis."

Chapter 10 addresses self-organization in the plant kingdom with the concept *of* biosemiotics, or exchanges of signals between animals and their environment, elaborated in the 1930s by the ethologist Jakob von *Uexküll (1864–1944) and his concept of Umwelt* (Uexküll 1982). Marc-Williams Debono confronts the paradigm with his work based on pioneering phytoelectrography experiments. The results demonstrate the essential role of the electrome within the dynamic coupling between the plant and its singular milieu. These new interfaces open a new field of investigation by revisiting the concepts of plant cognition and more generally of bio- or eco-semiotics.

The quantum world is in permanent agitation, but the long durations of cosmogenesis and biogenesis show universal principles of order or of structural stability (Bois 2002), which allow distinguishing a chronology, a continuity between two different instants and not a stochastic dispersion without reference or information stabilized and reproducible. This information refers to nuclear forces and implies exchanges with the electronic orbital as developed in the nuclear–electronic orbital (NEO) approach (Hammer-Schiffer 2021).

Diogo Queiros-Condé, Jean Chaline, and Ivan Brissaud analyze in Chap. 11 a log-periodic law by showing its meaning and its relationship with fractality described by quantifying its length, time, and mass. Relying further on the work of Louis de Broglie's "hidden thermodynamics of the particle," they introduced kinetic–thermal chaining of lineage evolution that allows a fractal and quantum thermodynamic description of log-periodicity, which leads to what could be called a "*quantum thermo-fractality" of the evolution of systems, especially species, astronomical, economic, historical, artistic, and social.*

Chapter 12 presents the embryonic and phylogenetic origins of the vertical organization of our species, of which permanent bipedal locomotion is one of the many postnatal consequences (Anne Dambricourt Malassé). This discovery is replaced in its historical context that of the classification of species with Georges Buffon and Jean-Baptiste de Lamarck with the theory of evolution, two characters who have profoundly marked the naturalist tradition of the National Museum of Natural History (Paris). The discovery highlighted a dynamic architectural and morphogenetic unity between dental occlusion and the orientation of the axial endoskeleton that supports and protects the central nervous system from the brain stem. The process was demonstrated as early as 1987. The phylogeny matches with the curve of the increasing complexity of the brain, but the strengthening occurred according to a succession of long stable periods followed by increasing angulation thresholds. The first stage of the verticality was the *Hominidae* (vs semi-erect *Panidae* and *Pongidae*), the last one being ours (sapiens). The stability of the evolutionary trajectory does not conform to divergent representations of chaotic bifurcations and allowed us to infer memorization properties specific to gametes. The emergence of the operating chains at the threshold of verticality called here the *cerebro-cerebellar Rubicon*, and the symbolic thought would result in the integration of the cerebellum in the loops of cognitive reflection of the brain, necessary for the control of its balance, the stability of the organism, and to anticipate the fall.

Chapter 13 closes the volume with Edgar Morin who has devoted his life looking into human nature and its singularity in the evolution of life, namely the highest evolutionary degree of the reflexive consciousness of the world and oneself. His method is the most extensive transdisciplinary approach that can be conceived, from quantum mechanics to cybernetics, and human societies to ecosystems and reflexive consciousness. His approach is unified by a definition of the complexity that recognizes through the antagonisms, the manifestations of a single reality that assimilates these conflicts by self-organizing recursive loops, and from which new properties emerge. Fundamental research attempts to grasp these properties at the basis of emergence, and the mind, then, notes the ever-widening extent of the unknown of which it is itself a stakeholder, emerging from universal evolutionary creativity. Reflexive self-consciousness cannot objectively abstract from it. Confronted with all scales of its complexity, the awareness of the limits of the consciousness is a recognition of its mystery that returns this last to its links with the evolution of the living complexity and those processes of emergence.

These 13 chapters illustrate the diversity of evolutionary processes according to the space-time scales considered, as well as the relevance of the avant-garde schools of thought during the nineteenth and twentieth centuries in explaining the processes of self-organization. Open to the physics of chemistry, to the thermodynamics, mathematics, then cybernetics, and quantum mechanics, their common denominators are the interactions between particles, atoms, and molecules, ordered into their form according to energy levels, capable of association, source of biochemical innovations with the natural creation of autonomous systems, and consequently a complexification of their environment and interactions. The concept of natural selection has paved the way to their discovery for an even finer approach to the threshold of the emergence of life and the modalities of the self-reproduction of unicellular that imply preexisting self-memorization properties. Those modalities have allowed adaptation to their environmental diversifications, fluctuations, and complexified interactions, and then emergences of complexified organizations into multicellular organisms. The concept of natural selection nevertheless is devoid of these looping processes of integration and self-amplification and does not match the natural logic of the creative complexity with memorization properties. Such living properties may react to the risks of Anthropocene extinction, thanks to innovative creativities, but also to the memory of processes proper to the different lineages, which were useful for their survival in the past.

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