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EDITORIAL

Comprehending the Semiosis of Evolution

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Most contemporary evolutionary biologists consider perception, cognition, and communication just like any other adaptation to the environmental selection pressures. A biosemiotic approach adds an unexpected turn to this Neo-Darwinian logic and focuses not so much on the *evolution of semiosis* as it does on the *semiosis of evolution*. What is meant here, is that evolutionary forces are themselves semiotically constrained and contextualized. The effect of environmental conditions is always mediated by the responses of organisms, who select their developmental pathways and actions based on heritable or memorized past experience and a variety of external and internal signals. In particular, recognition and categorization of objects, learning, and communication (both intraspecific and interspecific) can change the evolutionary fate of lineages. Semiotic selection, an effect of choice upon other species (Maran and Kleisner 2010), active habitat preference (Lindholm 2015), making use of and reinterpreting earlier semiotic structures – known as semiotic co-option (Kleisner 2015), and semiotic scaffolding (Hoffmeyer 2015; Kull 2015), are some further means by which semiosis makes evolution happen.

Semiotic processes are easily recognized in animals that communicate and learn, but it is difficult to find directly analogous processes in organisms without nerves and brains. Molecular biologists are used to talk about information transfer via cell-to-cell communication, DNA replication, RNA or protein synthesis, and signal transduction cascades within cells. However, these informational processes are difficult to compare with perception-related sign processes in animals because information requires interpretation by some agency, and it is not clear where the agency in cells is. In bacterial cells, all molecular processes appear deterministic, with every signal, such as the presence of a nutrient or toxin, launching a pre-defined cascade of responses targeted

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at confronting new conditions. These processes lack an element of learning during the bacterial life span, and thus cannot be compared directly with complex animal and human semiosis, where individual learning plays a decisive role.

The determinism of the molecular clockwork was summarized in the dogma that genes determine the phenotype and not the other way around. As a result, the Modern Synthesis (MS) theory presented evolution as a mechanical process that starts with blind random variation of the genome, and ends with automatic selection of the fittest phenotypes. Although this theory may explain quantitative changes in already existing features, it certainly cannot describe the emergence of new organs or signaling pathways. The main deficiency of such explanations is that the exact correspondence between genotypes and phenotypes is postulated a priori. In other words, MS was built like Euclidean geometry, where questioning the foundational axioms will make the whole system fall, like a house of cards.

The discipline of biosemiotics has generated a new platform for explaining biological evolution. It considers that *evolution is semiosis*, a process of continuous interpretation and re-interpretation of hereditary signs alongside other signs that originate in the environment or the body. According to Hoffmeyer and Emmeche (1991: 144),

> [e]xpressed in the metaphorics of language, the zygote 'reads' the 'book' in its DNA, 'interprets' its meaning as a kind of 'manual' for the construction of a tool for survival, the individual organism. With the help from this tool, the egg cell can hope to continue its cell-line for yet another generation on the condition, of course, that the tool is sufficiently well-made to survive and reproduce in its *ecological niche*. Implied in this view is a very important but widely overlooked fact: *The DNA does not specify the zygote, the zygote must be there beforehand*."

This view of evolution differs radically from widely accepted ideas in biology and science in general; and more explanations are therefore necessary. The first and main challenge is to define agency within living cells and demonstrate that this agency supports creative interpretation of signs. Molecular processes in cells are not deterministic but goal-directed. They are prone to errors, but most errors and faulty regulations are detected and become corrected or compensated in many different ways to minimize adverse effects on cellular functions, survival, and reproduction (Bruni 2008). As for learning capacity, this is not always seen within a single cell cycle; but learning certainly occurs in multi-generational lineages of reproducing cells, as exemplified by the, on our human timescale, rapid development of resistance to antibiotics in bacteria. Although multi-generational learning is supported by differential reproduction of genotypes, the evolution involved does not depend on a specific mutation happening. Any mutation out of hundreds could work equally well, if only it is interpreted properly in the context of cellular organization and helps to resolve the problem (Sharov 2014). Moreover, cells may initially utilize epigenetic memory to modify their functions, which may become enhanced later, genetically. Thus, living cells are agents capable of inventing new ways of living; in other words, they possess a degree of *semiotic freedom* (Hoffmeyer 2014).

The second problem in understanding the semiosis of evolution is the need to explain the emergence of interpretation capacity in primordial systems at the origin of life. Third, a scale of sophistication in semiotic systems has to be outlined, spanning from simple molecular signaling to creative cognition in humans and some animals. Fourth, we need to explain the remarkable consistency of phenotypic traits (i.e., heritability) in the absence of genetic determinism. The fifth challenge is to explain adaptability, which is the capacity to generate new solutions to problems of life in critical conditions. And the sixth problem is to describe the process of integration of living systems into higher-level super-systems or super-organisms. All these issues need to be addressed by biosemiotics, by convincingly identifying and describing the semiotic component at the different levels of biological organization. These six challenges are extensively discussed in this issue of Biosemiotics.

The paper by Hoffmeyer and Stjernfelt elucidates steps in the evolution of semiotic competence in living organisms, which are: molecular recognition, prokaryote-eukaryote transformation, division of labor in multicellular organisms, emergence of phenotypic plasticity, sense perception, behavioral choice, active information gathering, collaboration, deception, learning and social intelligence, sentience, and consciousness. The initial step (molecular recognition) can be described in terms of physical and chemical relations, but yet qualifies for being called "semiotic" because it is embedded in the context of complex cellular processes, where physics and chemistry are only means for reaching the organism's goals. This approach is based on the fundamental assumption of unity between life and semiosis: "life, semiosis, and agency make up one conceptual complex which, once realized in the wild, constitutes the basis of ongoing sophistication during evolution". In contrast to semiosis, perception is viewed as a distinctively high-level activity that is constituted by a multitude of smaller-scale semiotic interactions. Sense perception is not limited to mental knowledge, but also includes bodily knowledge, which occurs even in brainless animals. The authors reject the idea that semiotic evolution started from iconic relations and then progressed into indexial and symbolic relations, because, in their view, all "semiotic processes typically include both iconic, indexical, and symbolic aspects". They further argue that "even very simple sign processes [are always] truth related; [and] that the ability of informing an organism about aspects of environmental states-of-affairs, such as they truly are, forms the most basic *raison-d'ê tre* for signs in the first place." In other words, a kind of propositional logic is claimed to be used by organisms from the very beginning of agency and life.

The paper by Giorgi and Bruni is focused on germ cells as minimal interpreters of hereditary signs that link subsequent generations of organisms into lineages. The authors summarize the properties and capacities of germ cells that give them semiotic agency. Namely, germ cells store a self-descriptive program and accumulate resources and molecular machinery that are necessary for interpretation of the genome and for self-construction. Biological evolution, then, is driven not just by changes in the genome, but also by changes in interpretation and in self-construction networks. These are not fully prescribed by the genome, and operate in a context-dependent way. In particular, germ cells modify their semiotic competence via interaction with the parental organism during cell migration and maturation. As a result, "germ cells come to constitute a channel of communication between the developing organism and the species[‘] genomic memory". Development of embryos is regulated by communication between cells and organs, as well as by sensorial input from the environment. Structural and functional novelty can therefore emerge epigenetically.

Gilbert presents the process of embryo development as context-dependent interpretation of developmental signs. The context includes the previous history of the responding cell, and external factors. Cells therefore respond differently to the same signal (e.g. hormone or growth factor): some cells proliferate, some cells differentiate, and other cells die. In addition, organisms have evolved to alter their development in response to differences in temperature, diet, the presence of predators, or the presence of competitors. This plasticity of development allows organisms to generate a wide range of phenotypes on the basis of the same genotype. Some organisms have also evolved to expect developmental signals from symbionts, and these organisms develop abnormally if the symbiont signals are not present. These examples show that embryo development is a regulatory hub that supports both the heritability and the adaptability of the phenotype via integration of genetic, physiological, and ecological channels of communication.

The papers by Kull and Markoš respectively discuss the semiotic nature of biological species from different points of view. Kull argues that a species is a self-defining entity integrated by the capacity of organisms to recognize each other as potential mating partners. The logical category of species is based on "family resemblance", as defined by Wittgenstein (membership in a category due to overlapping similarities), rather than on shared fulfillment of a common criterion. In contrast to Mayr, who viewed interbreeding as a *criterion* of species, Kull views mate recognition as a semiotic process that *holds the species together* in practice and in actual fact. Further, Kull develops a model where the extent of heritable variation in a population is controlled by the width of the *recognition window* that is accepted by individuals. Organisms mate successfully only if the difference in their features does not exceed the width of the recognition window. Highly diverse populations either reduce their variation in evolution via low mating capacity of strongly deviating individuals, or they segregate into multiple phenotypically distinct groups with preferential inter-group mating. This model explains sympatric speciation without inferring additional factors such as separation of niches. It also explains character displacement in the areas of species coexistence.

Markoš develops an idea of Rappaport and Flegr, namely that the long-term evolution of biological species is isomorphic to the historical change of human cultures. Both processes are deeply rooted in the history, which is materialized in memory, experience, and internal dynamics. Both evolutionary and cultural changes result from continuous reinterpretation of conservative digital texts as well as from changes in the interpretative process itself. This semiotic process results in a continuous inventing of new ways of living.

The paper by Turner is focused on the evolution of super-organisms, taking the termite colony as an example. The termite mound is a complex structure which has many important functions for the life of the colony. It is the surrounding environment for termite workers who inhabit, interpret, and rebuild it, and is the hereditary legacy of past generations of workers. Because abandoned mounds can be re-colonized, their structure provides an additional channel of long-term heredity. Turner describes the termite nest as a system with "swarm cognition", where individual workers respond to chemical signs such as CO_2 perturbations and recruit other workers for rebuilding the nest if necessary. The process of mound repair is regulated by feedback signals from the circulating air in the nest. Mound repair reveals a complex decision-making system at work in the termite colony. A mound, with its higher-level adaptations, can be understood as the body of a super-organism, and its repair process resembles wound healing.

Sharov describes biological evolution as preservation, advance, and emergence of functional information in natural agents (organisms, cells, molecular agents, populations, and symbiotic consortia). He defines functional information as a network of signs (including memory, internal messengers, and external signs) that are used by agents to preserve and regulate their functions. Organisms preserve functional information via active processes of copying [1] and construction: the digital components are copied, whereas interpreting subagents, scaffolds, tools, and resources are constructed. The advance of functional information includes improvement and combinatorial modification of already existing functions. Selective reproduction of agents at any level of a hierarchy helps to improve functions over time in varying environments. Under stress, agents can produce adaptive phenotypes very fast by utilizing complex regulatory pathways, which have been developed in a long-term evolution that intermittently included crisis events. Each new feature can then be tested in the context of a different body part or stage in a life cycle. Finally, the emergence of new functions is based on the reinterpretation of already existing information. These include cases of preadaptation/exaptation and the Baldwin effect. The major steps in the progressive evolution of functional information were *protosemiosis*, where signs correspond directly to actions, and *eusemiosis*, where agents associate signs with objects. Sharov assumes that primitive organisms bear no internal representations of objects; this capacity, he holds, emerged only with the appearance of eusemiosis. The notion of protosemiosis helps to explain the origin of life, because eusemiotic organisms are too complex to emerge spontaneously from non-living matter.

The paper by Deacon shifts the discussion on evolution from traditional terms, such as replication, mutation, and selective retention of genes, to the more basic living functions. These include the generation and reproduction of organic forms via self-organizing and self-assembling molecular and cellular processes. These processes, in turn, require specific constraints and boundary conditions that need to be produced reciprocally by other self-organizing processes. Deacon describes how two or more self-organizing processes can be coupled so that they generate each other's supportive boundary conditions. This coupling is a higher-order constraint, which constitutes a sign vehicle that is "interpreted" when it helps to make the form of a new physical system equipped with the same future competence. This semiotic-dynamical relation constitutes Darwin's "several powers" that make evolution possible.

In recent years, the attention paid to evolution in biosemiotics has increased considerably (see e.g. Barbieri 2008; Markoš et al. 2009; Deacon et al. 2012). Comprehending the relationships between evolution, signs and life is essential for developing the theoretical foundations of the biosemiotic paradigm. It also assists biosemiotics in finding its position among the biological sciences. The emergence of evo-devo theory, the extended synthesis, epigenetic studies and other like-minded schools of thought in biology has produced fertile soil for future discussions. Our understanding evolves.

[1] Specific features of copying are recursion and digital-type stability at the level of components (e.g., DNA monomers).

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