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COMMENTARY

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Towards a Biosemiotic Theory of Evolution

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Abstract

The target article by Denis Noble is an excellent overview of the illusions of the Modern Synthesis that still remains in textbooks despite of the recent criticism. Overcoming these illusions shows the active role of organisms in the evolutionary process and accounts for additional mechanisms such as plasticity of embryo development, epigenetic heredity, multilevel selection, Baldwin effect, and niche construction, which are components of the Extended Evolutionary Synthesis. Adding these mechanisms is certainly an important step forward, but I argue that it is not sufficient for building a new theory of evolution. What is missing is a clear understanding of such notions as agency, autonomy, semiosis, interpretation, and goal-directedness, which so far belong to the humanities and have not been applied seriously in science. Organisms are autonomous and goal-directed semiotic agents capable of interpreting hereditary signs and making meaningful models of their environment. Evolutionary biology needs a semiotic vocabulary to talk about higher level functions in organisms, where specific molecules and mechanisms are only means for integrating functions over the life cycle and adapting to the environment without compromising organism integrity and identity. Such a vocabulary is being developed in biosemiotics; thus, I expect the emergence of a biosemiotic theory of evolution.

Keywords Semiotic agency · Autonomy · Genetic accommodation · Interpretation · Evolution

Illusions of the Modern Synthesis (MS) in evolution, according to Denis Noble, include natural selection, the Weismann barrier, the rejection of Darwin's gemmules, and the central dogma of molecular biology. The first of them means that the transfer of genetic information between generations is controlled by a passive environmental filter (i.e., natural selection) and not by the activity of organisms themselves. The second

Commentary to the target article by Denis Noble "The Illusions of the Modern Synthesis"

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assumption is that acquired traits are not heritable. The third assumption is that somatic cells cannot affect the germ line cells. Finally, the fourth assumption is that information is transferred in one direction only: from genes (DNA) to RNA, and then to proteins. Noble shows that all these assumptions are either misleading or plainly wrong. In addition, the theory of evolution needs to account for such mechanisms as multilevel selection, Baldwins effect, epigenetic heredity, niche construction, and symbiogenesis.

The contemporary theory of evolution, known as Extended Evolutionary Synthesis (Pigliucci & Müller, 2010), incorporates the mechanisms that have been neglected or denied by the MS. However this theory stays mostly within the traditional paradigm of mechanistic biology and cannot account for creativity in adaptive evolution. It is necessary to recognize spontaneous activities of organisms, which is more than physical causation. Organisms have freedom to respond to signs in the genome, cell components, neural networks, and the environment. To describe emergent organism functions we need such notions as agency, autonomy, sign, semiosis, and goal-directedness (Tønnessen, 2015; Sharov, 2018), which so far belong to the humanities and have not been used seriously in science. These notions are being developed in biosemiotics, which integrates biology with semiotics, a theory of meaning and signification in living systems (Hoffmeyer, 2008; Barbieri, 2008; Sharov et al., 2015).

From the start, biosemiotics was considered more than interdisciplinarity because it targets revisiting central theoretical constructs in both biology and semiotics. In particular, both biology and semiotics require a developed notion of semiotic agency (Sharov et al., 2015). Examples of semiotic agents are all living organisms, organs, tissues, individual cells, organelles, and functional macromolecules and molecular complexes. Super-organism agents are represented by functional groups of organisms (e.g., families, colonies, symbiotic consortia, populations, species, human organizations, businesses, and nations). In addition, autonomous or semi-autonomous human artifacts (e.g., thermostats, cars, computers, and robots) are human-dependent agents that are analogues of cell organelles or functional macromolecules (Sharov, 2018). Cells produce their subagents to perform various functions, such as metabolism, copying nucleic acids, and synthesizing proteins. Similarly, humans produce artifacts (cars, computers, printers, and robots) to support their functions.

Semiotic agents are defined as autonomous goal-directed systems capable of semiosis (i.e., interpreting and producing signs) (Tønnessen, 2015; Sharov, 2010). Both, autonomy (self-governing) and goal-directedness are based on semiosis because they require such sign processes as heredity, memory, sensing, and regulation of activities. Except primordial systems at the origin of life, all agents are produced by one or several parental agents (Sharov, 2010). The rule that agents are produced by other agents is also applicable to subagents of organisms. For example, new cells in multicellular organisms always emerge via division of parental cells of the same kind.

Most agents are process-dependent self-organized systems, and these features are shared by crystals, tornados, and fires. However, self-organization and autocatalysis are not sufficient for a system to become an agent (Sharov, 2016). In contrast to tornados and flames, agents change their far-from-equilibrium state by modulating the flow of energy, and enable descendent agents to repeat the same change later on. As a result, the trajectory of agent state becomes a heritable habit or function. Heredity and control of the far-from-equilibrium state requires construction and interpretation of signs. Thus, agents are semiotic systems (Sharov, 2018).

Evolution of living organisms followed through a sequence of major transitions of their semiotic organization. Prokaryotes are signal-driven protosemiotic agents which are not capable of perceiving outside objects (Sharov & Vehkavaara, 2015). They live in a solipsistic world with no distinct pathway for interpreting signals of internal and external origin. The capacity to perceive and categorize objects apparently emerged with the origin of eukaryotic cells, which can crawl over surfaces, and recognize and ingest food particles via phagocytosis. This level of semiotic development is called eusemiosis (Ibid.). The following major transitions include the origin of multicellularity, embryo development, and the emergence of nervous system in animals. Habits of multicellular organisms became more complex in evolution. In plants and fungi, habits are based mostly on differential growth and cell differentiation, whereas in animals they include various movements. Primitive animals use innate movement habits which self-organize based on heritable body parts with or without help from the nervous system. Development of neural networks is likely programmed genetically via chemical sensing that directs the growth of projections from cell body of neurons, and the establishment of synapses between neurons. Higher animals develop cognition, which enormously increases the plasticity of the nervous system and supports associative learning (Ginsburg & Jablonka, 2019). Humans developed symbolic languages, rational thinking, abstract logic, and educational techniques, which all promoted accumulation of knowledge and its cultural dissemination and propagation.

Biosemiotic understanding of evolution starts with acknowledging *the essential role of semiotic agency in heredity, variation, and natural selection.*[1] The MS assumes that genes determine proteins and their role in metabolism and development of phenotype. However, genes do not determine phenotype. The sequence of nucleotides in a gene is a string of abstract coding units – triplets of nucleotides – which need to be interpreted (Sharov, 2014). There is no physical law that associates these units with aminoacids, and such association is not encoded in the genome. Instead, it is the job of intra-cellular subagents (including ribosomes) to interpret a triplet as a command to add specific aminoacid to the elongating polypeptide chain. Moreover, genes determine neither the 3-dimensional folding nor the function of the protein. These features are established by a collective action of many subagents within a cell. Although the construction of these subagents is encoded in the genome in an abstract way, the cell needs actual physical sub-agents to interpret genomic signs and perform cellular functions (Ibid.). The phenotype of the whole organism is constructed via embryo development which includes multiplication, differentiation, collective movement, and communication of cells. The capacity of cells to interpret the genome in the context of embryo location and environmental factors is an emergent property which is sustained epigenetically. Thus, the transfer of phenotypic traits between generations requires an interaction between two hereditary channels: informational and agential (Ibid.).

The concept of two-channel heredity explains how organisms preserve their morphology and functions across generations despite the fact that genes do not determine the phenotype. It has been envisioned by Hoffmeyer and Emmeche (1991: 127) in their paper on code duality, where they claim that life "needs at least two codes: one *code for action* (behaviour) and one *code for memory* – the first of these codes necessarily must be analog, and the second very probably must be digital" (emphasis original).

The idea of neo-Darwinism that mutations are the primary causes of evolutionary change is not supported by facts. There is no evidence of mutations that appear beneficial in natural undisturbed conditions. Such adaptive mutation would require at least one precise nucleotide substitution. Considering that the rate of mutations is very low – only $2.2*10^{-9}$ per base per year in mammals (Kumar & Subramanian, 2002), it would take thousands of years for an adaptive mutation to appear. However, time to adaptation arrival is critical; if an adaptive mutation arrives after a thousand years of waiting it's too late because either the population gets extinct or conditions change, and the arrived trait would no longer be adaptive.

In contrast, biosemiotics considers mutations as disturbances that disrupt normal functions of cells and organisms. However, some mutations are creatively interpreted by cells and their subagents based on their historical experience, encoded genetically and epigenetically. Thus, mutations are not primary causes of adaptation, but being interpreted by subagents, they indirectly facilitate robustness, plasticity, and genetic assimilation.

The role of natural selection also needs to be reevaluated in the light of biosemiotics. Natural selection, which is differential survival and reproduction of organisms, can affect population numbers of individuals with different genotypes or phenotypes, but acting alone, it cannot generate new adaptive traits. But natural selection can facilitate adaptive evolution indirectly if it interacts with agential capacities of organisms and their components. Semiotic agents are endowed by evolution and learning with certain level of creativity, known as "semiotic freedom" (Hoffmeyer, 1996). Each part (e.g., organ, tissue, cell, protein complex) has many potential functions or affordances including those that have never been used before. It is well known that human artifacts can perform functions they were not designed for. A screwdriver, designed to rotate a screw, can also be used as a measuring device, ruler, lever, or weapon. Thus, it is conceivable that organisms use their parts in unusual ways.

It appears that natural selection can facilitate adaptive changes in organisms indirectly by increasing the numbers of organisms with stronger adaptation capacities/affordances. In other words, the current level of adaptation in organisms (it can be measured by relative fitness) is a good predictor of the future adaptive potential in the lineage. Thus, natural selection supports future adaptations by increasing the abundance of those organisms that are more likely to produce further adaptations in their progeny. Initial adaptative change is usually not heritable but it can modify epigenetic processes to support similar changes in the progeny. After several repeats, a new adaptive function often becomes supported by epigenetic memory.

Although mutations are not the primary causes of adaptation, they are needed for stabilizing adaptive traits in evolving lineages, an effect known as genetic accommodation (West-Eberhard, 2003). If new adaptations are not reinforced genetically, they are not stable. Thus, genetic change via natural selection is needed to increase the heritability of new adaptations. This requires non-specific random mutations (as explained below), which occur every generation, and thus there is no long waiting time. The same epigenetic state of a cell can be achieved in many alternative ways mediated by various mutations. For example, the amount of protein produced by a gene can be changed by modifying transcription factor binding, chromatin modifications, alternative splicing, mRNA degradation rates, protein folding, interference through protein-protein interactions, protein modifications and degradation, and so on. As a result, there are thousands of genome locations where mutations can change the expression of a gene. The idea of the phenotypic origin of adaptations followed by genetic accommodation was formulated as “genes are followers not leaders in evolution” (West-Eberhard, 2003: 20).

This sketch of a biosemiotic approach to evolution emphasizes the active role of organisms and their subagents in generating adaptive changes that become heritable over time. Biosemiotics does not contradict mechanistic approaches in biology, in fact, interpretation processes at the lowest functional level are operated by molecular mechanisms. The main advantage of the biosemiotics framework is that it leads scientific explanation *beyond mechanisms* – to those complex processes, where mechanisms are easily redirected or replaced based on the context of signs. I believe that notions of semiosis and agency will become incorporated into the theory of evolution and then mechanisms discussed by Denis Noble will be evaluated from the position of biosemiotics.

Notes

1. Although the term “natural selection” has been abused in MS, I prefer keeping it after separating from the metaphor of “passive sieve”.

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