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The symbiotic phenomenon in the evolutive context

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Abstract

We live in a symbiotic world, and one of the key characteristics of the biological systems is to establish associations and connections with other organisms. This manifestation is one of life's main characteristics and its diversity. In a way, life has not established itself or developed to exist alone. Since the introduction of the symbiosis concept by Anton de Bary in 1878 and the new theoretical formulation on the field – symbiogenesis – by Constantin Mereschkowsky, in 1909, this domain of science has been a place of controversy and discussion. The symbiogenesis concept was a landmark for the development of further studies on biology and evolution, that the most remarkable example was the development of the Serial Endosymbiotic Theory (SET) by Lynn Margulis in 1967. Throughout the twentieth century, biologists have generally considered symbiosis as a curiosity. Its study fell largely outside the conceptual and technical framework of biology, and namely of neo-Darwinism. However, most living forms have symbiotic relationships with microorganisms, and so symbiosis seems to play a very important role in the origin, organization and life evolution. In this sense, evolutionary changes can be explained by an integrated and synergistic cooperation between organisms, in which symbiosis acts, not as an exception, but as the dominant rule in nature. Without denying many of the Darwinist principles, the worse thing we could do within the study of the process of evolution would be to mix up or limit evolution to the Darwinist or neo-Darwinist perspective. Other evolutionist approaches exist and it is necessary for them to be deepened and discussed within biological and social sciences. In this sense, we would like to bring a set of principles and data that could be integrated in a Symbiogenic Theory of Evolution that could contribute towards a new epistemological approach of the symbiotic phenomenon in the evolutive context. This, in our

point of view, could be the beginning of a new paradigm in science that rests almost unexplored.

Introduction

Symbiosis has frequently been considered as a biological curiosity, and not as a solid scientific concept, namely in the scope of evolution. Nevertheless, symbiosis is a widespread phenomenon, with great biological relevance, that has a fundamental role in the origin, organization and evolution of life. Despite this fact, it has not received proper attention either from the scientific community, or from the university and high school curricula. This situation reflects itself in an interpretative reality of the biological evolution, based on two classical scientific theories: Darwinism and neo-Darwinism, the only ones that, traditionally, try to explain this process and where symbiosis is not adequately understood nor handled. For traditional evolutionist authors, symbiosis is nothing more than a residual aspect of the evolution problem, and its study fell largely outside the conceptual and traditional framework of biology, and namely of neo-Darwinism. Recent data, however, point to the opposite direction, showing that symbiosis is a factor of evolutive change, which cannot be included or adequately explained by the Theory of Modern Synthesis.

The symbiotic relations appear as dynamic relations that are not limited to the classical concepts of interspecific relations. Three main theoretical concepts are important to consider in the new approach on symbiogenic evolution. The first one is *symbiosis*, defined as "the living together of unlike named organisms", and introduced in 1878 by the German biologist Anton de Bary (De Bary, 1878). Associated with this concept, is *symbiogenesis*, developed by the Russian biologist Constantin Mereschkowsky in 1909, as "the origin of organisms through the combination or association of two or more beings that enter in symbiosis", and based on the role of cyanobacteria in the origin of chloroplasts in plants (Mereschkowsky, 1905, 1909). The third concept, presented by the American biologist Lynn Margulis in 1967 – the *Serial Endosymbiotic Theory* (SET) –, was a remarkable contribution to the rehabilitation and development of the symbiogenic ideas applied to the cellular world, explaining in an elegant way the transition bridge between the prokaryotic and the eukaryotic levels of the biological organization (Sagan, 1967). This reality demonstrates the need for conceptual changes in the traditional vision that has been passed on to the organism's structures and functions, whose profound consequences for the biological, medical and social domain have remained practically unchanged.

Questions for the 21st century

One of the main concepts Charles Darwin contributed to change radically was the idea of the constancy of species, which allowed for the development of the theory of common descent and also challenged the natural theology principles that had ruled natural science for centuries. For natural theology, the order in nature was the convincing proof of a supreme being that could explain the harmony and the purpose of the creation. For this reason, we can understand the difficulties and the resistance which these new ideas were met when they were introduced to the general society (Mayr, 1982).

Evolution is a complementary process of divergence and integration. Divergence in the production of new life forms, and integration when entities join to form new ones (Sapp, 2003). In this context, evolution is a dynamic process that evolves and responds not in the sense of perfection or progress, but in the sense of adaptation to new conditions. We can ask in what way symbiosis can be involved or associated to evolution. In our point of view, symbiosis is the way through which the acquisition of new genomes and new metabolic capacities occur, making possible the evolutive construction of biological organisms. As it was referred by Joshua Lederberg (Lederberg, 1952), endosymbiosis is comparable to hybridization, allowing for the introduction of philogenetically distinct genomes into associations of organisms with its own characteristics. We believe that it is held to have also played a central role in the pre-biotic evolution, in the emergency and evolution of eukaryotes, in the origin of land plants, and in a myriad of adaptive evolutionary innovations (Sapp, 2003; Carrapiço et al., 2007). It is at the basis of important ecosystems from deep-sea vents to the most biodiverse communities on Earth, such as rainforests and coral reefs (Sapp, 2003, 2004). The development of these new evolutive characteristics by the associated organisms is inconsistent with the main tenets of neo-Darwinism, but represents, in our opinion, the main rule in nature, and the main evolutionary mechanism in the establishment and maintenance of biomes, as well as the foundation of biodiversity.

Questions such as the following ones should have a clear and scientific answer and should not be put aside simply because they do not correspond to the mainstream discourse. Why is the symbiotic phenomenon so widespread in nature? Why and how does it perpetuate itself through time? What is its degree of importance for the intervening organisms? Why do living beings present structural, physiological and/or behavioural changes so well adapted to this relationship? What is the role of the symbiosis in the evolutionary process? In this sense, symbiogenesis should be understood as an evolutive mechanism and symbiosis as the vehicle, through which that mechanism unfolds (Chapman and Margulis, 1998; Carrapiço et al., 2007). This fact represents a point of view different from that sustained by the Modern Synthesis, and opens new approaches for new models to understand the evolutive process.

Symbiogenic revolution

One of the main characteristics of biological systems is the establishment of associations and connections with other organisms, thereby creating diversity and varied combinations of its forms, which are prodigious novelty generators. Thus, once established, life did not stop evolving or remained a single form. In this context, symbiosis is an important factor in generating evolutionary change, giving rise rather suddenly to evolutionary novelty, based on the creation of new metabolic, anatomical and organismal characteristics (Margulis and Fester, 1991). Symbiosis is also a robust phenomenon, offering many opportunities for the occupation of ecological niches otherwise unviable, and is highly relevant for survival purposes. One good example can be found in the organisms living in the hydrothermal vents ecosystems, which survive and evolve based on symbiotic associations (Sapp, 2003; Carrapiço et al., 2007). Symbiogenesis creates new important selection units (symbiomes) arising through the integration of varied parts followed by progressive differentiation of the whole, providing a competitive advantage that goes beyond traditional neo-Darwinian selection. In this theory, evolution is a gradual process, essentially consisting of a natural selection conducted on minimal phenotypical variations, which are a product of genetic and chromosome exchange. However, we think that natural selection acts not only in the minimal phenotypical variations, but also in variations resulting from different symbiotic adaptations.

Actually, and specially since 1859, evolution has been considered as the fundamental concept and organizing factor of modern Biology, as well as its structural pillar. Without denying many of the Darwinian principles, the worse thing we could do within the study of the process of evolution would be to mix up or limit evolution to the Darwinist or neo-Darwinist perspective. These points of view are mainly used to explain the biological evolution, contributing to the generalized belief that evolution could be explained by these two scientific theories. This led to the erroneous idea that Darwinism, or neo-Darwinism, are synonyms of biological evolution. Other evolutionary approaches exist and it is necessary for them to be deepened and discussed within biological sciences.

In this sense, we would like to bring to your attention a set of principles and data that could be integrated in a Symbiogenic Theory of Evolution. This theory includes Darwinist principles, but does not limit itself to the latter in its attempt to promote and explain the development, organization and evolution of the biological world. This approach does not present the cooperative perspective as the only leitmotif in its explanation of the biologic phenomena. As it was mentioned previously, considering symbiogenesis as an evolutive mechanism implies that evolution should be understood in a broader context, where symbiosis plays an essential role in the organization and structuring of the biological world. Consequently, the concept of symbiosis does not imply a strict compartimentation of interspecific relationships, thus it should be regarded as a continuous and dynamic process of different relations, such as mutualism, parasitism and commensalism. In this process, the acquisition of new genes through lateral transfer plays an important role. The same applies to the development of new metabolic capacities acquired by an organism from other organisms associated to it. The existence of mutual benefit should, however, not be considered, as the plus or common denominator of the symbiotic process, following the idea presented by Dubos and Kessler, in 1963, during the 1st International Conference on Symbiosis, in London, "the nutritional effects of symbiosis are not its most interesting manifestation. More remarkable is the fact that many symbiotic systems produce substances and structures that neither one of the two components produces when growing alone" (Dubos and Kessler, 1963). This new approach cites the central role of interactions, in which a new entity emerges through incorporation of one existing entity into another. The theory involves horizontal mergers, which can be rapid, and are usually discontinuous, creating permanent and irreversible changes, the basis of evolutive novelty. The new entity can then evolve vertically, but this is always preceded by a horizontal merger between two or more entities.

In ecological terms, each plant and animal must be considered as "superorganism"-symbiome, which includes their own genes, those of cellular organelles (mitochondria and, or chloroplasts), as well as the genetic information of symbiont bacteria and virus living within the organism (Sapp, 2003). This is also important to be considered when we look to the fitness and how we validate it in terms of symbiotic prevalence. It goes beyond the reproductive view of each individual and reinforces the ecological behaviour of the symbiotic system as a whole (Bouchard, 2007). However, for many biologists, symbiosis is still considered as an exception among biological phenomena and not as a common rule in nature. The approach of the traditional evolutionist authors, in relation to this phenomenon, consists in considering it as nothing more than a residual aspect of the evolution problem. Recent data, however, point to the exact opposite direction, demonstrating that symbiosis is a factor of evolutive change, which cannot easily be included and explained in the framework of the neo-Darwinism theory, and moves the studies on evolution into the context of a post neo-Darwinian perspective (Carrapiço, 2010).

Final Remarks

The understanding of the natural world is an important goal for mankind. For many scientists, the comprehension of nature is based on the assumption that "nature is competitive, and cooperation is a strange case that needs to be explained" (Speidel, 2000). In this article we have presented several ideas about symbiosis in evolution, involving concepts that are not commonly taught or considered in current biology, but must be discussed in the domain of the philosophy of science. Evolution is usually taught as the result of mutations and genetic recombinations combined with natural selection, but most living forms have symbiotic relationships with microorganisms, and so symbiogenesis seems to play a very important role in the origin and life evolution. Symbiosis is an important support for the acquisition of new genomes and new metabolic capacities that drives living forms evolution. In this sense, evolutionary changes can be explained by an integrated synergistic cooperation between organisms, in which symbiosis acts, not as an exception, but rather as the rule in nature. Beginning with the eukaryotic cell formation, symbiogenesis appears to be the main evolutionary mechanism in the establishment and maintenance of biomes, as well as the foundation of biodiversity, based on rather suddenly evolutionary novelty, which challenges the Darwinian gradualism.

The symbiogenic concept allows for an innovative and broader approach to evolution, given that symbiosis is a fundamental rule in the establishment and development of life on Earth and elsewhere (Carrapiço et al., 2007). It implies a new paradigm for the comprehension of chemical and biological evolution. This change can be explained by a synergistic integrated cooperation between organisms, in which symbiosis acts, not as an exception, but rather as a rule in nature. We believe that competition and cooperation can co-exist in the same scenario of evolution, and probably take place in discontinuous bursts of activity, depending on the internal and external conditions that drive evolution. It means that the same population can evolve using competitive and/or cooperative processes during the time and space of a hypercycle evolutive scenario (Carrapiço et al., 2007). Thus, a series of synergistic and cooperative effects produced a wide source of creativity and functional advantages that pushed the emergence of complex and functionally integrated biological systems through the evolution of self-organization, self-catalysis and higher complexity.

These principles can be applied to the life on Earth and beyond, following the idea that the general mechanisms governing the evolutionary principles must be universal, surpassing the terrestrial dimension and projecting themselves in the universe. The biological organisms resulting from this process acquire characteristics inherent to the ecosystems where they are established and develop.

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