Biosemiotics as an Alternative Paradigm for Biology: A Rational Reconstruction of the History of Biosemiotics*

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Abstract: Biosemiotics is dedicated to studying semiosis, meaning, information and communication in nature. As a paradigm shift, it treats life processes as meaning-making informational processes rather than mechanical ones. It believes that life processes can be fruitfully explained within semiotic framework. It arose from two anomalies implied by neo-Darwinian biology. The anomalies may lead the current predominant paradigm of biology to crisis. Biosemiotics proposed a semiotic response to the crisis. With Peircean semiotics, biosemiotics re-conceptualises biology through redefining facts, problems and methods of biology. There are indications that biosemiotics has turned to the phase of normal science. However, it must overcome both internal and external challenges to prosper further.

Keywords: biosemiotics, semiosis, neo-Darwinian biology, paradigm

生物符号学作为生物学的另一种范式——生物符号学史的理性建构

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摘　要： 生物符号学致力于研究自然中的符号过程、意义、信息与交流。生物符号学作为范式转换，将生命过程看作是意义产生过程、

* 本文为中国博士后基金第61批面上资助“当代信息研究中的本体论承诺与方法论选择研究”(2017M611789)的研究成果。

信息过程，而不仅仅是机械过程。根据生物符号学，生命过程在符号框架内可以被丰富地解释。生物符号学产生于达尔文生物学的两个反常。这两个反常可能会导致生物当前的主流范式走向危机。面对这个危机，生物符号学提出了符号学的回应。生物符号学利用皮尔斯符号学通过重新定义生物学的事实、问题与方法，重新概念化了生物学。一些迹象表明，生物符号学已经进入了常规科学的阶段。然而，要想进一步发展，它必须面对内部、外部的挑战。

关键词：生物符号学，符号过程，新达尔文生物学，范式

DOI：10.13760/b.cnki.sam.201802004

The biosemiotic community strongly believes that biosemiotics can provide a paradigm for biology. From its inception, early biosemioticians have interpreted the semiotic perspective on science represented by biosemiotics as "a radical shift in scientific paradigm" (Anderson, et al., 1984), a notion that has been passed from generation to generation. In addition, the history of biosemiotics has been rewritten several times (Kull, 1999; Sebeok, 2001; Favareau, 2007; Kull, Emmeche & Favareau, 2008; Barbieri, 2009, to name but a few). Then, why do we still need a study on biosemiotics as a paradigm for biology and a rational reconstruction of history? Although most studies argue that biosemiotics can be a paradigm for biology①, this study examines whether biosemiotics has become a paradigm or the phrase of normal science. In other words, my research analyses whether biosemiotics is mature. To this end, I use Thomas Kuhn's theory of scientific revolution (1962/2012) with Imre Lakatos's reformulation to evaluate the current state of biosemiotics.

In this study, I first discuss the concept of paradigm according to Kuhn. Next, I argue that two anomalies implied by neo-Darwinian biology may lead to the crisis of the predominant paradigm of biology and examine the semiotic response to the crisis proposed by biosemioticians. In Peircean semiotics,

① Favareau's great work on the history of biosemiotics (2007) is an exception. In the epilogue, Favareau explicitly refers to Kuhn's account of paradigm and argues that biosemiotics is working towards becoming a normal science of biology. My study here can be considered a further endeavour in this approach.

biosemiotics reconceptualises biology by redefining its facts, problems and methods. Several clues indicate that biosemiotics has almost become a paradigm for biology. However, it still faces internal and external challenges.

Ⅰ. The Structure of Paradigm

In Kuhn's philosophy of science, it is well known that the concept of paradigm is a polysemous concept. In an often cited but rarely read paper, Margaret Masterman lists the 21 meanings of paradigm used by Kuhn in *The Structure of Scientific Revolution* (Masterman, 1970). This source provides a good starting point for better understanding the concept of paradigm. One reason why this concept is considered unclear is that Kuhn's numerous uses are more descriptive and empirical than conceptual and normative. Fortunately, Lakatos (1968) reformulates the concept of paradigm as a research programme with a clear normative structure. Instead of discussing which account is best suited to the philosophy of science, I propose that they provide two sets of valuable descriptive and normative criteria for assessing whether a science is mature. These criteria are as follows.

Kuhn's account of paradigm and normal science is the most relevant here. To a certain extent, these two terms are synonymous. Only when a science acquires a paradigm can we say that it has reached the state of normal science. A paradigm refers to past achievements in a scientific field that can be used as an exemplar for future scientists in the field. Descriptively, a paradigm denotes achievements that are:

a. "sufficiently unprecedented to attract an enduring group of adherents away from competing mode of scientific activity";

b. "sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve". (Kuhn, 1962/2012, p. 11)

In other words, a paradigm guides and restricts the group referred to as the scientific community on how to practice science. How does it work? When they accept these achievements as exemplars for their own research, scientists follow a network of commitments based on the paradigm, although they do not need to be aware of these commitments.

This network consists of sets of metaphysical, methodological,

conceptual, theoretical and instrumental commitments (Kuhn, 1962/2012, p. 42). The highest level of commitment determines what scientists must do. This is called the spirit of scientists. Metaphysical commitments describe the world as it is. These commitments are also referred to as the worldview. Methodological commitments denote ultimate laws and fundamental explanations. Theoretical and conceptual commitments refer to the theories and concepts that must be followed in a sustainable manner in future studies. Finally, instrumental commitments define the instruments and how to use them.

In short, the network of commitments determines significant phenomena (facts), how to identify problems, how to collect and explain data (methods) and defines the legitimate theories and concepts. In Kuhn's words, the network of commitments describes "On what aspects of nature do scientists report? What determines their choice?... [W] hat motivates the scientists to pursue that choice to a conclusion?" In short, it defines the activities of normal science: it actualises the promise of success of a paradigm by "extending the knowledge of those facts that the paradigm displays as particularly revealing, by increasing the extent of the match between those facts and the paradigm's prediction, and by further articulation of the paradigm itself" (Kuhn, 1962/2012, p. 24). To articulate a paradigm, from a theoretical perspective, the activities of normal science involve the prediction of new facts and the clarified reformulation of theories. Experimentally and observationally, the activities of normal science refer to the discovery of significant facts and the matching of facts with theories and experiments.

The descriptive and empirical criteria of a paradigm proposed by Kuhn can be complemented by Lakatos' account of a conceptual and normative scientific research programme (1968). Consistent with Kuhn, Lakatos argues that science does not designate isolated individual theories but a network of interconnected theories, which he calls "scientific research programme". "The programme consists of methodological rules: some tell us what paths of research to avoid (negative heuristic), and others what paths to pursue (positive heuristic)" (Lakatos, 1970/1978, p. 47). Lakatos' programme is characterised by its "hardcore". In other words, the hardcore defines a programme.

Lakatos' hardcore corresponds to the metaphysical, methodological and sometimes theoretical and conceptual commitments of Kuhn's theory:

> The negative heuristic specifies the "hardcore" of the programme which is "irrefutable" by the methodological decision of its proponents; the positive heuristic consists of a partially articulated set of suggestions or hints on how to change, develop the "refutable variants" of research-programme. (1970/1978, p. 50)

The negative heuristic equates to the theoretical activity of clarifying a paradigm through reformulation, while the positive heuristic consists of theoretical, conceptual and instrumental commitments and other research activities. The positive heuristic sets up a series of problem-solving mechanisms, often in the form of complicated models simulating reality.

Using these two sets of criteria, we can now examine biosemiotics.

Ⅱ. Anomalies and Crisis of Neo-Darwinian Biology

The first question asked by those who are not familiar with biosemiotics is often "Why do we need another paradigm for biology when we already have neo-Darwinian biology?" The main answer is that there are anomalies in neo-Darwinian biology that may lead to crisis.

Neo-Darwinian biology, the predominant paradigm of today's life science, refers to the modern synthetic theory of biology. In this modern synthesis, Darwin's theory of natural selection is combined with Mendelian genetics. Basically, the paradigm has three essential factors: (ⅰ) natural variation of genes, (ⅱ) differential reproduction and (ⅲ) inheritance (Brian, 2010, p. 50). According to this paradigm, most characters of organisms are affected by many genes, all of which have small effects. Natural variations of genes are produced by the random mutation of old genes and are heritable. The survival or fitness values of these variations differ, thus differential reproduction happens when variations with different survival values pass from one generation to the next. Variations with higher values will produce more offspring. In short, the environment in which organisms live selects characters that give them a reproductive advantage, leading to the evolution

of species.

Natural selection is a wholly mechanistic process. Therefore, it can be completely mathematised. In this way, the teleological properties of organisms that are incompatible with modern science are eliminated. Because of this mechanisation, biology has become a science. However, teleological concepts, such as function, adaptation, design and information, are essential in biology. Generally, biologists treat these concepts as metaphors or abbreviations of phenomena that can be explained by mechanistic causality. Therefore, in the paradigm, organisms are passively subject to the universal laws of nature like other physical entities (Hoffmeyer, 2008). Hence, according to the paradigm, life is lifeless. Although neo-Darwinian biology is scientific in a mechanistic sense, it is counter-intuitive, as organisms' actions are teleological and have agency. Therefore, neo-Darwinian biology necessarily involves dualism: it explains the part that can be mechanised but leaves the teleological part behind or simply assumes that this part can be mechanically explained, while it cannot. Put differently, nature violates the induced explanations of neo-Darwinian biology that govern the normal science of biology. Kuhn calls this violation an "anomaly".

However, advocates of neo-Darwinian biology argue that the goal-directed phenomena in organisms are pseudo-purposeful. For instance, Ernst Mayr convincingly contends that we fundamentally mix different phenomena when using the concept of teleology (1992/2004, pp. 48－49). Teleonomic processes are one of the five phenomena concerned here.① Teleonomic processes refer to goal－directed processes in organisms. Usually, these processes are believed to result from an agency or intrinsic purposeful drive. In contrast, Mayr argues that teleonomic processes involve goal-directed processes, but they are not caused by some sort of agency. Instead, they are caused by genetic programmes, which are the products of natural selection. These programmes control the processes leading to a goal. The negative process of cybernetics is an excellent exemplar showing how goal-seeking

① The other four phenomena are teleomatic processes (autonomously end-directed processes), purposeful behaviour in thinking organisms, adapted features and cosmic teleology (God created the cosmos; Mayr, 1992/2004, p. 49).

behaviour can be achieved mechanically without an agency. Consequently, Mayr proposes that the goal-directed processes of organisms can be explained by universal physical laws and genetic programmes without the involvement of agency. In this way, the goal-directed processes of organisms are reduced to information processing, which is mechanistic.

Conversely, Terrence Deacon rejects this idea, proposing that this argument "inverts the location of agency and dynamics" (2012, p. 132). He contends that the mechanism involved in information processing is necessary to explain goal-directed processes because of its contribution to something else (Deacon, 2012, p. 123). In other words, teleonomy cannot explain the purposes of organisms. Therefore, the anomaly of neo-Darwinian biology is not eliminated. We want an account of life that can explain life, especially the properties that differentiate living organisms from inanimate things, while neo-Darwinian biology only provides an account without life (Emmeche, 1998). This may lead to a crisis of the paradigm.

Ⅲ. Biosemiotics as a Semiotic Response to the Crisis

According to Kuhn, a paradigm supplants a previous one because it can better "solv[e] a few problems that the group of practitioners has come to recognize as cute" (1962/2012, p. 24). As a result, biosemiotics proposes a semiotic response to the anomaly that neo-Darwinian biology cannot solve. Biosemiotics seeks to explain the phenomena left unexplained by neo-Darwinian biology from the perspective of semiotics, namely a living or meaning-making aspect of life. After decades of hard work by generations of biosemiotians, biosemiotics has become a paradigm. In this section, I justify this claim based on the two sets of criteria proposed in section Ⅰ.

The ontological and metaphysical commitments, or hardcore, of biosemiotics, are as follows:

a. Life and semiosis are coextensive according to Sebeok's thesis;

b. Biology calls for a natural history of meaning. (Stjernfelt, 2002; Kull, et al., 2008; Barbieri, 2008; Kull, Emmeche & Hoffmeyer, 2011; Sharov, Maran & Tønnessen, 2015)

Sebeok's thesis (Thesis Ⅰ) proposes two claims: (ⅰ) by nature, life

processes are meaning-making, informational processes, namely semiosis (sign processes) and (ⅲ) there is no semiosis without life. Claim (ⅰ) is in conflict with neo-Darwinian biology, which does not take meaning-making but morphological, metabolic, evolutionary and other material and structural properties as essential characters of life (Bedau & Cleland, 2010, Part Ⅳ). Claim (ⅲ) argues against pansemiotics that the universe is infused with signs and that everything is semiological in nature (Brier, 2008a, p. 357). According to biosemiotics, "[s]emiosis is what distinguishes all that is animate from lifeless" (Sebeok, 1988, p. 1089).

Semiosis is a fundamental process that carries meaning and in which meaning is created:

> It is the process—not at all simple—that mediates purpose and causality, living and dead aspects of nature, and makes it possible to see how to overcome a crude dualism of mind and matter, as well as how the dynamics of the actions of signs provides a better approach to living systems than our dichotomies of mental versus physical properties . (Kull, et al., 2009, p. 2)

Thesis Ⅱ asserts that meaning, which is considered normative, has a natural origin and thus requires a naturalistic explanation. In traditional research, meaning is a subject of the humanities and is excluded from natural science on the basis of Cartesian dualism. Therefore, Thesis Ⅱ is in conflict with The Two Cultures thesis. Bridging the gap between two cultures, namely the humanities and natural science, is one of the aims of biosemiotics (Anderson, et al., 1984; Barbieri, 2007, p. xi; Sharov, et al., 2015; Cobley, 2017, p. xii). Or, in Hoffmeyer's words, biosemiotics seeks to explore "how could natural history become cultural history?" (1996, p. viii). In addition, biosemiotics opposes intelligent design and creationism. The origin of meaning is not mysterious but a natural phenomenon. Therefore, its explanation does not need to appeal to a supernatural agency (Barbieri, 2009).

Based on the negative heuristic, many studies seek to distinguish biosemiotics from other accounts of biology, such as mechanism, vitalism and organicism (Stjernfelt, 2002; Kull, et al., 2008; Kull, et al., 2009;

Emmeche & Kull, 2011, to name but a few). Using the specificities of biosemiotics, biosemioticians resolve attacks on the hardcore.

According to Kuhn, a revolution of science corresponds to changes in the worldview. Indeed, scientists live in a different world in which they adopt new instruments and look in new places. They can also find different and new things when examining previously studied places (Kuhn, 1962/2012, p. 111). It should be noted that the rise of biosemiotics as a scientific revolution in biology (Favareau, 2007, p. 50) does not add a semiotic or meaningful dimension to neo-Darwinian biology but replaces it with a new paradigm. Therefore, biosemiotics provides a new worldview that differs from that of neo-Darwinian biology. In biosemiotics, we see life through "the perspective of sign actions, processes, purposefulness, interpretation, and generality" (Emmeche, 2011, p. 94). Compared with the mechanistic world of life described by neo-Darwinian biology, the living world studied by biosemiotics is meaningful and qualitative. "To recapitulate, the biosemiotics notion of life is a notion of a complex web of sign and interpretation processes, typically with the single cell seen as the simplest possible autonomous semiotic system" (Emmeche, 2011, p. 96).

These two theses also emphasise the methodology of biosemiotics: a methodology that studies signs. There are two types of signs: Ferdinand de Saussure's semiology and Charles Sanders Peirce's semiotics. The basic model of semiology is a dyadic model composed of signified and signifier. Using semiology, Saussure studies language in a functionalistic way. In contrast, Peircean semiotics proposes a triadic model of semiosis. Based on this model, semiosis is a triadic relationship between three necessarily irreducible elements: sign, object and interpretant. In light of these two theses, biosemiotics adopts Peircean semiotics for the following reasons: (ⅰ) semiology focuses solely on language, arguing that only linguistic signs are signs, which goes against Sebeok's thesis; (ⅱ) semiology is considered an instrument for normative cultural science that differs from causative natural science (Cassirer, 1942), which is incompatible with Thesis Ⅱ (Brier, 2008b); (ⅲ) Peircean semiotics is not only compatible with these two theses, but also provides rich methodological and metaphysical resources for

biosemiotics (Vehkavaara, 2007).

Jacob von Uexküll's theory of Umwelt proposes a more specific model simulating semiosis in the living world (von Uexküll, 1940/1982). Umwelt is a meaningful subjective world centered on an organism in which everything has significance for this organism. Through functional circle, a neutral object becomes a meaning-carrier for an organism. Peircean semiotics integrates the theory of Umwelt into the positive heuristic of biosemiotics. With negative and positive heuristics, biosemiotics as normal science accomplishes the following activities:

Since its inception, one of the most important theoretical activities of biosemiotics has been to classify biosemiotics by reformulating biology. Legitimate questions of biosemiotics are defined accordingly (Kull, et al., 2008). The first set of questions addresses the essential distinction between life and inanimate processes. Conceptually, it examines how to understand the distinction? Empirically, it explores how semiosis emerged from non-semiotic processes? In short, this set of questions reflects the problem of the origin of life formulated in terms of semiotics. Biosemiotians argue that there is a semiotic threshold between life and lifeless processes. Deacon proposes a significant model of the origin of organism, autogenesis (2012). The second set of questions includes how to formulate evolution in semiotics, how to understand selection, function, adaptation and genetic information, how human language evolved from basic signs (symbolic threshold?), etc. Hoffmeyer's theory of semiotic scaffolding is one of the remarkable theories of evolution in biosemiotics (2007). This theory suggests that the evolution of the complexity of organisms increases in parallel with the semiotic freedom of organisms. This theory takes into account the agency and active role of individual organisms in evolution.

Biosemiotics also reformulates biology synchronically. This set of questions includes the analysis of the relation between semiosis and physical processes, what the basic unit of semiosis is, how an organism interacts with its local environment through semiosis, how to understand semiosis inside an organism, etc. The first question is not a problem for neo-Darwinian biology, but it is crucial for biosemiotics. Most biosemiotians accept Howard Pattee's

idea that the complementarity principle can bridge the epistemic cut between semiosis and physics (Pattee & Rączaszek-Leonardi, 2012). Instead of living in a physical meaningless world enslaved by causal laws, biosemiotics proposes that an organism lives in a meaningful subjective world called Umwelt, in which the organism is the centre and everything has some value for it. Through functional circle, a neutral object becomes a meaning-carrier for an organism. As an organism interacts (to a certain extent) with the local environment it lives in through semiosis, the local environment becomes a semiotic niche. Different organisms interact with each other through semiosis, constituting a consensual domain. Generally, they construct a semiosphere that is as important as the atmosphere, the hydrosphere, and so on. Accordingly, the branches of biosemiotics include endosemiotics, phytosemiotics, zoosemiotics, ecosemiotics, among others (Queiroz, Emmeche, Kull, & El-Hani, 2011).

The reformulation of biological theories is often accompanied by the identification of significant biological facts and the reinterpretation of facts previously explained by neo-Darwinian biology. Based on its ontological commitments, the optimal phenomena that biosemiotics can explain are semioses or phenomena that can be formulated as semioses. For instance, genetic information, signals at different levels of organisms, such as signals in the immune system, nervous system or animal communication system, codes and messages, are reinterpreted in biosemiotics terms. Through reinterpretation, these biological facts reflect and further define biosemiotics. All empirical work on biosemiotics can be classified in these activities.

In addition to solving problems previously solved by neo-Darwinian biology and reformulating theories in semiotic terms as discussed above, biosemiotics has some advantages over neo-Darwinian biology. These advantages are the following: (ⅰ) defining life as meaning-making processes is consistent with the understanding of biology as a science of living organisms; (ⅱ) taking into account the notion of agency, biosemiotics considers the evolution of life as not only passive but also active; (ⅲ) it proposes a bridge between ontogeny and phylogeny that is absent in neo-Darwinian biology.

Biosemiotics clearly satisfies the two sets of criteria mentioned in section Ⅰ. Therefore, we can conclude that biosemiotics is a paradigm or research programme for biology. The next question is whether it has become the phase of normal science, that is, whether it has matured.

Ⅳ. Some Empirical Signs of the Maturity of Biosemiotics

According to Kuhn, the "Acquisition of a paradigm and of the more esoteric type of research it permits is a sign of maturity in the development if any given scientific field" (1962/2012, p. 12). As illustrated in section Ⅰ, to be a paradigm, achievements must have two characters: (ⅰ) attract an enduring group; (ⅱ) be open-ended to leave problems to resolve. Biosemiotics clearly meets these requirements. First, the biosemiotics community is a small but steadily growing group of scholars from different disciplines meeting annually and publishing research on biosemiotics in various academic journals (Favareau, 2010, preface). Second, the sets of biosemiotics questions are well defined, leaving room for open-ended investigations. (Kull, et al., 2008)

In Kuhn's term, the esoteric nature of research means that research is conducted following the network of commitments of a paradigm. The community of a paradigm is an esoteric group that is exclusive. The boundary between the members and outsiders of a paradigm is based on the network of commitments discussed in section Ⅰ, in addition to an esoteric glossary, research methods, rules and evidentiary procedures. Without long-term esoteric or professional training, a person cannot fully grasp these commitments and thus has no license to be a legitimate member of the community and is excluded from it. As mentioned in the previous section, in biosemiotics, the esoteric glossary, methods and legitimate problems have been established through the work of generations of biosemioticians. In addition, as a community, biosemiotians consciously reconstruct the history, identity, research theses, questions and methods of biosemiotics. For instance, the terminology of biosemiotics is an important topic for biosemioticians (Danesi, 2007). In 2014, the biosemiotics community launched "The Biosemiotic Glossary Project" in the effort to (ⅰ) "solidify

and detail established terminology" used in the field of biosemiotics for the benefit of newcomers and outsiders and (ⅱ) involve the entire biosemiotics community. (Tønnessen, 2015)

Moreover, Kuhn (1962) proposes three other signs of maturity of a paradigm: (ⅰ) being isolated from philosophy; (ⅱ) the end of the debate on metaphysical and methodological commitments; (ⅲ) the end of competing schools. In summary, no fundamental novelty is allowed, and puzzle-solving occupies almost all of the research activities of normal science. Although some scholars may associate biosemiotics with the philosophy of biology, biosemiotians "emphasize its scientific and often practical orientation" (Sharov, et al., 2015). With an agreement between major schools in biosemiotics, biosemiotians agree "to put their differences aside in the interest of a greater goal" (Barbieri, 2005). Therefore, biosemiotics shows these three signs of maturity. Unlike the early years of biosemiotics, there are less discussions about the fundamental commitments of biosemiotics and more about specific topics. (Maran, Sharov, & Tønnessen, 2017)

Furthermore, biosemiotians claim that biosemiotics is an inter-trans-disciplinary science, which is intuitively in conflict with the defining characters of paradigms as esoteric and somewhat exclusive. On the one hand, some object that the inter-trans-disciplinary nature of biosemiotics cannot be a paradigm in Kuhn's sense. On the other hand, if biosemiotics abandons this inter-trans-disciplinary nature, it will lose its originality and innovativity. Other scholars complain that biosemiotics today is not as exciting as it was in the early days because most research is boring and technical and aims to solve trivial problems. Therefore, original creative innovation is no longer possible in biosemiotics research. However, Kuhn suggests that normal science is not about fundamental novelty but puzzle-solving. Therefore, the disappearance of this inter-trans-disciplinary character offers another evidence that biosemiotics is a paradigm.

Finally, Kuhn argues that "in the sciences, the formation of specialized journals, the foundation of specialists' society, and the claim for a special place in the curriculum have usually been associated with a group's first reception of a single paradigm" (1962/2012, p. 19). There are numerous

examples of such scholarly developments. For instance, the International Society for Biosemiotic Studies (ISBS) was established in 2005. The Nordic Association for Semiotic Studies and The International Association for Cognitive Semiotics are also important societies for biosemiotics. In addition, various journals, such as *Semiotica*, *Sign Systems Studies* and *Cybernetics and Human Knowing*, were important platforms during the early days of biosemiotics. In 2008, the official journal of ISBS, *Biosemiotics*, published by Springer, was launched. Moreover, since 2001, the annual Gathering in Biosemiotics conference has been uninterruptedly held for 18 years, while the World Congress of Semiotics provides another platform for biosemiotics. Finally, courses in biosemiotics are taught all around the world. In particular, Tartu University in Estonia and Charles University in Prague are specialised in training young biosemiotians.

All this evidence supports the claim that biosemiotics has matured; in other words, it has become the phase of normal science. However, it still faces challenges.

Ⅴ. Internal and External Challenges

It can be argued that biosemiotics is not a science but provides a way to reinterpret, reformulate, reconfigure and reshape biology from the perspective of semiotics. Indeed, biosemiotics has no predictive power and the results of biosemiotics research cannot be justified experimentally. However, I propose that this objection is not strong enough to argue against biosemiotics as a paradigm. The reformulation of facts and theories is a large part of the work at the early stage of a new paradigm, because the paradigm must not only solve problems that previous paradigms have failed to solve, but it must also show that it can at least equally solve problems previously solved by old ones. Various empirical studies show that biosemiotics is more powerful in explaining the semiotic aspect of nature, but also offers experimentally testable models (see, Deacon, 2012, for instance) and predicts new facts, for example, Barbieri's theory predicts the triadic structure of organic codes in organisms (2003). Nevertheless, biosemiotics still faces external and internal challenges.

Externally, what is the relationship between biosemiotics and neo-Darwinian biology? Neo-Darwinian biology does not ignore sign phenomena in nature. For instance, there are studies on animal signals and communication formulated under the paradigm. How can biosemiotics participate in these studies? The general answer to this question is inspired by Pattee's formulation of the relationship between physics and semiotics, which proposes that biosemiotics is complementary to neo-Darwinian biology rather than an alternative paradigm (Kull, 2007; Kull, et al., 2008; Emmeche & Kull, 2011). Yet, this answer is closer to a compromise than a solution because the metaphysical commitments of biosemiotics are in conflict with those of neo-Darwinian biology. For instance, neo-Darwinian biology categorically denies teleology and homotropic inheritance and opposes vitalism, while biosemiotics admits without hesitation its kinship with them. Hence, perhaps the answer involves an ontological synthesis (Cao, 1997, pp. 362－365) between these two paradigms, namely the parts of neo-Darwinian biology useful for biosemiotics should be reserved and reconceptualised in biosemiotics. Indeed, ontological synthesis is only possible when these reserved parts are reconceptualised in fundamentally different ideas.

Internally, there are different schools in the biosemiotics community: sign, Darwinian, code and hermeneutic biosemiotics (Barbieri, 2009). Although these schools were once competitive, following the agreement mentioned above, their differences have been put aside. However, this is a temporary strategy for the greater good. To become a unified science, a way to choose or synthesise must be found. Grygar provides a middle way, suggesting that these schools complement each other in Bohr's sense. Therefore, he concludes that biosemiotics is "one of the special sciences or its potential as a cross-disciplinary branch of study" (2017). However, the persuasiveness of this argument remains to be proven. According to Kuhn, competitive schools will disappear if one school wins out. Although many scholars do not want it, perhaps this will happen to biosemiotics.

Be that as it may, if biosemiotians want to complete the revolution of biology, they must face these challenges and make a choice.

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