1

Introduction: Towards Integrating Studies of Meanings with Science

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1.1 Crossing the Great Paradigm Divide

Human knowledge is deeply divided into natural sciences that pursue mechanisms and their modeling, and the humanities that are focused on meaning, value, communication, and interpretation. This book is conceived as a dialogue between interdisciplinary scholars on how to cross this *great paradigm divide* and contribute to integration of natural sciences with semiotics, a theory of meaning-making and signification, also known as *semiosis*. Developments in biology clearly indicate that semiosis is not limited to humans or vertebrate animals, but exists in all living organisms [1.3] [1.38], and this fact inspired integration of biology and semiotics into biosemiotics. In order to function and survive, all organisms strive to capture the meaning of their environments and their own activities. According to the theory of meaning proposed by Jakob von Uexküll [1.80], animals develop species-specific models of their environment (umwelten) that link environmental cues with living functions. An elementary unit of such a model is a functional circle that includes sensing, perception, and action, all integrated into a self-sustaining loop [1.78] [1.79]. This introduction chapter overviews other chapters of the book in light of major concepts of biosemiotics.

Terminology is one of the challenges in studying meanings because biosemiotics has to overcome the anthropocentric nature of all terms related to signs, meanings, agency, mind, consciousness, communication, learning, and knowledge. There is no easy solution because if the meaning of terms is expanded to all living organisms, then the differences between types of semiosis in various taxonomic groups can be lost. An alternative strategy of using parallel sets of terms for each taxonomic group is also problematic because

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such terminology would be awkward for broad evolutionary studies. Another problem with terms is related to the difference between the first-person experience (i.e., in object agent) and third-person experience (i.e., in meta-agent) [1.76]. For example, a human researcher (meta-agent), considers glucose molecules as signs that can be perceived by bacteria searching for metabolic resources. But a bacterium (object agent) does not "know" that glucose exists outside; it simply responds to incoming signals from chemoreceptors and changes its activity according to its inherited program [1.70]. Biosemiotics certainly needs a set of generic terms applicable to all organisms and its subagents, and it can be based only on meta-agent understanding. Such a set includes "sign," "interpretation," "semiosis," and "agency" [1.38]. The range of application of other terms, for example, "meaning," "mind," "consciousness," and "learning," is still debated and there is no consensus.

Donald Favareau and Kalevi Kull [1.21] present a historical overview of how signs and meanings are conceptualized in the natural sciences. Ancient studies of signs mostly considered conditions when evident facts can be used to predict the non-evident, and then used to guide human actions to change the outcome (e.g., cure a patient or succeed in other goal-directed activity). One of the early achievements was recognition of deep contextuality of any predictions by Sextus Empiricus (2-3rd century), a supporter of the school of Pyrrhonial skepticism. He assumed that objects change with time and in response to various factors; and human impressions of objects depend on position, activity, and beliefs. Hence, judgments need to be suspended until the validity of induction is carefully verified. Notably, Sextus disagreed with the notion that knowledge is not achievable, which was a typical belief (according to his writings) in the school of Academic skepticism of that time.

The great paradigm divide emerged during the age of Enlightenment (17–18th centuries), when the whole domain of science was restructured to eliminate any cognitive elements (*res cogitans*) and focus on intrinsic properties of things (*res extensa*), which were assumed fully objective and verifiable. This worldview was typical for physics and chemistry, but it also influenced the development of biology and supported mechanistic mentality and the heuristic of reductionism. However, the need for the theory of signs and meanings reemerged in the contemporary science and resulted in the development of semiotics theories that were initially associated with the humanities (i.e., philosophy, linguistics, and psychology), but recently spread to biology, cybernetics, and other sciences. Favareau and Kull [1.21] describe in detail the general semiotic theory and its further development in biosemiotics, which has advanced in formulating such terms as sign, interpretation, semiotic agency, umwelt, semiosphere, scaffolding, and habit. In contrast to the mechanistic metaphor of computation, biosemiotics considers *semiotic modeling* which is embodied, anticipatory, and supported by a hierarchy of meanings. Favareau and Kull pay special attention to the problem of *semiotic realism* presented as a middle path between radical skepticism and naïve realism. They follow Peirce's notions of pragmatic maxim and final interpretant "toward which *the actual* tends" [1.54], CP 5.312, as guiding principles. In conclusion, "it is thus through signs that we are *more fully joined* to the world" [1.21] (italics original).

Bashir Ahmad and Richard Gordon [1.1] show that the old reductionist heuristic in science, stating that higher-level phenomena can be reduced to the processes occurring at lower levels, fails as physical reality is studied at progressively smaller scales and "the burden of proof on smaller entities became ever larger." The problem is not limited to the immense combinatorial complexity of combinations at the lower level, but in addition, higher-level emergent phenomena actually change what happens at a lower level. Examples

of top-down causation are most numerous in living systems, where catalytic biomolecules enable chemical reactions and quantum effects that never occur in the non-living nature. Ahmad and Gordon present numerous examples of such non-reductionist effects in physics that include the second law of thermodynamics (increasing of entropy), rounding of liquid drops, percolation, gravity, and superconductivity. Following Arthur Koestler [1.36], they argue that each hierarchical level has its own rules of operation and these rules have bi-directional effects on both lower and higher levels; thus, physics is not reductionist and the world needs to be explained by Janus-faced[1] hierarchies.

The theories of information [1.62] and cybernetics [1.83] were thought to provide a link between natural sciences and human communication, but the term "information" is interpreted differently on each side of the paradigm divide. Terrence Deacon [1.18], p. 71, describes the difference:

> At one extreme, abstraction of the formal concept of information from its referential and normative properties in everyday use and in the many areas of natural science—such as biology and cognitive neuroscience, where these nonquantifiable properties are relevant—has led to generations of efforts to formally incorporate these properties, but without widespread acceptance. At the other extreme, semiotic theories, which take issues of reference and interpretation as their focus, have largely remained confined to discussions in the humanities and social sciences, and efforts to formalize these theories have also gained limited widespread acceptance.

Deacon further explains that physicists and engineers are interested in the transmission of information no matter what it means for the end user. In contrast, biology and psychology analyze information in the context of function and reference, and linguists are interested in symbolic relations between words and their meanings. To integrate these aspects of information, Deacon turns to the semiotic theory of Charles Morris, who distinguished syntax, semantics and pragmatics as three aspects of semiosis. Deacon generalizes these aspects to make them applicable beyond human language and describes them as "*medium or signal properties* (with syntax as a special case), *referential properties* (with meaning as a special case), and *normative or functional properties* (with pragmatics as a special case)" [1.18], p. 75. In simple cases (e.g., in icons and indexes), interpretation is mediated by medium/signal properties and yields referential properties. But symbols require additional conventional and socially shared rules that integrate all three levels of semiosis.

Deacon addresses the problem of semiotic grounding, which "is the property of 'aboutness,' the non-intrinsicality of reference" [1.18], p. 77. He argues that "[s]ign vehicle properties don't therefore determine reference, instead they serve as *affordances* that aid the interpretation process." The two major classes of such affordances are: "(i) shared formal properties between sign vehicle and object (iconicity), and (ii) some physical-temporal correlation or contiguity between sign vehicle and the object of reference (indexicality)." In contrast, symbolic reference is not linked on the features of a sign vehicle but instead relies on "a kind of iconicity between different interpretive habits in a community of symbol users" (ibid., p. 79).

To develop a unified approach to the studies of physical, biological and social systems, Anton Sukhoverkhov and Arran Gare [1.73] delineate three domains of information

[1] Janus is a two-faced Roman god, associated with beginnings and entrance-exit opposition.

(or "memory") in the universe: physical, biological, and social.[2] Following Nöth and Deely, they consider physical "virtual signs" that carry information about past events no matter if they are observed or not. These signs constitute *physical memory* that can be used to reconstruct the past or make prediction of the future. At the second level, *biological memory* connects physical reality with internally represented reality, such as objects or mental associations. Finally, the third level is represented by *social memory* that stores collective experience in symbols, myths, inferences (e.g., causation models), and social activity. Social memory and language supports modeling functions such as production of resources and dwelling structures. This conceptual framework is then applied to describe the origin and evolution of human language.

A similar monistic approach to meaning is proposed by George Mikhailovsky [1.46], who considers a hierarchy of meanings that integrates the physical world, living organisms, cognition, and the noosphere of human social systems. In the physical world, meanings take the form of symptoms (meaning-in-itself) that potentially can be interpreted by organisms. In organisms, meanings represent intentions that connect perception with action; and in human language, meanings are expressed in words and other symbols. The qualitative changes of systems occur via adding new levels of hierarchy, a process called *hierarchogenesis*. Mikhailovsky describes 15 hierarchogenic steps in the evolution of the world, which are further grouped into cosmic (six steps from quark-gluon plasma to galaxies) and substantive (nine steps from heteroatomic molecules to noosphere) branches. The latter branch includes the origin of life, prokaryotic cells, eukaryotic cells, multicellular organisms, agroecosystems, and nations/states. Qualitative steps in the evolution of meanings includes actualization of potential meanings, the rise of judgments, paradigms, and worldviews. These two components of evolution (substance and semantics) show a tendency of conversion, especially since the end of the last century.

Mikhailovsky then introduces the new term "eventity"— a shorthand for "evolving entity" which can be represented by a sequence of events constituting its evolution.[3] Meanings exist only in eventities, since any meaning presupposes conditioning either by a preceding (causality) or a consequent (purposiveness) event. Abiotic eventities, such as stars, contain only potential meanings, while living eventities (agents) can actualize the meanings of other eventities as well as their own. Mikhailovsky identifies a nine-level structural semantic hierarchy of living eventities consisting of three triplets ("word" – "text" – "phrase") for several hierarchical steps of general evolution. In addition, he delineates the behavioral semantic hierarchy of living beings spanning from elementary meanings through judgments and paradigms to complex worldviews. The first two belong to biosemiotics, and the last two are unique to humans. In this way, both types of semantic hierarchy are intertwined with several later steps of general hierarchogenesis.

In contrast to Sukhoverkhov, Gare, and Mikhailovsky, who assume that meaning or information exists even in the physical world without life, Alexei Sharov [1.68] takes a biosemiotic approach to the ontology of meanings, according to which meanings exist only due to their relation with interpreters: living organisms and life-dependent semiotic agents. The latter category of agents includes ribosomes and functional proteins in living cells, and

[2] The last two domains are represented by life and human civilization on Earth and by hypothetical biospheres and civilizations on exoplanets.

[3] A similar term is "occurrent," which is used by Caetano-Anollés [1.13].

autonomous human artifacts (computers and robots). However, according to Sharov, the relation between meanings and interpreters can be actual or potential, and thus, *actual meanings* are those that are currently interpreted by semiotic agents, whereas *potential meanings* are those that are interpretable (i.e., knowable) by some agents, which are currently either not present or not active. In physics, potentiality is described as a field that can be measured at any point in space by an appropriate device. Sharov proposes that potential meaning can be similarly presented as a *semiotic field* measurable by some competent semiotic agent if it is placed near the meaning carrier. Natural resources are potential meanings that existed long before the origin of life, but they are recognized as "potential meanings" only retrospectively, after the emergence of organisms capable of sensing and using these resources for their own benefit. Sharov wrote:

> Such ontology of meanings is agency-dependent, similar to radical constructivism [1.77], but in addition, meanings are pragmatic and become corrected through repetition of the corresponding functional cycle. It is initially subjective but can spread via interaction and communication and become objective within the community of agents. Such collective knowledge is updated with the emergence of each new kind of agency: first, actual meanings are updated in space and time proximity of these new agents, and second, potential meanings are updated in the whole universe, as well as in the reconstructed past, and in the projected future [1.68], p. 150.

Alexander Kravchenko [1.37] develops the ontology of meanings starting from principles of radical constructivism, which "highlights the crucial role of the observer in constructing a universe as 'objectivity in parentheses.'" However, the theory of constructivism is traditionally applied to humans and therefore it is inherently anthropocentric. To overcome this limitation, Kravchenko extends this approach to non-human organisms, which, according to biosemiotics, are capable of perception and purposeful behavior. Also, in contrast to radical constructivism which treats meanings as artificial constructs, Kravchenko considers meaning as a "value-based relationship between the organism and its world of experience," following Zlatev [1.85]. In other words, meaning integrates the observer and the observed in the process of normative-controlled iterative interaction. In the case of humans, these relationships are encoded in language, and thus, meanings cannot be fully separated from the historically developed word use:

> Much, if not all, of what we think we, as observers, know about the world, is the result of our operations of distinction we make in language, or naming – specification of an entity by operationally cleaving it from a background. Once such a distinction is made, a thing with the properties that the operation of distinction specifies is added to the enlanguaged world. [...] and there are as many realities as there are observers [1.37], p. 171.

Kravchenko notes that the actual and potential are ontologically different, although in language we claim both of them as "existing." In this respect, "'past' and 'future' are mental constructs that *belong to the present* just as any other act of thinking" [1.37] (italics mine). However, in contrast to biosemiotics tradition, he rejects using the notion of "sign" from the position of a third-person observer. As a result, he proposes to apply this notion only if an organism can categorize a thing as a "sign." In particular, Kravchenko disagrees with Maritain [1.44], p. 53, that all animals "make use of signs without perceiving the relation of signification."

1.2 What is Meaning?

Meanings or ideas are generally considered as *components of mind* that comprise human understanding and knowledge [1.39], Book II, chapters I, XII. These components are brought to our attention by sensing, perception, reflection, contemplation, and by interpreting words and other language units. In linguistics, meaning appears as a *signified* associated with a *signifier*, which is a sound pattern of a word [1.17]. Gottlob Frege noticed that meanings, besides being mental components, also refer to objects in the real world. Thus, he distinguished two aspects of meaning: *reference* and *sense* [1.23], a dichotomy that is similar to opposing of *object* and *concept*. Then, Charles Peirce proposed a triadic sign relation: "I define a sign as anything which is so determined by something else, called its Object, and so determines an effect upon a person, which effect I call its interpretant, that the later is thereby mediately determined by the former" [1.55], EP2.478. One contemporary understanding of Peirce's sign is that object is akin to a signified or reference, and interpretant is a relation between the sign vehicle and its object [1.4]. In other words, the object and interpretant are two aspects of meaning communicated by the sign. Peirce assumed that sign relations are grounded in transcendental logic, and thus, they can be non-human and even non-mental. Hence, he applied it to habits of animals and plants (e.g., sunflower [1.54], CP 2.274).

But if meaning is not necessarily mental, then what is it? The authors of this book propose different answers. Favareau and Kull [1.21], p. 28, assume "that 'meaning' is always and everywhere, a function of sign relationships," understood as Peirce's triadic relations and functional circles of von Uexküll [1.80]. In other words, meaning integrates a knower (semiotic agent) with something known. Mikhailovsky considers meaning as a "component of the world that takes the form of indicator or symptom in the non-living world, intention of organism action, or something expressed in words or other symbols [in human language]" [1.46], p. 101.

According to Sharov [1.68], p. 137, "meaningful things, processes, or relations are those that have significance for organisms as indicated by either behavioral choice or regulation of innate habits and processes." Some meanings are intrinsic to non-living things (e.g., gravity, chemical valence, or catalysis); they exist in a potential form until discovered by agents, and then turn into actual meanings, as they gain agent-related normativity. Other meanings are products of evolution or learning, which are established by agents for their specific purposes. Neo-Darwinism reduces significance to a single variable—fitness (a combination of survival and reproduction rates). However, Caetano-Anollés [1.13] discusses additional dimensions of significance: economy (e.g., efficiency of metabolic reactions), mechanisms that support flexibility of function and behavior (umwelt), and robustness (e.g., preparedness for unperceived and unknown). According to Sharov [1.68], meanings outlive their carrier-organisms because due to semiosis, meanings are transferred among agents and overcome the limitations of individual matter-energy systems: "meanings once actualized keep existing and evolving."

Abir Igamberdiev [1.32], p. 266, connects meaning with final causation: "Meaning in the action of agent refers to the Aristotelian final cause, which, in his views, retrocausally directs the development of the system shaped by the material, the efficient, and the formal causes." He applies this notion to three levels of agency organization: autopoietic closure, evolution, and social systems. The normative nature of meaning is also recognized by Kobus Marais

[1.43], p. 6: "[...] significance is related to the interest of the organism and, therefore, always normative, and [...] this significance can grow in complexity, from a choice to eat or being eaten, to a large and complicated cognitive system like 'the law.'"

Alexander [1.2], p. 327, explores meaning in the context of subjective-objective duality:

> I start with the assumption that the concept of *meaning* implies a subjective perspective of a living system. Because binary logic may suggest to some that *subjective* meaning is the opposite of *objective*, I counter with the argument that subjectivity is better understood as *relative objectivity*. Subjectivity arises with the formation of internal biosemiosic relations [...] There are different levels of subjectivity; inherited or habitual and newly formed. Subjectivity is essentially selfhood, and subjective interpretations about the qualities of sign-vehicles are generally made for the sake of, or rather with the effect of, maintaining the self." (italics original)

Alexander considers three aspects of sign: *sign vehicle,* the *response,* and the *object*, which resemble but are not identical to Peirce's triadic relation. In particular, the object is defined as "the effect that the response has on the living system's ability to respond to the sign vehicle in that way. [...] the ultimate object of any semiosic process is reinforcing the conditions that allow that sign reading to recur." She further argues that biosemiosic meaning is dynamic and appears in two modes: *directionality* and *originality*. The former preserves the core aspects of the meaning despite ever-changing conditions or context, and the latter adds new components of meaning.

Marais [1.42] presents meaning as a process that includes two complementary aspects: interpretation and translation, which are inseparable as particle and wave aspects of light. He explains the difference between these two: "translation refers to a constraint-centered observation of semiosis while interpretation refers to an interpreter-centered observation." The importance of translation in biology resonates with the theory of organic codes, where meaning appears as a result of translation from one world of information units (e.g., triplets of nucleotides in mRNA) to another world (e.g., amino acids in peptides) [1.6]. Furthermore, Marais connects his understanding of translation with the theory of semiosphere developed by Yuri Lotman. He proposes that the evolution of meaning is powered by alternative translation (cf., Alexander's notion of misinterpretation [1.2]), where new interpretants provide additional degrees of freedom of functional responses of agents. Because new translations appear possible due to additional constraints, the evolution of meanings follows a paradox, where "an increase in freedom is only to be achieved through an increase in constraint" [1.42], p. 416.

In his chapter, Robert Prinz [1.56] reviews the relationship between meanings, agents, and codes in biosemiotics and in a more mechanistic theory of *organic codes* (also known as *code biology*), developed mostly by Marcello Barbieri [1.6] [1.7] [1.8] [1.9] [1.10]. The main idea of the theory of organic codes is that

> "Biological codes in this framework are arbitrary connection rules established in evolution through an adaptor that mediates between two other molecules of different type and cannot be explained based solely on physical or chemical laws. All codes in the narrow (Barbierian) sense thus consist of a set of adaptors that map a set of components from one independent world to a set of components from another independent world." [1.56], p. 245.

The notion of organic code provides a useful terminology for describing molecular-level translation processes in living systems such as protein synthesis, protein transport and degradation, mRNA splicing, DNA repair, signal transduction from membrane receptors to the nucleus, and many other molecular processes in cells [1.56]. These coding processes are mediated by adapters (e.g., aminoacyl tRNA synthetase in the genetic code) that specifically bind to coding units (e.g., triplets of nucleotides) and provide links to corresponding molecules of another type (e.g., amino acids). Translation is physically executed by a molecular agent, which Barbieri calls *codemaker,*[4] such as ribosome. Prinz provides an overview of various codes in living systems, including organic codes (at the molecular level) and neural codes (at the level of neurons and neural networks). These types of codes are further divided into structural and regulatory. Prinz argues that Barbieri erroneously ascribes meaning to material molecules (e.g., proteins) or larger units constructed in the course of the code execution. What is missing in Barbieri's theory is the role of these molecules in the life of cells and multicellular organisms, which are higher-level agents. Prinz [1.56], p. 256, proposes extending the code biology theory to the level of organism agents, where meanings appear subjective and agent-dependent:

> The outputs of coded processes are meaningful to the underlying system in terms of persistence, propagation, and survival—necessitating at the same time choices between response options. Meaning reveals two sides here: it is objective through the artifacts or outputs of coded processes, and subjective through the consequences of their readout (or interpretation) by its carrier.

To summarize these approaches: (i) meanings are always associated with agency and its goal-directedness, (ii) meanings are features and relations that are significant for organisms and other kinds of semiotic agents, (iii) by semiosis, meanings are transferred to other agents or subagents, and (iv) meaning keeps changing via evolution, development, and learning through the cycle of translation processes.

1.3 The Origin of Life

How to distinguish semiosis from non-semiotic physical and chemical processes? This question poses a serious challenge because semiotic agents do not contain any supernatural processes that are not physical and chemical, and yet, semiosis is a qualitatively different phenomenon. As the phenomenon of entropy increase in thermodynamics cannot be explained at the level of micro-states, the phenomenon of semiotic agency is associated with higher-level macro-processes that appear to be collectively meaningful. Self-organizing non-equilibrium systems, such as dissipative structures, hurricanes, or flames, somewhat resemble living organisms because they preserve their non-equilibrium state despite perturbations, which is similar to homeostasis in living cells. Some of them can even reproduce (e.g., a flame can split and continue burning in different directions). But this similarity is mostly superficial because self-organizing systems are not goal-directed and their non-equilibrium state is not encoded. Sharov and Tønnessen wrote: "Physical self-organized

[4] This term is somewhat confusing because this molecular agent executes the code rather than makes it. Prinz calls it *code user*.

systems eventually stop functioning without affecting any future self-organizing events, whereas living systems produce the next generation of living systems of the same kind" [1.69], p.127. Similarly, Sukhoverkhov and Gare wrote: "For the origin of life, living systems need, as a prerequisite, chemical autocatalytic circles (sets) with some stable memory-like structures" [1.73], p. 90. A hurricane cannot pass its experience to its progeny hurricanes to increase their stability and spread. Simple self-production (e.g., randomly breaking crystals or division of lipid-world vesicles) is also not sufficient to display goal-directedness. These systems have no means to accumulate memory of their past experience and reuse it to become more efficient in the future.

Although physicochemical self-organized systems do not qualify as living agents, they should have supported the origin of life because living systems could not emerge in a simple environment, such as uniform gas cloud. Howard Pattee [1.53], p. 3, was the first to note that molecules become messages only in a complex and meaningful environment: "[...] the first 'messages' were expressed not in the highly integrated and precise genetic code that we find today, but in a more global set of geophysical and geochemical constraints, which we could call the primeval 'ecosystem language.'" Similarly, John Deely argued that the complexity of environments is increased by "virtual semiosis," which at some point in history ignited the origin of life [1.19], p. 61. This idea is consistent with the emerging relational paradigm in physics, where complex objects are treated as *ontolons*, units of dynamic change, which play the role of primitive observers that keep traces of previous interactions [1.12]. Igamberdiev [1.32], p. 267, explained: "The observers appear as living subjects only at the highest level of organization, while at the physical level they materialize as the dynamic units of complex reality, i.e., the units of dynamic change. It has been suggested to define these units as *ontolons* to emphasize their profoundly ontological rather than epistemological nature." He also proposed that the relational framework in physics needs to be connected with contemporary developments in quantum mechanics. Mikhailovsky [1.46] called such systems *eventities*, whereas Sukhoverkhov and Gare called them *physical memory*. Sharov reformulated the idea of Deely in terms of complexity measured by the number of non-redundant potential meanings relevant for projected physicochemical systems that later gained the capacity of adaptive evolution [1.68]. With the origin of life, some of these potential meanings were converted into actual meanings by being combined into a self-supporting and evolving whole. Other potential meanings became actualized in the subsequent adaptive evolution.

Sharov [1.67] proposes that proto-life emerged in the form of self-producing simple organic molecules capable of *context-sensitive catalysis*. His scenario also assumes agency-niche coupling, where molecular agents modify their local environment (e.g., oil droplets in water) in such a way that facilitates reproduction of these agents in a niche-dependent way. In other words, the function of first primordial agents was *niche construction*.[5] Sharov rejects the hypothesis of primordial soup; he argues that even if such soup was created by some unknown forces, it would immediately degrade due to dilution, hydrolysis, photolysis, and oxidation before any life-like system would be able to emerge in it. According to Sharov, only hydrocarbons (linear, branching, and aromatic) were available as organic resources before the origin of life, whereas all other kinds of organic resources were produced by evolving living systems long after their origin via metabolic pathways that emerged in the course of simplified natural selection without nucleic acids.

[5] This term was introduced by Odling-Smee [1.52].

Similar ideas on the origin of life are discussed by Sukhoverkhov and Gare [1.73], p. 90:

> For the origin of life, living systems need, as a prerequisite, chemical autocatalytic circles (sets) with some stable memory-like structures. Such strictures can preserve and accumulate new (functional) information that is needed to maintain these reproductive circles and provide further cumulative development of such systems [...]

1.4 Semiotic Agency

The fundamental question in biosemiotics is why organisms are capable of semiosis? Sharov wrote that

> [...] organisms are not the only systems that are capable of semiosis because interpretation and production of signs also takes place in organism parts and in multi-organism systems such as colonies, populations, and ecological consortia. Thus, it makes sense to use the notion of *semiotic agency as a generalization of organism in semiotic context*. Sharov and Tønnessen [1.69], p. 153, defined semiotic agents (or simply 'agents') as systems with "a capacity for acting purposefully and using signs to make informed choices." [1.68], p. 143.

Some semiotic agents are not alive (e.g., ribosomes and robots), but they all depend by origin and/or by function on living organisms, and thus, the main assumption of biosemiotics that semiosis is coextensive with life [1.3] [1.38] still holds. Primary agents are defined as those capable of self-reproduction, whereas secondary agents are produced by other kinds of agents (e.g., robots are produced by humans and machines) [1.69]. There is no single component or single function that is uniformly present in all agents. Instead, agency is characterized by end-directed behavior[6] [1.38], p. 171, and autonomy, which means "[s]elf-sufficiency, self-government, and (relative) independence from the environment" [1.69], p. 350.

The importance of the notion of semiotic agency is reiterated in several chapters of this book. Here is a brief summary of novel ideas related to this notion. Norris and Sharov [1.50] consider bacterial cells as "composite agents whose functions are mediated by assemblies of molecules and macromolecules that are termed hyperstructures," which are capable of semiosis, and thus play the role of semiotic subagents. It appears that the network of communicating hyperstructures can support rapid change of cell function in response to stress conditions. Norris and Sharov (ibid., p. 299) wrote:

> The proposed model of *competitive coherence* describes how such a network can assemble and function through two levels of selection among components: certain molecules are selected by signalling of either preceding or co-occurring molecules to form hyperstructures, and certain hyperstructures are selected to produce a phenotype that is consistent with the environment and the needs of the cell.

The model is explained using bacterial cell cycle as an example.

Fomin [1.22] discusses the semiotic nature of memes, a term proposed by Richard Dawkins [1.15] for gene-like units of replication in human culture (e.g., jokes or opinions).

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[6] Also known as goal-directedness, teleology, teleonomy, or normativity.

The peculiar feature of memes is that they are more than signs, and can be also seen as self-reproducing agents that "infect" people and provoke them to spread meme copies. Following the theory of semiotic agency [1.69], Fomin characterizes memes as "a particular kind of secondary subagents [i.e., not self-reproducing] that trigger the production of cultural signs" [1.22]. As signs, memes have distinct external and internal forms: a sign vehicle (e.g., spoken or written) and interpretant (mental), respectively. It is the latter one that functions as a secondary subagent. Sharov and Tønnessen wrote that although sign-role (to signify) and agent-role (to interpret signs and act) are distinct, they can be combined [1.69], as happens in memes.

1.5 Mind and Consciousness

By recognizing the semiotic nature of all organisms, biosemiotics opened a can of worms by initiating discussions on where to place the boundaries of mind, cognition, consciousness, intelligence, sentience, learning, and other notions previously restricted to human mentality.[7] There is also no consensus among biologists on how to define these notions and avoid anthropocentric connotations. The extreme position is attributing cognitive terms to all organisms, including bacteria, whereas moderate approaches suggest applying these terms to certain phylogenetic branches in the tree of life.

Arthur Reber *et al.* [1.58] in their chapter "The Sentient Cell" defend the former approach and argue that "all biological and evolutionary development is directly related to intelligent cells and their suite of sentient, problem-solving behaviors." Components of cellular consciousness include sensing and perception, memory, learning and effective problem-solving using genes and other tools. The existence of perception is supported by the presence of "semantic elements, meaning, and significance for the organism." Learning of cells is inferred from selective growth of slime mold directed by previous experience, and from anticipative response of bacteria exposed to alternating stimuli. According to Reber *et al.*, conscious properties of cells emerged early in evolution in the form of excitable plasma membrane filled with interacting biological macromolecules, which together form a bioelectric field called *senome*. However, authors assume that "non-biological entities cannot become conscious." Reber *et al.* do not deny progressive evolution from primitive cells to more robust and efficient multicellular organisms. However, they assume that "the primate mind, avian cognition, cephalopod mental representations, plant sentience are all varied tokens of an underlying cognitive system that's been an inherent component of all life forms," which is "the *ur*-sentience of prokaryote." In other words, major components of cognition are already present in bacteria, and evolutionary change is mostly quantitative rather than qualitative.

The notion of cognition in bacteria was earlier inspired by James Shapiro's book *Evolution: A View from the 21st Century* [1.63]. In response to critical reviews of his book, Shapiro [1.64], p. 211, wrote: "I described exactly what I meant by cognition (=action based on knowledge acquired through sensing)." In this citation, Shapiro wrote about bacterial

[7] Some of these opinions emerged independently from biosemiotics *per se*, but were inspired by related ideas in second-order cybernetics, systems theory, symbiogenesis, autopoiesis, and extended evolutionary synthesis.

"knowledge" from the third-person's (human scientist') point of view rather than bacterium's first-person experience, which is limited to elementary responses of molecular subagents to incoming signals [1.70].

The idea of minimal cognition in microorganisms is explored by Victoria Alexander in her chapter "Self-reinforcing Cycles and Mistakes: The Emergence of Subjective Meaning" [1.2], p. 326. She wrote that "The activity of slime mold may be considered an example of minimal cognition, displaying chemical memory and adaptable searching behaviors." To support this view she asks "Can it [slime mold] teach itself a new rule or invent a new tool for finding food?" This question draws the line between two "different levels of subjectivity; inherited or habitual and newly formed." To answer this question, Alexander cites a published experimental study, where slime mold changed its preference to temperature depending on the location of food [1.72], and interprets it as classical conditioning. However, authors of the paper do not use the term "conditioning" and describe it as "plasticity,"[8] which I think is more relevant. As discussed in the next subsection, such plasticity is inherited (i.e., prescribed), and usually short-term and low-specific.

In contrast, most biosemioticians do not employ cognition-related terms to describe signaling and regulation of molecular processes in living cells in order to avoid confusion with representational cognition and learning in conscious animals and humans. Instead, the key feature that separates life from non-living systems is *semiotic agency* with its goal-directedness, autonomy, and semiosis [1.67] [1.69]. This terminology helps to avoid over-reaching metaphors and is consistent with von Uexküll's umwelt theory [1.78] [1.79]. Functions of agency are preserved by biological memory/heredity, which is defined by Anton Sukhoverkhov [1.73] "as a set of system processes of maintenance, transmission, and reproduction of living systems by means of heritable genetic and non-genetic information." Then reproduction (and development) appears equivalent to memory retrieval: "The processes of self-reproduction could thus also be viewed as empirically observable and physically (biologically) embodied processes of memory 'retrieval'" (ibid., p. 90).

According to Sharov and Vehkavaara [1.70], semiotic processes in bacteria are much simpler than in eukaryotic cells. Thus, these authors proposed distinguishing two major types of semiosis: protosemiosis,[9] which is responding to molecular signals without perception of objects in prokaryotes, and eusemiosis, which integrates a large set of diverse and patterned signals to yield perception and categorization of objects in eukaryotes, and manifests a primitive mind. Sharov [1.66], p. 487, wrote:

> In protosemiosis, (i) individual signals are processed either directly or via simple logic gates, (ii) no reality is assumed outside the cell as a source of receptor excitation, and (iii) signals are processed in a threshold-based way. In contrast, eusemiosis, which is equivalent to minimal mind, includes (i) rich and diverse sensory input that is filtered via cascades of signaling networks, (ii) capacity to attribute sensory patterns to objects in the environment, and (iii) categorization of objects based on patterns of sensorial stimuli.

Neural version of eusemiosis is an important evolutionary transition that can be called "cognition" [1.66]. Nerves support fast signaling between organs and sensory-motor

[8] In an earlier publication, Shirakawa *et al.* [1.71] call it "associative learning" and compare it to Pavlovian conditioning.

[9] The term was introduced by Prodi [1.57].

connections. Early forms of cognition are based on innate classifiers and simple reflexes, which are further tuned by habituation and sensitization.

The dominating view in biology is that consciousness exists only in animals with a nervous system and strong integration between sensory, motor, memory, and value-generating processes [1.20]. More recently, Ginsburg and Jablonka [1.25] proposed that the core feature of consciousness is Unlimited Associative Learning (UAL), which is an "open-ended, representational, generative, and recursive form of associative learning" [1.34], p. 401. These authors wrote that consciousness is found in three lineages of animals: vertebrates, some arthropods, and some cephalopods. Similarly, Hoffmeyer and Stjernfelt [1.31] place learning, sentience, and consciousness at the highest levels of the "great chain of semiosis," well above the molecular recognition and eukaryotic cell levels (cf. [1.43]).

Despite the progress in biology, it is still not clear how the brain can support consciousness. The widely accepted connectivism paradigm, which claims that "brain's entire knowledge and thinking skills are [...] stored in the connections; and the mental operations are executed by network computations" [1.48], fails to explain the *scaling problem* of consciousness. The problem is that doubling the number of recognized objects requires as much as a ~500-fold increase in computing resources, whereas the brain handles functional complexity in a more economical way (ibid.). Nikolić [1.48] hypothesized that in addition to synaptic connectivity, consciousness is supported by the activity of neurons themselves, which can selectively activate or repress their dendritic branches via metabotropic receptors and G protein-gated ion channels. These changes can modify the activity of other neurons through synapses, and thus, specific neural subnetworks can be organized by multimodal states of individual neurons. This hypothesis is consistent with the previously discussed mechanism of dendritic computation [1.40].

Alternatively, there were attempts to explain the function of consciousness by quantum mechanics effects within microtubules composed of tubulin protein molecules [1.27] [1.28], which are present in axons and dendrites of neurons. In his chapter [1.75], Jack Tuszynski explored information processing rates in microtubules and came to the conclusion "that tubulin is not likely to operate at a quantum level if its functions include information storage and processing." However, the model indicates that "ion channels, if synchronized may be able to operate at a quantum mechanical regime." The latter conclusion is interesting because it opens a possibility that G protein-gated ion channels, identified by Nikolić as potential operators of consciousness (see above), can be synchronized and act in the quantum mode.

1.6 Semiogenesis and Learning

The term "learning" emerged in relation to the human mind, but then its meaning was extended to animals, other organisms, and even to computers and robots. Jablonka and Ginsburg [1.34] define learning as "a process leading to an experience-dependent behavioral response of a system." A similar definition of learning is found in the chapter by Caetano-Anollés [1.13], p. 229: "system's use of information obtained during one interaction with its environment to improve performance in future interactions." Although such broad definition of "learning" is relevant in systems theory, it may appear confusing in biology. For example, biologists prefer distinguishing between learning and evolution, although natural

selection fits the definitions of learning mentioned above. Thus, Sharov and Tønnessen [1.69] propose using the term "semiogenesis" for all learning-like processes, including natural selection; and reserve the term "learning" for "development and storage of non-innate interpretation mechanisms, which generally require representational cognition. Learning is opposed to adaptive plasticity, which is based on an innate program." Thus, semiogenesis includes adaptive evolution, development, plasticity (e.g., habituation and sensitization), and learning.

The dominating evolutionary theory, known as "Modern Synthesis" is based on the gene-centric paradigm, which is radically mechanistic. It assumes that natural selection is a passive sieve of genetic alleles, differentiated according to their propagation rate in a population, called "fitness." According to Modern Synthesis, genes are passively copied, and their interpretation (i.e., semiotic function) is ignored [1.49]. An alternative approach was developed by Jesper Hoffmeyer and Claus Emmeche [1.30] in their "code-duality" paper, where they argue that genes (and other signs) are used by organisms in two different ways: as digital units that can be stored as memory and copied, and as analog functional forms that represent parts of a semiotic agent (cell or organism). These two representations are interdependent because the digital code can be translated into analog functional subagents, and these subagents support both copying of the digital code and its translation into functional units. Thus,

> [...] heritability of phenotypes across generations cannot be explained by the transfer of genetic information. Another and equally important channel of heredity is represented by agents capable of reading and interpreting genetic information together with necessary tools and scaffolds within cells [1.65], p. 213.

Sharov [1.68] discusses three examples of simple, intermediate, and complex biological memory: plasticity of chemoreceptor sensitivity in bacteria, hereditary function of the genome, and distributed memory in the nervous system. He emphasizes that memory may include passive potential signs that do not signify their meaning unless activated by subagents guided by syntax-signs. Sukhoverkhov and Gare [1.73], p. 91, noted that "some forms of behavior and cognition are acquired and transmitted throughout generations not via the internal, genetic (epigenetic) memory, but through the *external* behavioral, ecological and cultural 'inheritance systems' (Jablonka, Lamb), 'semiotic scaffoldings' (Hoffmeyer), or 'developmental niches' (Stotz)."

There is no doubt that bacteria have long-term genetic and epigenetic memory, as well as short-term operational memory (e.g., adjustable chemoreceptor sensitivity). But there is no consensus on whether bacterial cells are capable of learning. Reber *et al.* [1.58] and Norris [1.50] assume this capacity in bacteria is based on the system's theory definition of learning. In contrast, Sharov assumes that innate plasticity (habituation and sensitization) is responsible for adjusting of chemoreceptors sensitivity, and this effect is not true learning "since bacterial cells 'learn' only those signals for which they already have specialized devices" [1.50]. He also rejects claims that bacteria are capable of Pavlovian conditioning:

> Mitchell *et al.* [1.47] showed that *E. coli* can learn to anticipate carbon source change after exposure to another stimulus. However, in contrast to Pavlovian conditioning which develops within one and the same animal, bacterial "conditioning" requires hundreds of generations. One conclusion could be that this phenomenon is an example of associative natural selection rather than associative learning (ibid., p. 318).

Modulation of slime mold's response to temperature in the experiment of Shirakawa and Sato [1.72] also does not qualify as Pavlovian conditioning. By default, slime mold avoids cold temperature, but if the nutrient (oatmeal) is placed in the cold area far away, then after some time the slime mold overcomes the inhibition and moves into the cold area. This effect, however, is not the result of associative learning, but instead is caused by hunger and stress, which jointly repress the reflex of avoiding the cold. In behavioral studies, such effect is known as dominance [1.61], when a stronger stimulus (in this example – hunger) non-specifically overrides weaker stimuli, including temperature preference. Dominance has a short-term and low-specific effect in contrast to conditioning that is supported by long-term specific memory [1.25].

True learning (i.e., excluding plasticity) requires a strongly integrated nervous system with brain and represents another evolutionary transition towards learning-based cognition which is called consciousness [1.25] [1.66]. I agree with Jablonka and Ginsburg [1.34] that the main feature of consciousness is integration of multiple stimuli coming from diverse sense organs, or stimuli composed of multiple spatial or temporal elements. Neural integration helps sentient animals to combine elemental actions into new activity patterns and relate them to the perceived context.

According to Ginsburg and Jablonka [1.25], learning is based on the "exploration-stabilization" principle, which is the extension of the more known "variation-selection" principle in evolution. Exploration-stabilization requires agency for its both components. Exploration is represented by copying genetic mutations, sensing changes in the environment, locomotion, establishment of synapses between neurons, and free will in behavior and communication. But it can be supported also by non-agential fluctuations and processes (e.g., Brownian motion). Examples of stabilization are the system of genetic heredity supported by DNA replication, transcription, and translation. Other stabilization systems include epigenetic heredity [1.33] [1.35], developmental regulation [1.82], and neural memory [1.24]. An important addition to this principle, in relation to evolutionary and developmental growth, is proposed by Caetano-Anollés [1.13], p. 220, who developed a biphasic model of unification-diversification:

> This model predicted both the evolutionary establishment of nested arrangements (hierarchies) of modules, and the formation of tightly linked modular groups by convergence under optimization or selection. [...] The biphasic model creates novelty via two evolutionary phases that are often asynchronous. In Phase 1, parts associate in different combinations but are weakly linked to each other. [...] In Phase 2, evolutionary variants of the newly constructed modules diversify and become new parts of modules populating higher-level organization.

This model means that stabilization opens up new possibilities and is followed by a new round of diversification at the emerged level of integration. Caetano-Anollés illustrated this model by the evolution of the F_1/F_0 ATP synthase complex, and by the construction and reconstruction of the Empire State Building in New York city.

One of the fundamental problems of semiogenesis is the source of qualitatively new adaptations that cannot be reduced to quantitative adjustment or optimization of already existing functions. Interestingly, Alexander [1.2], p. 328, assumes that truly novel behaviors appear through *mistaken* choices: "When the organism takes a new direction, it forges a new path. I call this *misinterpreting*." Mistaken choice brings qualitatively new solutions

in contrast to trial-and-error learning which "only helps the agent make gradual improvements on an already existing tool or procedure or just helps the agent find an optimal strategy for reaching its usual, pre-defined goal."

Organisms can improve learning by using learned models, which is one of the mechanisms of "learning to learn" [1.11], p. 173. The expression "learned models" is crucial because innate models such as simple reflexes do not provide sufficient flexibility and context. According to Sharov and Tønnessen [1.69], p. 249, "models are generalized representations [...] that remain true or bring success in a large number of similar situations." By using models, animals and humans can verify their perceptions and anticipate context-dependent outcomes of their activity. An important milestone in exploring the use of models was the development of the Modeling Systems Theory by Sebeok and Danesi [1.60].

In his chapter [1.84], Hongbing Yu explores one kind of model: modeling of danger in animals and humans. He distinguishes semiotic roles of models and signs: "models supersede, whereas signs signify." Model supersedes in the sense that it is a part of subjective existence when it is "brought to the front for salience, accessibility, and operability." Using the well-known fable of "cry wolf" he explored several aspects of the associated danger model, which, besides the danger of a wolf itself, includes "the danger of losing others' trust as a result of raising false alarms." The model uncovers the "reality-vs-illusion" dichotomy and appeals to certain social rules of conduct.

Models are routinely used for logical inference, such as deduction, when the conclusion is derived from premises (e.g., causing factors), or induction, when a general principle is uncovered in multiple observations. In both cases, the model remains in place and just applied to different objects or situations. To these kinds of reasoning Charles Peirce added *abduction*, which takes place when the model is absent and needs to be suggested to explain a given observation or set of observations [1.54], CP 5.189. Lorenzo Magnani [1.41] considers two major kinds of abduction: selecting from the set of known models – selective abduction, or constructing a new model from scratch – creative abduction. All three types of logical inference can be found in both innate models and learned models. The only difference is that abduction with innate models may require many generations and thousands of years of evolutionary change, whereas abduction with learned models can be achieved much faster, especially by humans. For example, chess players select reasonably good moves in unique positions within a minute.

The main topic of Magnani's chapter is niche construction, and specifically, cognitive niche construction. Niche construction theory has been pioneered by Odling-Smee *et al.* [1.51]. The idea is that "while organisms adapt to their environments, they also adapt to environments that they or other organisms create" [1.41]. Examples include bird nests, spider webs, and termite mounds. Magnani proposes that natural "selection favors *purposive organisms*, that is, good niche constructors."

Niche construction is especially important for conscious animals and humans because they modify their environment consciously, and thus changes in their knowledge and experience is remembered and applied systematically to their future activity. In addition, many conscious species imitate each other's behavior, which results in a socially supported hereditary habit. Cognitive niche includes artifacts that serve as "anchors of meaning" that help to acquire or store knowledge and working skills. Magnani assumes that cognition is spread across individuals, objects, artifacts, and external representations. This makes cognition distributed as it includes the following components systematized by Sutton [1.74]:

> 1) external cultural instruments and devices, artifacts, and symbol structures; 2) natural environment elements appropriately enriched with cognitive value; 3) intersubjective and social distribution or the so-called cognitive "scaffolding"; 4) embodied capacities and skills intricately entwined with our use of technological, natural, and social resources of the preceding cases; 5) internalized cognitive artifacts [1.41], p. 389.

The most remarkable component of human cognitive niche is natural language:

> The human process of constructing cognitive niches—for example, we can immediately anticipate that, in the case of human animals, natural language is a fundamental example of a cognitive niche—is a useful further integration of the intellectual framework [...] [1.41], p. 381.

Human cognition cannot be explored without considering its collective nature. Sukhoverkhov and Gare [1.73] wrote: "we need to admit that at some stage of evolution, the individual 'umwelt bubble' became collective and shared as a 'mitwelt.'" They considered social systems as higher-level distributed agents: "in addition to retrospective and historic approach to memory, this research proposes to study social memory also as 1) actual cumulative and distributed system processes that are maintained over generations and 2) semiotic processes and structures responsible for the production and re-production of the social system." Human society is integrated by communication and language, and Sukhoverkhov and Gare discuss the problem of how language could emerge without pre-existing language, a sort of chicken-and-egg dilemma. They wrote: "the language had to emerge in social reality *ex nihilo* and people were able to understand each other *naturally* without any socially imposed conventions or agreements." Such communication can start from reciprocal actions alone and then gradually transform "into more culture-specific, conventional (artificial, arbitrary) systems that require teaching and learning."

1.7 Global Dimensions of Biosemiosis

Similar to physics, which was initially focused on objects around us and then appeared relevant for distant star systems and galaxies, principles of biology and semiotics are ready to become global and applied to the extraterrestrial biospheres and habitable exoplanets. One such process is complexification of some components of the universe [1.45], which inadvertently prepared conditions for the origin of life. Deely [1.19] called it physiosemiosis, Sukhoverkhov and Gare [1.73] – physical information, Deacon [1.18] – medium or signal properties, and Sharov [1.68] – potential meaning (assigned retrospectively by humans). Mikhailovsky [1.46] considered hierarchogenesis in the combined physical and biological evolution.

The discipline of astrobiology emerged in the 1960s and 1970s together with the start of space exploration [1.14]. But initially it was mostly focused on empirical problems. Now, however, after we have realized that life has a semiotic nature and biosemiotics was born, it is time to start the analysis of meanings in the global dimension. There are many habitable exoplanets in our galaxy and beyond [1.26], and it is highly likely that a large portion of them carry microbial life because microbes are highly adaptable to extreme conditions [1.59] and hypothetically can travel in space on asteroids and rogue planets [1.5] [1.81].

In light of these discoveries and hypotheses, the call of Julian Chela-Flores [1.14] and Yogi Hendlin and Constantijn-Alexander Kusters [1.29] for the development of "astrobiosemiotics" appears quite timely. Chela-Flores discusses philosophical overlapping of humanities and astrobiology, and in particular, the relevance of the Singer's principle of equality, an ethical position that interest of non-human animals have equal weight to human interests. Chela Flores extends this principle to all forms of life because of the phenomenon of evolutionary convergence that constrains randomness, and according to which many lineages of life follow a trend that may lead to consciousness. He cites Christian de Duve [1.16], p. 291: "Life is an integral part of the universe; it is even the most complex and significant part of the known universe."

Hendlin and Kusters [1.29] extend further the ethical challenges of space exploration. They develop the line of argument that modeling of danger needs to be applied to extraterrestrial life, and doing this can be learned by caring about earthly life. They wrote: "Slow space exploration—starting with stabilizing the biotic conditions on our own planet—presents a biosemiotically-informed perspective on how organisms of various complexities can fit with (drastically) new environments with different temporal needs" [1.29], p. 453. The authors draw attention to the difference in developmental and evolutionary plasticity of various kinds of organisms, which may affect the change of biosphere on earth and exoplanets. These differences can be addressed by assuming agent-specific time scales, as proposed by Bergson in contrast to the physical notion of universal space-time or its relativistic modification [1.29]. The difference in temporal scales may cause unpredictable consequences in cases of symbiosis or mutualism between organisms from far-separated branches of the evolutionary tree, such as microbiota of prokaryotes inside various organs of animals and humans. Such interaction poses a challenge for predicting health and cognition consequences for host organisms. Besides different rates, agent-specific time is characterized by different "thickness" as proposed by Whitehead, which represents organism capacity to recall its past experiences and apply this information for anticipating the future. Hendlin and Kusters wrote:

> Taking both Bergson's and Whitehead's critique to heart, we must try and move away from the idea that any one model can span the variations which space-time might play in all possible biological relations. Moving towards a less anthropocentric and more pluralistic understanding of time experience might thus be illuminating in situations where a general theory of relativity might come up short explanatorily, such as in the cases of lifeworlds [1.29], p. 460.

1.8 Conclusions

This book shows an example of how the study of meanings crosses traditional bounds of semiotics and humanities, and can be applied to various fields of biology (molecular biology, physiology, ecology, neuroscience, evolutionary biology, and astrobiology), cognitive science, physics, cybernetics, logic, and artificial intelligence. This interdisciplinary project attempts to bridge the *great paradigm divide* and contribute to integration of natural sciences with semiotics. In particular, it explores the objective-subjective duality and offers

new balanced versions of semiotic realism that acknowledge agent-specific subjectivity and the growth of objective meaning through semiotic interaction. An important achievement is the discussion of different levels of semiosis (e.g., protosemiosis, eusemiosis, cognition, and consciousness) and semiogenesis (e.g., natural selection, plasticity, and true learning). Finally, this book opens a perspective for the development of astrobiosemiotics, where meaning is systematically studied in the context of cosmic conditions and processes.

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