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ORIGINAL PAPER

A Theory of Life as Information-Based Interpretation of Selecting Environments

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Abstract This essay employs Charles Peirce's triadic semiotics in order to develop a biosemiotic theory of life that is capable of illuminating the function of information in living systems. Specifically, I argue that the relationship between biological information structures (DNA, brains, and human languages), selecting environments, and the adapted bodily processes of living organisms is aptly modelled by the irreducibly triadic relationship between Peirce's sign, object, and interpretant, respectively. In each instance of information-based semiosis, the information structure (genome, brain, or language) is a complex informational sign that represents the informational object (the present environment according to the respects in which recurrent features of the selecting environment have proved salient over the course of a history of natural selection); and the bodily, behavioral, mental, or intellectual processes that are organized by the informational sign to more or less accurately interpret the present environment constitute a complex informational interpretant—a living, interpreting organism. The essay begins by discussing the precise sense in which this biosemiotic theory is based upon Charles Peirce's semiotic theory. Next, the theory is developed at length in relation to genetic information structures. Finally, I present a brief outline of how the theory applies to neural and linguistic information structures. The essay concludes with a reflection upon the anti-reductionist implications of the theory.

Keywords Information · Interpretation · Semiosis · Charles sanders peirce · DNA · Brain · Language

Introduction

The fundamental explanandum of biology, both ancient and modern, is the dramatic contrast between the end-directed design of living things and the purposeless entropic decay that characterizes all non-living physical-chemical systems. In general, contemporary biological theory explains this contrast in two basic ways: by explaining in meticulous biochemical

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detail how specific biological processes work and by explaining why biological processes result in organisms designed to fit a particular environment on the basis of a mathematically sophisticated, population-based theory of natural selection. These two remarkably successful explanations naturally belong together, but their explanatory unification requires an adequate conception of "information". Because every adaptive phenotypic process is counterfactually dependent upon genetic information and every organism's genetic information is counterfactually dependent upon a history of natural selection, "information" is the conceptual hinge on which contemporary biological explanation turns. I agree with others in the biosemiotics community (Deacon 2010, 2012; Arnellos, et al. 2012) that non-semiotic definitions of information, usually derived from Claude Shannon's (1948) work in information theory, fail to facilitate this explanation. As Eva Jablonka (2002: 579) pointed out, according to purely mathematical or thermodynamic conceptions of information, a nonsense sequence of nucleotides that fails to produce a functional enzyme carries just as much information as an equal length sequence of nucleotides used to construct a functioning enzyme. Anyone concerned to explain the contrast between end-directed life and purposeless chemistry must find such conceptions of information hopelessly inadequate.

The purpose of this essay is to present a semiotic conception of information and life that is capable of unifying the types of biological explanation introduced above. Specifically, I will argue that living systems are information-based interpretations[1] of selecting environments, or, using modified Peircean terminology, living systems are complex informational interpretants that collectively interpret the present environment (informational object) as it is represented by complex informational signs (including at least DNA, brains, and human languages). The essay is organized into four sections: (1) a discussion of how the theory relates to Charles Peirce's semiotics; (2) an application of the theory to genetic information; (3) an outline of how the theory applies to neural and linguistic information structures; (4) a concluding reflection on the anti-reductionist implications of the theory.

How this Theory Relates to Peirce's Semiotics

Restricted Continuity Between this Theory and Peirce's Philosophy

Although I think the wider implications of this theory resonate harmoniously with Peirce's overarching philosophical system, only a very restricted continuity with Peirce's semiotic theory is essential. Specifically, that continuity is expressed in the claim that the relationship between biological information structures, selecting environments, and the adapted bodily processes of living organisms is aptly modelled by the irreducibly triadic relationship between sign, object, and interpretant in Peirce's semiotic theory. Focusing only upon the core triad of Peirce's semiotics comes with risks, but the strategy is ultimately necessitated by the present theory's emphasis upon the biological information structures that ground living semiosis.

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[1] I refer to organisms as interpretations rather than interpreters to emphasize the point that interpretation is not in the first instance something organisms do, but the process by which organisms are constituted. Every discrete process that is organized on the basis of information constitutes an interpretation of the selecting environment. Considered as the integrated complex of all these underlying interpretive processes, an organism can be thought of as an "interpreter", but there is no "interpreter" that is separable from these more basic interpretations.

The primary risk of this restricted focus is that it will obscure the richness and depth of Peirce's semiotic theory by isolating it from the rest of his thought. Because he was a brilliant systematic thinker, Peirce's semiotic theory is deeply integrated with other key elements of his overall philosophy such as his metaphysics of firstness, secondness, and thirdness (Peirce 1998, EP 2.160–178); his logical theory (EP 2.267–288); and his pragmaticism (EP 2.398–433). Thus, discussing Peirce's semiotics in isolation from the rest of his philosophy inevitably obscures the inter-theoretical connections that imbue his semiotic theory with robustness and depth.

Despite this risk, restricting this essay to the triadic core of Peirce's semiotics is necessary to prevent confusion. The triadic semiotic relationships that are central to the present theory are not the same as the triadic relationships that were the focus of Peirce's own semiotic theory. As discussed below, Peirce attempted to ground his semiotic theory in the structure of the brain, but he did not develop a semiotic theory that explicated the triadic relationships between biological information structures, the selecting environment, and the adapted bodies, behaviors, experiences, and thoughts of living organisms. To sustain this distinction, I will refer to the triadic relations just mentioned as informational semiosis; information structures like DNA, brains, and languages as informational signs (sign_i); the environment as it is represented by biological information structures as the informational object (object_i); and the bodies, behaviors, experiences, and thoughts that constitute organisms as informed interpretations of selecting environments as informational interpretants (interpretant_i). When the terms sign, object, and interpretant are used without subscripted 'i's, I intend to refer to the elements of Peirce's mental model of semiosis, or any other model of semiosis that fits what I describe as "secondary semiosis" in section 1.3., below.

The Basic Continuity Between this Theory and Peirce's Semiotics

This theory of informational semiosis employs Peirce's core triad of sign, object, and interpretant to develop a biosemiotic theory of life that is capable of illuminating the function of information in living systems. Focusing on DNA, the basic claim is that an organism's DNA is a complex[2] sign_i that represents the present environment[3] according

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[2] It may be more intuitive to think of an individual gene as a sign, as do El-Hani et al. (2006): 21. However, the expression and splicing of individual genes varies profoundly depending upon the larger genetic, phenotypic, and environmental context (Sober and Lewontin 1982; Griffiths and Gray 1994; Sterelny 2000; El-Hani, et al. 2006) and individual proteins often play multiple roles in different parts of a cell or multicellular organism. Thus, genes are components of the massively complex functional system of the entire cell, which depends upon the entire complex of genes in the DNA. I therefore prefer to conceptualize both the bodily interpretants and the informational signs as complex wholes, irreducible to functionally meaningful parts.

[3] The selecting environment includes all factors in all past environments that were potentially relevant to determining the differential reproduction of the information structures possessed by an organism. In terms of genetic semiosis, only reliably recurring, highly salient affordances and threats will drive adaptation and come to be represented in the DNA; these recurrent, salient features of the selective environment, as they are represented by the DNA, constitute the genetic object_i. The present environment is the selecting environment for an individual organism, and it is always more than and sometimes different than (due to recent geological or ecological changes) the sign_i represents it to be. The distinction between the selecting environment and the object_i corresponds to Peirce's distinction between the dynamical object and the immediate object, respectively (EP 2:495). Moreover, the object_i is basically equivalent to von Uexküll's (1940) "Umwelt". An organism interprets only those features of the environment that are represented by the information structures by which it is constituted, which is to say that the organism is only equipped to interpret those recurrent affordances and threats that have proven salient over the course of various information-generating processes of natural selection.

to the respects in which recurrent features of the selecting environment have proved salient over the course of a history of natural selection (object$_i$), and that the organism's adapted body is a complex interpretant$_i$ that interprets the present environment as it is represented by the sign$_i$ of DNA. This matches the essential relations in Peirce's semiotics wherein a sign represents an object and the interpretant constitutes an interpretation of that object as it is represented by the sign. The present theory also agrees with the basic relations of determination in Peirce's theory: "I will say that a sign is anything, of whatsoever mode of being, which mediates between an object and an interpretant; since it is both determined by the object relatively to the interpretant, and determines the interpretant in reference to the object, in such wise as to cause the interpretant to be determined by the object through the mediation of this 'sign'" (EP 2.410). In the case of genetic information, it is the selecting environment that determines the genetic information (via selection of interpretants in ancestral environments), which in turn determines the adapted body; thus, the adapted body is determined by the selecting environment through the mediation of genetic information.

Most importantly, the present theory affirms the irreducibility of the triadic relations between sign, object, and interpretant in Peirce's theory. According to Peirce (1998),

> [a]ll dynamical action, or action of brute force, physical or psychical, either takes place between two subjects,—whether they react equally upon each other, or one is agent and the other patient, entirely or partially,—or at any rate is a resultant of such actions between pairs. But by "semiosis" I mean, on the contrary, an action, or influence, which is, or involves, a cooperation of three subjects, such as a sign, its object, and its interpretant, this tri-relative influence not being in any way resolvable into actions between pairs". (EP 2.411)

This point is crucial and represents the dividing line between non-semiotic and semiotic conceptions of life and information. Restating Peirce's point in terms of genetic information, an adapted body, and a selecting environment—no two-part relation among these three is genuinely explanatory. One cannot explain why an adapted body fits an environment without reference to genetic information, why decoding genetic information produces an adapted body without reference to past selection pressure from the environment, or why certain genes were selected by the environment without close attention to the fallible fitness of living organisms.

Information-Based Semiosis in Peirce's Thought

In this section, I argue that the core idea of the present theory of information-based semiosis was first suggested by Peirce. Generally speaking, Peirce assumes a "mental model" of semiosis: not only did Peirce regularly define his semiotics such that the interpretant of a sign is an "idea in a person's mind" (Peirce 1992, 1998, EP 2.482, 1.38, 2.492–3), but his consistent model of semiosis begins when the interpreter encounters an external sign which is taken to be about some object, the sign is cognized by the interpreter via the production of internal mental interpretants, these mental interpretants become signs in a further sequence of mental semiotic processing, and, finally, the entire process culminates in a concrete behavioral response (the final interpretant) to the external object as it is represented by the sign (Short 2004). When the same behavioral response leads repeatedly to successful interpretation, the behavior becomes ingrained as a "habit".

Peirce's account of mental semiosis, on its own, does not constitute a satisfying explanation. Rather, the familiar phenomenon of mental semiosis depends upon a process of informational semiosis whereby information evolves in the physical structure of the brain throughout the course of the organism's lifelong interpretation of the environment. Thus, a temporally-proximate process of mental semiosis like seeing an apple can only be fully explained by embedding it within a temporally-extended process of neural informational semiosis whereby the brain developed to permit sight. This may sound like a radical rejection of Peirce's semiotic theory, but Peirce himself expressed a similar view and hypothesized a physical, neural grounding for mental semiosis.

In his 1887–8 essay, "A Guess at the Riddle", Peirce (1992) not only argues that mental semiosis depends upon the brain (EP 1.262), but he also lays out five basic principles that would cause the structure of the brain to evolve such that it would regularly produce adaptive responses to the interpreted environment (EP 1.264–5). In other words, Peirce sought to ground his concept of a mental "habit" in an evolving neural architecture. Expressed in updated terminology, the five basic requirements for the structure of the brain to evolve according to its capacity to produce adaptive behavioral responses are: (1) synaptic connections linking neurons are initially established via a chance process; (2) a tendency for a firing neuron to increase (or decrease in the case of inhibitory neurotransmitters) the activity of those neurons whose dendrites receive input from the initial neuron; (3) the cessation or relative abatement of neuronal signaling upon the removal of the stimulus that first initiated neuronal firing; (4) the tendency for synaptic connections that are repeatedly used to be reinforced (via long term potentiation); and (5) "a principle of forgetfulness" (Peirce 1992, EP 1.265) whereby unused synaptic connections are pared away. Each of these requirements is supported by contemporary neuroscience so that Peirce's early hypothesis remains plausible today.

The present theory of informational semiosis is an attempt to expand and develop this early insight of Peirce's. Just as Peirce (1992) sought to ground "the cloudiness of psychological notions" (EP 1.292) in the evolving structure of the brain, the present theory argues that every instance of semiosis depends upon evolving information structures that form living bodies, behaviors, experiences, and thoughts so that they fit the interpreted environment. Peirce also speculated about the basis of the interpretive powers of "protoplasm", (EP 1.268–70, 1.341–8) but, with no knowledge of DNA, he was unable to imagine the informational ground of this form of brainless semiosis. Using the pattern Peirce established between the mental semiosis and the brain, I will argue that all cellular semiosis is grounded in the evolving information structure of DNA and that the uniqueness of human behavioral and mental life depends upon the evolving information structures of human languages.

Formalizing the Distinction Between Primary Semiosis and Secondary Semiosis

In this section, I draw a formal distinction between the two interdependent types of triadic semiosis suggested in the previous section and argue that this distinction helps to clarify a persistent confusion in the literature of biosemiotics.

The first type of semiotic triad is primary semiosis or informational semiosis, which is illustrated above by the temporally-extended process by which the neural architecture of the brain evolves. The next two sections of this paper are devoted to explaining the processes of genetic, neural, and linguistic primary semiosis, so here I will only specify the triadic relations involved. In each of these three instances, the information structure (genome, brain, or language) is a complex sign_i that represents the object_i (the present environment according to the respects in which recurrent features of the selecting environment have proved salient over the course of a history of natural selection); and the bodily, behavioral, mental, or intellectual processes that are formed by the sign_i to interpret the present environment constitute a complex interpretant_i—a living organism. As discussed below, in each case these triadic relations are established via a temporally-extended process of natural selection.

The second type of semiotic triad is secondary semiosis, which is illustrated above by Peirce's mental model of semiosis. Secondary semiosis involves a discrete interpretive event which occurs over a relatively short span of time. Secondary semiosis encompasses all the concrete processes by which an organism encounters and interprets itself or its environment; thus, secondary semiosis could also be labeled "actual" or "manifest" semiosis. The triadic relations involved in secondary semiosis are as follows: some physical contact is made between an informationally-structured receptor (for instance, a receptor protein in the cell membrane of an immune system B-cell (Arnellos, et al. 2012: 352–3) or a cone in the human retina) and a recurrent feature of the internal or external (see note 5) environment (for instance, an antigen or a photon). This contact event constitutes an initial sign, which initiates a complex signaling cascade (beginning, for instance, with the release of a second messenger inside the cell membrane or with the passive diffusion of electric current from the cone into bipolar cells and horizontal cells in the retina). The signaling cascade eventually results in some behavioral or mental response—the final interpretant—that helps the organism avoid the threats and utilize the affordances in the present environment (for instance, the destruction of a nearby pathogen or the visual perception of an apple).

Every instance of secondary semiosis depends upon a process of primary/informational semiosis of which the instance of secondary semiosis is a concrete, local, and brief expression. Thus, every instance of secondary semiosis is a reliable indicator that a temporally-extended process of primary semiosis is continuing at the organism's informational core. Because primary semiosis is a process that depends upon a source of environmental selection pressure, primary semiosis only takes place via countless concrete instances of secondary semiosis. These concrete instances of secondary semiosis serve as the locus of the actual selection pressure that drives primary semiosis, which proceeds abstractly over the course of thousands of interpretive iterations (living generations, firings of the synapse, or uses of a word, phrase, sentence, or theory). In other words, every time a protein plays a functional role in some cellular process, it becomes a locus of potential selection pressure in the temporally-extended process of genetic primary semiosis which occurs during thousands of living generations. Every time a neurally-mediated behavior or experience interprets the environment it becomes a locus of potential selection pressure in the temporally-extended process of neural primary semiosis which occurs during the course of the animal's life. Similarly, every instance of language-use—whether spoken, written, or internally thought, forms behavioral, mental, and intellectual interpretants, which become loci of potential selection pressure in the temporally-extended process of linguistic primary semiosis that occurs during the centuries and millennia of a culture's history. Thus, primary and secondary semiosis constitute two distinct types of triadic semiosis, which are mutually dependent upon one another and, therefore, always found together.

This distinction between primary and secondary semiosis helps to illuminate a problem in biosemiotics that was recently highlighted by Marcello Barbieri (2013). According to the distinction introduced above, the basic problem is that biosemioticians regularly highlight instances of secondary semiosis without grounding those instances in the processes of primary semiosis that make semiotic language genuinely explanatory (see, for instance, Hoffmeyer 2008; Arnellos et al. 2012; Brier and Joslyn 2013). In other words, these theorists appeal to Peirce's mental model of semiosis without realizing, as Peirce did, that this model ultimately requires further explanatory grounding in some process of informational semiosis.

For example, Arnellos and colleagues describe in great detail the chemical processes that result when an antigen binds to a receptor protein on the cell membrane of an immune system B-cell (2012). Consistent with the model of secondary semiosis introduced above, they interpret the antigen (or, more precisely, 'the event of the antigen binding to the protein') as a sign that refers to the presence of the pathogen in the environment (object), which is interpreted by a complex signaling cascade that issues in a final interpretant (presumably the destruction of the pathogen) that adaptively orients the organism to a threat in its environment. The problem is that after one has assigned these semiotic labels, the biochemistry that actually explains these processes remains the same. The net result is that already complex biochemistry is further complicated by the introduction of Peirce's semiotic terminology, yet the scope and depth of explanation matches standard biochemical accounts. As Barbieri points out (2013), one cannot explain apparently interpretive processes by merely attaching a semiotic vocabulary. While something "seems" to be getting explained, this impression depends entirely upon the employment of a mental model wherein the receptor protein "recognizes" the antigen as a sign "representing" or "indicating" a pathogen via its "molecular form" (ibid., 353). The process is apparently similar to when a human being recognizes the form of a shoeprint in the mud as a sign representing or indicating that another person recently stepped there, but, without eyes and a brain, I see no reason to attribute such advanced intelligence to receptor proteins. Apart from this implicit attribution of intelligence (which I doubt Arnellos and colleagues would actually defend), all of the explanatory work is accomplished using standard biochemical tools.

In terms of the present theory, the solution is to ground the semiotic terminology used in this instance of secondary semiosis in the process of primary semiosis by which the receptor protein (and the rest of the proteins involved in the complex signaling cascade) was formed to fulfill this adaptive function. Secondary semiosis is the actual concrete interpretive process, but primary semiosis is the process that explains and grounds the semiotic relations in secondary semiosis.

Illustrating the Theory with Genetic Information

The present theory strongly affirms other theorists' (Anderson, et al. 1984; Sebeok 2001; Battail 2009, 2011) insistence that information marks the boundary between life and non-life, i.e., between the end-directed organization of living systems and the purposeless entropic decay that characterizes all non-living physical-chemical processes. Of course, this statement is not very meaningful until one provides a theoretically grounded definition of information. On one hand, the present theory is focused upon biological structures—like DNA, brains, and human languages—that appear from the perspective of information theory to be exquisitely adapted to accurately transmit massive amounts of information (see Bergstrom and Rosvall 2011: 167 concerning DNA; Marois and Ivanoff 2005: 296 concerning brains; Deacon 1997: 321–375 concerning language). On the other hand, the present theory insists that we cannot fully understand biological information structures unless we can specify how this information informs some interpreter about something else.

As the terms "fitness" and "adaptedness" imply, every living organism bears the imprint of the selecting environment upon its adapted body. Whence this design, this intricate structural and behavioral organization that allows organisms to maintain and replicate themselves by utilizing environmental affordances and avoiding environmental threats? On this theory, organisms' end-directed design is determined by the environment through the mediation of information structures like DNA. The selecting environment determines the sign_i (on the basis of the interpretive structures and processes it organized in ancestral environments) and the sign_i organizes the adapted bodily $\text{interpretant}_\text{i}$, such that the $\text{interpretant}_\text{i}$ is organized by the selecting environment through the mediation of the sign_i (see EP 2.410). Put differently, DNA is a sign_i that represents the object_i (the present environment represented according to those respects that have proved salient throughout a process of natural selection) and the adapted body of a living organism is an $\text{interpretant}_\text{i}$ that interprets the present environment as it is represented by the genetic sign_i.[4] The preceding formulations use singular nouns for sign_i, object_i, and $\text{interpretant}_\text{i}$ in order to express the conviction that it is necessary to conceptualize these entities as complex wholes, irreducible to functionally meaningful parts (see footnote 2). Nevertheless, the same idea can be expressed more messily using plural nouns: recurring environmental affordances and threats are the objects_i which determine a complex set of genetic signs_i which together determine a densely interconnected network of protein-based $\text{interpretants}_\text{i}$ (a living organism) that collectively interpret the environmental objects_i as they are represented by the genetic signs_i.

The claim that DNA is a sign_i that represents the selecting environment requires clarification. Representation should not be conceived as involving imagination or mental phenomena. The interpreting organism does not "recognize" a sequence of DNA as a sign representing some feature of the selecting environment such that the organism gets an "idea" of that environmental object. Rather, representation is grounded in the process of natural selection that first shaped the genome. A gene that encodes a protein essential to the voltage-gated sodium channels in neurons vaguely represents the high-concentration of sodium ions that typically exists outside the axon precisely

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[4] This identification of the semiotic triad of sign, object, interpretant is the most important distinction between the present theory and that of El-Hani et al. (2006) who also attempt to understand genetic information in terms of Peirce's semiotic triad. The basic triad they propose is that a gene is sign that stands for one or more amino acid sequences (object) and the interpretant of this sign are the processes of transcription and translation that select a particular sequence of nucleotides and translate that sequence into a protein. This is a simplified version of their proposal, but it helps to clarify the fact that this triad is utterly different from the one proposed in the present theory. Whereas El Hani et al. assume with Maynard Smith (2000) that the genetic sign stands for the amino acid sequence or the protein, my theory proposes that the object of the genetic sign is the selecting environment and that proteins are interpretants of genetic signs.

because that gene, when decoded in ancestral organisms, reliably produced a protein that interacted with sodium ions outside neuronal axons in ways that proved essential to the proper function of ancestral organisms' neurons and, ultimately, the survival and successful reproduction of ancestral organisms. Stated generally, a gene is a sign$_i$ that represents those recurrent features of the environment—whether internal or external to ancestral organisms[5]—that were essential for determining the adaptive function of the protein(s) decoded from that gene in ancestral environments.

Having highlighted the evolutionary basis of the capacity for DNA to represent the environment, it is necessary to emphasize with Maynard Smith (2000) and Hoffmeyer (2008) that sequences of DNA function as symbols according to Peirce's most important division of signs into icon, index, and symbol. Genes do not represent the environment via some qualitative resemblance like an icon (a photograph is an icon of the person it represents), nor do genes represent the environment via a causal connection like an index (a footprint is an index representing the foot that caused it). Rather, a gene is a symbol, which is a sign that represents its object according to a rule or an arbitrary convention (Peirce 1998, EP 2.274, 2.317). Human words are a prime example of symbols: the written word "dog" and the sound "dawg" could just have easily referred to the animals we call cats. Likewise, as Maynard Smith notes (2000, p.183), the connection between a codon and the amino acid it codes for is arbitrary, meaning, I assume, that there is no chemical necessity pairing the anticodon and amino acid binding sites on tRNA molecules. The symbolic nature of genes is crucial to the plausibility of this theory as a theory of non-mental interpretation. Precisely because a gene is transcribed and translated according to an arbitrary code, it is possible for an unthinking chemical process to accurately interpret the represented object$_i$ on the basis of the genetic sign$_i$. There is no need to recognize similarity or infer a causal connection between the gene and the object it represents.[6] Thus, the entire process can proceed without consciousness, intentionality, or thought.[7]

As I suggested in section one, the irreducibly triadic relationship between information structures (sign$_i$), adapted bodies and behaviors (interpretant$_i$), and represented environments (object$_i$) is established via a process of natural selection. Information is encoded in DNA, brains, and human languages as a consequence of the processes whereby information structures are used by living organisms to interpret their environments. DNA bears information because a living organism uses the DNA to constitute itself as an ongoing

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[5] This theory accounts for both the internal and external environments of evolutionary adaptation. As mentioned above, the relevant environmental object$_i$ of a sequence of DNA is determined by the functional context of the proteins decoded from that sequence of DNA. Since the vast majority of proteins function primarily within the internal environment of the cell, it is true to say that selection is usually for adaptive fit with the internal environment of the cell. However, the distinction between the internal and external objects$_i$ is only meaningful when one considers individual proteins and their respective genes in isolated abstraction from the thoroughly integrated complex of a living organism. If I claim that "modern automobiles and all their components have been designed by manufacturers to sell in a competitive automobile market," it does not constitute a serious objection to reply that "actually, the function of the engine fan is just to prevent the engine from overheating." The ultimate reason proteins function effectively and efficiently in the "internal" environment is a process of natural selection whereby organisms with well-integrated, efficient "internal" processes were more successful at reproducing in ancestral environments than organisms with poorly-integrated, inefficient internal processes.

[6] On this point see Alexei Sharov's (2012) brief, but decisive critique of Kalevi Kull's (2009) interpretation of DNA as an icon.

[7] Here my view corresponds closely with the code-semiotics or code biology advocated by Barbieri (2012; 2013). However, whereas I am trying to articulate a triadic semiotic conception of interpretation that is applicable to organisms without brains, Barbieri restricts the use of the term "interpretation" to organisms that possess brains.

interpretation of the environment-as-it-is-represented by the DNA. The present environment is always more than and frequently different than it is represented to be (e.g., due to recent geological or ecological changes). Thus, some organisms (either within the same species population or in a different species competing for the same ecological niche) inevitably fit the present environment better, and, therefore, those better fit organisms reproduce more frequently than their competitors. This selection against the complex bodily interpretant$_i$ constitutes simultaneous selection against the underlying genetic information structure by which the organism constituted itself, because (1) the bodily interpretants$_i$ are the decoded expression of the genetic information and (2) the adapted fit of the bodily interpretants$_i$ is essential for the preservation and replication of the genetic information structures. Information structures do not persist if they inform bodies that are selected against by the environment. This negative constraint is the ultimate basis of all positive genetic information. As the remainder of a process of elimination, genetic information has been written in relief by natural selection (Deacon 2012: 413–419). Natural selection is, at its core, an information-generating process.

The net result of this process is that genomes (complex sign$_i$) that are used to produce living organisms (complex interpretant$_i$) that better fit a particular selecting environment are differentially reproduced. This results in genomes that, when decoded, produce bodies that are designed to accurately interpret the environment: this is what it means to call DNA "information". Living bodies are informed about the environment: they are composed of proteins—information-infused molecules—organized into an integrated complex of processes designed to maintain and reproduce itself by extracting matter and energy from the environment. Though the physical properties of DNA suggest its information-bearing function[8] (Bergstrom and Rosvall 2011), according the present theory DNA does not constitute information because of some feature of its physical structure. Rather, DNA is information because it is embedded in a triadic relationship such that it shapes or in-forms living bodies so that those bodies constitute more or less accurate interpretations of the environment.

Because the present theory emphasizes the role of genetic information in determining the adapted design of living organisms, it is prone to being misunderstood as a form of genetic reductionism. Since Dawkins' (2006: xxi) portrayal of living organisms as "survival machines—robot vehicles blindly programmed to preserve the selfish molecules known as genes", many biological theorists, including some biosemioticians (Hoffmeyer 2008), are highly suspicious of any gene-centered theory. Often this type of reductionism is resisted by appealing to developmental systems theory (DST), an approach to biology that emphasizes the role played by environmental influences in the development of organisms (see Griffiths and Gray 1994: 278, note 1 for a concise DST bibliography). While I cannot provide a very in-depth analysis here, I want to briefly express the compatibility of the present theory with DST.

There is no basis for granting explanatory priority to either genotype or phenotype, because neither makes any sense apart from the irreducibly triadic relationship between the genotype, phenotype, and the selecting ecosystem. Furthermore, genes are radically

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[8] This model has no difficulty accounting for selection pressure against the information structures themselves, which is necessary to explain why DNA, brains, and human languages appear so well-designed to encode information. Storing, preserving, and decoding information is energetically costly. Organisms that evolved mechanisms to store and process their information more efficiently and accurately than competitors would, on average, reproduce more frequently.

dependent for their expression upon the interpreting phenotype, apart from which they do not constitute information in any biologically or semiotically meaningful sense. After cell division in a single-celled species, the "daughter" cell (if the distinction between parent and offspring is not entirely arbitrary) receives not only the genetic information but the fully articulated expression of that information: a cell complete with adaptively permeable membranes, a supportive cytoskeleton, protein-rich cytoplasm, all necessary organelles, etc. Within every contemporary organism the genetic information and the phenotype are bound together in a process of mutual dependence that has, presumably, proceeded without interruption since the origin of life on Earth. Consistent with DST, the present theory assumes that the expression of genetic information in any organism is intensely dependent upon phenotypic modulation based upon feedback from the environment (see the excellent discussion of "anticipatory function" in Arnellos, et al. 2012: 345–9). An organism that mechanically expressed a preset genetic "program" without making adjustments based upon feedback from the environment would be poorly adapted to most real, fluctuating environments. However, regardless of how important and extensive these modulating feedback mechanisms are, phenotypic flexibility via feedback is not incompatible with the insistence that organisms are adapted (via such feedback mechanisms) to a range of possible environments because that range of environments is represented by the genetic information being processed at the core of the organism. Ultimately, all such feedback processes involve proteins that have been decoded from genetic information to play these regulatory roles. Beyond this last qualification, my only major disagreement with DST theorists is that they often employ a causal, physical model of information wherein any two causally related systems provide information about each other and the distinction between channel and signal depends entirely upon interpretive context, which leads these theorists to argue that a phenotype is equally informed by the environment and by genetic information (Griffiths and Gray 1994; Sterelny, et al. 1996; Griffiths 2001). As mentioned in the introduction, I am convinced that such dyadic conceptions of information are incapable of distinguishing life from non-living chemistry.

In summary, four basic elements of the conception of information introduced above require explicit articulation. First, information is only information if it is embedded in a triadic relation such that it used to organize an interpretive process that interprets an object as it is represented by the information. Information represents an object in a way that "makes a difference" (Bateson 1972) to some process that interprets the represented object. Second, information shapes or imposes a form upon the interpreting process: the decoding of genetic information forms chemicals into the functional shape of proteins and protein-based cellular structures; neural information forms the behaviors and mental experiences of multicellular organisms; and linguistic information forms the individual and social behaviors, mental experiences, and intellectual processes of human beings. Third, information involves a relation of dependence that is more temporally complex than the simple immediacy of physical-chemical causation: via the mediation of genetic information the adapted design of present organisms is determined by a history of selection in ancestral environments.[9] Similarly, an

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[9] This point resonates with Battail (2009) and Pattee's (2007) appeals to a form of "memory" inherent in living systems and Hoffmeyer's (2008) claim that "the DNA code is capable of conserving experiences". While I want to resist these mental metaphors due to their lack of applicability below the level of neural semiosis, the basic point is the same: information structures make a distant past causally relevant to the organization of present biological structures and processes.

organism's motor behavior and mental experience is determined by the positive and negative outcomes of the organism's entire history of interpretation which produced a brain rich in information about the environment. Fourth, information structures that function to inform organism lineages over long processes of natural selection tend to undergo selection for the capacity to encode information more efficiently and accurately (see note 8). Though the definition of information implied here is much richer than those common in information theory, the last point implies that if a structure has evolved to bear information, it should be apparent upon an information theoretical analysis of the structure's storage capacity, efficiency, fidelity, etc.

Application of this Theory to Brains and Human Languages

DNA is not the only biological information system that is aptly modeled by the present theory of informational semiosis. The goal of this final section is to illustrate how this theory applies to both brains and languages.

Brains are complex multicellular structures that, like all other biological structures, depend for their existence (though not their final structure, which is informed by a selection process occurring within the animal's lifetime) upon genetic semiosis. Organisms cannot develop brains without genetic information. Furthermore, genes play crucial roles in guiding and constraining brain development, resulting in species-typical brain architecture. Similarly, languages are informational codes that evolved upon a substrate of more basic communication signals used by social animals, and only animals with brains can employ the types of inter-animal signaling necessary to sustain social life. Languages would be useless without brains to process them. Furthermore, the inherited architecture of the brain has profoundly constrained and canalized the evolution of human languages. As Terrence Deacon (1997: 122) explains, "[h]uman children appear preadapted to guess the rules of syntax correctly, precisely because languages evolve so as to embody in their syntax the most frequently guessed patterns. The brain has co-evolved with respect to language, but languages have done most of the adapting". Summarizing the main point, human language would not have emerged without massive expansion of the species-typical human brain, an expansion which depended upon prior alterations in the human genome (Vallender, et al. 2008). Thus, in terms of the historical process of emergence, languages depend upon brains which depend upon DNA. However, it is also important to note that selection pressure flows downward from languages to brains to genes. This selection pressure occurs because larger scale information structures are always complex interpretants$_i$ of the smaller underlying information structures. Brains are one of many complex multicellular interpretants$_i$ produced by genetic primary semiosis, and, as such, brains constitute a basis of selection against the genetic information that guides and constrains brain development. Likewise, language use is a complex behavioral interpretant$_i$ of neural semiosis, and, as such, it constitutes a basis of selection against the neural architecture that forms language use. By selection against neural architecture, I mean both that the brain of a child who is learning language changes rapidly to ensure successful language use and that our ancestors' capacity to use language was intensely selected for, resulting in changes in species-typical brain architecture (Deacon 1997). The latter changes could only occur on the basis of genetic selection, which reveals how selection pressure for increasing semiotic power at higher levels trickles down as selection pressure against underlying information structures.

Brains[10]

Brains as Information Structures Brains are multicellular organs genetically selected for the capacity to encode massive amounts of information about the environment during the organism's lifetime and to organize a multicellular organism's behavioral response to the environment on the basis of that information. The assumption that the brain is an "information" processing system—in some sense—is nearly universal within neuroscience and cognitive science. From the perspective of information theory, it is difficult to imagine a similarly-sized structure capable of more unique configurations: with 100 billion neurons and over 100 trillion synaptic connections (Marois and Ivanoff 2005) and each synapse firing up to 1,000 times a second, the number of possible firing patterns that can be realized by a human brain over the course of 1 min is almost limitless. Like the structure of DNA, the physical structure of brains strongly suggests that they evolved to encode and process information.

Triadic Relations of Neural Semiosis The object_i of neural semiosis is the selecting environment as it is represented by the informational organization of the brain (sign_i) which processes certain environmental inputs (light, sound, chemicals in air and food, pressure, vibration, etc.) and produces an interpretive mental and/or behavioral output (interpretant_i). This interpretive output either aids the organism's end-directed engagement with its world, in which case the neural architecture is preserved and/or reinforced; or the interpretive output misleads in some way (results in physical pain, confusion, sickness, social embarrassment, etc.), in which case the neural architecture that produced the interpretive behavior is subject to inhibition, rearrangement, or dissolution. This process—occurring in countless pathways on a millisecond scale throughout the organisms' life—results in a brain rich with information in the specific sense that the physical structure of the brain accurately represents recurrent patterns in the external world, thereby allowing the animal to interpret its world intelligently—to avoid threats and obtain affordances. Thus, information about the environment is encoded in the brain through a process of selection occurring during the brain-using animal's lifetime. As with genetic semiosis, the emphasis here is not on the immediate process of interpreting a particular object, such as an apple seen with the eye (this is secondary neural semiosis). Rather, the focus is upon the process extended across the animal's lifetime whereby the information-rich structure of the brain evolves via the

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[10] By focusing on "brains" rather than nervous systems, I intend to make a very general distinction between those parts of the nervous system that encode information over the course of an organism's lifetime (loosely "the brain") and those parts that develop relatively inflexibly on the basis of genetic or epigenetic codes. Genetic and epigenetic codes at least constrain and canalize the development of the brain and they may strictly specify certain portions of the brain, so the distinction is not intended to be anatomically precise.

animal's ongoing interpretation of the environment. In other words, the present perception of the apple depends not only upon the temporally-proximate firing of specific neural networks, but upon the temporally-extended information-encoding process that previously organized those networks in order to permit successful vision.

Selection Pressure Encoding Neural Information Whereas the informational structure of DNA is typically stable over the course of the organism's lifetime, the information in the brain must be encoded from scratch between the birth and death of the organism (see note 10). Like genetic semiosis, selection of information-rich neural networks is ultimately determined by the correspondence of neurally-mediated behavioral and mental interpretants with the external environment, but, unlike genetic semiosis wherein negative selection pressure from the environment is direct and entails the death or reproductive failure of the organism, selection pressure against neural information structures is mediated by assessment mechanisms internal to the organism. The evolutionary process suggested by Peirce in 1887–8 is well-recognized by neuroscientists (Edelman 1987, 1993; Deacon 1997) and involves the scheduled overproduction of synaptic connections in various brain regions followed by paring down lesser used connections (Johnson 2001; Casey, et al. 2005), linear increases throughout development in white matter connecting diverse brain regions (Casey, et al. 2005), and myelination and long-term potentiation of frequently used axons. The end result is an information-rich brain capable of integrating massive amounts of incoming sensory signs into a coherent mental experience of the external environment and also producing behavioral outputs that are generally well-adapted to that perceived environment.

Adapted Neuronal Interpretants$_i$ Brains only bear information if they form behavioral and/or mental interpretants$_i$ that usually fit (interpretive error is always a possibility) the environment. From a bee flying toward a flower's sugar-rich nectar, to a fleeing rabbit's evasive maneuvering, to a chimpanzee studying its rival's posture for signs of fear—the power of brains to adaptively shape animal behaviors to the affordances and threats in the external environment are obvious and uncontroversial.

Human Language[11]

Languages as Information Structures Like genetic information evolving within the physical substrate of macromolecules and like neural information evolving within the physical substrate of synaptic firing patterns, linguistic information is evolving within

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[11] The present theory assumes that the emergence of linguistic information structures approximately 100,000 years ago (Berwick, et al. 2013) depended upon prior genetic adaptation that altered normal human physiological (Fitch 2000) and neural development (Deacon 1997; Dunbar and Shultz 2007). The theory is compatible with any evolutionary story regarding the process by which language developed (Hauser et al. 2002) and also with the existence of any degree of communicative sophistication among other Earth species, including primitive language (but see Berwick, et al. 2013 for reasons to think language is unique to humans). Inclusion of language as an information structure analogous to DNA and brains is motivated by a simple empirical fact: without the information encoded in a human language, an individual human's knowledge would not significantly exceed that of a chimpanzee; yet by accessing linguistically-encoded information throughout her lifetime, that same human's potential knowledge is limited only by the intelligibility of the universe and the ingenuity of ancestral inquiry.

the physical substrate of sensory communication signals similar to those used by other animals to organize their complex societies. Pre-linguistic sensory communication signals emerged predictably along with the evolution of brains, these signals constitute the foundation of all animal societies, and in their diversity they manifest all stages of complexity—from pheromone signals sent between insects to the complex bird and dolphin vocal signaling systems that appear to be on the cusp of the linguistic breakthrough (Fitch 2000; Berwick et al. 2013). The idea that languages are information structures—in some sense—is relatively uncontroversial. As a very crude measure of the information carrying capacity of human language, if it were the case that all letters in the English language occurred with equal probability, then this 279 digit sentence would carry an enormous amount of information because it is only one out of 26^{279} possible combinations. Deacon (1997: 321–375) provides a helpful analysis of the ways human languages have evolved to allow humans to communicate massive amounts of information efficiently and accurately.

Triadic Relations of Linguistic Semiosis The object_i of primary linguistic semiosis is the natural and cultural environment as it is represented by the vast, interconnected web of symbolic sounds and markings that constitute a language (sign_i). When the world is taken to be as it is represented by a language, the result is a culture ($\text{interpretant}_\text{i}$), a society constituted by patterns of behavior, rituals, institutions, laws, critically-established knowledge, ethical aspirations, aesthetic norms, etc.—all of which are embedded in, organized by, and endowed with meaning by language. Here perhaps the present theory's emphasis on the information structure and primary semiosis is most counterintuitive. Secondary linguistic semiosis—a concrete instance of language use—is far more intuitive: my friend tells me over the phone, "I'll pick you up in 15 min" and I walk outside 15 min later and get inside his car. However, the words in this sentence are only meaningful because they are embedded in the vast system of words and grammatical rules that constitute the English language. And the words and rules of an entire language are only meaningful due to thousands of years of unbroken language-based interpretation of reality. As in genetic and neural primary semiosis, the process of using language to interpret a world that resists our interpretations is what gradually endows language with rich information about reality. Human languages only permit an interpretation of reality, but there is every reason to suspect that our linguistic interpretations grasp reality itself, however perspectivally and incompletely. In its support of a fallibilist realist epistemology, this theory manifests a deep allegiance to Peirce's pragmatism (see Wildman 2010: 167–205 for a contemporary pragmatic epistemology/theory of inquiry).

Selection Pressure Encoding Linguistic Information Every actual use of language (whether spoken, written, or thought to oneself) to interpret reality is an instance of secondary semiosis that serves as a potential locus of selection in the temporally-extended process of primary semiosis that endows a language with rich information about reality. Every individual employment of a word, phrase, sentence, or theory to interpret reality plays a miniscule part in either reinforcing or altering the meaning of the linguistic elements employed and/or either increasing or decreasing the likelihood of those linguistic elements being reproduced in similar circumstances.The selection pressures that encode information in human languages are fully natural and partially socio-cultural. Due to human retinal cones being most sensitive to wavelengths around 419 nm, 531 nm, and 559 nm (Kolb and Whishaw 2014: 291–3), human cultures reliably develop words for red, green, and blue before naming other colors (Deacon 1997: 116–120). Likewise, the fact that more human cultures have words for "tree" than for "quark" illustrates the basic way that our linguistic signs attach themselves to perceptible objects in the natural world. Like "tree," the noun "quark" also corresponds to a recurrent pattern detected—albeit in very unusual circumstances—within nature. On a more profound level, grammatical conventions like tenses are presumably modelled after real and deeply basic features of temporality, what philosopher Robert Neville (1993) calls "the modes of time". Because our language represents to us three different ways of being in time, we can conceptualize, experience, and interpret all three of those modes of time.

All of the above are instances of language-informing selection pressures that are purely natural, but there also exist selection pressures that are irreducibly cultural. A simple example is the way words and phrases used by famous people gain rapid cultural currency regardless of how useful those phrases are in illuminating reality. Snoop Dogg raps the phrase "fo' shizzle" and ten million high schoolers repeat it. More disturbingly, philosopher-historian Foucault (1961, 1975) described the way linguistically-mediated "knowledge" is employed to inscribe power relations upon human bodies—to organize people's thoughts and behaviors in ways that actualize the unstated goals of powerful people and groups. As Foucault's work illustrates, words and symbols are powerful tools—filters that organize how the world shows up for us and lures that lead us to respond in historically- and socially-constructed ways.

Adapted Linguistic Interpretants Almost everything that makes human beings unique among Earth's organisms depends upon our minds and bodies being organized by a third biological information structure: language. Language is the scaffolding of human culture, and most human behaviors, experiences, and thoughts are formed by language in one way or another. With language we trade across oceans and vote on laws that will bind us; with language we sustain scientific inquiries into the deep patterns of nature at mind-boggling micro and macro, spatial and temporal scales; with language we sustain friendships and fall in love; with language we argue about goodness, truth, and beauty; with language we ponder the ultimate meaning of existence; with language we become human.

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Concluding Thoughts on Anti-Reductionism In conclusion, I want to make a brief comment about the anti-reductionist implications of this theory of informational semiosis. The theory implies a principled anti-reductionism: interpretive processes that are organized by each layer of informational semiosis cannot be fully understood in terms of lower level processes. This is because information forms matter: DNA forms chemistry into proteins and living cells, brains form animal minds and behaviors to fit the sensed environment, and languages form human behavior, experience, and thought according to the understanding and values that accumulate over centuries of cultural-linguistic interpretation of nature. It is futile to attempt to reduce a bacterium to the expression of physical and chemical laws, an animal's behavior to the expression of its genes, or a cultural practice in any human society to an expression of genetic and neural predispositions. Concerning human beings, this view implies that physical and genetic causes underlie every human process, neural causes underlie most human behaviors and all human experiences, and linguistic and cultural influences also shape a large percentage of human behaviors and most of our experiences and thoughts. Thus, if we want to understand why people behave the way they do, the more we know about physics, genetics, and neuroscience, the better, but we will almost always also need to understand the beliefs and ideas that shape the person's behavior as well as how those beliefs and ideas have developed throughout a culture's history.

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