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Information, Meaning and the role of Semiosis in the Development of Living Systems

Abstract:
The claim here is that semiosis is concomitant with life and not simply one of several possible adaptive mechanisms. Signs, particularly indices, serve as steering mechanisms for even the most primitive organisms, completing a circuit between the detection of energy sources and behavior that is conducive to acquiring those sources. Without that kind of agency, no form of life is possible. To show this, an understanding of the interrelation among energy, matter, information, and meaning is required, and how they are interlaced in the notion of work. One specific thesis of the paper in this respect is that meaning is the propagating work of information. Peirce's theory, with some modifications, can be used to articulate this account of things, and brings a powerful analytical tool to the problem.

Introduction

It may be obvious to most that sign-capacity is particularly adaptive, since being able to extract information from the world about us is surely needed for survival. But not everything that is adaptive need necessarily occur in the process of natural selection. It is quite possible that successful organisms can be differently adapted. The claim here is that semiosis is *integral* to the development of life and the work of living. The goal, then, is to help understand why it is concomitant with life. As it will be argued, signs, particularly indices, serve as steering mechanisms for even the most primitive organisms, completing a circuit between the detection of energy sources and behavior that is conducive to acquiring those sources. Without that kind of agency, no form of life is possible.

Along the way, this will involve an understanding of the interrelation among energy, matter, information, and meaning, and how they are interlaced in the notion of work. Specifically, one core thesis of this paper is that meaning is the propagating work of information. This requires an appropriate understanding of information, its distinction

from meaning, and how it extracts work from sign agencies. It will be no secret that Peirce's semiotic theory will play an important role in articulating that account. However, in order to bring this powerful conceptual tool to bear on this problem, some modifications to the theory are necessary. In particular, a non-semantic, Shannon-based concept of information needs to substitute for Peirce's semantic interpretation of information. Second, the innovative concept of interpretant, which is articulated by Peirce in terms of habits of action engendered by signs, has to be translated into the framework of the concept of work. With this accomplished, the conceptual links between information, work, and meaning will be complete, with the result of a particularly helpful analysis semeiosy.

The Possibility of Life

In Stuart Kauffman's clever phrase, life hinges on the ability of an organism to "make a living," that is, to be capable of work cycles sufficient for reproduction, sustainability, and growth (2000: 4). But, in order to do the work of living, it must first be capable of finding energy. As Kauffman notes:

> …that emerging organization concerns the appearance in the evolving universe of entities measuring relevant rather than nonrelevant properties of nonequilbirum systems, by which they identify sources of energy that can perform work (2000: 83).

This is reinforced by Jesper Hoffmeyer: "…living creatures… differentiate between phenomena in their surroundings and react to them selectively, as though some were better than others" (1996: 48). Signs play this very important role in the emergence of living organism, detecting what is necessary for the sustenance of life.

To understand the chain of reasoning leading up to this claim, we need to begin with the second law of thermodynamics. There are a number of informally stated versions of the law:

Heat flows irreversibly from a hot body to a cool one (Clausius 1865);

Heat cannot be completely converted into useful work (Kelvin 1851: 179);

Every closed system tends toward disorder in the long run (Boltzman 1886).

It is precisely because heat flows irreversibly from a hot body to a cool one that work is possible--where work is understood in its most generic physical sense as the transfer of energy, through a force, to a body sufficient enough for its displacement (Lange 2002: 126). That heat cannot be completely converted into useful work requires a continuous replenishment of energy, and the need for economy and efficiency. Because closed systems tend toward disorder in the long run, then life is possible only in an open system, that is, it must be capable of exporting entropy in order to keep its own entropy at a minimum—a notion Schrödinger famously called negentropy (1949).

Like Boltzmann, Peirce thought the Second Law was a statistical law rather than a physical law (see W 3:244; CP 6.47; see Short 2007:117ff). Peirce argued that the second law, like most chance processes, is *finious*, that is, they have a certain directedness that is asymmetrical and irreversible. This makes them distinct from conservation forces, such as gravity which are symmetrical and, in principle, reversible (CP 6.127). Time, for example, seems to flow in one direction, and is not reversible. Evolution tends toward optimal adaptation of organisms to their environment; life itself seems to move through a cycle from growth to decay.

Peirce thought that because finious processes have directedness, they are a kind of non-purposive teleological process which makes them distinct from mechanical ones. Whereas mechanical processes produce the same end, outcome, or effect by the same means, finious processes achieve the same end by a variety of means (see Short 2007: 126ff). Thus, no matter how gas particles interact, in the long run, they will reach a state of equilibrium, as expressed by the Maxwell-Boltzmann distribution. No matter how the dice are tossed, in the long run, their sums will be expressed in a normal distribution. No

matter how random Brownian motion, the length of the displacements of the particle will be normally distributed, as Einstein showed.

Peirce believed that it was the element of chance in the universe that made finious processes possible since it allowed for the very possibility of a variety of means to the same end (CP 6.297). Finious processes are also central to Peirce's concept of self-organization in the universe, since even chance events have a tendency toward habit-taking. There is nothing mysterious about the finious character of chance events, since outcomes are matched by their likelihood. For example, the fact that the sum of dice rolled in the long run, will eventually describe a normal distribution of their sums is due to the fact that rolling seven is the most likely outcome, since there are simply more possible combinations summing at seven than any others, the sum of six and eight being the next likely, and so forth. Francis Dalton's "Quincunx" is a good illustration of this as well. Balls channeled through a series of pins laid out in rows and columns will eventually have a normal distribution at the bottom. Since each ball, entering the quincunx at the same point, will fall either left or right of each pin it hits, and since either direction is equi-probable, it is more likely that balls will be directed roughly as much as to the left as to the right and, so, have more of a likelihood of ending in the center than the extremes. In other words it is more unlikely that the ball will consecutively bounce left, making it more unlikely to land in the bottom corners. The result, for a sufficient number of trials, is a normal distribution of the balls. Of this Galton remarked: "scarcely anything so apt to impress the imagination as the wonderful form of cosmic order expressed by the 'Law of Frequency of Error'…." (quoted in Kevles 1985: 13-14). Apparently, it also impressed Peirce. For him, it proved, literally, no matter how the dice were tossed, in the long run, their sum will be normally distributed.

The Second Law of Thermodynamics, under this reading, is a statistical law. The law predicts that in a closed container, divided into sufficiently small equal-sized cells, gas particles will eventually be uniformly distributed through those cells, that is, entropy or disorder is the likely result. The reason is that it is simply more likely that those particles

will be uniformly distributed than if they are distributed asymmetrically in the container. As Richard Feynman explains it:

…we now have to talk about what we mean by disorder and what we mean by order. … Suppose we divide the space into little volume elements. If we have black and white molecules, how many ways could we distribute them among the volume elements so that white is on one side and black is on the other? On the other hand, how many ways could we distribute them with no restriction on which goes where? Clearly, there are many more ways to arrange them in the latter case. We measure "disorder" by the number of ways that the insides can be arranged, so that from the outside it looks the same. *The logarithm of that number of ways is the entropy* (Feynman 1963: 1.46-5)

To simplify the problem, imagine a two celled container with four particles. Counting each particle independently, there are sixteen possible permutations; of those only two are possible with a distribution of the four particles in one or the other cell. Thus the chances are likely that the particles will be more uniformly distributed throughout the closed system. Since a differential of distribution of energy is needed to do work, the uniform distribution of particles is equivalent to a state of entropy for that system. The Second Law, then, tells us indirectly what is required for life to flourish. In order for something to live, it must be capable of slowing its own entropy, as Erwin Schrödinger suggests (Schrödinger 1949: Chapt. VI). Robert Rosen puts it succinctly, "a system autonomously tending to an organized state cannot be closed" (1991: 114). In order to do that, it must:

　　1. be capable of constraining energy to do work;

　　2. acquire energy sufficient to do the work of living;

　　3. find the energy sufficient to do the work of living at a cost that does not exceed the amount of energy acquired.

The fact that life cannot develop or survive in a closed system, but must be part of an open, dissipative system, and the fact that it must be capable of constraining energy to do work, requires that a living organism have boundedness, a containment, a boundary, a membrane; otherwise, it could not do work in any practical manner, since the containment acts to focus the effect of the work on itself (see Kauffman 2000: 97). In effect, as Stuart Kauffman has ably shown, the bounded processes must be the equivalent of a chemical version of a Carnot engine in order to successfully work (2000: 64-65). The boundedness inherently creates the possibility of an open system, relative to a closed one (Kauffman 2000: 16). An open system is possible when there are sufficient renewable sources of energy outside of itself, which it can use to do the work of living, and that which is inside the container has the means to process that energy to do work of some sort or another. This can be scaled, so that not only can the smallest organisms be open systems relative to energy sources on the earth, but the ecology of the earth can be considered an open system, relative to the energy source available in its solar system. Open systems do not violate the second law of thermodynamics, they are only possible in regions of closed systems far from equilibrium (Kauffman 2000: 97). Clearly as the sun phases through its predicted stages and less energy becomes available in our solar system, open systems in our region will be less possible.

Boundedness inherently creates the distinction between an inside and outside. The process inside must have a tendency to work in a coordinate rather than a competitive fashion in order to process the energy needed to do the work of living. Coordination requires connection and communication of some sort or another among these processes, and the understanding of primitive chemical communication in cells demonstrates how fundamental that operation is (see Hoffmeyer 1996: 73ff). Typically we call the bounded processes, organisms, and the connotation of the term suggests a coordination of processes that generally serve the function of sustaining those processes. Happenings outside those bounded processes typically offer resistance to the organism—it is the place

where the "struggle for existence" takes place, an ecology in which other organism compete for energy resources.

Living Beings as Propagating Organization

According to Kauffman, not only must a living thing be within a dissipative structure, it must be capable of using the energy available within that system to do work—not just any work—but propagating work, that is, work connected to some constraint infrastructure that contributes something to the task of living (2000: 98). Kauffman gives an imaginative example: a cannonball fired from a cannon lands some distance in the dirt, making an impression in the ground while heating the dirt surrounding it. A second infrastructure is set up whereby the fired cannonball hits a paddle wheel tied to a bucket that lifts water from a well and irrigates a bean field. Although the same amount of energy is expended in both cases, and each organization, technically speaking, does work, the second system does propagating work, that is extends the constraints on the release of energy, and as tied to some purpose or teleology, which gives it a completeness and coherence.

A living cell, according to Kauffman and his colleagues, must be a propagating organization, a sort of chemical Carnot engine that must be capable of thermodynamic work cycles. Information processing in the cell is good example: "…the cell operates as an information-processing unit, receiving information from its environment, propagating that information through complex molecular networks, and using the information stored in its DNA and cell-molecular systems to mount the appropriate response" (2008: 28). Indeed, a good example of propagating work is the translation of the information in DNA into proteins. As is well known, tRNA molecules are transcribed from the DNA of the cell. Each is attached at one end by a special activating enzyme to a specific amino acid. Each contains an anticodon that fits an mRNA codon for that particular amino acid, and so is schematized for that amino acid. The process of translation begins when an mRNA strand is formed on the DNA template and enters the cytoplasm. At the point of attachment of

the mRNA to a ribosome, the matching tRNA molecule, with its accompanying amino acid, plugs in momentarily to the codon in the mRNA. As the ribosome moves along the mRNA string, a tRNA linked to its particular amino acid fits into place and the first tRNA molecule is released, leaving behind its associated amino acid, which is linked to the second amino acid by a peptide bond. As the process continues, the amino acids are brought into line one by one, following the exact order dictated by the DNA—the result being a protein of a particular sort.

The Role of Semiosis in the Work of Living

A living propagating system, embedded in a dissipative organization, with its inherent distinction between inside and outside, must be capable of finding the energy sufficient for it to do the work of living. This is the point at which semiosis play a critical role in the sustainability of life. The philosopher, Fred Dretske, hypothesizes that organisms must have indices to accomplish this task. Indices work to identify and locate energy sources by doing what Peirce so clearly articulated: They vary as an outside environmental condition varies, thus cueing the organism to what the index indicates. A windvane, for example, indicates the direction of the wind by being physically moved by the wind (CP 2.286). More than cueing the organism, as the index varies, it varies conditions or events within the organism in such a way as to create a positive feedback loop between the environmental condition and the organism's behavior (Dretske 1992: 55ff). The result is that the sign acts as a steering mechanism for the organism (Dretske 1992: 80ff). In Peirce's language, the index is associated with a dynamical interpretant and, in the long run, a final interpretant as the organism acquires that pattern of action as a habit (CP 4.536; 5.491).

Indices must serve a steering function for obvious reasons. If indices were only able to detect states-of-affairs on the outside, but the organism was not capable of acting or reacting to them, then indices would be of no practical use to the organism. Conversely, if the organism had steering mechanisms, but no indices, then it would be blind to its

environment and, consequently, unable to adapt to it. In effect, signs create the possibility of primitive agency, that is, organisms capable of directedness—and it is a directedness that has its basis in the directedness of finious thermodynamic processes. One could not ask for better support for this claim than in a statement made by Howard Berg on the behavior of the primitive bacterium, E. coli:

> E. coli's behavior is fundamentally stochastic: cells either run or tumble. Their motors spin either counterclockwise or clockwise. Transitions between the latter states are thermally activated. E. coli's irritability derives from the basic laws of statistical mechanics. This irritability is modulated by the cell's reading of its environment (2003: 6).

E.coli, commonly found in the human gut, finds its energy source in glucose gradients in its aqueous environment. As Berg describes it, "*E. coli*, a self-replicating object only a thousandth of a millimeter in size, can swim 35 diameters a second, taste simple chemicals in its environment, and decide whether life is getting better or worse" (2001:1). Chemotaxis in *E. coli*, has been well-studied and supports the notion that chemoreceptors at the boundary of the bacterial cell surface act as indices, performing a steering function by chemically communicating with the flagellar basal structures to elicit appropriate motor response in the flagellum (for particulars see Lukat, Stock and Stock 1990). As Berg summarizes:

> It modifies the way in which it swims to move toward regions in its environment that it deems more favorable. Each flagellum is driven at its base by a reversible rotary motor, driven by a proton flux. The cell's ability to migrate in a particular direction results from the control of the direction of rotation of these flagella. This control is effected by intracellular signs generated by receptors in the cell wall that count molecules of interest that impinge on the cell surface (2003: 3).

We have a very detailed understanding of the flagellum mechanism and the chemical cascade that causes it to move either clockwise, thus tumbling in different directions, or, counterclockwise, and continuing to move in the same direction (see Berg 2001:3). The end result is that the detection of a sufficiently dense glucose gradient causes the organism to continue in the direction of the gradient, while the detection of lessening amounts of glucose in the gradient causes it to tumble randomly and search for more profitable sources of energy, thus creating a positive feedback loop between detection and behavior. This positive feedback loop is, in effect, a propagating organization which does the important work of detecting sources of energy that enables *E. coli* to do the work of living.

If, as Stuart Kauffman argues, "semiotic behavior can identify a source of free energy…from which work can be extracted and propagate in the cell," then, to fully understand this behavior, it must be part of "a theory that unifies matter, energy, information, and propagating organization" (2008: 40). Peirce's semiotic theory may be the best vehicle for that effort; however, it will be claimed here that it requires some modification to do so—particularly in light of developments of semiotic behavior in the biotic sphere and theories of information. In fact, Peirce envisioned this mutually corrective relationship between the formal science of semiotic and the empirical sciences (see Liszka 1996:15).

The Concept of Information

A first step in such an analysis is to start with the fundamental notion of information—a knotty concept to articulate. Claude Shannon's classic account of information may provide a good starting point.

Shannon's concern was primarily that of the engineer: How to transmit accurate messages efficiently. "The fundamental problem of communication," he says, "is that of reproducing at one point either exactly or approximately a message selected at another point" (1948:

379). For Shannon, information is constituted by the presence or absence of a feature that stands in some binary relation with another feature. For example, a flip of a coin has one bit of information, since it will be either in the state of heads or tails; a switch, which can be either on or off, also has one bit of information. Anton Zeilinger's definition is similar. An elementary system is a system that has one binary state, essentially a binary difference in a feature of that system, which is quantified as one bit of information. The archetypal elementary system is the spin of an electron. The only possible outcome of measuring an electron's spin is 'up' and 'down', regardless of which axis it is measured along (see Zeilinger 1999; see von Baeyer 2001). Zeilinger, like John Wheeler before him, conceptualizes information as a physical entity, and so is capable of articulation in terms of matter and energy. There are very reasonable grounds for supposing the same view for Shannon, although certainly bits of information can be abstracted for mathematical purposes. Despite these agreements, Zeilinger does not believe that Shannon information is adequate for analyzing quantum behavior, since it is tied too closely to classical notion of measurement (Brukner and Zeilinger 2001). However, a spate of recent articles defends the applicability of Shannon information to quantum mechanics (see Shafiee et al. 2006; Mana 2004; Timpson 2003).

Several thinkers dispute the material basis of information. Certainly the Anthropologist, Gregory Bateson, was known for his argument against identifying energy, matter, and information. Information is the result of the apprehension of a difference in energy and matter by living systems, "a difference that makes a difference," as he famously said. Atoms, molecules, or stones receive energy and move with energy, but living beings respond to energy through its own source of energy (Bateson 1979: 100ff). Recent discussions take a similar position. Eva Jablonka argues that "a source becomes an informational input when an interpreting receiver can react to the *form* [my emphasis] of the source…in a functional manner" (2002: 602). She seems to suggest that reception of information by an organism is due to the organization of energy and matter in that bit of information rather than the energy content (2002: 603). Even Stuart Kauffman and his

colleagues at times treat information as an abstraction that is somehow instantiated in material things (2008:37-38). However, it is questionable whether one can separate energy from its organization other than in some old-timey metaphysical way for the purpose of conceptual analysis. As John Maynard Smith notes, even though the same message can be transmitted by different material media—a sound wave, an electromagnetic wave, a fluctuating current in a wire, or a chemical molecule—we should not conclude that matter does not matter in information (2000: 180-181). In fact, we would argue that information cannot be separated from some material medium.

What counts as one bit of information may also be scaled, relative to the receiver and destination—to use a Shannon term. Although the mechanisms of human eyes can detect and are affected by patterns of electrons, a human perceiver sees the heads of a coin at a certain scale, even if it is made possible by the patterns and lengths of light waves, which are detected at some systematic level by the eye. In this case, it is not the spin of an electron that counts as information, but whether the coin is in one of two states. However, a human perceiver can use a medium or instrument, such as a quantum dot, to detect one bit of information in the spin of the electron, in which case a bit of information is scaled down to that level. This suggests that what counts as a bit of information depends on the channel, receiver, and destination, but it does not necessarily infer that the whole scale of information depends on detection by some sign agent. At least for macroscopic phenomena, it is presumed that the coin has the state of heads, independently of whether it is detected by some sign-agent. At the quantum level, this may be a more complicated proposition.

All of that being said, Shannon's concern was primarily the communication of messages. Communication becomes especially problematic if there uncertainty about the source message. Shannon defines *information entropy* as the measure of that uncertainty. In a formula that is strikingly similar to Boltzmann's formula for thermodynamic entropy, Shannon quantifies the entropy of a message as a logarithmic function of the likelihood of each information unit in the set of units in the message being sent. If each information unit is equi-probable then the source has maximum entropy, that is, there is the most uncertainty about the message at the source. One could say, by analogy to thermodynamics, that there

is the maximum of disorder in such a message. Entropy is zero if an information unit or the ordering of such units has a probability of 1 (see Shannon 1948: 390). In that case it is highly ordered. One can think, by analogy, to the framework of thermodynamics, where a uniformly diffuse distribution of particles in a closed system is highly entropic, or disordered, while a clustered arrangement of such particles is highly ordered, that is, has low entropy and, thereby, has greater potential for useful work.

What is striking about Shannon entropy is that in measuring the number of bits of information needed to reduce the uncertainty of the information source, it thereby also measures the maximum efficiency of the delivery of the message. In other words, the number of bits of information needed to reduce the uncertainty of the message at its source cannot go below the number of bits of its information entropy. Consider the following example.

Imagine a game in which one is attempting to guess a card a friend is holding, from a deck of standard cards. The information at the source is at maximum entropy since any card is as equally likely to be held by your friend. By Shannon's calculation, since there are 56 possibilities at the source, all equiprobable, then the entropy at the source is 5.6 units [H = -56 (1/56) log (1/56)]. Thus, the minimum efficiency by which one could reduce the uncertainty about the state-of-affairs of the source would be on average 5.6 bits of information. An efficient way to reduce the uncertainty of that state-of-affairs is to ask a set of framing questions with a yes/no answer; thus the response is exactly one bit of information. The most efficient list of questions would be: is it red or black; if red, hearts or diamonds; if diamonds, is it 6 or less; if not, is it between 7 and 10; if not is it either a Jack or a Queen. Altogether it would take between 5 and 6 bits of information, the entropy of the source message. The first bit of information confirming the color of the card reduces the uncertainty at the source by ½, the second bit of information reduces that uncertainty by ½, and so forth, until we identify the card in the hand.

If, in thermodynamics, entropy is a measure of the inability of the system to do work, then it might be hypothesized that, by analogy, the amount of information entropy in a message is the measure of the information's inability to do work, or the amount of

information it would take to remove the uncertainty and make it available for work—assuming it can do work on some system. Imagine that a bit of information is a key which either turns a switch on or off, the switch steering a propagating organization that produces some behavior, then that bit of information does work on the system. For example, a codon in the tRNA, such as UUU maps the amino acid, phenylalanine, while ribosomes, reading codons in the mRNA, biosynthesize proteins by assembling the appropriate amino acids. Imagine, on the other hand, a bit of information which neither turns the switch on nor off. In that case, the bit of information does no propagating work. As Kauffman reflects:

> How does an agent detect yuck? A concrete case would be that a yuck molecule binds a yuck receptor, constraining the receptor's motions, which in turn acts as a constraint in unleashing a cell signaling cascade leading to motion away from yuck. Further, if yuck is present below a detection threshold, it will not be detected by the agent. Hence that threshold, and the receptor itself, act as constraints partially determining the behavior of the agent in fleeing or not fleeing" (2008: 39).

This may be part of the key to understanding the relation among "…matter, energy, information, and propagating organization" (2008: 40).

Interestingly, Kauffman and his colleagues do not think that Shannon information can be properly applied to living systems. One complaint which Kauffman raises is that Shannon information is not connected with semantics, but biotic agents have purpose and hence meaning (2008: 38). Although Shannon makes it perfectly clear that his concept of information has nothing to do with meaning (1948: 379) that does not mean there is no relation between Shannon information and meaning. Kauffman wants to collapse the concept of meaning with concept of information, but separating information from meaning solves several problems in semiotic theory, as will be shown. For Kauffman, information is the acting constraint on a propagating organization (2008: 31), exactly the way in which a glucose molecule may bind, thereby constrain, the behavior of a receptor on the *E coli.*

What will be argued here is that the meaning of that information is precisely the work it performs on that propagating system. As John Maynard Smith argues "…genetic information is 'meaningful' in that it generates an organism able to survive in the environment in which selection has acted" (2000: 190).

Meaning as the Work of Information

With this account of information, it is easier to support the thesis that meaning is the work of information. The train of reasoning to that conclusion is as follows: information is non-semantic and should be kept distinct from meaning; information is a material feature of things, capable of extracting work on a sign agency; meaning of that information is nothing other than the work information extracts from the sign agency, the most robust manifestation being its role as a steering mechanism for the sign agent.

According to Shannon, information can be treated separately from any meaning it may have (1948: 379). It is important to distinguish information from meaning since, as Fred Dretske suggests, "once this distinction is clearly understood, one is free to think about information (though not meaning) as an objective commodity, something whose generation, transmission, and reception do not require or in an way presuppose interpretive processes (1999: vii). Dretske argues that signs *carry* information and, thereby, may have a meaning, but not every bit of information a sign carries is meaningful (1999: 44). Someone may hear the doorbell ring. That signal carries a number of bits of information, not only that someone is outside the door, but that the doorbell has been depressed, the electrical circuit has been completed to trigger the inside bell, that electrons are flowing through the wiring, and an indefinite number of other bits of information (1999: 72). Yet what is meaningful for the receiver—to put some words in Dretske's mouth--is tied to the sort of work that information performs on the sign agent. In this case, the sound of the doorbell (understood as a sign), acts as an index, steering the behavior of the person to come to the front door and cautiously open it to see who is there. The fact that the sound of the doorbell also carries information that the bell was

depressed by someone has no particular meaning in this context. However, if after trying to depress the doorbell no sound is emitted, and the visitor starts to knock on the door, the fact that the visitor depressed the doorbell may have meaning for the occupant in trying to fix a broken system.

Since, as it has been argued, information is a material feature of signs that carry it, information has causal force, and can perform work on a living system. If indeed it is able to perform work on that living system, then that information *has meaning* for the destination; if it does no work, then it has no meaning relative to that living system. However, it is not just any kind of work, but *propagating* work. In our model living system, E*. coli*, the feedback loop created between detection of a glucose gradient and the movement of the organism is an example of propagating work. It is not enough that a chemoreceptor detects dense gradients of glucose, it must also steer the organism in a direction that takes advantage of those dense gradients, thus reinforcing the organism's ability to do the work of living.

This account is consonant with Dretske's notion that "…meaning, or something's *having* meaning, is to do the kind of work expected of it…." (Dretske 1992: 80). More specifically, "…an element's causal role in the overall operation of the system of which it is a part is determined by its indicator properties, by the fact that it carries information. The element does *this* because it indicates *that*…" (Dretske 1992: 80); "…representational structures acquire their meaning…by actually *using* the information it is their function to carry in steering the system of which they are a part" (Dretske 1992: 81). In sum, the meaning of a sign is tied to the propagating work it does.

As a note of caution, however, we can use Dretske's language to make the distinction between information *having* meaning, and information having meaning *for* the sign agency. For information to be meaningful *for* a sign agency, it must have a second-order capacity, specifically, the capacity for having purposes, or *goal-intended* behavior, that permits it to constrain the constraint at the first level, relative to those purposes. On the other hand, we can think of information as meaningful, plain and simple, if it extracts

useful, that is, propagating work from the organism. Meaning in the latter sense is something that researchers could discover and could attribute to an organism, even if it is not possible to be meaningful *for* that organism. It is also important to note that articulating meaning in terms of the concept of work is not a re-hashed form of behaviorism. Work is a broader concept than behavior. It is quite possible that the work performed by a sign is purely cognitive work with little ostensible observable behavior, nor does the notion entail that mental entities can be translatable into behavioral equivalents.

Using Peirce's Semiotic to Analyze the Role of Information and Meaning in Living Systems

With some modification, Peirce's semiotic theory can serve as a rich tool for the analysis of this account of the role of information and meaning in living systems. One such modification is to substitute Shannon's non-semantic concept of information for Peirce's semantic one. For Peirce, information is not a primitive element of sign processes, but the product or result of sign apprehension by interpreters. In a very interesting analysis, he conceives of information as the product of coordinated breadth and depth, that is, reference and sense (or content) of the sign. Information occurs when a predicate applies to a subject or referent. Thus, a young student studying biology may be surprised with the information that the predicate 'mammals' applies also to the subject or referent, 'whales', and so is informed accordingly (see CP 3.608; Liszka 1996: 28).

If we integrate the Shannon notion of information into the basic framework of Peirce's semiotic, the result is a clearer picture of how signs operate in living systems. For Peirce, signs are not special types of things, but anything can function as a sign if it meets what Peirce famously identifies as three necessary conditions: It must be about something, it must convey something about the thing it is about, and it must convey that to something else (see Peirce LW, 32; Liszka 1999: 314). Using the Shannon notion of information, we can say that a sign, in order to function as such for some agent, must refer to something,

must convey some information about its referent, such that the information it conveys directs, or has a "significate effect" on, the behavior or processes of that agent, literally speaking, it must be capable of informing the agent (CP 5.473, 5.475, 2.228, 8.191; see Liszka 1996: 25). The critical point of Peirce's theory, however, is that these three conditions must be triadically related for the sign to function as such and, when they are, they produce an interpretant or meaning for that sign. An index, for example, must serve to connect some information about something with the effect that information has on the sign agency. As in the case of our model organism, *E. coli*, the chemical presence of glucose sends cascading messages to the chemical motor of the flagellum, which then causes it to move toward the direction of the glucose gradient. Thus the index connects source, information, and behavior in a positive feedback loop. To use Kauffman's language, this triadic relation among the three functions of a sign essentially defines a constraint on work on the propagating organization for the organism.

The interpretant, understood as the meaning of a sign, is not something that is necessarily associated with a self or human agent, but is simply understood as the "signficate" effect of the sign has on a system at some level (CP 5.473, 5.475, 2.228, 8.191; see Liszka 1996: 25): "When a sign determines an interpretation of itself in another sign, it produces an effect external to itself, a physical effect, though the sign producing the effect may itself be not an existent object but merely a type" (CP 8.191).

Peirce outlines three types of interpretants or levels of meaning in this context. The *immediate* interpretant of a sign is manifested in the fact that the sign is recognizable as such, and bears information, even if it is unclear what the information may mean at this point (LW 110; Liszka 1996: 26). We assume there is an indefinite amount of information in a sign agent's environment that is not readable by that agent, just as a human eye cannot detect ultraviolet light, but a human eye reading a spectrometer might. In order for the sign to be readable in principle, it has to be *schematized*, that is, the information at the source has to be translated in a way that can be read by the receiver of the sign agent. The *dynamic* interpretant, on the other hand, is the actual effect the information in the

sign may have on the sign agency, and that may be simply a single, one-time effect (LW 110; CP 4.536: Liszka 1996: 26). The *final* interpretant is the fullest type of interpretant, in the sense that it engenders a continuing habit of such action as the significate effect of information (LW 110; Liszka 1996: 27). As Peirce writes,

> To develop its meaning, we have, therefore, simply to determine what habits it [the sign] produces, for what a thing means is simply what habits it involves. Now, the identity of a habit depends on how it might lead us to act, not merely under such circumstances as are likely to arise, but under such as might possibly occur, no matter how improbable they may be (CP 5.400).

If the first modification to Peirce's semiotic theory was a substitution of a non-semantic concept of information for a semantic one, the second requires an articulation of the notion of interpretant in terms of work, specifically the propagating work of information. This is not far-fetched, since Peirce's pragmatic maxim—at least in one of its more simple formulations---connects to the practical workings of concepts: "…the possible practical consequences of a concept constitute the sum total of the concept" (CP 5.27). Indeed, the notion of habit-generation as the core of the interpretant is conducive to such an interpretation—particularly the kind of work associate with steering behavior. In recent work, Stuart Kauffman and his colleagues define information in terms of the constraints inherent in any propagating organization (2008: 29). To take a simple example, when an enzyme acts as a catalyst by binding two substrates and holds them so that the potential energy barrier that prevents them from joining is lowered, it acts as a constraint on their motion. In this sense, the constraint directs energy in the form of work within the cell. "The cell, we want to say, has embodied knowledge and know-how with respect to the proper responses to yuck and yum, which was assembled for the agent and its descendants by heritable variation and natural selection" (2008:39). If information is identified with the constraints in a propagating organization, then the work it extracts by

directing or steering the organism counts as the meaning of that information, or, in Peirce's terms, the habit of action engendered in the sign activity. In the case of our model organism, *E. coli,* the information in its indices literally puts that information to work by steering the organism toward its food source, and creating a positive feedback loop.

Using Dretske's language, this feedback loops constitutes *goal-directed,* but not *goal-intended* behavior (1992: 111). Some have used the term *teleonomic* to distinguish the former from the latter (see Von Wright 1971). Following Larry Wright's account (1976), goal-directed or teleonomic behavior is behavior that not only tends to have a certain result but occurs precisely *because* it tends to have this result (1976; Dretske: 1992: 111). As Peirce puts it, "But now when a microscopist is in doubt whether a motion of an animalcule is guided by intelligence, of however low an order, the test he always used to apply when I went to school, and I suppose he does so still, is to ascertain whether event, A, produces a second event, B, as a means to the production of a third event, C, or not. That is, he asks whether B will be produced if it will produce or is likely to produce C in its turn, but will not be produced if it will not produce C in its turn nor is likely to do so" (CP 5.473). For Peirce this is precisely what distinguishes dyadic from triadic behavior (CP 5.472). As Stuart Kauffman and his colleagues argue, "we believe that autonomous agents constitute the minimal physical system to which teleological language rightly applies," where autonomous agents are defined as bounded beings, capable of discrimination of signs, and at least one choice of action (Kauffman et al., 2008: 29-30).

However, for an organism to have *goal-intended* behavior, it must have complex abilities to intend an outcome or goal. These require more developed internal capabilities of desire and belief (see Dretske 1992: 109ff). Despite Jesper Hoffmeyer's arguments in favor of intentional behavior for organisms even at the primitive level of the amoeba, it is hard to claim in any literal sense that *E. coli* intends its behavior (see Hoffmeyer 1996: 47-48). What we see in the behavior of *E. coli* is a kind of teleological behavior more complex than the directedness found in finious processes, but less complex than the sort of purposive

behavior characteristic of human agency. The complexity results from the necessity of a living creature to convert energy into work sufficient to sustain itself, and the essential role that signs must play in that process.

Peirce suggests an interesting thesis in this regard, namely, that there is a correlation between the kind of teleological behavior and the kind of semeiosy present in an organism (see Liszka 1996: 33). The teleonomic behavior of the *E. coli* involves a lower level of semeiosy, based primarily on indices. Symbols, Peirce argues on the other hand, are correlated with purpose (NEM 4: 243), that is, with *goal-intended* behavior---to use Dretske's language. This suggests that indices are more primitive kinds of signs, evolutionarily speaking, than symbols, a position claimed also, for example, in the work of Terrence Deacon (1997: 22). The presence of purposefulness, in turn according to Peirce, is co-extensive with the ability of the organism to self-control or, more importantly, to self-correct—thus exhibiting a more robust kind of agency (CP 5.427). Teleonomically-organized organisms are not capable of self-correction; the correction of behavior occurs externally through the impingement of environment upon the organism, and the alignment of internal changes to those impingements—that is, through a process hewn by natural selection. Using our vocabulary, natural selection is a *goal-directed* process (but certainly not *goal-intended* or *purposive)* in the sense that, perforce, it constrains organisms by a variety of means to a definitive end–the adaptation to their environment. In that case all existent organisms are also adapted to various degrees, and if they are maladapted they do not exist (or soon will not exist). Thus, however such a connection between the detection of energy sources and behaviors that allows organisms to get those energy sources arises, that will be adaptive; and if they have not been successful in that regard then they do not exist (or will shortly not exist). The correction of the behavior then is a process external to the organism, constrained by the organism's environment. For this reason, teleonomic behavior exhibits what Peirce calls a *quasi-mind* (CP 4.551, NEM 4: 318). It is triadic but not intentional.

How Signs Convey Information, Refer, and Inform

Two modifications to Peirce's theory have been proposed: a non-semantic notion of information, and an interpretation of the interpretant as the work of that information. Given these modifications, Peirce's theory provides exquisite detail about sign structure that may be useful in articulating how signs such as indices function in primitive organisms like *E. coli.* If we focus on the three anchors of any semiosis—sign, object, interpretant--the sign itself can be analyzed from three dimensions, reflecting the three conditions of a sign-function: the manner in which a sign refers, the manner in which it conveys information, and the manner in which it informs the sign agency.

In order for a sign to function as such it must certainly be the bearer of information, that is, it must be capable of conveying something. The informational content of the sign may be carried in three different ways. Following Peirce, if the information in the sign shares the same quality as the information in its source, for example, the way in which a color photograph is red in the way in which the actual rose is, then the sign is qualisemiotic, the adjectival form of Peirce's notion of a qualisign (CP 2.244). If the information in the sign is carried by contiguity, for example, the way in which a horn blast over a loudspeaker may convey to listeners that an important message follows, then the sign is sinsemiotic (CP 2.245). If the information in the sign is carried by means of a pattern or regularity apprehendable or discoverable by the sign agency, for example, the way in which a message may be sent by Morse code, then sign is legisemiotic (CP 2.246).

In order for a sign to function as such, it must also refer, that is, it must be about something. Signs may do this in three general ways, according to Peirce: A sign is iconic if it refers by being similar to its referent, in the way in which a map may refer to a terrain; a sign is indexical if, as we have seen, it refers by being contiguously or physically connected to the referent, for example, as the way in which a windvane indicates the direction of the wind by physical contact with the wind; a sign is symbolic if it refers by means of some general regularity, such as the manner in which a collection of phonemes that constitute a word such as 'dog' refers to the animal we know and love (CP 2.276, 2.247-2.248, 2.297).

In order for a sign to have a "significate" effect, that is, to extract work from the sign agency, to produce an interpretant of the information it conveys about something, it must be capable of informing the agent. If the sign informs the sign agent by serving as information equivalent to other information already apprehended by the sign agent, or as a substitute for some other piece of information, then it is semic (CP 4.538; 8.373). A very basic example would be a dictionary definition which, in fact, equates definiendum with definiens, or the translation of a term in one language into another. If the sign informs by connecting two or more disparate bits of existing information, then the sign is phemic (CP 4.538; 8.373). A classic example is a basic proposition, such as 'whales are mammals' which, in connecting a subject with a predicate, creates more information about each term than the terms convey alone. If a sign informs by connecting its information into higher ordered systems of information, then it is delomic, in the manner in which a signal in a cell is amplified, or the way in which a logical argument colligates propositions toward a conclusion (CP 4.538; 8.373). The conclusion provides more information than found in the propositions separately considered.

We might use the behavior of the gametes of allomyces, the common water mold, to illustrate how signs carry information in primitive organisms. Male and female gametes must obviously conjoin in order to have successful reproduction, but first they must find each other. This is made possible through a chemical communication system of pheromones, which the female gamete emits as it emerges from the gametangia, and which the male gamete is able to detect.

A study by William Agosta shows how this works (1992: 14-18, 29-31). A few minutes before the female gamete leaves the gametangia of allomyces, it starts to secrete the pheromone, *sirenin,* and continues to do so over a six hour period. Water currents and the motion of its molecules disperse it in gradients. The male gamete is able to detect differences in the gradient through chemoreceptors in its membrane, and uses that to navigate toward the female. William Agosta's hypothesis is that the gradient is measured temporally rather than spatially. If the gametes measured the sirenin spatially, it would

have to have chemoreceptors at each end of its body, to simultaneously sample and compare local concentrations of the pheromone; in that way it could determine whether it was swimming up or down the gradient, depending on whether the front-end sample registered more concentration of serenin than the back-end. If the gamete detects the gradient temporally, then the same chemoreceptors would do so by comparing successive local concentrations of sirenin. The male gamete behaves similarly to the *E. coli:* If the concentration is increasing with time, that causes it to move forward; if decreasing in time, then it tumbles randomly. To distinguish which of the two techniques of measurement is the case, experiments were designed in which the amount of serenin was increased uniformly with time. The male gamete behavior exhibited longer straight runs and less frequent turns, which showed that it determined the gradient temporally.

In order for the information to be conveyed by the chemical messaging within the gamete, it must exhibit patterns that map the density of the serenin in the aqueous environment, and in the temporal manner suggested by Agosta. This is similar to the way in which information is processed in the familiar waggle dance of the bees, where the dance angle maps direction of the food source, and dance duration maps distance (see Sebeok 1990). Thus the dance is quali-semiotic to the extent that its qualities diagrammatically shares qualities with the information source; sinsemiotic to the extent that the presence of the dance excites other bees to the contemporaneous presence of a food source, and legisemiotic to the extent that the patterns in the dance are regularized for that species, that is, all known species of honey bees exhibit the behavior, with some differences. Basically, this is not unlike the manner in which a windvane indicates the direction of the wind, since it is so designed that when the wind physically pushes it, the pointing arm swings in the direction of the wind. The positions of the arm diagram the information at the source.

Another good example of how information is carried by signs is that part of the process of human hearing, where the amplitude and frequency of sound waves are mapped through transduction by eardrum and ossicles as vibration patterns and, eventually, as fluid waves

in the cochlea (see Liszka 1999: 325-6). Regardless of which of the three dominant theories of pitch we consider—Helmholtz's place theory, Rutherford's frequency theory, or Wever's volley theory--all agree that the neural firing patterns somehow retain the pattern expressed by the frequency of the sound wave which reaches the pinna of the ear, they simply disagree on how that neural pattern expresses it. In that case, the neural patterns are qualisemiotic since they retain the qualities of the information source. Helmholtz claimed that particular points on the basilar membrane vibrate maximally in response to sound waves of particular frequencies (1866). Georg Békésy (1957) showed specifically that as the frequency increases, the point of maximal vibration produced by the traveling wave on the basilar membrane moved closer to the oval window; and as the frequency of the stimulus decreased, the point of maximal vibration moved farther from the oval window. The frequency theory argues that, especially for waves below 1000Hz. the entire basilar membrane vibrates, but in direct proportion to that frequency. The neurons will also fire at the same frequency as the vibrations of the basilar membrane. Wever (1937) suggests that in the presence of certain frequencies, neurons will fire in volleys, so that it is both the simultaneous, cumulative and frequency of firing of the neurons which preserve the pattern of frequency in the sound waves.

What is important to notice in all of these examples is that the sign in effect *schematizes* the source information. Schematization---a classic concept employed by Kant, and recognized by Peirce--is the manner in which information is prepared so that it is compatible with the categorical schemes by which the agent cognizes or perceives things (see Kant 1781, A137; B176; see Peirce CP 2.385). For example, as a sign, the dancing movements of the bee are significant for other bees, so to speak, precisely because they are schematized for bee perception (or perhaps even cognition), just as the way in which the key-and-lock mechanism of the chemotactic receptors at *E. coli's* cell surface are schematized for glucose binding, or the way in which phosphorylated CheY protein is schematized for interacting with the flagellar switch to change the direction of flagellar rotation from counter clockwise to clockwise.

Conclusion

The two modest modifications to Peirce's semiotic theory—the substitution of a non-semantic notion of information for a semantic one, and, the understanding of the interpretant as the propagating work of that information, provide a clearer picture of how signs convey information, refer to sources of that information, and inform sign agencies. These reformulations, in turn, allow us to use Peirce's semiotic theory to give a productive account of how semiosis functions in living systems.

There is no doubt that the modifications proposed have interesting implications for some of the other concepts in Peirce's semiotic, particularly how the dynamic and immediate objects are understood. It may also have some implications for a theory of reference as well. Rather than interpreting dynamic objects as well-formed entities to which representations attempt to approximate, this interpretation tends toward characterizing them as indefinite sources of information. Rather than construing them as real—with all the metaphysical baggage that entails—this interpretation suggests that dynamic objects—or better dynamic systems--are simply the unschematized information that is there, independently of the sign agent, which constrains any representation of it, while immediate objects are the correlates of schematized information.

Semiosis performs a critical role in the functioning of living systems. The sign is an efficient mechanism for conveying information about the world around us. Precisely because signs make possible an economy of information, they are critically adaptive. We only need point to language as an obvious example of how a small amount of information has the capability of representing vast amounts of information, and generates untold systems of meaning. Indeed the brain itself is a marvelous natural example of an efficiency of information processing and storage and, it is no secret that this ability rests primarily on its talent as a sign agency. The genetic code is another good example of information efficiency in this respect, since it is capable of storing enough information to build an organism. The prey need not represent every bit of information in the dynamic system of its environment to get information about that predator. It need only have certain indices:

the sound of branches cracking, the whiff of something in the wind. We may think of signs analogously in the same way in which we consider controls on a complicated electronic device. They represent an economic way for us to control and operate a mechanism which contains a great deal of information. We do not need to know all the information necessary to understand how that power gets turned on, all we need to know is that by pushing the on button, the power does turn on. Signs are inherently information efficient in the same sense and enormously helpful in doing the work of living.

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