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Energy, Semiosis and Emergence — the place of biosemiotics in an evolutionary conception of nature

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Abstract

Autonomy, i.e., self-ruling or self-regulation, is a distinctive mark of organisms and living systems in general. Organisms are parts of the world that segregate themselves from the rest of it (their environment) through structures (membranes) that allow selective passage of various forms of matter, energy and information in and out of their constituted interior. Processes within such interiors obey the same laws of physics that govern events in the environment, but are additionally constrained by further restrictions arising from the conjunction of those laws and the peculiar boundary conditions that characterize the internal dynamics of autonomous systems.
Among the different orientations in biosemiotics, those moved by Peircean ideas tend to agree that this organization of inert parts into autonomous agents cannot be made intelligible without supplementing the traditional resources of the physical sciences with novel kinds of causation. This is true in particular with regard to that form which Peirce called **semiosis**—the influence by which signs mediate the determination of interpretants by their objects. In this view the promise of biosemiotics far exceeds its role as a biological sub-discipline in charge of the semiotic aspects of living processes (cellular signaling, organic codes, etc.). Important as that task is, it does not exhaust biosemiotics' project, which should include two other important endeavors: first, if semiosis is essential to the constitution of the objects of biological science, biosemiotic ideas must have foundational and integrative roles comparable to those of evolutionary conceptions; and second, these roles should promote a wholesale redefinition of the place of biology within the sciences.

This paper addresses the latter two points by contrasting the logic and heuristics of causal explanations in physics and chemistry with those operating in biology. This examination clarifies the relations between semiosis and ordinary physical causation. It also proposes a new perspective on the evolutionary nature of emergence by taking into account the increasing importance of evolutionary explanations in some branches of contemporary physics.

1. Biosemiotics changes the way biology relates to physics

Autonomy, i.e., self-ruling or self-regulation, is a distinctive mark of organisms and living systems in general. Organisms are parts of the world that segregate themselves from the rest of it (their environment) through special structures (membranes) that allow selective passage of various forms of matter, energy and information in and out of their complexly organized interior. Processes taking place within such interiors obey the same laws of physics that govern events in the environment, but their course is additionally constrained by further restrictions arising from the conjunction of those universal laws and the peculiar boundary conditions that characterize the internal dynamics of autonomous systems. By submitting to more exacting constraints organisms paradoxically enjoy new forms of spontaneity and freedom of action not to be found among inert objects. In contrast to inert objects they behave as autonomous agents pursuing individual purposes.

There are different philosophical orientations in biosemiotics, but researchers who find inspiration in Peircean ideas should agree that this organization of inert parts into autonomous agents cannot be made intelligible without supplementing the traditional resources of the physical sciences with new conceptual and methodological tools apt to meet the special explanatory needs of biology. I believe that among these additions biosemiotics requires the adoption of novel kinds of causation, in particular that peculiar form of causal action which Peirce called **semiosis**—the influence by which signs mediate the determination of interpretants by their objects.

When this perspective is embraced the promise of biosemiotics far exceeds its role as a biological sub-discipline in charge of the semiotic aspects of living processes (cellular signaling, transduction, organic codes, etc.). Important as those functions are, they do not exhaust biosemiotics' project, which in this light should include two other significant features. First, if we consider semiosis as an essential component in the constitution of the objects of biological inquiry**,** we can expect that **biosemiotic ideas should acquire a high foundational and integrative status, comparable perhaps to the one presently assigned to evolutionary conceptions**. Second, we can also expect that this role would promote a wholesale **redefinition of**

the place of biology within the sciences, especially with respect to the way biology is grounded on the continuously evolving theories, concepts and methods of physics.

This paper addresses the latter two points by contrasting the logic and heuristics of traditional causal explanations in physics and chemistry with those operating in biology. This examination attempts to clarify the relations between semiosis and ordinary physical causation. It also advances a new perspective on the evolutionary nature of emergence by taking into account the increasing importance of evolutionary explanations in some branches of contemporary physics.

2. Summary of a previous proposal for modeling semiotic causation

As I will explain further on, I believe biosemiotic explanations, in contrast to ordinary physical explanations, require the simultaneous application of bottom-up and top-down explanatory paths. In last year's contribution to this forum I advanced a sketchy and tentative proposal aimed at providing an intuitive scheme for expanding the presently restricted application of top-down explanations in biology (Fernández 2010a). My goal was to redefine the roles of ordinary (physical) and semiotic forms of causation through a conception partially based on ideas first suggested by Charles Peirce. According to this proposed view physical causes act by channeling the spontaneous tendency of energy towards its dissipation. This channeling takes place through the agency of resistive constraints, which act through the embodiments of habits, i.e., propensities to reproduce similar behavior each time similar triggering circumstances are reproduced.

This leads us to distinguish between two basic kinds of physical processes: those that occur spontaneously down an energy gradient (e.g. a ball rolling downhill) and those that are forced to proceed against a gradient (e.g. photosynthesis, the working of a refrigerator). This forcing is always achieved through a link (coupling) to a more energetic spontaneous process, by means of resistive constraints.[1]

[1] Biological examples of this coupling are countless. Active transport processes across the cell's membrane, such as the action of the sodium pump, are good illustrations. Sodium and potassium ions travel against their electrochemical potential gradients by coupling to the energy flow generated by ATP hydrolysis.

I illustrated this idea using the image of a river paddleboat that remains moored to the bank for long periods while the current turns the paddles, which are mechanically connected to a generator that charges a battery. This is done using the reactive (resistive) action of the moorings, preventing it from being dragged by the current. Once the battery is charged, the boat can sail upstream for a short period, using the generator in reverse as a motor. By a similar process the electric generator drives the electrons up against the thermodynamic gradient to charge the battery. At the turn of a switch (re-channeling of the energy flow by elimination of resistive constraints) the battery discharges spontaneously through the motor. This rotates the paddles against the resistance of the water, propelling the ship upstream until all of the energy is dissipated irreversibly into heat.

This image suggests a heuristic approach to causal top-down explanations. It is based on the interplay of three factors:

> 1) A source of free energy moving **spontaneously** towards its complete dissipation;
> 2) Structures that resist, redirect and channel the flow of energy in various ways (boundary conditions and **constraints**); and
> 3) A tendency to reproduce similar effects every time similar energy flows and constraints are reproduced (**habit**).

These three factors, **spontaneity**, **constraint** and **habit** are instances of the Peircean categories of **firstness, secondness and thirdness.**

Based on this triadic conception of physical causation I further proposed to envision semiosis as a form of **second-order causation**: semiosis causes changes in the causal action itself. It alters the way in which energy is channeled by acting upon the habits embodied in the constraints that guide the flow of energy toward thermal equilibration. I gave these illustrations:

> Beyond a minimal threshold semiotic causation, in contrast to ordinary causation, is quantity-independent. When we press a button to “call” an elevator, for instance, the signal’s strength is independent of the pressure exerted and uses a negligible amount of energy. This is sufficient to produce the desired **interpretant**

> (release of a large flow of energy to move the elevator) by altering the configuration of the switching devices (**constraints** on the flow of electrical current). Examples more suited to biosemiotics are commonplace: an animal that interprets a peculiar noise as an index of an approaching predator goes through a similar process to release abundant energy for speedy flight. At the basic cellular level the organic codes embody systems of genetically preset habits ready to be triggered by physical or chemical signals into releasing energy flows. These flows are channeled through biochemical pathways toward their specific interpretants, e.g. the opening of an ion channel by the binding of a ligand to a protein receptor. (Fernández 2010a)

It is not my intention to advance a new contribution to the complex and tangled literature on the philosophy of causation. I merely aim at suggesting a new heuristic model of causation, conceived and communicated in purely metaphorical language, that may prove valuable for extending the explanatory reach of biology, and especially of biosemiotics, beyond the resources inherited from traditional physics and chemistry. This can be useful because it has become increasingly clear that the use of metaphors, and of analogical reasoning more generally, has been again and again a crucial aid in the early articulation of novel hypotheses and the generalization and extension of received theories and conceptions (see e.g. Keller 2002, Fernández 2011).

3. Explanations: bottom-up and top-down

The addition of semiosis to the traditional forms of causation usually invoked in the physical sciences allows the deployment of new explanatory schemes in which semiosis and traditional causation become related in new ways. This is best brought out by briefly indicating the principal ways in which physics makes sense of the world **in the absence of semiotic transactions**. After that we can consider new explanatory patterns arising in biosemiotics as a result of the introduction of semiotic causation.

Albert Einstein published in 1919 a short and memorable article for the popularization of relativity theory (Einstein 1919) in which he introduced a seminal distinction between two different types of theories

(and forms of explanation): **constructive theories** and **theories of principle**.

Constructive theories postulate the existence of basic singular parts, with simple properties and forms of interaction, and proceed to explain more complex phenomena by constructing combinatorial models out of those elements. These are typically the mechanical models and mechanisms that figure prominently in physical and biological explanations, such as, e.g., the molecular underpinnings of the processes of genetic replication, transcription and translation. Constructive theories typically provide **bottom-up explanations**.

In contrast, theories of principle generate **top-down explanations** of lower level laws and regularities, starting from high-level principles of great generality. These are, e.g., the symmetries of space and time, or highly confirmed empirical generalizations such as the impossibility of perpetual motion machines. In physics we have phenomenological thermodynamics and relativity theory as typical instances of theories of principle. In biology it is difficult to find clear examples, but the theory of evolution through natural selection, of great foundational importance, appears to be a combination of both types of theory.

Constructive theories privilege the role of parts over that of wholes, and render phenomena intelligible by articulating the patterns of efficient causation that map the interactions of those parts, making the process visualizable and intuitively appealing. In contrast, theories of principle privilege the role of the whole over that of its parts, and render phenomena intelligible through unification, thanks to their subsumption under principles from which they can be inferred. This makes the explanations logically appealing. I believe both types of theories (and explanations) are necessary and frequently complementary, and that in many biological and biosemiotic situations they need to be simultaneously applied.[2]

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[2] I follow Peirce's conception of a complementary relation between efficient and final causes. This subject is too vast and complicated to be developed here. Without going into details, the following remark may perhaps cast some light on this issue. The relation between efficient and final causation is logically analogous to the relation of the parts to the whole that contains them. Says Peirce: "Efficient causation is that kind of causation whereby the parts compose the whole; final causation is that kind of causation whereby the whole calls out its parts." (CP, 1.220, in Peirce 1931). From this point of view top-

Systems biology reveals that in complex self-organized systems there is no privileged level of functionality. Parts act on the wholes they integrate and those wholes in turn act through circular loops upon their parts. Here explanations must start *in medias res*, and bottom-up and top-down explanatory schemes may be simultaneously invoked. My proposal for a triadic view of causation naturally integrates both forms of explanation into a single scheme. The spontaneous flow of energy towards dissipation is a top-down consequence of the laws of thermodynamics, while the channeling of that flow by resistive constraints is embodied in the mechanisms typically featured in bottom-up explanations.

4. Differences among differences

After more than two hundred years of displaying a totally ahistorical portrait of nature, physics is now evolving into an **evolutionary science** able to develop new points of contact with biology. We have an evolutionary cosmology intimately linked to an evolutionary Standard Model of particle physics, rooted at the most basic level on the conceptions of symmetry and spontaneous symmetry breaking. The fundamental forces and their concomitant varieties of particles arise progressively through successive breakings of the original all-encompassing symmetries, as the universe "cools" throughout its continuous expansion (See e.g. Balashov xxx, Fernández xxx).

Frank Wilczec aptly characterizes symmetry as a "distinction without a difference" or a **difference that makes no difference** (Wilczec 2008, p. 58 *et passim*). Biosemioticians no doubt will be reminded of Bateson's contrasting definition of information as "**a difference that makes a difference**." This asymmetry between differences is not accidental. As we shall consider later, information (and therefore semiosis) is closely related to symmetry breaking, the process by which a difference no longer makes no difference. Modern physics was born with the discovery of Galilean symmetry, the fact that an observer moving inertially inside an ideally smooth-sailing boat cannot detect a

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down explanations appeal to final causes, just as bottom-up explanations invoke efficient (mechanical) causes.

difference between being at rest and being in motion — unless information from the external world is allowed to enter through a porthole. Non-accelerated motion makes no difference.

Because of the multiple and contentious acceptations of the term "information" I here distinguish between "physical information" and semiosis (semiotic information). The first, "physical information," is a physical quantity that can be measured as stored (bits of memory) or transmitted (bits per second of bandwidth). The second, semiosis, is a species of formal causation, different from efficient and final causation. It consists in the transfer of a **form** that is embodied in an energetic process and that brings about a special effect (interpretant). In contrast to other kinds of causation, **it is quite independent** —above a minimal threshold— **of the quality and quantity of its embodiment**.

Semiosis is a difference (transfer of a form) that makes a difference (production of an interpretant). The form transmitted is what Peirce called a "would be," not an actual existent but a transmissible power, "the fact that something would happen under certain conditions." [3]

In an organism the reception of this form usually amounts to a triggering. In the simplest example, a metastable configuration acting as a switch (posed symmetrically between two divergent courses of action) breaks its symmetry upon receiving such a form. The making of a difference between symmetrically divided courses of action, or between quiescence and action, constitutes a non-spontaneous symmetry breaking. There are countless examples of this difference-making: the firing of a retinal photoreceptor neuron upon reception of information-carrying photons; the explosion of a terrorist's bomb with a

[3] "That which is communicated from the Object through the Sign to the Interpretant is a Form; that is to say, it is nothing like an existent, but is a power, is the fact that something would happen under certain conditions. This Form is really embodied in the object, meaning that the conditional relation that constitutes the form is true of the form, just as it is in the Object. In the Sign it is embodied only in a representative sense, meaning that whether by virtue of some real modification of the Sign, or otherwise, the Sign becomes endowed with the power of communicating it to an interpretant." [See Peirce 1998, p. 544].

mobile phone detonator, upon reception of a well-defined string of bits, etc.

5. Semiosis, emergence, and evolution

In the last two decades the subject of emergence (short for emergence of novelty) has aroused great interest and generated a copious literature. In a recent paper (Fernandez 2010b) I have attempted to develop Peirce's fledgling conception of *variescence* into an account of the nature of emergence, grounded on his view of a cosmic evolution propelled by the universal habit of acquiring habits. Here I will advance a few remarks on the relation of a Peircean conception of emergence to our present considerations regarding semiosis as a form of information creation and transfer.

"Emergence" as the rise of new properties, relations, kinds of processes, or causes, is frequently characterized in terms of wholes that display new features not found in the parts that make them up. These totalities are often complex systems, and their emergent novelties are usually attributed to processes of self-organization, a characteristic of many complex dynamic wholes, such as tornados, organisms and ecosystems.

Information has an obvious connection to novelty. A message that delivers no new information delivers no information at all. This fact suggests generalizing the idea of information in order to understand emergence as the generation of new information. I propose to distinguish between three kinds of information with respect to the type of novelty with which they are associated. They are:

1) **Local novelty**: information that conveys novelty to living systems in relation to their internal representation of the environment (**semiosis**).
2) **Mereological novelty**: new information as the rise of novel features in a whole, which are new in relation to the properties of its parts (**emergence**).
3) **Cosmic novelty**: the formation of radically new structures with respect to the previous history of the universe, such as the creation of stars, life, new species, new organs, new theories (**evolution**).

If this proposal proves viable it would open an avenue for including biosemiotics within an emergent trend in physics — toward foundational notions rooted in the evolutionary emergence of laws and entities through symmetry and symmetry breaking. It would simultaneously disclose an unsuspected connection between Peircean semiotics and Peircean cosmology. It would link semiosis to the cosmic generation of novelty through the universal habit of habit acquisition.

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