LIVING IS SURVIVING: CAUSATION, REPRODUCTION AND SEMIOSIS

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ABSTRACT

Since Darwin's appropriation of Spencer's phrase "survival of the fittest," differential survival has become the basis of explanatory accounts of biological evolution through natural selection. Beyond extrinsic survival (e.g., finding food, avoiding dangers, etc.), intrinsic survival demands continual internal repair and reconstruction to offset the effects of unrelenting internal decay and depletion. The organism must constantly **re-produce** the conditions of its own existence. The individual's survival is nevertheless subordinate to that of the species. The survival of the species is achieved through biological **reproduction** in the ordinary sense (i.e., assemblage of a working copy of the organism itself, capable of surviving and reproducing in turn.)

In this contribution I attempt to explain how these two types of reproduction (i.e., for the survival of the individual and of the species) are related to other kinds of replication, such as the reproduction of a picture, of a melody, or of a movement. I believe all of these reproductive forms are based on a fundamental one, which is the condition of possibility of all forms of replication. This fundamental kind of reproduction resides in the **spontaneous reproduction of events under physical causation**.

Since its inception in the 17th century, modern natural philosophy appeals to a scheme of causal explanation in which a physical system causally isolated from its surroundings is characterized by a quantitative description of its *state* during an arbitrarily short–term interval. When this set of particular, contingent determinations (*initial conditions*) are injected as inputs into mathematical functions known as *laws of nature,* an*y* future state of the system can be computed in principle. Every time we are able to **reproduce** sufficiently similar initial conditions nature spontaneously and automatically **reproduces** sufficiently similar future states. This modern conception of physical causation replaced the medieval Aristotelian view based on the idea of powers or capacities, inherent in things of a common nature, ready to be enacted upon the occurrence of well-defined triggering conditions. I try to show that these different causality conceptions are not

incompatible but, on the contrary, Peirce's conception of **habit** makes possible their synthesis into a more general notion, which is well suited to the needs of biosemiotics and biology in general. In the spirit of current accounts of causation in terms of powers or dispositions, I propose a thermodynamic interpretation of physical causality. On this basis I advance an interpretation of semiosis as a type of second-order causation: at the level of biosemiotic transactions, semiosis acts by altering habits embodied in the constraints that in turn causally determine the extent and direction of physical changes.

Finally, I indicate some commonality between the present proposals and the work of a variety of investigators who use top-down thermodynamic notions in different fields of research through the application of the principle of maximum entropy production.

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> The great contradictions which man discovers in himself – freedom and necessity, autonomy and dependence, self and world, relation and isolation, creativity and morality – have their rudimentary traces in even the most primitive forms of life, each precariously balanced between being and not-being, and each already endowed with an internal horizon of "transcendence". [1]

Neurath's ship and the ship of Theseus

In this contribution I attempt to explain how two different types of biological reproduction (for the survival of the individual and of the species) are related to other kinds of replication, such as the reproduction of a picture, a melody, a movement, or a gesture. I conjecture that all forms of reproduction are based on a fundamental one that resides in the **spontaneous reproduction of events under physical causation**. Next, I develop in a purely impressionistic manner (with no pretensions of formal rigor or demonstration) a perspective on the relations between semiosis and physical causation that may have heuristic value for biosemiotics. This high-level, informal argumentation, partially based on Peirce's ideas, is supported by illustrative images and metaphors that may have intuitive appeal.

Since Darwin's appropriation of Spencer's phrase "survival of the fittest," the expression has become nearly synonymous with natural selection in textbook treatments of biological evolution. In these accounts, survival is tacitly equated to **external survival**: competition, procurement of energy sources, avoidance of dangers, etc. Meanwhile, twentieth-century developments in biology cast a new light on the meaning of survival.

Through the strictures of the second law of thermodynamics we now realize that survival is not merely one among the manifold activities in which organisms engage. On the contrary, v*ivere est supervivere*: **the act of survival and the act of living are coextensive**. To survive — from its Latin roots *super* (above) + *vivere* (to live) — is to actively stay afloat in the sea of life. In what we may call **internal survival**, the entire functional orchestration of physical and chemical activities transpiring at every instant within every organism aim to maintain, repair and replace structures that need to be continuously rebuilt against unrelenting deterioration and decay.

An organism is ever at the brink of death, even when at perfect peace with its environment. Every vital function or mechanism at work within an organism is permanently engaged in the service of **individual survival**, unless it is at the service of **reproduction** i.e., the **survival of the species**. Survival of the fittest means survival of the successful reproducers. The perpetuation of the form takes precedence over that of the individual.

Science and folklore afford innumerable examples of the immolation of parents for their offspring, including altruistic suicide of sterile members of insect colonies to save the reproducers, suicidal mating, and many others. Apoptosis and other forms of programmed cell death show the extent to which the non-survival of individuals is instrumental to the survival of multicellular systems and species.

Otto Neurath aptly characterized the life of science with a famous metaphor: **science is like a boat that must be continuously rebuilt while remaining afloat**.2 This trope is **equally applicable to life in general**, when we consider the continuous re-production and replacement of the organism's parts that must be achieved without interrupting the metabolic and reproductive cycles.

There is another nautical simile that is relevant to this issue. Plutarch told the story of the **ship of Theseus**, which was kept indefinitely afloat by the replacement of decayed planks by new ones until none of the original parts were left. The question whether the ship remains the same one or becomes a new, different ship sparked one of the paradoxes of identity that have exercised philosophers since antiquity to the present.

Since we the inquirers happen to be multicellular organisms and most of our cells are periodically replaced every few years, I feel inclined to side with the Aristotelian answer to this paradox and consider that we remain our same selves thanks to the survival of the *formal cause*. In modern terms, this means that the invariance and continuity of the cyclic processes, causes and effects that keep us alive in spite of thermodynamic degradation constitutes our identity. The formal cause is a temporal, relational structure that persists unaffected by the coming and going of material parts until trauma or senescence leads to its dissolution. The ship of Theseus sinks at the end but — in successful reproducers — not without first building working replicas of the mother ship, using materials obtained onboard.

At present numerous authors in the philosophy of biology agree that the essential attributes of life include functional **autonomy** and **self-reproduction**. Biosemiotics adds a third one: **semiosis** or semiotic causation. These three attributes partake of a common trait, that of having an essential self-referential structure. Autonomy (*auto*: self + *nomos*: law) and self-reproduction show their self-referential credentials on their etymological components. I have called attention to the self-referential nature of semiosis in previous contributions (see e.g. Fernandez 2009, 2010).

John Collier characterizes autonomy ably and tersely:

> Autonomous systems, as with autopoietic systems (deriving from "self- producing"), both produce their own governance, and use that governance to maintain themselves. A system is autonomous if and only if the organization of internal aspects of system processes is the dominant factor in the system's self-preservation, making both itself and the processes that contribute to autonomy functional. […] It is worth noting that autonomy is [an] organizational property constituted of process[es] with some degree of closure, though the closure to external influences need not be complete (Collier 2002).

Autonomy is thus intimately related to the functions that insure internal survival, (i.e., of the **continuous and recursive re-production** of the conditions required for maintaining life as a process). In this sense organisms—and some other far-from-equilibrium open systems—can be said to persist by **recursively reproducing the conditions of possibility of their own existence**. In common usage, the term reproduction is reserved for self-reproduction in a special sense— the assemblage of a working copy of the organism, able to survive and reproduce in turn. This wholesale organismal replication is the outcome of a long chain of events comprising many more basic forms of reproduction.

All kinds of reproduction in general (e.g., of forms, actions, pictures, words, music, photocopies and organisms) are made possible by the rule of probabilistic **nomic necessity** in the physical world. We can conceive logically possible “worlds” lacking this kind of physical necessity, but they would be sorry worlds, not graced by the presence of organisms, or even physical objects.

The most general principles of physics are the first and second laws of thermodynamics. The first law, the principle of conservation of energy, proves valid at all spatial scales. As a consequence of Noether’s first theorem, in closed systems energy conservation is reciprocally entailed by one of the most basic symmetries of nature: **the invariance of phenomena under time translation**. In rather imprecise terms this invariance means that the laws of physics will **reproduce** the same results every time the same initial conditions are themselves reproduced. The conservation of linear and angular momentum insures that this reproduction happens regardless of location (invariance of the laws of nature with respect to space translation and rotation.) The paramount importance of this fact is seldom sufficiently emphasized. On these symmetry principles rests not only the **possibility of science** (e.g., we test theories by **reproducing** experiments at different times and places) but also the **possibility of life** itself.

A bit of history

To further develop the relationships between reproduction and causation in the light of Peircean biosemiotics we must embark on a brief digression into the history of causation in physics and biology. I hope this may lead to a realization that as a consequence of the introduction of biosemiotic ideas into the conceptual fabric of biology, our inherited epistemic relations between physics and biology must be reconsidered and placed on a new, more satisfactory basis.

Since the seventeenth century, classical physics' schema for explaining natural phenomena has stemmed from the mutually supporting employment of mathematical formalism and instrumental experimentation. Historically this revolutionary explanatory project was implemented by means of mathematical idealization and a comprehensive redefinition of basic notions (e.g., **motion** and **causation**) through a radical rejection or modification of their prevalent counterparts in the then-dominant Aristotelian natural philosophy. This program led to the expurgation of the ideas of **spontaneity** and **final causation** from the inventory of valid scientific concepts. Causation was reduced to a form of restricted efficient causation by redefining the concept of force as an agency for the alteration of the state of motion of bodies.

In Aristotelian physics motions in the sublunary realm were divided into natural (spontaneous) and violent (forced). Natural motion was represented by spontaneous migration towards the center of the earth (gravity) or away from it (levity). **Rest** was considered the **causal default state** and only departures from rest or natural motion required explanation by the action of suitable agents.

In classical mechanics **inertial motion** is the causal default state. Only departures from inertial motion (accelerations) demand explanation, which is achieved by specifying **forces** of the proper magnitude and direction. The quantitative values of these two mathematical attributes are computed from instrumentally obtained data (e.g., times, distances, masses) by means of the **laws of nature**. These laws are mathematical functions that describe in exact terms the causal dependence of such quantities on each other's values. The laws of nature were conceived from the start as external to nature and were originally regarded in theological terms, as strictures imposed by the deity on the course of events.

The new explanatory program met with unparalleled success in two stages. The first stage witnessed the mathematical encoding of empirical laws (e.g. Kepler's laws of planetary motion, Galileo's laws of fall, projectile and pendular motions, etc.). The second stage was initiated with Newton's discovery of **higher order laws**, from which such empirical laws could be deductively inferred.

Explanations of a great variety of phenomena, through extension and further elaboration of the classical program, consolidated its success and simultaneously entrenched methodological, metaphysical and ideological tenets that were explicitly or tacitly associated with its creation and development. The type of intelligibility sought by physics and the conceptual and methodological instruments deployed in its pursuit became paradigmatic for the sciences of nature in general.

Biology, striving to grow under the tutelage of physics, benefited greatly from physics' discoveries and methods. Yet it has also been hampered by some strong limitations induced by conceptual and philosophical restrictions that were instrumental for the early success of physics as corpuscularian mechanics. Among these burdens we find the proscription of notions such as spontaneity and teleology, the narrowing of causation to the consideration of purely external actions between inert and passive structures, and the associated ideal of the superiority of bottom-up explanations. [3]

Developments starting in the second half of the nineteenth century (e.g., phenomenological thermodynamics and field theory) and continuing to the present (e.g., condensed matter physics, non-equilibrium thermodynamics, complexity and self-organization theories, etc.) have gradually liberated physics from earlier shackles. Today biologists, philosophers and biosemioticians are busy employing new ideas from contemporary physics to expand the explanatory horizons of biology.

I believe we can go beyond the mere adoption of physics' new discoveries into biology if we are willing to reassess some philosophical conceptions that were rejected during the rise of Newtonian physics. Reassessing such discarded notions, in the light of ideas stemming from new discoveries and from their partial anticipation by Peirce, may lead to fruitful reformulations of Aristotelian intuitions—once they are rendered compatible with current physics and are motivated by biology's own conceptual and explanatory needs.

Spontaneity, constraints, and habits

During the last half of the twentieth century, problems with the received views of explanation and causation led different authors to contemplate the adoption of an ontology of powers and dispositions, which seems like an updated version of some Aristotelian views. I refer to a variety of approaches by such authors as Harré, Cartwright, Mumford, Suárez, and many others (see e.g., Cartwright 1993, Harré 1970, Mumford 2008, 2009, Suárez 2007, Thompson 1988). More than a century ago Peirce sought to update the Aristotelian model of causation along similar lines, in order to meet the requirements of the scientific practice of his day.

Inspired partially by Peirce's ideas as well as by discoveries of twentieth century science unknown to him, I would like to sketch a revision of the Peircean notion of habit that could help meet biology's conceptual needs by relating them to physics' explanations in a new way. This approach is modeled after thermodynamics, which emphasizes top-down over bottom-up explanations.

As early as the second half of the19th century phenomenological thermodynamics had reintroduced *sotto voce* the Aristotelian notion of **spontaneity**, in the guise of a universal tendency of energy to dissipate towards thermal equilibrium. Statistical thermodynamics achieved something similar with the associated idea of chance. Peirce introduces these notions to illustrate his conception of final causality:

> Those non-conservative actions which seem to violate the law of energy [conservation], and which physics explains away as due to chance-action among trillions of molecules, are one and all marked by two characters. The first is that they act in one determinate direction and tend asymptotically toward bringing about an ultimate state of things. If teleological is too strong a word to apply to them, we might invent the word finious, to express their tendency toward a final state. The other character of non-conservative actions is that they are irreversible. (CP 7.471, c.1898, in Peirce 1958).

According to Peirce's conception of causation, in all finious (irreversible) processes the course of events is determined by cooperation of efficient and final causes. This leads to explanatory schemes in which top-down and bottom-up approaches are complementary rather than exclusive, since different explanatory contexts may require emphasizing either efficient or teleological causation.

Sailing upstream

By gaining access to free energy, organisms and ecosystems avoid their permanently impending descent down the thermodynamic gradient. We find the modern analogue of Aristotelian “forced motion” in changes that take place against the energy gradient, such as the processes of photosynthesis or the workings of a refrigerator. They fight this uphill battle by establishing a coupling to larger energy flows that run spontaneously, in the opposite direction, down the thermodynamic gradient.

To proceed in our vein of nautical analogies we can illustrate this coupling with the idea of a sailboat that is able to sail upwind by “tacking”: sailing against the wind in a zigzag pattern and using the energy of the wind by means of the **resistance of the keel and rudder**. Better still; we can envision a river paddleboat that remains moored to the bank for long periods while the current turns the paddles, which are connected to a generator that charges a battery. After the battery is charged, the boat can sail upstream for a shorter period, using the generator in reverse as a motor.

Just as the tacking sailboat relied on the reaction of its keel for using the energy of the wind to proceed against the wind, the paddleboat uses the **reaction of its moorings**, which prevents it from being dragged by the current. A similar process also occurs inside the boat: the electric generator drives the electrons up against the thermodynamic gradient to charge the battery. Later the battery’s current discharges spontaneously after a turned switch removes great resistances to its passage. In its way, from one terminal of the battery to the other, the current produces work in the motion of the paddles against the resistance of the water, until all of the energy is finally dissipated irreversibly into heat.

These nautical images illustrate a heuristic approach to causal top-down explanations, well suited to the needs of biology. In all of these examples we find the interplay of three factors: 1) a source of **free energy** spontaneously directed towards its complete **dissipation** (thermal equilibrium); 2) structures that resist, redirect and channel the flow of energy in different ways (boundary conditions and **constraints**) [4]; and 3) a tendency to reproduce similar results every time similar energy flows and constraining structures are reproduced (**habit**). These three factors, **spontaneity**, **constraint** and **habit** are instances of the Peircean categories of **firstness, secondness and thirdness.**

According to this triadic scheme all irreversible physical changes can be visualized as “finious” processes directed towards a general type of outcome, independently of the particular details of each situation. This final state is the leveling of energy gradients and the attainment of thermal equilibrium (most probable state). In the final analysis all causal powers are instances of one general disposition, the tendency of energy to dissipate, modulated by **resistances** or reactions that direct the processes according to **habits** embodied in their resistive configuration.

Causation, habits and semiosis

Peirce considered semiosis to be the formal analogue of physical causation. We make the physical world causally intelligible to ourselves by reading into the temporal succession of events a form of concatenation— a form analogous to that which obtains in the succession of our thoughts. But events are not thoughts; they are snapshots of changes that take place in a suitably isolated, continuously changing region of the universe. An event contains a potentially infinite set of dynamical objects of possible signs. The cause is a **fact** about the event, an i**dea** (corresponding to the immediate object), abstracted from the event and having the form of a true proposition about it.

> Sign may be defined as a Medium for the communication of a Form. […]. As a *medium*, the Sign is essentially in a triadic relation, to its Object which determines it, and to its Interpretant which it determines [...] 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 which constitutes the form is *true* of the form 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. (MS **793**:1-3, 1905, my emphasis, reproduced in part in Peirce 1998).

Building on my proposed scheme for causation I venture an interpretation of semiosis as second-order causality. **While ordinary causation directly constrains the amount of**

energy and the direction of the resulting changes, semiosis acts indirectly by causing changes on the constraints themselves.

Beyond a minimal threshold, semiotic 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.

The interpretation here advanced is consonant with other essential characteristics of semiosis proposed in previous contributions. Aside from triadicity (which it shares with physical causation), semiosis, I believe, is marked by radical temporality (it is a relation whose relata cannot coexist simultaneously) and self-reference (it is a relation where some of the relata relate to themselves through their relations to the other relata). I cannot elaborate on this consonance in this brief communication and I will only advance the following two observations about it.

1. **Representation is a special kind of reproduction**. Physical causation reproduces actual, existent states of a system located in space and time. Semiosis, according to Peirce’s previous quotation, reproduces a potentiality, a mere disposition that would become actual if suitable precipitating conditions were to obtain. Semiosis consists of the transmission of a form that “is embodied only in a **representative** sense.” Such representation is real but, like time itself, is not actually existent. The temporal nature of semiosis partakes of the temporal nature of causality. We measure the passage of time through the phenomenon of precise repetition. This is the automatic, recursive reproduction of the same initial conditions by nomic necessity in systems functioning as

natural or artificial clocks, like the rotating earth or a swinging pendulum. In a fictional "world" without nomic necessity there is no passage of time.

2.The self-referential character of semiosis is related (in ways to be investigated) to the fact that it is a form of meta-causation: it determines changes indirectly, by causing changes to the causal configurations that direct the course of physical changes.

Concluding remarks

To recapitulate the course of our voyage from the nature of survival to the nature of semiosis we revisit some salient points of the itinerary:

- Some essential characteristics of living systems, such as autonomy, are based on the correlation of external and internal survival.
- Internal survival depends on the recursive reproduction of the organism's internal cyclic dynamics against its impending descent into deterioration and decay.
- All kinds of reproduction, including biological reproduction, are special manifestations of the most basic one: the reproduction of similar physical states by the action of physical laws when similar initial conditions are reproduced.
- In the spirit of current accounts, based on neo-Aristotelian views of causation in terms of powers or dispositions, I propose a thermodynamic interpretation of physical causality. Causes act by channeling the spontaneous tendency of energy towards dissipation, by means of constraints that embody habits in their resistive configuration.
- Finally, building on this view of causal determination, I advance an interpretation of semiosis as second-order causation. Semiosis acts by altering habits embodied in the constraints that causally determine the extent and direction of physical changes.

Whether successful or not, these proposals aim at basing biology and physics on a non-reductionist common ground, through the application of the top-down explanatory schemes of phenomenological thermodynamics. This new perspective may open new possibilities for integrating and deploying biosemiotic notions to understand the workings of living systems.

There are currently several lines of research that seem to be animated by similar goals. Among them I should mention the explanatory roles of finious energy flows in the theories advanced by such authors as Annila, Dewar, Salthe, Morowitz, Kleidon, Lorenz, Paltridge, Ulanowicz, their associates, and many other researchers.[5] Starting with the pioneering work of Ron Swenson, the investigations of these authors, covering such diverse topics as the origin of life, cellular metabolism, natural selection, ecosystem dynamics, climate change and economic stability, are unified by their common reliance on one version or another of the principle of maximum entropy production (MEP). MEP refers to the tendency of dynamic systems to seek thermal equilibrium at the maximum possible rate compatible with their constraints.

The application of the maximum entropy production principle in these investigations prompts a final remark on finality. We should regard the MEP as a “superfinious” or “metafinious” principle, since it imposes a higher-level teleology on other finious processes. They must comply with another extremal condition — they must not only seek a final state, they must reach it at the fastest possible rate consistent with their constraints.

NOTES

1 Hans Jonas in his preface to *The Phenomenon of Life* (Jonas 1956, [ix]), cited by Gare 2008.

[2] Thomas Uebel in his contribution to Cartwright *et al*. 1996 traces the history and evolution of this metaphor for epistemological holism from its birth in early 20th century Marxian polemics down to its epigraphic role in Quine’s philosophy of science. In *World and Object* we read: “We are like sailors who on the open sea must reconstruct their ship but are never able to start afresh from the bottom. Where a beam is taken away a new one must at once be put there, and for this the rest of the ship is used as support. In this way, by using the old beams and driftwood the ship can be shaped entirely anew, but only by gradual reconstruction.” (Quine 1960, p. 3f.)

3 As Alicia Juarrero has repeatedly remarked, another conceptual impediment originating in Aristotle was preserved and transmitted by modern science — the impossibility of self-referential causation. No physical process can cause itself.

4 Juarrero bases her account of causation on the notion of constraint, and the views advanced here have affinities with hers. See Juarrero 1999. In his seminal article, “Life’s irreducible structure”, Michael Polanyi originated some of these ideas in relation to the role of boundary conditions. (See Polanyi 1968.)

[5] See e.g. Swenson 2000, Annila & Kuismanen 2009, Karnani & Annila 2009, Kleidon 2010, Schneider & Kay 1994, Ulanowicz 2004, Morowitz & Smith 2007, Tuisku *et al.* 2009. For some reason some of these authors do not cite each other. An entire issue of the Philosophical *Transactions of the Royal Society B*. (**365** (1545) May 2010) was dedicated to applications of the Maximum Entropy Production Principle in ecological systems.

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