

Reconsidering Darwin’s “Several Powers”

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Abstract Contemporary textbooks often define evolution in terms of the replication, mutation, and selective retention of DNA sequences, ignoring the contribution of the physical processes involved. In the closing line of *The Origin of Species*, however, Darwin recognized that natural selection depends on prior more basic living functions, which he merely described as life’s “several powers.” For Darwin these involved the organism’s capacity to maintain itself and to reproduce offspring that preserve its critical functional organization. In modern terms we have come to recognize that this involves the continual generation of complex organic molecules in complex configurations accomplished with the aid of persistent far-from-equilibrium chemical self-organizing and self-assembling processes. But reliable persistence and replication of these processes also requires constantly available constraints and boundary conditions. Organism autonomy further requires that these constraints and co-dependent dynamics are reciprocally produced, each by the other. In this paper I argue that the different constraint-amplifying dynamics of two or more self-organizing processes can be coupled so that they reciprocally generate each other’s critical supportive boundary conditions. This coupling is a higher-order constraint (which can be distributed among components or offloaded onto molecular structures) that effectively constitutes a sign vehicle “interpreted” by the synergistic dynamics of these co-dependent self-organizing process so that they reconstitute this same semiotic-dynamic relationship and its self-reconstituting potential in new substrates. This dynamical co-dependence constitutes Darwin’s “several powers” and is the basis of the biosemiosis that enables evolution.

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Introduction

Although mainstream cellular-molecular and organismic biologists have become comfortable with the ubiquitous use of information terms to talk about many aspects of living dynamics including evolution, only biosemioticians have gone beyond a mere heuristic use of these terms to explicitly define life and evolution in semiotic terms. For the biosemiotician, adaptations are defined by their end-directed character and are thus intrinsically teleological and semiotic. In contrast, most contemporary versions of Darwinism neglect focusing on the fundamental role of end-directed organismic processes in generating the raw materials subject to natural selection and instead consider only the immediate chemical and physical processes involved. This not only denies the teleological and semiotic character of life, but also treats the physically anomalous thermodynamics of living processes as irrelevant to evolution.

Teleological explanations have generally been shunned by the natural sciences throughout most of the last century. This exclusionary stance is neither surprising nor problematic, because teleological explanations ultimately rest on black box mechanisms. They simply posit the existence of dispositions to achieve a general type of end without specifying how that end is achieved and assume that a representation of this yet-to-be-achieved end guides processes to achieve it. Currently, the standard view is that all apparently end-directed processes in biology are teleonomic (e.g. see Pittendrigh 1958; Mayr 1961), which analogizes them to feedback-based guidance mechanisms and computer algorithms. Implicitly, this analogy replaces a human designer with the process of natural selection as the source of design to produce devices with these properties. But natural selection only accepts or rejects certain organic processes and structures. It doesn't *produce* them. The production of living mechanisms is accomplished by processes that are surprisingly atypical from a thermodynamic point of view, in that they generate rather than degrade structural and dynamical constraints. Thus accepting a teleonomic view merely begs the question about the source of end-directed processes in evolution.

Completing Darwin's "one long argument".

"There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved." — Charles Darwin (1971 [1859])

Charles Darwin ended his paradigm-changing book *The Origin of Species* with the above poetic reflection on the origin of life and the initiation of the evolutionary process. Although Darwin avoided engaging in discussions about the origins of life, in this oblique passage he implicitly recognizes that the process of natural selection cannot account for the origin of life. Indeed, it depends on life's "several powers" coming into existence first, in order to occur. Though he could not have articulated their details at that point in the history of biology and physics, and could only recognize their specialness compared to inorganic processes, we are in a better position to identify them now, though some controversy yet remains. These "powers," must for example, include the generation of new component structures, the maintenance of non-

equilibrium conditions, and the repair and reproduction of the whole integrated organism. And the preservation and transmission of these capacities depends on the presence of an internally maintained source of information that is "about" the complex relationships between the organism's many levels of dynamics and its Umwelt: i.e. a semiotic relationship.

The genius of the theory of natural selection was that it inverted the logic of classical mechanistic causality in one important respect, and yet was consistent with the strictures of the mechanistic paradigm. It demonstrated that causal consequences—ends, not just prior conditions—could play a constitutive role in determining how living things are organized, collectively and individually. Most importantly it demonstrated a way that this could occur irrespective of any anticipatory or even functional feedback mechanism (or Lamarckian mechanism). But as this closing line of *The Origin* demonstrates, Darwin nevertheless recognized that these core distinguishing powers of life are not explained by natural selection, and indeed that natural selection depends on their presence.

In this respect, such abstract versions of Darwinism such as artificial life (e.g. Langton 1988), replicator selection (e.g. Dawkins 1976), and universal Darwinism (e.g. Dennett 1996), make non-trivial and quite complex assumptions concerning the prerequisites for this process to occur. To finally complete what Darwin once described as his "one long argument" we must explain the spontaneous emergence of dynamical systems capable of resisting the ravages of thermodynamics and of producing replicas of themselves, each inheriting this same general capability. Those "special powers" which emerged with life's origin did not cease to operate or diminish in importance thereafter. Evolution in all its many forms necessarily supervenes on these necessary preconditions.

Replication isn't free.

In the years just before his untimely death, the mathematician John von Neumann (1966) became interested in the logical and physical problems of machine self-reproduction. In his general model of such a device there was both an intrinsic reservoir of information (such as a set of design instructions for building the machine and copying these instructions) and a mechanism (a universal construction device) that could read from these instructions and use them to organize its construction processes. These are of course, roughly analogous to genetic information and metabolism in biology. He never ultimately pursued the effort to explain how to build such a device, merely noting that the physical requirements would be daunting to meet, and settled instead on the effort to precisely describe the logical (i.e. computational) requirements of machine self-replication. Separating the logical problem from the physical problem is analogous to narrowly defining evolution in terms of the replication of DNA alone, and ignoring the physical processes involved. Von Neumann made an explicit choice to temporarily set the mechanistic challenge aside, fully aware that, as an engineering problem, these practical details would unavoidably need to be addressed.

Unlike machine reproduction, however, organism reproduction can make use of spontaneous tendencies for molecules to generate new components and have them assemble themselves into useful structures. This means that organisms do not need extrinsic mechanisms to do the work of building and repairing themselves. Instead, they are self-organizing and self-assembling. But how? In an effort to provide a philosophically coherent account of the teleological features of living organisms the

philosopher Immanuel Kant (1790) focused on two critical features which seemed to set organisms apart from machines: causal circularity and the generation of form. In an oft-quoted passage he says:

“... a machine has solely motive power, whereas an organized being possesses inherent formative power, and such, moreover, as it can impart to material devoid of it — material which it organizes. This, therefore, is a self-propagating formative power ...” (p. 557)

and later,

“... in which, every part is reciprocally both end and means.” (p. 558)

He further argues that these distinctive properties of organisms appear to the observer to constitute something like “intrinsic finality” (alluding to Aristotle’s notion of final cause, or ‘that for the sake of which something occurs’). In the end of the critique, however, Kant refrained from considering this to be an ontological claim. Instead, he concluded that conceiving of this as teleological was a judgment that resulted from limitations of the mind and the nature of reason.

Despite the ubiquitous and unavoidable increase in entropy and the break-down of order that is made explicit by the second law of thermodynamics, living organisms persistently generate orderly structures and processes (forms). This physically atypical property of organism dynamics was elevated to a defining property of life by the quantum physicist Erwin Schrödinger (1944) in his influential book *What is Life*. His description of life as “feeding on negentropy” became its most enigmatic claim. In the generations that followed, Ilya Prigogine, Stuart Kauffman, and other researchers found a critical clue in the analysis of thermodynamic systems that persist far from equilibrium. This property has generally been described as “self-organization” (a concept often attributed to Kant) because the orderliness is not imposed from without, but rather emerges due to the recursive interactions among components.

Many subsequent philosophers of biology have resurrected Kant’s views in the context of modern systems thinking and the concept of self-organization, claiming that it is now possible to equate the apparent natural teleology of organisms with self-organizing dynamics (e.g. Jonas 2001; Maturana and Varela 1980; Juarrero 1999). But is this sufficient?

One problem is that the basis of functional unity and system coherence of an organism is merely assumed, not explained. This is reflected in the definition of *autopoiesis* (literally self-fabricating) that is often treated as a fundamental principle defining what it means to be alive. Thus Varela (1979) defines autopoiesis as follows:

An autopoietic system_ ..._ is one that continuously produces the components that specify it while at the same time *realizing it, the system, as a concrete unity* in space and time which makes the network of production of components possible.

This describes a set of (catalytic) components that reciprocally produce one another but as the italicized text indicates it is merely assumed that this will at some point produce a stable unity. But unity and stability are precisely not what self-organizing

processes produce, since they develop toward a mode of organization that maximally dissipates the conditions that produce that organization.

The modern concept of self-organization has become a key principle in complex systems theories and offers a way to begin to reframe Kant's concept of "formative power." It is evident in inorganic processes that spontaneously produce orderly patterns in the process of optimizing the flow of energy through an otherwise unorganized system, such as in snow crystal growth or heat convection through a fluid. In life, self-organization is particularly critical for organizing the molecular interactions within cells and for the differentiation of structures during embryogenesis. So it is not too much of a caricature to say that it is self-organization that generates the forms that natural selection operates upon. Genetic information effectively provides the network of constraints that serve as the boundary conditions enabling specific self-organizing dynamics to take place in these systems.

This seeming "negentropic" character of self-organizing processes has led many to assume that a living organism can be entirely characterized as a complex self-organizing process. But when we describe an organism as differentiating, repairing, defending, or reproducing itself the term 'self' takes on a teleological meaning. In living processes the production of organized forms is not merely the spontaneous result of far-from-equilibrium dynamics. They are effectively prefigured within the organism almost entirely irrespective of the vagaries of extrinsic factors and with a characteristic locus of autonomy and a self-referential causality that is missing in non-living phenomena.

The unmentioned missing link in this argument is well-exemplified in others' efforts to explain how autopoiesis might account for the origin of life. For example, in his book *The Biology of Wonder*, Andreas Weber (2016) says:

"The magical tipping point is reached when so many molecules are swarming inside the organic broth that every variant catalyzes a reaction leading to the production of another variation of molecules, which in turn catalyzes yet another reaction. At this point *a phase shift happens* and the molecular network migrates to *a higher level of complexity that stabilizes itself* in regular reaction patterns." (pp. 74–5)

The nature of this "phase shift" is left unexplained and simply assumed. It is indeed a "magical" tipping point. So the question being begged is: What provides this unity and stability if not the self-organizing dynamics of the reciprocal catalysis? Or, to say this more simply; "What is it that provides the unity and stability that is the source of organism self? Most biologists would answer "information".

Although the modern technical concept of information has effectively been reduced to the concept of signal entropy, this is not sufficient to characterize its biological use. The use of information concepts in biology is inseparably associated with its referential and functional properties: i.e. its semiotic properties. And these are what contribute to the generation and preservation of biological form, or order.

In my recent book *Incomplete Nature* (Deacon 2012) I provide a simple empirically testable model system that I argue provides a proof of principle that autonomous agency can arise in an exceedingly simple molecular system. I call this an autogen (also 'autocell' in Deacon 2006). It is loosely based on the formation of viruses, but without DNA, RNA, or parasitic dependency.

A simple autogen consists of a reciprocally reinforcing linkage between two different but complementary self-organizing molecular processes. The most basic form of this relationship involves a reciprocally catalytic cycle comprised of at least two catalysts that besides producing one another also produces a side product molecule that tends to self-assemble into a polyhedral container or tube (as does a virus capsid). Given supportive energetic and substrate conditions reciprocal catalysis will rapidly deplete the local concentration of substrates, increase the local concentration of reciprocal catalysts, and increase the local concentration of capsid-forming molecules, but unless there is some inhibition of diffusion the interacting catalysts will diffuse away to the point that catalysis ceases. In parallel, the rate of capsid formation will be most rapid and efficient where the local concentration of capsid-forming molecules is high and will slow as this concentration drops. The reciprocal catalytic process described above will tend to continuously replenish the local concentration of capsid-forming molecules as the capsid grows, and growth of this containment will diminish diffusion of reciprocal catalysts. With capsid formation occurring most rapidly where reciprocal catalysis is most rapid the two processes will tend to strongly co-localize. The result will be a high probability that capsids will enclose the very catalysts that produce themselves as well as this containment. Though inert when enclosed, these processes will be reinitiated if the capsid is disrupted (e.g. by the effects of heat) in the presence of catalytic substrates, and thus reconstitute itself, i.e. repair damage. Depending on the extent of capsid disruption the reconstitution process might resume in a more distributed way, thus resulting in the production of two or more replicas; i.e. a form of replication. The logic of simple autogenesis is depicted in Fig. 1.

Like the more complex reciprocal constellations of complementary self-organizing processes that constitute simple organisms, the constraint-generating dynamics of each

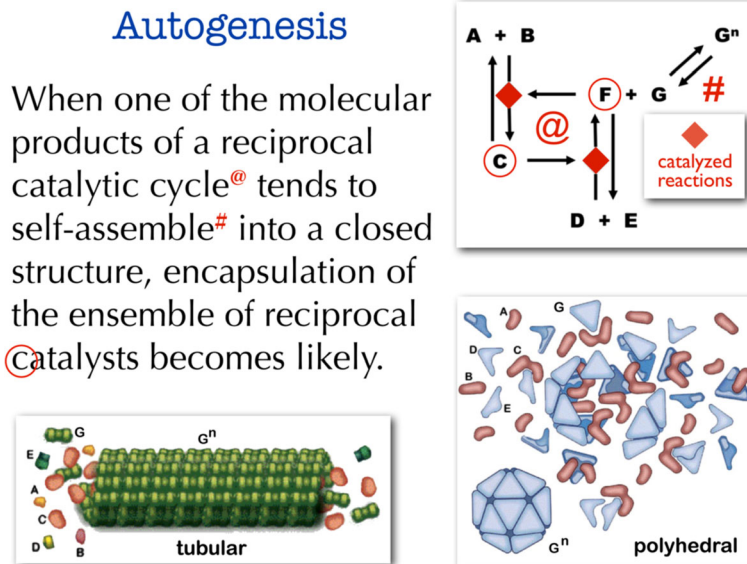


Fig. 1 The logic of autogenesis. *Lower left:* depiction of a tubular version of autogenesis. *Lower right:* depiction of a polyhedral version of autogenesis. *Upper right:* an abstract reaction diagram of autogenesis where letters represent distinct molecules, circles indicate catalysts, diamonds indicate catalyzed reactions, @ indicates a collectively autocatalytic cycle, and # indicates the self-assembly of capsid-forming molecules

of the component self-organizing processes in autogenesis reciprocally generate each other's supportive boundary conditions. This reciprocal co-dependent maintenance of critical boundary conditions constitutes a source of autonomy by providing a persisting locus for the specific global constraints required to channel energy in a way that does the work of continually preserving this very capacity. The critical boundary conditions for any self-organizing process (such as autocatalysis) are entirely provided by factors extrinsic to that process, no self-organizing process alone or merely linked with others (as in hypercycle relationships) can be a locus of its own autonomous self-regulation. Only this co-dependence of reciprocal boundary conditions can provide what amounts to autonomous self-preservation, and a precise dynamical determination of self versus non-self.

This intrinsically maintained self-specification is in this way both self-referential and self-determinative. In semiotic terms, this form of higher-order reciprocal constraint on constraint generation is effectively a form of information that is dynamically interpreted when it channels work to produce a new physical system in which it will again become embedded, complete with this same future capacity. This higher-order constraint is thus substrate-transferrable because it can be maintained across complete changes in the molecules that preserve and generate it. It is information: a form that informs. What makes this form of constraint more than a mere restriction, structure, or regularity is that its most distinctive property is not anything present or intrinsic but rather something that it potentiates.

I would argue that autogenesis exemplifies the simplest form of molecular system that can constitute biosemiosis, whereas processes described as *autopoietic*, if they only involve self-organized processes that are not reciprocally co-dependent, cannot provide the autonomous self-reparative, self-reconstituting, self-replicating dynamics necessary to distinguish the system-self from its Umwelt. This reciprocal form-generating dynamics is the foundation for biosemiotics because signs are ultimately forms that are interpreted via the generation of new forms, which in turn further contribute to the persistence of this interpretive dynamics. The synergy constraint between self-organized processes that is preserved in autogenesis is thus a formal sign which is interpreted by the process of being preserved by autogenic repair or replication. Lacking this self-referential dynamics there can be no "other" to be represented and no interpretive "self" for which this other is relevant.

These considerations may be important to keep in mind as we attempt to extend the evolutionary paradigm beyond the confines of current biology to investigate the origins of semiosis whether at the origins of life or the basis of cognition. To ignore these underlying formative processes risks falling prey to overly simple analogies that unwittingly sneak homunculi into our theories. Ultimately, this oversight makes evolution appear as mere preserved accident, with neither teleological nor semiotic character, when in fact evolution is the very expression of semiosis. And it treats cognition as mere computation, lacking processes that determine reference and significance.

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