God and the World of Signs: Semiotics and the Emergence of Life

with Andrew Robinson and Christopher Southgate, "Introduction: Toward a Metaphysic of Meaning"; Christopher Southgate and Andrew Robinson, "Interpretation and the Origin of Life"; Bruce H. Weber, "Selection, Interpretation, and the Emergence of Living Systems"; Jesper Hoffmeyer, "A Biosemiotic Approach to the Question of Meaning"; Robert E. Ulanowicz, "Process Ecology: Stepping Stones to Biosemiosis"; Andrew Robinson and Christopher Southgate with Terrence Deacon, "Discussion of the Conceptual Basis of Biosemiotics"

PROCESS ECOLOGY: STEPPING STONES TO BIOSEMIOSIS

by Robert E. Ulanowicz

Abstract. Many in science are disposed not to take biosemiotics seriously, dismissing it as too anthropomorphic. Furthermore, biosemiotic apologetics are cast in top-down fashion, thereby adding to widespread skepticism. An effective response might be to approach biosemiotics from the bottom up, but the foundational assumptions that support Enlightenment science make that avenue impossible. Considerations from ecosystem studies reveal, however, that those conventional assumptions, although once possessing great utilitarian value, have come to impede deeper understanding of living systems because they implicitly depict the evolution of the universe backward. Ecological dynamics suggests instead a smaller set of countervailing postulates that allows evolution to play forward and sets the stage for tripartite causalities, signs, and interpreters—the key elements of biosemiosis—to emerge naturally out of the interaction of chance with configurations of autocatalytic processes. Biosemiosis thereby appears as a fully legitimate outgrowth of the new metaphysic and shows promise for becoming the supervenient focus of a deeper perspective on the phenomenon of life.

Keywords: biosemiosis; causality; coherence domain; ecology; emergence; metaphysics; natural selection; process ecology; process thought; supervenience

---

Robert E. Ulanowicz is Professor Emeritus, University of Maryland Center for Environmental Science, Chesapeake Biological Laboratory, Solomons, MD 20688-0038. Currently, he is Courtesy Professor with the Department of Biology at the University of Florida, Gainesville, FL 32611-8525; e-mail ulan@umces.edu.

[*Zygon*, vol. 45, no. 2 (June 2010)]
www.zygonjournal.org

A EUROPEAN PREDILECTION?

The emerging discipline of biosemiotics seems to have found special favor in Europe, and this despite the fact that Americans such as Charles Sanders Peirce, Charles W. Morris, and Thomas Sebeok were prominent among its founders and notwithstanding the contributions by contemporary practitioners such as Terrence Deacon, Howard Pattee, and Philip Clayton. Skepticism in America is possibly sustained by the stress placed there on individualism, in contrast to a European outlook that emphasizes social interactions. Another likely contributing factor is the distrust entrenched in North American scientists for any enterprise that even remotely smacks of anthropomorphism. Biosemiotics, counting among its keywords *sign* and *interpreter*, therefore, becomes immediately suspect. Europeans, more at ease with humanistic discourse, are less likely to recoil when *Homo sapiens* are brought into scientific discourse, as inevitably they must be.

One could argue that Americans by and large shun biosemiotics because they place inordinate faith in the prevailing scientific metaphysic. After all, the fundamental but rarely discussed assumptions of how nature operates arose out of considerations about laws acting on individual *nonliving* objects. These key postulates were formulated mostly in England during a period of strong clericalism and following in the wake of Newton's *Principia* (Depew and Weber 1995). They were intended to distance science as much as possible from the transcendental and human realm (Ulanowicz 2009a).

TOP-DOWN APOLOGETICS

In response to the charge of anthropomorphism, biosemioticians have thought it useful to provide examples of signs that have emerged among lower organisms. One didactic case is Jesper Hoffmeyer's (2008) poignant example of the emergence of sign among the mating rituals of several species of balloon flies belonging to the genus *Empididae*. In a more evolved species of these flies, it is necessary for the male to present his prospective mate with an empty spun cocoon before the female will permit mating to commence. The origins of this ritual can be traced in more primitive species of balloon flies to a requisite bridal gift of dead prey, which serves to occupy the female while the male goes about the business of insemination. In intermediate species the female is distracted for even longer intervals, because the prey comes sealed in a spun cocoon, which takes time to unravel. Ultimately, the value of prey as food lost its significance to the female, but the accompanying empty cocoon as sign did not.

The example has the advantage of locating the creation of sign well apart from human cognition. Hoffmeyer's intriguing example does not elicit the respect it deserves from most biologists, however, because his argument proceeds top-down in the sense that concepts originating in the human realm are projected downward to less cognitive lower animals. Conventional science has adopted Francis Bacon's disregard for top-down scenarios and accords more respect to bottom-up narratives. Thus, if biosemiotics is to command more widespread attention from the scientific community, it will have to address the issue of how notions such as *sign* and *interpreter* can emerge naturally from among the welter of lower phenomena.

ENLIGHTENMENT FOUNDATIONS

The challenge of constructing bottom-up scenarios prompts the question of whence the narrative ultimately proceeds. That is, what are the foundational assumptions from which one projects upward toward the human social realm? Unanimity no longer exists regarding the fundamental postulates that support contemporary science. Such was not always the case. In the early 1800s, following a century of familiarity with Newtonianlike laws, there emerged a widespread consensus as to how nature fundamentally behaves. David Depew and Bruce Weber in *Darwinism Evolving* (1995) thoughtfully elaborate the assumptions that precipitated:

1. Newtonian systems are causally *closed*. That is, only mechanical or material causes are legitimate, and they always co-occur. Other forms of action are proscribed, especially any reference to Aristotle's "final," or top-down, causality.
2. Newtonian systems are *atomistic*. They are strongly decomposable into stable least units, which can be built up and taken apart again. Atomism combined with closure gives rise to the notion of reductionism, whereby only those causes originating at the smallest scales are of any importance.
3. Newtonian systems are *reversible*. Laws governing behavior work the same in both temporal directions. This is a consequence of the symmetry of time in all Newtonian laws. Aemalie Noether (1983) demonstrated how reversibility implies conservation—the other side of the same coin.
4. Newtonian systems are *deterministic*. Given precise initial conditions, the future (and past) states of a system can, in principle, be specified with arbitrary precision.
5. Physical laws are *universal*. They apply everywhere, at all times and all scales. The key adverb here is "everywhere." In combination with determinism, universality leads many to believe that nothing occurs except that it be elicited by a fundamental physical law.

As hinted above, no one today believes fully in all five of these historical tenets. For example, soon after Pierre-Simon Laplace ([1814] 1951) had exulted in the absolute power of Newtonian laws, Sadi Carnot ([1824] 1943) demonstrated the *irreversible* nature of physical *processes*. Later, Charles Darwin (1859) invoked history (that is, irreversibility and indeterminism) in his narrative. Then at the beginning of the twentieth century relativity and quantum theories surfaced to cast serious doubts on universality and determinism.

None of which is to say that the Enlightenment consensus has lost its sway over contemporary science. Closure, for example, is strictly maintained in the neo-Darwinian scenario of evolution (Dennett 1995). Atomistic reductionism continues to dominate biology, given the contemporary prominence of molecular biology. And many scientists today continue to eschew the reality of chance, maintaining instead that probability only papers over an underlying determinacy (Bohm 1989, for example).

THE ESCAPE FROM TOTALIZING STASIS

A little reflection should reveal that it is well-nigh impossible to start from the mechanical postulates and argue for the emergence of anything entirely new. To begin with, the entirely new would contravene determinism outright. It would hardly be conservative, and thereby violate reversibility. This poses a dilemma for the semioticist: He/she must either demonstrate that what are labeled *sign* and *interpreter* were implicit in the early physical universe (the pansemiotic hypothesis) or reject the mechanical worldview, because it leads one astray of the nature of reality.

The problem with pansemiosis (Brier 2008) is that it retrojects what many perceive as anthropocentric attributes onto the world of simple matter.[1] Furthermore, most scientists today are wont to eschew the encumbering attribution as unnecessary baggage in the sense of Occam. The only option remaining is to question the appropriateness of the material/mechanical assumptions.

In considering the validity of the material metaphysic, it should be noted that it emerged out of research on very simple systems or collections of many rarefied, homogeneous, and independent objects (for example, the statistical mechanics of Ludwig Boltzmann [1905] and Josiah W. Gibbs [(1901) 1981] or the "Grand Synthesis" of R. A. Fisher [1958] and Sewell Wright [1968]). Under the assumption of atomism, those postulates that were derived for rare, homogeneous, and weakly interacting collections were extrapolated into the realm of the living, where matters are dense, highly heterogeneous, and strongly interdependent. It is hardly self-evident that such extrapolation is justified. By contemporary accounts, for example, the universe began not in a rarefied state but rather as an incredibly dense, compact medium. Sparse, noninteracting systems appeared only much later. Why, then, force the universal clock backward? Why not instead seek postulates that conform better with playing the universal story forward? Or is everything in nature fully reversible, as once assumed?

Turning from reversibility to closure, the most enduring of the five mechanical postulates, the reader should note how the neo-Darwinian view of evolution adheres strictly to mechanical laws. Certainly, biosemiosis would be universally rejected were it to rest on the violation of physical laws. What remains debatable is whether those physical laws are sufficient to *determine* outcomes in living systems. Here a distinction is drawn between the actions of *conformance* and *determination*.

It is argued here that the sufficiency of physical laws to determine matters hinges upon the relative homogeneity of physical systems. However, both Walter Elsasser (1969) and Gregory Bateson (1972) have emphasized that biological systems are characterized by an enormous abundance of heterogeneity. For example, there are manifold ways that an organism can change in responding to surrounding conditions. Are the four force laws of physics and two laws of thermodynamics sufficient to account for all possibilities? In any given problem the levels of action by the six laws can be parameterized by at most $6!^2$ (720) combinations. It is not uncommon, however, for a living system to have thirty-five or forty or even hundreds of degrees of flexibility. In a system capable of some 35! (10^{40}) variations, it follows that the application of any combination of laws will be satisfied by billions of possible organism responses. The laws are always satisfied, but in any particular combination by a massive redundancy of possibilities. That is, laws themselves are insufficient to determine a particular outcome. Something else must specify the precise result.

Now, the reader may object that any problem consists of not only its field equations but its boundary conditions as well; it is the latter that specifies the result in any particular situation. Turning attention toward boundary constraints, note how they may arise in one of several ways: (1) They can be determined artificially—a situation of insufficient generality to be of interest here (unless one is willing to transcend the bounds of methodological naturalism). (2) They can be set by the physical environment: temperature, light, humidity, and so forth. Such general physical specifications remain relatively few in number, and the combinations among them are overwhelmed by the plasticity of living systems in the same way as the fundamental laws were.[3] (3) They can result from pure chance—the usual assumption in evolutionary theory. (4) They could be created by the living system itself (a violation of closure). I now consider each of the last two modes of boundary specification in turn.

A WORLD OF RADICAL UNCERTAINTY

As mentioned earlier, there is some disagreement among scientists as regards the ontological status of chance (mode 3). For many, chance is merely a matter of appearance. One never knows matters in all detail and with exact precision. Were such knowledge possible, events that are called chance would be seen as lawful and predictable (Patten 1999). Others claim that chance events elude characterization by laws (Elsasser 1969; Ulanowicz 2009a). Chance events can even be unique.

It seems absurd to think of any event as unique, given the immensity of the universe and its enormous age, but Elsasser invoked an argument from combinatorics similar to that just presented to show otherwise. He noted that there are fewer than 10^{81} elementary particles in the whole known universe, which itself is about 10^{25} nanoseconds old.[4] This means that, at most, 10^{110} simple events may have occurred over all physical time. It follows that if any event has considerably less than 10^{-110} probability of reoccurring, it will never do so in any physically realistic time.

Now, 10^{110} is a genuinely enormous number. It may surprise some readers to learn, however, that it does not require Avogadro's Number (6×10^{23}) of distinguishable entities to create a number of combinations that exceeds Elsasser's limit on physical events. It does not require billions, millions, or even thousands. A system with merely seventy-five or so different components will suffice! It can be said with overwhelming confidence that any particular event *randomly* composed of more than seventy-five distinct elements has never occurred in the history of the physical universe. In living systems composed of hundreds or thousands of distinguishable organisms (as is common with ecosystems), one must reckon with not just an occasional unique event but legions of them. Unique, singular events are occurring all the time, everywhere.

A unique event may act as a boundary determinant in the face of the inability of the laws themselves to specify an exact outcome. In such case, the singular event has the potential to initiate a novel, emergent phenomenon. However, random unique events are occurring everywhere, all the time. Fortunately for science, most are extremely transitory and of little consequence. In order for a phenomenon to emerge and be incorporated into ensuing dynamics, it must persist. But persistence becomes questionable in the face of ubiquitous singular chance and the limited combinations of physical laws. And yet in the realm of living systems one encounters the persistence of order at every turn. What sustains that order? Certainly, laws play a part; but they are not the whole story. Chance can initiate new forms and dynamics but seems inadequate to the task of sustaining them. Something that in essence is more general than law, but in effect is more circumscribed, must be at work.

PROCESS AND THE PROMISE OF SUSTAINABILITY

All of which brings the discussion around to mode 4, boundary determinants. A suitable generalization of law has already been suggested by Darwin (1859). It is called process. The point of view that events are more fundamental than objects has a solid history in philosophy (Whitehead 1929; Hartshorne 1971). Because the term *process* has been used by so many in such different ways, it becomes necessary for the purposes of this discussion to adopt a working definition (Ulanowicz 2009a):

> *A process is the interaction of random events upon a configuration of constraints that results in a nonrandom, but indeterminate, outcome.*

The juxtaposition of *nonrandom* with *indeterminate* is liable to be confusing, so a simplistic example of a process is in order. A convenient but artificial illustration of process is Pólya's Urn (Cohen 1976), named after the Hungarian mathematician György Pólya. His process requires a collection of red and blue balls and an urn containing one red ball and one blue ball. The urn is shaken and a ball is blindly drawn from it. If that ball is the blue one, a blue ball from the collection is added to it, and both are returned to the urn. The urn is shaken and another draw is made. If a ball drawn is red, it and another red ball are placed into the urn, and so forth.

The first question to arise is whether a long sequence of such draws and additions would, in the limit, approach a constant ratio of red to blue balls. It is easy to demonstrate that after some 100 draws the ratio indeed converges to the close neighborhood of some constant, say, 0.54591, as shown in Figure 1. That is, the ratio becomes progressively *nonrandom* as the number of draws increases. That the system in this instance does not converge to exactly 0.5000 prompts a second question: What would happen if the urn were emptied and the starting configuration recreated? Would the subsequent series of draws converge to the same limit as the first? Experiment reveals a virtual certainty that it will not. After a second 100 draws it might approach a limit in the vicinity of 0.19561 (Figure 2). The Pólya process is clearly indeterminate. Repetition of the process many times reveals that the ratio of balls is progressively constrained by the particular series of draws (a history) that have already occurred.

Karl Popper (1990) suggested how physical forces were particular degenerate limits of more general entities that he called *propensities*. Similarly, the histories of some processes force them to converge to behaviors

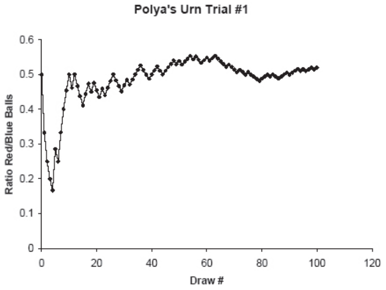

Fig. 1. Pólya's Urn, Trial #1 after 100 draws.

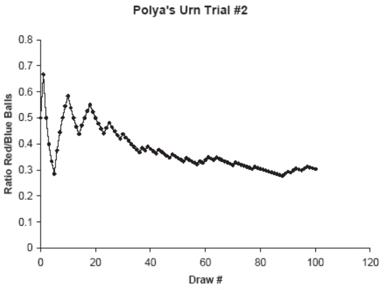

Fig. 2. Pólya's Urn, Trial #2 after 100 draws.

that are difficult to distinguish from mechanical, lawlike dynamics, interrupted by occasional noise. This situation is illustrated for a particular sequence of Pólya's Urn in Figure 3. The possibility of such metaconvergence prompts the speculation that scientific laws may have arisen as degenerate forms of what initially were less constraining processes. The known physical laws, however, precipitated early enough in the evolution of the universe that they became universal in effect (Chaisson 2001). Processes that arose much later, and especially after the appearance of significant heterogeneity, were likely to remain indeterminate and circumscribed in time and space.

For later reference, three features of the Pólya example should be noted:

1. It involves chance.
2. It involves self-reference.
3. The history of draws is crucial to any particular series.

Although Pólya's Urn is a didactic illustration, it remains an artificial process. A scientific description of the development of order in living systems requires *natural* processes. Fortunately, Bateson (1972) provided a clue on where to look for natural processes that might impart order to noisy systems. He noted that the outcome of random noise acting upon a feedback circuit is generally nonrandom. It happens that progressive order is especially evident in one particular form of feedback—autocatalysis (Ulanowicz 1997). By *autocatalysis* is meant any instance of a positive feedback loop wherein the direct effect of every link on its downstream neighbor is positive (Figure 4),

A convenient example of autocatalysis in ecology is the community that forms around the aquatic macrophyte *Utricularia* (Ulanowicz 1995). All members of the genus *Utricularia* are carnivorous plants. Scattered along its featherlike stems and leaves are small bladders, called utricles. Each utricle has a few hairlike triggers at its terminal end that, when touched by

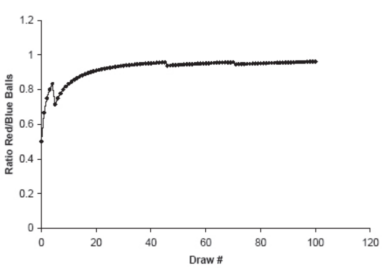

Fig. 3. Pólya 's Urn, Trial #3 after 100 draws.

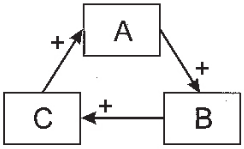

Fig. 4. A three-component autocatalytic configuration of processes.

a feeding zooplankter, open the end of the bladder, and the animal is sucked into the utricle by the negative osmotic pressure maintained inside the bladder. In nature the surface of *Utricularia* plants is always host to a film of algal growth known as periphyton. This periphyton serves as food for any number of species of small zooplankton. The autocatalytic cycle is closed when the *Utricularia* captures and absorbs many of the zooplankton.

LIFE AS PROCESS

A key feature of autocatalysis is the selection pressure that it exerts upon all of its components and their attendant mechanisms. Any change in a characteristic of a component that makes it either more sensitive to catalysis by the upstream member or a better catalyst of the element that it acts upon will be rewarded. Other changes will be at best neutral but more likely decremented by the feedback. A very important aspect of selection is that it reinforces any changes that bring more material or energy into a participating element. Because such reinforcement may pertain to any member of the autocatalytic cycle, the entire loop serves as the focus of what can be called (in Newton's word) the centripetal flow of resources (Figure 5).

It is difficult to overstate the importance of centripetality to the phenomenon of life. Conventional Darwinism, for example, conveniently overlooks the role of "striving" in evolution (Haught 2003). Although all the various organisms are competing with one another in epic struggle, one is pressed to ask what accounts for their drive. Such striving is considered epiphenomenal to neo-Darwinist accounts, but here is what Bertrand Russell had to say on the topic: "Every living thing is a sort of imperialist, seeking to transform as much as possible of its environment into itself and its seed. . . . We may regard *the whole of evolution* as flowing from this 'chemical imperialism' of living matter" ([1960] 1993, 22; emphasis added). It is clear that by "chemical imperialism" Russell was identifying centripetality. From the perspective of systems ecology, he correctly placed it at the very core of evolution.

Of almost equal significance is that centripetality stands as a prerequisite for competition. Without the generation of centripetality at one level, competition cannot arise at the next. Mutuality is an essential aspect of life; competition, by comparison, is an accidental consequence. An illustration of how mutuality can give rise to competition is presented in Figure 6. In the second graph element D appears

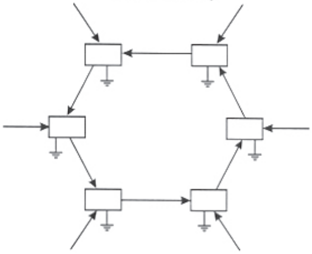

Fig. 5. Autocatalysis induces centripetality.

spontaneously in conjunction with A and C. If D is more sensitive to A and/or a better catalyst of C, the ensuing dynamics of centripetality will so favor D over B that B will either fade into the background or disappear altogether. That is, selection pressure and centripetality can guide the replacement of elements.

There is nothing special about element B in Figure 6, so that the argument presented there could be applied as well to C and how it might be replaced by E, or to A and its extirpation by F. The implication is that, in the long run, the lifetime of the autocatalytic configuration can exceed that of any of its components or their attendant mechanisms. Such supervenience by the whole over its parts explicitly contradicts the Newtonian dictum of closure (Clayton 2004).

Nor do the other material/mechanical presuppositions fare any better. In a world where systems are constantly being affected by unique events, it becomes senseless to speak of determinism. The asymmetric directionality in autocatalysis makes the system highly irreversible. The fact that each component in an autocatalytic system always develops in the context of its coparticipants renders them all highly codependent over the course of time, so that the organic complex is no longer amenable to atomistic decomposition. Finally, the domain of any individual process is hardly universal, being circumscribed in time and space and subject to mitigation by processes at other levels.

Setting aside the assumption of atomism is noteworthy for at least two reasons. Although the introduction of feedback into this discussion probably upset few readers, it was only because feedback has hitherto always been regarded in the context of the atomist assumption. Feedback first entered the scientific narrative via entirely artificial systems, such as electrical circuits or control mechanisms. In artificial constructs the assumption of atomism remains appropriate, and feedback becomes a consequence of a particular "atomic" assembly. Now, however, the reader is being asked to envision feedback, and especially autocatalysis, at work in natural systems where atomism is not appropriate. More generally, the very nature of the components involved in autocatalytic dynamics is the result of the feedback itself, and those participants are unlikely to persist outside the context that formed them. In ontological terms, feedback appears prior to and more essential than atomism.

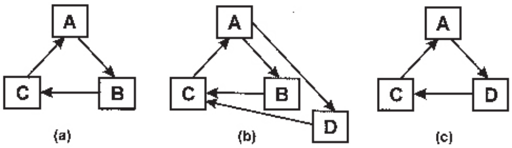

Fig. 6. Centripetality induces competition.

Second, it has been remarked that the science of rarefied systems was thought to apply as well to dense and heterogeneous compositions, via the assumption of atomism. But atomism now appears wholly inappropriate to the treatment of systems that develop in organic, mutualistic fashion. Insistence on atomism thereby obfuscates the true dynamics of complex systems. The assumption literally can blind one to reality.

PROCESS ECOLOGY—READING NATURE FORWARD

The reader may begin to sense that matters are terribly amiss with the conventional foundations of science. Science began as the consideration of stable material, laws, and rarefied systems, primarily because it was easiest to work in such terms. Certainly, humanity has benefited enormously in the material sense from the accomplishments that resulted from using these starting points, but it is a mistake to construe these expedient assertions as the ontological foundations of the physical universe. Under contemporary cosmogenesis, stable material, laws, and rarefied systems were nowhere present at the beginning of the physical universe. They are all the degenerate outcomes of more general processes, but processes themselves have been around since the first inhomogeneity appeared in the primal medium. It is high time to stop looking at reality in reverse. The moment is long overdue to place the horse before the cart and to undertake discussion of the natural world in terms of processes.

The reader will recall that Pólya's Urn displayed three basic properties: chance, self-influence, and history. These attributes are fundamental to all processes, and it is upon these pedestals that a new scientific metaphysic can be constructed—an ecological metaphysic, so to speak.

Accordingly, the first postulate is to establish chance as a reality:

1. *Radical contingency:* Nature in its complexity is rife with singular events.

Organic systems are constantly being exposed to unique contingencies, but, because of the self-stabilizing properties of autocatalysis, most of these events do not upset the prevailing dynamics. A minuscule few, however, may carry a system into a wholly different mode of *emergent* behavior—now perceived as an entirely natural phenomenon (Ulanowicz 2007).

It appears that the constraints of closure and atomism are at odds with the needs of living systems to maintain their integrities and grow (Ulanowicz 2009a). By contrast, autocatalytic action, a form of self-influence, is capable of augmenting form and pattern in nature. Accordingly, both closure and atomism are replaced by the second postulate:

2. *Self-influence:* A process in nature, via its interaction with other natural processes, can influence itself.

Third, in place of reversibility it is necessary to recognize (as did Darwin) that a system must retain some record of its past configurations. That is, it must possess a

3. *History:* The effects of self-influence are usually constrained by the culmination of past such changes as recorded in the configurations of living matter.

Under today's preoccupation with stable material forms, the mention of history will immediately conjure up images of DNA, RNA, and similar molecular forms. Once again, this is reading things backward. It is far more likely that the first records of organic history were written into the topologies of stable, long-lived configurations of processes.

These three postulates constitute a natural platform from which to cast an ecological perspective on life. They are the kernel of what can be called, for want of a better term, *process ecology* (Ulanowicz 2004; 2009a). Note especially that each of the three postulates *reverses* one or more of the original mechanical foundations. As Stuart Kauffman (2008) put it, it is necessary to live life forward. The same goes for science.

Putting ontological priorities in proper order could clear up several enigmas that continue to vex contemporary science. I remarked earlier how autocatalytic dynamics provide a useful exegesis of the "striving" that is conspicuously absent from evolutionary theory. The same goes for another explanation that eludes conventional evolutionary theory: the origin of life. The rampant preoccupation with dead matter focuses the scientific search for the origin of life on the appearance of just the right molecules. For example, simple compounds are placed in retorts that are then zapped with electrical charges (Miller and Urey 1959) or heated (Fox 1995) in the hope that the building blocks of life will result. Once those units are present, it is assumed, they will magically assemble into living entities.

Starting with processes, however, allows a quite different approach. The ecological metaphysic suggests that the origin of living entities is best sought among configurations of ongoing processes. Howard Odum (1971), for example, proposed that protoecological systems must already have been in existence before protoorganisms could have arisen. In his scenario at least two opposing (agonistic) reactions (such as oxidation reduction [Fiscus 2001]) had to transpire in separate spatial regions. One volume or area had to contain a source of energy and another had to serve as a sink to convey the entropy created by use of the source out of the system. Physical circulation between the two domains was necessary. Such a protoecosystem or circular configuration of processes provides the initial animation notably lacking in earlier scenarios. As was suggested by Bateson, circular concatenations of processes can exert selection; they also can naturally give rise to more complicated but smaller cyclical configurations (protoorganisms).

In principle, such transition poses no enigma. Irreversible thermodynamics holds that processes engender (and couple with) other processes all the time. Large cyclical motions spawn smaller ones as the normal course of affairs, such as when large-scale turbulent eddies shed smaller ones. The facile transition from one set of processes to another will figure prominently once the discussion returns (presently) to biosemiotics.

The three fundamental assumptions just proffered support two corollary tenets. First, one discerns two opposing propensities in ecodynamics. Autocatalysis provides the animation for systems to grow and maintain themselves. Opposing this drive is the inexorable action of the second law that degrades and dissipates existing structures. The direct conflict between these drives ameliorates at higher levels, however. Without the action of radical contingency, novel structures could never emerge. Conversely, larger, more constrained structures perforce dissipate more resources. The chief lesson behind this dialectic is that the phenomenon of life is not monistic, as most positivist treatments assume. It emerges from a transactional milieu. Furthermore, should either side of the transaction extirpate too much of its agonist, the system falls into jeopardy (Ulanowicz 2009b).

The second corollary relates strongly to biosemiosis. It holds that the agency active in a developmental scenario derives more out of configurations of processes than from objects and laws. Life itself is ineluctably bound up with configurations of processes. For example, Enzo Tiezzi (2006), a professor of thermodynamics and part-time hunter, asked what was different about a deer that he had just killed from the one that had been alive three minutes earlier. Its mass, form, bound energy, genomes—even its molecular configurations—all remained virtually unchanged immediately after death. What had ceased with death and was no longer present was the configuration of processes that had been coextensive with the animated deer—the very agency by which the deer was recognized as being alive.

BIOSEMIOSIS EMERGING

Thus far, autocatalysis has been presented as a circular concatenation of dyadic relationships. Implicit in the initial representation is a characteristic lag between when an element affects its downstream member and when the reward for that action is returned by its upstream neighbor. This lag could be significant, especially in inchoate configurations. But empirical evidence exists suggesting that autocatalytic systems converge toward a state that has been called by physicists a *coherence domain* (Ulanowicz 2009b, c; Brizhik et al. 2009; Ho 1993). All of the elements in a coherence domain contribute simultaneously and equiponderantly to the persistence of the entire configuration. For example, in quantum theory coherence domains arise among collections of water molecules, where they are created and maintained by the overall electromagnetic field.

Exactly what sustains coherence in an ecosystem has not yet been resolved. It is not necessarily the overall electromagnetic field, as in quantum physics. It is required only that some means of communication be operating on a characteristic time that is very short with respect to the elementary reward lag. For example, when several species engage in the autocatalytic cycling of materials, the reward lag could be days or even years. Communication via signs (light, touch, olfaction) that is very rapid in comparison to mass transfer could provide the prompt for all elements to fall into coherence.

Coherent configurations of processes are relevant to biosemiosis on at least two levels. At the level of individual participants coherence is likely established and maintained via signification. At the level of the whole configuration, the near simultaneity of action supersedes having to depict the system as a collection of dyadic interactions. Hence, Peirce's tripartite causality emerges naturally from first principles, facilitated especially by the postulate on feedback.

A WIDER PERSPECTIVE ON EVOLUTION

Indeed, much of what transpires during evolution is unnecessarily proscribed or neglected by the conventional narrative. It is important to realize that Darwin's *Origin of Species* described not a law, or even a theory, so much as a process in the strict sense defined above. Process, however, with its accompanying randomness and feedback, did not sit well with the Enlightenment metaphysic. As with almost all new inventions (McLuhan 1964), the response in the wake of Darwin was to interpret his discovery in terms already familiar—that is, using the material/mechanical narrative. Attention was thus split between changes in species' characteristics and a wholly independent agency called natural selection.

The later stunning discovery of the DNA molecule and the elaboration of its digital encoding shifted the focus on change markedly downward into the molecular scales. The result is a rather schizoid narrative that bounces back and forth between events separated by ten or more orders of magnitude. Admittedly, the correlation of a macroscopic phenomenon with its submicroscopic genome is of great interest and utility. The downside is that attention has inevitably been diverted from the entire domain of events transpiring in between. A consequence of this excluded middle is that the agency of maintenance and change has, by default, been attributed to the molecular genome. It is becoming increasingly clear that the agency that actually reads, edits, and acts on the genetic code is dispersed among the network of proteomic and enzymatic actors at the next level up (Coffman 2006). Neo-Darwinian theory thereby misattributes efficient causality (*sensu* Aristotle) to the molecular genome, which functions more in the capacity of a *passive* material cause.

The neo-Darwinian focus is strictly on material objects and mechanisms. Actions and attributes such as directionality, striving, signing, and interpretation are either vigorously abjured or conveniently dismissed as epiphenomena—all in a procrustean effort to remain consistent with the material/ mechanical ideology. Prominent among what has been excluded is the centripetality that Tiezzi maintains is key to life itself and that Russell saw as the very core of evolution. This neo-Darwinian consensus, which is defended with almost religious zeal against all critics, in reality is a sacred cow pocked full of holes. It is minimalism masquerading as simplicity. In significant ways, it leads adherents astray from reality.

That the conventional metaphysic distorts the nature of dynamics is evident in the metaphor that Daniel Dennett (1995) chose to depict evolution. Dennett described the stages of evolution as analogous to "cranes built upon cranes," whereby new features are hoisted on to the top of a tower of cranes and become available to build yet another crane in a repeating sequence. Dennett cautioned his readers to dismiss any influence from above that was not connected with the supporting foundation—the usual proscription against top-down causality.

How this rigidly mechanical analogy omits what often transpires in evolution can be seen by comparing it with an alternative, more organic, simile—that of the muscadine grapevine (Ulanowicz 2004). Soon after a gardener plants a muscadine grapevine, he/she usually trains the initial shoot upward eventually to become the trunk from which in succeeding years horizontal branches are espaliered to establish the fruiting wood. This method of pruning is common to raising all species of *vinifera*. The muscadine family of grapes, however, exhibits a growth habit different from most other grapes. Several years along, they usually let *down* from the lowest branches several adventitious roots that meet the ground not far from the established trunk. These parallel growths can swell to substantial thickness. In very many instances, the main trunk dies for one of a number of reasons and rots away completely. Sustenance of the framework of vines is then taken over by the newer connections.

The muscadine grapevine provides a far more appropriate metaphor for the dynamics of evolution. The plant represents an evolving, hierarchical system. No skyhooks are involved, because the system always remains connected with its foundation of bottom-up causalities, which remain integral to the narrative. Consistent with process ecology; however, it is the later, higher structures that create new connections, which either passively replace or actively displace their older counterparts. Such top-down influence is commonly referred to as supervenience (Clayton and Davies 2006; Peterson 2009). It is important to note the temporal offset whereby the events and structures at the upper levels do not simply influence their progenitors; they sometimes replace them altogether. Deacon (2006), as was mentioned, argued that RNA and DNA-like molecules most likely arose out of the context of autocatalytic processes to eventually displace those configurations as the primary means of information storage in living systems.

EVOLUTION TURNS BIOSEMIOTIC

Out of autocatalytic coherence domains can emerge tripartite causalities, signs, and interpreters—that is, biosemiosis. Under the muscadine-grapevine analogy, this emergent pattern of behavior, rejected by the architects of neo-Darwinism, could become the cornerstone of future evolutionary narratives. Such change in vision will likely take time, however, because for so long attention has been diverted away from semiosis by conventional evolutionary dogma.

Meanwhile, process ecology remains entirely within the limits of methodological naturalism. That is, it supports a wholly natural discourse. Furthermore, it paves the way for Hoffmeyer's (2010) top-down apologetics to be buttressed by a bottom-up description of the emergence of biosemiotics. Both apologies are grounded on natural assumptions that are more in line with contemporary cosmogenesis. Process ecology enables one to pursue science forward rather than backward. It provides a stage on which sign and interpretation not only can appear as legitimate actors in the ongoing evolutionary drama but can move into the spotlight.

NOTES

1. This only exacerbates the skepticism of those who eschew biosemiosis.
2. Read "six-factorial" and indicates the product of all integers up to six.
3. Some conditions are so extreme as to preclude the existence of all living forms and thereby remain beyond the scope of this discussion.
4. A nanosecond is one-billionth of a second—the timescale of atomic reactions.

REFERENCES

Bateson, Gregory. 1972. *Steps to an Ecology of Mind*. New York: Ballantine.

Bohm, David. 1989. *Quantum Theory*. Mineola, N.Y.: Dover.

Boltzmann, Ludwig. 1905. *Wissenschaftliche Abhandlungen*. Leipzig: J. A. Barth.

Brier, S. 2008. *Cybersemiotics: Why Information Is Not Enough!* Toronto: Univ. of Toronto Press.

Brizhik, Larissa, Emilio Del Giudice, Sven E. Jørgensen, Nadia Marchettini, and Enzo Tiezzi. 2009. "The role of electromagnetic potentials in the evolutionary dynamics of ecosystems." *Ecological Modelling* 220:1865–69.

Carnot, Sadi. [1824] 1943. *Reflections on the Motive Power of Heat*. New York: ASME.

Chaisson, Eric J. 2001. *Cosmic Evolution: The Rise of Complexity in Nature*. Cambridge: Harvard Univ. Press.

Clayton, Philip. 2004. *Mind and Emergence: From Quantum to Consciousness*. New York: Oxford Univ. Press.

Clayton, Philip, and Paul Davies, eds. 2006. *The Re-emergence of Emergence: The Emergentist Hypothesis from Science to Religion*. New York: Oxford Univ. Press.

Coffman, James A. 2006. "Developmental Ascendancy: From Bottom-up to Top-down Control." *Biological Theory* 1:165–78.

Cohen, Joel E. 1976. "Irreproducible results and the breeding of pigs." *Bioscience* 26:391–94.

Darwin, Charles. 1859. *On the Origin of Species by Means of Natural Selection, or, The Preservation of Favoured Races in the Struggle for Life*. London: J. Murray.

Deacon, Terrence W. 2006. "Reciprocal Linkage between Self-organizing Processes Is Sufficient for Self-reproduction and Evolvability." *Biological Theory* 1 (2): 136–49.

Dennett, Daniel C. 1995. *Darwin's Dangerous Idea: Evolution and the Meanings of Life*. New York: Simon and Schuster.

Depew, David J., and Bruce H. Weber. 1995. *Darwinism Evolving: Systems Dynamics and the Genealogy of Natural Selection*. Cambridge: MIT Press.

Elsasser, Walter M. 1969. "Acausal phenomena in physics and biology: A case for reconstruction." *American Scientist* 57:502–16.

Fiscus, Daniel A. 2001. "The ecosystemic life hypothesis I: Introduction and definitions." *Bulletin of the Ecological Society of Am*erica 82 (4): 248–50.

Fisher, Ronald A. 1958. *The Genetical Theory of Natural Selection*. New York: Dover.

Fox, Sidney W. 1995. "Thermal synthesis of amino acids and the origin of life." *Geochimica et Cosmochimica Acta* 59:1213–14.

Gibbs, Josiah W. [1901] 1981. *Elementary Principles in Statistical Mechanics*, Woodbridge, Conn.: Ox Bow.

Hartshorne, Charles. 1971. *Reality as Social Process*. New York: Hafner.

Haught, John F. 2003. *Deeper Than Darwin: The Prospect for Religion in the Age of Evolution*. Boulder, Colo.: Westview.

Ho, Mae-Wan. 1993. *The Rainbow and the Worm: The Physics of Organisms*. River Edge, N.J.: World Scientific.

Hoffmeyer, Jesper. 2008. *Biosemiotics: An Examination into the Signs of Life and the Life of Signs*. Scranton, Pa.: Univ. of Scranton Press.

———. 2010. "A Biosemiotic Approach to the Question of Meaning." *Zygon: Journal of Religion and Science* 45:367–90.

Kauffman, Stuart A. 2008. *Reinventing the Sacred: A New View of Science, Reason, and Religion*. New York: Basic Books.

Laplace, Pierre-Simon. [1814] 1951. *A Philosophical Essay on Probabilities*. Trans. F. W. Truscott and F. L. Emory. New York: Dover.

McLuhan, Marshall. 1964. *Understanding Media*. New York: Mentor.

Miller, Stanley L., and Harold C. Urey. 1959. "Organic Compound Synthesis on the Primitive Earth." *Science* 130:245.

Noether, Aemalie. 1983. *Gesammelte Abhandlungen*. Ed. Nathan Jacobson. New York: Springer.

Odum, Howard T. 1971. *Environment, Power and Society*. New York: John Wiley and Sons.

Patten, B. C. 1999. "Out of the Clockworks—Ecology." Review of *Ecology, The Ascendent Perspective*. *Estuaries* 22:339–42.

Peterson, Gregory. 2009. "Who needs emergence?" In *Envisioning Nature, Science and Religion*, ed. J. D. Proctor, 166–79. West Conshohocken, Pa.: Templeton Foundation Press.

Popper, Karl R. 1990. *A World of Propensities*. Bristol: Thoemmes.

Russell, Bertrand. [1960] 1993. *An Outline of Philosophy*. New York: Routledge.

Tiezzi, Enzo. 2006. *Steps towards an Evolutionary Physics*. Southampton: WIT Press.

Ulanowicz, Robert E. 1995. "*Utricularia's* secret: The advantage of positive feedback in oligotrophic environments." *Ecological Modelling* 79:49–57.

———. 1997. *Ecology, the Ascendent Perspective*. New York: Columbia Univ. Press.

———. 2004. "Ecosystem Dynamics: A Natural Middle." *Theology and Science* 2 (2): 231–53.

———. 2007. "Emergence, Naturally!" *Zygon: Journal of Religion and Science* 42:945–60.

———. 2009a. *A Third Window: Natural Life beyond Newton and Darwin*. West Conshohocken, Pa.: Templeton Foundation Press.

———. 2009b. "The dual nature of ecosystem dynamics." *Ecological Modelling* 220:1886–92.

———. 2009c. "Increasing entropy: Heat death or perpetual harmonies?" *The International Journal of Design and Nature & Ecodynamics* 4 (2): 1–14.

Whitehead, Alfred N. 1929. *Process and Reality*. New York: Macmillan.

Wright, Sewell. 1968. *Evolution and the Genetics of Populations: A Treatise*. Chicago: Univ. of Chicago Press.