Chapter Four
Process-First Ontology

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Whence Biotic Organization?

The argument could be made that the philosophy of biology is preoccupied with ontogeny. We exist, after all, most identifiably as organisms, and we are naturally predisposed toward narcissism. Furthermore, ontogeny invites a focus upon mechanism in biology, because our own bodies exhibit a myriad of mechanical-like phenomena as part of our constitutive dynamics. So it is not unreasonable in light of a scenario that appears so strongly scripted and regulated to focus on the material and the mechanical as the crux of our scientific narrative of organisms. It is only relatively rare exceptions to mechanism that give one pause.

Such cogent reasoning notwithstanding, a mechanical narrative of organisms and their development eventually encounters difficulties. In particular, the neo-Darwinian script whereby the molecular genome directs the construction of the organism via a sequence of molecular mechanisms leads to a particularly less-than-satisfying end. Such was the conclusion by Sidney Brenner and his associates after years of trying to map out the domains of influence exerted by each gene upon the 959 cells comprising the simple roundworm, *Caenorhabditis elegans*:

> At the beginning it was said that the answer to the understanding of development was going to come from a knowledge of the molecular mechanisms of gene control. . . . [But] the molecular mechanisms look boringly simple, and they do not tell us what we want to know. We have to try to discover the principles of organization, how lots of things are put together in the same place.[1]

To paraphrase Brenner, we may have to pay less attention to objects moving according to universal laws in order to emphasize better the relationships among parts and processes. Here our fixation upon organisms tends to divert us, because organization there is quite rigid and not at all unmechanical. Organization elsewhere, however, exists alongside far greater flexibility. As Gunther Stent noted,

> Consider the establishment of ecological communities upon colonization of islands or the growth of secondary forests. Both of these examples are regular phenomena in the sense that a more or less predictable ecological structure arises via a stereotypic pattern of intermediate steps, in which the relative abundances of various types of flora and fauna follow a well-defined sequence. The regularity of these phenomena is obviously not the consequence of an ecological program encoded in the genome of the participating taxa.[2]

Stent was independently supporting Brenner's suggestion that the focus upon the mechanisms of transcription from genome to phenome should not overshadow more relevant organizational influences expressed at the level of the entire system. It would be a mistake, however, to follow our narcissistic inclinations immediately into the human sciences, such as economics, sociology, anthropology, because amidst such higher-level ensembles intentionality can cloud our search for the rudimentary non-mechanical organizing principles. Fortunately, ecology seems to occupy a propitious middle ground in that ecosystems appear to exhibit considerable flexibility in abstraction of human volition. As Stent hinted, it may be the preferred theater in which to describe non-mechanical agencies.

The focus here, then, is upon ecology, as we probe beyond the mechanical to gain deeper insights into biological reality. For the time being, however, our attention remains with mechanism, specifically as it is manifested via universal physical laws. In particular, the Enlightenment assumptions of causal closure, atomism, and universality taken together imply that "law determines all"—namely, nothing at all happens except that it be *elicited* by the workings of the universal laws. In particular, our argument here will be that biology resembles more a theater of repeated particulars than a playbook of universal laws. In Peircean terms, nature tends to take on habits.

The Logic of It All

The notion that universal laws can somehow elicit actions is misguided, because all actual events involve at least some particulars. It is almost tautological to note that universal laws can be described only in terms of universal variables. In that vein, Gregory Bateson observed how the "stuff" of conventional sciences consists of only generic and homogeneous categories (which he collectively called "pleroma"), such as mass or energy.[3] Solving actual problems involves more than generality, however—a fact that is implicit, even in classical physics. Real problems consist of a field or domain over which the general law in question determines behavior and a required boundary or initial point at which conditions *necessarily remain contingent*. Heretofore, the contingency of the boundary problem has almost always been overshadowed by our fixation on the deterministic behavior within domain. In classical physics the boundary *conditions* are usually assumed to be *specified* (made particular) by the individual who states the problem. Whence our Newtonian bias in favor of the detached observer tempts us to ignore the boundaries as part of the physical problem, but to do so is a palpable error. It is impossible to state any real problem in full without involving both determinacy and *contingency.*

While the foregoing might seem like semantic quibbling to some, the necessity of contingency has made for historical footnotes at times (as with the rise of Deism during the seventeenth and eighteenth centuries). Although contingency at the boundaries causes no headaches in posing simple classical problems, the importance of obligatory contingency grows as problems become ever more complex. Aside from the intentional action of specifying boundary contingencies, there are at least two other ways by which initial and peripheral constraints can arise *naturally*: (1) They can be fully contingent, i.e., they can appear from outside the considered domain by pure chance. This is pretty much the scenario for "natural selection" in Darwinian discourse. (2) The conditions can arise via the regular interference of some subsystems on others, behavior which usually is referred to as "self-organization" (as discussed further below).

Regardless of how contingency enters the problem, it must always be present, simply because it is impossible to determine the particular and/or the heterogeneous entirely in terms of the general and the homogeneous. Universal laws can never *determine* all—a conclusion commensurate with Gödel's proposition that any formal, self-consistent, recursive axiomatic system cannot encompass some true propositions. The ability of universal laws to determine actions erodes in combinatory fashion as one encounters ever more particulars, and it effectively vanishes with sufficient heterogeneity (such as always exists in living systems). Bateson, for example, pointed out how in biology one is forced to deal with heterogeneous tokens, each of which can be distinguished from the others. It was Walter Elsasser who suggested that such transition from the homogeneous to the heterogeneous requires that the investigator employ a qualitatively different logic:

> When in the early years of this century Whitehead and Russell succeeded in combining logic and mathematics into one edifice, modern mathematics 'took off.' It is almost entirely based on sets whose elements are assumed to have no internal structure. This makes modern mathematics ideally suited for dealing with the constituents of matter discovered by the physicist. It is an experimentally well-established fact that those constituents, electrons, protons, and so forth are indistinguishable; their properties are such as to make these particles rigorously identical with each other. The more refined experiments allow one to specify this identity quantitatively to many decimal places. It is a well-established principle of physics that when one forms a class of, say, electrons, all elements of that class are strictly indistinguishable; it is as a matter of principle impossible to "label" the members of such a class so as to distinguish

them individually. We shall speak of classes with this property as perfectly homogeneous classes.[4]

Further on, Elsasser purports that the logic of homogeneous classes is distinct from that of heterogeneous collections and that one cannot pass unaffected from the homogeneous into the heterogeneous: "and while homogeneous classes are the equivalent of a mathematical treatment, heterogeneous classes do not lend themselves easily to mathematical treatment."[5] He concluded that any laws as one might discover in biology cannot be of the universal form that appear in physics. In particular, this frustrates our efforts to predict with the same confidence as is possible in physics.

A caricature of the prediction that is possible in working with homogeneous classes is provided in Figure 4.1, where a class of five identical integers 2 operates in some way (say multiplication of arbitrarily paired tokens) upon a similar homogeneous class of integers 4. The result is yet another *homogeneous* class consisting entirely of the integer 8.

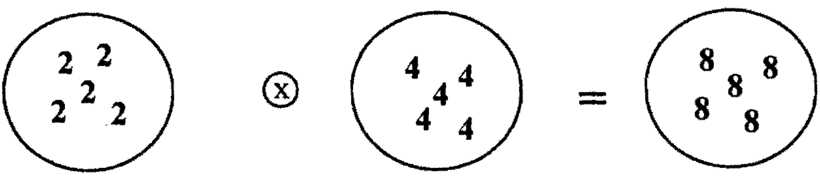

Figure 4.1: Operations between homogeneous classes are determinate. (Source: Robert E. Ulanowicz, *A Third Window: Natural Life beyond Newton and Darwin*, copyright 2009, Templeton Foundation Press. Reprinted with permission of the publisher.)

By contrast, the same operations between heterogeneous groupings do not in general yield tokens of any single heterogeneous grouping. To see this, we consider heterogeneous collections of the integers from 1 to 5, 6 through 10, 11 to 15, etc... When the same operation that was applied to the homogeneous integers is repeated for the first heterogeneous category acting on itself, the results scatter among the classes (Figure 4.2), culminating in a diffuse indeterminacy.

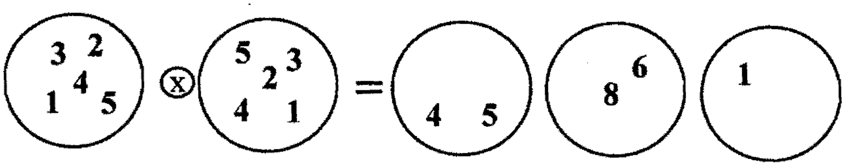

Figure 4.2: Operations between inhomogeneous groupings are indeterminate. (Source: Robert E. Ulanowicz, *A Third Window: Natural Life beyond Newton and Darwin*, copyright 2009, Templeton Foundation Press. Reprinted with permission of the publisher.)

When dealing with heterogeneous classes, the unexpected or indeterminate is always possible (see Kauffman's foreword in this volume). Kauffman also remarked on the combinatoric unmanageability of what he called the "adjacent possible."[6] Yet again, universal laws are seen to be intrinsically incapable of dealing with particularities.

The Limits of Probability

Indeterminacy is hardly new, of course, even though its existence is sometimes questioned. It is the ubiquity of variation that keeps statisticians employed in biology, and they have been very successful in quantifying statistical regularities throughout the living realm. Does that infer, however, that we thereby retain the advantage of prediction, albeit in a statistical sense? Elsasser answers with a definitive "No!" to this question by demonstrating that probability theory cannot be invoked for all chance phenomena.

In conventional probability theory, tacit assumptions are made that all chance events are simple, generic, and repeatable. Elsasser demonstrated, however, that the overwhelming majority of stochastic events in biology are totally unique, never again to be repeated.[7] This statement sounds absurd at first, given the enormity and age of our universe, but his assertion happens to be surprisingly easy to defend. Elsasser noted that there are fewer than 10^{85} elementary particles[8] in the whole known universe, which itself is about 10^{25} nanoseconds old.[9] This means that, at the very most, 10^{110} simple events could have occurred over all physical time. It thereby follows that if any event has considerably less than 10^{-110} probability of re-occurring, it will never do so in any physically realistic time. Of course, 10^{110} is a genuinely enormous number. It does not, however, require Avagadro's Number (10^{23}) of distinguishable entities to create a number of combinations exceeding Elsasser's limit on physical events. Nor does it require billions, millions, or even thousands. A system with merely 75 or so distinguishable components will suffice. It can be said with overwhelming confidence that any event randomly comprised of more than 75 distinct elements has never occurred earlier in the history of the physical universe. Ecosystems, which conservatively are comprised of hundreds or thousands of distinguishable organisms, must give rise, not just to an occasional unique event, but to legions of them. In ecology, unique, singular events are occurring all the time, everywhere!

A prerequisite for applying probability theory to chance phenomena is that the events in question re-occur at least several times, so that a legitimate frequency can be estimated. Singular events, however, occur only once, never to be repeated. Any probabilities assigned to them transcend physical reality. Furthermore, such particular singular events elude the abilities of universal laws to predict. Akin to Heisenberg uncertainties or the Pauli Exclusion Principle, such singularities are a necessary part of nature, not some epistemological lacuna awaiting theoretical elaboration. Yet again, determinism is judged not to be a ubiquitous characteristic of nature. Gradually, a larger picture is beginning to emerge: in very simple problems, the action of universal law provides most of the explanation needed for a particular behavior. Boundary considerations remain quite simple and constitute but a small part of the explanatory narrative. As one considers ever more complex, heterogeneous problems, the burden of explanation shifts away from the constraining universal laws and involves more the complicated boundary statements. Furthermore, such contingent constraints come to interact with one another, and it is those interactions, not the laws themselves, that actually *elicit* new behaviors. For in a world where radically contingent complex constraints can appear, entirely new behaviors can emerge quite naturally. It is not that the physical laws are necessarily violated. They continue to be part of the overall configuration of constraints. It is just that the most cogent explanation is to be found among the boundary phenomena.

We should have seen this coming. If we consider, for example, the number of conceivable combinations of the four force laws of physics and the two laws of thermodynamics, we are faced with a considerable count of possible juxtapositions ($6! = 720$). That magnitude pales, however, in comparison to the tally of all changes possible amongst a complex system having, say, 35 loci for incremental change (approximately 10^{40}). Any particular juxtaposition of laws likely will be satisfied precisely by a *very large* multiplicity of possibilities—conceivably billions or more. We conclude, therefore, that laws continue to constrain complex biological phenomena, but they are woefully insufficient to *determine* particular results. The contingencies that do specify outcomes must lie elsewhere. But where?

Enter Process

Although universal physical laws cannot deal fully with the individualities of a heterogeneous ecology (or of biology in general), many particulars, as Stent observed, do recur in ecosystems with evident regularity. What then, if not universal laws, determines particular outcomes or fosters their recurrence? In certain respects the answer is quite conventional—it lies with Darwinian process. What remains unmentioned, however, is that most evolutionary theorists either fail to apprehend or intentionally ignore the full implications of Darwin's paradigm, equating the Darwinian scenario instead with Ayala's conception of matter moving in accordance with universal laws. While evolution does not violate any universal laws, an unhealthy preoccupation with those laws can blind one to the larger nature of evolution as process.

In order to make clear how process differs from universal law, it behooves us to define the former more precisely. Accordingly, we suggest that: "a process is the interaction of random events upon a configuration of constraints that results in a non-random, but indeterminate outcome."[10] This definition is likely to strike some readers as foreign, and the juxtaposition of "non-random" with "indeterminate" is possibly confusing. It should prove helpful, therefore, to consider a simple example of an artificial process called Polya's Urn.[11] This exercise begins with 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 paired with 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, etc... The first question arising is whether a long sequence of such draws and additions would culminate in a virtually constant ratio of red to blue balls? It is rather easy to demonstrate that after some one thousand or so draws, the ratio indeed converges to the close neighborhood of some constant, say 0.54591. That is, the ratio becomes progressively non-random as the number of draws progresses.

That the system does not converge closely to 0.5000 prompts a second question—what would happen if the urn was emptied and the starting configuration recreated? Would the subsequent series of draws converge to the same limit as the first? It can readily be demonstrated that it almost certainly will not. After a second thousand draws, the ratio might approach a limit in the vicinity of 0.19561. That is, the Polya process is clearly *indeterminate.* Repetition of the Polya process many times reveals that the ratio of balls is evenly distributed over the interval from zero to one. It can be any real number in that range. Furthermore, the ratio is progressively constrained by the particular series of draws (history) that have already occurred. We note further that some histories converge to behaviors that are difficult to distinguish from mechanical, law-like dynamics interrupted by occasional noise. The possibility thus arises that law-like behavior might constitute limiting forms of more general, less constraining processes.[12] For later reference, we emphasize three features of the artificial Polya process: (1) it involves chance; (2) it involves self-reference; (3) the history of draws is crucial to any particular series.

Natural Origins of Constraint

Polya's Urn, unfortunately, is not a natural process. Gregory Bateson, however, hinted how natural processes might create constraints that impart order to noisy affairs. He noted that the outcome of random noise acting upon a feedback circuit is generally non-random.[13] Following this lead, we now focus upon a particular form of feedback—autocatalysis.[14] By "autocatalysis" is meant any manifestation of a positive feedback loop wherein the direct effect of every link on its downstream neighbor is positive (Figure 4.3).

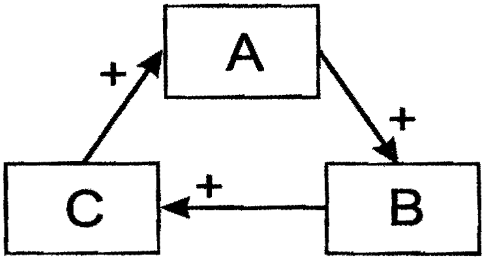

Figure 4.3: A three-component autocatalytic configuration of processes. (Source: Robert E. Ulanowicz, *Ecology, the Ascendent Perspective*, copyright 1997 Columbia University Press. Reprinted with permission of the publisher.)

An illustration of autocatalysis in ecology is found in the community that forms around the aquatic macrophyte, *Utricularia*.[15] All members of the genus *Utricularia* are carnivorous plants. Scattered along its feather-like stems and leaves are small bladders, called utricles (Figure 4.4a) Each utricle has a few hair-like triggers at its terminal end, which, when touched by a feeding zooplankter, opens the end of the bladder, and the animal is sucked into the utricle by a 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 in turn 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 (Figure 4.4b).

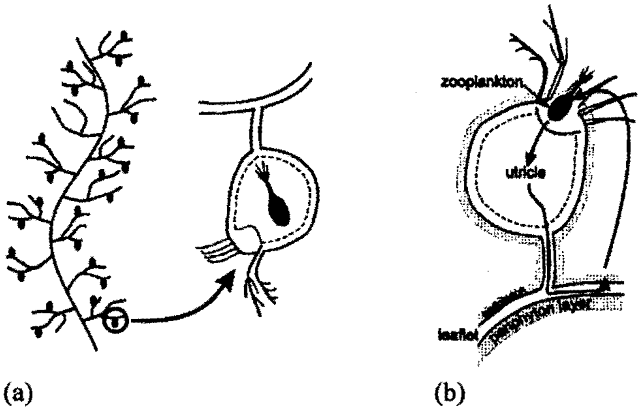

Figure 4.4: (a) Stem of Utricularia with closeup of utricle. (b) The autocatalytic processes inherent in the Utricularia system. (Source: Robert E. Ulanowicz, *Ecology, the Ascendent Perspective*, copyright 1997, Columbia University Press. Reprinted with permission of the publisher.)

Perhaps the most important feature of autocatalysis is that it exerts selection pressure upon all of its components and *any of their attendant mechanisms*. Any change in a characteristic of a component that either makes it more sensitive to catalysis by the upstream member, or a better catalyst of the element that it catalyzes, will be rewarded. Other changes will at best be neutral, but more likely will be decremented by the feedback. An immediate and cardinal effect of such internal selection is that it re-enforces those changes that bring more material or energy into a participating element, resulting in what can be called (in Newton's terminology) "centripetality" (Figure 4.5).

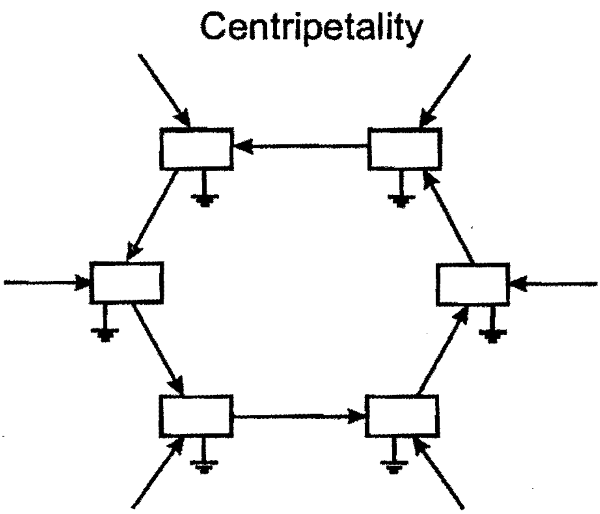

Figure 4.5: Autocatalysis induces centripetality. (Source: Robert E. Ulanowicz, *Ecology, the Ascendent Perspective*, copyright 1997, Columbia University Press. Reprinted with permission of the publisher.)

It is almost impossible to overstate the importance of centripetality for the nature of life. Conventional Darwinism conveniently ignores the role of "striving" in evolution.[16] Because the various organisms are competing with one another in epic struggle, one is moved to ask what accounts for their drive? Although striving is considered epiphenomenal and absent from most Darwinian accounts, here's how Bertrand Russell regarded the phenomenon: "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."[17] Obviously, by "chemical imperialism" Russell is writing about centripetality; and, as we may infer from systems ecology, he correctly identifies it and not blind chance as the drive behind *all* of evolution.

Equally important is that centripetality is a prerequisite for competition. Without the generation of centripetality at one level, competition simply cannot arise at the next. We note that mutuality behind centripetality is essential, whereas competition is an accidental consequence. To see how centripetality induces competition, we regard the sequence in Figure 4.6. In the second graph element D appears spontaneously in conjunction with A and C. If D is more sensitive to A and/or a better catalyst of C, then 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.

Returning to Figure 4.3, we can envision how C might be replaced by E and A by F, so that it is likely that the lifetime of the autocatalytic configuration will exceed that of any of its components *or their attendant mechanisms*. Such is an example of supervenience by the whole over its parts, and it explicitly contradicts the Newtonian dictum of closure.[18] In fact, all the other Enlightenment postulates describing a mechanical world fare no better.[19] As already noted, determinism is rare in complex systems.

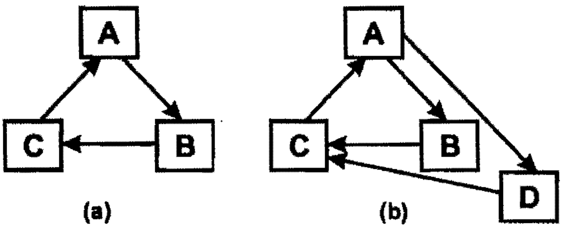

Figure 4.6: Centripetality induces competition. (Source: Robert E. Ulanowicz, *Ecology, the Ascendent Perspective*, copyright 1997, Columbia University Press. Reprinted with permission of the publisher.)

The asymmetric nature of autocatalysis contravenes reversibility. Because each component develops within the context of its co-participants, they will all become progressively co-dependent over time, so that an organic complex will no longer be 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.

New Fundamental Assumptions

At least within the realm of ecology, all five Enlightenment postulates—closure, atomism, reversibility, determinism, and universality (see chapter 1 of this volume)—fail in some way or another to describe living dynamics. What is needed is an entirely new, but wholly naturalistic, metaphysic—an ecological metaphysic. In particular, the new framework requires that we shift our focus away from laws and objects toward configurations of processes. Furthermore, we want the new postulates to reflect the primacy of process, and so we return to the three features of the Polya process earmarked earlier—namely, that process requires chance, self-influence, and history.

Our first postulate establishes the ontological reality of chance:

> (1) *Radical Contingency*: Nature in its complexity is rife with singular events.

Organic systems are constantly encountering unique contingencies, but the self-stabilizing properties of autocatalysis keep most of these events from upsetting the prevailing dynamics. A miniscule few, however, may divert a system into a wholly different mode of *emergent* behavior, so that emergence appears as an entirely *natural* phenomenon under the new assumptions.[20]

The Newtonian constraints of closure and atomism did not allow systems to maintain their integrities or grow.[21] By contrast, autocatalytic action, a particular form of self-influence, can impart form, constraint, and pattern to nature. Thus, we replace both closure and atomism by allowing for

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

Thirdly, instead of reversibility we recognize, as did Darwin, that a system must retain some record of its past configurations—namely, 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.

In this context the reader will likely think immediately of RNA, DNA, or similar molecules, but it is more likely that, well before material genomes came onto the scene, the first records of organic history were written into the topologies of stable, long-lived configurations of *processes*.

The three postulates thus constitute a natural platform from which to project a process-oriented view of ecology. In this framework, agency exerted by configurations of processes takes precedence over universal laws acting on objects. Furthermore, life itself can be closely identified with configurations of processes. This was made clear by the example of the dead deer provided by the late Enzo Tiezzi, who was a thermodynamicist and part-time hunter. Tiezzi asked what was different about a deer that he had just shot 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 actual agency by which the deer had been identified as being alive.[22]

Secondly, one discerns a definite opposition between the first two attributes of process. While autocatalysis imparts animation for systems to grow and maintain themselves, this action is opposed by radical chance, which serves to degrade and dissipate existing structures. This observation is hardly original. Diogenes reported how Heraclitus taught that nature was the outcome between agonistic tendencies that build-up as opposed to those that teardown (see also chapter 5 of this volume for a "pluralism that refuses the dualistic option"). The conflict between these drives is not absolute, however. At higher levels novel structures could never emerge without the action of radical contingency. Conversely, larger, complex and more constrained structures persist only by dissipating more resources.[23] Together the three fundamental postulates, along with their two corollary observations, constitute the framework of what has been called "process ecology."[24]

Moving Away from Objects

As one passes from the homogeneous world of physics into the highly particularized realm of ecology, it is becoming clearer that we must cease looking to universal laws and fixed mechanisms for full explanation and turn rather to the study of the organizing constraints exerted by process. That matter is moving according to universal laws simply does not tell us much, and our preoccupation with law diverts our attention away from the more complex nature of reality. In ecology, reality is scripted by process.

With the rise of computer technology has dawned the feasibility of creating "autonomous agent models" of ecosystems.[25] The focus in such models on object-object encounters has fostered the adoption of an "object-oriented-ontology" (O-O-O).[26] Although this emerging philosophical thrust does de-emphasize dependence on universal laws, it also plays down the relational nature of feedbacks that may arise in the actual systems. Focus in O-O-O is on the trees (objects), while the forest (processes) remains ignored.

O-O-O represents the natural culmination of a widespread trust in materialism, which, as Richard Lewontin wryly remarked, remains the *sine qua non* for most scientists:

> We take the side of science in spite of the patent absurdity of some of its constructs, in spite of its failure to fulfill many of its extravagant promises of health and life, in spite of the tolerance of the scientific community for unsubstantiated just-so stories, because we have a prior commitment, a commitment to materialism. It is not that the methods and institutions of science somehow compel us to accept a material explanation of the phenomenal world, but, on

> the contrary, that we are forced by our a priori adherence to material causes to create an apparatus of investigation and a set of concepts that produce material explanations, no matter how counter-intuitive, no matter how mystifying to the uninitiated. . . .[27]

As we have seen, however, the priority given to objects over processes is ill-considered for several other reasons: For one, matter, as we usually conceive it, is exceedingly rare in a cosmos where more than ninety-nine percent of matter consists of hydrogen and helium radicals. Matter in solid form is the rare exception in the universe. Furthermore, stable atoms themselves, according to the Big Bang scenario, did not appear until (logarithmically speaking) well along in the development of the cosmos. Finally, what gave rise to matter appears, for the entire world, to be process.[28]

Presumably, the universe began as a chaotic, incredibly dense mass of extremely high-energy photons—pure flux.[29] As this continuum began to expand, some of the photons came together (collided) to form pairs of closed-looped circulations of energy called hadrons—the initial matter and anti-matter. For a while, these hadrons were destroyed by collisions with photons about as fast as they appeared. Continued expansion put space between the elementary particles so that matter and anti-matter pairs annihilated each other with decreasing frequency, and the diminishing energy of the photons made their collisions with extant material less destructive. Matter was beginning to appear, but was also disappearing at much the same rate.

Meanwhile, a very subtle (one in a billion) asymmetrical chance event produced slightly more matter than anti-matter, so that the mutual destruction of anti-matter by matter resulted in a growing residual of matter (feedback). Further expansion gave rise to yet larger configurations of emerging matter and the appearance of weaker forces. Eventually, matter coalesced under gravity (into stars) to a density that ignited chain fusion reactions (more feedback), producing larger, more complex aggregations—the heavier elements. From these it became possible to construct solid matter. And so the history of the physical universe reads, "process first—material later."

Life, according to the materialist scenario arose out of dead matter. Missing from this proposition is the "how." It likely will remain a mystery until our obsession with matter is eschewed in favor of process. That process is antecedent to life (as it presumably was to matter) was intuited by ecologist Howard T. Odum, who proposed that proto-ecological systems must already have been in existence before proto-organisms could have arisen.[30] In his scenario, at least two opposing (agonistic) reactions (like oxidation-reduction[31]) 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 created entropy out of the system. Physical circulation between the two domains was necessary. Such a "proto ecosystem" or circular configuration of processes provides the initial animation notably lacking in substance-based scenarios. We have seen that circular configurations of processes are capable of engendering selection, and they are capable of giving rise naturally to more complicated but smaller cyclical configurations (proto-organisms).

The spawning of proto-organisms poses no enigma. In irreversible thermodynamics, processes are assumed to engender (and couple with) other processes all the time (n.b. that one form of change begets another is dimensionally consistent, unlike the spontaneous appearance of a rate emerging from a substance). Large cyclical motions spawn smaller ones as the normal matter of course—as, for example, when large-scale turbulent eddies shed smaller ones. Corliss has suggested that a scenario like the one described by Odum might have played out around Archean thermal springs[32]—an idea that recently has found new enthusiasts in Harold Morowitz and Robert Hazen.[33] Yet again, origins reside in process, which mediates and gives form to material. We thus reckon that material and life share a common origin—process. No longer are we forced to accept the scenario of dead material mysteriously jumping up and coming alive.

What is common to all these reconsiderations is that process does not force us to view the cosmos going backwards. Conventional materialist models begin by considering systems that are homogeneous, rarified, and weakly interacting. We give priority to these assumptions, because they fit with our simplistic mental preconceptions. True, using this approach we have been extremely clever at projecting back into time to construct a history for our universe. But that is definitely not the way the world came at us. The cosmos apparently began as an incredibly dense, strongly interacting system, from which systems that are homogeneous, rarified, and weakly interacting could evolve only *after a very long time*. It is nigh time to put the horse before the cart and recognize, both historically and conceptually, that material and mechanism are secondary, and to a point accidental, in comparison to primal and generative process.

Notes

1. Sidney Brenner, quoted in Roger Lewin, "Why Is Development So Illogical?" *Science* 224 (1984): 1327.
2. Gunther Stent, quoted in Lewin, "Why Is Development So Illogical?" 1328.
3. Gregory Bateson, *Steps to an Ecology of Mind* (New York: Ballantine Books, 1972), 489.
4. Walter Elsasser, "A Form of Logic Suited for Biology?" in *Progress in Theoretical Biology, Vol. 6*, ed. Robert Rosen (New York: Academic Press, 1981), 23.
5. Elsasser, "A Form of Logic," 30.
6. Stuart Kauffman, *Reinventing the Sacred: A New View of Science, Reason and Religion* (New York: Basic Books, 2008), 127.
7. Walter Elsasser, "Acausal Phenomena in Physics and Biology: A Case for Reconstruction," *American Scientist* 57 (1969): 508.

8. Today the figure is put at closer to 10^{81}.

9. A nanosecond is one-billionth of a second—the timescale of atomic reactions.

10. Robert E. Ulanowicz, *A Third Window: Natural Life beyond Newton and Darwin* (West Conshohocken, PA: Templeton, 2009), 29.

11. Joel Cohen, "Irreproducible Results and the Breeding of Pigs," *Bioscience* 26 (1976), 391.

12. Paul C. W. Davies, *The Mind of God: The Scientific Basis for a Rational World* (New York: Simon and Schuster, 1993), 73.

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