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Dimensions Missing from Ecology

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Abstract: Ecology, with its emphasis on coupled processes and massive heterogeneity, is not amenable to complete mechanical reduction, which is frustrated for reasons of history, dimensionality, logic, insufficiency, and contingency. Physical laws are not violated, but can only constrain, not predict. Outcomes are predicated instead by autocatalytic configurations, which emerge as stable temporal series of incorporated contingencies. Ecosystem organization arises out of agonism between autocatalytic selection and entropic dissolution. A degree of disorganization, inefficiency, and functional redundancy must be retained by all living systems to ensure flexibility in the face of novel disturbances. That physical and biological dynamics exhibit significant incongruencies argues for the formulation of alternative metaphysical assumptions, referred to here as "Process Ecology".

Keywords: agonism; apophasis; autocatalysis; centripetality; contingency; endogenous selection; heterogeneity; indeterminacy; process

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1. A Clash of Scientific Cultures?

Ecology, although it deals directly with plants and animals, is more fundamentally the study of relationships within an ensemble or community. Now, the study of relationships among many disparate types is rarely a theme in physics, which concentrates primarily on collections of homogeneous objects acting according to universal laws [1]. While physics can certainly inform other disciplines, there is growing recognition that adequate treatment of heterogeneous interactions is missing from many fields of science and that ecology might provide a more comprehensive framework in which to study them. Witness the journals "Ecological Psychology" and "Ecological Economics" or books on "The Ecology of Mind" [2] and "The Ecology of Computation" [3]. Even evolutionary theory has been ordered in procrustean manner to follow the norms of physical theory. "Natural selection" is almost always considered to originate external to a population or a system and marginal attention is paid to the effects of interactions within the living community. Such insufficient emphasis upon collections of relationships has caused many to worry that the status quo in science could be leading society towards catastrophe [4].

In the late 1970s, Eugene Odum [5] presciently argued in a position paper for *Science* magazine entitled, "The Emergence of Ecology as a New Integrative Discipline", against obligate reductionism as an inadequate tool with which to address the natural living world. Ecology, which offers the possibility of top-down causality, provides the gateway to a fuller understanding of nature, he suggested. Years later, he personally related to this author that his intention in this essay was to propose that ecology replace physics as the central focus of ongoing science and even suggested that the metaphysical grounds of ecology probably differ from those of Enlightenment science.

Odum's posture contrasts markedly with the later assertion by Nobel Laureates Murray Gell-Mann, Stephen Weinberg, and David Gross that "all causality originates from below and that there is nothing 'down there' but the laws of physics" [6]. Today, if one surveys the literature, it would appear that Odum has lost out to those who believe that simply by compiling mechanism upon mechanism, one eventually will achieve a full understanding of ecological dynamics.

The argument here is that the dream of complete "mechanical reductionism" is a minimalist ideology. The contemporary focus in ecology on objects and mechanisms obscures perfectly natural dimensions that arise once one adopts a vision of ecosystems in terms of their constitutive processes [7].

2. Stumbling Blocks?

Space will permit only superficial mention of the problems associated with pure reductionism, and these include history, dimensionality, logic, insufficiency, and contingency. To begin with an historical aside, it is noted how Isaac Newton never presented his second law in its familiar form: force equals mass times acceleration (F = ma). That formulation belongs to Leonhard Euler, who saw the world as a continuum. Newton's statement, by comparison, was discrete and irreversible, and he argued strenuously against the continuum assumption, because it equates cause with effect [8]. The ensuing mathematics of Leibniz and Euler gave rise to a physics of "objects moving according to universal laws". Ecology, however, is intended to focus, not upon objects, but on relationships, most of which appear as irreversible **processes**. Processes explicitly involve time and thus cannot be fully characterized by the time-reversible force laws of physics.

In addition, there is the logic underlying the laws of physics, which Whitehead and Russell [9] demonstrated is irrevocably grounded in operations on homogeneous sets. Physics is all about homogeneous tokens. Biology, by contrast, involves **heterogeneity**—in fact massive heterogeneity [1,10]. The problem posed by heterogeneity is that the combinations and possibilities among differing types quickly become hyper-astronomical. Walter Elsasser, for example, showed how the number of combinations among 75 distinguishable types exceeds how many simple events could possibly have occurred anywhere over the whole duration of the known cosmos.

This enormity of possible combinations hampers efforts to represent heterogeneous systems in terms of homogeneous laws. One cannot simply write separate equations that govern each different type without running into major complications posed by combinatorics during the formulation of the boundary-value conditions. Stuart Kauffman [11] refers to such boundary-value complications as "unprestateable". His simplistic example of the problem is his challenge to enumerate all the possible uses of a screwdriver. Of more biological interest is the exaptation of an organism structure to some purpose other than the one under which that structure has developed (e.g., a lung transforming into a swim bladder).

But the inability to pose adequate boundary conditions is a matter of epistemology. It might still be possible that the laws of physics determine all outcomes, even if one remains incapable of formulating the problem. But the predictive ability of the laws is also challenged by heterogeneity. Massive heterogeneity usually results in a very dense array of combinations of very small differences arbitrarily near to any chosen starting condition. Whence, infinitesimal noise, at the level of the continuum assumption, can send the system onto a number of possible trajectories. All such pathways will continue to satisfy the law, but which one will manifest itself remains indeterminate. That is, the laws are not broken, they continue to constrain what can possibly occur, but beyond some degree of heterogeneity they lose their power to determine particular outcomes. They constrain but can no longer predict particular outcomes.

The mention of noise, however infinitesimal, introduces the role of **contingency** in influencing outcomes. Here it is useful to avoid the word "chance", because that term conventionally is applied to events that are simple, directionless, indistinguishable (homogeneous), and repeatable—assumptions that permit the application of standard statistical analysis. Such requirements, however, encompass only a small fraction of the much wider spectrum of contingencies. Elsasser [10], for example, argues that the number of compound events that can arise is so enormous that many will be *unique* over all space and time.

Obviously, such unique events are more radical than blind chance, whereas other forms of arbitrary phenomena can occur under increasing degrees of constraint. Conditional probabilities, for example, refer to events that exhibit some degree of bias in directions that are influenced by surrounding events. Such bias can grow quite dominant, resulting in almost law-like *propensities* that yield the same outcome in a large preponderance of instances [12]. Hence, we see that there exists an entire spectrum of contingencies, ranging from radical unique happenings through blind chance to conditioned outcomes to propensities that border on determinism.

3. Origins of Order?

It follows that the notion of complete mechanical reductionism *fails rational scrutiny*. But if physical laws can only constrain, what then does determine and maintain the obvious order we observe in living systems? Here it becomes tempting to identify the material genome as that which creates and sustains order. Material causality, however, is a poor basis for dynamical agency. The goal in ecology is to focus on processes, and especially upon configurations of processes. Descriptions of living systems are far better accommodated in terms of processes than as objects moving according to laws. [13]. Furthermore, processes, with their innate indeterminacy, interacting with the complexities of contingencies, become capable of providing the agency behind development and evolution. In particular, attention must be paid to chains of irreversible processes that fold back upon themselves—feedback loops that by their very nature defy the closure restriction of Aristotelian logic [14].

Among feedback configurations, one type deserves special attention—that of **autocatalysis**. An autocatalytic cycle is one wherein every constituent process (link) benefits its succeeding one. Such serial mutual beneficence grows whenever any component process becomes more beneficial to its successor and it declines whenever any benefit diminishes. The result is a ratcheting dynamic that will promote those changes that benefit the ensemble—a form of *endogenous* group **selection** [15,16]. Furthermore, because living entities always require energy and materials to survive, such selection will favor any change that augments the acquisition of resources. Such a contribution can be made by any member of the cycle, cumulatively resulting in ever greater flows of resources into the loop, or what might be called "**centripetality**". None other than Bertrand Russell [17] identified this dynamic as "the drive behind *all* evolution". Centripetality, after all is what induces competition. If two independent autocatalytic configurations exist within a field of resources, their respective centripetalities will grow eventually to intersect one another, the group that builds faster under prevailing contingencies will come to dominate or extirpate the other in a form of group selection. Competition is thereby seen as secondary. It cannot occur at any level unless active mutual beneficence is already transpiring at the next lower level [16].

To summarize thus far, physical laws and ubiquitous contingencies do not appear adequate to promote and sustain living systems. Ensembles having only those dynamics are more likely to fall apart and decay. Fortunately, combinatorics also make it highly likely that autocatalysis will arise among any sufficiently complicated collection of processes [18]. When autocatalytic selection and centripetality are combined with system memory, then growth and development become possible, such that the members of an autocatalytic system are constantly exposed to arbitrary contingencies. Most such disturbances do not affect the system in any significant way. Some are harmful enough to degrade system performance and survivors will adopt responses to redress such perturbations. A small minority of contingencies will enhance mutual beneficence, and memory can then incorporate such changes into a more developed system dynamic.

4. A Non-Random but Indeterminate World?

Two caveats are pertinent to this scenario. Firstly, it is not necessary that memory initially be vested in material objects (such as RNA/DNA). Ensembles of processes can take on very stable configurations that can serve as memory until such time as a material structure might appear to record memory. Terrance Deacon [19], for example, believes that the precursors of RNA originally performed some function like energy storage and/or transfer and only later were exapted to serve as a memory repository. Secondly, the scenario naturally develops a perceptible direction, although that course is always subject to change as a consequence of later contingencies.

One can characterize the developmental scenario as proceeding in a nonrandom, but indeterminate fashion. Now, "nonrandom and indeterminate" sounds at first like an impossible combination, but its palpability can be illustrated through a metaphor used by physicist John Wheeler [20] to describe the development of science:

Guests at a party decide to play a parlor game. One individual is sent out of the room, while the others choose a particular word to be guessed by that individual. Upon returning to the room, the subject questions members of the group in some loose rotation. Responses to the questions are limited to a simple binary "yes" or "no". As soon as the questioner leaves the room, one guest suggests that the group *not* choose a word. Instead, the first respondent can answer 'yes' or 'no' on unfettered whim. Similarly, the second person is at liberty to make either reply, the only constraint being that his/her answer may not contradict the first reply. Similarly, the succeeding answers may not contravene any of the previous answers. The game ends when the subject asks, 'Is the word XXXXX?' and the only possible response is 'yes'. At any time this game is nonrandom, being dependent upon the previous history of questions and answers. The end result, however, cannot be predicted at the outset.

5. A Fundamental Agonism

Serendipitously, the game metaphor also illustrates a second important feature of natural development. The exercise takes the form of a conversation, where the questioner seeks to narrow the realm of possibilities, while the respondents endeavor to broaden the field with each answer. Such **agonism** between ends is usually characterized as dialectic. The analogous natural agonism pits structure-building processes, such as autocatalysis, against entropic disorder and decay.

It has long been postulated in evolutionary circles that living systems progress towards ever more efficient configurations. Data on ecosystem trophic transfers, however, reveal that such progression is dramatically limited. It is possible, using information theory, to quantify both the efficient organization of a network of processes as well as its complementary (and mutually-exclusive) measure of its disorganization [21]. The data on values of organization/efficiency cluster around a level that is significantly below what is imaginable, and disorganization exceeds order by a reasonably constant ratio of 60:40 [22]. Exactly why this particular ratio is favored remains unknown, but the necessary persistence of disorganization, or *lack* of constraint, owes to the fact that the measure of disorganization also reveals trophic functional redundancy [23,24], which becomes necessary as "insurance" if a system is ever to recover from a novel perturbation.

6. The Missing Missing

Quantifying **apophasis**, or that which is missing, is virtually absent from physics, which is built almost entirely upon positivist objects [2]. Now, reckoning what is nonexistent is not as nonsensical as it may first seem [25] (Consider, for example, a glass that is half-full). Suffice it to point out that some degree of apophasis is necessary to enable the flexibility of every living system to persist. Biodiversity, for example, was first related to apophasis by Robert MacArthur [26], when he used the formula for *statistical* entropy to quantify it. That biodiversity is at its core an apophasis, clarifies why no positivist model has been able to justify its necessity for sustaining living ensembles. When one compares the biodiversity of an ecosystem with is trophic functional redundancy (a kindred apophasis), one discovers that the two are poorly correlated [27], underscoring the necessity for an alternative measure of system sustainability.

It should be noted that entropy, as it was originally defined by engineers, is pure apophasis, which is why so many have great difficulty apprehending the concept. It is also necessary to realize that the causal action of apophasis is very different from that of an active determining agency, such as the selection pressure exerted by autocatalysis. Entropy does not push or constrain, it withdraws or disappears. The result, more often than not, appears in a negative light as dissolution or decay, but alternatively can also manifest itself as opportunity. It is thus necessary to reflect upon the significance of the maximum entropy formulism when applied to ecosystem behavior [28]. In any event, attempting to understand ecosystem dynamics without any regard for apophasis is like observing nature with one eye shut.

7. An Alternative Metaphysics

It should be apparent that the dynamical narrative sketched here significantly challenges the Enlightenment metaphysics that has undergirded science for at least three centuries. Fully apprehending living nature requires an alternative and complementary **metaphysics**, which [7] has been called "Process Ecology".

Odum's proposal to pursue a single new dimension in ecology (top-down control) seems modest in comparison to the eight new directions that have been presented above. Unfortunately, experience has taught this author that some entrenched authorities, who cling irrationally to a mechanism-only ideology, will viciously attack and seek to censor all attempts to push the edge of the ecological envelope. This is not to say that new mechanisms won't continue to be discovered that will add pieces to the ecological puzzle. The prospect, however, is that their importance will pale in comparison to the incredible richness that ecology can uncover in developing directions that relate only remotely, if at all, to the realm of physics.

How then to proceed in the near future? Perhaps it might be helpful to take a page from the playbook of the engineers, who very often are contracted to work on problems for which no clue exists as to the underlying dynamics. The system is then regarded as a "black box" and the operative approach is one of phenomenology. That is, combinations of measurable parameters of the system (preferably chosen to have dimensionless units) are examined for either constancy or repeatable patterns of change across differing systems. A constant, such as the balance point between organization (40%) and disorder (60%) mentioned above, is indicative of an ordering principle that begs for further investigation. Similarly, a repeatable pattern of change exhibited by a parameter or group of parameters would hint at a law-like principle that likely would prove useful in ecosystem management. With eight new dimensions to explore, such a search is likely to yield significant new insights.

In any event, the time is ripe for ecology to advance to center-stage and become the "new integrative discipline" for the science of life.

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