ECOLOGY, THE SUBVERSIVE SCIENCE?

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ABSTRACT

In 1964 Paul Sears asked whether the findings of ecology might act to subvert social and political orders. But ecology might also serve to challenge deeply-held scientific assumptions. To explore how ecology tends to change scientific perspectives, the fundamental assumptions that characterized the 19th Century Newtonian worldview are enumerated as a reference: Nature was assumed to be (1) causally closed, (2) deterministic, (3) universal, (4) reversible, and (5) atomistic. Contemporary ecology, and especially network analysis and the theory of increasing ascendency, are more consonant with an entirely different set of guiding postulates. The emerging ecological worldview differs significantly from the Newtonian metaphysic on all five points: Ecology reveals that nature can be (1) ontically open, (2) contingent, (3) "granular" in space and time, (4) historical, and (5) organic, respectively.
Key words: Aristotelian causalities; ascendency; autocatalysis; indeterminacy; information theory; organicism; propensity; Stochasticism; Telos.

ECOLOGIA, A CIÊNCIA SUBVERSIVA?

Em 1964, Paul Sears indagou se as descobertas da ecologia poderiam agir de modo a subverter as ordens política e social. Mas a ecologia poderia também servir para desafiar pressuposições científicas profundamente arraigadas. Para explorar como a ecologia tende a alterar as perspectivas científicas, as pressuposições fundamentais que caracterizaram a visão de mundo newtoniana do século 19 são enumeradas como referenciais: a Natureza era tomada como sendo (1) causalmente fechada, (2) determinística, (3) universal, (4) reversível e (5) atomística. A ecologia contemporânea, e especialmente a análise de redes e a teoria da ascendência crescente são mais consonantes com um conjunto inteiramente distinto de postulados orientadores. A visão de mundo ecológica emergente difere significativamente da metafísica newtoniana em todos os cinco pontos: a ecologia revela que a natureza pode ser (1) onticamente aberta, (2) contingente, (3) "granular" no espaço e no tempo, (4) histórica e (5) orgânica, respectivamente.
Palavras-chave: Causalidades aristotélicas; ascendência; autocatálise; indeterminação; teoria da informação; organicismo; propensão; estocasticismo; Telos.

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INTRODUCTION

Thirty- six years ago Paul Sears (1964) wrote in the pages of *BioScience* that ecology possibly could "endanger the assumptions and practices accepted by modern societies, whatever their doctrinal commitments." Since then, we have seen the discoveries of ecology pose very prominent challenges that to some degree already have restructured our societies and governments (and the country of Brasil has played a very central role in prompting many of these changes.) So that today, we see whole political movements clustered around "green" concerns and initiatives.

But it is not social or governmental directions that I wish to consider. Rather, I wish to redirect Sear's suggestion away from the social and towards the strictly scientific. I would like to pose the question whether the attitudes of ecologists possibly could "endanger the assumptions and practices accepted by modern *scientists*" for the last 300 years? How could that be, the reader might well ask, given that ecology appears to many not to be the most robust of sciences? Nor does it take much reflection to discover that, even within the ranks of ecologists, perceptions of the nature of the discipline remain ambiguous and conflicted. For example, attitudes among ecologists range from the "Deep Ecology" of Arne Naess (1988), who maintains that ecology affects one's life and perception of the natural world in a profound and ineffable way, to the widespread view of ecology as merely corollary to newtonian and evolutionary theories. Hence, we are left to wonder – is ecology either inscrutably mysterious or trivially derivative?

I wish to suggest that such confusion is the result of the reluctance by ecologists to articulate the fundamental assumptions they invoke when viewing the natural world – the ecological metaphysic, so to speak. It is my belief that explicitly formulating a metaphysic proper to ecology will reveal that this discipline is neither as inscrutable as Naess would have everyone believe, nor as corollary as many of its practitioners think it is.

To be sure, there is something *special* about ecology. Why else would colleagues in other disciplines wish to cloak their endeavors in the mantle of ecology? One encounters, for example, books on "the ecology of computational systems" (Huberman, 1988) or entire institutes devoted to the "ecological study of perception and action" (Gibson, 1979.) What is it about ecology (and ecosystems theory in particular) that so differs from the fundamental assumptions that have channeled our worldview over the past two centuries? To answer this question, we need first to review the basic postulates that have guided science during its "classical" period in the 19th Century, so that we may have a set of references against which to distinguish the ecological vision.

According to Depew and Weber (1994), science during the 19th Century was overwhelmingly newtonian in scope. They identified four postulates under which newtonian investigations were pursued:

Newtonian systems are causally *closed*. Only mechanical or material causes are legitimate.

Newtonian systems are *deterministic*. Given precise initial conditions, the future (and past) states of a system can be specified with arbitrary precision.

Newtonian systems are *reversible*. Laws governing behavior work the same in both temporal directions.

Newtonian systems are *atomistic*. They are strongly decomposable into stable least units, which can be built up and taken apart again.

After consulting with these authors, I have added a fifth article of faith (Ulanowicz, 1997), namely that

Physical laws are *universal*. They apply everywhere, at all times and over all scales.

Early in the 19th Century, the notion of reversibility had been challenged by Sadi Carnot's thermodynamical elaboration of irreversibility and several decades later by Darwin's historical narrative. The development of relativity and quantum theories early in the 20th Century worked to subvert even further the assumptions of universality and determinism, respectively. Despite these problems, many in biology (and especially in ecology) continue to operate under a mechanistic umbrella that differs little from the classical Enlightenment metaphysic I have just outlined. Many do, that is, but not all!

In his historical analysis of ecosystems theory, Joel Hagen (1992) identified three distinct metaphors by means of which ecologists have attempted to make sense of ecological phenomena. As I have just alluded, the most familiar and widely- accepted metaphor is that of the ecosystem as a machine, or clockwork, which, of course, runs according to the newtonian scenario. This tradition has been kept alive and well by the likes of George Clarke (1954), Howard Odum (1960) and Thomas Schoener (1986.) Interestingly, however, the mechanical metaphor was preceded in the ecological arena by Frederic Clements' (1916) suggestion that ecosystems behave like organisms. Clements directly credited Jan Smuts (1926) as his inspiration, but ultimately he was following in the traditions of Leibniz and Aristotle. The organic analogy was advanced in subsequent decades by G. Evelyn Hutchinson and Eugene Odum. Finally, a contemporary of Clements, Henry Gleason (1917), countered the notion of ecosystems as organisms with the idea that ecological communities arise largely by chance and in the absence of any major organizational influences. Such stochasticism follows the lead of nominalism and deconstructivist postmodernism, and has found voice in contemporary ecology through the writings of Daniel Simberloff (1980), Kristin

Schrader- Frechette (and McCoy, 1993) and Mark Sagoff (1997), all of whom deride the mechanical and organic metaphors as unwarranted realism.

ECOSYSTEMS AND CONTINGENCY

Reconciling chance with deterministic mechanics is no easy task, and the problem has occupied some of the best minds over the past two centuries. Ludwig von Boltzmann and Josiah Gibbs dominated the effort during latter 19^{th} Century to construct a statistical mechanics that would salvage newtonian precepts from the challenge posed by the irreversibility inherent in thermodynamics. Then early in the 20^{th} century, Ronald Fisher used almost identical mathematics to join the gradualist narrative of Darwin to the discrete phenomena observed by Mendel, resulting in what came to be known as "The Grand Synthesis". I wish to bring to your attention the fact that both these attempts at reconciliation are relevant only to systems of many components that are largely decoupled from one another – hardly the description of an ecosystem!

Because these attempts at reconciliation were so narrow in application, biology today remains somewhat "schizophrenic". Narrative constantly is switching back and forth between the realms of strict determinism and pure stochasticity, as if no middle ground existed. In referring to this regrettable situation, Karl Popper (1990) remarked that it still remains for us to achieved a truly "evolutionary theory of knowledge", and we will not do so until we reconsider our fundamental attitudes toward the nature of causality. True reconciliation, Popper suggested, lies in an intermediate to stochasticity and determinism. He proposed, therefore, a generalization of the newtonian notion of "force". Forces, he posited, are idealizations that exist as such only in perfect isolation. The objective of experimentation is to approximate isolation from interfering factors as best possible. In the real world, however, where components are loosely, but definitely coupled, one should speak rather of "propensities". A propensity is the tendency for a certain event to occur in a particular context. It is related to, but not identical to, conditional probabilities.

Consider, for example, the hypothetical "table of events" depicted in Table 1, which arrays five possible outcomes, b_1, b_2, b_3, b_4, b_5, according to four possible eliciting causes, a_1, a_2, a_3, and a_4. For example, the outcomes might be several types of cancer, such as those affecting the lung, stomach, pancreas or kidney, while the potential causes might represent various forms of behavior, such as running, smoking, eating fats, etc. In an ecological context, the b's might represent predation by predator j, while the a's could represent donations of material or energy by host i.

TABLE 1 Frequency table of the hypothetical number of joint occurrences that four "causes" (a_1...a_4) were followed by five "effects" (b_1...b_5)

	00	00	00	00	0 0	000
00	00	000	00	00	0	000
00	00	0	0	00	00 0	000
00	000	0	00	000	0	000
00	0	0	000	00	0 0	000
000	000	000	000	00 0	000	0000

We notice from the table that whenever condition a_1 prevails, there is a propensity for b_2 to occur. Whenever a_2 prevails, b_5 is the most likely outcome. The situation is a bit more ambiguous when a_3 prevails, but b_1 and b_4 are more likely to occur in that situation, etc. Events that occur with smaller frequencies, e.g., [a_1,b_3] or [a_1,b_4] result from what Popper calls "interferences".

We now ask how might the table of events appear, were it possible to completely isolate phenomena? Probably, it would look something like Table 2, where every time a_1 occurs, it is followed by b_2; every time a_2 appears, it is followed by b_5, etc. That is, under isolation, propensities degenerate into mechanical- like forces. It is interesting to note that b_4 never appears under any of the isolated circumstances. Presumably, it arose purely as a result of interferences among propensities. Thus, the propensity for b_4 to occur whenever a_3 happens is an illustration of Popper's assertion that propensities, unlike forces, never occur in isolation, nor are they inherent in any object. They always arise out of a context, which invariably includes other propensities.

TABLE 2 Frequency table as in Table 1, except that care was taken to isolate causes from each other.

	00	00	00	00	0 0	000
00	0	000	0	0	0	000
00	0	0	0	0	000	000
00	000	0	0	0	0	000
00	0	0	00 0	0	0	000
000	000	000	00 0	0	000	0000

Popper's notion of propensity encompasses both chance and law-like behavior under a single rubric. We note that the transition depicted from Table 1 to Table 2 involves proceeding from less-constrained to more constrained circumstances. It is the appearance of progressive constraints that we mean when we use the term "development". We now ask the questions, "What natural agency might contribute to the transition from Table 1 to Table 2?"; or, in a larger sense, "What lies behind the phenomena we call growth and development?", and "How can one quantify the effects of this agency?"

AUTOCATALYSIS AND ORGANIC SYSTEMS

One clue to an agency behind growth and development appears as soon as one considers what happens when propensities act in close proximity to one another. Any one process will either abet (+), diminish (-) or not affect (0) another. Similarly, the second process can have any of the same effects upon the first. Out of the nine possible combinations for reciprocal interaction, it turns out that one interaction, namely mutualism (+,+), has very different properties from all the rest. Investigators such as Manfred Eigen (1971), Hermann Haken (1988), Humberto Maturana (and Varela, 1980), Stuart Kauffman (1995) and Donald DeAngelis (1986) all have contributed to a growing consensus that some form of positive feedback is responsible for most of the order we perceive in organic systems. I now wish to focus attention upon a particular form of positive feedback, autocatalysis. Autocatalysis is a form of positive feedback wherein the effect of each and every link in the feedback loop remains positive. In the framework of the newtonian assumptions, as autocatalysis is usually viewed in chemistry, such feedback appears merely as a particular type of mechanism. As soon as one admits some form of indeterminacy, however, several highly non- mechanical attributes suddenly make their appearance.

To be precise about what form of autocatalysis I am referring, I direct the reader's attention to the three-component interaction depicted in Figure 1. We assume that the action of process A has a propensity to augment a second process B. I wish to emphasize my use of the word "propensity" to mean that the response of B to A is not wholly obligatory. That is, A and B are not tightly and mechanically linked. Rather, when process A increases in magnitude, most (but not all) of the time, B also will increase. B tends to accelerate C in similar fashion, and C has the same effect upon A.

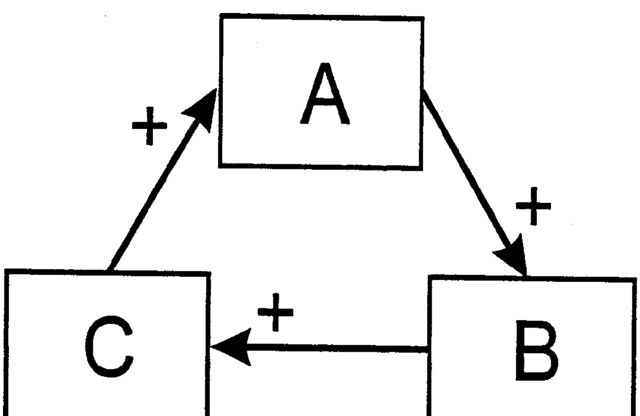
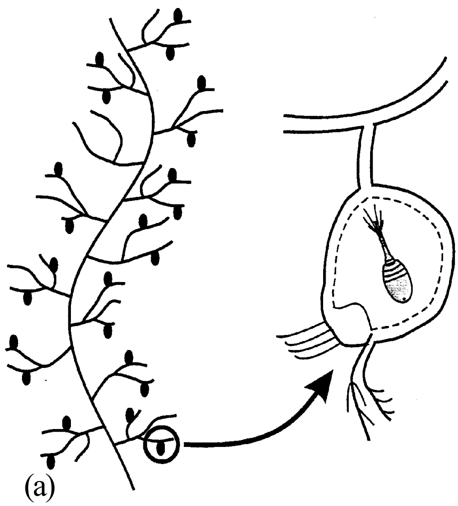


FIGURE 1 – Schematic of a hypothetical 3-component autocatalytic cycle.

My favorite ecological example of autocatalysis is the community that centers around the aquatic macrophyte, *Utricularia* (Ulanowicz, 1995.) All members of the genus *Utricularia* are carnivorous plants. Scattered along its feather- like stems and leaves are small bladders, called utricles (Figure 2a). Each utricle has a few hair- like triggers at its terminal end, which, when touched by a feeding zooplankton opens the end of the bladder and the animal is sucked into the utricle by a negative osmotic pressure that the plant had maintained inside the bladder. In the field *Utricularia* plants always support a film of algal growth known as periphyton (Figure 2b). This periphyton in turn serves as food for any number of species of small zooplankton. The catalytic cycle is completed when the *Utricularia* captures and absorbs many of the zooplankton.



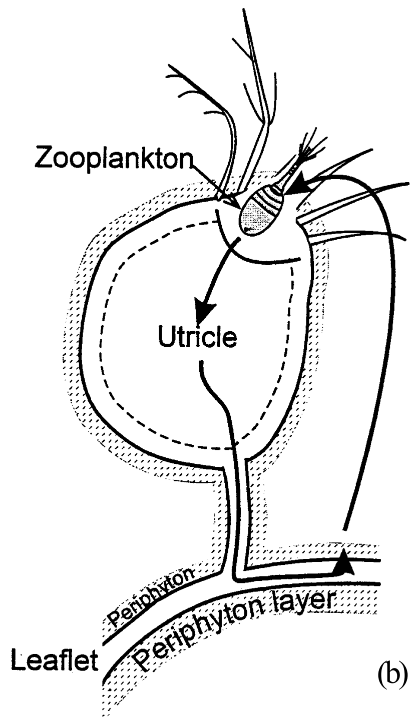


FIGURE 2 – (a) Sketch of a typical "leaf" of *Utricularia floridana*, with detail of the interior of a utricle containing a captured invertebrate. (b) Schematic of the autocatalytic loop in the *Utricularia* system. Macrophyte provides necessary surface upon which periphyton (striped area) can grow. Zooplankton consumes periphyton, and is itself trapped in bladder and absorbed in turn by the *Utricularia*.

Autocatalysis among propensities gives rise to at least eight system attributes, which, taken as a whole, comprise a distinctly non-mechanical dynamic. We begin by noting that by our definition autocatalysis is explicitly *growth-enhancing*. Furthermore, autocatalysis exists as a *formal* structure of kinetic elements. More interestingly, autocatalysis is capable of exerting *selection* pressure upon its ever-changing constituents. To see this, let us suppose that some small change occurs spontaneously in process B. If that change either makes B more sensitive to A or a more effective catalyst of C, then the change will receive enhanced stimulus from A. Conversely, if the change in B either makes it less sensitive to the effects of A or a weaker catalyst of C, then that change will likely receive diminished support from A. We note that such selection works on the processes or mechanisms as well as on the elements themselves. Hence, any effort to simulate development in terms of a fixed set of mechanisms is doomed ultimately to fail.

It should be noted in particular that any change in B is likely to involve a change in the amounts of material and energy that flow to sustain B. Whence, as a corollary of selection pressure, we recognize the tendency to reward and support changes that bring ever more resources into B. As this circumstance pertains to all the other members of the feedback loop as well, any autocatalytic cycle becomes the center of a *centripetal* vortex, pulling as much resources as possible into its domain.

It follows that, whenever two or more autocatalytic loops draw from the same pool of resources, autocatalysis will *induce competition*. In particular, we notice that whenever two loops partially overlap, the outcome could be the exclusion of one of the loops. In Figure 3, for example, element E is assumed to appear spontaneously in conjunction with A and C. If E is more sensitive to A and/or a better catalyst of C, then there is a likelihood that the ensuing dynamics will so favor E 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. Of course, if B can be replaced by E, there remains no reason why C cannot be replaced by F or A by D, so that the cycle A, B, C could eventually transform into E, F, G. One concludes that the characteristic lifetime of the autocatalytic form usually exceeds that of most of its constituents. This is not as strange as it may first seem. With the exception of our neurons, virtually none of the cells that composed our bodies seven years ago remain as parts of us today. Very few of the atoms in our body were parts of us eighteen months ago. Yet if our mothers were to see us for the first time in ten years, she would recognize us immediately.

Autocatalytic selection pressure and the competition it engenders define a preferred direction for the system – that of ever more effective autocatalysis. In the terminology of physics, autocatalysis is *symmetry-breaking*. One should not confuse this rudimentary directionality with full-blown teleology. It is not necessary, for example, that there exist a pre-ordained endpoint towards which the system strives. The direction of the system at any one instant is defined by its state at that time, and the state changes as the system develops. I have used the term "telos" to denote this weaker form of directionality and to distinguish it from the far rarer and more complex behavior known as teleology.

Taken together, selection pressure, centripetality and a longer characteristic lifetime all speak to the existence of a degree of *autonomy* of the larger structure from

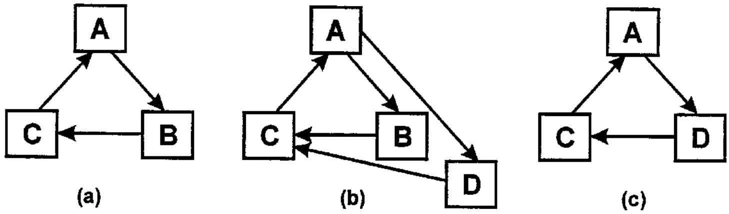


FIGURE 3 – (a) Original configuration. (b) Competition between component B and a new component E, which is either more sensitive to catalysis by A or a better catalyst of C. (c) B is replaced by E, and the loop section A-B-C by that of A-E-C.

its constituents. Again, attempts at reducing the workings of the system to the properties of its composite elements will remain futile over the long run.

In epistemological terms, the dynamics I have just described can be considered *emergent*. In Figure 4, if one should consider only those elements in the lower right-hand corner (as enclosed by the solid line), then one can identify an initial cause and a final effect. If, however, one expands the scope of observation to include a full autocatalytic cycle of processes (as enclosed by the dotted line), then the system properties I have just described appear to emerge spontaneously.

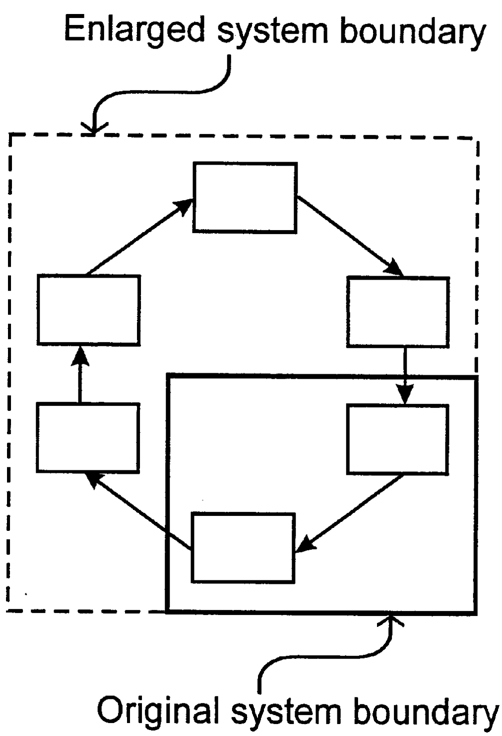


FIGURE 4 – Two hierarchical views of an autocatalytic loop. The original perspective (solid line) includes only part of the loop, which therefore appears to function quite mechanically. A broader vision encompasses the entire loop, and with it several non-mechanical attributes.

CAUSALITY RECONSIDERED

It is important to note that selection pressure that arises from autocatalysis acts from higher scales downwards. Top-down influence is familiar to ecologists in the context of trophic interactions, but the newtonian metaphysic allows only influences originating at lower realms of time and space to exert their effects at larger and longer scales. Prior to Newton, however, the prevailing view on natural causalities had been formulated by Aristotle, who explicitly recognized the existence of downward causation.

Aristotle identified four categories of cause: (1) Material, (2) Efficient (or mechanical), (3) Formal and (4) Final. An effective, albeit unsavory, example of an event wherein all four causes are at work is a military battle. The swords, guns, rockets and other weapons comprise the material causes of the battle. The soldiers who use those weapons to inflict unspeakable harm on each other become the efficient agents. The topography of the battlefield and the changing positions of the troops on the battlefield with respect to each other and with respect to natural factors, such as sun angle and wind, constitute the formal cause. Final cause originates mostly beyond the battlefield and consists of the social, economic and political factors that brought the armies to face each other.

Encouraged by the simplicity of Newton's *Principia* and perhaps influenced by the politics of the time, early Enlightenment thinkers acted decisively to excise formal and final causalities from all scientific description. We are urged, however, by contemporary thinkers, such as Robert Rosen (1985) to reconsider how appropriately these discarded categories might serve for the interpretation of complex phenomena. Indeed, there appear to be especial reasons why Aristotle's schema provides a more satisfactory description of ecological dynamics, and those reasons center around the observation that efficient, formal and final causes are hierarchically ordered – as becomes obvious when we notice that the domains of influence by soldier, officer and prime minister extend over progressively larger and longer scales.

The Achilles heel of newtonian-like dynamics is that it cannot in general accommodate true chance or indeterminacy (whence the "schizophrenia" in contemporary biology.) Should a truly chance event happen at any level of a strictly mechanical hierarchy, all order at higher levels would be doomed eventually to unravel. How much more accommodating is the Aristotelian hierarchy! Any spontaneous efficient agency at any hierarchical level would be subject to selection pressures from formal autocatalytic configurations above. These configurations in turn experience selection from still larger constellations in the guise of final cause, etc. One may conclude, thereby, that the influence of most irregularities remains circumscribed. Unless the larger structure is particularly vulnerable to a certain type of perturbation (and this happens relatively rarely), the effects of most perturbations are quickly damped.

One might even generalize from this "finite radius of effect" that the very laws of nature might be considered to have finite, rather than universal, domain (Allen and Starr, 1982; Salthe, 1993). That is, each law is formulated within a particular domain of time and space. The farther removed an observed event is from that domain, the weaker becomes the explanatory power of that law, because chance occurrences and selection pressures arise among the intervening scales to interfere with the given effect. To the ecologist, therefore, the world appears as granular, rather than universal. The ecologist, then, has good reason to look with skepticism upon any physicist who would attempt to marry phenomena belonging to widely disparate scales, such as, quantum phenomena and gravity (Hawking, 1988.)

THE ORGANIC MIDDLE GROUND

At this point we seem to be devolving rapidly into deconstructivism. Lest we travel any farther down this pathway, it behooves us to stop and reconsider the constructivist suggestion by Popper that we should no longer be satisfied with the prevailing image of rigid mechanisms set opposite to complete disorder, with nothing in between. Popper urges us to consider a middle ground, wherein propensities interacting with each other give rise to non-rigid structures that nonetheless retain their coherence over time, i.e., the world of the truly organic. The major problem with earlier organic metaphors has been that their proponents, such as Clements, cast them in mechanical terms that were too rigid. We turn our attention, therefore, to agencies that potentially could give rise to organic-like, non-rigid structures, and our vision focuses quickly again upon autocatalysis.

Out of our considerations on autocatalysis we abstract two major facets to its actions: Autocatalysis serves to increase the activities of all its constituents, and it prunes the network of interactions so that those links that most effectively participate in autocatalysis become dominant. Schematically this transition is depicted in Figure 5. The upper figure represents a hypothetical, inchoate 4-component network before autocatalysis has developed, and the lower one, the same system after autocatalysis has matured. The magnitudes of the flows are represented by the thicknesses of the arrows. To the right appear the matrices that correspond to the pattern of flows. One recognizes that the transition resembles that between Tables 1 and 2 that was presented earlier in connection with Popper's propensities.

There is not sufficient space to present in detail how the two facets of autocatalysis come to be quantified. Suffice it here simply to present the results. We begin by defining the transfer of material or energy from prey (or donor) i to predator (or receptor) j as T_{ij}, where i and j range over all members of a system with n elements. The total activity of the system can be measured simply as the sum of all system processes, $T = \sum_{T,j} T_{Tj}$ or what is called the "total system throughput".

Growth thereby becomes an increase in the total system throughput, much as economic growth is reckoned by any increase in Gross Domestic Product.

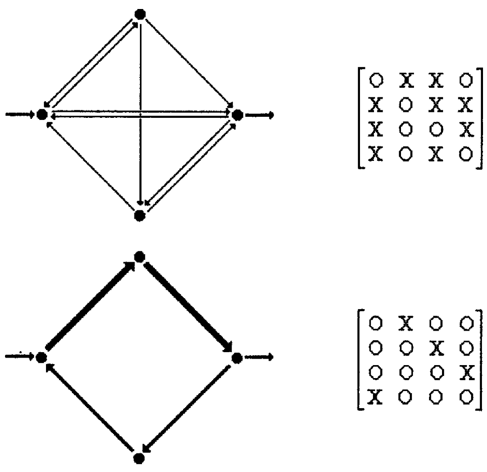


FIGURE 5 – Schematic representation of the major effects that autocatalysis exerts upon a system. (a) Original system configuration with numerous equiponderant interactions. (b) Same system after autocatalysis has pruned some interactions, strengthened others, and increased the overall level of system activity (indicated by the thickening of the arrows.) Corresponding matrices of topological connections indicated to the right.

As for the "pruning", or development effected by autocatalysis, it will be related to changes in the probabilities of flow to different compartments. We note, therefore, that the joint probability that a quantum of medium both leaves i and enters j can be estimated by the quotient T_{ij}/T, and that the conditional probability that, having left i, it then enters j can be approximated by the quotient $T_{TP} \sum_k T_{Tk}$.

One can then use these probability estimates to calculate how much information is provided by the increased constraints. The appropriate measure in information theory is called the "average mutual information" or AMI,

$$III = \sum_{I,I} \frac{I_{II}}{I} \log \left[\frac{I_{II} I}{\sum_p I_{pI} \sum_I I_{II}} \right].$$

To demonstrate how an increase in AMI actually tracks the "pruning" process, I refer the reader to the three hypothetical configurations in Figure 6. In configuration (a) where medium from any one compartment will next flow is maximally indeterminate. AMI is identically zero. The possibilities in network (b) are somewhat more constrained. Flow exiting any compartment can proceed to only two other compartments, and the AMI rises accordingly. Finally, flow in schema (c) is maximally constrained, and the AMI assumes its maximal value for a network of dimension 4.

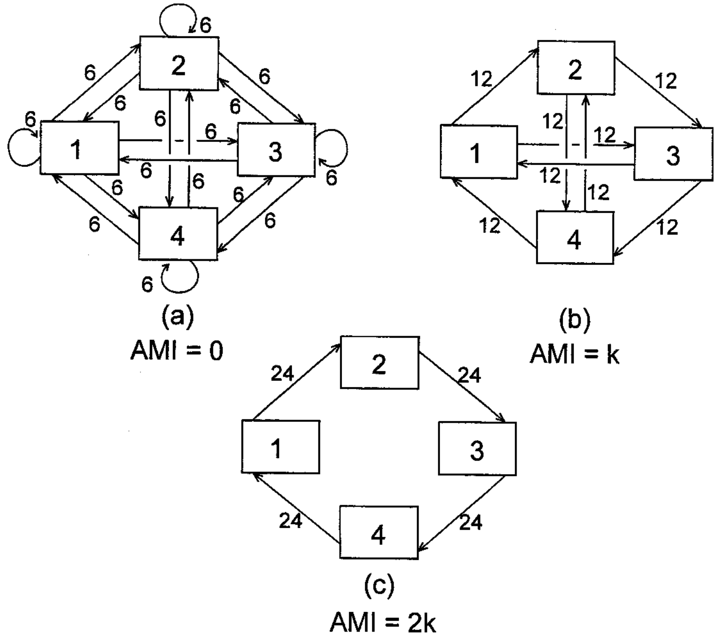


FIGURE 6 – (a) The most equivocal distribution of 96 units of transfer among four system components. (b) A more constrained distribution of the same total flow. (c) The maximally constrained pattern of 96 units of transfer involving all four components.

Because autocatalysis is a unitary process, we can incorporate both factors of growth and development into a single index by multiplying them together to define a measure called the system ascendency, A = T x AMI. In his seminal paper, “The strategy of ecosystem development”, Eugene Odum (1969) identified 24 attributes that characterize more mature ecosystems. These can be grouped into categories labeled species richness, dietary specificity, recycling and containment. All other things being equal, a rise in any of these four attributes also serves to augment the ascendency. It follows as a phenomenological principle that “in the absence of major perturbations, ecosystems have a propensity to increase in ascendency.” Increasing ascendency is a quantitative way of expressing the tendency for those system elements that are in catalytic communication to reinforce each other to the exclusion of non-participating members.

I should hasten to emphasize in the strongest terms possible that increasing ascendency is only half the story. Ascendency accounts for how efficiently and coherently the system processes medium. Using the same type of mathematics, one can compute as well an index called the system overhead that is complementary to the ascendency (Ulanowicz and Norden, 1990.) Overhead quantifies the degrees of freedom, inefficiencies and incoherencies present in the system. Although these latter properties may encumber overall system performance at processing medium, they become absolutely essential to system survival whenever the system incurs a novel perturbation. At such time, the overhead becomes the repertoire from which the system can draw to adapt to the new circumstances. Without sufficient overhead, a system is unable to create an effective response to the exigencies of its environment. The configurations we observe in nature, therefore, appear to be the results of two antagonistic tendencies (ascendency vs. overhead) working off of each other in a relationship that resembles a dialectic.

THE NEW VIEW

Let us now take stock of our subversive ecological worldview as I have interpreted it. As for the underlying metaphysic, we have concluded that the classical newtonian motif is inadequate on each and every point:

1. Ecosystems are not causally closed. They appear to be *open* to the influence of non-mechanical agency. Spontaneous events may occur at any level of the hierarchy at any time. Efficient (or mechanical) causes usually originate at scales inferior to that of observation, and their effects propagate upwards. Formal agencies appear at the focal level; and final causes exist at higher levels and propagate downwards (Salthe, 1985; Ulanowicz, 1997.)
2. Ecosystems are not deterministic machines. They are *contingent* in nature. Biotic actions resemble propensities more than mechanical forces.
3. The realm of ecology is *granular*, rather than universal. Models of events at any one scale can explain matters at another scale only in inverse proportion to the remoteness between them. On the other hand, the domain within which irregularities and perturbations can damage a system is usually circumscribed. Chance does not necessarily unravel a system.
4. Ecosystems, like other biotic systems, are not reversible, but *historical*. Irregularities often take the form of discontinuities, which degrade predictability into the future and obscure hindcasting. The effects of past discontinuities are often retained (as memories) in the material and kinetic forms that result from adaptation. Time takes a preferred direction or telos in ecosystems – that of increasing ascendency.
5. Ecosystems are not easily decomposed; they are *organic* in composition and behavior. Propensities never exist in isolation from other propensities, and communication between them fosters clusters of mutually reinforcing propensities to grow successively more interdependent.

Hence, the observation of any component in isolation (if possible) reveals regressively less about how it behaves within the ensemble.

The ecological worldview is not entirely subversive, however, and by following Popper's evolutionary leads we retain some connections with the orthodox and the classical. Unfortunately, it remains beyond the scope of this paper to demonstrate exactly how Popper's propensities are imbedded in the expression of the ascendency. Furthermore, because propensities are generalizations of newtonian forces, it can be shown how the principle of increasing ascendency resembles a generalization of newtonian law upwards into the macroscopic realm, in a way similar to how Schroedinger's wave equation is an extension of Newton's second law downwards into the netherworld of quantum phenomena (Ulanowicz, 1999.)

In conclusion, I hope I have convinced the reader that ecology is not trivially derivative of more conventional disciplines. It is a robust endeavor with its own direction! It is also my desire that the perspective on ecological dynamics that I have presented will support the belief that neither is ecology entirely mysterious. Ecology does indeed "endanger the assumptions and practices accepted by modern scientists." It challenges us to take a postmodern look at science, but one that is not wholly deconstructive. Rather, the ecological perspective promises a new and coherent view on nature that leaves ample room for the inclusion of the human. As Paul Sears also opined, ecology, if taken seriously can act "as an instrument for the long-run welfare of [human]kind." The subversion in ecology is one that no one need fear. It holds the promise for a truly new outlook on the phenomenon of life – one that could catapult the ecological perspective to become the ascendant scientific worldview of the 21st Century.

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Table 1 from page 141.

	b_1	b_2	b_3	b_4	b_5	Sum
a_1	40	193	16	11	9	269
a_2	18	7	0	27	175	227
a_3	104	0	38	118	3	263
a_4	4	6	161	20	50	241
Sum	166	206	215	176	237	1000

Table 2 from page 141.

	b_1	b_2	b_3	b_4	b_5	Sum
a_1	0	269	0	0	0	269
a_2	0	0	0	0	227	227
a_3	263	0	0	0	0	263
a_4	0	0	241	0	0	241
Sum	263	269	241	0	227	1000