The Natural Philosophy of Ecology: Developmental Systems Ecology

Stanley N. Salthe

Emeritus, Biology, City University of New York
Visiting Scientist, Biological Sciences, Binghamton University
Mailing Address: Natural Systems, 42 Laurel Bank Avenue, Deposit, New York 13754 USA
E-mail: ssalthe@binghamton.edu; Phone: 607-467-2623

Abstract

Complexity is here approached through an extension of natural philosophy to ecology. Complexity generally has two components -- synchronic and diachronic. The first, extensional complexity, explores the structure of form, and of process, as nested homeostatic spacetime systems of differing scale. In comparison, intensional complexity is essentially developmental, modeling the structure of change as a sere of stages. These occur in a canonical sequence: immaturity -> maturity -> senescence, which is proposed as the basis of a Developmental Systems Ecology. Infodynamics is based in the empirical fact that, as systems develop, they store increasing amounts of information.

Development is driven by thermodynamic potentials. Energy gradient instability invites energy consumption, leading to growth, which leads to change. The Second Law of thermodynamics can be seen to be the final cause of any development, including succession. It can also be taken, in its Carnot / Clausius formulation, as the final cause of ecological systems, because inefficiency of energy use is an important source of a diversity of energy availabilities. Final cause can be found, not only in variational principles like the Second Law, but is also suggested in widespread similarities (like ecological vicariants) not explained by common descent. It is proposed that deep structures might be considered as a source of these similarities. Structures suggest a semiotic approach, as in, for example, the Umwelt construction of Uexküll, which can be related to the Eltonian niche.

In a frictional world, no developing system can resist individuation, which is the source of evolution. Continued individuation in organic evolution results in Hutchinsonian niche deployment. It is driven by mutation, and afforded by a Fourth Law of thermodynamics which, in non-equilibrium systems generates increases in system workspace. This increases informational entropy as well, resulting ultimately in a diversity of species. While form facilitates physical entropy production, the informational entropy embodied in biological diversity facilitates the fastest possible entropy production at a given locale.

The paper ends with a brief on internalism, concerning the generativity of material systems.

Author Keywords: Complexity, Development, Ecological niche, Entropy, Finality, Hierarchy, Internalism, Semiotics

Introduction

This paper deals with Nature, our discursive construct, not with the world. This is embodied in texts, films, museum displays, models, equations and diagrams, and experimental setups. Discourse dynamics provides the medium for representations of natural dynamics and kinematics, and therefore acts as a final cause for all. For example, scientific texts embody two-valued logic, honoring the principle of the excluded middle. A locale in Nature, therefore is currently inhabited by either this or that, and we will not find examples of entities that are both this and that, or neither this nor that. Complexity has recently become acknowledged to be a part of Nature, and is an emerging modeling strategy. But models are still cast in two-valued logic, not itself a complex system.

Natural philosophy (Shaffer, 1981) withered away at the end of the last century (save in Thomistic philosophy and among Marxists) as the focus of science came to be directed ever more toward pragmatics. While Twentieth Century philosophy was largely centered on linguistic analyses, with some effort going into ethics as well as historical studies, natural philosophy was and remains an attempt to use scientific knowledge to construct an intelligible picture of the world, and to suggest what our own place in it might be. Lately, natural history museums have been increasing their emphasis on this use of scientific knowledge. Texts akin to natural philosophy have been produced by scientists trying to convey the import of their work to the general public. And, of course, the debate about ‘environmental ethics’ intersects natural philosophy as well. It is my position that it can function as an overall guide to research as well.

In this respect it is interesting to note its connection to the Unity of the Sciences project as well.

Natural philosophy acquired, and maintained throughout the Nineteenth Century, a particular form that characterizes it, which I believe is canonical. It has the form of a story about beginnings, and about tendencies of development toward ends. Indeed, it could construct our contemporary creation myth, and needs to be taken up again for that reason alone. The attitude of natural philosophy is developmental; it focuses on the study of repeatable aspects of changes observed in natural phenomena. If we have multiple instances of some kind of change, we will find that some aspects will tend to be found in all or most of them. On the supposition that these are constitutive of the kind of system being observed these changes have a special status as important attributes of the systems displaying them.

It is a curious fact that today, probably in some way linked to the great importance placed upon decoding the human genome, biology has come to emphasize, not development, but evolution (which I define as the irreversible accumulation of the effects of historical contingency -- Salthe, 1993a). The link between the genome and history is the cumulation of variety within lineages by way of genetic mutation, leading ultimately to a variety of lineages. The focus of biology and related fields, including some of ecology, has turned from prediction toward explaining variety -- why are there so many kinds of organisms? Natural philosophy does not pay special homage to that question, and, indeed, takes it to be trivial (I give a thermodynamic explanation below). Taking a cue from neoDarwinism, the variety of biological forms can be explained just as a result of chance -- chance mutations and recombinations, chance preadaptations, genetic drift, capricious environmental changes informing natural selection, and chance population isolations leading to speciation, all conspiring to deliver organismic changes that are viewed as having just happened to have happened, and that are largely unpredictable. Change viewed in this way is unintelligible, and, therefore meaningless. Natural philosophy seeks meanings. We might note here as well that variety, in and of itself, is not a sign of complexity.

Complexity

(1) The structure of form

I have argued that one source of complexity in nature is the fact that more than a single system generally occupies any locale (Salthe, 1985). While systems of the same scale might exclude each other -- or further each other symbiotically, systems of different scale, since they cannot directly interact, do neither. They exist, not side by side, but within and around each other, and so do not directly interact, but instead mutually constrain each other, somewhat as stable constants relate to variables in an equation. But since change is presumably occurring at all scales, the dynamical result is non-linearity and, in immature systems, chaotic dynamics (Salthe, 2004). These are signs of what I call extensional complexity (Salthe, 1993a), which concerns the way forms occupy space and, as a concomitant, the way behaviors going at radically different rates indirectly affect each other (Salthe, 2004). When dynamics going at different rates are completely entangled we get turbulence; when partially separated we get nonlinearities; when fully separated we get smooth coexistent dynamics.

a) Extensional Complexity

Nature can be modeled as a scalar hierarchy, with systems embedded in other systems, and holding still others within them. They are nested, as in [ecosystem [population [organism [cell]]]] (any level could be ignored for particular descriptive purposes in a given locale). Generally, as one proceeds inward there are more coordinate systems contained at each lower scalar level. Larger, more slowly changing systems (say, weather) regulate many smaller ones (say, organisms). But the aggregate effects of many lower scale systems can influence larger ones too (as when accumulated waste from burning fossil fuels generates increasing amounts of CO^2 globally). Formally, the extension of scale just keeps going endlessly, although for any practical problem there would effectively be largest and smallest scales of influence upon given focal level processes. An observed system is in principle exactly in the center of the hierarchy.

In this view, ‘extensional complexity’ is defined as the presence in one locale of kinematics or dynamics of different scale that, because they change at such different rates, cannot directly interact, but do mutually constrain each other. In general, slower changes contextualize faster ones, and, when the very slowest changes do register upon faster ones, can impose dramatic effects upon them, by way of a loss of reliable context. Note that ‘change’ here does not refer to mere translational motion (which can be fastest in systems that change most slowly in the sense used here), but to change in direction (involving acceleration), or of kind (as in chemical reactions or development) or of status (as in diffusion). Slower kinetics are ultimately regulatory in any material system, and reflect the base line of average reliable energetic input (as from the sun onto the earth). In a simple world, constants representing slower dynamics would either never change, or would carry information only from changes in systems so far distant in scale from focal kinetics that they would effectively not change in models of focal level processes.

This model of the world came out of organicism (especially Paul A. Weiss and Ludwig von Bertalanffy -- see Bertalanffy, 1969; Weiss, 1971), in its efforts at trying to construct a non-mechanistic materialism. In repudiating mechanicism, organicism attributed life's unique properties to organization, obviating any role for vitalism in the thinking of those for whom mechanicism had been unintelligible. It is now clear that abiotic dissipative structures are also organized in this way (Li, 2000), but, of course, at a much simpler, or vaguer, level of elaboration. All material systems are organized as scalar hierarchies (show extensional complexity).

The scalar hierarchical formalism is taken up (as, e.g., by Schneider, 1994, Maurer, 1999) by those who use it to reflect the spacetime structure of the material world. In this view, process stability has been gained by interpolating levels (by way of the emergent cohesion of lower level units) between primal smallest and largest scales as the system developed. Each level, by deflecting or using energies devolving from the largest (say, on the earth, sunlight from the level of the solar system), allows the next lower level to develop by presenting it with more moderated, less energetic energy sources (Allen and Starr, 1982). In this way the relatively large scale (slow) activities of autotrophs mediates solar energy to the much more delicate (because more complicated) and relatively faster rate -- and so functionally smaller scale -- heterotrophs. Something can occur at a given scalar level only because adjacent levels have made room for it (Conrad, 1983). The slow build up of energy gradients by large scale autotrophic and geological processes detains the sun's energy in forms that can be released by heterotrophs (and technologies) to be still further utilized by detrivores (Lotka, 1922).

This global process ('process' is change that continues unchanged from a given point of view) is the object of the studies of equilibrium models in classical systems ecology (e.g., Innis and O'Neill, 1979; Patten, 1982; Odum, 1983; Pimm, 1991), and, for that matter, studies of organismic homeostasis -- that is, study of synchronic aspects of natural systems, with which, largely, ecology began. This perspective lends itself to the view of the ecosystem as superorganism, or, more cogently, the organism as superecosystem (Depew & Weber, 1995). This terminological play is a way of noting that this approach is that of systems science, which looks for those relationships in any system that can be generalized across all of them. And this approach can be generalized all the way to studies of the origin of life (Ehrensvärd, 1960; Cairns Smith, 1982) as well, projected today into the idea of life as having originated in the likes of submarine hydrothermal (molecular eco)systems (Corliss, 1988). This is a kind of assembly line concept, the tremendous heat involved in the first steps of eobiosynthesis are quickly left behind as the flow of water carries the products to ever cooler regions, allowing more and more delicate refinements as the system is projected into the condition of protocells. This example broaches another sort of complexity.

b) Intensional Complexity and Development

Material systems display not only homeostatic processes; they change as they endure as well. In today's nonequilibrium ideology (for ecology, see Wiens, 1984), homeostasis is seen as slow homeorhesis. When a system changes it becomes qualitatively different, which differences can, from the point of view of natural philosophy, be assimilated to the general sequence, immature -> mature -> senescent. When applied to nature as whole, the developmental stage concept can be exploited to map its developmental trajectory as in the following specification hierarchy (Salthe, 1993a): {physical world {material world {organic world {biological world {social world {psychological world }}}}}}; ({ } represents a class). I discuss below why, e.g., the social world would be taken to be more mature than the biological world. In short, it is because it requires more information to construct (and describe) a social system, insofar as biological, as well as chemical and physical, constraints would be involved in the description as well as socially emergent ones. Note that ecological processes could exist at any of these levels. The ecological world as often conceived might be viewed as coordinate with the social world (e.g., Kuchka, 2001). In today's largely hominized world, 'ecosocial' (Lemke, 1995) might be more appropriate for this level.

This hierarchy represents, e.g., the biological world emerging out of chemistry, which is taken to be logically, as well as historically, prior to it -- there could be no biology without having chemistry first. Biology in turn harnesses chemistry to its interests, by way of the selective promotion of some chemical pathways. So, it integrates chemistry under its emergent rules. In this scheme all worlds conspire together to give rise to the observer -- to discourse, the innermost subclass; the discourse/observer subsumes (and implies) all other viewpoints. Note that, formally, there can be more than one coordinate subclass at any level. The specification hierarchy is formally a tree. So, abiotic dissipative structures like tornadoes and icicles (the ‘organisms’ of physics) would be placed in a subclass coordinate with the biological world.

There is a synchronic reading of this hierarchy as well. Plato was the first to organize nature in this form, while it was Aristotle who used it to depict development (Salthe, 1993a). In its synchronic form this hierarchy displays what I have called ‘intensional complexity’ -- a coexistence of different qualities in one system, delivering susceptibility to being analyzed in more than one way. An ecosystem could be viewed merely as a dynamic material system, with inputs and outflows in rain, winds, leaching and streams. Or it could be viewed as an active system of matter and energy deployment, as in energy pyramids, flow cycles, food webs, or even more detailed processes like control by keystone predators. Or it could be viewed as a system of specifically biological interactions, using concepts of diversity and symbiosis. Ecology can be that most general scientific viewpoint, as it tries to see different levels of organization, or integrative levels, in relation to each other in a given biome.

(2) The structure of change

(a) Change

Aristotle implicitly made a diachronic reading of the specification hierarchy, with integrative levels understood as stages of development (Salthe, 1993a). Today such a reading is found in the concept of ‘general evolution’ in systems science, a term signifying progressive change, which originated in anthropology to distinguish it from ‘special evolution’, which was allocated to Darwinism. But this concept of evolution as progressive goes back to the Nineteenth Century philosophers of nature (e.g., Schelling, Spencer, Peirce) for whom evolution was to be constructed as an intelligible process. That is, evolution was viewed as that process which gave rise to humans as a result of working through some principles of change and/or reflecting some form of finality. Darwinian evolution by natural selection is not a process as such, but mere willy-nilly alterations taking place for no reason at all, driven and mediated by accidents and contingencies. That is to say, it is at base radically historical, and so, unintelligible in the absence of other principles. Insofar as natural selection has been demonstrated to occur, both directly in experiments (Bell, 1997) and indirectly in natural populations (Endler, 1986; Mitton, 1997), contemporary natural philosophy does not dismiss it, but relegates it to a subordinate role in evolution -- the maintenance of adaptation to local conditions (Williams, 1975; Brooks and

McLennan, 1991), as suggested by observations in nature (e.g., Salthe and Crump, 1977).

It can be shown (Salthe, 1989; 1993a) that, when measured using very general aspects applicable to any material system (e.g., nonequilibrium thermodynamic and informational properties), all so far investigated show a general progression from being relatively small and vague with a high rate of energy throughput (immature) to being relatively more definitely elaborated, larger, thermodynamically weaker and slower changing (senescent). Since no material changes yet investigated (including ecological succession; Jørgensen, 2001) does not to show this pattern (we could call it Minot's law, after its first rough formulation -- Minot, 1908, or, since Aoki really generalized it, the Minot-Aoki Law), it can be asserted as a potentially fruitful possibility that organic evolution would also show developmental aspects in these kinds of general variables. The natural philosophy of ecology (and biology) from this perspective holds both ecological succession and organic evolution, along with organismic ontogeny, to be developmental processes in the service of a final cause -- the Second Law of thermodynamics, about which more below. Studies oriented around the canonical sequence: immature -> mature -> senescent have acquired the label infodynamics (Salthe, 2001b; 2003a) -- informational changes driven by thermodynamic potentials (Salthe, 1993a). This paper is informed by infodynamics.

In a specification hierarchy the observer / discourse (as the innermost subclass) can, in some readings, be taken to be the final cause of the development of the world -- that is, as the beginning of a series of implications [in the sense of material implication (Kampis, 1991), or conceptual subordination], as in: discourse implies (or conceptually subordinates) biology, biology implies chemistry, chemistry implies a physical world. This is a logically based version of the physicist's anthropic principle (and relates as well to the idea of observation causing decoherence of the quantum wave function as well). Of all the realms that emerged from chemistry (i.e., out of the material world), like various abiotic dissipative structures such as tornadoes and icicles, biological ones came to dominate, presumably because of their construction of greater stability in the face of change, via the replacement of worn-out parts on the basis of internal (genetic) information.

Furthermore, higher integrative levels would have historically emerged from lower ones, which would have been primal (as shown in 1, b above), but what is being suggested here is the possibility that this sequence was developmental, meaning that material systems on planets anywhere would be expected to follow the same sequence. Since the free growth of specification takes the form of a tree, we could not actually suppose that biology, and not some other coordinate system of equal specification (and stability), necessarily emerges from the material world everywhere. If it were concluded that biology had to supervene upon chemistry, rather than some alternative kind of dynamical macroscopic stability, then biology would be the final cause of the prior emergence of chemistry, just as, in a sere, a mature forest can be taken to be the final cause of an old field.

(b) Non-equilibrium thermodynamics

For dynamic material systems away from equilibrium, the following rules hold in toto or in part (Salthe, 1989):

(1) the mass-specific energy throughput increases rapidly during development, up to a maximum and then gradually declines,

(2) the system grows in mass and gross energy throughput, the rate of increase diminishing after specific energy throughput drops. This can be interpreted as a necessary increase in stored internal information. (The' ascendency' of Ulanowicz relates closely to this rule, which is the basis of infodynamics.)

(3) the internal stability of the system increases -- its growth and internally generated activity gradually slows as a result, in my view (Salthe, 1993a), of friction caused by information overload,

(4) the stability to external fluctuations diminishes after specific energy throughput drops, setting the system up for recycling, when its own stored energy will be degraded as part of the physical entropy increase in its locale.

Assuming that the universe is an isolated system, these rules can be seen to be entrained by the Second Law of thermodynamics. Dissipative structures, and any systems that expand or grow, can be viewed as maximizing their entropy production, subject to constraints (which increase with age). The expansion of material systems can in general be viewed as a way to maximize their local entropy production because growth itself requires entropy production, and also delivers new work space and access to new energy gradients. Both Kauffman (2000) and Jørgensen (2001) think that this fact ought to be marked as a fourth law of thermodynamics (see more below). This principle of local entropy production maximization is contextualized / entrained by the accelerated expansion of the physical universe (Watson, 2002), so that the global system has been, and is, departing from thermodynamic equilibrium, activating gravitation and, as a reaction, the Second Law (and eventually ascendency increase as well -- Ulanowicz, personal communication). The local vicar of the Second Law is the necessity for any dynamical system to continually produce entropy (Prigogine, 1967). Those that survive for a while ship it out toward the energy sink.

So, individual dynamical systems change by way of reorganization necessitated by growth. But why do they grow? The first answer is that they are not at equilibrium; the second is that the equilibrium in question is at base thermodynamic, and this means that equilibrium must necessarily be sought in the material world [as in Boltzmann's (1886) model of entropy increase]. But why should a local system's contribution to the global search for energetic equilibrium result in its growth?

The basic phenomenon of the material world is the instability of energy gradients (Schneider and Kay, 1994). At the least provocation, they spontaneously dissipate, as in wave front spreading, mass wasting and diffusion. In the process of dissipating, a portion of a gradient (the exergy) may be used to do work for a system able to tap it, resulting in a buildup of form, and storage of energy and information, in that consumer, as well as underwriting its behavior. The rest is dissipated into other forms of energy, including heat, which is energy that cannot be focused for use because it has become completely disordered. This heat is the energetic basis of Brownian motion at the molecular level, where no net motion takes place, and nothing can be accomplished. Energy mobilization in given directions is the basis of all form and behavior of dissipative structures, like tornadoes and icicles, which emerge from, and in turn facilitate, energy flows. So it is with living cells, as well as with the higher scale forms organized around their activities, like organisms and social systems.

Given a particular energy gradient with several consumers, the one that can use it fastest will get most of it. As demonstrated by Carnot (1824), the faster it gets used the less efficient is the process of using it for work. The entropy produced by the work in question can be measured as energy lost from a gradient that was not successfully harnessed as exergy for the work done during the period of gradient utilization. Entropy in this sense is negefficiency (Salthe, 2003b), and some of the energy lost is often still of fairly high grade, in the sense of being available to other kinds of systems. So, available energy in a gradient can be used as exergy / work, and also, under the influence of entropy production, converted to forms of energy unavailable to do that work. One system’s unusable energy could almost certainly be another system’s available energy. Looked at from a global system (or First Law) point of view instead of from that of a particular consumer, the entropic dissipation of gradients could be taken (Taborsky, 2000) to be the process of spreading energy availability as widely as possible by withholding some of it from the greediest consumers to the degree that they are greedy. As such, entropy production (not energy) may be the fundamental source of ecosystems (taking these to be systems of interdependent dynamical subsystems).

So, the dissipation of some of the energy from the sun, as Lotka pointed out, gets delayed on the surface of the earth by driving dissipative structures, including photosynthetic systems, that eventually were colonized by life. With further evolution, photosynthesizers came to represent energy gradients for detrivores and, eventually, for herbivores, which themselves (often by way of carnivores) became gradients for detrivores. If, say, one kind of herbivore could use up all the gradient in local autotrophs, there could be no remains that could serve as energy sources for different detrivore communities, and these would have become less diverse, leaving unelaborated some avenues for entropy production, thereby restricting it to fewer pathways, and, importantly, to a more sequential, slower overall energy dissipation (in the Second Law sense). In this case that herbivore would have dissipated all of the energy (would have been more ‘dissipative’ in the Second Law sense). On the contrary, it seems reasonable to postulate that the evolution of ecosystems generally has proceeded so as to multiply avenues for energy degradation, thereby enhancing the rate of simultaneous entropy production, as well as more thoroughly dissipating incident solar energy into forms unusable by living systems (se also Schneider and Kay, 1994). Put otherwise, this thermodynamic proposal is that ecosystem evolution has on the whole been drawn in the direction of furthering the Second Law, in the sense both of facilitating the rate of degradation of the basic energy gradient, as well as more thoroughly depleting it to heat. Polar alternatives here would be slow, relatively efficient exploitation by a few versus rapid, inefficient exploitation by many -- with a positive feedback on the ‘many’ coming from the wastefulness of rapid utilization by way of the byproduct of diversified, left over energy gradients.

In this scenario, individual kinds of organisms are effective energy consumers in the First law sense, dissipating gradients into several kinds of energy still available to other living systems -- that is, they are poor dissipators in the Second Law sense of degrading it all the way to the lowest level of heat. At the same time, whole ecosystems are overall fairly good dissipators in the Second Law sense (Odum, 1983).

Behind these considerations lies the Big Bang theory of the origin of the universe. According to Frautschi (1982), Landsberg (1984) and Layzer (1976), the expansion of the universe has been so fast that the system went out of global equilibrium rapidly, and has been tending to return to equilibrium ever since. As the system cooled, physical particles emerged, which gave rise to matter, and this in turn gave rise to mass, which continually aggregated as collisions brought about by a random search for equilibrium evoked gravitation. We now know (Watson, 2002) that the system has been getting further and further away from an equilibrium distribution of energy and particles because its expansion is accelerating, thereby increasing the drive toward equilibration, making the Second Law of Thermodynamics an ever more powerful attractor.

Given the brute fact of masses of matter stuck in agglomerations nowhere near equilibrium, what can a system do to facilitate its approach to equilibrium? Following Schneider and Kay (1994), the massive frictional world finds a way to increase entropy production by way of convections facilitated by organized configurations abutting the energy gradients (see also Swenson, 1997). This is the general explanation for abiotic dissipative structures like hurricanes and eddies; increasing the steepness of energy gradients spontaneously triggers the organization of macroscopic systems that will dissipate these gradients as rapidly as possible. From this perspective, living systems are continuing this project of reducing energy gradients. The evolution of animals is especially easily interpreted in this way: detrivores acquired movement to burrow into gradients; then they acquired mouths and claws to hurry the disintegration; then predators, and then herbivores, evolved to hurry the production of detritus; then some of these became homeothermic so that gradients might continue to be dissipated even in the absence of activity; then some of these invested in large nervous systems, which consume large amounts of energy continuously. This scenario provides a basic ‘meaning’ of ecological systems, whose successional phenomenology shows a tendency to maximize energy flows (Lotka, 1922; Odum and Pinkerton, 1955) by way of configurations and processes at many scalar levels. The punch line: form results from, and further mediates, convective energy flows, which more effectively degrade energy gradients than would slow frictional conduction, like diffusion.

The last statement suggests the interpretation that the Second Law is the final cause of all form (Salthe, 1993a). Available energy from gradients is dissipated into both physical entropy (disorder) and, via work, informational constraints in new gradients, of lesser amount but of greater quality (Odum, 1983), whose “purpose” is to further facilitate energy throughput. That is, form has teleological meaning. The sequence {teleomaty {teleonomy {teleology }}} -- otherwise {natural tendency {function {purpose }}} -- shows the relations between teleo types. In words, intentional teleology, or purpose, is an example of a kind of functionality, which in turn is a kind of natural tendency along the lines of the Second Law of Thermodynamics -- that is, function is a subclass of (or a more highly developed example of) variational principles. The eliciting of form does not exhaust the role of the Second Law in ecology. As mentioned above, by preventing the most rapid consumers of energy from getting all of it in a gradient, and by imposing this to the extent that they are effective (haste leading to poor energy efficiency), it spreads energy laterally into other forms of availability. In both of these roles, the Second Law elicits -- calls for, entrains, affords -- the subdivision of niche space that is biological diversity, so that entropy may be produced as fast as possible everywhere on the earth.

When examined from the very general perspectives of thermodynamics and information theory, the developments of widely different kinds of systems show a canonical structure for all dissipative structures (with fairly complete evidence from organisms, ecosystems and simple abiotic systems -- Schneider, 1988; Salthe, 1989). Summing up, each individual system begins as a small swerve inside a fostering dissipative structure, which may be a later stage of a preexisting system of the same kind (as in organisms), or as different as a supercell in a thunderstorm for tornadoes. If conditions are favorable, it develops [grows and differentiates -- viz. the “ascendency” of Ulanowicz (1986, 1997)] through a relatively unformed or simple immature condition devoted to acquiring form by way of harnessing relatively strong energy throughput, into a mature condition where the presence of form has maximized gross energy throughput (the Lotka/Odum maximum power principle), and beyond that into an information-bound (formally overconnected, functionally underconnected) senescence, where elaborated form has begun to interfere with energy flows, and where habitual tracks and overdetermined behaviors begin to undercut system adaptability. Having accumulated multiple habits, a system loses flexibility in its responses to perturbations. And so it is eventually recycled, or, as part of resilience (Holling, 1973), scuttled back to a more immature stage. This framework is the basis of developmental systems ecology, based on the works of Holling, Jørgensen, the Odums, Schneider and Kay, and Ulanowicz.

We might note for contrast the recent appearance of so-called Developmental Systems Theory (DST) in evolutionary biology (Griffiths and Gray, 1994), which connects with the Grinnellian concept of the ecological niche (i.e., environmental affordances). According to this viewpoint, the object of study in evolutionary biology should not be populations of organisms, but populations of developmental trajectories taken together with all the “resources of development”. The latter involve, e.g., pack rat nests and beaver ponds, open land for seedling growth of species living in fire disclimax areas, healthy earthworm populations for plant species, non-pathogenic microflora for various kinds of organisms, deep sea vents, symbionts and so on. In other words, in order to undercut the oversimplifying viewpoint of genetic determinism, DST suggests that the entire ecological setting of a population should be taken into account in understanding the evolution, as well as the ontogeny, of its members. It is possible that this perspective could unite with developmental systems ecology.

(3) Forms of final causality

(a) Aristotelian Causal Analysis

Above, in connection with intensional complexity (Section 1), I noted that the innermost or highest integrative level of any system has the role of Telos, or Aristotle’s developmental final cause. We need now to explore Aristotle’s causal analysis more fully, insofar as it is still a major contender for being an important approach to causality in complex systems. Briefly, we have two pairs of causal agencies -- the synchronic, material / formal and the diachronic, efficient / final. Material cause is found in the tendencies of system components, as in organismic or cell reproduction being the material cause of population growth, or, evaporation being the material cause of cooling. Formal cause can be aligned with the laws of matter and of nature (e.g., various power laws and scaling rules, gravitation and so on), propensities and tendencies, the governing influence of cycles -- any regularities imposed upon a system and modeled in, say, a descriptive equation. Formality disposes what materiality proposes. Efficient cause is that which perturbs or forces a system, triggering a response. It is represented as a push, while final cause can be represented as a pull. Finality has, of course, been problematic in modern science; it is that for which some activity or result occurs. Therefore it can be a goal or purpose, and is teleotypic . In Darwinian discourse, for example, population fitness increase is implicitly taken to be the goal of reproduction insofar as the latter is represented as its necessary result. In developmental systems ecology, as noted above, the Second Law is viewed as a final cause of form and diversity.

In Section 1 it was hinted that the purposes of discourses act as final causes of the observations and conclusions. One could say, for example, that a final cause of the importance of natural selection in our representations of nature is that this ‘nature’ was constructed by thinkers in a capitalist economic system for whom competition is the encompassing idea. Or, consider that, in connection with controlling insect pests of crops, chemical companies offer the LD 50s of various toxins as a way of regulating population growth, while biotechnology companies propose predatory insects, and environmentalists champion intercropping. The problem of insect pests of crops can itself be said to have been created by the agribusiness style of agriculture. Also, the mere fact that observations are always guided by theory means that they are affected by finality, insofar as the results of tests are limited to alternatives suggested by a given theory.

Another final cause is found, as already noted, in the global tendencies of variational principles like the Second Law of Thermodynamics, which could be viewed, as in a previous section, as a final cause of form. There are other final causes to be noted, such as the internalist one pointed to by Matsuno (Matsuno and Salthe, 2000). In the material world, communication between locales takes finite time -- it is lagged to one degree or other. If the world is to hang together without gaps, then local behaviors must in part be influenced by a need for global consistency, even though there can be, as far as we know, no instantaneous communication across locales. This means that among the forces and propensities contending in a given locale there must also be some tendency for the result to align itself with global consistency, as in the example of conservation rules. The only way to avoid this finality is to admit that one’s data are fudged (as by way of statistical rounding off) so as to produce the needed consistent results over the range of one’s model -- in this case, however, the goal of material conservation still would remain a final cause of the results!

In materially complex systems with multiple scalar levels, efficient perturbations from higher scale boundary conditions are accompanied at the same time by these same conditions “calling for” (Patten, 1982) certain responses -- at the ‘same time’ because the higher scalar level system will change only very slowly compared to the perturbed system. Larger scale moments (Salthe, 1985) contain numerous smaller scale ones. At an appropriately larger scale, the past and future of a smaller scale exist simultaneously (located in the same large scale moment), and so the origins of efficient push and final pull at the lower level are indistinguishable in this relationship.

Another possible form of finality of import to ecology is the pull of deep structural attractors on material systems.

(b) Structures and semiotics

There seems to be no ready general explanation in science for widespread similarities in nature (like the ubiquitous presence of tree forms or vortices) which are not directly inherited from ancestral systems of the same kind (as would be the case with genes in biology). One explanation for these non-inherited similarities could be entrainment by structural attractors.

Structuralism is a comparative discourse focused upon similarities (see references in Salthe, 1985; 1993a). It is worth noting here that important biological discourses impacting ecology have repudiated similarity as being of no interest. Darwinism and cladism are both focused on the accumulation of differences as being the only process of interest. Leaving aside biology, I believe that this is a bit thin for ecology, which is interested in more than just the inheritance and display of internal information. To make this apparent, consider the Eltonian concept of the ecological niche (essentially a generalization of a way of life, like, say, the terrestrial mustelid way of life, or the panfish or cactus ways of life -- Elton, 1927), which was advanced to focus ecological vicarage and convergent evolution, and which also impacts the ecological notion of vegetation as well. Compare, for example, the temperate lichen, old man's beard, with the semi-tropical bromeliad, Spanish moss -- and, furthermore, consider the overall similarities of the vegetations of the biotas in which these exist: pine barrens on sandy soils along the east coast of North America. These biotas are extremely similar north and south even though few of the species are the same.

For an example of convergent evolution that I think focuses the structuralist viewpoint especially well, consider chameleons and sea horses. They have only a very distant genealogical relationship, and none of the interconnecting forms are similar to them, as each is quite unusual within its own clade. Yet they are similar in surprisingly many respects. Both are slowly creeping, bushwhacking predators of about the same size, creeping about in vegetation. Both have independently moving eyes. Both are cryptic, and have prehensile tails. Both strike at prey suddenly and quickly. The viability aspects of their ways of life are almost identical. These are the kinds of similarities which (as in this case), emerging in the absence of directly inherited similar genetic information, suggest the effects of structural attractors. In my view, these kinds of similarities are not very different from those that entrain the form of, say, treeforms, where the material and efficient causes differ for each kind of tree (e.g., blood vessels, drainage systems).

So, what are structures? Deep structures are postulated immanent tendencies or possibilities (formal causes) inherent in nature, which may be accessed by developing material forms, and so become reflected in surface structures, which reveal the similarities. But what are these possibilities? One suggestion is that they are suites of informational constraints that have been partially reduced by previous events earlier in the development of the world, promoting metastable immanent forms, which may be accessed by any material system that reduces enough of the still remaining unreduced constraints so that the structure becomes manifest by way of an overwhelming likelihood of reduction, during development, of the remaining informational constraints in the suite. If it were not for the widespread emergence of similarities among material forms where efficient and material causes are different, and where there are no internal formal causes such as genes (either in common or at all), we would not need to postulate the likes of deep structures, which are alien to natural science as it has been practiced in the Twentieth Century, informed as that has been by a reductionist ideology. But, after all, they would be but kinds of external formal causes -- boundary conditions -- and these have received some attention of late (Ulanowicz, 1986; 1997). In my view they might be like universal constants, reflecting the history of our particular Big Bang, making some forms especially favorable at this period in its universal expansion.

Examples of convergent form and behavior suggest that meaning exists in nature outside of human discourses. Semiotics is the study of the construction and interpretation of meaning by way of sign processes (semiosis). The semiology of Saussure is focused on the conveyance of meaning in human languages, but the semiotics of C.S. Peirce is pitched more generally than this (Deely, 1991). Biosemiotics (Hoffmeyer, 1996; Salthe, 1998) has two well known applications -- (a) the derivation of meaning from genes by cells, and (b) animal communication (zoosemiotics). It has been my position that, if meaning can be successfully generalized from human language into the biology of cells, then nothing stands in the way of generalizing semiosis even further to abiotic dissipative structures, generating a pansemiotics. The motive for this position is ultimately to confront the problem of the origin of life. It is clear that, in a materialist position, nothing is derived from nothing ; everything must have a precursor. That means that zoosemiosis is a more general precursor of human communication, and that biosemiosis in cells is more general than zoosemiosis, and that sign processes in abiotic nature (physiosemiosis -- Deely, 1990) must be more general than biosemiosis, and it suggests that the more general forms were also historically prior sources of the more refined examples.

As an example of physiosemiosis, consider the relationship between temperature and physical entropy. Where will a tornado wander? Its form provides a pathway for hot air to rise precipitously into the atmosphere, expanding and cooling as it gets there, dissipating energy and generating entropy. A tornado “feeds” on hot air as it wanders here and there, even as a flame “feeds” on the highly concentrated energy in wood. But, does it seek warmth? There is no known physical process that draws a poised tornado in the direction of hotter air; if it hits a cold spot it just “dies” of entropy -- senescing and falling apart. The purely physical point of view here is that its continuance is just a matter of chance. Yet, the warmer side of a tornado would expand, while the colder side would, relatively, contract, giving a slight bias toward the heat. That being so, we are at liberty to suppose that it has an ever-so-slight “intention” to lean in the direction of hotter, and away from cooler, air. Nothing of greater substance than the principle of parsimony prevents this supposition of proto-intentionality -- nothing more than an esthetic judgment! I mean, of course, a very slight tendency in the tornado, as in the slight difference between one spot on the surface of the earth as a connection for lightning, as opposed to another nearby. Pushing this argument to its limit, if there were no net force acting upon a simultaneously jostled system, something must still happen in order that the fabric of nature not be disrupted, and, merely for simplicity’s sake, or for pragmatic reasons, the direction taken would typically be allocated to chance, since nothing in the world of affairs hinges upon the difference between chance and choice. But it has been my position that absolute chance is not formally different from choice -- a random event cannot be differentiated from an arbitrary one (Salthe, 1993b).

Whitehead (1925) took the view that choice is as plausible as chance (and much more interesting) with respect to microscopic events at the quantum level, since events there are supposed to be as completely uncaused as any in the world. If something must happen to keep events flowing, but there are no known causes bearing upon a situation to move it more one way than another, then volition is as good an explanation as -- what? Nothing! Indeed, randomness may generally just be the result of taking a view unrelated to the perspective of a system being studied -- the statistical view. For example, if one tallies the number of times a given move follows another in 100 champion chess games, these events are binomially distributed, yet no one would argue that the moves were generated randomly (Salthe, 1975). My view is that choice would even be more likely than chance in the behavior of complex systems balanced between many slight differences in forces and propensities. If such differences are great, of course, then a purely physical determinism suffices to understand an event -- even as a blunder would inevitably be followed by a check in chess. In any case, heat would, in the pansemiotic perspective, be viewed as being taken by a tornado to be a sign of energy availability.

In order to balance this argument from other side of the divide between life and non-life, consider a bird feeding on seeds densely scattered over your back porch. In order to find out which kind of seed is being favored, you try to anticipate where the next peck will come. I, for one, cannot do it. The next peck seems to be completely random. Recalling berry picking on a full bush, I don't think I could predict even my own next move as I grasp here and there. So, indeed, it may be that the bird is moving randomly. Yet, I think most biologists would suppose that there is some minimal preference deciding each move in both cases. Consider the formal relations here. A tree of possible events moving from the trunk outwards can represent physically allowable outcomes of a situation. From this perspective what occurs can seem random. However, after something occurs, the random has been converted to the arbitrary, as we trace the event back along one line to its conditions in the trunk. Choice among possible events will be arbitrary to the degree that they are equally possible given the conditions. It seems to me that, unless we take a view like this, we cannot explain how biological systems came to semiosis, because there would then be no precursor tendency toward semiosis in nature.

Thermodynamics makes no distinctions between different kinetics having comparable rates of energy dissipation, and so semiotics will be needed in order to understand why one biological form rather than another is working a particular gradient in a given locale. History explains the parsing of genetic information over time, but the connection of this phylogenetic process with the deployment of form and behavior is complex.

Given an energy gradient with various consumers, the one that can use it fastest will degrade most of it. As pointed out above, the poor efficiency necessarily associated with rapid gradient utilization will spill some the energy over into gradients available to other forms. These possibilities would be generated by thermodynamics alone. But if there are two forms with different kinetics able to degrade a gradient equally rapidly, no thermodynamic distinction could be made between them. So thermodynamics alone can lead to diversity only in respect to different work efficiencies. This alone might give rise to food chains of increasing energy use efficiency, moving, say, from herbivores to top carnivores. To get further branching into food webs, we would need to have different possible approaches to given gradients, based partly on different consumer forms and behaviors (reflecting history). Varying forms would be assured by evolutionary searches in the adjacent possibilities, given multicellularity. To get different approaches to a single gradient beyond the leftovers afforded by poor Second Law efficiencies would require that the gradient be complicated, with a top and bottom, surface and inside, and so on. The material world seems to generate such differences willy nilly. If these complications are present as well as the leftovers from rapid degradation, then we would have a web of open Eltonian niches waiting to be filled by evolution.

Eltonian niches are generalizations of ways of life. Elton (1927) formulated this concept in order to provide a framework for comparing similarities in ecology in different biomes. Each niche associates with a viewpoint on the world; only a particular combination of gradients, places and times of activity would be acceptable for each one. This means that organisms working particular niches must be entrained to various indications from counterstructures associated with gradients from which they can construct signs of food. The construction of signs on the basis of interaction / communication with the gradient, and their interpretation, would constitute a form of biosemiosis. Since the suite of affordances associated with particular kinds of gradients frequently occur together in more than one biome, we can take the Eltonian niche to represent a deep structure, and organisms would gain access to that structure by way of semiosis.

Individuation and evolution

(1) Individuation

I begin with a general definition of evolution: the irreversible accumulation of historical information (Salthe, 1993a). This is equivalently a definition of individuation, which is a process that unavoidably accompanies all developments in the material world (which is characterized by delay, contingency and friction). Looked at another way, evolution would not occur unless some material system were developing. As noted above, development is characterized by the constitutive changes characteristic of each kind of system -- ecological succession would be an example. It has been a failing of the organic evolution enterprise to ignore this fact, and to attempt to describe biological evolution as if it were purely evolutionary, with no inherent tendencies (see, e.g., any later text by S.J. Gould). We can now see this as merely a consequence of the (neo)Darwinian conquest of the imagination in biology, which, more generally, is part of the recent hegemony of radical historicism in many discourses. I here attempt a more balanced interpretation.

First I note that in the material world there is never a tabula rasa awaiting inscription. Wherever anything begins there already are some forms, propensities and affordances, however vague. Local events will be entrained by different structural attractors to varying degrees. Deep structures represent order in nature, and would have been present as immanent propensities already prior to most later material developments. A question of interest to physicists (and theologians too) -- whether this primal order was contingent or necessary -- need not detain us here.

The trajectory of the world, then, would fundamentally have been one of gradually working out the consequences of these early informational constraints as matter continued to agglomerate, in a of process of epigenesis (building upon). Here history enters the picture, as contingencies intrude at every turn and twist. This means that, as the world developed into ever more material embodiment, the complication of the forms involved continued a net increase as one historical accident after another marked the material world (whose basic nature is to be marked). The record of living systems on Earth gives an example of later stages of this development. What we see is an ever increasing complicatedness (Maynard Smith and Szathmary, 1995) added to prior simpler systems, which are by and large conserved as well, so that we could conceptually break this process down into a series of developmental stages, with the addition of new information at each one -- not unlike what is found in a sere of stages during ecological succession.

So, I think we need to see an interplay between stable universal forms, plus accumulations of more locally instituted forms (like mountain ranges and genes, which change slowly) -- both providing formal causality -- and the continuing intersection of contingent events (efficient causation) giving rise to newly emergent, often synergetic surface structures -- all of this being pulled into the future by the finality of the Second Law of thermodynamics.

This gives us a picture of an interplay between conserved tendencies and history. At the beginning we have powerful but vague structural attractors; after eons of evolution of various kinds (cosmic, biological, cultural) we have a diversity of very detailed, definite embodiments reflecting the deep structures to varying degrees, but all highly individuated, and therefore quite different among themselves as well. Each of these highly evolved kinds has become a self-organized locus of meaning, a viewpoint on the world. In ecological systems this cumulative individuality can be represented by the Hutchinsonian niche (Hutchinson, 1978), a construction that takes into account as many factors in the way of life of a population as it takes to differentiate it from its neighbors in its local habitat. (A consequence of the present view that, unfortunately, is difficult to test, would be that Hutchinsonian niches have gradually become, on average, more and more elaborate on the earth during organic evolution -- via processes like, e.g., character displacement.)

Entrainment by structures should be stronger in immature systems, like embryos or depauperate ecosystems, because there is less history embodied in them (see von Baer's law for organisms for the formal structure of this argument -- Salthe, 1993a). The effects of history, built into biological systems by genetic drift and natural selection, should increase in importance into senescence, which is necessarily a more elaborate condition. And we should expect Hutchinsonian niches in depauperate ecosystems to be determined by fewer dimensions than in those in highly diverse systems, the development would go by the addition of more and more specialized forms (Kolasa and Li, 2004). The canonical development from immaturity through maturity to senescence is repeated in the career of every organism (e.g., Zotin, 1972; Aoki, 2001), and there is evidence that it occurs during secondary succession in ecology as well (Schneider, 1988; Aoki, 2001; Jørgensen, 2001). In this latter setting, the sequence can be interrupted and set back by increasing energy flows through the system, delivering a kind of rejuvenation (as with eutrophication via pollution in aquatic systems). Holling (1973) views this return to immaturity as an integral part of ecosystem resilience. Stronger energy flows are inconsistent with, or are destructive to, the more elaborated communities of mature and senescent ecosystems. In the more tightly constrained forms of organisms (viz the superecosystem idea of Depew and Weber, 1995) increased energy flows cannot impede development, but also cannot be maintained in the senescent individual, leading instead to exhaustion and recycling. In all material systems it appears that individuation is an inevitable concomitant of development. Its continuation signifies the reduction of more and more informational constraints as development proceeds.

(2) Evolution As Entropy

Any system that expands or grows can be interpreted to be maximizing its entropy production, subject to constraints (which increase with age). This expansion, as a consequence of the influence of the Second Law in local nonequilibrium systems, was generalized to the biosphere as whole by Kauffman (2000), and dubbed a “Fourth Law” of thermodynamics. Jørgensen (2001) proposed a closely related Fourth Law, to the effect that, given alternative developmental pathways, a local system will choose that which results in the greatest amount of stored energy. Odum (1983) reminds us that Lotka (1922) suggested that the maximum power principle might be thought of as a Fourth Law as well. In this version, stored energies in a system are used to facilitate a maximization of gross energy throughput. The expansion of material systems can in general be viewed as a way to maximize their entropy production because, given the poor energy efficiency of natural work processes, on average half of the dissipated energy will be lost as entropic byproducts (Odum, 1963, p. 116). So the work of expansion itself generates on average as much entropy as work, and also, as a result of the work, would provide access to more kinds of energy gradients (Swenson, 2000), as well as increasing the size of a system’s workspace (Kauffman (2000), providing two positive feedbacks on entropy production. McKelvey (2004), in a paper reviewing much of the recent complexity/self-organization literature, has proposed a closely related Zero’th Law of thermodynamics. Of course, all of this depends upon there being sufficient energy gradient to support the required informational constraints (Jumarie, 1995). The main effect of such local nonequilibrium energy dissipation by dissipative structures is not the accumulation of matter, but the export of entropy generated by the work done, and is referred to as ‘the entropy principle’ (Mauersberger, 1995; Li, 2000).

As noted, this is entrained ultimately by the expansion of the physical universe, which has been so rapid that the global system has departed increasingly from thermodynamic equilibrium, thereby activating both gravitation and the Second Law, as opposing entrainments. (Again, in invoking consequences of the Second Law in local nonequilibrium systems, I am assuming that the universe itself is an isolated system.) It seems clear that a system that can expand its surface area as rapidly as possible must be maximizing its energy throughput as well in order to do it, and, furthermore, because it is growing, could easily be seen to be maximizing its acquisition of embodied energy too. So all the “Fourth Laws” are closely related, and converge too on the infodynamic principle that information, and as a consequence, informational entropy, must increase in dissipative structures (Brooks and Wiley, 1988; Salthe, 1990, 1993a). It should be noted that this Fourth law is not quite a ‘law of nature’ like the Second Law, but is rather what has been referred to as a ‘law of matter’, as it is local, not global (positive entropy production is the local vicar of the global Second Law) and depends upon particular contexts. Of course, these contexts appear to be common almost everywhere.

Infodynamics views the accession of form as a system grows to itself be an example of the Second Law entraining an increase in informational entropy in nonequilibrium systems. That is, growth entails the acquisition of informational constraints, while their subsequent differentiation produces information neat as a system matures. Jørgensen’s version of the Fourth Law of thermodynamics, that, when a system early in its development has choices of possible directions in which to develop, will chose that which will yield the “most ordered structure”-- clearly relates the putative Fourth Law to increasing informational entropy. So that pathway would be the one that would also entail the most potential informational entropy. Before they are reduced, the open possibilities of unreduced informational constraints contribute directly to system H, while after they are reduced they are poised to contribute to H by being disrupted, or by way of excursions into unusual forms during perturbations of various kinds -- functional (as in the acquisition of memory -- see also Ulanowicz, 1997) or not (as in being scarred). An increase in information, as by growth, entails an increase in informational entropy, one way or another.

In living systems, the dissipation of energy into informational constraints as well as into heat, explains the continuous production of mutations of all kinds, increasing informational entropy in gene pools, as well as among the somatic cells of multicellular organisms (Brooks and Wiley, 1988). The informational constraints in question can be modifications of previous configurations, hence mutations. And the expansion of a population’s range by way of emigration increases the variety of locations where a species may be found. This leads eventually to the isolation of some of the populations, leading in turn to different populations acquiring divergent genetic configurations via mutation, delivering greater variety among gene pools. So, spontaneous mutation and the opportunistic wanderings of organisms, as well as various tectonic and climatic changes (all of which increase physical entropy in the universe), lead inevitably to an increase in the variety of biological information (Brooks and Wiley, 1988). This is entrained by the fact that all biological systems tend to expand by way of growth and reproduction (Swenson, 2000). This, then, is the ultimate explanation of the general increase in biological taxa through time, which can be seen on this account to be entrained by the Second Law of thermodynamics, or, in another interpretation, by way of Jørgensen's version of the Fourth Law.

In this scenario, natural selection has a somewhat ambiguous role. Numerous studies have shown that selection is acting in natural populations, but most of them point toward a role in maintaining adapted configurations by eliminating the relatively unfit. Yet most Darwinians assume that it has a role in constructing adaptations as well, noting that in experimental populations of microorganisms a heavy selection pressure maintained for some generations can result in a rare type becoming predominant in a population. It is my opinion, based on genetic load arguments, that, since population sizes are rarely very large (except in microorganisms), selection would be limited in this role to one or two independent traits at time. In any case, the origin of new traits is clearly the result of mutational search in the "adjacent possible" phase space (Kauffman, 2000) of gene pools, entrained by entropy production in a frictional world.

New traits would be required in order to engage new energy gradients, or to form new relations with already exploited ones. Experiments with various abiotic dissipative structures, like Bénard cells, has shown that form facilitates entropy production, in the sense that macroscopic convections will dissipate a gradient much more rapidly than would slow conduction (Swenson, 1989; Schneider and Kay, 1994). In general, consider that, if we place a form of some kind on a previously rather empty stage, like a featureless sandy ocean bottom, or in a desert landscape, local entropy production will be increased spontaneously by the interaction of winds and currents with that form -- to say nothing of the way it would stimulate the activities of living systems locally. Form facilitates energy gradient dissipation -- orderly form especially so, and different forms would do so differently. The promotion of informational entropy by the establishment of spontaneous mutations ultimately generates new forms to be deployed against whatever energy gradients are at hand, generating a diversity of ways of life, as well as new gradients embodied in the new forms themselves. So, the increase in information capacity necessitated by system expansion is the source of a plenitude of Hutchinsonian niches. Dissipative structures will spontaneously arise in response to the presence of significant energy gradients (this is taken to be a restatement of the Second Law by Schneider and Kay). In abiotic systems this can be as rapid as a phase change, in biology it would be mediated by the more prolonged processes of mutation/dispersal and, perhaps, selection. The forms of dissipative structures embody, and also may create by their activities, further gradients. This process can become highly elaborated in living systems, given their extraordinary stability, which allows very fine distinctions to be made among ways of life.

Internalism: an introduction

Traditional science -- here called ‘externalist’ because it models systems as seen globally from outside -- cannot explain the generation of new forms and behaviors. Its models are aimed at explaining and predicting the behaviors of aspects of known natural systems. These models, being fully explicit on methodological grounds, are mechanistic. In mechanisms, including conceptual ones like (most of) mathematics, nothing new occurs except by mistake (i.e., mutations).

Consider a situation where a finite energy source is being dissipated into an isolated cold environment (Matsuno and Swenson, 1999). There are several energy consumers abutting the dwindling supply, and the setup is complicated enough so that new consumers could possibly appear in the system as it wends its way to equilibrium. Classical thermodynamics would be concerned only with the initial and final equilibrium states of the global system. It would find an increase in entropy, and perhaps some products of work done by some of the consumers along the way. Non-equilibrium thermodynamics would in addition seek to measure the entropy production of a selection of the energy consumers. In these pursuits the First Law of thermodynamics is the main guide; as one form of energy is transformed into others, everything must add up to an overall conservation of energy. The evolution of new consumers within the system would be of no concern in these traditional externalist pursuits. Neither, indeed, would be the detailed, moment to moment behavior of known consumers -- even those whose entropy production is being monitored periodically for a trend. Such detailed moment to moment behavior would, however, be of concern to those interested, for example, in the origin of life (Matsuno, 1989) -- or, indeed, in the origin of anything at all, and in this lies the origin of internalist approaches.

If we consider momentary affairs, we will note that the heat given up by an energy supply might not add up to the heat transferred from it by its various consumers at any given particular moment, being, as it were, in transit (even though, at smaller scales, locales may be close to their own local equilibrium). In the traditional overall approach, such local and fleeting inequalities will average out over the whole period of equilibration, and so would be unobservable. Neither would the evolution of new consumers during that time be observed. There could be all kinds of energetic hanky-panky going on at any moment -- tradeoffs, delays, borrowing on the margin -- that will be missed by traditional approaches based on globally synchronous time, which is an external measure. These inequalities, some of us believe, are the basis of generative events in any material system. In particular, it must be the case that the situation at any given imagined stop-action moment would be unbalanced, with some local inequalities and tensions having been resolved, but with others having been generated in the doing, or left over and passed forward to the next moment, which in its turn will remain unresolved. Internalism is concerned with tracing the details of such moment by moment transactions because generativity would arise as a response to local incompleteness, inconsistency and nonequilibrium.

It might be thought that ecology -- at least macroscopic, non-molecular ecology -- would have no interest in internalism, being concerned more with homeostatic aspects of macroscopic systems than with generation. Even Holling's developmental model of resilience could be said to be homeostatic over a series of larger scale moments. But then we come to Ulanowicz's (1986, 1997) developmental model, which could be taken to represent a phase of the Holling model, and where the appearance and loss of players can explicitly be represented as a factor as a system develops. This reminds us as well of the Hutchinson - MacArthur worries about the invasability of ecosystems (Cody and Diamond, 1975). Internalists would argue that resilience and homeostasis, being ongoing dynamic activities cannot really be observed in action by externalist approaches (Kampis, 1991).

Here is where semiotics could make an appearance. Von Uexküll (1926) referred to the "Umwelt" of a kind of organism (Salthe, 2001a). He detailed an organism's relationships with external resources of importance to it, and the Umwelt is the whole of these aspects of environmental factors supplying, in their "counterstructures", indications for that organism. These signs link a kind of organism with its environmental resources, which, if viewed externally, would make up its Grinnellian niche (James et al, 1984) -- its environmental affordances (Gibson, 1966). Semiosis is the process by which these signs are constructed and interpreted, and where the interpretants act as further signs internally, in a sequence that ends by returning action into the surroundings. We would have a systems model of the interior of a particular kind of consumer. By comparison with the organismic Umwelt, the Hutchinsonian niche could be viewed as the Umwelt of a population, which could be seen, in turn, to be a particular restriction on the Eltonian niche of that kind of organism (Salthe, 2001a). So the Umwelt could be taken to be an internalist interpretation of the Eltonian niche, which, being comparative, could be seen to be an externalist account of the Umwelt.

One question that might be addressed internally would be, in connection with Jørgensen's (2001) situation of an immature ecosystem choosing among several possible routes of successional development, an in-principle examination of the point of choice that will lead ultimately to the greatest embodiment of energy. This point of choice could be observable because of the vastly different scale of ecosystemic dynamics compared with those of the human observer. Many of our moments [see my (1985) 'cogent moment'] would come and go during a single ecosystemic one. So, a stop-action externalist moment can be the occasion for a switch to internalist observation. This means that we could observe, as if in slow motion, a critical moment when an ecosystemic choice is actually being made -- a creative moment. In this analysis we could make use of the fact that there are three versions of the Fourth Law, some of which might be more easily rendered internally as a moment by moment tendency at our observational time scale. Jørgensen's own version has a finalistic sense -- a mode that in science we are unused to considering. Odum's drive of the system to increase it energy throughput by means of positive feedbacks within the system might be observed as consequences of internal dynamics. Kauffman's version -- that the system will expand into adjacent possible configurations (therefore expanding its workspace) as fast as possible, could be viewed as a result of proximate mutations and excursions that might, perhaps, be observed by smaller scale observations. The remaining problem would be to relate these small scale observations of a large scale system to that system's own further behavior.

Conclusions

This paper suggests the primacy of the Second Law of Thermodynamics as a final cause in ecology, its non-equilibrium realization (entropy production) resulting in system development, as well as in evolution. Evolution can be interpreted as the deployment of Hutchinsonian niches so as to maximize local entropy production. Organisms are relatively poor dissipators in the Second Law sense (to heat energy), and therefore through their dissipative activities energy is made available to other biological systems. In this way the Second Law opens up the possibility of local ecosystemic relations. Structural attractors are suggested as explanations of ecological vicariance. As such they would be sources of meaning. Semiotics is a way to understand energy acquisition differences in the face of equal consumer power; adaptation to local energy gradients represents the construction of meanings in nature. This paper signals as well a turn to final causation as a way to understand ecosystems. Infodynamics, founded upon the already well-developed works of Aoki, Jørgensen, Holling, Kay, Schneider, the Odums, and Ulanowicz, opens up the potential for a new direction in ecology in the form of a developmental systems ecology.

Acknowledgements

I have had input from Dan Brooks, John Collier, Jay Lemke, Bai-Lian Li, Koichiro Matsuno, Edwina Taborsky and Bob Ulanowicz.

References

Allen, T.F.H. and Starr, T.B., 1982. Hierarchy: Perspectives for Ecological Complexity. University of Chicago Press, Chicago.

Aoki, I., 2001. Entropy and the exergy principles in living systems. in S.E. Jørgensen (Editor), Thermodynamics and Ecological Modelling. Lewis Pubs., Boca Raton, FL., pp. 167-190.

Bell, G., 1997. Selection: The Mechanism of Evolution. Chapman and Hall, New York.

Bertalanffy, L. von, 1969. General System Theory. Braziller, New York.

Boltzmann, L., 1886/1974. The second law of thermodynamics. In B. McGuinness (Editor), Ludwig Boltzmann, Theoretical Physics and Philosophical Problems. D. Reidel, Dordrecht. Pp 13-32.

Brooks, D.R. and McLennan, D.A. 1991. Phylogeny, Ecology, and Behavior. University of Chicago Press, Chicago.

Brooks, D.R., and Wiley, E.O. 1988. Evolution As Entropy: Towards a Unified Theory of Biology. University of Chicago Press, Chicago.

Cairns-Smith, A.G., 1982. Genetic Takeover and the Mineral Origins of Life. Cambridge University Press, Cambridge, UK.

Carnot, S., 1824 / 1960. Reflections on the motive power of fire, and on machines fitted to develop that power. In E. Mendoza (Editor), Reflections on the Motive Power of Fire and Other Papers. Dover Pubs., New York, Pp. 3-22.

Cody, M.L. and Diamond, J.M. (Editors), 1975. Ecology and Evolution of Communities. Harvard University Press, Cambridge, MA..

Conrad, M., 1983. Adaptability: The Significance of Variability From Molecule to Ecosystem. Plenum, New York.

Corliss, J.B., 1988. Hydrothermal energy flow on planetary bodies and the creation of living systems. In G. Marx (Editor), Bioastronomy -- The Next Steps. D. Reidel, Dordrecht.

Deely, J.,1990. Basics of Semiotics. Indiana University Press, Bloomington, IN.

Deely, J.,1991. Modeling anthroposemiosis. In M. Anderson and F. Merrell (Editors), On Semiotic Modeling. Mouton de Gruyter, Berlin, pp. 525-594.

Depew D.J., and Weber, B.H., 1995. Darwinism Evolving: Systems Dynamics and the Genealogy of Natural Selection. MIT Press, Cambridge, MA.

Ehrensvärd, C., 1960. Life: Origin and Development. University of Chicago Press, Chicago.

Elton, C., 1927. Animal Ecology. Sidgwick and Jackson, London.

Endler, J.A., 1986. Natural Selection in the Wild. Princeton University Press, Princeton.

Frautschi, S., 1982. Entropy in an expanding universe. Science 217, 593-599.

Gibson, J.J., 1966. The Senses Considered As Perceptual Systems. Houghton Mifflin, Boston.

Griffiths, P.E. and Gray, R.D., 1994. Developmental systems and evolutionary explanation. Journal of Philosophy 91, 277-304.

Hoffmeyer, J., 1996. Signs of Meaning in the Universe. Indiana University Press, Bloomington, IN.

Holling, C.S., 1973. Resilience and stability of ecological systems. Annual Review of Systematics and Ecology 4, 1-23.

Hutchinson, G.E., 1978. An Introduction to Population Ecology. Yale University Press, New Haven.

Innis, G.S. and O‘Neill, R.V. (Editors) 1971. Systems Analysis of Ecosystems. Fairland

International Co-operative Publishing House, Fairland, MD.

James, F.C., Johnston, R.F., Wamer, W.O., Niemi, G.J. and Boecklen, W.J., 1984. The Grinnellian niche of the wood thrush. American Naturalist 124, 17-37.

Jørgensen, S.E., 2001. A tentative fourth law of thermodynamics. In S.E. Jørgensen (Editor) Thermodynamics and Ecological Modelling. Lewis Pubs., Boca Raton, FL., pp. 303-348.

Jumarie, G., 1995. Self-organization via the creation of constraints: an information theoretic approach. Kybernetics 24: 35-48.

Kauffman, S.A., 2000. Investigations. Oxford University Press, New York.

Kampis, G.,1991. Self-modifying Systems in Biology and Cognitive Science: A New Framework for Dynamics, Information, and Complexity. Pergamon Press, Oxford.

Kolasa, J. and B.-L. Li, 2004. Removing the confounding effect of habitat specialization reveals the stabilizing contribution of diversity to species variability. Proceedings of the Royal Society of London, B (Supplement) 270: S198- S201.

Kuchka, H.E., 2001. Method For Theory: Prelude to Human Ecosystems. Journal of Ecological Anthropology 5, Special Issue.

Landsberg, P.T., 1984. Can entropy and “order” increase together? Physics Letters 102 A, 171-173.

Layzer, D., 1976. The arrow of time. Scientific American 233. 56-69.

Lemke, J.L., 1995. Textual Politics: Discourse and Social Dynamics. Taylor and Francis, London.

Li, B.-L., 2000. Why is the holistic approach becoming so important in landscape ecology? Landscape and Urban Planning 50: 27-41.

Lotka, A.J., 1922. Contribution to the energetics of evolution. Proceedings of the National Academy of Science. 8, 147-151.

Matsuno, K., 1989. Protobiology: Physical Basis of Biology. CRC Press, Boca Raton, FL.

Matsuno, K. and Salthe, S.N., 2000. Implicate final causes in developing natural systems. International Journal of General Systems 29, 965-987.

Matsuno, K. and Swenson, R., 1999. Thermodynamics in the present progressive mode and its role in the context of the origin of life. BioSystems 51, 53-61.

Maurer, B.A., 1999. Untangling Ecological Complexity: The Macroscopic Perspective. University of Chicago Press, Chicago.

Mauersberger, P., 1995. Entropy control of complex ecological processes. In B. C. Patten and S. E. Jørgensen (Editors), Complex Ecology: The Part-Whole Relation in Ecosystems. Prentice-Hall, Englewood Cliffs, NJ, Pp. 130-165.

Maynard Smith, J. and Szathmary, E., 1995. The Major Transitions in Evolution. Oxford University Press, Oxford.

McKelvey, B., 2004. Toward a 0th law of thermodynamics: order-creation complexity dynamics from physics and biology to bioeconomics. Journal of Bioeconomics 6, 65-96.

Minot, C.S., 1908. The Problem of Age, Growth and Death. Murray. London.

Mitton, J.B., 1997. Selection in Natural Populations. Oxford University Press, New York.

Odum, E.P., 1968. Energy flow in ecosystems: a historical review. American Zoologist 8, 11-18.

Odum, E.P., 1969. The strategy of ecosystem development. Science 164, 262-270.

Odum, H.T., 1983. Systems Ecology: An Introduction. Wiley Interscience. New York.

Odum, H.T. and Pinkerton, R.C., 1955. Time's speed regulator, the optimum efficiency for maximum output in physical and biological systems. American Scientist 43, 331-343.

Patten, B.C., 1982. Environs: relativistic elementary particles for ecology. American Naturalist 119, 179-219.

Patten, B.C. and Auble, G.T., 1981. System theory of the ecological niche. American Naturalist 117, 893-922.

Pimm, S.L., 1991. The Balance of Nature? Ecological Issues in the Conservation of Species and Communities. University of Chicago Press, Chicago.

Prigogine, I., 1967. Introduction to Thermodynamics of Irreversible Processes. Third Edition. Wiley Interscience: New York

Salthe, S.N., 1975. Problems of macroevolution (molecular evolution, phenotype definition, and canalization) as seen from a hierarchical viewpoint. American Zoologist 15, 295-314.

Salthe, S.N., 1985. Evolving Hierarchical Systems: Their Structure and Representation. Columbia University Press, New York.

Salthe, S.N., 1989. Self-organization of / in hierarchically structured systems. Systems Research 6, 199-208.

Salthe, S.N., 1990. Sketch of a logical demonstration that the global information capacity of a macroscopic system must behave entropically when viewed internally. Journal of Ideas 1, 51-56.

Salthe, S.N., 1993a. Development and Evolution: Complexity and Change in Biology. MIT

Press, Cambridge, MA.

Salthe, S.N., 1993b. Creativity n natural science. WESSCom 3, 30-33.

Salthe, S.N., 2001a. Theoretical Biology as an anticipatory text: the relevance of Uexküll to current issues in evolutionary systems. Semiotica 134, 359-380.

Salthe, 2001b. What is infodynamics? In G. Ragsdell and J. Wilby (Editors), Understanding Complexity. Plenum, New York, pp. 31-38.

Salthe, S.N., 2002. An exercise in the natural philosophy of ecology. Ecological Modelling 158, 167-179.

Salthe, S.N., 2003a. Infodynamics: a developmental framework for ecology / economics. Conservation Ecology 7 [online] URL: http://www.consecol.org/vol7/iss3/art3.

Salthe, S.N., 2003b. Entropy: what does it really mean? General Systems Bulletin 32, 5-12.

Salthe, S.N., 2004. The origin of new levels in dynamical hierarchies. Entropy, 6 327-343. http://www.mdpi.net/entropy/list04.htm.

Salthe, S.N. and Crump, M.L., 1977. A Darwinian interpretation of hindlimb variability in frog populations. Evolution 31, 737-749.

Schneider, D.C., 1994. Quantitative Ecology: Spatial and Temporal Scaling. Academic Press, San Diego, CA.

Schneider, E.D., 1988. Thermodynamics, ecological succession and natural selection: a common thread. In B.H. Weber, D.J. Depew, and J. D. Smith (Editors), Entropy, Information and Evolution: New Perspectives on Physical and Biological Evolution. MIT Press, Cambridge, MA., pp. 107-138

Schneider, E.D. and Kay, J.J., 1994. Life as a manifestation of the Second Law of thermodynamics. Mathematical and Computer Modelling 19, 25-48.

Shaffer, E.,1981. Naturphilosophie. In W.F. Bynum, E.I. Browne, and R. Porter (Editors), Dictionary of the History of Science. Princeton University Press, Princeton, pp. 292- 293

Swenson, R., 1989. Emergent attractors and the law of maximum entropy production: foundations to a theory of general evolution. Systems Research 6, 187-198.

Swenson, R., 1997. Autocatakinetics, evolution, and the law of maximum entropy production. Advances in Human Ecology 6, 1-47.

Swenson, R., 2000. Spontaneous order, autocatakinetic closure, and the development of space-time. Annals of the New York Academy of Sciences 901: 311- 319.

Taborsky, E., 2000. The complex information process. Entropy 2, 81-97. (www.mdpi.org/entropy)

Uexküll, J. von, 1926. Theoretical Biology. Kegan Paul, London.

Ulanowicz, R.E., 1986. Growth and Development: Ecosystems Phenomenology. Springer-Verlag, New York.

Ulanowicz, R.E., 1997. Ecology, The Ascendent Perspective. Columbia University Press, New York.

Watson, A. 2002. Cosmic ripples confirm universe speeding up. Science 295, 2341- 2342.

Weiss, P.A., 1971. The basic concept of hierarchic systems. In: P.A. Weiss, (Editor), Hierarchically Organized Systems in Theory and Practice. Hafner, New York, pp. 1-44.

Whitehead, AN., 1925. Science and the Modern World. Macmillan, New York.

Wiens, J.A., 1984. On understanding a non-equilibrium world: myth and reality in community patterns and processes. In D.A. Strong, Jr., D. Simberloff, L.G. Abele and A.B. Thistle (Editors), Ecological Communities: Conceptual issues and the evidence. Princeton University Press: Princeton, pp. 439- 457.

Zotin, A.I., 1972. Thermodynamic Aspects of Developmental Biology. S.Karger: Basel.