Int. J. General Systems, Vol. 21, pp. 207–228
Reprints available directly from the publisher
Photocopying permitted by license only

AUTOCATAKINETICS, YES—AUTOPOIESIS, NO: STEPS TOWARD A UNIFIED THEORY OF EVOLUTIONARY ORDERING

ROD SWENSON

Center for the Ecological Study of Perception and Action,
University of Connecticut, Storrs, CT 06269

(Received December 11, 1990; in final form January 8, 1991)

Autopoiesis was introduced into the literature by Maturana and Varela as the name for a particular system description which they claimed was necessary and sufficient to define the living and also to explain it. The term has been widely applied in the literature instead to spontaneous order production or self-organization in general, whether living or not. Zelený and Hufford, authors of the focal paper for this volume, would like to continue this tradition. While their effort to seek the generic behavior of spontaneous order is to be commended, this particular move must be rejected. In the first place, if the concept of autopoiesis can be used in this way it immediately shows the concept's failure to define and explain the living, making it enigmatic as to what is being generalized. In the second place, the whole concept of autopoiesis is contrived at its foundations where it is miraculously decoupled from the physical world to promulgate a solipsistic epistemology with abhorrent social consequences.

An alternative ecological physical view is presented here which shows that purposive, creative behavior is a consequence of natural law itself where order is produced such that order acts back upon order to produce more order. The ecological view rejects subject-vs.-object debates ("us" vs. "reality") as academic; all ordered states are higher-order symmetry states of the world itself. Social praxis and evolutionary competence have an amplifed meaning in such a world, one that is not yet fully determined and where small actions, intended or unintended, can produce large consequences.

INDEX TERMS: Autocatakinetics, autonomy, autopoiesis, emergence, ecological realism, ecological physics, entropy production, self-organization, symmetry, teleology.

INTRODUCTION

Autopoiesis (meaning "self-production") was first coined and introduced into the literature by Maturana and Varela[1,2,3,4] with the claim that it both defined the necessary and sufficient organization of living systems and explained them. The term has gained a number of strong proponents over the years, but almost all of the most prominent proponents have used it in a way inconsistent with the claims and stated intentions of the original authors by generalizing it to nonliving and/or cultural (here meaning human social) systems, e.g., Jantsch[5,6] Zelený,[7,8] and Luhmann.[9,10] Since the way the second generality (the cultural) is usually achieved is in a way which also admits the first (the nonliving), the effect of both generalizations is the same: it immediately falsifies the claims of the original authors by destroying their argument of sufficiency, viz., if nonliving systems are autopoietic then autopoiesis is insufficient to define the living. These generalizations are particularly enigmatic since by the necessity of first demonstrating the failure of the term to perform as claimed, it is unclear what the secondary authors are generalizing. Despite this state of affairs, the original authors have repeatedly avoided opportunities to refute these arguments or reformulate their position,[11] leaving the term they coined to become more and more meaningless.

Recently, in an attempt to eliminate the ambiguity of the original formulation(s), Fleischaker[12] has argued that the sufficiency argument can be recovered if (and only if) autopoietic criteria are amended so as to be limited to membrane-bounded chemical systems whose dynamics are generated by energy throughput at the molecular scale. The Zelený and Hufford[13] paper which is the "focal" paper for this present volume, in contrast, carries the tradition forward by seeking to exploit the ambiguity in the original formulation(s) and extend the application of the term autopoiesis to nonliving and cultural systems. The major problem in addressing their work is that it is not clear, as with earlier papers in a related vein, what explanatory value they claim or hope to have by this move. In earlier work, pointing to the history of the idea of "self-production", Zelený[7] takes autopioesis as an old idea with its roots in social systems analysis. On this line of argument, Maturana's and Varela's formulation becomes just one particular "sense" of autopoiesis. But autopoiesis was coined by them and cannot be separated from the content of their writing or what they claim it means.

While I support the interest of Zelený and Hufford in spontaneous social ordering, I reject the use of the term autopoiesis not simply because it lacks explanatory value but because behind it, in its original form, is a noxious and reprehensible epistemological doctrine. By contrast, according to the view I will present here, we are ourselves ordered states in a spontaneous evolutionary ordering process by which order acts back upon order in the production of more order. Until recently this fact was unaccountable on a physical view of nature, but this is no longer the case. In this paper, I will address the problem of autopoiesis and indicate some of the insights into a creative and purposive physical view of the world gained from the perspective of ecological physics.

OBSCURANTIST BAGGAGE

The obvious must be said at once: the generic properties that distinguish living from nonliving order production cannot, by definition, be the same generic properties common to all spontaneous order production or self-organization,[14] whether living or not. Using the same word indiscriminately for both sets of properties obfuscates the difference and must be immediately rejected, whatever the word. When Jantsch,[5,6] for example, simply equates self-organization with autopoiesis he does violence to both terms; in particular, to self-organization. The fact that most, if not all, self-organizing systems, living or nonliving, cellular or cultural, can be shown to meet the definition(s) of autopoiesis—as originally defined[1] or even the more specific criteria[3,11] (although not Fleischaker's[12]) depending on the way the terms "component production" and "boundary" are defined—merely points to the ambiguity and failure of the autopoietic model. Certainly it *does not commend wholesale adoption of the term* as Jantsch, Zelený, Luhmann, Zelený and Hufford and others would like to do. Not only does the conception add nothing to the explication or understanding of spontaneous ordering, but it obfuscates such an effort with obscurantist metaphysical baggage which when unpacked reveals a set of ontological and epistemological claims and assumptions not merely so unfounded in fact as to be absurd on their face but, with regard to social praxis, are not harmless in their consequences.

That most who use the term autopoiesis tend to ignore the bulk of the contrived and tautological scheme to which it is attached is not surprising. Only a few typical cases that capture the flavor of the general morass can be given here. For example, whereas to Zelený[8] and a preponderance of others in the literature autopoietic systems are self-organizing,[15] Maturana[16] says he would "never use the notion of self-organization, because it cannot be the case . . . it is impossible. That is, if the organization changes, the thing changes."[17] Self-organization cannot occur for Maturana because autopoiesis is maintained only if the organization of a system remains invariant[3]; Maturana's sleight of hand, required for such a conservation of "organization" to obtain, is to reduce organization to the internal relations that define a system's membership in a class.[18] Given this redefinition, the organization during the growth of an acorn into a full-size oak tree remains the same.[15] In another case, whereas Klir[19] has referred to autopoietic systems as "goal-oriented" (an apparently uncontentious characterization, given that Maturana and Varela describe them "as homeostatic systems"[20,21,22] that "subordinate all changes to the maintenance of their own organization"[23]), Maturana and Varela characterize them as systems without purpose, aim, or function.[2,16] Whereas Zelený says that social systems are autopoietic and to study them as mechanisms is "bound to be misplaced,"[8] Maturana says that providing a scientific explanation requires proposing a mechanism and an autopoietic system is a mechanistic system.[4] Whereas to Luhmann autopoietic systems "do not create a material world of their own. They presuppose other levels of reality,"[24] according to Maturana's "bringing forth" epistemology, reality is invented by observers.[25]

This kind of solipsistic proclamation, that everything is the invention of the observers, that "what we do not see does not exist,"[26] is grounded on a miraculous disassociation from the physical world built deeply into the foundational literature of autopoiesis. The claim that for autopoietic systems the "only product is themselves"[27] is a claim for a perpetual motion machine of the second kind—a denial of the second law of thermodynamics.[28] The autonomy of an autopoietic system, perhaps the core concept of autopoiesis,[2,3,4] is presented with the definition of an autonomous system as one that "can specify its own laws."[29] This impoverished ontological and epistemological framework (what Zolo, referring to Maturana's work, has called a "desolate theology of repetitive autism which proceeds by violence of syntax and tautological iteration"[30]) contaminates the term autopoiesis, regardless of the intentions or conceptions of those who would want to use it or redefine it to the contrary.

To deny an independent reality is to deny the laws or invariances of nature. Yet no "observer" has ever been able to define, construct, or invent these invariances in or out of existence. The denial of the existence of such invariances, whether a doctrine of academic dilettantism, of a fanaticist cult, or the result of pure naivete (ignorance), is pernicious with respect to evolutionary competency. The proof of this fact is seen by asking the would-be "inventor of reality" to go down to the local interstate highway and stand in the path of a fast-moving truck. If the inventor refuses, or agrees but then runs before being hit by the truck, you are dealing with a dilettante whose beliefs are not evolutionarily competent because (s)he runs from these beliefs. If on the other hand the inventor goes out onto the highway but does not run, (s)he will be killed and the beliefs are not competent. Whatever the construction—whether the inventor calls the moving vehicle a truck or a lorry, or covers her eyes and ears, or imagines a bird instead of a truck or a sphere instead of a large rectangle dilating in her optic field—(s)he will be killed by the truck if she does not get out of the way.

SOME BACKGROUND

As Kenny and Gardner have noted, Gaines has criticized the claim to novelty in the original papers on autopoiesis and the "unfortunate tendency of Maturana not to list any references other than himself."[31] In fact Zelený[7,8,32,33] has provided some excellent short historical reviews of seminal work on what has variously been called self-producing or self-organizing systems. He notes that Trentowski used concepts of autonomy, circularity, and spontaneous self-organization in the middle of the 19th century in his work with biological and sociocultural systems,[32] credits Menger in 1883 with being first to use the term "spontaneous organization"[8] (although Spencer certainly popularized the idea much earlier, see below), and notes that Bogdanov in 1912 saw living systems as not only self-regulating and self-maintaining but also self-producing.[33] Introducing "holism" in 1926, Smuts[34] saw living systems as irreducible wholes in continuous *autogenesis*, and unable to explain the spontaneous functioning of previously incoherent "parts" to create and maintain new wholes which he took to be the "vera causa" of cosmic evolution, Smuts remarked that it was "as if the Great Creative Spirit hath said: Behold, I make things whole."[35] Within two years, Morgan[36] published his work on emergent evolution and Wheeler[37] published his on emergent evolution and the development of societies (see Swenson[38]).

It is remarkable that in his historical surveys dealing with spontaneous social order, Zelený does not mention Spencer[39] whose "law of evolution"—the "instability of the homogeneous" or the "transformation of the incoherent into the coherent (which) holds uniformly . . . from the earliest traceable cosmical changes down to the latest results of civilization"[40]—was not only the first general theory of evolution but one founded on spontaneous ordering as a property of natural law. In his paper, "The Social Organism," Spencer[41] speaks of both organisms and sociocultural systems as being characterized by "a perpetual removal and replacement of parts, joined in a continued integrity of the whole."[42] "The whole," said Spencer elsewhere,[43] "has an ongoing unity and nature, though the units change."[44] Zelený's and Hufford's statement that "all biological (living) systems are social systems"[45] follows Spencer's remark that not only are social systems organisms, but organisms are social systems ("societies"), too.[46] Beginning in the 1920's and for nearly half a century, Weiss[47,48] and Bertalanffy[49,50] studied the generalized behavior of living systems as self-producing, self-organizing patterns of flow. Living systems, said Bertalanffy, "are the expression of a perpetual stream of matter and energy which passes the organism and at the same time constitutes it . . . a continuous building-up and breaking down of the component materials."[51]

Weiss advocated study of the "hard scientific core (of) emergent collective order," attacking both "micromechanical reductionism" and the "bogus literary versions"[52] of holistic thinking. Among his most important ideas were the necessity for field descriptions in understanding spontaneous order, the relation between macrodeterminacy and micronondeterminacy[53] (his principle of the "conservation of overall pattern by the coordination of the erratic flux of component elements"[54]), continuum vs. discontinuum (the emergence of new levels of order), and progressive mechanization.[55] Bertalanffy's major contribution was his recognition of the generic behavior in open systems occurring spontaneously as the result of a continuous exchange of matter and energy with the environment. In addition to a variety of allometric laws, this behavior includes the progressive reduction of internal entropy in the production of a final ordered state,[56] equifinality in approach to this state,[57] and homeostasis once it was achieved.[58]

Autopoiesis is said to *explain* living systems, but since "living systems are given"[59] to begin with, it explains nothing. What is more, as so many writers have shown, autopoiesis in its original form does not offer even an adequate description. Since an autopoietic "machine"[60] is said both to fully and strictly determine itself and at the same time conserve the *same* circular network of productions that defines it, even if such a system (defying the laws of physics) *could* be (miraculously) "given" it would do nothing, being strictly determined by itself, except go forever around in the same circle. Living order production, as a particular instantiation of spontaneous order production, is creative. It is characterized by discontinuous transformations (disordered to ordered states), progressive determinism, and homeorrhesis. This creative and directed phenomenology is not captured by the decoupled mechanism of autopoiesis. Strictly determined systems, by definition, cannot be creative since they are already determined. This begs the question of how the world, if it has no existence except by our invention (if as Maturana claims "we literally create the world"[61]), can ever be created if its creators (us), being strictly determined, are denied *a priori* the ability to create. On a less grandiose level it begs the whole question of social praxis since there cannot be any under these conditions, thus further substantiating the malevolence of the autopoietic doctrine. On the other hand, taking ourselves as productions of a world in its own spontaneous ordering, where order (productions) acts back upon order (productions) in the production of new productions (order), entails a world that is not strictly determined, one in which small nondeterministic seedings can have large, ultimately macrodetermined, consequences. Such a world not only affords the possibility for social praxis but amplifies the role, intended or unintended, that individual actions can have in possible future states, desirable or catastrophic.

PURPOSELESS PHYSICS NEEDS MIRACULOUS ORDERING

From its inception at the time of the Greeks, the science of physics ("phusis" or "physis") was taken to be the study of nature, and the nature of a thing or process in the Aristotelian sense was the end for which it exists.[62] Physics thus began as teleology—the science of ends or final causes. Following the virulent attacks on Aristotelian causality by Bacon[63] and Descartes, the rise of modern science in the 17th century, which was hooked to the stunning success of Newtonian mechanics, saw the virtual banishment of teleology from the scientific discourse. The material world was reduced to the deterministic, reversible, summative, and analytically continuous mechanical interactions of purposeless particles (efficient cause). It was no accident that spontaneous creative or goal-directed behavior was removed *a priori* from inside the world[64,65]: it kept the Newtonian watchmaker intact outside the mechanical world,[66] thus satisfying the requirements of the religious ordering of the time. Despite the dramatic advances it permitted in physics, the price tag on this extremely narrow materialism was an incapacitated causal framework and an ontological dualism that has persisted in the fabric of scientific inquiry to the present time; 17th-century mechanisms need makers.[67,68,69,70,71]

By the middle of the 19th century, empirical evidence made the notion that the world was ordered (the "clock" was produced) in a single creation event no longer tenable.[72] Within a ten year time span, Spencer[39] pronounced his "law of evolution," Darwin[73] published his *On the Origin of Species by Means of Natural Selection, or the Preservation of Favored Races in the Struggle for Life*, and Clausius[28,74] and Thomson[75] formulated the second law of thermodynamics. Spencer published voluminously on evolution which he defined as the production of increasingly higher states of order, while Darwin never even used the word "evolution" until the sixth edition of *Origin*.[76] It is remarkable to note that Darwin never put forward a "theory of evolution".[77] It was only later that "evolution," first widely introduced by Spencer as a theory of spontaneous ordering from the nonliving through the cultural, was reduced to natural selection (a particular facet of bioevolution). The sociology of knowledge that accounts for this reduction is clearly beyond the scope of this paper, yet that Darwinian theory, grounded on a generalization of Malthus' theory of population[78] and Hobbes' law of "bellum omnium contra omnes," is incapable of living up to its present role as *the* theory of evolution should be obvious: it assumes at the start precisely what a comprehensive evolutionary theory should otherwise explain.[38]

More precisely, according to neo-Darwinian orthodoxy, evolution is taken to be the result of natural selection acting on populations of replicating or reproducing entities showing random variation and competing for fixed resources (the "struggle for life"). But this *assumes replicative ordering or "the struggle for life" to begin with.*[65,67,68] Evolution did not come into the world with life; life was the product of it.[38] In addition, it is now well-recognized that the Earth system at its highest level has evolved, functions, and is evolving as a single global entity,[79–83] but because there is no competing population of Earth systems on which natural selection can act, that is, *because the global Earth system is a population of one,* neo-Darwinism cannot address this global evolution[65,67,68,84] and in fact denies it.[85] Since natural selection cannot thus account for the spontaneous and active production of replicative order out of a "dead", purposeless, or aimless world of physics which it requires first to act, and since it cannot explain global evolution itself, it is clear that evolution is not reducible to natural selection. In fact Darwinian evolution or natural selection can only be a process internal to a more general evolutionary process which is the product of a more fundamental *principle of selection that must reside in physical law* (since if principle of selection does not involve competing replicating or reproducing entities it cannot be *biological*).[65,67,68,86] Selection in this case, and thus competition (without implying end-in-mind), must be between macro or ordered and micro or disordered modes.[87] But given Boltzmann's claim that according to the second law of thermodynamics ordered states are "infinitely improbable,"[88] how can this possibly be?

Koestler underscored the problem during the Alpbach Symposium of 1968 (whose participants included Bertalanffy, Waddington, and Weiss) when he stated that the production of higher and higher states of order in evolution "goes against the second law of thermodynamics."[89] Bertalanffy had already shown in his work on open systems that "spontaneous order, and even an increase in the degree of order, can appear in such systems"[90] as long as they compensate for their own increase in order, viz., internal entropy can decrease as long as an equivalent amount of entropy is produced to satisfy the second law.[91] But the fact that ordered states are *permitted* to exist as long as they pay their "entropy debt" or their "cost of doing business," as it is sometimes expressed, does not account for why, if "infinitely probable" they *do* exist; it does not provide an account, given Boltzmann's claim, of where such "debt payers" can come from. That is, how does purposiveness or active goal-directed agency come into a purposeless or aimless "dead" world of physics to begin with? In 1873 von Baer[92] argued

> my goal is to defend teleology . . .. I too am convinced that everything that exists and continues to exist in nature arose and will continue to arise through natural forces and material substances. But these natural forces must be coordinated and directed. Forces that are not directed—so-called blind forces—can never, as far as I can see, produce order (the efficient and material causes need to be coordinated).[93]

An argument from parsimony suggests that since a highly-ordered physical world of purposeless mechanical particles (reversible Newtonian or collapsing-to-equilibrium Boltzmann) needs a miraculous maker (or makers) to order it, as Boyle and Newton themselves pointed out, the *world of physics cannot be reducible to purposeless mechanical particles.*[69] That is, the *physical* description is of necessity incomplete. In fact, it is now understood that the Boltzmann conception of the second law has been completely on its head.[38,69,82] Boltzmann's attempt to save the mechanical world view by reducing the second law to a stochastic collision function is easily falsified by simple physical experiments. Order production is not improbable but inexorable, and it is the lawful behavior of the natural world that makes it so. The next section briefly sketches this understanding.

FIRST PRINCIPLES OF FLOW

It was Planck who first made explicit the connection between the second law of thermodynamics and final cause (*causa finalis*). In fact, the second law as defined by Thomson and Clausius precisely fits the definition of final cause given by Bunge[94] as the "end to which everything serves and which everything strives" or in Aristotle's own words "the end of every motive or generative process." "The entropy of the world," said Clausius[74] in his formulation of the second law, "strives to a maximum." "Nature prefers certain states," Planck said later, "and the measure of this preference is Clausius' entropy."[95] The first law of thermodynamics which grew out of the work of Meyer, Joule, Helmholtz, and others showed that all forms of energy, e.g., mechanical, chemical, and heat, are interconvertible into each other, and that the total amount of energy is conserved (energy is neither created nor destroyed). Although this revolutionary work demonstrated the underlying unity of all physical processes, the work of Fick, Davies, and Carnot flagged a profound problem that was recognized and solved by Clausius and Thomson. In particular, an inconsistency in the work of Carnot (the fact that he showed that the "availability" for producing dynamical change, viz., the motive force, was irreversibly destroyed) led to the stunning insight that if the first law was not to be violated, in addition to a quantity that was conserved, there must be another that was not.

Clausius coined the word "entropy" as the name for this quantity so as to make it sound like energy and emphasize the relation between the two. The second law states that all natural processes (all real-world dynamics) proceed spontaneously so as to maximize the entropy. The state of maximum entropy, the time-independent end state where all evolution or macroscopic change stops, is known as thermody-

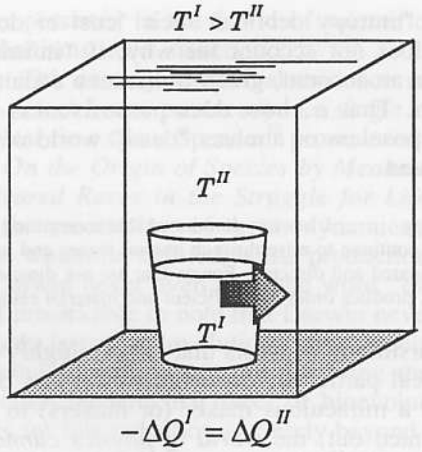


Figure 1 The active end-directed nature of the second law and the relation between entropy and energy can be illustrated with a glass of liquid at temperature T' placed in a box at temperature T'' such that $T' > T''$. The box has been sealed against energy flow from the outside such that given the first law of thermodynamics, the amount of energy in the box is conserved. The entire interior of the box constitutes a *flow field*, and the difference in temperature between the liquid in the glass and the air in the box constitutes a nonuniform distribution of energy which produces a field *potential*. The potential spontaneously drives a flow of energy in the form of heat from the glass to the box $-\Delta Q'$ that drains the potential until it is minimized (or, equivalently, the entropy is maximized) at which time thermodynamic equilibrium is achieved ($T' = T''$) and all flows stop. Note that since the energy has remain unchanged throughout it is only its distribution throughout the field, a measure of the entropy of the system, that determines whether any change is produced. This was the profound insight of Clausius and Thomson. If energy is conserved it cannot itself be the cause of change which is instead the spontaneous action of nature to maximize the entropy. Note further that the system can be prepared so that the energy is distributed in any number of ways, e.g., $T' < T''$, in which case heat would flow from the air to the liquid. Regardless of how it is prepared, however, the final state will be precisely the same; it is completely determined by the symmetry condition specified by the second law. From this it can be seen what entropy maximization (or field potential or availability, to use Carnot's term, minimization) as *final cause* means: when the entropy is maximized there is no macroscopic change; when the entropy is not maximized the appropriate dynamics are *spontaneously produced* as drains until it is. Adapted from R. Swenson, "Order, Evolution, and Natural Law: Fundamental Relations in Complex System Theory," in C. Negoita (ed.) *Cybernetics and Applied Systems*, New York: Dekker, pp. 125–148). © 1991 Marcel Dekker, Inc. Adapted by permission.

namic equilibrium. Note that when entropy is maximized, all field potentials are minimized; thus the second law can be equivalently expressed as *entropy maximization* or *field potential minimization*. Both are expressions of the same symmetry (see Figure 1). The preceding makes a powerful and important point: the first and second laws of thermodynamics are not ordinary laws of physics; they sit above the ordinary laws as laws about laws, expressing the dynamical symmetry of the laws of physics themselves.[86,99] The conservation principle described by the first law expresses the time-translation symmetry of physical law, and the symmetry expressed by the second law is likewise a symmetry that governs all the other laws but in a completely unique and fundamental way. While the first law is a law of equivalence, the second law, in fields with nonuniform distributions of conserved quantities, expresses a *symmetry unfulfilled*, and it is precisely this unfulfilled symmetry that underlies the "preference" of Planck, the "striving" of Clausius, and the "motive force" of Clausius which motivates and directs the dynamics of the natural world.[67,68,86]

While classical thermodynamics tells us that all dynamical processes are produced so as to maximize the entropy at equilibrium, it tells us nothing about which dynamical processes, which pathways, will be chosen to get there. If we borrow some of the tools of the classical thermodynamicists—a monatomic gas placed in an adiabatically sealed box (one closed to the flow of heat) divided into two compartments—and add some devices that allow the addition and removal of constraints, a powerful principle is demonstrated[86]: the system as a whole, when started from a nonequilibrium condition regardless of the way it is set up, will allocate its resources, or select the pathways from available pathways, so as to bring itself to equilibrium, viz., minimize its field potential or maximize its entropy at the fastest possible rate given the constraints (see Figure 2).[65,68,86] This *law of maximum entropy production* (MEP)[38,65,68,69,82,83,86] leads immediately to an understanding of why the world is in the order-production business: *order produces entropy faster than disorder*. Macro is selected from micro precisely *because* spontaneous order increases the rate of entropy production of the field from which it emerges (see Figures 3, 4, 5, 6).

The world is not reducible to the aimless local collisions of a set of "elementary" particles—to a stochastic collision function or any other kind of linear, summative, purposeless behavior. Whereas the state of thermodynamic equilibrium may be the state of maximum disorder, the path of choice in a world where the potentials are strong enough to support it is not the linear, summative, and inefficient kinetics of disordered collisions but the *autocatakinetics*[98] of self-organizing states of macroscopic order (see Figure 7). Under these conditions, the most direct path to equilibrium is not a straight line but a circle.[38] Autocatakinetics defines the minimal and therefore the most generalized description of a spontaneously ordered or self-organizing system. An autocatakinetic system maintains its "self," constituted and empirically traceable by a set of nonlinear ("circular") relations, through the dissipation or breakdown of field potentials in the continuous coordinated or ordered motion of its components [*auto-*, "self" + *cata-*, "down" + *kinetic*, "of the motion of material bodies and the forces and energy associated therewith" from *kinein*, "to cause to move"]. No claim is made concerning components; in fact it is purposely avoided. Thus dust devils, tornadoes, Bénard cells, bacteria, ecosystems, civilizations, and the global Earth system as a whole are all examples of autocatakinetic systems. The dissipative dynamics of autocatakinetics, both motivated and explicated by MEP, powerfully captures under a single term the general phenomenology of "open systems" *in sensu* Bertalanffy, the "systemtheorétique" of Weiss, and the "law of evolution" of Spencer, e.g., equifinality, progressive mechanization (progressive determinism), macrodeterminacy and micronondeterminacy, continuum v. discontinuum (the instability of the homogeneous, or the transformation of the incoherent into the coherent, viz., disorder to order or micro to macro). The term autocatakinetics is baggage-free and suggests precisely what it is supposed to mean.

BUILDING AN ECOLOGICAL PHYSICS BY HOOKING AUTOCATAKINETICS ONTO KINEMATIC FIELDS

The coupling of autocatakinetics and MEP produces a remarkable repertoire of purposive, opportunistic, level-independent behavior that accounts by natural law for much of what was once thought to be specific (although inexplicable) to the living.[38,82] It must be remembered, however, that the particular kind of autocatakinetics

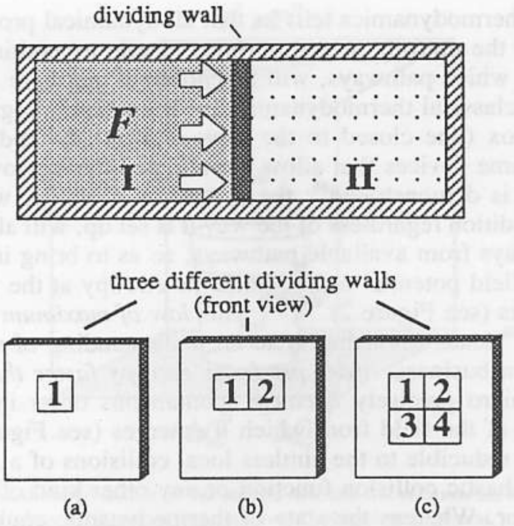
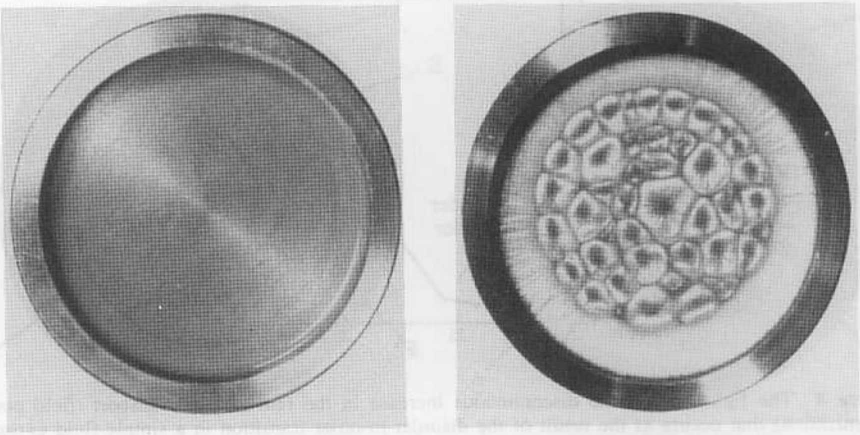


Figure 2 An adiabatically sealed chamber is divided with an adiabatic wall into two equal compartments, each holding equal quantities of a monatomic gas such that $T^I > T^{II}$, producing a field potential with force F. If a section of the adiabatic seal is stripped off the dividing wall (a), a flow of energy in the form of heat (a drain) is spontaneously produced from I to II until the potential is minimized (the entropy is maximized) given the constraints. The rate of the entropy production is given by

$$\frac{dS}{dt} = \frac{dQ^I}{dt}\left(\frac{1}{T^I} - \frac{1}{T^{II}}\right) \tag{1}$$

where dQ^I/dt and $(1/T^I - 1/T^{II})$ are the flow and force respectively. Equation (1) shows immediately *ceteris paribus* that the rate of entropy production is determined by the coefficient of conductivity of the wall. In (b) a second portion of the adiabatic seal is stripped off, but the wall underneath is composed of a different material with a different coefficient of conductivity. It is easy to see that if the rate of 2 relative to the rate of 1 is sufficient to drain some quantity of the potential before 1 drains it all, then that quantity is automatically assigned to 2. If, with different relative coefficients, 2 can drain all the potential before 1 can drain any, then the entire quantity is assigned to 2 and 1 gets none. If more drains are added (c) the behavior is precisely the same: regardless of the particulars of the system, not only (as in Figure 1) will the system produce the appropriate dynamics to get it to the same final state, but it will select the assembly of pathways or drains amongst the available dynamics—it will allocate its resources—so as to get to the final state (minimize the field potential or maximize the entropy) at the fastest possible rate given the constraints. This universal selection principle, the *law of maximum entropy production* (MEP), provides a physical basis for the inexorability of evolutionary ordering. From R. Swenson, "Order, Evolution, and Natural Law: Fundamental Relations in Complex System Theory," in C. Negoita (ed.) *Cybernetics and Applied Systems*, New York: Dekker, pp. 125–148. © 1991 Marcel Dekker, Inc. Reprinted by permission.

entailed depends upon the particular level-dependent substrate on which the level-independent laws operate.[99] The job of building a general theory of evolutionary ordering, of spontaneous order production, is the job of building an ecological physics,[65,67,68,100,101] that is, the physics dealing with the emergence of autocatakinetic levels and their operation with respect to the level-independent and level-dependent laws that govern. This is an expanded view of physics, one taking the position that phenomena outside of physical theory are outside only because current physical theory is incomplete, not because there is none that can address the phenomena.[65,101] It is also a decidedly non-reductionistic conception since it says that level-dependent



(a) (b)

Figure 3 In an experiment first devised by Bénard in 1900, a viscous fluid (silicone oil, in the case photographed here) is held in a circular container between a source (heat supplied uniformly from below), T', and a sink (cooler temperature or air above), T'', producing a potential with a force F, the magnitude of which is determined by the difference between them $(1/T' - 1/T'')$ as in (1). In (a), where F is below a critical magnitude, the flow is produced by the disordered (incoherent) collisions of the molecules, and the fluid appears macroscopically homogeneous. When F is increased above a critical minimum, however, stochasticities that were previously dampened are instead amplifed as spontaneous order (b) is produced from the previously disordered flow and hundreds of millions of molecules exhibit macroscopically coordinated behavior. There is nothing improbable, given MEP (Figure 2), about this transition from disorder to order—it is a lawful opportunistic consequence of F's exceeding a minimal level. Order is spontaneously selected from disorder as soon as the field potential is strong enough to support it, and the rate of entropy production increases dramatically (see Figure 4). Order production is thus just another drain or path (albeit with a rich and qualitatively different repertoire of behavior) by which the field acts to minimize its potentials, a drain that becomes discontinuously available only at certain levels of F. Order increases the entropy production of a field by increasing its space-time dimensions and thus its dissipative surfaces by orders of magnitude. Whereas in the disordered regime (a) the intrinsic units of space and time are mean-free-path distances and relaxation times of the order of 10^{-8} cm and 10^{-15} sec., in the ordered regime (b) these increase to centimeters and seconds. What has emerged in this fluid are ordered states relative to the scale of the molecules that if scaled to a human being would constitute a macrostructure many times greater than the circumference of the Earth and persisting over time scales greater than the full 4.5 billion years of global evolution. From R. Swenson, "Emergent Attractors and the Law of Maximum Entropy Production: Foundations to a Theory of General Evolution," *Systems Research,* vol. 6, no. 3, 1989, p. 192. © 1989 Pergamon Press. Reprinted by permission.

laws are emergent, irreducible, and specific to the ecological level at which they operate. Interactions between higher-ordered entities, as Rosen[102] has pointed out, involve different observables but observables that are just as *physical* nonetheless. The ecological physics of evolutionary ordering seeks to identify both the level-independent laws and the level-dependent substrates on which they operate that bring about the spontaneous ordering of the natural world.

Despite the remarkably generic behavior of autocatakinetics, the striking difference between living and nonliving order production, given the autocatakinetic analysis which pays close attention to sources and sinks, is immediately apparent: the self-producing non-living are *slaves to their local gradients while the living are not.* That is, with respect to systems like tornadoes, dust devils, and Bénard cells, if the local potential is removed (e.g., if the heat in the Bénard experiment is turned off),

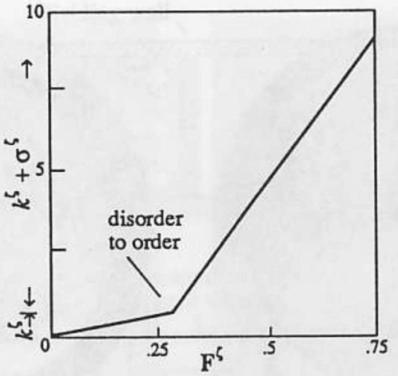


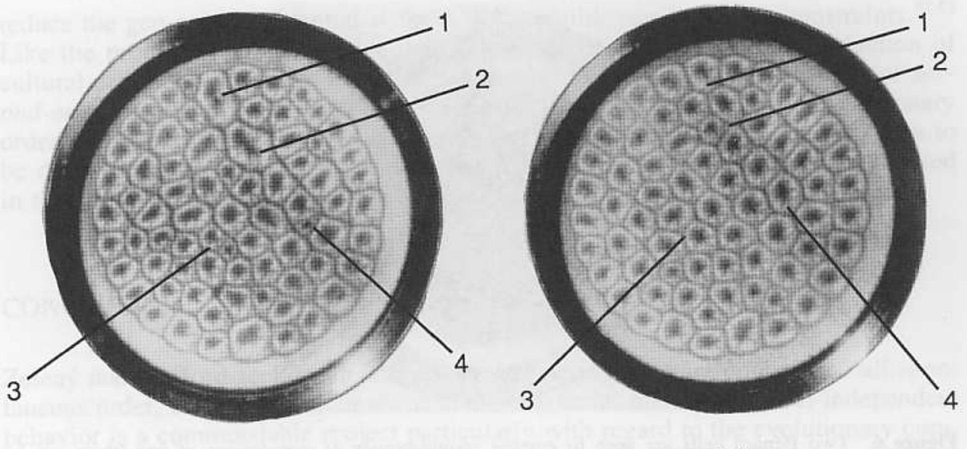
Figure 4 The figure shows the discontinuous increase in the rate of heat transport (field potential minimization) that occurs as the result of the disorder-to-order transition in a simple fluid experiment similar to that in Figure 3. The rate of heat transport in the disordered regime (or Boltzmann regime) is given by k^ζ, while $k^\zeta + \sigma$ is the rate of heat transport in the ordered regime (3.1×10^{-4} H (cal. cm.$^{-2}$ sec.$^{-1}$)).[97] Because order produces entropy faster than disorder, it is spontaneously selected as soon as F reaches the minimum level that will support it. From R. Swenson, "Engineering Initial Conditions in a Self-Producing Environment," in M. Rogers and N. Warren (eds.) *A Delicate Balance: Technics, Culture and Consequences,* IEEE catalog no. 89CH2931-4, Los Angeles: Institute of Electrical and Electronic Engineers, p. 70. © 1989 IEEE. Reprinted by permission.

the ordered state "dies." This is not the case even with the simplest bacteria: when their potentials are removed or dissipated (when they run out of food), their activity often increases. *The autocatakinetics of living systems are coordinated with respect to macroscopic variables in kinematic fields that permit them to "skate" across local potentials and access higher orders of dissipative space.*[65,67,68] That is, where in the nonliving the autocatakinetics are governed by local field potentials with dimensions of mass, length, and time ("mass-based" fields), the autocatakinetics of the living are governed by non-local potentials specified by observables with dimensions of length and time (kinematic or information fields).[103] Living systems hook their internal potentials (see Figure 7) onto kinematic invariants to search out potentials discontinuously located in space and time. Bacteria, for example, are able to move away from harmful substances and find desirable resources not only by acting on the molecules they consume but by perceiving and acting with respect to molecular gradients that afford the discovery of the molecules they do consume and avoidance of those that are harmful—gradients that provide them *information about* higher order-field potentials.[65,67,68]

The ability to act arbitrarily with respect to local potentials, and thus the facility to build higher states of order by accessing higher-order dissipative space, is the hallmark of the *replicative ordering* that characterizes the living.[65,67] Replicative ordering is the particular kind of autocatakinetics that entails the internal production of components by replication and is taken to be definitional of the living.[104,105,106] The deep relation between MEP, the progressive emergence of more highly-ordered states of matter in evolution, replicative ordering, and the evolution of perceiving-acting cycles, that through their ability to hook end-directed dissipative dynamics onto kinematic invariants and thus provide access to otherwise inaccessible dimensions of dissipative space, is seen in the primitives of replicative ordering itself.[67] As part of its constitutive relations, replicative ordering requires a set of internal

ransport (field potential
simple fluid experiment
(or Boltzmann regime)
$.1 \times 10^{-4} H$ (cal. cm.$^{-2}$
usly selected as soon as
ing Initial Conditions in
cate Balance: Technics,
stitute of Electrical and

blest bacteria: when
food), their activity
dinated with respect
'skate" across local
hat is, where in the
als with dimensions
netics of the living
with dimensions of
tems hook their in-
earch out potentials
e, are able to move
only by acting on
espect to molecular
ume and avoidance
ation about higher
nd thus the facility
bative space, is the
[65,67] Replicative or-
internal production
the living.[104,105,106]
nore highly-ordered
ation of perceiving-
issipative dynamics
inaccessible dimen-
ve ordering itself.[67]
es a set of internal



(a) (b)

Figure 5 In these photographs, two later time slices in a Bénard cell experiment show further aspects of the rich behavioral regime that follow from the physics of spontaneous ordering as the system, by progressively selecting (constraining) the degrees of freedom of its components (thereby reducing the number of accessible microstates), converges on its time-independent end state (limit set or attractor), characterized by a uniform array of hexagonal cells. The progressive determinism (from stochasticities amplified at above-critical threshold to an unchanging end-state of hexagonal cells) observed in the evolutionary behavior of the system captures the level-independent properties of equifinality or homeorrhesis in its approach to its final state, micronondeterminism and macrodeterminism (the relation between nondeterministic fluctuations and its exploitation by macrodeterministic law, viz., MEP), and homeostasis (in its final state). Likewise the relation between competition (between accessible component microstates at the level of molecules and the level of cells) and cooperation (collective behavior inter- and intra-cellular) are seen as two sides of the same ordering process. Selection can be seen to operate at two levels: (i) by each cell on the degrees of freedom of its molecular components; and (ii) by the system as a whole on the population of cells as its components. Comparison of a(1) to b(1), and a(2) to b(2) reveals spontaneous fission where two oversize cells divide into four smaller ones as the result surface/volume effects;[38,69] comparison of a(3) to b(3) shows subsumption (one irregular four-sided cell and one smaller three-sided cell combine to form one maximally efficient hexagon); and comparison of a(4) to b(4) shows the competitive exclusion of a smaller cell by a larger one with a faster rate. From R. Swenson, "Emergent Attractors and the Law of Maximum Entropy Production: Foundations to a Theory of General Evolution," *Systems Research*, vol. 6, no. 3, 1989, p. 193. © 1989 Pergamon Press. Reprinted by permission.

constraints that are discrete, sequential, and rate-independent relative to the rest of the autocatakinetic cycle.[107] The order of the sequences, like the words on this page or the sequence of base pairs in a DNA string, are thermodynamically arbitrary with respect to the rate at which they are "written" and "read."[108,109] It is precisely by exploiting this arbitrariness that replicative ordering, through the interplay of micronondeterminacy and macrodeterminacy, affords the construction of perceiving-acting systems that in their arbitrariness to local potentials are able to coordinate higher levels of dissipative order with respect to information lawfully specified by kinematic fields (new higher-order macroscopic invariants or observables).

In the larger evolutionary context, learning is induced by problems and the problem from the physical point of view is the disequilibrium at the geo-cosmic interface. Global evolution can be seen as an epistemic process by which the global system, as an autocatakinetic system through the production and selection of its own internal microstates, learns to maximize the extension of its dissipative surfaces so as to

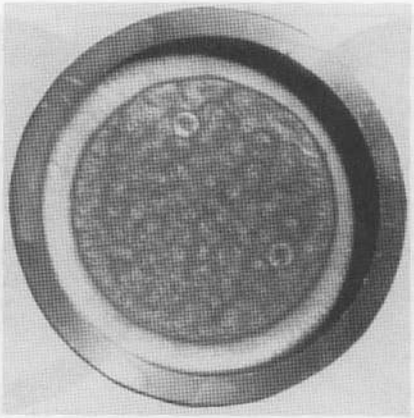
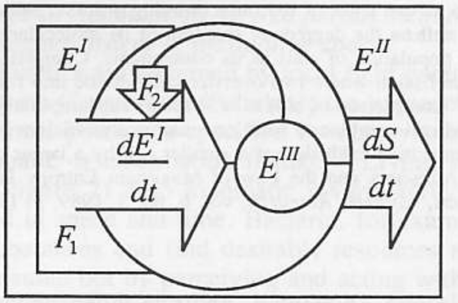


Figure 6 Two Bénard cells are seen to emerge spontaneously as *populations of one* (there are no interactions between them at this stage) right after the minimal field threshold has been reached prior to Figure 3(b). Their existence, *ceteris paribus*, is dependent only on the fact that ordered (macro) modes are selected instead of disordered (micro) mode because they drain field potential (nonlinearly pull resources into their own ordered or collective dynamic) faster than the micro mode from which they emerge. From R. Swenson, "Emergent Attractors and the Law of Maximum Entropy Production: Foundations to a Theory of General Evolution," *Systems Research*, vol. 6, no. 3, 1989, p. 194. © 1989 Pergamon Press. Reprinted by permission.



Generalized Autocatakinetics

Figure 7 The figure shows a level-independent schematic of a minimal autocatakinetic system and the generalized relations that it entails: the outer perimeter of the drawing indicates the necessity of a field description, E^I and E^{II} indicate a source and sink with the difference between them constituting a potential with a field force F_1, dE^I/dt indicates the drain on the potential (energy flow) constituted by the ordered motions of the autocatakinetic state, $dS/dt = dE^I/dt(F_1)$ where dS/dt is the entropy production, E^{III} is the internal potential carried in the potential and kinetic energy embodied in the relations of the ordered (autocatakinetic) system, and F_2 is the internal force carried by the internal potential that feeds back to amplify (or at the limit, maintain) dE^I/dt (the use of order for the production of more order). As a result of their internal amplifiers, autocatakinetic systems grow as self-amplifying sinks by extending the intrinsic space-time dimensions of the fields from which they emerge.

The understanding that autocatakinetic systems are produced, bifurcate, or spontaneously fission, are subsumed, subsume, and become components in higher-order autocatakinetic systems in the context of fields acting towards their own ends, obviates dualism in a profound way: autocatakinetic systems are higher-order symmetry states of the field itself in its own evolution.

reduce the geo-cosmic potential at the fastest possible rate given the constraints.[82,83] Like the production of replicative order from the nonreplicative, the production of cultural order through the autocatakinetic harnessing of linguistic constraints or *second-order kinematics* produced a step function in the elaboration of evolutionary ordering on Earth.[65,68,82] Autocatakinetics with second-order kinematics is taken to be definitional for cultural systems (the particular kind of autocatakinetics entailed in their self-production).

CONCLUSION

Zelený and Hufford seek to identify general principles that are common to all spontaneous order, calling that order social and autopoietic. Identifying level-independent behavior is a commendable project particularly with regard to the evolutionary competence of our social praxis as it concerns accelerating global ordering which, as Robb has tried to show,[110,111,112] is invisibile to us without the understanding and application of such principles. The extent to which we can "act locally but think globally" certainly requires that we seek to understand as rigorously as possible the evolutionary nature of global change. Our cognizance of some of these principles points us to the fact that the future of the global system is not strictly determined but will exploit locally nondeterministic actions at critical thresholds to produce discontinuities (large irreversible macroscopic change) in its macroscopically deterministic behavior. This can only stress the importance of individual action.[69]

The task of building a level-independent, level-dependent theory of spontaneous order is the task of building an ecological physics, including an ecological psychology. While identifying the phenomena and building the theory is of the greatest importance, the terms we use are somewhat arbitrary (although they cannot be arbitrary with respect to their common meaning or the history attached to them). I have used *autocatakinetics* to define the level-independent behavior of spontaneous ordering (those properties and laws that are invariant under transformations of scale and that are common to spontaneous order in general, regardless of how it is instantiated), *replicative ordering* to define the particular kind of autocatakinetics characteristic of the living, and *replicative ordering with second-order kinematics* to define cultural (human social) systems. With respect to using the word 'social' for all such behavior (equivalent to saying "all autocatakinetic systems are social systems"), I am not sure what it would buy except to emphasize the common nature of all collective phenomena.[113] This is well and good except that this common nature must be identified, and this exercise pursued as I have done in this paper with regard to some key distinctions, to distinguish between what is general and what is more specific. Methodologically, the ecological study of spontaneous order seeks always to squeeze the most explanatory power out of the most general laws while recognizing the existence of level-dependent laws on which the level-independent laws act (but which are not reducible to the general laws). Thus part of the job is to make distinctions, albeit as parsimoniously as possible.

With respect to the authors' use of the word 'autopoiesis', I reject it. The word does not refer to the generic or historical notion of self-production or spontaneous order but to an epistemological doctrine that is in fact inimical to spontaneous ordering, not only in its obscurantism but in the (lawfully) impossible ontology that it promulgates. With respect to the broader question of social praxis and global ordering, the doctrine of autopoiesis is horrendous: it puts us out in the middle of the highway denying the reality of high-speeding trucks. The claim that "what we do not see does not exist" permits the denying of all atrocities and robs other beings of their existence including their dignity, pain, and joy. On the ecological view espoused here, we are productions (order) of a world that by its productions (order) produces more order (productions). Whereas it has produced and exploits intentions in its order production, the world is purposive but unintended. While its order production is an active inexorable process flowing from the symmetries of natural law, the world is not strictly determined. Global evolution is an epistemic process by which new order is produced by hooking dissipative dynamics onto new higher-order macroscopic invariants. Controversies concerning observer-subject dualisms are academic; all ordered states are necessarily and lawfully coupled to their fields[114]—they are higher-order symmetry states of them. In this sense there is no "us" vs. the "world": we *are* the world opportunistically searching for ways to bring itself further into being under the directive of natural law.

APPENDIX

From Micro To Macro In The Bénard Fluid

Unlike the well-known fluid experiment designed later by Lord Rayleigh which involves only buoyancy (see Swenson[38]), the mechanism for the Bénard experiment involves surface tension and has a much richer phenomenology which is why it was chosen for the photos here. Since surface tension like density varies inversely with temperature, any temperature gradient across the surface of the fluid results in a surface-temperature gradient as well. Any statistical fluctuation (stochasticity) that results in the upward displacement of a warm "parcel" of fluid (meaning a number of molecules are displaced by random collisions as a group), whether or not it is dampened by buoyant forces, will necessarily raise the surface temperature and lessen the surface tension in the area directly above it. In the disordered regime, the potential carried in the embodied energy of the parcel, E^{III} (as in Figure 7), is dissipated by viscous drag and diffusion through disordered collisions from surrounding molecules and the stochasticity is dampened (has no apparent macroscopic effect); the fluid remains macroscopically homogeneous (Figure 3(a)). Beyond the critical field threshold, however, the potential of the surface-tension gradient between E^{III} and E^{II} (in this case the cold upper surface) exceeds the minimum necessary for force F_2 delivered by the potential to amplify the motion of the parcel, driving the bulk fluid into the region of lower temperature and greater surface tension and pulling more warm fluid up behind it while the cooler fluid in front begins to sink: an autocatakinetic cycle is complete and macroscopic order is established, increasing the flow of heat from source to sink dramatically. It should be pointed out that beyond the critical field threshold, fluctuations or stochasticities above a minimum instability amplitude are ubiquitous; thus not one, but a speciation event occurs and a whole population emerges almost simultaneously, at which point competition and selection ensues between the cells (Figure 5). It is also of great interest to note that precisely because stochasticities are ubiquitous when the minimal threshold is crossed, and because nonlinear effects amplify small differences in amplitude as well as order of appearance (those cells emerging first grow faster), the time-dependent behavior in the experiment (e.g., precisely where the first cells emerge (Figure 6) or what the system will look like while it is "young" (Figure 3(b)) is highly variable relative to the scale of the molecules. The final state is always hexagonal cells of a particular size determined by the symmetry conditions of the field. The generic point worth noting is that there are times when small difference can make big differences, viz., times when the system is very creative, and other times when it is completely insensitive to microscopic input.

REFERENCES

1. The autopoietic organization is defined by Varela *et al.*[3] as "a network of productions of components which (i) participate recursively in the same network of productions of components which produced these components, and (ii) realize the network of productions as a unity in the space in which the components exist." The definitions vary somewhat from paper to paper (the reader should consult references below).
2. H. Maturana and F. Varela, "Autopoiesis: The organization of the living" [1973]. In *Autopoiesis and Cognition—The Realization of the Living*, edited by H. Maturana and F. Varela, D. Reidel, Dordrecht, Holland, 1980, pp. 73–141.
3. F. Varela, H. Maturana, and R. Uribe, "Autopoiesis: The organization of living systems, its characterization and a model." *BioSystems*, **5**, 1974, pp. 187–196.
4. H. Maturana, "The organization of the living: A theory of living organization." *Int. J. Man-Machine Studies*, 7, 1975, pp. 313–332.
5. E. Jantsch, *The Self-Organizing Universe*. Pergamon Press, New York, 1980.
6. E. Jantsch, "The unifying paradigm behind autopoiesis, dissipative structures, hyper- and ultracycles." In *Autopoiesis, Dissipative Structures, and Spontaneous Social Orders*, edited by M. Zelený, Westview Press, Inc., Boulder, CO, 1980, pp. 81–87.
7. M. Zelený, "Autopoiesis: A paradigm lost?" In *Autopoiesis, Dissipative Structures, and Spontaneous Social Orders*, edited by M. Zelený, Westview Press, Inc., Boulder, CO, 1980, pp. 3–43.
8. M. Zelený, "Spontaneous social orders." *Int. J. General Systems*, **11**, 1985, pp. 117–131.
9. N. Luhmann, "The autopoiesis of social systems." In *Sociocybernetic Paradoxes*, edited by F. Geyer and J. van Zouwen, Sage Publications Ltd., London, 1986, pp. 172–192.
10. Luhmann (above) even advocates developing "a truly general theory of autopoiesis" as self-organizing systems that "carefully avoids references which hold only for living systems" (p. 172).
11. See V. Kenny and G. Gardner, "The constructions of self-organizing systems." *The Irish Journal of Psychology*, **9**, 1, 1988, pp. 1–24.
12. G. R. Fleischaker, "Autopoiesis: The status of its system logic." *BioSystems*, **22**, 1988, pp. 37–49.
13. M. Zelený and K. Hufford, "The application of autopoiesis in systems analysis: Are autopoietic systems also social systems?" *International J. General Systems*, **21**, 1991, pp. 145–160.
14. Consistent with most of the literature (e.g., Weiss,[47] who uses emergent collective order and self-organization synonymously), spontaneous order production is taken to be emergent collective order and both are used synonymously here with self-organization.
15. J. Mingers, "An introduction to autopoiesis—Implications and applications." *Systems Practice*, **2**, 2, 1989, pp. 159–180.
16. H. Maturana, "Everything is said by an observer." In *Gaia, A Way of Knowing*, edited by W. Thompson, Lindisfarne Press, Great Barrington, MA, 1987, pp. 65–82.
17. Maturana, 1987, p. 71.
18. H. Maturana, "Autopoiesis: Reproduction, heredity and evolution." In *Autopoiesis, Dissipative Structures, and Spontaneous Social Orders*, edited by M. Zelený, Westview Press, Inc., Boulder, CO, 1980, pp. 45–79.
19. G. Klir [*Architecture of Systems Problem Solving*. Plenum Press, New York, 1985] as cited in Zelený and Hufford, 1991, p. 146.
20. Maturana, 1975; Maturana and Varela, 1980.
21. To say that a system is homeostatic and not goal-directed (end-directed or purposive) simply flies in the face of what these two words are conventionally taken to mean (e.g., see E. Nagel, "Teleological explanation" or A. Rosenblueth N. Weiner, and J. Bigelow, "Behavior, purpose, and teleology." In *Purpose In Nature*, edited by John Canfield, Prentice-Hall, Inc. Englewood Cliffs, NJ, 1966, pp. 67–88 and pp. 9–26 respectively). It is important to note that goal-directed behavior

does not assert intentional or "end-in-view" behavior, although it *can* be intentional. To say, as Maturana does, that all the dynamical behavior of an autopoietic system is subordinated to the homeostatic maintenance of its autopoiesis is precisely equivalent to saying, as Jantsch[6] does, that the function of an autopoietic system is its autopoiesis. To invoke end-directed behavior on the one hand and deny it on other is paradigmatic nonsense. Although it may be simpler to deny it than explain it, autopoiesis can hardly be said to explain the living without accounting for this end-directed behavior.

22. General system theory has long recognized homeostasis (time-independent dynamical steady states) and equifinality (the convergence from different starting points to the same dynamic end state as the product of time-dependent behavior) as a spontaneous property of open-systems. In the more modern language of dynamical systems theory and nonequilibrium thermodynamics, such end states are the "attractors" of dissipative systems. The range of perturbations from which a system returns to its original state, or the range of starting points from which the system will converge on the same limit set, defines the "basin of the attractor."
23. Maturana and Varela, 1980, p. 80.
24. Luhmann, 1986, p. 174.
25. Kenny and Gardner, 1988.
26. H. Maturana and F. Varela, *The Tree of Knowledge*. New Science Library, Shambhala, Boston, 1988, p. 242.
27. Maturana and Varela, 1988, p. 49.
28. For the impossibility of a circular process that is not entropy producing, see R. Clausius, "On the Application of the Theorem of the Equivalence of Transformations to the Internal Work of a Mass of Matter." *Philos. Mag.*, ser. 4, **24**, 1862, pp. 81–97, 201–213.
29. Maturana and Varela, 1988, p. 48. The more general definition of autonomy in systems theory is taken to be the range of perturbations over which a system will return to the same state (see basin of attraction[22]). This merely underscores not only *the existence of a field* within which the attractor is embedded, but, given that a change in field conditions can result in the production of a new "autonomous" entity, *the creative role of the field* in the production of the new entity (see further discussion in text).
30. Zolo, as cited in Kenny and Gardner, 1988, p. 8.
31. Kenny and Gardner, 1988, p. 7.
32. M. Zelený, "Cybernetyka." *Int. J. General Systems*, **13**, 1987, pp. 289–294.
33. M. Zelený, 'Tectology." *Int. J. General Systems*, **14**, 1988, pp. 331–343.
34. J. Smuts, *Holism and Evolution*. Macmillan, New York, 1926.
35. Smuts, 1926, p. 106.
36. C. Lloyd Morgan, *Emergent Evolution*. Williams and Norgate, London, 1927.
37. W. M. Wheeler, *Emergent Evolution and the Development of Societies*. W. W. Norton, New York, 1928.
38. R. Swenson, "Emergent attractors and the law of maximum entropy production: Foundations to a theory of general evolution." *Systems Research*, **6**, 3, 1989, pp. 187–197.
39. H. Spencer, *First Principles*. Williams and Norgate, London, 1862.
40. Spencer, 1862, p. 148/149.
41. H. Spencer, "The social organism" [1860]. Reprinted in *Essays—Scientific, Political, and Speculative*. D. Appleton and Co., New York, 1892.
42. Spencer, 1860, p. 273.
43. H. Spencer, *The Principles of Sociology* [1876]. Reprinted in *Herbert Spencer: Structure, Function and Evolution*. Charles Scribner's Sons, New York, 1971.
44. Spencer, 1876, p. 114. Spencer stressed the conservation of the ongoing relations, not the individual components which were continuously re-produced and replaced (e.g., new cells in organisms, and new humans and commodities in sociocultural systems). It is ". . . the constant relations among its parts (that) make it an entity . . . the general persistence of the arrangements among them throughout the area occupied" (p. 102), said Spencer, with regard to both organisms and sociocultural systems.
45. Zelený and Hufford, 1991, p. 147, p. 156.
46. Spencer, 1876, p. 109.
47. P. Weiss, *The Science of Life*. Futura Publishing Company, New York, 1973.
48. P. Weiss, "1 + 1 ≠ 2 (When one plus one does not equal two)." In *The Neurosciences: A Study Program*, G. Quarton, edited by T. Melnechuk and F. Schmitt, Rockefeller University Press, New York, 1967, pp. 801–821.
49. L. von Bertalanffy, *General System Theory*. George Braziller, New York, 1968.
50. L. von Bertalanffy, *Problems of Life*. Watts & Co., London, 1952.

51. von Bertalanffy, 1952, p. 124.
52. Weiss, 1973.
53. Weiss originally used "micro*in*determinacy," but I have substituted "micro*non*determinacy" so as to render his meaning more precise. In the sense of their use today, *in*determinacy can refer to an observer's ignorance even where a system is micromechanically deterministic where Weiss's sense is observer-independent. For Weiss, macrodeterminacy "can demonstrably exist on a higher level without being based on any correlated microdeterminacy on the next lower level."[47] This fundamental point, essential to Weiss's argument against mechanistic explanations, also holds the key whereby stochasticities provide seeds at critical thresholds for symmetry-breaking events signaling the discontinuous emergence of new levels of order (new higher-ordered attractors).
54. Weiss, 1973, p. 52.
55. Inherent in the idea of self-organization, and recognized by Spencer and also by Bertalanffy, "progressive mechanization" refers to the progressive loss or "freezing out" of degrees of freedom that occurs during spontaneous ordering—the bridge between micronondeterminacy and macrodeterminacy.
56. Emergence and self-organization entail the progressive addition of constraints on previously disordered or less-ordered components to produce more-highly-ordered states. At the final state (attractor), constraints are maximal and the internal degrees of freedom are minimal. "The directiveness," said Bertalanffy,[49] "which is so characteristic of life-processes that it was considered the very essence of life, explicable only in vitalistic terms, is a necessary result of the peculiar system-state of living organisms, namely, that they are open systems."
57. With the recognition of equifinality, by which open systems converge on the same end states regardless of the initial conditions within some range of initial conditions, viz., the "basin of attraction," homeostasis, and progressive mechanization (which I will call "progressive determinism"), end-directed behavior as the spontaneous result of dissipative flows was acknowledged as playing a fundamental role in the production of living order.
58. Waddington later introduced the term homeorrhesis (rrhesis from the Greek "rhein" to flow) which characterizes the same dissipative attractor dynamics as equifinality [C. Waddington, "The theory of evolution today." In *Beyond Reductionism: New Perspectives in the Life Sciences*, edited by A. Koestler and J. Smythies, The Macmillan Company, New York, 1969, pp. 357–410].
59. Maturana, 1975, p. 317.
60. Maturana and Varela, 1973, p. 78.
61. H. Maturana, "Biology of language: The epistemology of reality." In *Psychology and Biology of Language and Thought*, edited by G. Miller and E. Lenneberg, Academic Press, New York, 1978, p. 61.
62. B. Russell, *History of Western Philosophy*. George Allen & Unwin Ltd., London, 1961.
63. See, e.g., Bacon's disdainful remark that "inquiry into final causes is sterile, and, like a virgin consecrated to God, produces nothing" [A. Woodfield, *Teleology*. Cambridge University Press, London, 1976].
64. The constraint of summativity excludes collective behavior, the constraint of analytically continuous functions excludes discontinuous (thus creative) behavior, and reversibility precludes goal-directed or purposive behavior.
65. R. Swenson, "End-directed physics and evolutionary ordering: Obviating the problem of the population of one." In *The Cybernetics of Complex Systems: Self-Organization, Evolution, and Social Change*, edited by F. Geyer, Intersystems Publications, Salinas, CA, 1991, pp. 41–59.
66. As Boyle pointed out, such a mechanical world, which he compared to the "ingenious clock of Strasburg-Cathedral" [F. Lange, *The History of Materialism*. The Humanist Press, NY, 1950 (trans. 2nd edit orig. publ. 1877, p. 303], like the Strasburg-Cathedral clock, must have an intelligent creator or, in Newton's own question, given "these things being properly ordered, do not (these) phenomena show us that there is an incorporeal Being, living, intelligent, omni-present, who in infinite space as His sensorium sees things themselves intimately, knows them completely, and thinks?" [E. Gilson, *From Aristotle to Darwin and Back Again*. J. Lyon (trans.), University of Notre Dame Press, Notre Dame, IN, 1984, p. 159].
67. R. Swenson, "A robust ecological physics needs an ongoing crackdown on makers conjured out of thin air." *PAW Review*, **5**, 2, 1990, pp. 60–65.
68. R. Swenson, "Order, evolution, and natural law: Fundamental relations in complex systems theory." In *Handbook of Systems and Cybernetics*, edited by C. Negoita, Marcel Dekker, Inc., New York, 1991, pp. 125–148.
69. R. Swenson, "Engineering initial conditions in a self-producing environment." *Proceedings of the IEEE and SSIT Conference "A Delicate Balance: Technics, Culture and Consequences, 20–21 Oct. 1989, Los Angeles*, edited by J. Biddle, IEEE SSIT, Los Angeles, 1990, pp. 68–73.

70. B. Weber, "Implications of the application of complex systems theory to ecosystems." In *Proceedings of the 8th International Congress of Cybernetics and Systems*, 11–15 June 1990, New York, F. Geyer (ed.), Intersystems Publications, Salinas, CA (in the press).
71. B. Weber, and D. Depew, "Evolution and general systems theory: Towards a robust synthesis." *Proceedings of the 33rd Annual Meeting of the ISSS*, **33**, 3, 1989, pp. 38–45.
72. E.g., Kant's nebular hypothesis, advanced nearly a hundred years earlier, that the solar system had *come into being* from an incoherent gas within the context of a larger universe (thus meaning that the Earth and the life upon it had come into being, too) was now accepted although not necessarily in its details.
73. C. Darwin, *On The Origin of Species by Means of Natural Selection, or the Preservation of Favored Races in the Struggle for Life*. John Murray, London, 1859.
74. R. Clausius, "Ueber verschiedene für die anwendung bequeme Formen der Hauptgleichungen der mechanischen Wärmetheorie." *Annalen der Physik und Chemie*, **7**, 1865, pp. 389–400.
75. W. Thomson, "On a universal tendency in nature to the dissipation of mechanical energy." *Philosophical Magazine and Journal of Science*, **4**, 4th series, July-December, 1852, pp. 304–306.
76. In fact the word 'evolution' is not found in the twenty-one chapters of *The Descent of Man* nor in any of the summaries of these chapters nor in the summaries of the fifteen chapters of *The Origin* [Gilson, 1984].
77. As Carniero has noted, the term 'evolution' was first used by the Swiss preformationist Bonnet with reference to embryology (to mean the "unfolding" of the embryo). Lamark did not use the word at all in his theory on the transformation of species first put forward in 1809. It was Spencer who introduced the first comprehensive theory of evolution and who popularized the word in the 19th century [R. Carneiro, "The devolution of evolution." *Social Biology*, **19**, 1972, pp. 248–258; Gilson, 1984]. Spencer gave a precise (non-preformationist) definition to evolution as "a change from an indefinite, incoherent homogeneity, to a definite, coherent heterogeneity; through continuous differentiations and integrations" [1862, p. 216]. This is precisely what we mean today as "spontaneous ordering." As the title of Darwin's 1859 work makes clear, his intention was only to show i) that species had changed over time, and ii) that they were modified by a process he called "natural selection." It was later that the word evolution became identified with his work and evolutionary theory became reduced to natural selection.
78. In fact Darwin borrowed the phrase "struggle for existence" from Malthus who had already claimed the "struggle" as a general property of the "animal and vegetable kingdoms" [Gilson, 1984, p. 76] (Darwin also borrowed the "survival of the fittest" from Spencer).
79. L. Margulis and J. Lovelock, "Biological modulation of the Earth's atmosphere." *Icarus*, **21**, 1974, pp. 471–489.
80. J. Lovelock and L. Margulus, "Atmospheric homeostasis by and for the biosphere: The Gaia Hypothesis." *Tellus*, **26**, 1974, pp. 1–10.
81. L. Margulis and J. Lovelock, "The biota as ancient and modern modulator of the Earth's atmosphere." *Pure and Applied Geophysics*, **116**, 1978, pp. 239–243.
82. R. Swenson, "Emergent evolution and the global attractor: The evolutionary epistemology of entropy production maximization." *Proceedings of the 33rd Annual Meeting of the ISSS*, **33**, 3, 1989, pp. 46–53.
83. R. Swenson, "The Earth as an incommensurate field at the geo-cosmic interface." In *Geo-Cosmic Relations: The Earth and its Macroenvironment*, edited by G. Tomassen, W. de Graaf, A. A. Knoop, and R. Hengeveld, PUDOC Science Publishers, Wagengingen, The Netherlands, 1989, pp. 46–53.
84. This has been called the "Vernadsky Paradox" by C. Barlow and T. Volk, "Open systems living in a closed biosphere: A new paradox for the Gaia debate." *BioSystems*, **23**, 1990, pp. 371–384.
85. R. Dawkins, *The Extended Phenotype*. W. H. Freeman, San Francisco, CA, 1982.
86. R. Swenson, "Gauss-in-a-box: Nailing down the first principles of action." *PAW Review*, **4**, 2, 1989, pp. 60–63.
87. Micro and macro in the level-independent theory presented here are defined relative to each other and not in any absolute sense.
88. L. Boltzmann, "The second law of thermodynamics." *Populare Shriften, Essay 3*, address to a formal meeting of the Imperial Academy of Science, 29 May 1886. Reprinted in *Ludwig Boltzmann, Theoretical Physics, and Philosophical Problems*, S. Brush (transl.), D. Reidel Publishing, Co., Boston, 1974, pp. 13–32. Consequent to his claim to have reduced the second law to a law of probability, Boltzmann said that molecules or "bodies" moving at the same speed and in the same direction . . . is the most improbable case conceivable, . . . an infinitely improbable configuration of energy" [pp. 22].

89. A. Koestler, discussion following the lecture by P. Weiss, "The living system: Determinism stratified," in *Beyond Reductionism: New Perspectives in the Life Sciences*, edited by A. Koestler and J. Smythies, The Macmillan Company, 1969, p. 30.
90. Bertalanffy, 1952, p. 145.
91. A living system, said Schrödinger, feeds on "negative entropy" thereby "freeing itself from all the entropy it cannot help producing while it is alive" [E. Schrödinger, *What Is Life?* The Macmillan Company, New York, 1945, p. 72]. Later, Prigogine used the term "dissipative structure" for the general class of phenomena which Bertalanffy had addressed as "open systems" [I. Prigogine, *Thermodynamics of Irreversible Processes*. Interscience Publishers, New York, 1955]. Because a theorem of minimum entropy production proposed by Prigogine was erroneously thought to apply to order-producing systems, some confusion still remains and needs some comment. Very briefly (for a fuller account see Swenson[39]) the theorem states that for a system extremely close to equilibrium with more than one force (potential) driving flows (and thus producing entropy), if one force is maintained constant but the others are allowed to dissipate, the entropy production will decrease until it reaches a minimum (relative to its earlier states) in the steady state. This statement is completely unsurprising: since close to equilibrium the flows are a linear function of the forces, as the forces dissipate the flows will necessarily decrease until only the one held constant remains. This tell us only that the flows are linearly dependent on the forces in the near-equilibrium regime (a fact well-known since Onsager) and that potentials are spontaneously minimized—the second law. It does not tell us which flows or paths to equilibrium are selected, given these facts. The answer to that question (shown below in the text) is: the pathways or flows, given the constraints, that get it to equilibrium or minimize the potentials the fastest. This is the principle that accounts for ordering.
92. K. von Baer, "Controversy over Darwinism." In *Darwin and His Critics: The Reception of Darwin's Theory of Evolution by the Scientific Community*, edited by D. Hull, Harvard University Press, Cambridge, MA, 1973, pp. 416–427.
93. von Baer, 1973, p. 421.
94. M. Bunge, *Causality in Modern Science*. Dover Publications, New York, 1979.
95. M. Planck, *Scientific Autobiography and Other Papers*. Philosophical Library, NY, 1949.
96. H. Callen, *Thermodynamics and an Introduction to Thermostatistics*. John Wiley & Sons, New York, 1981.
97. W. Malkus, "Discrete transitions in turbulent convection." *Proceedings of the Royal Society of London*, **225**, 1954, pp. 185–195.
98. I have recently re-introduced autocatakinetics into the literature[65] in its updated and more precisely defined form. The term, first used by Ostwald, was noted later by Lotka [A. Lotka, *Elements of Mathematical Biology*. Dover Publications, New York, 1956].
99. In terms of global evolution, this fact is easily seen. There had to be prokaryotic substrate before eukaryotes, a eukaryotic substrate before higher-ordered forms, agriculture before the state, etc.
100. The need for an ecological physics was a central insight of the ecological psychology of J. J. Gibson with his recognition of the operation of lawful relations scaled to the ecological level of perceivers [J. J. Gibson, *The Ecological Approach to Visual Perception*. Houghton Mifflin, Boston, 1979].
101. M. Turvey and C. Carello, "Cognition: The view from ecological realism." *Cognition*, **10**, 1981, pp. 313–321.
102. "Such considerations immediately lead to . . . a reconsideration of physics itself. They imply that the basis for physical interactions between systems is far wider than has been considered heretofore . . . a wider class of observable quantities . . .. Physics has been dominated by the idea that there is ultimately a single mode of system analysis, involving the isolation of 'elementary particles'; the laws of interaction between these particles ultimately determine every property of any natural system." [R. Rosen, *Fundamentals of Measurement and Representation of Natural Systems*. North-Holland, New York, 1978, p. xii-xiii].
103. P. Kugler, M. Turvey, C. Carello and R. Shaw, "The physics of controlled collisions: A reverie about locomotion." In *Persistence and Change*, Erlbaum, Hillsdale, NJ, 1985, pp. 195–229.
104. Thus the global Earth system as a whole is a living system, and so is a mule even though it does not reproduce (it does not produce more mules). Whereas fission or the splitting of entities into two is a property of autocatakinetics (physics) under the appropriate field conditions (e.g., Bénard cells (see Figure 8) and villages), it is not diagnostic of the living. The generality of the replicative autocatakinetic definition of the living should also be noted; it does not require specifying any particular scale or components, or a boundary. On this view cultural systems (human social systems) are living systems, too, although of a particular kind: their autocatakinetics is specified by second-order kinematic fields (see text).

105. The adjective "replicative" as distinct from "replicating" is borrowed by Csanyi [V. Csányi, *Evolutionary Systems and Society*. Duke University Press, Durham, NC, 1989].
106. R. Swenson, "Evolutionary systems and society." *World Futures*, **30**, No. 3, 1991, pp. 199–204.
107. The primitive nature of this particular kind of constraint was introduced by Polanyi [M. Polanyi, "Life's irreducible structure." *Science*, **160**, 1968, pp. 1308–1312] and has been refined and argued with great force over the years by Pattee [H. Pattee, "Dynamic and linguistic modes of complex systems." *International Journal of General Systems*, **3**, 1977, pp. 187–197; and "Cell psychology: An evolutionary approach to the symbol-matter problem." *Cognition and Brain Theory*, **5**, 4, 1983, pp. 325–341].
108. E.g., the amount of ATP required to replicate DNA is the same regardless of the particular sequence; the difference in the amount of entropy production involved in writing or printing two alternate phrases on this page (even if they have completely contradictory meanings) is inconsequential with regard to which one gets written; in geological time this page and the ink (the chemistry) that instantiates the words will dissipate extremely rapidly regardless of the sequence of the words, but they are absolutely stable or inert (rate-independent) relative to the rate at which they are written (printed) or read, regardless of the sequences.
109. It is precisely this rate-independence of DNA strings relative to the rest of the cellular dynamics that renders illegitimate, *a priori*, the attribution of any kind of active, purposive behavior to genes, e.g., "striving," "selfish" replicators: it is denied absolutely by their function. They are inert relative to the dynamics of the cell. The autocatakinetic cycle is the minimal selfish unit; genes are harnessed by autocatakinetics towards their own dissipative ends.[65,67]
110. F. F. Robb, "On the application of the theory of emergence and of the law of maximum entropy production to social processes." *Systems Practice*, **3**, 4, 1990, pp. 389–399.
111. F. F. Robb, "Are institutions entities of a natural kind?" In *Handbook of Systems and Cybernetics*, edited by C. Negoita, Marcel Dekker, Inc., New York, 1991, pp. 149–162.
112. R. Swenson, "Comments on Robb's research note, 'On the application of the theory of emergence and of the law of maximum entropy production to social processes'." *Systems Practice*, **3**, 4, 1990, pp. 401–402.
113. I have some sympathy for the authors' position here, having used the word "sociophysics" for such purposes myself.[69]
114. A double-dual formalism (not a *dualism*!) has been proposed by Shaw and Alley to capture the ecological relationship between perception and action where the values of X are environmental properties, and the corresponding values of Y are properties of a living system. As a mathematical duality, D is an operation establishing an isomorphic correspondence between X and Y such that for any function f that establishes a value in X there is another function g that establishes a corresponding or dual value in Y. The duality operation, $f: X \rightarrow Y$, is perception and its values, *affordances*; the inverse duality operation, $g: Y \rightarrow X$, is action and its values, *effectivities*. The operations f and g, $D: X \rightarrow Y$, designate a system of constraints comprising the ecological relation between perception and action [R. E. Shaw, and T. Alley, "How to draw learning curves: Their use and justification." In *Issues in the Ecological Study of Learning*, edited by T. Johnston and A. Pietrewicz, Erlbaum, Hillsdale, NJ, 1985, pp. 275–304].

Rod Swenson Originally an accomplished experimentalist in mass culture, Rod Swenson, who completed his graduate work at Yale, began working in biology and physics in an effort to address the deeper and unanswered questions of evolution. For the past decade his work has focussed on evolution as spontaneous order production and its ontological and epistemological consequences for being in what he calls a "global self-organizing becoming." The recipient of numerous awards, he is currently a Research Fellow at the Center for the Ecological Study of Perception and Action at the University of Connecticut, Storrs, where he is working on problems of ecological (multileveled) physics. His book, *Spontaneous Order, Evolution, and Natural Law* (Lawrence Erlbaum Associates, Hillsdale, NJ), will be published later this year.