Spontaneous Order, Autocatakinetic Closure, and the Development of Space–Time

ROD SWENSON[a]

Center for the Ecological Study of Perception and Action, Department of Psychology, University of Connecticut, Storrs, Connecticut, USA

ABSTRACT: Over its 4.6 billion year history, the time-dependent behavior of planet Earth, from the origin and emergence of life to the explosive globalization of human culture today, shows the progressive and accelerating production of increasingly more highly ordered dynamic states. Understanding our place as both productions and producers in this rapidly accelerating global becoming is a requisite step to the meaningful grounding of virtually every other discipline, most particularly those disciplines relating to the endeavors and activities of humans themselves. Recent advances in the study of spontaneous ordering provide both a minimal ontological framework required for causally addressing such systems, and the nomological basis for understanding the ubiquitous or universal generic nature of such ordering itself. This paper briefly outlines the main points.

INTRODUCTION

Given the first law of thermodynamics, which in its deepest sense refers to the time-translation symmetry or continuity of all natural (known) processes, evolutionary or emergent processes can be understood as differentiations or time-asymmetric developments of (or out of) a continuum. The relationship between symmetry, broken symmetry, and what we may now refer to as the development of space–time, has been recognized in various forms; although not well understood from the time of the preSocratic dispute between the Parmenidean and Heraclitean schools. These matters have continued to occupy the attention of the deepest thinkers in modern times, from the likes of Spinoza and Leibniz to such otherwise apparently disparate thinkers as Spencer, Marx, and Engels. One could argue, that as a result of the development of space–time itself, we are in a far better position today to be able to understand these matters. The implications run deep across the disciplines.[1–3] Given the limited length of this article, I concentrate on, and briefly review, two main points. The first may be thought of as an ontological assertion that yields a strategic or methodologic point. It addresses the issue of what it is that we must minimally consider, even in some very generalized sense, when we talk about emergent or evolutionary systems and their dynamics.[4] The second, is a more recent theoretical point that gives us a principled basis for understanding spontaneous ordering or emergent dynamics themselves. Why, in contrast to what was previously given as an incommensurability between continuum and discontinuum (viz., between biology,

7.

psychology, and physics), the supposed *infinite improbability* of the production of order from disorder, as Boltzmann saw it, we now understand that the opportunistic development of space–time, the development of discontinuum out of continuum, or in different terms the production of progressively higher ordered from lesser ordered states follow directly from natural law.[5,6]

AUTOCATAKINETICS, THE MINIMAL ONTOLOGY, AND THE DEVELOPMENT OF SPACE–TIME

All living things, including cultural systems as well as terrestrial life at the planetary level, that operate as a single system on which the other more ordinarily considered forms depend as component productions or processes, can be seen as part of a progressive (time asymmetric) process characterized by the production of increasingly more highly ordered states—literally, as is illustrated below, the progressive development of space–time itself.[1,2] FIGURE 1 shows the development of more highly ordered forms over evolutionary time as a function of the progressive increase in planetary oxygen levels, a consequence of life itself, and the most obvious prima facie demonstration for operation of the planetary level as a unitary system.[6] Since the emergence of life on the Archean Earth some 4.5 billion years ago, the amount of terrestrial matter has remained roughly constant, and the production of dynamic order constituting the development of life, including human culture, is thus seen as the cycling of this same matter under the impress of the geocosmic gradient into progressively higher ordered forms or dimensions of space–time. Such forms (including us) are, therefore, flow or process structures. They (we) are *autocatakinetic* systems.

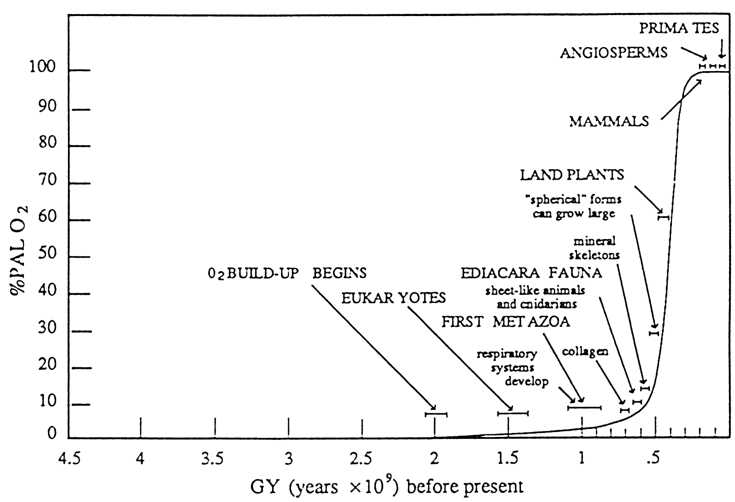

FIGURE 1. The production of progressively higher states of order as function of increasing levels of atmospheric O_2 in geological time; *PAL* is present atmospheric level. (From Ref. 12, reproduced by permission of IEEE.)

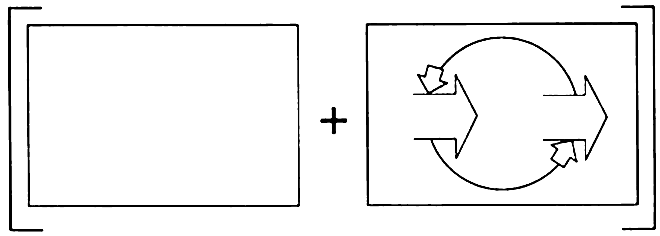

FIGURE 2. A schematic for the conjunction capturing the generalized minimal ontology of an autocatakinetic system. The *right side* shows the circularity of the self–other relation and the one-way flow (time asymmetry) of the (time symmetric) conservation (*left side*) through which it is constituted or distinguished. (From Ref. 7, reproduced by permission of Erlbaum and Associates.)

FIGURE 2 shows the generalized conjunction capturing the *minimal ontology* of an autocatakinetic system.[4,7] An autocatakinetic system is one that maintains itself "as an entity constituted by, and empirically traceable to, a set of nonlinear (circularly causal) relations through the dissipation or breakdown of environmental potentials (or 'resources') in the continuous coordinated motion of its components."[6]

It is the closure, or circularity of the autocatakinetic relations whereby the output works back on the input that defines and maintains the autocatakinetic system as a distinct entity, but one whose identity only exists and is maintained through its environment. When we talk of autocatakinetic systems, therefore, we are necessarily talking about a *relational ontology.* This makes the strategic methodologic point advertised in the introduction: that the discontinuum is only intelligible through an understanding of the continuum from which it emerges, arises, is a differentiation or production, and through which it is constituted. In different terms, it is the whole conjunction depicted in FIGURE 1 that must be included. This is in contrast to the Cartesian tradition with its various ramifications that attempt to invoke the self as existing independently from the other (or environment), as well as the more encompassing continuum itself (the left-hand side of the conjunction). For example, theories of perception, where what is perceived are "mental states" (the *Cartesian circle*), or its contemporary symbol-processing extension with the mind-as-computer model of cognitive science; and various closed-cycle theories, or functionalist schemes in social theory, where a set of cyclic relations only refer back to themselves.[2–4,8] From an *a posteriori*, or empirical, standpoint, no such systems exist in the world other than in the minds of humans; and from an *a priori* standpoint, given the law of energy conservation (or time-translation symmetry that defines the event horizon of what is causally efficacious and/or knowable) such systems *cannot* exist. The dysfunctional theoretical consequences of what is often a transparent importation of Cartesian assumptions under other names has been addressed in more detail elsewhere.[2,4,5,7,8] Among these consequences is the fact that such theories are essentially static or antievolutionary with no basis to explain or even to recognize origins and development. In a developmental world, one that is only deeply intelligible in the "present progressive",[9,10] this itself is a fatal problem.

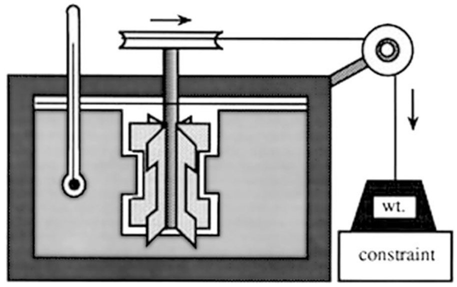

FIGURE 3. The experiment devised by Joule to demonstrate the conservation of energy. When a constraint is removed, potential energy in the form of a suspended weight is converted into the kinetic energy of a moving paddle wheel in a container of water sealed against other inflow or outflow of energy. The moving paddle wheel heats the water by a precise amount consistent with the falling weight. (From Ref. 3, reproduced by permission of JAI Press.)

In contrast, autocatakinetic systems (and the *world* of which they are productions or manifestations), are inherently developmental. FIGURE 3 shows two time slices from the Bénard cell experiment that shows this in a simple physical system. Here, the relationship between the development of autocatakinesis or spontaneous ordering and the instantiation of new levels of space–time is readily seen. Although in the disordered regime the intrinsic space–time dimensions are defined by mean free path distances and relaxation times (the distances and times between collisions) on the order of 10^{-8} centimeters and 10^{-15} seconds, in the ordered regime it takes the fluid some seconds to make an autocatakinetic cycle between source and sink, and the distance covered (the size of one cell) is measured in centimeters. The latter is orders of magnitude greater than the former, and does not exist in the disolved regime. The dynamics of autocatakinetic systems includes origins and development as characteristic properties.

WHY THE WORLD IS IN THE ORDER PRODUCTION BUSINESS: RESOLVING THE PROBLEM OF THE TWO *RIVERS*

Spontaneous ordering and development (the progressive development of space–time) are characteristic properties of autocatakinetic systems. However, this "flowing up" to increasingly more highly ordered dimensions, the "river that flows uphill", was until recently taken to be anomalous with respect to physics. Physics, with the second law of thermodynamics (the *entropy* law), was thought to dictate a progressive "flowing down" to disorder (the "river that flows downhill"). Evolution and the development of life were seen to negate physics and vice versa. This has had a profound obfuscatory effect on our understanding of living systems, from planetary evolution writ large, to culture theory, to psychology (clinical and otherwise). This old view, due largely to the work of Boltzmann, is no longer tenable and we now understand spontaneous ordering not to be "infinitely improbable" with respect to universal law, but instead a direct consequence of it.

SYMMETRY, BROKEN-SYMMETRY, AND THE FIRST AND SECOND LAWS OF THERMODYNAMICS

The laws of thermodynamics are special laws that sit above the ordinary laws of nature, as laws about laws or laws upon which the other laws depend. As noted above, the first law—the law of energy conservation—which says that all real world processes involve transformations of energy, and that the total amount of energy is always conserved, expresses time-translation symmetry. As far as the first law is concerned, nothing changes at all and this is just the definition of a symmetry, something that remains invariant, indifferent or unchanged given certain transformations. The remarkable point with respect to the first law is that it refers to that which is conserved (the quantity of energy) or remains symmetric under *all* transformations. Although intuited at least as early as the work of the Milesian physicists and in modern times particularly by Leibniz, the first law is taken to have been first explicitly "discovered" in the first part of the nineteenth century by Mayer, then Joule, and later Helmholz, with the demonstration of the equivalence of heat and other forms of energy. Discovery was completed in the twentieth century with Einsteins's demonstration that matter is also a form of energy. FIGURE 4 shows the experiment Joule devised to demonstrate the law.

The second law was formulated in the middle of the eighteenth century by Clausius and Thomson following Carnot's earlier observation that, like the fall or flow of a stream that turns a mill wheel, it is the *fall* or flow of heat from higher to lower temperatures that motivates a steam engine. The key insight was that the world is inherently active and that whenever an energy distribution is out of equilibrium a potential or thermodynamic force (the gradient of a potential) exists that the world

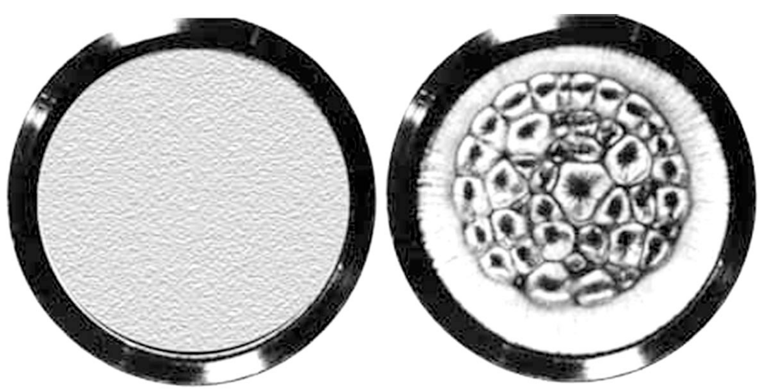

FIGURE 4. Two time slices from the Bénard experiment. When the gradient of the potential (the "force") between source (the heated surface below) and the sink (the cooler air at the top) is below a critical threshold (*left*) a flow of heat is produced by random collision of the molecules (conduction), and the system is in the disordered or Boltzmann regime, where the surface of the system (silicon oil) is smooth, homogeneous, and symmetrical. When the force is above the critical threshold (*right*), the symmetry of the system is broken and autocatakinetic order spontaneously arises. (From Ref. 19, reproduced by permission of Pergamon Press.)

acts spontaneously to dissipate or minimize. Whereas the first law expresses that which remains the same, or is time-symmetric, in all real-world processes; the second law expresses the fundamental time-asymmetry in all real-world process. Clausius coined the term "entropy" to refer to the dissipated potential, and the second law, in its most general form, states that the world acts spontaneously to minimize potentials (or equivalently maximize entropy). The balance equation of the second law, expressed by $\Delta S > 0$, says that in all natural processes the entropy of the world always increases and thus, whereas with the first law there is no time—past, present, and future are indistinguishable—the second law, with its one-way flow, introduces the basis for telling the difference.

The active nature of the second law is intuitively easy to grasp and to demonstrate empirically. If a cup of hot liquid, for example, is placed in a colder room a potential exists and a flow of heat is spontaneously produced from the cup to the room until the potential is minimized (or the entropy is maximized) at which point the temperatures are the same and all flows stop. Of important theoretical interest is the fact that Joule's experiment, although designed to show the first law, unintentionally demonstrates the second also. As soon as the constraint is removed, the potential produces a flow from the falling weight through the moving paddle through the thermometer. This is precisely the one-way action of the second law and the experiment depends upon it entirely.

BOLTZMANN'S VIEW OF THE SECOND LAW AS A LAW OF DISORDER

The active macroscopic nature of the second law posed a direct challenge to the "dead" mechanical world view that Boltzmann tried to meet in the latter part of the nineteenth century by reducing the second law to a law of probability following from the random collisions of mechanical particles (to efficient cause).[11–15] Following the lead of Maxwell, who had modeled gas molecules as colliding billiard balls, Boltzmann argued that the second law was simply a consequence of the fact that, with each collision nonequilibrium distributions became increasingly disordered leading, to a final state of macroscopic uniformity and microscopic disorder. Because there are so many more possible disordered states than ordered ones, he concluded, a system will almost always be found either in the state of maximum disorder or moving towards it.

As a consequence, a dynamically ordered state, one with molecules moving "at the same speed and in the same direction," Boltzmann asserted, was thus "the most improbable case conceivable…an infinitely improbable configuration of energy." Because this idea works for certain near equilibrium systems, such as gases in boxes, and because science until recently was dominated by near equilibrium thinking, Boltzmann's attempted reduction of the second law to a law of disorder became widely accepted. It became the apparent justification from physics for solidifying Cartesian incommensurability and establishing the view of the two incommensurable rivers—the river of biology, psychology, and culture, or the epistemic dimension of the world flowing up to increasingly higher states of order, versus the river of physics flowing down to disorder. Beyond making the epistemic dimension (e.g., biology, culture, psychology) of the world entirely anomalous and incommensurable with respect to the physical part, however, the Boltzmann view is readily falsified by simple physical experiments, such as the Bénard experiment mentioned above. In this experiment dynamic order, or autocatakinetics, is seen to arise not infinitely improbably, but with probability one, that is, every time and as soon as it gets the chance. Rather than incommensurabilty, or anomaly, this suggests a universality to spontaneous ordering that would unify the two *rivers*.

BERTALANFFY, SCHROEDINGER, AND PRIGOGINE AND THE BALANCE EQUATION OF THE SECOND LAW

An important contribution was made toward this discourse in the middle of this century by Bertalanffy[16] who showed that "spontaneous order…can appear" in systems with energy flowing through them; and Schrödinger,[17] who, comparing living things to flames, pointed out that such systems (all autocatakinetic systems) do not violate the second law as long as they produce entropy (or minimize potentials) at sufficient rates to compensate for their ordering (their increase in space–time dimensions or internal entropy reduction) and, thereby, satisfy the balance equation of the second law. The idea was further popularized by Prigogine[18] under the rubric of "dissipative structures". Such systems were thus given "permission" to exist given the classical view of the second law, but according to Boltzmann's interpretation they were still *infinitely improbable*. The question of why order is seen to arise whenever it gets the chance, in simple physical systems, in the evolutionary record writ large, in the "fecundity principle" on which Darwinian theory depends, and in the directedness towards, that characterizes the intentional content of epistemic activity in general remained.

THE LAW OF MAXIMUM ENTROPY PRODUCTION OR WHY THE WORLD IS IN THE ORDER PRODUCTION BUSINESS

The solution to the puzzle is found in two parts.[3,5,11,12] The first is the recognition of an important point found implicitly in the Bertalanffy–Schrödinger–Prigogine contribution but not noted explicitly by them. In particular, since to come into being and persist, an autocatakinetic system must increase the rate of entropy production of the system plus environment at a sufficient rate to satisfy the balance equation of the second law, then ordered flow, according to the balance equation, must be more efficient at dissipating potentials that disorder flow. FIGURE 5 shows the dramatic increase in the rate at which the potential is minimized, for example, in the Benard cell experiment in the transition from the disordered to ordered regime, and the balance equation tells us that this is precisely what must happen.

Now this becomes important only with the second part of the solution, which is the answer to a question that was never addressed in the Bertalanffy–Schrödinger–Prigogine discourse. In particular, which path(s) out of all available paths will a system take to minimize potentials or maximize the entropy? The answer (the *law of maximum entropy production*) is the path or assembly of paths that minimizes the potential (maximizes the entropy) at the fastest rate given the constraints. Just like

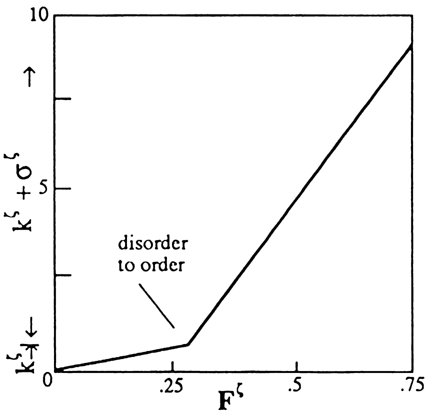

FIGURE 5. The discontinuous increase in the rate of heat transport that follows from the disorder-to-order transition in a simple fluid experiment similar to that shown in FIGURE 4. The rate of heat transport in the disordered regime is given by k^t, and $k^t + \sigma$ is the heat transport in the ordered regime (3.1×10^{-4}H cal $\times$ cm^{-2} $\times$ sec^{-1}). (From Ref. 19, reproduced by permission of IEEE.)

the second law, the law of maximum entropy production is intuitively easy to grasp and to empirically demonstrate. Imagine any system that is out of equilibrium, with multiple available pathways; such as a heated cabin in the middle of snowy woods.[6] In this case the system produces flows through the walls, the cracks under the windows, the door, and so on so as to minimize the potential. What we all know intuitively (why we keep doors and windows closed in winter) is that whenever a constraint is removed so as to provide an opportunity for increased flow, the system will reconfigure itself so as to allocate more flow to that pathway, leaving what it cannot accommodate to the less efficient or slower pathways. In short, no matter how the system is arranged the pattern of flow produced will be the one that minimizes the potential at the fastest rate given the constraints. Once this idea is grasped, examples are easily proliferated.

What does the law of maximum entropy production have to do with order production? Given the foregoing, the reader may have already jumped to the correct conclusion; namely, *if* ordered flow produces entropy faster than disordered flow (as required by the balance equation of the second law), *and if* the world acts to minimize potentials at the fastest rate given the constraints (the law of maximum entropy production), *then* the world can be expected to produce order whenever it gets the chance.[3,5,11,12] The world can be expected to act opportunistically in the production of dynamic order in the development of space-time because potentials are thereby minimized at a faster rate. The world, in short, is in the order production business, because ordered flow produces entropy faster than disordered flow and this, in most direct terms, provides the nomological basis for the reconciliation of two otherwise incommensurable rivers, discontinuum and continuum, of biology, psychology, and physics. Rather than being anomalous with respect to, or somehow violating, physical law the river that flows uphill characteristic of the active epistemic dimension of the world, of biology, psychology, and culture is seen to be a direct manifestation of it. A more detailed discussion on intentional dynamics and the nomological basis for meaningful relations is beyond the scope of this paper, and is provided elsewhere.[1–5]

REFERENCES

1. SWENSON, R. 1999. Epistemic ordering and the development of space–time: intentionality as a universal entailment. Semiotica. In press.
2. SWENSON, R. 1998. Spontaneous order, evolution, and autocatakinetics: The nomological basis for the emergence of meaning. *In* Evolutionary Systems. G. Van de Vijver, S. Salthe & M. Delpos, Eds. :155–180. Kluwer Academic Publishers. Dordrecht, The Netherlands.
3. SWENSON, R. 1997. Autocatakinetics, evolution, and the law of maximum entropy production: a principled foundation toward the study of human ecology. Adv. Hum. Ecol. **6:** 1–46.
4. SWENSON, R. 1998. Autocatakinetics, the minimal ontology, and the constitutive logic of ecological relations. Jap. J. Cont. Phil. **25:** 234–245. (Japanese.)
5. SWENSON, R. 1997. Thermodynamics, evolution, and behavior. *In* Comparative Psychology: A Handbook. G. Greenberg & M. Haraway, Eds. :207–218. Garland Publishing. New York.
6. SWENSON, R. & M.T. TURVEY. 1991. Thermodynamic reasons for perception–action cycles. Ecol. Psych. **4:** 317–348.
7. SWENSON, R. 1997. Evolutionary theory developing: the problem(s) with Darwin's Dangerous Idea. Ecol. Psych. **9:** 47–96.
8. SWENSON, R. 1992. Autocatakinetics, yes—autopoiesis, no: steps towards a unified theory of evolutionary ordering. Int. J. Gen. Syst. **21:** 207–228.
9. MATSUNO, K. 1999. The clock and its triadic relationship. Semiotica. In press.
10. MATSONO, K. & R. SWENSON. 1999. Thermodynamics in the present progressive mode and it's role in the context of the origin of life. Biosystems. In press.
11. SWENSON, R. 1989. Gauss-in-a-box: nailing down the first principles of action. Perceiving-Acting Workshop Review (Technical Report of the Center for the Ecological Study of Perception and Action) **5:** 60–63.
12. SWENSON, R. 1989. Engineering initial conditions in a self-producing environment. *In* A Delicate Balance: Technics, Culture and Consequences. M. Rogers & N. Warren, Eds. :68–73. Institute of Electrical and Electronic Engineers. Los Angeles, CA.
13. SWENSON, R. 1991. 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. F. Geyer, Ed. :41–60. Intersystems Publications. Salinas, CA.
14. SWENSON, R. 1991. Order, evolution, and natural law: fundamental relations in complex system theory. *In* Cybernetics and Applied Systems, C. Negoita, Ed. :125–148. Marcel Dekker Inc. New York.
15. BOLTZMANN, L. 1974. The second law of thermodynamics. *In* Theoretical Physics and Philosophical Problems. 13–32. D. Reidel Publishing. Boston, MA.
16. VON BERTALANFFY, L. 1952. Problems of Life. Watts. London.
17. SCHRÖDINGER, E. 1945. What is Life? Macmillan. New York.
18. PRIGOGINE, I. 1978. Time, structure, and fluctuations. Science **201:** 777–782.
19. SWENSON, R. 1989. Emergent attractors and the law of maximum entropy production: foundations to a theory of general evolution. Syst. Res. **6:** 187–198.