

Selection Is Entailed by Self-Organization and Natural Selection Is a Special Case

Rod Swenson

Center for the Ecological Study of Perception and Action
University of Connecticut
Storrs, CT, USA
rswenson@aya.yale.edu

Abstract

In their book, *Darwinism Evolving: Systems Dynamics and the Genealogy of Natural Selection*, Depew and Weber (1995) argued for the need to address the relationship between self-organization and natural selection in evolutionary theory, and focused on seven “visions” for doing so. Recently, Batten et al. (2008) in a paper in this journal, entitled “Visions of evolution: self-organization proposes what natural selection disposes,” picked up the issue with the work of Depew and Weber as a starting point. While the efforts of both sets of authors are to be commended, there are substantive errors in both the presentations of my work and of my work with colleagues (one of the “visions” discussed) that undermine theirs. My purpose here is to correct the errors in question, thereby removing the undermining effects and in so doing reassert the position my colleagues and I first advanced more than two decades ago, and that I still stand by and argue for today. The central points are as follows: (1) Self-organization or spontaneous ordering *is* a process of selection; (2) this selection process is governed by a “physical selection principle”; (3) this principle is the law of maximum entropy production; and (4) natural selection is a special case where the components are replicating.

Keywords

autocatakinetics, evolution, maximum entropy production, natural selection, physical selection, self-organization, spontaneous order

In the concluding and summary chapter of their book, *Darwinism Evolving: Systems Dynamics and the Genealogy of Natural Selection*, Depew and Weber (1995) argued that until the issue of self-organization was integrated into the theoretical corpus of evolutionary theory, in particular by establishing what its relationship was to natural selection, if any, evolutionary theory would remain incomplete. Reviewing what they viewed as the then leading efforts toward this end, they produced a taxonomy of seven different possible approaches and further discussed the consequences each would have with respect to orthodox Darwinian theory; e.g., if one or the other of the seven turned out to be the dominant new view, then to what extent would that mean that evolutionary theory was or was not any longer Darwinian? Recently Batten et al. (2008), in a paper entitled “Visions of evolution: Self-organization proposes what natural selection disposes,” revisited the problem and proposed what they say is a more comprehensive view that resolves the problem, incorporating in some way parts of the other views.

At the outset, I should say that, in my view, the work advanced by Depew and Weber on this subject, in particular their insistence that the issue of self-organization in evolution itself be explicitly addressed, has been of substantial importance. In the same vein, Batten et al. (2008) are to be commended for re-insisting on the importance of the issue and once again putting it so explicitly on the table. Having said that, however, there are some substantive errors made by both sets of authors with respect to my views as well as “facts of the world” that I hope to address here. Beyond the fact that it is still in print and widely read, the reason Depew and Weber’s book, now over 15 years old, finds its way into the current article is principally because Batten et al. build their paper on it, repeating many of the errors made by Depew and Weber. In Depew and Weber’s *Darwinism Evolving* and in the 2008 paper by Batten et al., “Vision 5” of the seven visions is attributed to me (e.g., Swenson 1991a; Swenson and Turvey 1991). It is particularly the errors or misstatements about my views that I will address here, not so much because of a wish not to have misattributions stand, although this is part of the reason, but because the view my colleagues and I advanced regarding the relationship between self-organization and natural selection more than two decades ago is the view I still hold today.

As already noted, Depew and Weber spend a good deal of time discussing to what extent evolutionary theory will still be “Darwinian” as a consequence of whether one or another of the seven views were to become the dominant view. For example, my view, abbreviated for convenience to *selection is entailed by self-organization and natural selection is a special case*, according to which they say “natural selection becomes an instantiation of the most basic physical processes” (Depew and Weber 1995: 483) is particularly problematic for Darwinism, while view six, “in some ways the opposite. . . (where)

. . . natural selection is . . . the author . . . or shaper of self-organization . . . (is) quite Darwinian in spirit” (Depew and Weber 1995: 484). My central interest, and focus here, however, is evolutionary theory in general and not “Darwinism” by whatever definition per se, and I will thus not spend time here on whether one view or another should or should not be taken, say, as an extension of Darwinian theory as opposed to a replacement for it.

My view has never been that natural selection, the core of Darwinian theory, is wrong, but rather that it is not sufficient, on its own, or as a primitive, to explain evolution. It is rather the consequence of the more general process of spontaneous ordering, or self-organization, and selection grounded in deeper thermodynamic law. Once the relationship between natural selection and self-organization is understood, the corpus of evolutionary theory is immediately greatly expanded.

Defining Self-Organization

Clearly all of us know that the outcome of an argument is altered if the definitions of the terms are changed, and thus crucial to assertions about the role of self-organization in evolution is a definition of what it is. While there is a good deal of discussion in *Darwinism Evolving* about “dissipative structures” and “open systems,” which as most generally construed would be consistent with where I come from with the term “self-organization” (and I will give more precision to this below), when it comes to the seven visions that Depew and Weber distinguish in their taxonomy, they include what are more generally construed as “developmental constraints,” “laws of form,” or allometry. Some of the work they discuss in this area has been substantially demonstrated and some hypothetically and abstractly modeled on computers. While not offering comment here in favor of or against any of the particular instances they cite (which is beyond the scope of this article), I should say that such principles, in my view, do have an important role in evolutionary theory. Laws of form of this kind play a crucial role in the way natural selection, and more generally self-organization, plays out, or can or cannot work. Having said that, however, they do not, at least by the definition I have used historically for self-organization and review further below, constitute self-organization itself.

Thus one of the problems with Depew and Weber’s presentation, perhaps the main overall problem, is that they use “self-organization” in multiple ways. Nowhere do they give a real definition as to what they mean by the term. Batten et al. (2008: 18), in contrast, to their credit, do provide an explicit definition. “Self-organization,” they say, adopting a definition from Camazine et al. (2001: 8), is

a process in which pattern at the global level of a system emerges solely from interactions among the lower level components of the

system. Moreover, the rules specifying interactions among the system's components are executed using only local information, without reference to the global pattern.

Unfortunately, the definition they adopt here is deficient in some profound ways, including its ability to be consistent with much of the way Batten et al. (2008) use the term self-organization in their own paper. The only place where a "global pattern" is produced solely from rules executed by "lower level components" is inside a computer, where the word "solely," given that the whole system is extrinsically programmed, is questionable at best. But even if the definition were expanded or enriched somewhat (by providing some additional "real world" ecological or macroscopic context and thus eliminating the word "solely" from the definition), a major problem would remain. Namely, by invoking "rule execution" as the means by which macro-order (or "global pattern") is established, all abiotic self-organizing systems, in particular those that have historically been used as classic exemplars of self-organization as well as by both sets of authors in the papers discussed here (such as the Bénard cell), would be eliminated from the category. In fact, it is worth noting that the process described with this definition by its original authors is the collective behavior of already highly evolved multicellular organisms (e.g., social insects) where the "subunits (or lower level components)," according to Camazine et al. (2001: 12), "behave according to particular genetic programs that have been subjected to natural selection."¹ They even make a point of saying that their definition *does not* apply to self-organization "in physical systems (where) . . . pattern is created through interactions based solely on physical laws" (2001: 12).

By making self-organization, in the best interpretation of the definition, the product of natural selection, Batten et al. (2008) not only foster a premise that is upside down with respect to self-organization as classically construed, but at odds with their own premise that *self-organization proposes what natural selection disposes*, the latter clearly (and rightfully) implying that self-organization in some sense is a process prior to natural selection to begin with. One finds their definition particularly surprising because one of the coauthors, Salthe (e.g., 1993), has been a strong advocate for incorporating and understanding the generic dynamics of nonliving, self-organizing systems into biological and evolutionary theory for many years. Indeed both sets of authors, Batten et al. (2008) and Depew and Weber (1995), attempt to do it. Clearly then, we need a different definition. In any case, to defend or explain what I have asserted and continue to assert about self-organization with respect to what is represented by both sets of authors as my views about it, it will be important to be explicit at least about how I have defined the term and have meant and continue to mean by it. I do this in the next section.

Self-Organizing Systems Are Autocatakinetic (ACK) Systems

The core of the problem beyond what Camazine et al. (2001), and thus Batten et al. (2008), explicitly put into their definition (viz., rules and rule-execution of the micro- or lower-level components) is what they explicitly leave out. Such a description takes the environment, the continuum or field with its conservations, laws governing their distribution, and the forces and flows through which all real-world self-organizing systems are constituted, out of the picture; and such decoupled systems do not exist in the natural world. We need to clearly distinguish between members of the class of "real-world" self-organizing systems and the use of the term for ideal systems such as rule-based systems that exist only on computers or other machines that are, in fact, clearly ordered by outside makers (programmers). Real-world, self-organizing systems are flow structures that arise and are maintained relationally with and through their environments (or the continua from which they as discontinua are at once constituted and through which they are distinguished). Such systems, to use the term my colleagues and I adopted and defined some two decades ago just to make and clarify such distinctions, are "autocatakinetic" (ACK) systems (e.g., Swenson 1991a, 1992, 1997a; Swenson and Turvey 1991). In particular, an ACK system is identified and defined as follows:

An autocatakinetic system is a system that maintains its "self" as an entity constituted by, and empirically traceable to, a set of nonlinear (circularly causal) relations through the dissipation or breakdown of field (or environmental) potentials (or resources) in the continuous coordinated motion of its components.²

It is the circularity or "closure" of the ACK relations whereby the output works back on the input that defines the ACK system as a distinct entity, but one whose identity is only maintained *through* the environment (or continuum) out of which it arises (see Figure 1). Figure 1 is presented as a conjunction to underscore that with an ACK system, we are thus necessarily talking about a *relational ontology*, and it is the whole conjunction, therefore, that must be included in the description. From this description, it is seen that all living systems, from cells to ecosystems at whatever scale, are ACK systems as are abiotic systems, such as dust devils, hurricanes, and tornadoes, and classic historical exemplars of the class, such as the Bénard cell used by Depew and Weber (1995) in their paper, discussed below, and reviewed in the Appendix, which I will refer to throughout to provide further details and illustrative examples (see also Swenson 1997a; Carriveau's (2006) hydraulic vortex model). What this definition explicitly does not include are machines, artifacts, or systems said to run exclusively on or by rules or rule execution. All of these systems, ideal or not, are found to be component processes of ACK systems but are not ACK systems themselves.

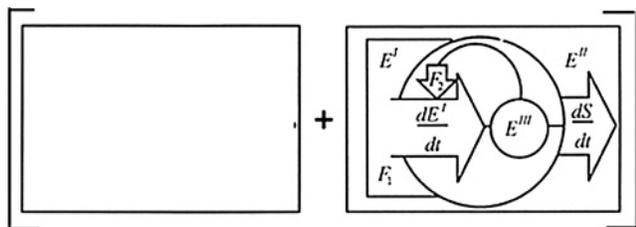


Figure 1.

A generalized schematic of an autocatakinetic (ACK) system, where the right side of the conjunction shows the circular relations (the basic “self”) defining the time asymmetric flow (from source to sink) of the conservation or continuum shown on the left side of the conjunction out of and through which it is constituted. E' and E'' indicate a source and a sink with a force F_1 (a gradient of a potential), the magnitude of which is a measure of the difference between them. dE'/dt is the energy flow at the input or drain on the potential that is transformed into entropy production dS/dt at the output. E''' is the internal potential carried in the circular relations that define the system by virtue of its distance from equilibrium that acts back with an internal force F_2 to amplify or maintain the input during growth or non-growth phases, respectively. Source: Adapted from Swenson 1989c, p. 191. Copyright © 1989 Pergamon Press. Reprinted by permission.

Where’s the Self?

Batten et al. (2008) say that “a locale may itself be predisposed toward changes that would systematically bias the outcome (of what occurs in nature) thus validating the label ‘self;’” but it is hard to see how a predisposition (which could be any inhomogeneous distribution of energy with ordinary laws as known) distinguishes a “self.” In an ACK system the self as identity and “actor” or “agency” comes from the empirically traceable ACK closure of the circular relations constituted through the asymmetry of the source–sink flow. Seeded at their origins by microscopic fluctuations or stochasticities (see the Appendix for further discussion), the “selfishness” of ACK systems is both manifested and located in the fact that through the circular relations that define them they are self-amplifying sinks, or “deviation-amplifying systems” (Maruyama 1963) acting back on themselves to pull environmental resources into themselves in their own space–time extension. To underscore how this “selfishness” works in a relational way, it is important to note that with the extension of their own space–time dimensions ACK systems concomitantly extend the space–time dimensions of the fields, continua, or environments from which they emerge and through which they exist. Given what we now understand about universal law (viz., the law of maximum entropy production (LMEP), which I have reviewed below), the mutual entailment of system and environment in autocatakinetic or the development of space–time is readily understood (Swenson 1999, 2000).

Citing work from our laboratory, although substituting the word “autocatalytic” for “autocatakinetic,” Depew and Weber (1995) use the classic exemplar of the Bénard cell experiment to identify the circular relations of autocatakinetic and rightly emphasize the dramatic increase in space–time dimensions that occurs in this system with the transition from disorder to order (or with the self-organization of the system). They write:

creating a macroscopic structure that is . . . at least 100 billion times the scale of molecular dimensions in water itself. Self-amplifications like these are ‘circularly causal’ in . . . that they take the form of an autocatalytic cycle, in which the incipient formation of structure . . . reflexively reinforces the formation of more structure until the system settles down to a new steady state (Swenson and Turvey 1991). This is an example of a stochastic fluctuation that breaks the symmetry of the linear regime . . . (taking the system into the) realm of nonlinear dynamics. (Depew and Weber 1995: 463)

While this description captures some important points (e.g., circular relations, amplification of stochasticities, expansion of space–time dimensions; see the Appendix for a review of the whole experiment),³ the use of the term “autocatalytic” in place of “autocatakinetic” is a substantive error unless one wants to expand the meaning of the term “autocatalytic” beyond its ordinary use for chemical reactions (which some have done), because there are no chemical reactions in the Bénard cell experiment. But expanding the definition does not seem to be Depew and Weber’s (1995: 462) intent because on the previous page of their book, where they introduced the term, they define “autocatalytic cycle” in the conventional way as “a chemical reaction that produces a substance that can help the production of another reaction just like it.”

This confusion about terms surrounding the idea of self-organization, and where to apply what, becomes more substantive later in Depew and Weber’s book with their discussion of the origin of life, where they continue to use the term in its conventional sense, and then rely on it to distinguish the class of systems using chemistry from simpler “physical” systems such as the Bénard cell that do not thus directly contradict themselves. This conflicting and confusing use of terms underscores the failure here to thus appropriately integrate the generic behavior of the broader class of systems with its kinds, in particular the generic behavior of ACK systems in general (including simpler “physical” systems) and what they call “autocatalytic cycles” or “networks of autocatalytic cycles,” referring to systems with chemistry. This problem with identifying the generic behavior of the broad class of self-organizing systems then finds its way into their mischaracterization of “physical selection” as “selection for the stable” (see below) by which they assert a false dichotomy between “physical” and “natural” selection. To the extent that Batten et al. (2008) simply restate or quote Depew and Weber (1995) *verbatim* without eliminating the errors, they then make the same mistakes. Among them are Batten et al.’s (2008) assertions about “physical selection” and the role of entropy production maximization, and these are addressed in what follows.

Physical Selection and the Law of Maximum Entropy Production (LMEP)

Identifying self-organization (and in what follows I will use the term “spontaneous ordering” synonymously) as a process

of autocatakinesis, viz., that self-organizing systems *are* ACK systems, provides us with the understanding that the class includes both abiotic and biotic systems, and this then tells us that to account for the generic behavior of the class (versus the distinctive or special behavior of some of its members or kinds) we cannot invoke natural selection as an explanation (because the class includes abiotic members, where there are no replicating components). It was just on this basis that my colleagues and I argued some two decades ago that there thus had to be a “physical selection principle” (e.g., Swenson 1991b: 131; Swenson and Turvey 1991) that would account for the generic behavior of the class, and, what is more, that evolutionary theory would remain incomplete until this principle was identified, understood, and integrated into biological theory (Swenson 1988, 1989b). The answer to the question was first advanced as the “principle of maximum entropy production” (Swenson 1988), and by 1989 had been formulated, stated, and demonstrated in its present falsifiable form as the “law of maximum entropy production” (Swenson 1989d, 1991a, 1991b, 2009; Swenson and Turvey 1991; Mahulikar and Harwig 2004; Martínez-Castilla and Martínez-Kahn 2010a and 2010b).

Summarizing my views in their book, Depew and Weber (1995: 483–484) wrote the following:

Swenson has argued that selection generically considered, will be a derived consequence of self-organization whenever a system is moving toward a state of maximum entropy production (Swenson 1989b; Swenson and Turvey 1991). “Selection is entailed by self-organization . . . and Darwinian selection (‘natural selection’) is a special case where the components are replicating. Thus self-organization (order production) is necessary (ontologically prior) to natural selection, but not the other way around. . . .”

This statement contains fundamental errors that are repeated by Batten et al. (2008) in their paper when they quote this passage without correction, not simply as the view of Depew and Weber (1995) but as an accurate statement of my views. The way this is stated, rather than showing how spontaneous ordering is a consequence of physical selection, makes physical selection (“selection generically considered”) somehow the consequence of self-organization and only under particular circumstances, namely, when a system is “moving towards a state of maximum entropy production.”

This is not at all what physical selection or LMEP is, as my colleagues and I have stated it, nor how self-organization or ACK systems (spontaneous macro-order) follows from it, with natural selection as a special case. Immediately below I review physical selection, or LMEP, and its relationship to self-organization.

Self-Organization Entails Selection

Reviewing briefly, the search for a physical selection principle followed from the view that unless the ubiquitous, opportunistic ordering characterizing the visible world was explained,

evolutionary theory would be profoundly incomplete (Swenson 1988, 1989b, 1989c). The relationship between selection and self-organization is found literally and precisely in the fact that the latter, which expands the space–time dimensions of the field/environment through which it is constituted, does so by the *selection* of some drastically reduced number of accessible microstates from some much larger initial set (Swenson 1988). In simple terms, the degrees of freedom and the positions and momenta of the components, starting with an “origin event” become increasingly more highly specified such that they move in a coordinated and coherent way together. The production of self-organization, or ordered from disordered flow (the origin and development of an ACK system), thus literally *entails the selection* of some reduced set of accessible microstates from some much larger initial set. Selection (“generically considered” or physical selection) is thus not something that follows from self-organization, as Depew and Weber (1995) and Batten et al. (2008) say I have said, under a particular set of circumstances, i.e., that sometimes self-organization leads to selection and sometimes it does not; but rather *always* happens or has *always* happened whenever self-organization occurs or has occurred. Self-organization requires selection to happen; it *is* a process of selection (see the Appendix for illustration).

What Is the Universal or Physical Selection Principle That Accounts for It?

The problem at the time these ideas were first proposed was that the second law of thermodynamics by the then most common view (still found in many quarters), largely due to Boltzmann’s attempted reduction of the second law, was taken to be a “law of disorder.” In fact, as many readers may know, in his attempt to reduce the second law to a stochastic collision function, Boltzmann asserted that just such a dynamically ordered state as we are describing here, in which the molecules or micro-components move “at the same speed and in the same direction . . . is the most improbable case conceivable . . . an infinitely improbable configuration of energy” (Boltzmann [1886] 1974: 20); more improbable, he analogized around the same time, than if “every inhabitant of a large country committed suicide . . . on the same day . . . [in other words] practically equivalent to *never*” (Boltzmann [1896, 1898] 1995: 444). To further contextualize this with respect to evolutionary theory, consider that in the same year Depew and Weber’s *Darwinism Evolving* was published, standard bearers for the most extreme forms of neo-Darwinian genetic reductionism, such as Dennett (1995: 69), were still describing living things as things that “defy” the second law of thermodynamics (for further discussion, see, e.g., Swenson 1997b).

Schrödinger (1945) and von Bertalanffy (1968), of course, had already shown that living things as dynamically ordered flow structures did not violate the classical version, or balance equation of the second law (that in all natural processes

entropy must always increase) as long as they produced entropy (or minimized potentials) at a sufficient rate to compensate for their own internal entropy reduction. In addition, Prigogine (1980), some of whose ideas I will return to shortly, had developed this idea under the rubric of “dissipative structures,” rightfully underscoring that at a minimal distance from equilibrium, for example in the Bénard example, Boltzmann’s statistical view “breaks down” (Prigogine [1977] 1993: 88). As my colleague Turvey and I (Swenson and Turvey 1991: 335) put it, order was seen not to emerge “infinitely improbably, but with a probability of one, opportunistically every time it got the chance.” But this leads directly to the question posed above: Where does all this order come from, or more particularly, what universal or physical selection principle, contrary to Boltzmann’s view about the improbability of such states, could account for it?

Prigogine’s Theorem of Minimum Entropy Production

Here I slightly detour to clarify a confusion that was widespread at the time, and can still be found today. Prigogine’s role in spurring interest in self-organizing systems can hardly be doubted, but some of his work, although certainly unintentionally played an obfuscating role as well, most notably with the over-promotion of his “theorem of minimum entropy production” (minEP) (Martínez-Castilla and Martínez-Kahn 2010a). Because of confusion over just what it meant (or really how minimal were its claims) many people have thought that minEP and LMEP were somehow at odds with each other, and this is not in any way the case. MinEP is not a universal principle, applying only to a narrow range near equilibrium; whereas LMEP is fully universal applying to all ranges. Reviewing briefly, what minEP says is as follows: Consider a system near equilibrium, specifically in the linear range, consisting of a number of thermodynamic “forces” (gradients of potentials or disequilibria), X_i and their corresponding flows J_i , where X_i are not replenished and so go progressively to zero except that some, or at least one—for example, a temperature gradient—are maintained; then the entropy production of the system will go monotonically down as the X_i are dissipated until the system gets as close to equilibrium as it can, where as long as the heat gradient in this case is maintained it will remain in a steady state, near but not at equilibrium. The entropy production in this time-independent state will now be at the lowest point, the minimum, of the whole time-dependent process and would have gone monotonically down to get there.

This is essentially all that it says, and it may be seen that this is really nothing more than the second law (that gradients of potentials or forces are spontaneously minimized) and the fact that in the linear range the entropy production is given by the sum of the product of the various flows and forces. In short, as the forces are monotonically dissipated, so too the entropy production must go monotonically down. In fact, some have

called the theorem trivial because it can be claimed that it does not add anything new (Martínez-Castilla and Martínez-Kahn 2010a). As a further note, of course, if the remaining force, the temperature gradient in this example, is no longer maintained, then it too would dissipate; and the entropy production would continue to go down until the system went to equilibrium where the entropy production would be minimized in the limit (the entropy would be maximized and the entropy production would be zero).

What minEP does not apply to and what Prigogine and his school repeatedly underscored (Prigogine [1977] 1993) is the case where the system is sufficiently far from equilibrium and autocatakinetics or self-organization arises, as in the Bénard cell exemplar when the system is above a critical level of X . In this range, rather than going monotonically down, the rate of entropy production dramatically increases (see Appendix Figure A2). Most crucially, however, with respect to LMEP, what minEP does not address at all with regard to minimizing the respective forces, whether in the linear near-equilibrium range, where it is valid, or the “far from equilibrium” nonlinear range, where it is not, is *which paths out of otherwise available paths* a system will take to do it. And this is exactly the question LMEP answers. *It is a question, in particular, about selection.*

Path Selection and LMEP

The question about path selection is exactly the same in the more general case of the second law itself; the second law says that nature works to minimize thermodynamic forces or gradients of potentials, but it is mute with respect to which paths it will take to do it. Yet it turns out that this question about path selection is just the question that begged answering. Why? Because the most salient point with respect to self-organization or autocatakinetics, the production of coherent macro from disordered or less ordered micro-flow, is that whenever this happens the entropy production always dramatically increases. In fact, *it has to* or else the second law would be violated. In short, whenever spontaneous ordering occurs, by definition it involves a local decrease in entropy, and this means that to satisfy the balance equation of the second law (that the net entropy in all natural processes must always increase) the entropy production of the system must increase to a level sufficient enough to compensate for the internal entropy reduction, a point made by Schrödinger (1945) and von Bertalanffy (1968) years before.

This led to the hypothesis that if it were the case that the world, in effect, chose those pathways out of otherwise available pathways that minimized potentials or maximized the entropy at the fastest rate given the constraints, we would have the physical selection principle that would account for the selection of ordered from disordered modes. The experimental model that we first used borrowed some tools from the experiments of early classical thermodynamicists (e.g., Swenson 1989d, 1991a, 1991b, 2009; Swenson and

Turvey 1991; Martínez-Castilla and Martínez-Kahn 2010). In particular, in this example, a gas is confined to an isolated chamber (“box”) divided into two compartments, *A* and *B*, by an adiabatic wall (so initially no heat can flow from one side to the other). *A* is heated to a temperature greater than *B* to produce a field potential or thermodynamic force between the two. In the center of the adiabatic wall are four rectangular sections of equal size (paths 1–4) where the adiabatic seal can be removed to expose in each case a material with a different coefficient of conductivity, or four paths each with a different rate.

With this system thus for four different runs, with the seal pulled off a different single path for each run, the system will achieve the same end state of thermal equilibrium where the entropy is maximized (or the potential or force minimized), but it will have done so at four different rates. If, instead, for additional runs the seals are pulled off of more than one of the pathways, the system will always preferentially choose the faster path, but as any given path will not typically eliminate all of the potential instantaneously, it will allocate what remains to the next fastest path (and so on if there are more than two), accordingly selecting the path or assembly of paths that minimizes the potential at the fastest rate given the constraints. It is of course completely reproducible. You can repeat it as many times as you want with any number of different setups and the result is always the same. This demonstration of LMEP in its current and falsifiable form was first published in 1989 in the Technical Report of the Center for the Ecological Study of Perception and Action (Swenson 1989d), and thereafter in various papers since the first publication (e.g., Swenson 1991a, 1991b, 1997a, 1997b, 2000, 2009; Swenson and Turvey 1991; Mahulikar and Harwig 2004; Martínez-Castilla and Martínez-Kahn 2010), with the law, LMEP, stated as follows:

A system will select the path or assembly of paths out of available paths that minimizes the potential or maximizes the entropy at the fastest rate given the constraints.

Of course, this applies not just to thermal gradients, but following the first law (the equivalence of mechanical energy and heat) due to Mayer, Joule, and others, to any energy gradients or forces (chemical, electric, etc.) that one wants to set up. LMEP is valid near equilibrium and far from equilibrium in all ranges, including the range where minEP is valid and the ranges it is not. Moreover, to underscore again, in the linear near equilibrium range, with steadily dissipating forces, the range where minEP is valid, there is no conflict with LMEP at all. All LMEP says, however, is that the path to equilibrium chosen will be the fastest available out of the given alternatives (or given the constraints).

Derivation of Universal Ordering Principle

LMEP as stated, of course, says nothing directly about self-organization or ACK systems (or “why the ubiquity of opportunistic macroscopic ordering?”), but as the previous

discussion has shown the derivation of LMEP as universal ordering principle, the selection principle accounting for self-organization, or the selection of macro from micro modes, is easy to see. Putting it explicitly, as my colleagues and I have done in numerous other places (e.g., Swenson 1991a, 1991b, 1997a, 1998a; Swenson and Turvey 1991), it is as follows:

IF (the world) selects the pathway or assembly of pathways that minimizes potentials or maximizes the entropy at the fastest rate given the constraints (LMEP),

AND IF ordered flow produces entropy at a faster rate than disordered flow (the balance equation of the second law),

THEN the world can be expected to select order from disorder whenever and as soon as it gets the chance.

The “Problem of the Population of One” Is the Problem of Macro (Ordered) from Micro (Disordered) Flow

Batten et al. (2008) seem to misunderstand “the problem of the population of one” and my position on it, and in this section I address the confusion. Citing my paper, “End-directed physics and evolutionary ordering: Obviating the problem of the population of one” (Swenson 1991a), a paper also cited by Depew and Weber (1995), Batten et al. (2008: 22) write: “Swenson’s view of selection is enigmatic”; because, quoting from Salthe’s 1993 book (Salthe 1993: 108), they write: “Swenson talks about a system ‘selecting’ . . . *from* a population of one . . .” (italics added) whereas a “cardinal principal of Darwinian natural selection theory is that several variants arise prior to the action of selection.” Here they seem to think that I have advocated a notion of selection where there is only one thing to choose from, but I have never advocated such a view at all. This entirely misunderstands the issue. I have never talked about selection “from” a population of one, but rather selection (a) “of” a population of one, on the one hand, and then (b) selection within or internal to a population of one (an ACK system) on the other. The former is just the selection of macro (ordered) from micro (disordered) (as discussed above under “Self-Organization Entails Selection” and shown and discussed throughout the Appendix); and the latter refers to the component selection process that occurs at a different level of description (specifically internal to the ACK system) as part of (a), that is, with the origin and development of any ACK or self-organizing system (see, e.g., Appendix Figure A3). Selection from micro to macro means the selection of the particular micro modes that constitute the dynamically ordered macrostate, specifically some subset of micro degrees of freedom or positions and momenta from some vastly larger, otherwise accessible, initial pool. This is what I said in the paper they had cited:

Given the law of maximum entropy production, it is at once easy to see why macro (order) is selected from micro (disorder) . . . and how the problem of the population of one is immediately obviated.

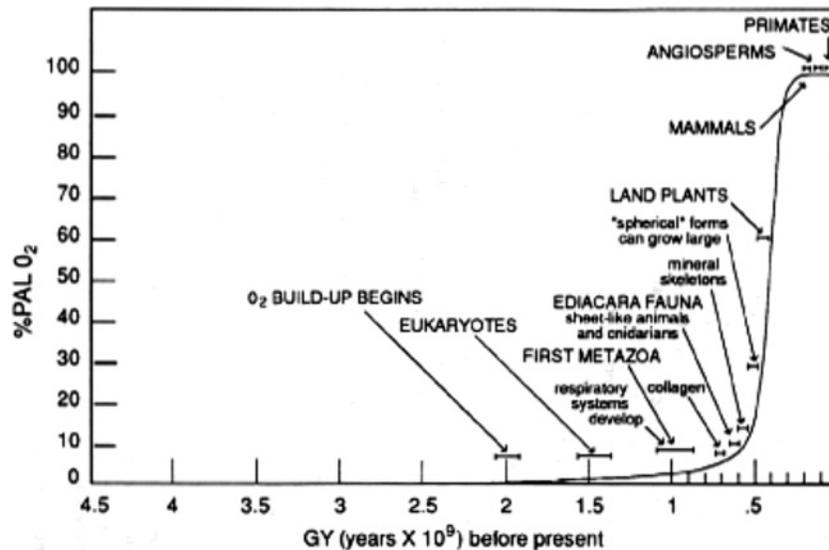


Figure 2.

The production of increasingly more highly ordered states over geological time as a function of increasing levels of atmospheric O_2 . The development, production, and maintenance of PAL O_2 (present atmospheric level) over evolutionary time is sufficient to demonstrate the fact of planetary autocatakinesis (ACK closure and the constitutive relations that define it) and with it the fact that all the usual biological forms that have typically been the focus of classical evolutionary theory have been literally constituted out of and through it as internal component processes. Planetary evolution is seen at its foundation as a process of autocatakinetics (or self-organization) following LMEP (as physical selection principle with the correlate of universal ordering), and natural selection is seen as a process internal to it where the components are replicating. Source: Swenson 1989a, p. 72. Copyright © 1989 IEEE. Reprinted by permission.

Selection is not between replicating competing entities but between ordered and disordered modes. (Swenson 1991a: 50)

Figure A4 (Appendix) has a detailed discussion showing the way competition and selection between macro and micro as alternative dissipative paths works in the Bénard system in the establishment of autocatakinetics following LMEP as the physical selection principle.

Biospheric Evolution as the Historical Context for the Term

While the solution to the problem of the population of one as outlined in my paper (Swenson 1991a; see also Swenson and Turvey 1991) that both sets of authors cite finds its ground and solution in the generic principles relating self-organization, selection, and LMEP, the particular issue addressed initially as the “problem of the population of one” arose in the context of biospheric evolution. By the early 1980s, if not before, important advances in palaeobiology and biogeochemistry over several decades had led to a widespread understanding that at its highest level, life had evolved and operated as a single planetary entity (e.g., Cloud 1976; Runnegar 1982; Schopf 1983; Vernadsky [1929] 1986; Schwartzman et al. 1994). Probably the most obvious *prima facie* evidence for this was the recognition that the atmospheric O_2 on which virtually all higher ordered (or multicellular) life forms depend was put there and maintained by life itself operating at a planetary level over evolutionary time. Life as a planetary phenomenon had shifted the redox state of the Earth, moving it sufficiently far from chemical equilibrium such that the requisite conditions

for the emergence and adaptation of higher ordered forms, in particular those that had been the typical objects of classical evolutionary theory, were met (see Figure 2, and for further discussion, Swenson 1991a; Swenson and Turvey 1991).

That “evolution on Earth” needed revising to “evolution of Earth”; that the fundamental unit of evolution was the planetary system itself, however, presented a profound anomaly for Darwinian theory, which had no basis within its theoretical corpus for recognizing or explaining such a unit of evolution. Evolution on its account was something that happened as a consequence of natural selection acting on a population of replicating entities, but here there was only one Earth system, and thus, on this ground, arch defenders of the reductionist orthodoxy, such as Dawkins, used just this point to argue against it. Writing in 1982, Dawkins argued that since evolution (as defined by Darwinists) is the consequence of natural selection operating on a population of replicating entities, the Earth as a single system could not evolve because there was no population of competing Earth systems on which natural selection could act. This is just what came to be known as the “problem of the population of one,” and was the specific problem addressed in my above-mentioned paper (1991a; see also Swenson and Turvey 1991) cited by Salthe (1993), Depew and Weber (1995), and Batten et al. (2008). Dawkins’s argument, of course, did nothing to undermine the fact of planetary evolution; it only unintentionally underscored the anomaly for Darwinian theory.

The problem of the population of one at the biospheric level, as noted above, is a consequence of the more general problem of Darwinian theory to come to grips with

self-organization or selection of macro from micro modes. It shows up in the origin of life, the development (or “succession”) of ecosystems at whatever level, cultural evolution, as well as biospheric or planetary evolution as a whole. All of these are ACK systems, but each bracketed out of evolutionary theory as particularities without any acknowledgement or recognition that they were all in fact one and the same problem—the problem of spontaneous ordering, or selection of macro from micro modes; this is or was “the problem of the population of one” that was solved by LMEP. When natural selection occurs, it is always internal to an ecosystem (at some level), that is, a self-organizing or ACK system. The fact of natural selection occurring is sufficient to show that ACK closure has occurred, with natural selection being the internal selection process that occurs in the selection of macro from micro modes where the components are replicating. The generalized notion of Malthusian pressure can be understood as the selection pressure consequent on the circular relations constituting ACK closure at the ecosystem level within which natural selection is occurring.

Physical Selection Is Not “Selection for the Stable”

Although at this point I would hope that my views regarding physical selection would be clear, there is a particular error and misattribution made by both sets of authors on this issue that is sufficiently serious to warrant highlighting briefly on its own. It is the notion put forward by Depew and Weber (1995: 444) when, in citing work from our laboratory on the Bénard cell experiment, they write: “(t)he Bénard cell is an example of physical selection, or selection for the stable.” This view is then echoed and elaborated on by Batten et al. (2008: 22) who write: “Swenson regards natural selection as a particular manifestation of deeper, directional laws governing all systems that select in favor of what is physically stable.” The first part of this last sentence is entirely correct (although better stated as: natural selection is a particular manifestation of physical law, viz., LMEP), but the second part (“that select [for what] . . . is physically stable”) is profoundly wrong. In fact, as I would hope the reader would recognize at this point, the utter opposite is the case both with respect to the “facts of the world” and with my assertions and those of my colleagues about them.

There are, of course, many kinds of stability, but because authors do not tell us differently, we take their use of the term “stable” to be the most common meaning of the term: “(a) resistant to change of position or condition” or “(b) not subject to sudden change . . . or fluctuation” (Houghton Mifflin 2009). It is hard to see how this could be construed as consistent with physical selection as governed by or equated with a principle (LMEP) that says, crudely put, that a system will opportunistically select the path or dynamics minimizing the

potential or maximizes the entropy at the fastest rate; or, more particularly, how this would be consistent with physical selection as a principle that, rather than selecting for the dampening of fluctuations, instead amplifies them. Or, how “selection for the stable” would be consistent, in different terms, with physical selection that predicts the opportunistic selection of macro from micro modes, which in effect overturns or transforms the entire system, maximizing its extension in space–time so as to extend its dissipative surfaces. This turns the whole matter completely on its head.

The original authors (Depew and Weber 1995) use the Bénard cell experiment as their exemplar both with respect to their claims about the world in this regard and also my views, but it is just the “instability of the homogeneous” to use Spencer’s (1857) felicitous and prescient term (see also Prigogine 1980; Swenson 1989b) that physical selection (as LMEP) explains. Rather than the progressive disordering or simply symmetry-maintaining behavior of the older “equilibrium” view, it is just the opportunistic symmetry-breaking (itself definitional of instability) that the Bénard experiment, known synonymously in the literature, to underscore the point, as “the Bénard *instability*,” describes. Our search for a physical selection principle from day one was motivated by trying to understand “the universality of the spontaneous *destabilization* of homogeneous fields and the emergence of new levels of macroscopic constraints” (Swenson 1989b: 188); “(i) what universality governs the *instability* (symmetry-breaking) of the incoherent regime; and (ii) what physical extremum governs selection of the microstates . . . ?” (Swenson 1989b: 187; italics added). The answer was LMEP, which thus is anything but the selection of the stable⁴ (see also Appendix Figure A1). The question asked and then answered with LMEP was what physical or universal selection principle accounts for the opportunistic ordering that characterizes the progressive (time-asymmetric) development of space–time of the visible world? It is hardly well described as “selection for the stable.”

Against Inaccurate Charges of Reductionism

Building on their erroneous idea of “physical selection for the stable” as part of the characterization of my work in their book, Depew and Weber (1995: 484) assert that my “conception exhibits a reductionistic tendency that downplays what is novel about specifically natural selection, and explicitly biological objects on which it works. . . .” Batten et al. (2008) then effectively reinforce this view, although without directly referring to Depew and Weber, when they say that Hoelzer et al. (2006) “adopt a similar view” to mine and quote them as saying: “We submit that natural selection is no more and no less than any other thermodynamic process” (Batten et al. 2008: 22). Now this *is* a statement of a reduction, but it is not at all similar to my position and I reject it completely as I do Depew and

Weber's characterization. If the Hoelzer et al. (2006) position were similar to mine, however, then Depew and Weber would be right about my position, because certainly the assertion by Hoelzer et al. (2006), by making natural selection completely substitutable or commutable with any other thermodynamic process, would downplay the novelty of natural selection or the biological objects on which it works in an absolute and indisputable sense; there would be no novelty or difference at all. Yet the role of natural selection or replicative ordering is profoundly and remarkably distinct from nonreplicative ordering.

In fact, the very greatest extent of the work my colleagues and I have done on these issues has been just to show, or at least attempt to show, exactly what *is* explicitly novel about living versus nonliving things. Swenson and Turvey (1991), for example, cited multiple times by Depew and Weber (1995) was very specifically focused on just this issue. Most particularly, it is the ability of living things to hook their autocatakinetics onto "information about" in Gibson's nomological sense (e.g., Gibson 1966; Swenson and Turvey 1991; Swenson 1998b), or maintain their autocatakinetics through epistemic relations that enable them to access nonlocal potentials in the production of their autocatakinetics and thereby opportunistically access otherwise inaccessible dimensions of space-time.

For example, quoting from my paper (Swenson 1991a: 54) cited by Batten et al. (2008) in their paper:

Tornadoes, dust devils, Benard cells . . . are all examples of the spontaneous ordering of autocatakinetics—macro is selected from micro through the time-dependent specification of some much smaller set of accessible microstates (order) from some much larger initially accessible number of microstates (disorder). But while increasing the dissipative dimensions of the fields from which they emerge by orders of magnitude the access to dissipative space of the nonliving is nonetheless limited; they are slaves to their local potentials, e.g., remove the local potential [the heat in the Benard convection] and the ordered state "dies." This is not the case with even the simplest living systems such as bacteria . . . the autocatakinetics of the living are coordinated with respect to macroscopic invariants in kinematic [non force or mass-based] fields [what ecological psychologists called "information about"] that allow them to act arbitrarily with respect to local potentials and access non-local potentials and thereby otherwise inaccessible dimensions of dissipative space.

In our further articulation of what we argue are the primitives that define or distinguish the living or replicative order from the nonliving as end-directed systems dependent on meaning, in Swenson and Turvey (1991: 343), a paper cited by Depew and Weber (1995), we wrote the following:

Behind this ability of living things to behave arbitrarily with respect to higher order field invariants ["information" in the Gibsonian sense] is the arbitrariness of the component production process (Swenson 1990). Replicative ordering requires a set of internal constraints that are discrete, sequential, and rate-independent relative to the rest of the autocatakinetic cycle. The order of the sequences, like the words

on this page, or sequence of base pairs in a DNA string, is thermodynamically arbitrary with respect to the rate at which they are "written" and "read." (Polanyi 1968)

That replicative ordering is seen as an intelligible consequence of LMEP (and natural selection a special case or particular instantiation of it) hardly makes replicative ordering identical, reducible, or substitutable with the nonliving. The ability to build dynamic order across nonlocal potentials through the use of kinematic as opposed to force-based fields that my colleagues and I have highlighted and stressed in our work underscores the point. It is hard to see how this could be missed. In simple terms, living things by our definition(s) are things that use ambient energy distributions as "information about" ways to deploy their "on-board" energy potentials to access nonlocal potentials in the constitution of their autocatakinetics.

In perceiving-acting, living things hook their on-board energy reservoirs onto invariants of ambient optical distributions, compression wave fronts, and wave trains, fields of diffusing volatile materials . . . to search out resources discontinuously located in space and time, and to access higher-orders of dissipative space. (Swenson and Turvey 1991: 343)

The claim is the very opposite of reducibility. While replicative ordering is precisely a manifestation of LMEP and its universal ordering corollary, i.e., the opportunistic filling out or "development of space-time" (e.g., Swenson 2000), the access to or the filling out of the particular dimensions of space-time made possible by replicative ordering and the use of kinematic fields as information about distal ends in the proximal present, we have claimed, cannot be done or reduced to the force-based kinetics of nonreplicative or noninformation-based fields (Swenson and Turvey 1991). These dimensions are literally inaccessible by nonreplicative, or nonperceptually guided means of dynamics (see also Swenson 1998a, 1998b, 1999). Our claims, contrary to the view suggested by Depew and Weber (1995) and more particularly Batten et al. (2008) as characterized by their citation of Hoelzer et al. (2006), are in fact for strong irreducibility. Natural selection, then, to the extent that it refers to selection involving replicating components or replicative ordering (by definition) is thus not reducible to nonreplicative ordering, although both are a consequence of selection governed by LMEP. Replicative ordering is a special case of physical selection.

LMEP, Final Cause, and Selection

In her book, *Evolution Extended*, published just a year before Depew and Weber's book, Barlow (1994: 127) wrote the following:

Within the self-organization research community, Rod Swenson has made the most dramatic claim. While others search for material and efficient causes of self-organization . . . and for formal causes . . . Swenson has been looking for the ultimate, the final cause. And

he believes he has found it: this entropic universe is pocked by local regions of intense ordering because. . . .

And she goes on, in her words, to talk about the idea of LMEP. In his book, Salthe (1993), one of the coauthors of the Batten et al. (2008) paper, also adopted what seemed to be this view writing about “the final cause of entropy-production maximization (Swenson 1989b, 1989c)” and citing my work. Being one among others, including Salthe (e.g., 1985, 1993), who has been critical of the attempt to reduce explanation or causal discourse in modern science to efficient cause, and writing about the way the laws of thermodynamics provided a principled basis for understanding the origins of end-directed behavior in the world (e.g., see Swenson 1991a, 1991b, 1997a; Swenson and Turvey 1991), I took this as consistent with my views. In Batten et al. (2008), however, where this theme is revisited, it is now stated or elaborated in a way that is profoundly wrong, viz., pointing to Salthe’s earlier work, they (Batten et al. 2008: 24) write:

Salthe (1993, 2000) suggests that the second law of thermodynamics—in the form of the maximum entropy production principle (Swenson 1989b; Dewar 2005)—is acting herein as final cause. This amounts to asserting that selection (among different rates of energy throughput) is a phenomenon in its own right, an emergent process of complex dissipative systems. . . .

This is profoundly wrong. LMEP, the selection among differing rates of energy throughput, occurs universally wherever there are alternative paths, and is thus not “an emergent process of complex dissipative systems.” The very reverse is the case: “emergent . . . dissipative systems” are a consequence of LMEP (the selection among different flow rates).⁵

Conclusion

Both Depew and Weber (1995) and Batten et al. (2008) refer to my work as one of the “visions” or approaches they discuss in their respective works. Errors made by Depew and Weber (1995) are repeated by Batten et al. (2008) without criticism who then make some additional errors of their own. These are not minor points but substantive errors, meaning that to make them, in my view, is to essentially misunderstand the issue and its solution. My purpose is thus not simply to point out errors; it is really to show what the relationship between self-organization and natural selection is, at least the way I see it, and the way my colleagues and I advanced it beginning more than two decades ago. The issues under discussion thus focus on self-organization, autocatakinetics or spontaneous ordering, physical selection (or selection most generally construed), with natural selection as a special case, LMEP, and how these relate.

Both sets of authors have problems with terms, including “self-organization” itself. Depew and Weber (1995) do not define it. Batten et al. (2008) do, but in a manner that is

inconsistent with most of the ways they use the term. As the wording in their title, “Self-organization proposes what natural selection disposes,” suggests, they end up reifying self-organization into some kind of a thing that is separate or opposed to natural selection (e.g., one acts then the other acts). This begins and ends in an impossible place.⁶ We start from a very different place, with the recognition that the spontaneous ordering (or self-organization) that characterizes the visible world *is* a process of selection of which replicative ordering is a special case (the case where there is component replication). The question thus is not really how are two otherwise unrelated and separate things related, or how as with the old problem of Cartesian interactionism do they interact, but rather what is the generic or universal physical selection principle that accounts for this selection. The physical selection principle is the law of maximum entropy production (LMEP), and natural selection is a special case where the components are replicating.

Appendix

The Bénard Cell Experiment: A Brief Overview with Highlighted Details

Depew and Weber (1995) use work by our laboratory with the Bénard cell experiment to make both general points about selection and self-organization and to summarize my views. Batten et al. (2008), citing Depew and Weber, repeat many of these same assertions. Both because the Bénard cell experiment is a rightfully classic exemplar of self-organization and thus an excellent point of discussion as well as because a number of Depew and Weber’s and thus also Batten et al.’s assertions are inaccurate with respect to it, I here give a brief overview of the experiment and highlight some details of particular relevance to this discussion.

Reviewing briefly, in the Bénard experiment a viscous fluid (in this case silicone oil) is held in a circular container between a uniform hot source below (here a uniformly heated plate) and a cold sink above (the open air) so as to produce a potential between them with a force X (a force being a gradient of a potential). Below a critical level of X entropy is produced (the potential or gradient is dissipated or reduced) by the flow of heat from source to sink resulting from the disordered collisions of the molecular components and the fluid appears macroscopically homogenous (Figure A1(a)). When X is increased above a minimal level of X , however, microscopic fluctuations are amplified to macroscopic proportions as macro (ordered flow) is selected from micro (disordered flow) and hundreds of millions of previously disordered components begin moving coherently together, dramatically increasing the transport of heat from source to sink and thus the rate of entropy production of the system (Figures A1(b)–A5). Over time, if the boundary conditions are maintained following a time-dependent process of selection of the accessible microstates

of the components, the system will reach a time-independent steady state of virtually same-size hexagonal cells.

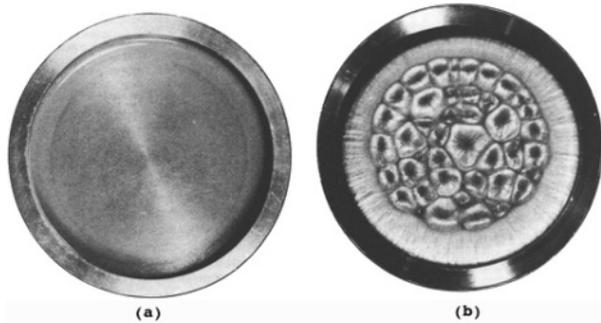


Figure A1. Two time slices in the Bénard cell experiment. (a) Shows the macroscopic uniformity of the system below a critical threshold of X as heat is transferred from source to sink by the disordered collisions of the micro-components (the disordered or micro-regime), while (b) shows spontaneous selection of ordered from disordered flow (“macro from micro”) that occurs after X is increased above the minimal threshold and hundreds of millions of molecules begin moving in a coordinated fashion together breaking the symmetry or homogeneity of the disordered regime. Order is opportunistically selected from disorder following LMEP because by dramatically extending the accessible space–time dimensions of the system alternative dissipative pathways are provided whereby the entropy production or movement of heat from source to sink is greatly increased (see Figure A2). The increase in space–time dimensions is literal and measurable as defined by the correlations between components. In the disordered regime the actual measurable dimensions are mean-free-path distances and relaxation times (the average distances and times between collisions) of the order of 10^{-8} centimeters to 10^{-15} seconds, while in the ordered regime these increase to centimeters and seconds. To give a rough idea of the transformation involved, if the molecular or micro mode were scaled to the size of a human being, then the macro mode would be 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 (Swenson 1989b). Source: Swenson 1989c, p. 192. Copyright © 1989 Pergamon Press. Reprinted by permission.

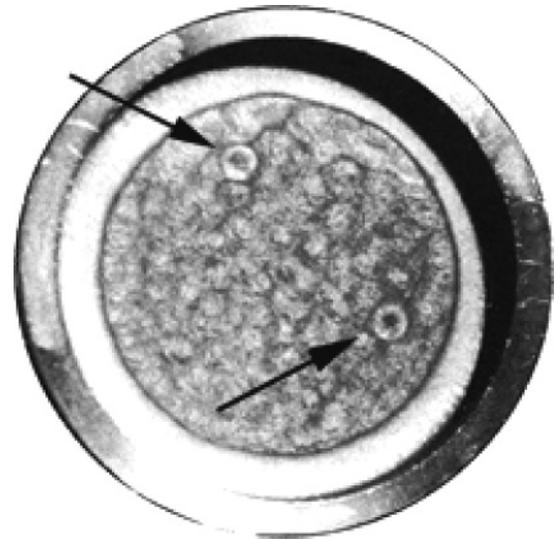


Figure A3. The figure shows a time slice in the Bénard cell experiment right after the minimum threshold of X is crossed and the production of macroscopic order or selection of macro from micro has begun.⁷ Here small fluctuations from the “blind” collisions of the disordered micro-components have been amplified to macroscopic levels (see Figure A4 for discussion of the mechanics) and two individual autocatakinetics or self-organizing systems (Bénard cells) emerge. Here it is important to note that these arise from two separate origin events with each being initially selected, produced, and maintained as a “population of one” where competition is between macro- and micro-modes. Macro is preferentially and opportunistically selected following LMEP because relative to the competing micro mode it greatly increases the dissipative rate (Figure A2). Source: Swenson 1989c, p. 194. Copyright © 1989 Pergamon Press. Reprinted by permission.

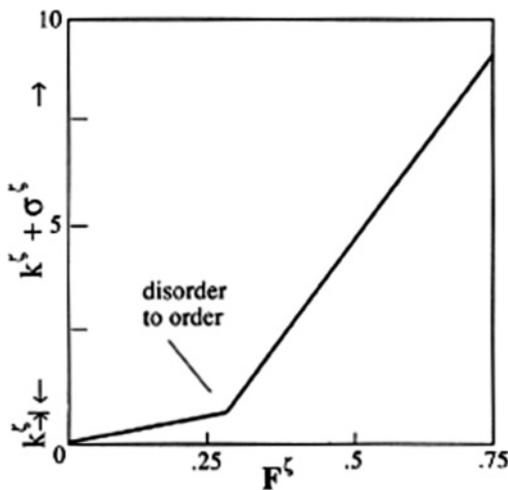


Figure A2. The figure shows the dramatic discontinuous increase in entropy production (in this case corresponding to the increase in heat transferred from source to sink) that occurs during the transition from disordered (micro) to ordered (macro) mode (Swenson 1989a). Source: Swenson 1989a, p. 70. Copyright © 1989 IEEE. Reprinted by permission.

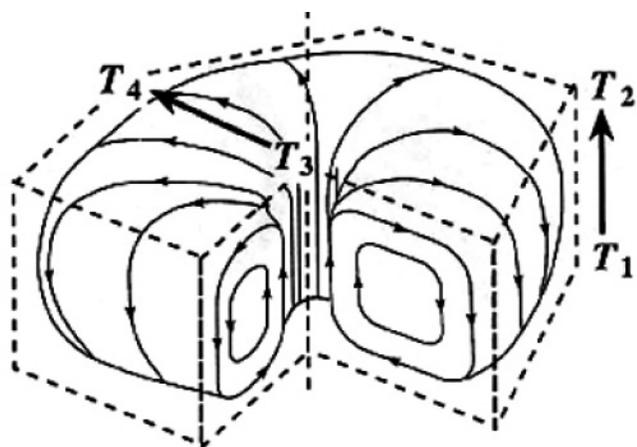


Figure A4.

A schematic of the ordered ACK flow constituting an individual Bénard cell, where the solid stream lines show the circular form of the cell as it originally appears as an individual ACK (“population of one”) or self-organizing system (Figure A3); the dotted lines show the hexagonal shape it assumes later as the result of selection acting on it as a component within a population of many in the larger system-wide self-organizing system as a whole. The streamlines show in detail the way the continuous flow of components at the micro-level constitutes the ordered structure (“identity through flow”) at the macro level. As discussed in Figure A1, and as this figure further helps to show, because the intrinsic space–time dimensions for any system or process are defined by the persistence of its component relations, the transformation from micro to macro or self-organizing mode dramatically increases the system’s space–time dimensions. The direction of the ACK flow constituting the cell is shown here by small arrows, $T_1 \rightarrow T_2$ is the gradient of the potential between the source below and the sink above constituting force X that drives the flow. Because density varies inversely with temperature, there is also a density gradient from bottom to top giving parcels of molecules displaced upwards by stochastic collisions (“stochasticities” or fluctuations) an upward buoyant force. If X is above the minimal threshold, the parcels (macro-flow) will move upwards faster than their excess heat can be dissipated by their surrounds (micro-flow) and it becomes the selected path following LMPEP because it has the faster dissipative rate. At the same time, such an upward flow will increase the temperature of the upper surface directly above it creating a surface tension gradient $T_3 \rightarrow T_4$ that acts to further amplify the upward flow by pulling the hotter fluid to the cooler outer surrounds. The upward displacement of fluid creates a vacuum effect pulling more heated fluid from the bottom-up behind it, which in turn makes room for the fluid cooled by its movement across the top to fall to the bottom and be heated again, as effects become causes and the circular relations constituting ACK closure of an ACK cycle are established. Source: Swenson 1997a, p. 24. Copyright © 1997 JAI Press. Reprinted by permission.

Notes

1. It is further misleading to say that “only local information, without reference to the global pattern” is used. The pheromone fields that determine the behavior of, say, termites that are of the kind of system they are talking about, change as a consequence of the global behavior and provide information about those changes to the components, which of course they get locally.
2. From auto (“self”) + cata (“down”) + kinetic (“of the motion of material bodies and the forces and energy associated therewith”), from kinein (“to cause or move”).
3. Noting here too that the experiment is not done in water, as they say, but in a more viscous substance, such as silicone oil, as used in the experiments shown here, or whale oil, as used at the time of Bénard when the experiment was first done.

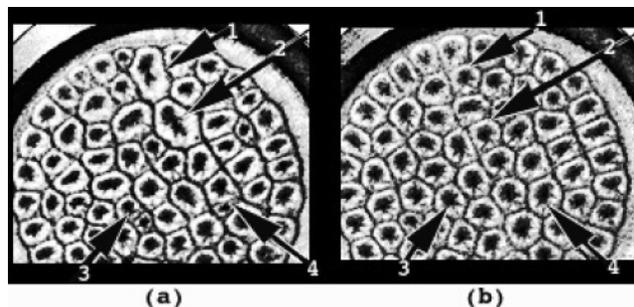


Figure A5.

Two time slices from the Bénard cell experiment show competition and selection between cells after the population of initially independent cells (Figure A3) grow in number and size until they begin to impinge on each other and a “generalized Malthusian condition” ensues (Figure A1(b)) and ACK closure occurs creating a new higher level, self-organizing system (ACK system) acting on the population of cells as its components. Comparison between (a)1 and (b)1 and (a)2 and (b)2 shows spontaneous division of two oversize cells into four smaller ones, and comparison between (a)3 and (b)3 and (a)4 and (b)4 shows the subsumption of two smaller irregularly shaped cells into one larger hexagonal cell. Source: Adapted from Swenson 1989c, p. 193. Copyright © 1989 Pergamon Press. Reprinted by permission.

4. Without wanting to belabor the point, I would also make a reference to Burgers’s (1963) felicitous characterization (Swenson 1989b) about such hydrodynamic systems as being governed by “a principle of the most unstable solution.”
5. Batten et al. (2008) make another error here with the addition of the reference to Dewar (2005) after Salthe’s (1993) earlier reference to me and the “principle of maximum entropy production.” The error is the implication that Dewar’s “principle of maximum entropy production,” also called “MEP” by his followers, is the same principle as LMPEP. As LMPEP was first introduced as the “principle of maximum entropy production” (Swenson 1988) and referred to in this way and as “MEP” in the literature for many years prior to Dewar, it is not surprising that since he and his colleagues (e.g. Kleidon and Lorenz 2005) adopted the same name without distinction, it encouraged the kind of error made here. But the principle Dewar claimed to have demonstrated (here “DeMEP”) is very different from LMPEP (or the original MEP) in a number of ways, including (but not limited to) the following: (1) whereas LMPEP is a universal (physical selection) principle from which a universal ordering corollary (selection of macro from micro) can be readily derived, DeMEP, even if it were correct, refers only to stationary states and is thus (a) not a universal path selection principle, and (b) consequently has nothing to say about the production of order from disorder at all; (2) whereas LMPEP is demonstrated like the classical laws of thermodynamics with a physical experimental model, DeMEP is an attempt at purely formal demonstration based on Jayne’s maxENT inference method (e.g. Jaynes 1980) with no necessary physical grounding at all; and (3) finally, not long after Dewar’s attempt (2005) was published, Grinstein and Linsker (2007) showed it to be invalid on mathematical error alone. None of this changes anything about LMPEP at all, but the two should not in any way be equated, as Batten et al. (2008) have done, although given Dewar (2005) and colleague’s misleading choice of terms it is certainly not surprising.
6. The *reductio* of this, which I will not discuss here, leads to a kind of Cartesian cul-de-sac with the usual problem in generic form of Cartesian interactionism.
7. Although many people are aware of the quite regular array of hexagonal cells that constitutes the final or time-independent state of the Bénard cell experiment (usually this is the only picture shown), crucially fewer are aware of how it happens. Depew and Weber (1995: 485) write: “Swenson (1989b) has

shown that the hexagonal cells initially generated . . . do not at first display the ordered array of cells of the same size . . . cells arise that are larger or smaller than the optimum final size, along with those that are just right.” But if Depew and Weber are not themselves confused, this description is sure to sponsor confusion because, initially, the main point is, as seen in this figure, that there are no hexagonal cells at all. By the time they are all hexagonal cells, the system is in or very near a time-independent state where all the competition/selective processes between cells for the most part are done.

References

- Barlow C (1994) *Evolution Extended: Biological Debates on the Meaning of Life*. Cambridge, MA: MIT Press.
- Batten D, Salthe S, and Boshetti F (2008) Visions of evolution: Self-organization proposes what natural selection disposes. *Biological Theory* 3: 17–29.
- Boltzmann L ([1886] 1974) The second law of thermodynamics. In: Ludwig Boltzmann, *Theoretical Physics, and Philosophical Problems* (McGuinness B, ed), 20. Boston, MA: Reidel.
- Boltzmann L ([1896, 1898] 1995) *Lectures on Gas Theory*. New York: Dover.
- Burgers JM (1963) On the emergence of patterns of order. *Bulletin of the American Mathematical Society* 69: 1–25.
- Camazine S, Deneubourg J-L, Franks NR, Sneyd J, Theraulaz G, Bonabeau E (2001) *Self-Organization in Biological Systems*. Princeton, NJ: Princeton University Press.
- Carriveau R (2006) The hydraulic vortex—an autocatakinetic system. *International Journal of General Systems Research* 35(6): 707–726.
- Cloud P (1976) Beginnings of biospheric evolution and their biogeochemical consequences. *Paleobiology* 2: 351–387.
- Dawkins R (1982) *The Extended Phenotype*. San Francisco, CA: Freeman.
- Dennett D (1995) *Darwin’s Dangerous Idea*. New York: Simon and Schuster.
- Depew D, Weber B (1995) *Darwinism Evolving: Systems Dynamics and the Genealogy of Natural Selection*. Cambridge, MA: MIT Press.
- Dewar RC (2005) Maximum entropy production and the fluctuation theorem. *Journal of Physics A* 38: L371–L381.
- Gibson JJ (1966) *The Senses Considered as Perceptual Systems*. Boston, MA: Houghton Mifflin.
- Grinstein G, Linsker R (2007) Comments on the derivation and application of the “maximum entropy production principle.” *Journal of Physics A* 40: 9717–9720.
- Hoelzer GA, Smith E, Pepper JW (2006) On the logical relationship between natural selection and self-organization. *Journal of Evolutionary Biology* 19: 1785–1793.
- Houghton Mifflin (2009) *The American Heritage Dictionary of the English Language*. 4th ed. New York: Houghton Mifflin.
- Jaynes ET (1980) The minimum entropy production principle. *Annual Review of Physical Chemistry* 31: 579–601.
- Kleidon A, Lorenz RD (2005) *Nonequilibrium Thermodynamics and the Production of Entropy*. Berlin, Germany: Springer.
- Mahulikar SP, Harwig H (2004) Conceptual investigation of the entropy principle for identification of directives for creation, existence, and total destruction of order. *Physica Scripta* 70: 212–221.
- Martínez-Castilla LP, Martínez-Kahn M (2010a) The fourth law of thermodynamics: The law of maximum entropy production (LMEP), an interview with Rod Swenson. *Ecological Psychology* 22: 69–87.
- Martínez-Castilla LP, Martínez-Kahn M (2010b) Darwin y el descubrimiento de una nueva ley de la termodinámica [Darwin and the discovery of a new law of thermodynamics]. *Educación Química*, May: 2–9.
- Maruyama M (1963) The second cybernetics: Deviation-amplifying mutual causal processes. *American Scientist* 51: 164–179.
- Polanyi M (1968) Life’s irreducible structure. *Science* 160: 1308–1312.
- Prigogine I (1980) *From Being to Becoming: Time and Complexity in the Physical Sciences*. New York: Freeman.
- Prigogine I (1993) Time, structure and fluctuations. In: *Nobel Lectures, Chemistry 1971–1980* (Forsén S, ed), 264–285. Singapore: World Scientific.
- Runnegar B (1982) The Cambrian explosion: Animals or fossils? *Journal of the Geological Society of Australia* 29: 395–411.
- Salthe SN (1985) *Evolving Hierarchical Systems: Their Structure and Representation*. New York: Columbia University Press.
- Salthe SN (1993) *Development and Evolution: Complexity and Change in Biology*. Cambridge, MA: MIT Press.
- Salthe SN (2000) Ecology and infodynamics. *Journal of Social and Evolutionary Systems* 21: 223–237.
- Schopf, JW, ed (1983) *Earth’s Earliest Biosphere*. Princeton, NJ: Princeton University Press.
- Schrödinger E (1945) *What is Life?* New York: Macmillan.
- Schwartzman DW, Shore SN, Volk T, McMenamin M (1994) Self-organization of the Earth’s biosphere, geochemical or geophysiological? *Origins of Life and Evolution of the Biosphere* 24: 435–450.
- Spencer H (1857) Progress: Its law and cause. *Westminster Review*, April: 179–222.
- Swenson R (1988) Emergence and the principle of maximum entropy production: Multi-level system theory, evolution, and non-equilibrium thermodynamics. *Proceedings of the 32nd Annual Meeting of the International Society for General Systems Research* 32.
- Swenson R (1989a) Engineering initial conditions in a self-producing environment. In: *A Delicate Balance: Technics, Culture and Consequences* (Rogers M, Warren N, eds), 68–73. IEEE Catalog 89CH291-4. Los Angeles, CA: Institute of Electrical and Electronic Engineers.
- Swenson R (1989b) Emergent attractors and the law of maximum entropy production: Foundations to a theory of general evolution. *Systems Research* 6: 187–198.
- Swenson R (1989c) Emergent evolution and the global attractor: The evolutionary epistemology of entropy production maximization. *Proceedings of the 33rd Annual Meeting of the International Society for the Systems Sciences* 33: 46–53.
- Swenson R (1989d) 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, University of Connecticut) 5: 60–63.
- Swenson R (1990) A robust ecological physics needs an ongoing crackdown on makers conjured out of thin air. *Perceiving-Acting Workshop Review* (Technical Report of the Center for the Ecological Study of Perception and Action, University of Connecticut) 6: 35–38.
- Swenson R (1991a) 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* (Geyer F, ed), 41–60. Salinas, CA: Intersystems Publications.
- Swenson R (1991b) Order, evolution, and natural law: Fundamental relations in complex system theory. In: *Cybernetics and Applied Systems* (Negoita C, ed), 125–148. New York: Marcel Dekker.
- Swenson R (1992) Autocatakinetics, yes, autopoiesis, no: Steps toward a unified theory of evolutionary ordering. *International Journal of General Systems* 21: 207–228.
- Swenson R (1997a) Autocatakinetics, evolution, and the law of maximum entropy production: A principled foundation toward the study of human ecology. *Advances in Human Ecology* 6: 1–46.
- Swenson R (1997b) Evolutionary theory developing: The problem with Darwin’s dangerous idea. *Ecological Psychology* 9: 47–96.

- Swenson R (1998a) Thermodynamics, evolution, and behavior. In: *The Handbook of Comparative Psychology* (Greenberg G, Haraway M, eds), 207–218. New York: Garland Publishing.
- Swenson R (1998b) Spontaneous order, evolution, and autocatakinetics: The nomological basis for the emergence of meaning. In: *Evolutionary Systems* (van de Vijver G, Salthe S, Delpo M, eds), 155–180. Dordrecht, Netherlands: Kluwer.
- Swenson R (1999) Epistemic ordering and the development of space-time: Intentionality as a universal entailment. *Semiotica* 127: 181–222.
- Swenson R (2000) Spontaneous order, autocatakinetic closure, and the development of space-time. *Annals of the New York Academy of Sciences* 901: 311–319.
- Swenson R (2009) The fourth law of thermodynamics or the law of maximum entropy production (LMEP). *Chemistry* 18: 333–339.
- Swenson R, Turvey MT (1991) Thermodynamic reasons for perception–action cycles. *Ecological Psychology* 3: 317–348.
- Vernadsky VI ([1929] 1986) *The Biosphere*. London: Synergetic Press.
- von Bertalanffy L (1968) *General System Theory*. New York: George Braziller.