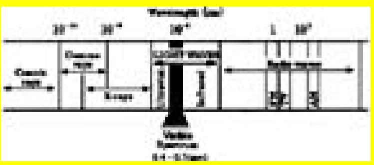
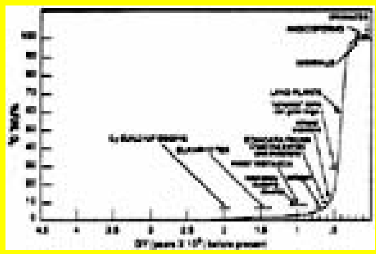
ecological psychology

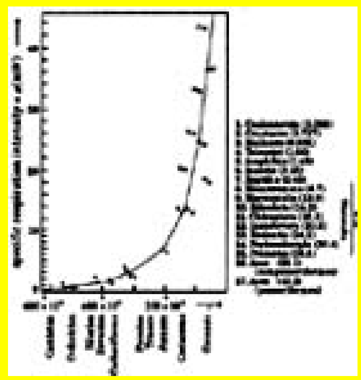
physics, biology, psychology: finding the nomological basis for the relationship between knower and known

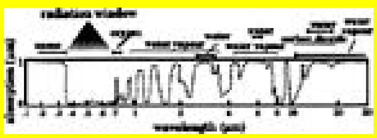
To study Ecological Psychology is to study of the relation between knower and known. Because every other discipline, by definition, begins with an epistemic agent (the knower), and an intentional object of knowledge (the known) as well as explicitly or implicitly held epistemological or ontological assumptions, ecological psychology, which is just the study of these things, can appropriately be thought of as the most fundamental of all disciplines. In this role it forms a fundamental bridge, both drawing from and informing, what are otherewise usually take as separate disciplines such as physics, biology, evolutionary theory, and cognitive theory.

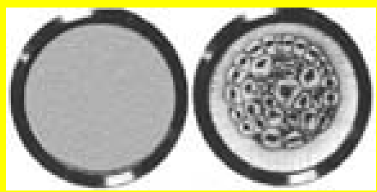
Review of this article











ECOLOGICAL PSYCHOLOGY: LEAD ARTICLE

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Thermodynamic Reasons for Perception-Action Cycles

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Abstract An argument is developed to show that the origin and evolution of the perceptual guidance of movements and the movement enhancement of opportunities to perceive, that is, perception-action cycles, have a direct and deep connection with thermodynamic principles. The cornerstones of the argument are: (a) maximum entropy production as a physical selection principle (thermodynamic fields will behave in such a fashion as to get to the final state - minimize the field potential or maximize the entropy -at the fastest possible rate given the constraints); (b) the inexorability of order production (order production is inexorable because order produces entropy faster than disorder); (c) evolution as a global phenomenon (the Earth system at its highest level evolves as a single global entity); and (d) information in Gibson's law-based, specificational sense (invariant relations exist between higher order properties of structured energy distributions and their environmental sources). In the coordination of self-organizing dynamics with information in the specificational sense, access is provided to otherwise inaccessible opportunities to produce ordered flow and to dissipate, thereby, the geocosmic potential at faster rates. The progressive emergence of perception-action cycles in the evolution of the Earth as a global entity is the lawful product of opportunistic physics: There was no other way to produce the collective (ordered) states that would engender these higher levels of dissipation. Perception-action cycles express higher order symmetries of the world itself, in its own becoming. Perception-action is the physics at these higher levels.

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SWENSON AND TURVEY: THERMODYNAMIC REASONS

INTRODUCTION

The modern roots of psychology can be traced back to the 17th century when the idea of an immaterial "mind" (or spirit or "thinking I"), immune from the laws of physics, was advanced by Descartes as part of the dualistic world view that gained ascendancy along with the Scientific Revolution. At the point of this conceptual origin, psychology can thus be seen as the study of all that is not physical. Because the "matter" of the physical world was taken by Descartes to be composed of purposeless, reversible, analytically continuous, and quality-less particles (without color, taste, or smell) governed by deterministic law, the lion's share of worldly properties was clearly left to the immaterial or "mental" portion of the world. Although philosophy became historically separated from psychology as the discipline whose job it was to address ontological and epistemo logical problems (generated, largely, by the inherent incommensurability of the Cartesian schem ' e itself), this separation has always been fuzzy at best because from the time of Descartes psychological arguments (in particular, theories of perception) were almost invariably used, or assumed, as the starting point for epistemological and ontological claims.

While Descartes saw the entire natural world, including "organic nature" (with the exception of the immaterial mind of humans), as a giant deterministic machine, Kant (1790/1929), taking the view that it was impossible for the purposiveness of living things to be described in mechanical terms, argued for the "autonomy of biology" from physics (Cassirer, 1940/1950). Although, like Descartes, Kant had formulated his argument to serve his own transcendental doctrine, his criticism of mechanism was entirely correct. The consequence of his "autonomy of biology" argument, however, was the establishment of a new dualism-a dualism of life versus physics (living vs. nonliving or organism vs. environment). This same argument, of the incommensurability of physics and the characteristic properties of living things (to strive, perceive, and act purposively), is still used in contemporary science to back the case for a biology largely indifferent to the general principles of physics (e.g., Mayr, 1985).

The fundamental mutuality claim of ecological psychology (Gibson, 1979/1986), that living things as perceiver-actors and their environments constitute single and irreducible dynamical systems (Mace, 1977; Turvey & Carello, 1981), rejects the traditional view that the properties of living things and physical law are incommensurable. Recent work by Swenson (1988, 1989b, 1989c, 1989e, in press-b) on the thermodynamics of self-organizing systems, when coupled with the law-based account of information in the specificational sense (Gibson, 1966, 1979/1986; Kugler & Turvey, 1987), shows how the active, end-directed behavior of living things has its origins in the symmetry properties of physical law and how the mutuality claim of ecological psychology can be shown to directly follow. While a number of the central themes of this article are laid out in detail, many others can only be sketched. A more complete development will be presented in a subsequent work (Swenson, in press-d).

Thermodynamics and Perception-Action Cycles

From a thermodynamic point of view, animals move so that they can eat, and eat so that they can move (lberall, 1974). Form and function demand a continuous production of entropy (degradation of energy), and to preserve form and function, therefore, an animal's on-board energy supply must be regularly replenished. Although many living things have their fuels served to them, animals by and large must service themselves; they move so they can eat.

From a different point of view, which takes as its focus the perceptual capabilities of animals, one might say that animals move so that they can perceive, and perceive so that they can move (Gibson, 1979/1986). As underscored by Gibson (1966), the commonplace, directed behaviors of animals comprise continuous cyclic relations between the detection of information and the performatory and exploratory activities that serve, in significant part, to facilitate that detection and which, in turn, are guided and shaped by it. In a wedding of the perceptionist's view with that of the thermodynamicist, perception-action cycles are seen as supporting the self servicing that maintains an animal's on-board potential at appropriate levels. The perceptual guidance of movements and the movement enhancement of opportunities to perceive, extend to animals particular benefits in their search for, and consummation of, energy resources.

Clearly, perception-action cycles can be placed into a thermodynamic perspective, as the foregoing attests: Perceiving and acting capabilities are what they are, in part because the thermodynamical requirements of living things are what they are. The emphasis of this rationalization -of perception steering actions and actions amplifying perceptual opportunities-is on "energy replenishment" or "acquisition of energy resources." It is an emphasis that draws on an indirect connection between thermodynamics and perception-action cycles. The second law of thermodynamics is about the production of entropy -about the dissipation of energy resources, not their replenishment. The argument advanced in this article is that perception-action cycles have a much deeper and more direct connection with thermodynamic principles. That is, perception-action cycles are what they are because they extend the means for dissipating energy resources, for enhancing the rate of environmental entropy production.

Respiration Intensity and Atmospheric Oxygen

The study of global evolution reveals the amplification of biospheric entropy production with the growth and differentiation of living matter over geological time. The increase in atmospheric oxygen shown in Figure I characterizes a progressive departure of the global Earth system (as a single planetary entity) away from equilibrium, The transformation of the redox state of the planetary system, from reducing when life first appeared some 3.8 billion years ago (GYA-i.e., giga years ago) to mildly oxidative some 2 GYA to its presently highly oxidative state, is a measure of a progressive ordering or internal entropy reduction of the planetary system as a whole. Given the balance equation dictated by the second law, this progressive increase of order is also a measure of an increasing rate of entropy production for the geo-cosmic field: Local reductions of entropy in a field (the local production and maintenance of order) necessarily increase its rate of entropy production (the rate at which it minimizes its potentials).

Because the atmosphere on the Archean Earth when life emerged was mildly reducing, life is presumed to have had an anaerobic beginning. That is, it was essentially fermenting and limited by the availability of abiogenically formed organic compounds. The first photosynthetic bacteria (presumed to be similar to extant purple and green bacteria) provided the means by which the production of life was linked directly to the sun (solar source) by using many of the incompletely metabolized waste products of the fermenters as well as outgassed reduced compounds from volcanic emissions such as hydrogen sulfide and sulfur for reducing power (as electron sources). Expansion was now limited by the availability of these ready-macle hydrogen compounds. The water (H20) on Earth provided an almost unlimited source of electrons, but the original photosynthesizers could not muster the energy to split the water molecules.

About 3.5 GYA proto-cyanobacteria (ancestors of contemporary cyanobacteria that were formerly called blue-green algae) learned to link two light sinks (light-trapping systerns) together so as to apply the necessary two photons to the cleavage of one water molecule. The result was the linking of the virtually unlimited supply of photons from the sun to the virtually unlimited supply of electrons in water and the release of oxygen (02) into the atmosphere. In consequence, along with a massive acceleration in the expansion of life, the Pre-Phanerozoic (the "Pre-Cambrian" in the ealier literature) bore witness to a buildup of atmospheric 02 and a shifting of the planetary redox potential from reducing to oxidative. Before this global bifurcation could occur, however, natural reservoirs -chemical elements such as sulfur and iron that combine readily with 02 -acting as 02 sinks had to be filled. The biogeochemical evidence for this occurring approximately 2 GYA includes the abrupt termination of the formation of banded-iron formations, the appearance of continental redbeds, and the disappearance of thorium-rich uraninite and pyrite (Cloud, 1976, 1988). When the sinks were filled, the availability Of 02 in the atmosphere produced a chemical potential providing the opportunity for an even greater production of living matter. Whereas anaerobic fermentation of one mole of glucose to lactic acid produces a flux of 56,000 calories of free energy, the complete oxidation of the same amount of glucose to carbon dioxide and water produces a flux of 686,000 calories.

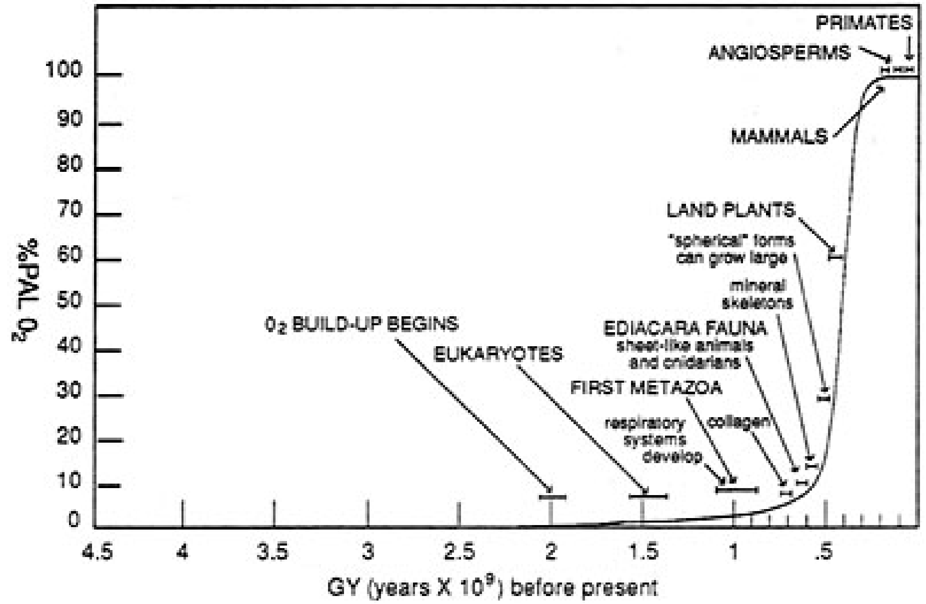

FIGURE 1 Buildup of atmospheric O_2 in geological time (PAL is present atmospheric level.) From "Engineering Initial Conditions in a Self-Producing Environment" by R. Swenson, in M. Rogers and N. Warren (Eds.) *A Delicate Balance: Technics, Culture and Consequences* (p. 71), 1989d, Los Angeles Institute of Electrical and Electronic Engineers (IEEE). Copyright 1989 by IEEE. Reprinted by permission. Data originally fro Cloud (1976) and Runnegar (1982).

The opportunistic production of increasingly more highly ordered states as a function of increasing planetary 0_2 is shown in Figure 1. Thus, the buildup of atmospheric 0_2 can be seen not only as a measure of the distance of the planetary system from equilibrium, but as the buildup of an internal potential that operated over evolutionary time as an internal amplifier driving the planetary system even further from equilibrium. Figure 2 unpacks this thermodynamic scenario still more: It shows that not only does terrestrial entropy production increase as the result of the increase in the quantity of order or living matter over geological time, but so does the intensity of entropy production or mass specific entropy production. In fact, as the discussion above indicates, this property to expand both qualitatively (nonlinearly) and quantitatively (linearly) has been characteristic of life from its beginnings.

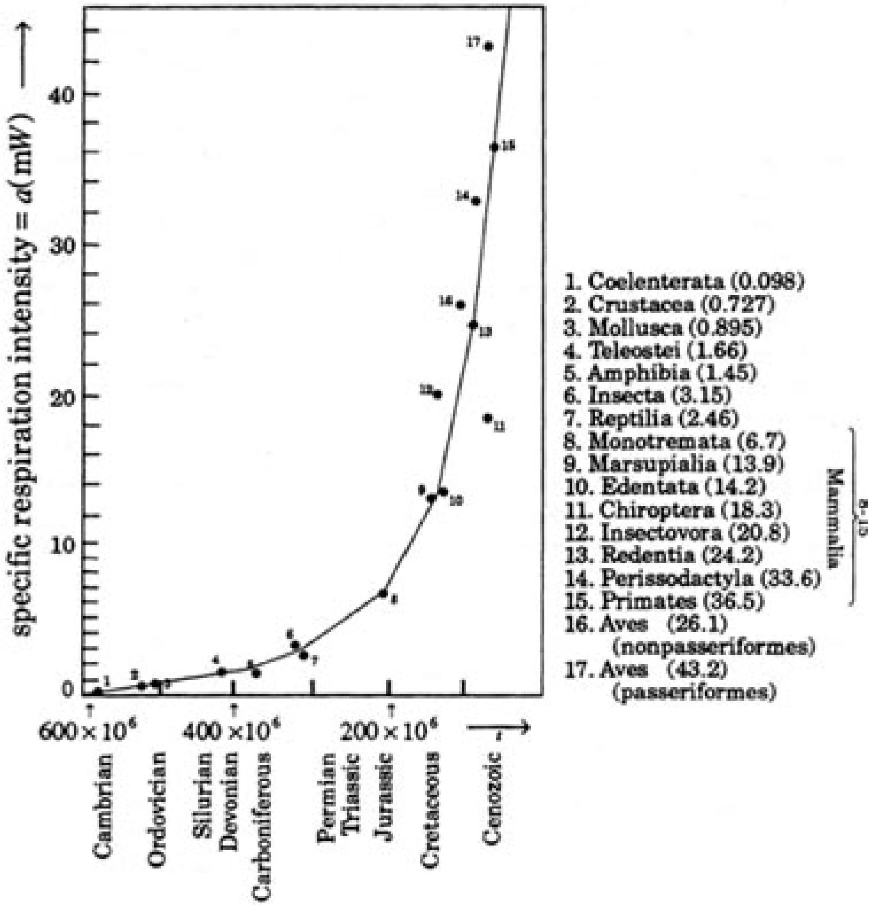

FIGURE 2 Growth of specific respiration intensity as a function of geological time. From "Bioenergetic Trends of Evolutionary Progress of Organisms" by A. Zotin, in I Lamprecht and a.I. Zotin (Eds.), *Thermodynamics and Regulation of Biological Processes* (p.453), 1984, Berlin: Walter de Gruyter. Copyright 1984 by Walter de Gruyter. Reprinted by permission.

Specifically, Figure 2 depicts the respiration intensity per unit mass of living things as a function of the Earth's last 600 million years (MY). Aerobic respiration (oxidative phosphorylation) is the process by which living things employ 0_2 to release the energy potential from their food. 0_2 is used to "burn up" or oxidize food in the same manner that 0_2 is used in the burning of a flammable material to produce fire. In aerobic respiration, one molecule Of 0_2 iS used for the conversion of each atom of organic carbon. The mass specific respiration intensity is the rate at which chemical resources are dissipated or burned by 0_2 into waste or heat products per unit mass of body weight. It is thus a measure of the specific or per-unit-mass rate of entropy production. Taken together, Figures I and 2 reveal the global nature of evolutionary ordering: Higher order states require higher rates of dissipation to maintain their extension; the increase in atmospheric oxygen over evolutionary time provided the potential required for progressively higher ordered states (the steep increase in the respiration intensity function [Figure 21 corresponds to the steep increase in the buildup of atmospheric 0_2 [Figure l]; the higher order states act as sinks that dissipate the potential.

A well-recognized fact is that for a living thing to exist it must add continuously to the universal level of entropy (e.g., Schr6dinger, 1945). A much less well-recognized fact is conveyed by Figures I and 2, namely, that when considered at a planetary scale and in geological time, the expansion and differentiation of living matter through the production of more and more living things has increased the mass specific planetary rate of entropy production. The insight made famous in Schr6dinger's statement "Life feeds on negentropy," and first put forward by Bertalanffy (1952), is that living things are not equilibrium states but rather steady states maintained away from equilibrium by a continuous flow of energy and matter. To be a living thing implies converting energy into organization and doing so ceaselessly, and thus the order defining a living thing continuously adds to the universal entropy; what Figure I highlights is that with the production of more order, with more numerous and more richly organized living things, and with the progressive production of higher states of order, the additions to the universal entropy are made at a greater rate. The insight conveyed by Schr6dinger's statement now seems too static given Figures I and 2, which show the opportunistic emergence of order as a function of the evolutionary increase of atmospheric 0_2. Schr6dinger's insight is mute with respect to the directed nature of life as an opportunistic planetary process of self-organization characterized by progressive differentiation and complexification. Conjointly, Figure I and Figure 2 supply a potentially more encompassing insight: Life proliferates horizontally (increase in number) and vertically (increase in levels of order) because the rate of entropy production is thereby increased. It is this insight that provides the context for inquiring about the thermodynamic status of perception-action cycles.

To summarize, Figures 1 and 2 suggest (a) the impossibility of conceiving of living things as separate from their surrounds, (b) that both together are part of a directed single planetary or global evolutionary process or entity, and (c) that this direction is characterized by an opportunistic strategy that produces progressively more ways, and more intense ways, for this global system to generate entropy (first prokaryotes fermented naturally forming organic compounds on an anaerobic Earth; then "bacterial photosynthesizers" hooked solar energy directly to terrestrial sinks [to incompletely metabolized products of fermenters and outgassed reduced compounds] and produced organic matter directly; then proto-cyanobacteria discovered how to hook solar energy to the unlimited electron supply in water, thus also releasing 02 into the atmosphere; and the consequent atmospheric 0_2 provided the chemical potential to burn organic matter faster [oxidative metabolism] and produce progressively more highly ordered forms). It will be assumed that suggestions (a), (b), and (c), are pivotal to the thermodynamic rationalization of perception-action cycles.

A Physical Strategy

The perceptual guidance of movements and the movement enhancement of opportunities to perceive comprise a prominent aspect of the functional order at the ecological scale, the scale at which living things and their environments are defined. An argument is to be developed that the origins of perception-action cycles inhere in the second law of thermodynamics and are addressable through the concepts needed for understanding the phenomena depicted in Figures I and 2. In addressing such issues, Aristotle's methodology (without his explanations) is brought to bear: To arrive at an understanding of the nature of a thing, ask the ends that are served. Specifically, the strategy needed to understand perception-action cycles is the physical strategy of identifying the preceding generalized "field conditions" that produced or selected them at their origins and have continued to produce and progressively select them as viable states of dynamical order over evolutionary time.

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THE LIMITED SCOPE OF DARWINISM

Before pursuing the physical strategy in earnest, it is necessary to consider whether or not the nature of perception-action cycles is explainable through the conceptual tools of contemporary evolutionary theory. The answer that will be given is "no." Although the word "evolution" was popularized in the middle of the 19th century prior to its use in connection with Darwin, today evolution and "Darwinism" are typically taken to be synonymous. The "almost universally adopted definition of evoiution as a change of gene frequencies" (Mayr, 1980, p. 12) as the result of natural selection is, today, what is meant by Darwinism. As Mayr (1980, p. 43) noted, the synthesis or the rise of neo-Darwinism ("Darwinism" in its present form) was simply the "final implementation" of the basic Darwinian conception except that the focus was shifted from the differential reproduction of organisms to gene frequencies within a population. This narrow conception of evolution carries forward the dualistic tradition of decoupling the living from the physical world-a tradition (as noted earlier) that goes back in modern history at least as far as Kant..In so doing it renders itself incapable of addressing the nature of the living itself, in particular the purposive striving of perceiving-acting beings.

Spencer's Conception of Evolution and Darwinism

It was Spencer (1862) who first formulated a general theory of evolution, defining evolution as the lawful and progressive production of order from disorder governed by physical or universal law. He argued that the "instability of the homogeneous" or the "transformation of the incoherent into the coherent," the "law of evolution," as he called it, holds uniformly from the nonliving to the biological to the cultural (human social; Spencer, 1862). Although Darwin was well acquainted with Spencer's work (e.g., he credited Spencer with the phrase "the survival of the fittest") Darwin never used the word evolution until the last edition of The Origin of Species in 1872, more than a decade after it was first published (Carneiro, 1972).

In fact, as Huxley (1878/1954), Darwin's most well-known 19th century advocate himself noted, Darwin never intended to address the problem of general evolution or put forth a theory to account for it at all (Gilson, 1984)("Mr. Darwin," Huxley [Gilson, 1984, p. 73] said in 1878, "confines himself to the discussion ... of living matter assuming such matter to have once come into existence. On the other hand, Mr. Spencer ... has dealt with the whole problem of evolution."). Darwin's agenda, in short, was to dispel the then still widely held notion of the fixity of species. Thus, as the full title of his book (On the Origin of Species by Means of Natural Selection, or the Preservation of Favored Races in the Struggle for Life) indicates, Darwin assumed "the struggle for life" or the "struggle for existence"a term he borrowed from Malthus, and which Malthus had already claimed as a general property of animals and plants (Gilson, 1984)-as a necessary condition for natural selection to begin with. In short, Darwin assumed spontaneous opportunistic ordering, in particular, the purposive active properties of living things including their perceiving-acting capabilities, as the starting place for his theory.

Despite the fact that Darwin's theory of natural selection clearly lacked, by his own definition, the scope for a comprehensive theory of evolution (which its progenitor never claimed it had), in the intervening years, the word "evolution" came to be synonymous with Darwinism (Levins & Lewontin, 1985; Mayr, 1980). Because the central and limited conception of Darwinism remained natural selection, the notion of evolution was drastically reduced, from spontaneous universal ordering, to organic evolution (evolution of the living only), and finally to the product of natural selection. Evolution became defined by Darwinism itself as the result of natural selection acting on a Malthusian population, namely, a population of differentially replicating or reproducing entities competing for limited resources (i.e., fixed Malthusian parameters; Mayr, 1980). In sum, the existence of a purposive Malthusian population was assumed, but not accounted for, and given that this assumption is an assumption of perceiving-acting capabilities, an accounting of such capabilities is, *ex hypothesi,* beyond the scope of evolutionary theory as defined by Darwinism.

Decoupling Evolution from Physics

Whereas Spencer had envisaged biological and cultural evolution as spontaneous orderings conforming to a fundamentally physical or universal process, the effect of equating evolution with natural selection was to drive a wedge between evolutionary theory and physical theory. The repeated insistence of the autonomy of biology (e.g., Mayr, 1985), simply underscores that this dualistic decoupling has, in recent years, been promoted intentionally. The purposeless-particle view of physics (what might be called the "Newtonian-Boltzmann narrative") is taken to be both accurate and complete, and as such, the argument is made that physics is immaterial to biology and what are taken to be the inherent properties of the living (Mayr, 1985). Discontinuous change (and thus creative change) is excluded from the Newtonian world, and in the statistical Boltzmannian world order is said to be "infinitely improbable" (Boltzmann, 1886/1974). It is certainly true that if these conceptions were taken as comprising a correct and exhaustive description of matter, physics would have little to say with regard to biology or psychology. But these conceptions, conceptions from which the ordered world in which we live cannot be derived, were hardly accidental. They were impoverished from their beginnings and never intended to be exhaustive. In particular, Newtonian physics, in accomodating the religious demands of the time, was formulated with the assumption (and therefore the requirement) that there was a watchmaker capable of ordering the purposeless world of physics from the outside. A dualistic assumption was thuys built into the foundations of the modern scientific world view at its inception (cf. Depew & Weber, 1985; Weber & Depew, in press).

Consequences of a Non-purposive Physics

Historically, the purposeless materialism advanced by Newtonian mechanics was a radical departure from previous conceptions of physics. For the Greeks, the word "physics" referred to the study of nature, and the nature of a thing or process, in the Aristotelian sense, was the end it served or to which it strived. Thus the study of physics, at its inception, was the study of teleology or final causes. The attacks on Aristotelian causality by Bacon and Descartes laid the foundations for rejecting final causes, purposiveness, or the study of ends from modern physics. This rejection would eventually pose difficulties for disciplines (biology, psychology, and all the social sciences) that could not avoid the study of ends, namely, purposive, goal-directed, or intentional behavior. As noted earlier, Darwin himself simply assumed purposiveness as an inherent property of the living -"all organic beings are striving to increase at a high ratio and to seize on every unoccupied or less well occupied space in the economy of nature" (Darwin, 1859/1937, p. 152). But such an assumption left unnswered the question of the origin or nature of purposiveness in a physically aimless or purposeless universe (and the practical question of how the issue of purposiveness can be approached if teleology-the study of ends-is banned from discussion). Within biology and psychology, the failure to address adequately the origins issue has necessitated the repeated invocation of special extraphysical mechanisms as the sources of the order and purposiveness that it is assumed physics cannot provide. The word "teleonomy", meaning goal-directedness due to the operation of a program (Mayr, 1969, 1976), has been coined for use in the biological literature to allow teleological talk in what is otherwise taken to be a purposeless physical world. The dualism in such a move is obvious.

The Problem of the Population of One

Because natural selection (Darwinism) assumes replicative ordering to begin with, the incontestible point is that an evolutionary theory reduced or truncated to natural selection cannot be comprehensive -evolution did not come into the world with living things, rather, living things were the product of evolution. What is more, a growingcontemporary understanding is that evolution, as the previous discussion has already noted, is a planetary phenomenon, and that the Earth system at its highest level evolves as a single global entity (e.g., see Figure 1; Cloud, 1988; Margulis & Lovelock, 1974; Schopf, 1983). Natural selection cannot address or even recognize this global evolution (in fact denies it; Dawkins, 1982) because there is no population of replicating and competing Earth systems on which natural selection can act; the Earth is a population of one. T'his puts the question of (end-directed) physics directly back on the table and suggests that there must be a physical selection principle (because if it does not involve replicating entities it cannot be biological) that accounts for the selection of ordered (or macro) from disordered (or micro) states. It restores the notion of evolution -as Spencer finst defined it -to a universal (lawful) process of spontaneous order production flowing directly from natural law. Both the evolution of the living from the nonliving and the problem of the population of one suggest that evolution, or spontaneous order production, is fundamentally a generic physical process of which the characteristic qualities of living things, such as perception-action cycles, are special higher order consequences.

Global Evolution

Outside of Darwinism there has been both a general acknowledgment of evolution as a directed process of spontaneous ordering (e.g., Oparin, 1968) and a long-respected need for taking a planetary stance. Vernadsky (1929/1986, p. 81) wrote: "the organism cannot be considered apart from its medium ... Living organisms are a regular function of the biosphere erroneously contrasted with (their) medium as though the two were independent objects." In his view, evolution could not be understood except at a global level; the mass respiration of all organisms had to be taken into account. Biogeochemical energy, characterized by the progressive growth of free energy (reduction in entropy), acts back as an internal force to produce increasingly more highly ordered states (Figure I substantiates this claim). Vernadsky proposed a biogeochemical extremum principle governing evolution: The bioienic migration of chemical elements in the biosphere tends toward a maximum of manifestation. This migration is affected not only by the mass of atoms in circulation, but also by the intensity or rate of the circulation. just as Spencer's law of evolution was unexplained with regard to the known laws of physics, so too was Vernadsky's biogeochemical principle. Vernadsky believed that a physical account was possible, however, and urged that it be sought.

Lotka (1945, p. 167) also believed in the necessity of viewing evolution as a global whole evolving under the flood of light received from the sun. He remarked that "fundamental to the concept of evolution is the idea that it is in some significant sense a directed process" and proposed a law of maximum energy flux as the governing extremum: Natural selection will make the energy flux through the system a maximum, so far as is compatible with the constraints (Lotka, 1922). These extremum principles of Vernadsky and Lotka are closely similar. Vernadsky's inherently more physical view, however, is the deeper of the two. Because Lotka's principle is stated as the result of the imperialistic nature of living things in competition, it starts with the same assumptions as Malthus and Darwin.

Scope of Darwinism in Overview

In the previous discussion it was shown why the fact of perception-action cycles is outside the scope of Darwinism. Natural selection presupposes, at the outset, the characteristic achievements of living things -self-maintenance, adaptability, reproduction, and the abilities to perceive and act coordinately. Additionally, the steady supply of free-oxygen at appropriate levels needed for the progressive development of perceiving-acting cycles is a property of a persistent global entity that Darwinism is not designed to accommodate. Further, because it cannot address this functional global whole, Darwinian theory, despite the overwhelming evidence, adopts an agnostic and sometimes hostile posture toward the creative or progressive (meaning: going in a direction) nature of evolution (e.g., Maynard-Smith, 1969; Williams, 1966)[1]. Because adaptation is attainable at any level of organization (bacteria, amoeba, worm, insect, placental mammal), and because the reproductive capabilities of many simpler forms of life surpass those of greater complexity (Bertalanffy, 1968), it is impossible by Darwinian criteria to recognize the directed nature of evolution.

A selection principle is required that can account for the selection of ordered from disordered things and the progressive evolution of the global entity as a whole. Because competition for resources (where a generalized resource is a nonequilibrium field potential as defined later) is not between replicating entities but between macro (ordered) and micro (disordered) modes, the principle cannot, by definition, be biological. This forces the view that the overarching selection principle must be physical rather than biological and suggests the necessity of recoupling the world that has been dualistically pulled apart. Such a principle would be consistent with the view of the importance of identifying scale-or level-i'ndependent physical principles and laws that function with equanimity over all of nature's partitionings (e.g., Haken, 1983; Iberall & Soodak, 1987; Kugler & Turvey, 1987; Nicolis & Prigogine, 1989; Saithe, 1985; Swenson, 1988, 1989b; Weber, 1991; Yates, 1989).

The sections that follow are directed at the earlier claim that the strategy needed to understand perception-action cycles is the physical strategy of identifying the preceding field conditions which produced or selected them at their origins and have continued to produce or select them over evolutionary time. In developing this claim, the implicated physical selection principle will figure prominently. We proceed in two main steps. In step one, we identify and develop the physics appropriate to spontaneous orderings, the physics that spells out the preceding field conditions. In step two, we focus explicitly on the thermodynamic conditions formative of perception-action cycles with special emphasis on vision's guidance of action.

1.The following are a few of the examples that are easily proliferated to make the point (see Carneiro, 1987a, for further discussion): (a) "To attempt to compare members of distinct types on a scale of highness (of organization) seems hopeless; who will decide whether a cuttle fish be higher than a bee . . ." (Darwin, 1859/1937, p. 96). (b) "It would be a brave anatomist who would attempt to prove that recent man is more complicated than a Devonian ostracoderm" (Dobzhansky, 1970, p. 392). (c) ". . . all species from amoeba to man are basically equal" (Por, 1980, p. 390, summarizing the neo-Darwinian view). (d) '. . when we speak of progress in evolution we are already leaving the relatively firm ground of scientific objectivity . . ." (Huxley, 1942/1974, p. 565, quoting Haldane).

END-DIRECTED PHYSICS

It was during the same extraordinary decade that saw the works of Spencer and Darwin first published, that Thomson (1852) and Clausius (1865) formulated the second law of thermodynamics, a law that Eddington (1929) regarded as holding the supreme position among the laws of nature. As originally formulated, the second law was precisely a statement of final cause in the Aristotelian sense as the "end to which everything strives and which everything serves" or "the end of every motive or generative process" (Bunge, 1979, p. 32), a fact first explicitly stated by Planck (1949). "The entropy of the world," said Clausius (1865, p. 400), "strives to a maximum." The physical world, regarded for so long as aimless, was seen as end driven.

Eddington's (1929) statement reflected the fact that both the second and the first laws of thermodynamics are not ordinary laws of physics; they sit above the ordinary laws as laws about laws, expressing dynamic symmetries of the laws of physics themselves. The first law, the conservation law, growing out of the work of Meyer, joule, Helmholtz, and others, states that (a) all forms of energy, for example, mechanical, chemical, or heat, are interconvertible into one another, and (b) the total amount of energy is conserved (energy is neither created nor destroyed). It expresses the time-translation symmetry of the laws of physics. The second law similarly expregses a symmetry that governs the ordinary laws of physics, but additionally expresses a symmetry that governs the first law as well. (Hence, Eddington's claim for its supremacy.) While the first law is a law of equivalence, the second law expresses, for nonuniform distributions of conserved quantities (e.g., mass, energy, momentum), a symmetry unfulfilled. It is precisely this unfulfilled symmetry (the distribution is not uniform) that nomologically introduces end-directed behavior into the natural world and makes the second law a law of "preference" (Planck, 1949). Clausius's entropy is the measure of this preference of nature for certain states.

There is an inextricable relation between energy and entropy, and understanding its form is of crucial importance. The first law was formulated prior to the second, but energy was not fully defined until entropy was identified. Carnot (1824/1960) showed that the "availability" for producing dynamical change or work-the "motive force"-was irreversibly destroyed. The implication of this finding, as Thomson and Clausius recognized, was that if the first law were to hold, then there had to be a quantity that was not conserved in addition to the quantity (energy) that was conserved. The second law states that all natural processes proceed spontaneously so as to maximize this quantity, for which Clausius coined the word entropy (to sound like energy and, thereby, to stress the relation between the two). The state of maximum entropy, the end state at which all evolutionary or macroscopic change stops, is called thermodynamic equilibrium. Note that when entropy is maximized field potentials are minimized. A field potential exists whenever and wherever there is a nonuniform distribution in a conserved quantity. Thus, the second law may be expressed equivalently as entropy maximization or field potential minimization; they are both expressions of the same symmetry.

The active end-directed nature of the second law is readily appreciated. If a glass of warm liquid is placed in a room that is at a cooler temperature, a flow of heat is spontaneously produced from the glass to the room until the temperatures of the two are equal. The liquid and the room together constitute a thermodynamic flow field and the difference in temperature between the two constitutes a nonuniform distribution of energy called a field potential. As Carnot first realized, the difference or field potential determines a force, proportional in magnitude to the size of the difference, that drives the flow. The flow, which can be considered a drain on the potential, continues spontaneously until the potential is minimized given the constraints, or equivalently the entropy is maximized and the field is at thermodynamic equilibrium (when the two temperatures are equal).

To make the fundamental point about the energy with respect to the entropy, the room can be imagined as tightly sealed so that no energy can flow into or out of it. Note that the energy in the field (within the entire room including the glass) is precisely the same at the beginning of the process and at the end of the process; the only difference is the way ie is distributed. The latter situation highlights how energy and entropy are confounded in statements such as "energy is the measure of a system's ability to produce change." Only entropy, the extent to which it is maximized, is a measure of a system's ability to produce change. This measure of the ability to produce change is precisely the notion of Carnot's availability and why Soddy (1912) called the second law the "law of availability." Entropy maximization can, therefore, be conceived as availability destruction (or dissipation). The second law would then read: Nature proceeds spontaneously so as to maximize availability destruction or, synonymously, resource dissipation.

Note further how the example illustrates the notion of final cause. The second law defines the end state-the symmetry condition of maximum entropy-for the given temperature arrangement and for any other way the field (room and liquid in glass) is arranged. Thus, given the same quantity of energy, if the temperature of the liquid is cooler than that of the room, then the energy will flow from the room to the glass rather than the reverse, yet the end state will be precisely the same. Whatever the temperature configuration of room and contents, the field will produce the appropriate flows so as to maximize the entropy. In sum, the symmetry of the second law reveals in the "striving" of Clausius, the "preference" of Planck, and the "motive force" of Carnot that the laws of physics, governed as they are by this overarching symmetry, are hardly aimless or purposeless, but rather active and end directed.

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BOLTZMANN'S REDUCTION

The statement of the second law appeared as a contradiction of the mechanical world view. In response, Boltzmann attempted to salvage the Newtonian (purposeless, mechanical) paradigm by reducing the second law to a stochastic collision function, to a law of probability. His move, by making the spontaneous production of order "infinitely improbable" and thus branding the second law as the "law of disorder," deflected attention from the profound insight of Thomson and Clausius.

Modeling gas molecules as billiard balls, Maxwell (1871) showed that nonequilibrium velocity distributions would become increasingly disordered with each collision leading to a final macroscopic state of uniformity and symmetry. Boltzmann recognized this state, in which the macroscopic uniformity and microscopic disorder corresponds to the minimization of all field potentials, as the state of maximum entropy and claimed that the second law was simply a result of the fact that disordered states caused by local stochastic collisions were the most probable. From this interpretation, molecules moving "at the same speed and in the same direction" (ordered behavior) was in Boltzmann's (1886/1974, p. 20) view, "the most improbable case conceivable ... an infinitely improbable configuration of energy." As emphasized in the two sections that follow, this view (still found in numerous textbooks) is precisely on its head: Rather than being infinitely improbable, the production of order is lawful and inexorable.

A PHYSICAL SELECTION PRINCIPLE

Classical thermodynamics tells us that entropy is maximized at thermodynamic equilibrium but tells us nothing about the path of action selected to get there. An answer to the question can be framed in terms of a simple experiment, the consequences of which show a physics that is not only end directed but inherently opportunistic in attaining its ends. Figure 3 shows an adiabatically sealed (closed to the flow of heat) chamber divided by an adiabatic wall into two compartffients, each holding equal quantities of a monatomic gas such that there is a temperature difference T, > TI1 producing a field potential with force F. If a section (labeled 1) of the adiabatic seal is stripped from the dividing wall (Figure 3a), an incoherent flow of energy or heat (a drain) is spontaneously produced rrom I to II until the potential is minimized (the entropy is maximized) given the constraints. The rate of entropy production is given by:

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

where dQIdt and (IIV -1/7") are the flow and force respectively. Equation (1) shows that, ceteris paribus, the rate of entropy production is determined by the coefficient of conductivity of the wall. Figure 3b depicts the removal of a second portion

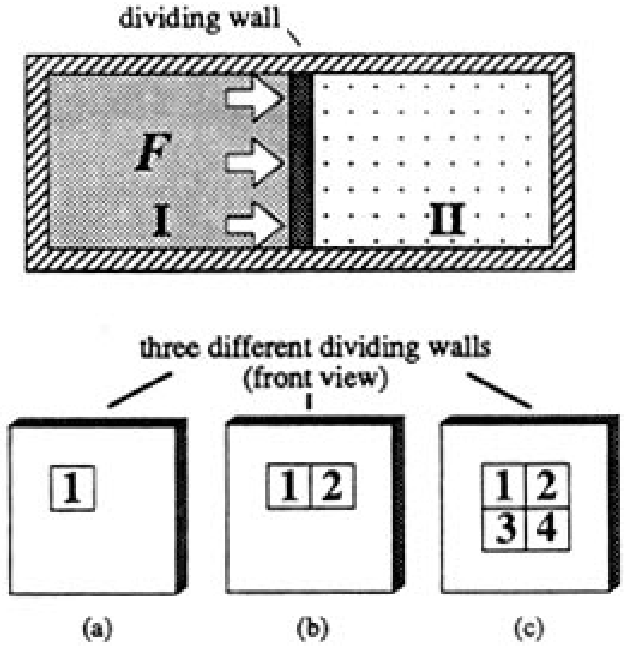

FIGURE 3 A simple experimental arrangement expressing the law of maximum entropy production. From "Order, Evolution and Natural Law: Fundamental Relations in Complex System neory" by R.Swenson, in C. Negoita (Ed.), Cybernetics and Applied Systems (in press-c), New York: Dekker. Copyright 1991 Marcel Dekker, Inc. Reprinted by permission

(iabeled 2) of the adiabatic seal. The wall underneath in this second case is composed of a different material with a different coefficient of conductivity. If the rate of 2 relative to the rate of I is sufficient to drain some quantity of the potential before I drains it all, then that quantity is automatically assigned to 2. If, with different relative coefficients, 2 can drain all the potential before I can drain any, then the entire quantity is assigned to 2 and I gets none. With the adding of more drains (Figure 3c), the behavior is precisely the same: Regardless of the particulars of the system, not only will it produce the dynamics appropriate to achieving the same final state, but it will select the assembly of pathways or drains among the available dynamics so as to get to the final state (minimize the field potential or maximize the entropy) at the fastest possible rate given the constraints. It has been proposed that the foregoing expresses a law of maximum entropy production, a universal selection principle that provides the physical basis for the inexorability of spontaneous, evolutionary ordering (Swenson, 1988, 1989b, 1989c, in press-b).

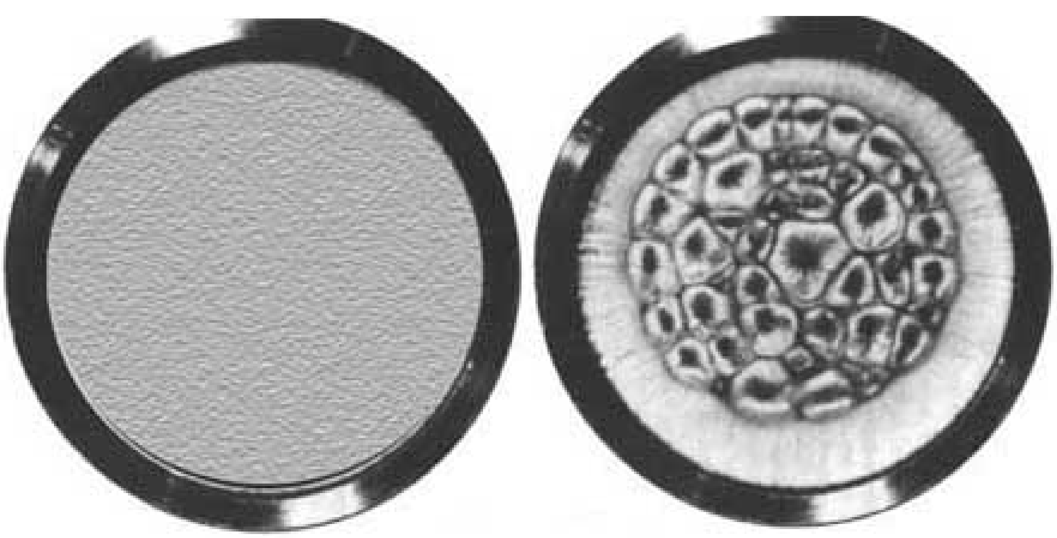

FIGURE 4 Two time slices from the Benard experiment where (left) shows heat transer in the disordered regime and (right) shows heat transfer through the spontaneous production of order above the critical minimal field potential threshold. From "Emergent Attractors and the Law of Maximum Entropy Production: Foundations to a Theory of General Evolution" by R. Swenson, 1989b, *Systems Research* 6, p. 192. Copyright 1989 by Pergamon. Reprinted by permission.

THE INEXORABILITY AND OPPORTUNISM OF ORDER PRODUCTION

A classic experiment in self-organization (first devised by Benard in 1900) is depicted in Figure 4. A viscous fluid is held between a uniform heat source below and the cooler temperature of the air above. That is, there is a potential difference with a field fbrce F of a magnitude determined by the difference between the two temperatures. When F is below a critical threshold heat flows from the source to the sink (entropy is produced) as a result of the disordered collisions between the constituent molecules (see Figure 4a); when F is increased beyond the critical threshold Bdnard "cells" emerge spontaneously, each cell consisting of hundreds of millions of molecules moving collectively together.

The major point to be emphasized here is that there is nothing improbable about the emergence of Benard cells; it is a completely lawful phenomenon. Each time F is increased beyond a critical threshold order emerges spontaneously. What is the critical threshold? It is simply the minimum magnitude of F that will support the ordered state. In other words, order production is entirely opportuni5tic: it occurs as soon as it gets the chance. The latter is understandable from the proposed law of maximum entropy production-systems will produce or select those dynamics that minimize their field potentials at the fastest possible rate given the constraints (Swenson, 1988, 1989b, 1989c, in press-b). Figure 5 shows the discontinuous increase in heat transfer that occurs with the production of the ordered state. Because the second law requires that entropy production increase concomitantly with the local entropy reduction of the ordered state, a phenomenon of the kind depicted in Figure 5 will be the case at whatever level order production occurs: Order is selected inexorably according to the law of maximum entropy production for precisely this reason.

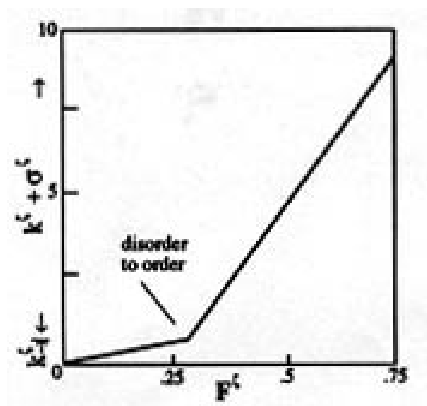

FIGURE 5 The discontinuous increase in the rate of heat transport effected by the disorder-to-order transition in a simple fluid experiment similar to that in Figure 4. The rate of heat transport in the disordered regime (Boltzmann regime) is given by V, and V + a is the heat transport in the ordered regime [3.1 x 10' H(cal x cm.-' x sec-')]. From "Engineering Initial Conditions in Self-Producing Environment" by R. Swenson, in M. Rogers and N. Warren (Eds.), A Delicate Balance: Technics, Culture and Consequences (p. 70), 1989d, Los Angeles: Institute of Electrical and Electronic Engineers (IEEE). Copyright 1989 by IEEE. Reprinted by permission. Data originally from Malkus (1954).

With the selection of order from disorder, a switch from the summative linear kinetics of the disordered regime to the autocatakinetics of the self-organizing state occurs and brings.with it a qualitatively different kind of behavior. The term autocatakinetics, which as Lotka (1945) noted was first used by Ostwald, has been reintroduced into the literature in an updated form as the minimal or most generalized description of a spontaneously ordered or self-organizing state (Swenson, in press-a, in press-b). An autocatakinetic system (Figure 6) maintains its "self" as a state constituted by, and empirically traceable to, a set of nonlinear (circularly causal) relations through the dissipation or breakdown of field potentials (or resources) in the continuous coordinated motion of its components (from auto-"self" + cata-"down" + kinetic, "of the motion of material bodies and the forces and energy associated therewith" from kinein, "to cause to move").

The generic dynamics of autocatakinetic systems, and of fields of autocatakinetic systems interacting together, is behaviorally rich. Autocatakinetic systems are self-amplifying sinks that opportunistically pull field potentials (resources) into their own self-production by extending the space-time dimensions of a field and thus its dissipative surfaces. The greater the dissipative space, the greater the per-unit-time coupling of sources and sinks (potentials and drains, respectively). This fact is readily seen in the Benard experiment. Whereas in the disordered regime (Figure 4a) the intrinsic units of space and time are of the order of 10 -8 cm and 10-5 g (the mean-free-path distances and relaxation times), in the ordered regime (Figure 4b) the intrinsic dimensions, as defined bythe coordinated motions of the components that constitute the cells, increased to centimeters and seconds. This extension of the dissipative space of the fluid by orders of magnitude accounts for the increase in the rate of entropy production seen in Figure 5.

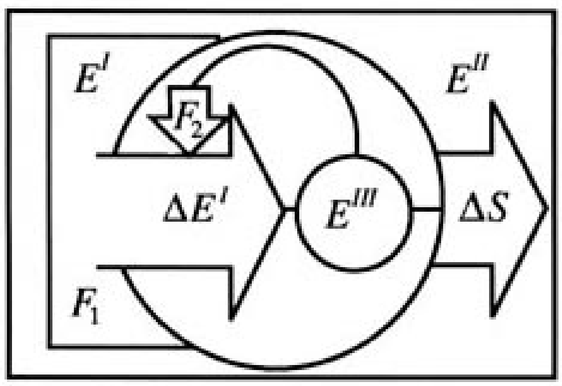

FIGURE 6. Figure shows generalized autocatakinetics where E' and E^{ll} indicate a source and a sink with the difference between them constituting a field potential with a force F_1, the magnitude of which is a measure of the difference. deltaE^I is the autocatakinetic flow and deltaS the entropy production. E^{III} is the internal potential carried in the autocatakinetic relations, and F_2 is the internal force produced by E^{III} that feeds back to amplify or maintain deltaE^I. From "Emergent Attractors and the Law of Maximum Entropy Production: Foundations to a Theory of General Evolution" by R. Swenson, 1989b, Systems Research, 6, p. 191. Copyright 1989 by Pergamon. Adapted by permission

Autocatakinetic systems spontaneously select their own internal degrees of freedom so as to maximize the extension of their dissipative surfaces, which in the Benard experiment produces a time-independent state of regularly arrayed hexagonal cells (not shown). Because surface area increases as the square of a linear dimension whereas volume increases as the cube, isometrically growing autocatakinetic systems bifurcate spontaneously above some minimal size and proliferate their dissipative surfaces by fissioning. The point is, the ability of an autocatakinetic system to capture and transform energy resources is limited by its inputs and outputs, which are a function of its dissipative surfaces. Consequently, because its volume increases faster than its surface, as the system grows, it becomes increasingly less efficient at capturing and transforming energy. At some minimal threshold it becomes unstable to spontaneous division or fissioning by which surface-to-volume ratio is immediately increased.

Such fissioning is commonplace. It is observed in the Benard experiment, in the multiplication of living cells, and in the increase in population through the proliferation of villages during the Paleolithic period from approximately 1,500 villages at the beginning to about 75,000 villages at the end (Carneiro, 1987b; Swenson, in press-c). Under the constraint of entropy production maximization, surface-volume ratios play a fundamental level-independent role in determining the way things are (the symmetry states they assume). Prokaryotes, because they are diffusion limited, are an order of magnitude smaller than eukaryotic cells; and eukaryotes, because they needed an increased internal surface area to maintain their size, which required a membrane and an energy system dependent on atmospheric 02 above a minimal level, did not appear on earth for 2.5 billion years. Figure 2 tells the story of how form literally explodes into being (in geological time) as soon as the global chemical potential (the internal force in Figure 6) is of a sufficient magnitude to drive specific dissipation rates inhering in respiration and transport processes that could support the volume. The proposed selection principle provides a physical basis for Haldane's (Carneiro, 1987a) claim that evolution is a struggle to maximize surfaceto-volume ratios which can be seen as the expected behavior of the Earth system as a global self-organizing whole to maximize the extension of its dissipative surfaces over evolutionary time.

In summary, it is noted that each level, and each kind of material substrate, will present specific conditions for spontaneous ordering. The exact details of the conditions sponsoring order will have to be worked out for each particular instance-level-independent law acts on level-dependent substrates and the substrates themselves are emergent. At the same time, the process that engenders spontaneous ordering is expressible in a very general fashion, indifferent to the specifics (Figure 6). What the proposed law of maximum entropy production addresses is the bias obs7erved from instance to instance, namely, that systems progress in the direction of the most rapidly dissipative states given the conditions.

OPPORTUNISTIC THERMODYNAMIC ORIGINS OF VISUALLY GUIDED ACTION

T'he physical account of evolution espoused here assumes that the Earth will evolve as a global entity so as to maximize the extension of its dissipative surfaces and to degrade, thereby, the geo-cosmic potential at the fastest possible rate given the constraints (Swenson, 1988, 1989a, 1989c). As intimated, this account has consequences for understanding the origins of the perceptual guidance of movements and the movement enhancement of opportunities to perceive. In this section and the next, the previous intimations are made explicit and the thermodynamic reasons for perception-action cycles are identified.

Another example of a thermodynamic field, similar to the glass of water in the room used earlier, is a warm mountain cabin sitting in cold, snow-covered woods. This field will spontaneously configure so as to dissipate (minimize) the temperature gradient or potential in whatever ways are possible. The opportunities include losing heat (producing energy flows) through the walls, through cracks in the walls, through the gap beneath the door, and through the window to the extent that it is open. In like manner, the geo-cosmic field can be expected to seize, in opportunistic fashion, accessible dimensions of dissipation as they are available. Examination of the solar absorption pattern for the planet shown in Figure 7, together with examination of the solar radiation spectrum for the planet shown in Figure 8, reveals a tremendous window of opportunity (in the very literal sense of an open window in the earlier warm cabin example) for producing thermodynamic flow with respect to the potential in the 0.4 to 0.7 nanometer range of the electromagnetic spectrum.

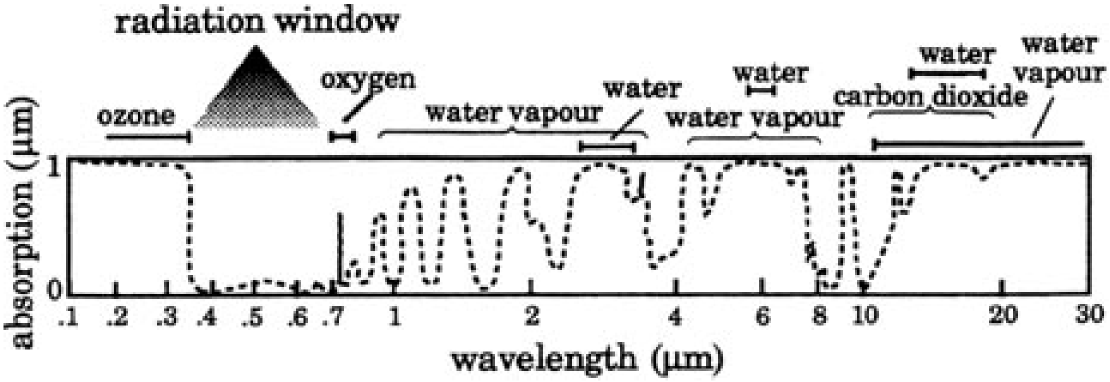

FIGURE 7 The absorption spectrum of the atmosphere where I = total absorption and 0 = no absorption. From Environmental Systems (p. 47) by 1. White, D. Mottershead, and S. Harrison, 1984, London: Allen & Unwin. Copyright 1984 by Allen & Unwin. Reprinted by permission.

Opening the window in the heated cabin would produce a heat flux through the window. Consistent with the same physical principles, the window in the absorption spectrum (Figure 7) coupled with the massive solar emissivity in this range (more than half of the total; Figure 8), would be expected to produce a dissipative flux. Because the quantity of matter on Earth can be taken to be conserved (it has remained relatively constant since Hadean times) then such a flux-consistent with Vernadsky's (1929/1986) earlier view-must be through the progressive ordering (cycling) of the constituent biogeochemical components. Given the lawful nature of progressive ordering or level-building behavior, it is hardly surprising that the light distribution supporting perceptually guided actions, namely, the visible spectrum, is precisely in this same narrow range as Figure 9 reveals. Indeed Wachtershauser (1987) showed that it could not have been otherwise[2].

As noted earlier, the first photosynthetic bacteria, by hooking the solar source to outgassed, reduced compounds such as hydrogen sulfide and sulfur, were able to transcend the limits on fermenting bacteria that were dependent on abiogenic organic compounds. Not much later in geological time, protocyanobacteria accomplished true photosynthesis, namely, oxygenic photosynthesis, by applying two photons to the cleavage of one water molecule. They linked the unlimited photon supply of the solar source to the unlimited supply of electrons in water, releasing oxygen into the atmosphere. The portion of the electromagnetic spectrum used for oxygenic photosynthesis is lawfully specified by the constraints of photocheriiistry. In particular, wavelengths higher than 700 nanometers are not strong enough to drive the reaction, and wavelengths below 400 nanometers chemically destroy the organic molecules, for example, proteins and DNA, entailed in the process. The mutuality of the photochemical laws and the potential of the solar window is readily appreciated: The facts of photochemistry afford the self-organization of autocatakinetic entities to drain the potential.

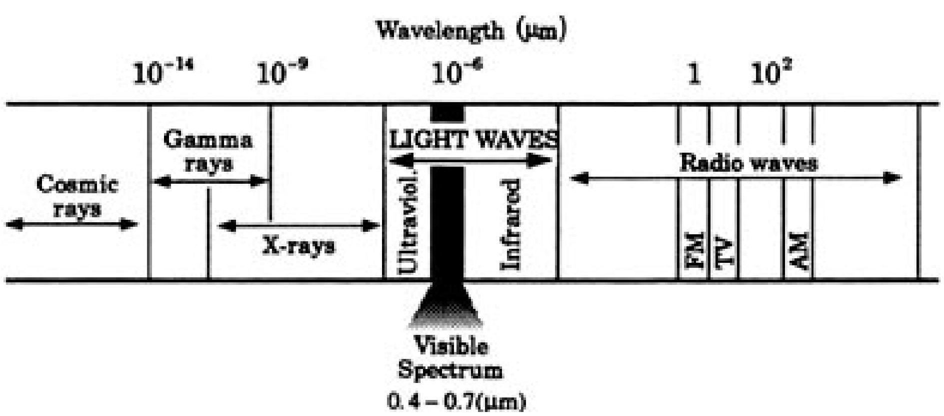

FIGURE 9 Visible wavelengths of the electromagnetic radiation spectrum.

The receptors for nonphotosynthetic bacteria were first used for detecting food. Similarly, photopigments were first used in photosynthesis, and in locating or moving toward or away from places where the wavelength of light was suitable or not suitable, respectively, for photochemistry (e.g., lower in the water where the visible spectrum is still strong but where the ultraviolet rays are no longer harmful). At some point, when cyanobacteria are presumed to have constituted a major portion of the biomass on earth, they themselves represented a field potential on which heterotrophs (which require carbohydrates both as an energy source and for biosynthesis) began to feed. The heterotrophs used the same photopigments for detecting light, but not to photosynthesize; instead the pigments were used to detect light that was specific to where the autotrophs (photosynthesizing cyanobacteria) were feeding (on the light). Light distributions specifying not light as food itself, but information about the location of food, was evolutionarily instantiated in its modern sense. Although the pigments making possible the registration of light distributions were derived from photosynthetic origins, they were not used for photosynthesis itself but for tracking down second-order photosynthetic potentials. The significance of the foregoing is that a higher order phenomenon (in this case, the autocatakinetics entailed by heterotrophic feeding off the cyanobacteria), constrained by a higher order description of light (not light as such, but what it specifies), increases the intensity of the thermodynamic flow. It provides an additional means of hastening the degradation of the geo-cosmic potential. Contemporary nonphotosynthesizers (e.g., ourselves) contribute to that hastening in a manner that is evolutionarily continuous with that of the heterotrophs: Maintaining the capacity to see requires vitamins, such as vitamin A, which must be obtained by consuming plants and/or bacteria.

2. It is not our intention here to endorse every detail of Wachtershauser's scheme. A deeper discussion is beyond the scope of this article, but his central argument, which is well demonstrated does not depend on those details.

A NEW CLASS OF OBSERVABLES AND AN OPPORTUNITY TO EXTEND DYNAMICAL INTERACTIONS

Living things are autocatakinetic systems with replicating components. Once the earth was sufficiently cool, replicative order emerged extremely rapidly by the standards of geological time. Following the arguments just identified, the rapidity of this growth is at once easy to understand. Replicative order opened up the exploration and accessing of otherwise inaccessible dimensions of dissipative space, the creating of ew drains for the geo-cosmic potential. This section elaborates the theme implicit in the preceding section: That the means for accessing these new dimensions of dissipative space were perception-action cycles. A confluence will be identified among physical laws, the production and proliferation on earth of replicative order, and the production and evolution of perception-action cycles (Swenson, 1989e, 1990). The missing piece to the argument advanced thus far is information in the specificational sense as advanced by Gibson (1966, 1979/1986) and elaborated in reference to physical issues by Kugler and his colleagues (e.g., Kugler, Shaw, Vicente, & KinsellaShaw, 1990; Kugler & Turvey, 1987, 1988).

Living things are immersed in energy distributions. Notable among these ambient energy distributions are those for which the mean energy content is extremely low relative to the energy associated with animals, for example, optical distributions and distributions of volatile materials ambient to a path of observation traversed by a flying insect or a running animal. The mass term can, therefore, be suppressed effectively in the descriptions of these energy distributions as they bear on the control and coordination of movement (Kugler & Turvey, 1987, 1988). The descriptions in the optical case, for example, are of the spatiotemporal structure-that is, adjacent and successive order-that is imposed on the ambient optical distributions by the layout of environmental surfaces (attached and detached objects, places, one's body, movements of one's body, surface displacements, deformations, collisions, etc.). Gibson's (1966, 1979/1986) ecological conception of information is founded on the assertion that lawful relations exist between layout properties of general significance to the class of new observables permitting interactions beyond those permitted by the observables (notably, forces) normally identified in physical theory (Kugler & Turvey, 1987, 1988; Turvey, 1990). Point (b) is of particular relevance to the present argument. These law-based kinematic, geometric, and temporal properties of structured energy distributions make possible an additional repertoire of stable and reproducible functions for any system able to establish a linkage (Rosen, 1978) between these properties and its own kinetic properties, specifically, its ability to produce forces from its on-board energy supplies (Kugler & Turvey, 1987). This ability, of course, characterizes living things. It has local and global consequences.

A striking difference between living autocatakinetic systems (replicative order) and nonliving autocatakinetic systems is that the nonliving are captives of their local potentials whereas the living are not. If the local energy resource is removed from a nonliving autocatakinetic system -for example, turning off the heat in the B6nard experiment-then the system "dies." When the local energy resource is removed from a living thing, however-for example, when food in the vicinity of an organism is depleted-an increase in activity rather than a decrease or stoppage of activity is usually the reaction. As observed at the outset, the perceptual guidance of movements and the movement enhancement of opportunities to perceive, extend to animals particular benefits in their hunt for, and consummation of, energy resources. In nature, food is often distributed in reasonably circumscribed patches (MacArthur & Pianka, 1966); with respect to birds, for example, patches comprise different trees, different branches, different regions of grassland, and so on. In the most general of cases, the energy value of patches is a random variable with patch values varying in time and with the frequency and density of exploitation. In perceiving-acting, living things hook their on-board energy reservoirs onto the invariants of ambient optical distributions, compression wave fronts and wave trains, fields of diffusing volatile materials, and so on, to search out resources discontinuously located in space and time, and to access, thereby, higher orders of dissipative space. Behind this ability of living things to behave arbitrarily with respect to local potentials and to coordinate their behavior with respect to higher order field invariants 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 the sequence of base pairs in a DNA string, is thermodynamically arbitrary with respect to the rate at which they are "written" and "read"[3] (Polanyi, 1968).

The role of perception-action cycles enhancing the maintenance of on-board energy resources is a description from the point of view of the level of the individual organism. The role of perception-action cycles enhancing the rate of dissipation of energy resources is a description in terms of the environment or field. Living things with the capacity to perceive how and where they are moving, and with the coordinating capacity to move in ways that allow them to perceive more and to perceive better, expand the patches of the planet in which energy degradation can take place. In the terms introduced above, they expand the Earth's dissipative space. Thus the purposes of living things are differentiations or productions, literally higher order symmetry states, of the environment itself towards its own ends.

In sum, the coordination of the autocatakinetics of living things with the observables of kinematic fields provides access to otherwise inaccessible opportunities to produce ordered flow and thereby dissipate potentials at faster rates. The progressive emergence of perception-action cycles and the exploratory behavior they entail, both phylogenetically and ontogenetically, in hooking autocatakinetics to new higher order observables in dissipative space is the spontaneous production of the global self-organizing whole. Perception-action cycles, in the words of Vernadsky (1929/1886), ar the regular functions of the global system itself. Progressive evolutionary ordering entails the production of increasingly higher ordered states, higher -ordered symmetries of the world itself in its own becoming, and perception-action is the physics at these levels. There is no other way to coordinate the dynamics at these levels.

3 For example, the amount of ATP to replicate a string of DNA is the same regardless of the particular sequence, or the difference in the amount of entropy produced in writing or printing two phrases of the same length but with completely different meanings is inconsequential with regard to which one gets written.

SEEKING SIMILITUDES

The search for similitudes in the present article has been what D'Arcy Thompson (1917/1961) referred t o as a community of principles or essential similitudes. A quest for physical causes often merges with a search for relations between, or similarities in, things that are apparantly disconnected. A similitude has been shown among such apparently disconnecte things as atmospheric oxygen, Benard cells, and percpetion-action cycles. Identifying similitudes is often rewarded by improved understanding in other matters. One example is given by way of summary.

Nearly half a century ago Bertalanffy (1952) showed that spontaneous order and even an increase in the degree of ordeer, can occur in open systems. The requirement, he observed, was that the entropy production compensate for internal entropy reduction so as to satisfy the balance equation of the second law, namely, changes in entropy must always be positive except at thermodynamics equilibrium when they are absent. However, given Boltzmann's claim that ordered states are infinitely improbable, the fact such ordered states are permitted to exist as long as they pay the price of doing business (their "entropy debt") does not account for why they exist. It does not account for where such debt payers, purposively struggling against the laws of physics, come from, or why they are ubiquitousty put into business in the first place.

The often-expressed theme of living things struggling against physical law is an expression of a more general tradition, that of holding animal and environment as distinct and logically independent. The inability to explain the business of living things and their reason for conducting it, magnifies the presumed discordance between the principles of living things and the principles of the world in which they live. Gibson (1979/1986) identified the cornerstone of an ecological approach to perception and action as animal-environment mutuality and took issue with the animal-environment dualism on which most perceptual theories, past and present, had been established (Lombardo, 1986; Shaw & Turvey, 1981; Turvey & Shaw, 1979; Turvey, Shaw, Reed, & Mace, 1981). Mutuality had been expressed with equal vigor several decades before in Vernadsky's (1929/1986) promotion of a global perspective on evolution.

The cognate hypotheses that living things coordinate their autocatakinetics with respect to information in the specificational sense, and in so doing provide access to further dimensions of dissipative space, flag the reciprocal relation between order production (internal entropy reduction) and entropy production. When a thermodynamic flow field produces spontaneous order, the rate of entropy production increases by a concomitant amount; the more order produced the faster the field minimizes its field potentials and maximizes its entropy. If the physical selection principle is that a thermodynamic field selects those dynamics that reduce its otentials at the fastest rate for the constraints, then ordered states are the productions of fields towards their own ends. They are the inexorable products of natural law rather than miraculous debt payers fighting against it. The paradox with respect to the second law and living things is thereby dissolved and the notion of mutuality between living things and the world is thereby lawfully entailed. *The world is in the order production business, including the business of producing living things and their perception and action capacitities, because order produces entropy faster than disorder.*

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