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THE COSMIC BELLOWS: THE BIG BANG AND THE SECOND LAW

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ABSTRACT: We present here a cosmological myth, alternative (but complementary) to “the Universe Story” and “the Epic of Evolution”, highlighting the roles of entropy and dissipative structures in the universe inaugurated by the Big Bang. This myth offers answers to these questions: *Where are we? What are we? Why are we here? What are we to do?* It also offers answers to the following “why” questions: *Why is there anything at all?* and *Why are there so many kinds of systems?*—the answers coming from cosmology and thermodynamics; *Why do systems not last once they exist?*—the answer coming from a materialist interpretation of information theory; and, *Why are systems just the way they are and not otherwise?*—the answer coming from evolutionary biology. We take into account the four kinds of causation designated by Aristotle as *efficient, final, material, and formal*, with the Second Law of thermodynamics in the role of general final cause. Conceptual problems concerning reductionism, “teleology”, and the choice/chance distinction are dealt with in the *specification hierarchy* framework, and moral implications of our story are explored in the conclusion.

KEYWORDS: Big Bang; Cosmic Evolution; Dissipative Structures; Ecology; Entropy; Finality; Historical Constraints; Myth; Natural Philosophy; Selection; Senescence; Specification Hierarchy; Teleology

INTRODUCTION

All societies and cultures have creation myths, often entailing morality. By “myths” we mean those deeply significant stories which provide a context for human thought and behavior by framing things and events for evaluation, without themselves being subject to evaluation. For example, if a biologist assumes that everything appearing to him as an adaptation has been produced by natural selection, and bases all his explanations on this assumption, then natural selection is here functioning as a myth, rather

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than as a scientific hypothesis requiring testing. A belief which can function as a myth for educated persons in our time must reflect scientific knowledge (Salthe 1990, 1992). Such a myth does not pre-empt the making of moral choices but provides “a framework for human orientation in life,” as Kauffman (1997) puts it. It is the renewed task of the philosophy of nature to provide such a myth (Salthe 2001; see also www.nbi.dk/~natphil/salthe/). Natural philosophy has the task of making scientific knowledge into an intelligible system, one which enables us to make sense of the world and our lives in it. Its task is mythmaking.

Brian Swimme and Thomas Berry presented a cosmological myth in *The Universe Story* (1992); versions of it have also circulated under other names, notably *the epic of evolution* (see Kauffman 1997). Here we present another cosmological myth, one that we consider complementary to the Swimme and Berry story, in that our myth brings to the fore an aspect of the cosmos which the “epic of evolution” acknowledges but leaves in the background. The naturalized myth presented here will focus prominently on physical forces. In order to head off charges of reductionism, we should first consider the relationship of the physical level to other integrative levels in the *specification hierarchy* (Salthe 1991, 1993a, 2000a). Most material objects can be understood from more than one viewpoint (Rosen 1985), a fact which gives rise to *intensional complexity* (Salthe 1993a) and a hierarchy of *integrative levels* (Salthe 1988, 1991, 1993a). Suppose we examine an organism, for example. We could do this at the *biological* level by investigating, say, cell division. Or we could look at metabolism, which shifts our focus from cells as functional units to *chemical* reactions. Or we could work from a purely *physical* standpoint, focusing on diffusion and other phenomena related to thermodynamics. Of these three levels, the physical is the most general and the biological most specific. Borrowing a logically appropriate format used to designate classes in set theory, we can represent this *specification hierarchy* as follows:

{ physical level { chemical level { biological level } } }

(see also Salthe 2000a). In this symbolism the higher and more specific integrative levels are placed inside the lower and more general ones, as subclasses, as they impose further informational constraints on those from lower levels. Note that this differs from the more commonly discussed *scalar hierarchy* (Salthe 1985); physical phenomena, for instance, can be observed at any scale ranging from the subatomic to the supergalactic.

Now, physical phenomena are more generally present in the world than are biological ones, and form the basis out of which chemistry and biology emerge. At the same time biology regulates, harnesses or controls—integrates—physical/chemical processes in its locale. For example, the physical process of diffusion is regulated, and harnessed, by circulatory systems. Focussing on a more general level does not logically constitute a denial of the vital role played by any more specific level of the hierarchy. If you decide to go for a walk, the cells in your body and the atoms in your cells have to go along for the ride, although (or because) the processes going on within them furnish the energy

for your walking (and your deciding). So if in the present context we choose to emphasize the physical phenomena in an organism, we are not reducing the biological to the physical. Instead, we are consciously taking a very partial view, because the myth we are telling appears most clearly at the most general (physical) level. One good reason for this strategy would be to contribute to the construction of a unity of the sciences (Neurath et al. 1938-1969; see also Agazzi and Faye 2001; Wilson 1998), a project concordant with the aims of natural philosophy. Its major principle in the present context is that a more generally applicable explanation of a phenomenon is preferable to one that is less able to be generalized because such an explanation facilitates comparative studies in the interests of a unified view of nature (see Brooks and Wiley 1988).

Questions of interest to all mythologies are: *Where are we? What are we? Why are we here? What are we to do?* Natural philosophy is geared to answering “why” questions, which generally entail “what” questions (leaving related “how” questions to science). So, our short answers to these questions are as follows: *Where are we?* We are in the expanding universe following the Big Bang. *Why are we here?* Because the universe requires our services to aid in its project of thermodynamic equilibration. *What are we?* In this context, we are dissipative structures (Prigogine 1980). *What are we to do?* The answer to this question is not so easy to encapsulate, and requires consideration of various alternatives in a complex setting; it will be taken up at the end of this paper. We have also structured our discussion in terms of several large cosmological “Why?” questions: *Why is there anything at all? Why are there so many kinds of systems? Why do systems not last once they exist?* and, *Why are systems just the way they are and not otherwise?* These will serve as major headings, while the other questions above will provide minor headings.

WHY IS THERE ANYTHING AT ALL?

WHERE ARE WE?

Among possible answers to this question, that most germane to this study is given by the Big Bang theory of the origin of the universe. According to Frautschi (1982), Landsberg (1984) and Layzer (1976, 1990), we can see the universe as losing its state of global energy equilibrium with that original event, and striving to regain it ever since—but in vain, because as the expansion of the universe accelerates, so does the striving. The pull toward equilibrium is expressed by the Second Law of thermodynamics, which imposes the rule that the entropy of an isolated system always increases as a result of both spontaneous and forced processes. We will define *entropy* below; the isolated system in our story is the universe itself. We suppose that it could hardly expand at all if it were not isolated from adjacent systems. As its expansion accelerated, the universal system cooled and physical particles emerged, which then gave rise to matter as embodied energy. This in turn coalesced into mass, which continually aggregated as collisions brought about by a random search for mattergy equilibrium evoked gravitation—a necessary detour, as it were, on the path to equilibrium. The fact of gravitation,

however we model it, is the pre-eminent sign of energy being radically delayed in its equilibration. Its strength reflects (as a mirrorlike reversal) the rate of universal expansion. In a sense it *is* the expansion in reverse.

Matter, mass and gravitation are all signs of radical disequilibrium in the universe. In this scenario the system has been getting further and further away from an equilibrium distribution of energy and particles as the universal expansion continues to accelerate (Watson 2002), thereby increasing the drive toward equilibration at the same time. This drive produces *entropy*, which we can think of generally as disorder (Boltzmann 1886; Salthe, 2003). Swimme and Berry (1992) in their glossary define it as “a measure of disorder or randomness of a physical system; a measure of the incapacity of a system to undergo spontaneous change.” The etymology of the word suggests a “turning” or transformation, whereas that of *energy* suggests that which can be harnessed for doing “work”; entropy stands in contrast to energy because its “turning”—“away”, one might say—cannot drive an orderly process. Entropy production becomes an ever-higher priority as the Second Law becomes an ever more powerful attractor in the material world as the universe continues to expand.

Given the brute fact of masses of matter stuck in agglomerations nowhere near equilibrium, what might the Universal System do to facilitate equilibration? Following Schneider and Kay (1994), we can focus on local situations where organized forms relate to *energy gradients* with which they make contact. An energy gradient can be visualized as energetic particles all concentrated in a particular place in some orderly manner. They are metastable and ready to dissipate. As they dissipate, spreading out in the process of being pulled toward an equilibrium distribution, some of their energy might be used by some consumer as *exergy*. As a result the usability of their energy will diminish, having been converted to heat energy, which by definition is not oriented in any particular direction (and so cannot be used to do work). In contrast, energy that is available to do work has an arrangement favoring its transformation to directed kinetic energy.

All energy gradients in our world are unstable, and susceptible to being dissipated as fast as may be. For example, a concentration of immature protein in solution embodies a double gradient: since the molecules have not yet folded into their native configurations, they have a relatively large measure of Gibbs free energy. At a later time, the concentration gradient will have fallen as well, and the now-native proteins will have developed further into a still lower free energy state. In the present view, the general process of gradient reduction is reflected also at a higher integrative level when, say, a steep social gradient (in prestige or power) tends to invite revolution. We take this to be a more highly specified example of the same principle, and not a mere analogy. It does not explain everything we need to know about a social gradient, including the history of its generation, but it illustrates how a focus on the most general level has the unifying effect which is proper to a naturalized myth.

Following the convention which depicts energy flow as moving from “source” to “sink”, we can say that the steeper the gradient, the more ready it is to spill into the sink. Organized forms facilitate convective energy flows, which dissipate these gradients in

an orderly manner—in other words they act as more effective “consumers” of energy than unorganized forces such as friction, conduction and diffusion. Since these consumers increase entropy production from a gradient, their local order actually serves the global drive toward equilibrium (see also Swenson 1997). This is the general explanation for the existence of abiotic dissipative structures such as hurricanes and eddies. (All biological systems are dissipative, but not all dissipative structures are biological.)

Just as the small-scale clumping of matter triggered the emergence of gravity at a higher scalar level, increasing the steepness of energy gradients at some point spontaneously triggers the organization of material systems there that will dissipate these same gradients as rapidly as possible. Living systems can be seen as a continuation of this project of reducing energy gradients. The evolution of animals is especially easy to interpret in this way: primitive detritivores acquired movement to burrow into gradients; then their descendants acquired mouths and claws to hurry the disintegration; then predators, as well as herbivores, evolved to hurry the production of detritus; then some of these became homeothermic (i.e. maintaining an optimal internal temperature) so that gradients might continue to be dissipated even in the absence of overt activity; then some of these invested in large nervous systems, which consume large amounts of energy continuously (Chaisson 2001). This general scenario provides the basic “meaning” of ecological systems, whose developmental (successional) phenomenology shows a tendency to maximize energy throughput (Lotka 1922, Odum and Pinkerton 1955, Vernadsky 1944) by way of configurations and processes at many scalar levels. The punch line: form results from, and further mediates, convective energy flows, which more effectively degrade energy gradients than would slower frictional processes. So, we are in a world that, in effect, does not want to be—a world of massive objects that destroy and replace each other incessantly in a perpetual dance of Shiva. We will find that we ourselves are just such objects.

WHAT ARE WE?

In the present perspective, we are dissipative structures (Prigogine 1980). That is to say, we are dynamic material systems deriving energy from embodied energy gradients, and dissipating it, via work, into form and activity (either internal or external to our bodies). Some of the available energy is used as *exergy*, i.e. to drive the work; but the faster any work is accomplished, the less of the energy is used that way, because more of it is lost instead through contamination by entropy (Carnot 1824, Clausius 1851).

Available energy is a gradient that, from the point of view of a given kind of consumer, has an orderly arrangement with respect to that consumer’s configuration (Salthe, 2003b), so that when the two come together, some of the energy in the gradient can be assimilated by the consumer and used for work. Any energy (gradient or not) which is not arranged in a way that allows a consumer to use it for work is entropic (disorderly) from that particular consumer’s point of view. From any material system’s viewpoint, the most entropic form of energy that we know is heat, which is so disordered that it

can drive nothing more than Brownian motion, unless focussed or harnessed through efforts not intrinsic to it. It should be noted here that forefront physical disciplines like quantum mechanics, astrophysics and string theory may find roles for heat energy, as well as forms of energy even more disordered (whatever that could mean); but we are concerned in our myth at present not with the ultimate underpinnings of physical reality but only with the material world, i.e. the world of things which beings of our scale deal with more or less directly. Future understandings (or technologies) may alter our scientifically informed myth, since, informed by science, it does not claim infallibility as many other mythic structures do.

Dissipative structures *grow*, either in size or throughputs, or both, up to a point, after which they decline (Salthe 1993a, Ulanowicz 1997). They grow for the same general reason that wave fronts spread and diffusion occurs—because the universe is far from equilibrium and getting further from it all the time. Diffusion and wave front spreading serve the Second Law of thermodynamics by moving local situations toward equilibrium. Dissipative structures do the same, by degrading energy gradients, during growth and repair as well as in their activities; in doing this they contribute to energy equilibration to an extent correlated with the rate at which they dissipate the gradients. That is, the faster a gradient is reduced, the less of its embodied energy can serve as exergy in the interests of its consumers, and the more of it will head toward the sink as (or further in the direction of) heat (Carnot 1824, Clausius 1851). This buildup of energy consumers is a tactic that works for the universe, because the portion of an energy gradient which becomes reembodyed in its consumers tends to be matched by the portion paid as tribute to the Second Law. Quoting Odum (1983, 116): “According to Lotka’s maximum power principle, systems tend to develop designs that maximize power [energy throughput] and thus may be expected to develop loadings [work loads] less than the most efficient. At maximum power half of the input energy must be dispersed with a corresponding entropy increase.” We could perhaps state this in more theological terms as follows: our efforts to sustain ourselves as embodied beings constitute our worship of, and service to, the more general and “eternal” thermodynamic Law, which accepts our sacrifice as it consumes us. If there is a moral implication lurking here, it might just be the work ethic.

A question arises here from the fact that the slower any work is done, the more efficient is the exergy extraction in its interest. An apparent exception to this is that designed machines have an operational point of maximum efficiency, and work slower than this will also be less efficient. But why are *natural* dissipative structures not more efficient? Why are organisms (including ourselves) in such a rush? The *Qur’án* (21:37) tells us that “Humankind is made of haste,” but does not explain why; the present myth offers an answer. Given any gradient, and several consumers abutting it, those that can dissipate it fastest will get most of it. Therefore they will burgeon, while the slowpokes will dwindle. In organisms, this competition gets translated into reproductive effort (Tinkle 1969), and thus gets mediated by natural selection (see below). Natural dissipative structures are in principle the least energy efficient of their kinds that might

exist. Of course there is a threshold of efficiency below which their kinds (given their complexity) could not exist in the first place, but above this threshold, dissipative structures in their activities are driven by competition for energy to be quite inefficient and wasteful, to use it up as fast as possible. The element of haste also appears, in organisms, in recovery from injury, in competition for mates, and generally in mating itself. Plants tend to grow as fast as possible because they produce most of their entropy by evapotranspiration, and need to replace eaten parts in this service too.

Summing up the story so far, we might say that the universe, in the quest to regain its lost equilibrium, was presented with a problem by the clumping of matter caused by its own extravagant expansion, and its solution was to destroy clumps by means of other clumps, a ploy which entrained the further evolution of complex forms, all the way to the living and the social.

WHY ARE WE HERE?

As we have seen, form is capable of initiating orderly convective flows that move energy from gradients toward the sink more effectively than can haphazard conduction, like diffusion (Schneider and Kay 1994; Swenson 1989a, 1991a). Thus we can say that the Second Law is the *final cause* of all form, or that form has *teleological* meaning. First, though, we must distinguish different levels of “teleological” meaning and arrange them in another specification hierarchy:

{ natural tendency { biological function { human purpose } } }

— or, in terms used by O’Grady and Brooks (1988) and Mayr (1988),

{ teleomaty { teleonomy { teleology } } } .

To expand this a bit: intentional teleology, or purpose, is an example of a kind of functionality, which in turn is a kind of natural tendency along the lines of the Second Law of thermodynamics—that is to say, function is a subclass of (or a more highly developed, or more precise or refined, example of) variational principles. All these *teleo* projects are examples of *final causality*, answering the question: “*Why* does something occur?”

Science in the modern period tends to avoid questions in the “why” form, inquiring instead into *how* something occurs. In different sciences, the *how* may involve one or another of: (a) *material cause*: an understanding of the situation that gives rise to an occurrence, as in “the reproduction of cells causes the growth of organisms”; (b) *efficient cause*: an understanding of what forced, or proximately pushed, the occurrence, as in “an influx of energy gradient stimulated the reproduction of cells”; and (c) *formal cause*, an understanding of the natural laws involved and the arrangements harnessing them in any given instance, as in “the cell divides because under certain conditions some of

its organelles contract in a particular way as a result of harnessing some energy from the spontaneous hydrolysis of ATP". Natural philosophy, on the other hand, is involved explicitly with finality, from its 19th Century beginnings in the Continental version with Schelling and Goethe, through Salthe (1993a), up to the present paper. For us this restores the full range of complex causality recognized by Aristotle (and by C.S. Peirce: see Peirce 1998, essays 9 and 22).

An understanding of specification hierarchies may cure the aversion to final causes which has dominated the sciences in the modern period. Since teleology conceived as "God's purposive activity ... has become quite problematical", as Kauffman (1997, 183) drily notes, scientists have dismissed it out of hand in the era of the "blind watchmaker". Although they continue to employ functional explanations in evolutionary biology and psychology, most scientists do not recognize function as a kind of final cause. In the rush to eliminate "teleology" from their theorizing, they have implicitly thrown out teleomaty and teleonomy as well, on the grounds that the complex (such as a mentality capable of planning) could not precede the simple. Similarly, failing to take a hierarchy of time scales into account may have led scientists to think that a final cause would be one preceded by its effect in a linear sequence of events. Such misunderstandings led to the 'why?' question being declared nonsensical or taboo, so that, for example, we cannot currently ask, within science, why the human mind evolved—it can only, instead, be seen as having resulted from a series of accidents. Natural philosophy, in contrast, puts the human mind in its place by modelling it as a recent specific development of tendencies which have been (and continue to be) vaguely and generally present in the universe. On this view, nature does not have purposes, but it does have what might be limned as {{{purposes}}}.

The specification hierarchy of integrative levels also shows why we are not being reductionist here. The maximum energy throughput program is instituted at the physical level. But this program alone cannot explain biological systems, because they could not exist under conditions of absolute entropy production maximization, as in combining with oxygen during an explosion. In biology, oxidation is much tamer (and more efficient), going by way of dehydrogenation, which allows a degree of complication of form that an explosion would not. In other words, entropy production in biology was placed under further *constraints*, the payoff of which, to Nature, was twofold: weaker gradients could be more effectively dissipated, and the dissipation could be taken further in the direction of heat energy, the kind most easily diffusible toward equilibrium. In terms of serving the Second Law, both rapidity of gradient dissipation and completeness of dissipation to heat are involved, but not often accomplished equally well by a single kind of dissipative system. The First Law, or energy "conservation" principle, calls for dissipation into multiple gradients of lesser quality, which is furthered by the haste entailed by competition for gradient; Second Law dissipation all the way to heat is furthered by some complication of form. Organisms serve both laws, and are, as it were, optimized between the two tasks. (In Swimme and Berry's perspective, diversity seems to work as a final cause, which is really the biological version of the view we have

outlined here in more physical terms; see below.)

Still further constraints were instituted historically by social systems, which could not exist except by insulating their members from (a) the more intense rates of dissipation that (as larger scale entities) they mediate, and (b) the polluting weaker gradients that hasty energy use produces as wastes. As more integrative levels emerge during evolution, the Second Law becomes, as it were, increasingly impatient, and therefore more powerful as an attractor of energy use. We suggest that the emergence of multiple integrative levels serves the purposes of the Second Law even if their energy utilization efficiency thereby increases, because higher integrative levels uncover previously inaccessible energy gradients to exploit, as when Western society dug into fossil fuels in a big way. So, in this view systems are seen to exist primarily in order to produce entropy, but also, ultimately, for various other reasons as well; all of these reasons—not the least of which is to move occult and elusive energy gradients in the direction of heat energy, as in pumping oil for the Global Capitalist Growth Economy—being consistent with the primacy of their final cause.

Summing this view, then: while we see our own purposes reflected in the work we undertake, the universe is “interested” in the entropy we generate while doing it. Returning to the original question of “why there is anything at all,” some may feel that the Big Bang is not a satisfactory answer because we don’t know why there was a Big Bang; however, the universal expansion does explain the Second Law, and we know of no other candidate myths that fulfill this requirement.

WHY ARE THERE SO MANY KINDS OF THINGS?

Form can catalyze increased rates of energy dissipation from gradients, and different forms can be effective in this regard with different gradients. Asteroids can pulverize planets, microbursts can level trees, while drainage systems wear away rocks, all producing heat and scattered—unsystematized—matter. In this scene living systems have their roles as well, as they consume gradients in the immediate interest of promoting the presence of their own kinds. These roles are of smaller scale than those of the coarser abiotic systems from which they emerged, but the finer gradients they consume would be left largely untapped without them. It seems plausible that the agency of massive, powerful abiotic systems was relatively more important earlier in the universal expansion, and that the roles of living systems could increase into the future. With the gross rate of recycling (and heat energy generation) having diminished over time as the universe cooled, living systems seem to represent a fine-tuning of the entropy production process: they are pulled into existence, and then into diversity, in order to dissipate the varied smaller-grained local gradients that hide within the cracks, escaping destruction by coarser consumers.

Therefore, the final cause of the origin of life will have been the pull of gradients to be demolished. Some of these, more accessible at the surface of appropriate planets, would simultaneously have been among the material causes as well (along with sup-

portive prebiotic chemical forms like various liquid crystal membranes). As with any dissipative structures, the laws of nature and of matter would have been the formal causes of the originating processes, while efficient causes would have come from the likes of winds, gravitation and fluid gyres, as well as the coming and going of light. In this perspective the continued evolution of living systems has been a finalistic search for untapped energy gradients, seeking ever more finely tessellated and inaccessible ones. If life began in shallow waters, it then moved into both elevated torrents and the abyssal depths, as well as onto land. Wherever it began, it has spread from there. The ecologies of all of these places were colonized by living systems, who provided ever more diverse forms suited to dissipating ever more elaborate and occult energy gradients. Increasing local biological diversity is a way to maximize the entropy production of a given locale (Salthe, 2002, 2003a, 2004) over and above what might be accomplished by abiotic agencies alone.

The Second Law also has another role in ecology. As shown by Carnot, energy consumption can never be fully efficient, and is less so to the degree that it is hasty. If we observe the feeding of animals (often quite hasty!) we find that heat energy, the most thoroughly degraded form, is not the sole product of gradient consumption. Rather, several other gradients are produced, from various scraps to feces, that can serve as gradients for other life forms. Haste tends to be promoted by competition for gradients, as those who use them up most rapidly will get the largest share and thereby increase their chances of reproduction. But since haste makes waste (picture the feeding frenzy of sharks), the most effective energy consumers inadvertently serve the Second Law by spreading energy laterally into other forms of availability (Taborsky 2000). In both of its roles, the Second Law elicits—calls for, entrains, affords—the subdivision of niche space that we refer to as biological diversity, so that entropy may be produced as fast as possible everywhere on the earth's surface.

WHY DO SYSTEMS NOT LAST ONCE THEY EXIST?

The primary fact about natural dissipative structures is that, as long as they survive, they grow in energy throughput (which in many cases entrains increase in size as well), until some point when they begin to get recycled. This growth has been noted in several studies, and even dubbed a Fourth Law of thermodynamics. Odum (1983) notes approvingly that Lotka (1922) suggested that the maximum power principle, more fully elaborated later by Odum himself, be thought of as a Fourth thermodynamic Law. This principle, characteristic of the successional development of ecosystems, has it that development will occur in such a way that the gross energy flow through a system increases, albeit at an ever decreasing rate after immaturity, until the system is perturbed back to an earlier stage. Odum sees this as working by way of stored energies in a system being deployed to maximize its energy throughput, for example, by providing activation energies at crucial points. His view is concordant with a Fourth Law suggested by Kauffman (2000), to the effect that dissipative structures continually extend the area of their work

surfaces, which would be one way to describe how a system might come to exemplify the Lotka-Odum maximum power principle. The growth of dissipative structures, which results from their increasing energy throughput, can in general be viewed as a way by which they can increase their entropy production, because it would tend to generate further energy-consuming surface area, in a positive feedback relation. Increased size would tend as well to extend access to further energy gradients (Swenson 1989b). So growth uses energy in such a way that more available energy may be encountered, producing entropy in the process. Furthermore, as growth in viscous systems often leads to instability tending to cause subdivision of the system, more (daughter) systems will be produced, who in turn will encounter new gradients.

Jørgensen (1999, 2001) proposed a closely related Fourth Law, to the effect that, given alternative developmental pathways to explore, a system will tend to develop in the direction which results in the greatest amount of stored energy. Here the system is seen to maximize its exergy mobilization potential. This stored energy would be embodied (as the potential energy crucial to Odum's concept) in a system's forms, which would include its work surfaces. Thus the ideas of "increased work surface," "increasing power" and "increasing energy" appear as aspects of a single coherent concept—entraining structural and behavioral "habits".

The proposed Fourth Law of thermodynamics is coherent as well with the major principle of *infodynamics* (Salthe 1993a, 2000b): dissipative structures continually incorporate new *informational constraints*, although the rate of incorporation eventually slows down. Almost any form with a variable configuration might be an informational constraint; such variability is 'information carrying capacity' or 'informational entropy'. *Information* here has the sense of 'reduction of uncertainty': we are uncertain which of its possible configurations the given form will take, until one is actually taken; this step being generally irreversible, the form now represents a *constraint* on further variability. Even before this, the form is already constrained by the limits which define it as a form and thus frame its configurational possibilities. (In similar fashion, uncertainty about which letter comes next in a printed message is constrained—thus made measurable and definitively resolvable—by the prior existence of a fixed alphabet.) When a form gets fixed at one configuration, then information itself has been instituted. Here we focus on the relationship between entropy and information carrying capacity: a system is informed by its environment by growing into it, which at first provides it with a greater range of behavioral options, only to gradually shrink the full range as it realizes some of them in actual behavior, so that toward the end of its developmental cycle it becomes habit-bound and inflexible.

So we have a system that, because of its existence only at a given range of scale, cannot keep growing endlessly. Every dissipative structure approaches its size limit at an ever decreasing rate. However, like all material objects, such structures are marked by historical encounters; so new information continues to be shipped on board as long as growth continues, refining and modifying existing informational constraints. The effect of this, in an already definitive, nongrowing system, would be to insert new constraints

in between already existing ones, with at least two results. First, given that a system is already functioning, it would insert here and there information that could interfere with its internal communications, causing lags and delays in responses to environmental perturbations. This same effect could as well start new directions in a system at variance with its habitual ones, which would tend to dissect it into subdivisions unnecessary to its continuance, a process that must eventually tear it apart—e.g., a river becomes a deltaic swamp with innumerable channels. The second major effect of inserting new information into an already definitive system would be to enhance or further overdetermine those of its habitual behaviors that have already become inertial, thereby diminishing its flexibility of response to perturbations. This effect is pathological in many kinds of senescent systems when combined with their reduced energy-specific (per unit mass) throughput (Aoki 1991, Zotin 1972). The result of these combined effects is system rigidity, setting it up for the recycling that has now become its best opportunity to further fulfill its entropy production destiny.

Thus, systems have only finite destinies because they cannot help incorporating new information as a result of their historical adventures, and this is because matter is a medium that gets marked. That is, with the universal expansion continuing apace, new information tends to precipitate into the world along with matter and mass. Yet, motivated by the Second Law, the material world allows no particular configuration to continue indefinitely.

WHY ARE SYSTEMS JUST THE WAY THEY ARE?

Our model so far accounts for diversity in general, but not for what specifies each of the diverse forms in the world. Objects and systems can persist if they are stable, and/or if types of them can replace their kind before their instances get recycled. Stability and “fitness” only exist in relation to the particular environment of a system. As environments generally antedate the systems in them, as well as being larger in scale, it makes sense to view them as being selective with respect to what may persist within them. A simple thought experiment projects this idea. Suppose we have a gently sloping board with its surface pitted with scattered holes of a particular size (picture a “Chinese checkers” board with an irregular arrangement of “niches”). We take a handful of marbles of several sizes to the top of the board and release them, as in a pinball machine. Those that happen to have a size fitting the niches, and that happen to encounter a niche, will persist on the board—will be stable there—while other kinds, as well as unlucky individuals of the same kind, are swept away. Selection here reflects a differential stability among relationships encountered by chance.

Consider next the formation of a drainage system. Water pours off a melting glacier, constructing runnels here and there which branch or run together according to the terrain. Some channels will deepen, others will flow into them and get drained. Gradually a major tributary will emerge according to geological conditions. Channels that allow the greatest rate of flow—i.e., afford the greatest entropy production—will

take the flow from others. Here we have selection, by conditions, of one configuration out of numerous possible others, according to its consequences (Skinner 1981) in entropy production (Swenson 1991b). Here fittingness is measured in entropy production. Note that in this model, selection does not choose among contending actual major channels as it does in the classical natural selection model (see below). On long time scales that might happen too, but here the environment finds a single channel on the basis of competition between many incipient ones in earlier stages of development. It is conceivable that there might have been an ultimately even more dissipative major channel developed out of a different earlier stream, but, of course, selection cannot foretell the future. It works every moment only upon choices present at that moment.

The concept of “natural kinds” or “species” is not limited to the biotic world. Consider hurricanes, for example: Atlantic hurricanes are one “species”, as compared to Pacific typhoons. These hurricanes, succeeding each other during each season over the years, make up a population (e.g. Tannehill 1938). The general boomerang shape of their trajectories over the map reveals the shape of the environmental affordances sculpting them. Their boomerang shape is analogous to the forms of organisms, which are also, in part, directly entrained by their immediate environment. Of course, with organisms their form is even more importantly shaped indirectly by past environments, which have selected information now imposed internally by means of genetic informational arrays. But the shapes of plants, for example, are also to a significant degree still molded directly by environmental forces, as the most primitive biotic systems must also have been.

Drainage systems and hurricanes reveal the basic nature of prebiotic selection. Stability is gained by fitting the greatest possible entropy production into the existing surrounds. The slanting board experiment uncovers a question about the relation of chance to the final outcomes. A marble will find itself in a fitting hole purely contingently. As well, the actual trajectory of a particular hurricane will have been affected by contingent events and configurations in the atmosphere. If a drainage system actually discovers the fastest possible route to the ocean, this could only be by the chance that in each of its earlier stages it just happened to be flowing faster than other contending streams were doing.

Particular instances of kinds of events are individuated by fluctuations in the initial and boundary conditions bearing upon them. So the differences between instances are historical in nature, and selection preserves some of these as historical records, which may get projected into the future as evolving traditions. But what about, say, the large scale initial and boundary conditions controlling the appearance of hurricanes in a given region year after year? These must be stable over many decades at least, but it is clear that ultimately they too must have been set by chance fluctuations in the history of the earth. The shapes of events and objects, the forms of systems, are all kinds of historical records. Those that recur represent evolving traditions. Things are the way they are because a series of events and contingencies just happened to happen.

It might be worth noting here that this interpretation reflects our current biases. Are

fluctuations random or arbitrary? After all, there is no way to tell whether a particular instance of a kind of event happened by caprice, or by choice (Salthe 1993b). Even in human activity, the experience of conscious will is not a reliable indicator of actual causes (Wegner 2002). The answer here would depend on whether or not the resulting ensemble of instances of a kind of event realizes one or another known frequency distribution, like the binomial or lognormal. If it does conform to one of these, we have reason to suppose the instances to have just spun chaotically out of chance configurations. But it is worth noting that populations of instances of types of moves in Master chess games are binomially distributed (Salthe 1975), even though no one would suggest that any of them were made at random. Each choice was certainly constrained by boundary conditions, but was not fully determined, and certainly was not made accidentally. Well, history is made up of both choices and chance events, and the point here is that historical contingencies of either kind, or both, determine the occurrence of actual events and the resulting configurations of systems. So these configurations all carry information, inasmuch as they might have been different, given the same expenditure of energy in their construction. A final cause such as the Second Law cannot by itself impart any special form to things, although it does provide a general mandate for specialization.

The information concept directs our attention to *biological* dissipative structures in particular, since, as is well known, the DNA in cells is considered to carry information relating to the past environments of ancestral populations. Cellular processes are informed by these arrays such that the resulting configurations resemble closely those of ancestral cells and organisms. The origin of life in forms capable of evolving was the origin of stable internal informational arrays (a process still remaining largely mysterious). So, in addition to the external boundary conditions considered above, living systems also have internal information to regulate their self-organization. Now the selective effects become the *natural selection* of Darwinians, and different kinds of individuals become different *genotypes*, and differences in stability among them becomes *viability*; and differential reproduction becomes as important a factor in selection as viability, or even more so. In other words, differential reproductive success (the fertility component of fitness—Thoday 1953) represents the consequences of concern in biology that flow from the interaction of genotypes with their environmental conditions. These interactions still, of course, involve a viability component of fitness, which is not conceptually different from the stability criterion that applies to abiotic systems, as discussed above.

The fertility component of fitness is a new effect instituted by biology, and represents an active projection of types into the future. This is something that could be accomplished by abiotic dissipative structures only very indirectly and haphazardly by way of modifying environmental conditions in such a way as to enhance the survival of subsequent similar instances, an effect which still occurs in biology too, but less haphazardly—for example, in the dams of beavers, or in the conditioning of soils by plants. So, instituting differential fertility was a refinement of prebiotic selection (Depew and Weber 1995), adding it to differential stability. The presence of internal information

enhances stability as well, since it can be used to replace worn-out protein components, and this affords significantly greater elaboration of form. These elaborations of form importantly allow exploitation of energy gradients not previously tapped by coarser abiotic dissipative agents. Furthermore, the instability (due to frictional effects) of the internal information leads, by way of resulting mutations, to a diversity of biological types (Brooks and Wiley 1988). This diversity serves the purposes of entropy production because each type is capable of exploiting a different mix of energy gradients in different locales.

Note that with the origin of reproduction, and thereby of natural selection, a new dimension is added to selection: competition between fully formed instances of different kinds. Biological individuals, unlike rivers or hurricanes, have to compete because they do not reproduce until maturity has been attained. Whatever failures there may have been during earlier stages of development are “visible” to selection only via reproduction, by contributing to the differential fertility of the different types in a population. If a genotype had less success than another in converting available energy into its own embodiment, but nevertheless outreproduced the other, its kind would be more represented in the next generation than the more efficient energy assimilator. For this reason the ancient stability/viability component of selection could actually even be nullified—for example, if resources became unlimited (as in the boom phase of a boom-and-bust cycle)—reducing fitness just to its fertility component. The possibility of this situation (rare in nature) emphasizes the ascendancy of competition between genotypes, rather than straight viability, as the mediator of natural selection.

How do these genotypes differ from other types? While all material configurations are historical in nature, types like Atlantic hurricanes result from stable boundary conditions. In biological systems, types result primarily from stable internal generative tendencies, inscribed in genetic information, stabilized by natural selection. These tendencies are inherited ways of fitting in—inherited traditions—which occupy biological systems, and use them to project themselves into the future (Dawkins 1976). We call these traditions *genotypes*, *races* and *species*. Each of us is a system deployed by, and representing, our genotypes and species, some of the information from which drives us eagerly to reproductive activity. We could say, for example, that penises and breasts belong, not to us, but to our species, as these form the material links within a species, but do nothing to make us more viable as individual organisms. To emphasize this point, we should note that reproduction is bad for us. It uses energies that could instead have been used for growth or repair. It throws animals in the way of personal danger, having, for example, to return to nesting sites, making it easier for predators to track them, or having to engage in dangerous battles over access to mates. We could also note breast and prostate cancers among people, or venereal diseases. We are indeed successfully entrained by our biological traditions (and, of course, since reproductive activities are typically “hot”, by the pervasive Second Law here as well).

We may recall here that these informational traditions, so assiduously committed to their own survival, must accomplish this trick in a world committed to the destruction

of all forms. They can survive only by fitting in, by relating effectively to other traditions, and, of course, by paying tribute in entropy—paid only by degrading energy gradients, most of which represent other traditions, as when lions eat wildebeests. Within a species, genotypes strenuously work to outreproduce other contending ones—the more strenuously, the more entropy will be produced. Slacker types do not succeed in surviving through many generations. Extending this line of thought to a higher scale, cultures survive as well by paying entropy tribute, as by building pyramids and airplanes, and, of course, by then destroying them in wars. Many have wondered why warfare of one kind or another is so characteristic of human cultures. The answer, at the lowest integrative level, is that in this way entropy can be extracted from the destruction of cultural artifacts, making way as well for more entropy-taxed construction. Cycles of this kind (build → burn → rebuild) are reflected as well in more abstract ways, such as business cycles (Soros 1998) and other kinds of modern potlatches.

This line of thought raises the question as to possible direct connections between the Second Law and natural selection (Depew et al. 1989). We can make the following argument. It is widely supposed that traits of organisms that are relatively more important in increasing their fitness (relative reproductive success) will display less variability than less important traits, as a result of a continued selective culling of individuals in relation to them over the generations. For example, Salthe and Crump (1977) showed that traits of frog hindlimbs (ratios of measurements) considered to be important for jumping were less variable than traits considered by functional morphologists to be less important in this regard. Furthermore, in kinds of frogs that do not jump, these same traits were not significantly less variable than other randomly constructed phenotypic ratios. Selection reduces variance in fitness (Fisher 1958). Salthe (1975) suggests that in behavioral and physiological traits (like heartbeat rate), variability will diminish in the direction of peak performance. For example, heartbeat would become increasingly critical, say, when escaping from predators, and so its peak performance would have been especially important in saving those that lived to breed. Peaks of importance should generally tend to coincide with peaks of intense activity. Preliminary evidence of several kinds supports this idea. Supposing the idea to be viable, we can tie the Second Law directly into selection, because peaks of intense activity would also tend to be peaks of entropy production, since this must increase with rate of activity. That is, at critical moments in the lives of individuals, they tend to be producing more entropy than during more routine moments. We can provisionally conclude that natural selection tends most intensely to review the performance of functional traits in the context of increased entropy production. Selection, then, tends to support systems that can most effectively produce entropy. In this way, the Second Law constrains the results of natural selection; or, fitness maximization is entrained by entropy production increase. Using the specification hierarchy formalism, we get

{ entropy production increase { fitness maximization } }

— that is, fitness maximization could be said to be a kind of entropy production maximization. Our myth is reinforced by seeing that its two major principles are mutually consistent.

Well, here we are in a world of historical traditions striving to maintain themselves in the face of the Second Law, and striving as hard as they can to serve this law at the same time, as the price of their continuance. The survivors include only those that have worked as hard as they possibly could (even though that might not be sufficient for success). Ours are among these surviving traditions, as we serve the interests of a species, of populations and cultures that have maintained themselves by building and burning, eating and procreating. We serve their interests despite their defiance of the Second Law, whom we also serve. So we are faced with a kind of trade-off. We can strive for our traditions only if we pay at least equal tribute to the Second Law—which means that this striving must be striving indeed!

WHAT ARE WE TO DO?

Morally, then, we have no choice but to serve the Second Law, but the question of *how* to serve it remains open. The kind of service currently embodied in Western civilization—rampant growth, capitalism globalized and triumphant—is the *de facto* answer. To embrace this as a divine edict means to continue recycling mature ecosystems and replacing them with cities, farms and fisheries, burning up resources as fast as we can, reproducing maximally, and outcompeting other contending social systems. We could further reinforce the compulsion to consume and compete by weeding out those rare practices in our tradition which require resistance to the pull of the Second Law: quietism, contemplation, meditation, voluntary simplicity. Ironically, simplicity of lifeways and reduction of our ecological footprint runs counter to the simplifying drive and reductionism of classical science, which has accelerated our cultural consumption through technology. Current attention to complexity in science may perhaps thwart the kind of scientific discovery which has been the basis of our growth economy. But if consumption is the prime virtue, then the vices to be weeded out would include laziness, procrastination, overcautiousness, and indecision, the last two of which are cousins to complexity—for diversity leads to disorder, which causes perplexity. We may note here as well that senescence involves complexity increase, and that a growth economy is one appropriate only to an immature system. Our culture appears devoted to prolonging cultural immaturity.

Radical devotees of the Second Law, though, might find our current service to it rather lukewarm. There are more apocalyptic options, such as all-out global nuclear warfare. However, this would be short-sighted, as it would leave vast stores of energy gradients (such as the remaining fossil fuels) still untapped, perhaps never to be tapped until the sun burns out. It also fails to notice that there might be better ways (from our own selfish point of view as organisms) to maximize entropy production, as in huge construction projects like the Three Gorges Dam in China. To evaluate the vari-

ous options properly, we would need comparative studies on the entropy production, or, more directly, the gradient dissipation power, of various courses of action—something probably doable even now. Of course these technological projects always produce unexpected effects, such as radiation and other pollutions, but these effects too serve the Second Law.

Another possible approach, since we already serve the Second Law by maintaining our traditions as organisms, is to make those traditions our first priority. As relatively long-lived organisms, and especially as sentient ones with language-constructed historical selves, we do not wish to burn up too fast, and, indeed, a leisurely old age surrounded by cherished objects is still appealing. As carriers of various traditions, we generally find existence fulfilling and continuance a value. In the present context, this memorializing is nothing less than a sign of original sin, a cleaving to the trespass of material being—especially *extended* material being—filling portions of a space that beckons instead (and as a result) for equilibrating dust and gas. We exist because an explosive expansion (the Big Bang) was so violent that it resulted in some local assembly rather than total global dispersal—something repeated in smaller scale when imploding stars forge heavy chemical elements. Swimme and Berry (1992) paid tribute to the *sacrifice* of Tiamat, whose self-immolation in a supernova furnished the heavier elements in what later became our solar system and thus enabled it to support our kind of life. They continue (60):

The primal human insistence upon sacrifice can be understood as an early intuitive grasp of the essential truth in the Second Law of thermodynamics. Rather than speaking of the movement toward entropy, the primal peoples would speak of the intrinsic pain that accompanies so many genuine advances.... The tension of existence in time within the phenomenal world is a primordial aspect of our existence.... To eliminate the tension would be to eliminate the beauty.

One aspect of the cosmic tension is our apparent choice between building and burning. We think that we choose to build (even while burning ferociously in order to carry it out!)—but in any case, building involves burning up gradients, and leads ultimately to senescent forms that will need to be burned up in turn. Of course, we will cleave to our traditions in any case, and that is why we construct the story of their origins with care. Here the tension rears its head again in a dilemma: are the organismic and human traditions intrinsically valuable because they are products of choice, or basically meaningless because they are the products of chance?

Just as we cannot cleanly decide materially between building and burning, so we cannot here choose logically between choice and chance. According to the Darwinian version of the “epic of evolution”, species, races and genotypes are all products of chance mutations, random genetic drift and accidental isolation of populations, shaped only by that blind watchmaker, natural selection. Sociocultures on the other hand have implicitly been taken as products of choices, despite the efforts of evolutionary psychologists and others to reform this habit. But the more we try to pin down the choice/chance distinction, the fuzzier it gets, especially if we take all four aspects of causation

into account. Besides, the “illusion of conscious will” (Wegner 2002) may be deeply connected with our lust for control. Bateson (1972) addressed this connection in an essay entitled “Conscious Purpose Versus Nature”. Berry (1988, 35) puts it this way: “So long as we are under the illusion that we know best what is good for the earth and for ourselves, then we will continue our present course, with its devastating consequences on the entire earth community.” We may of course continue our present course *unconsciously* with equally devastating consequences, but the point here is that hubris cannot help the situation. “The creature that wins against its environment destroys itself” (Bateson 1972, 493). Robinson Jeffers was a poet who saw clearly the devastating consequences of the culture we think we have chosen. It has overrun the earth with

Uneasy and fractional people, having no center
But in the eyes and mouths that surround them,
Having no function but to serve and support
Civilization, the enemy of man,
No wonder they live insanely, and desire
With their tongues, progress; with their eyes, pleasure; with their hearts, death.
(Jeffers 2001, 162)

Jeffers saw clearly that the ultimate “enemy of man” is also his creator: “The world’s God is treacherous and full of unreason; a torturer, but also/ The only foundation and the only fountain” (2001, 159).

The cosmic tension can also be felt between the Big Bang, the First Cause which destroyed equilibrium and set off the collecting/cascading cycles (Salthe, 1993a), and the Second Law, the Final Cause which engendered complexity and form in its quest to recover lost equilibrium. But for us humans, perhaps the deepest aspect of the cosmic tension is the splitting of our allegiance between our organic-biological traditions and our physical-material Creator, the Second Law. Some of our spiritual traditions encourage a stance of assent, or at least equanimity, toward the unresolvability of this tension. Consider the *Tao Tê Ching* (Waley 1958), Chapter 5:

Heaven and Earth are ruthless;
To them the Ten Thousand Things are but as straw dogs.
The Sage too is ruthless;
To him the people are but as straw dogs.
Yet Heaven and Earth and all that lies between
Is like a bellows
In that it is empty, but gives a supply that never fails.
Work it, and more comes out.
Whereas the force of words is soon spent.
Far better is it to keep what is in the heart.

“Heaven and Earth” here play the same role as our first and final causes, the cosmic expansion and the Second Law. Must our service to them be so frantic and futile? Can we moderate it, thus enhancing our *presence* to the earth community and the wider universe, as Berry (1988) has advised?

The path of moderation could be viable because there is, in highly evolved, com-

plicated systems, a stage in between immaturity and senescence—the mature stage. This stage (unknown in abiotic systems like tornadoes) uses significant energy flows and considerable embodied information to maintain itself, for a while. Why not try to preserve this stage of our socioculture as long as possible? It would mean dropping the capitalist notion of “grow or die”—even though it is mandated by the Second Law of thermodynamics. Thomas Henry Huxley (1898) took a similar contrary stance against the ethical implications of Darwinian evolutionism, which he acknowledged as being plausible. While the mature stage of a system is a product of informational arrays, the senescent stage is a product of too much information (Salthe 1993a). Can we resist getting information-bound, and resist hooking our system up to the most powerful possible energy gradients (which would rejuvenate it)?

We would need, in short, moderation in all things. We would need to preserve, not conquer; to contemplate as much as to act. We would need to judiciously discard as much information as we acquire, or at least to condense older information. We would need to abjure both evolution (into senescence) and revolution (into rejuvenation)—neither a whimper nor a bang! We might have an Age of Reclamation, a pulling together of what the peoples of the world have produced, focusing it into a moderate, non-growing civilization—a vision similar to Berry’s “Ecozoic Age”. We are almost at the point where Western civilization itself might manage such a transition, as it has almost eliminated possible organized opposition to its hegemony. If there were any other system as powerful, that system would consume the Western World if the latter went in for moderation; but there is no such competitor on the horizon. Current opposition comes only from marginalized peoples unlikely to succeed in derailing our culture even if they chose to try. So we might have a window of opportunity to conserve our traditions in a long drawn out maturity. The enormity of the challenge—opposition to a law of Nature—should not go unnoticed; it would require an heroic refusal to ‘do what comes naturally’. The time we have left, individually and culturally, is no doubt short enough already. Obsession with profit and growth and frantic consumption can only make it shorter. But if we could live the time that is left to us and our children deeply and reflectively, then perhaps we could say that neither the genuine achievements of our civilization nor the tribute we have paid to the Second Law would have been garnered/spent in vain.

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