THE NATURAL PHILOSOPHY OF ENTROPY

S.N. Salthe
Biological Sciences
Binghamton university
HCR 86, Box 228 Laurel Bank Avenue
Deposit, New York, USA 13754
ssalthe@binghamton.edu

ABSTRACT

This paper attempts to answer two questions: (1) why is there anything at all; and (2) why are there so many kinds of things? The first is explained by the fact that the universal expansion following the Big Bang accelerated so fast that the universe went out of global equilibrium. Matter precipitated from energy, and its clumping placed equilibrium even further from realization. This situation gave rise to the Second Law of thermodynamics. Since equilibration can be fostered by energy gradient destruction, and since form can catalyze gradient destruction, entrainment of a diversity of forms can be explained as the universe's mode of working toward global equilibrium in many locales simultaneously.

1 INTRODUCTION

The philosophy of nature (Shaffer 1981), as I understand it, has always had the task of making an intelligible story out of scientific knowledge. It is concerned more with 'why' questions than with 'how' questions. In the version I have taken up, mediated through Schelling and the **N**aturphilosophen, this discourse has had a developmental format (Salthe 1993a). That is to say, it is concerned with what is usually called general evolution (as contrasted with special evolution, which is given over to Darwinian process; Sahlins 1960). It marks the emergence of new levels of integration, as in, for example, figure 1, where each more inner subclass is seen to arise out of, and to be dependent upon — but also to reintegrate within its province — the properties of the earlier classes, in transitive fashion. Biology is a special kind of chemistry, which is, in turn, a special kind of physics. Integrative levels can in this context be viewed as developmental stages in the ontogeny of the world.

Figure 1: A specification hierarchy showing stages in the development of the world, with the stages modeled as subclasses.

From this (I emphasize, a non-reductionist) view, then, we see why biology, for example, cannot transcend chemistry or physics; it can only appropriate them, reinterpret them, rearrange them, harness them.

I will take up, in this framework, the question 'why is there anything at all?' and for good measure, also deal with 'why are there so many kinds of things?' Folks at the turn of the last century, when natural philosophy was still in fashion, would have been stunned to hear that I am proposing that the answers to these questions have at this juncture turned out to be related to the world's need to produce entropy.

2 THERMODYNAMICS

The story begins, appropriately enough, with the Big Bang (Layzer 1975; Chaisson 2001). The key idea is that the universal expansion has been accelerating so fast that the universe has been unable to remain in equilibrium internally (Frautschi 1982; Landsberg 1984; Layzer 1975) and it appears that it may be continuing to accelerate at present (Ostriker and Steinhardt 2001). This expansion beyond the range of possibility for global equilibration gave rise to the precipitation of matter, which might be viewed as delayed energy. Matter as well as energy has sought to regain universal equilibrium. In its random search, it has collided — clumping, and the clumps continued to clump as gravitation became revealed. It is not clear what gravity is, but it certainly can be taken as a preeminent sign of the absence of universal equilibrium. One might say that gravity is the fact that matter was 'left behind' in the accelerating universal expansion. We might recall that Einstein found no OBSERVABLE physical difference between gravitation and acceleration (THE EQUIVALENCE BETWEEN GRAVITATIONAL AND INERTIAL MASS). Taking a developmental point of view, we know that all dissipative systems so far investigated go through an "accelerating" immature stage, and gradually relax into senescence (Salthe 1993a). From this point of view, if we take the universe to be another such system (but dissipating internally), its acceleration, followed by its rate of expansion, could be expected to decline gradually in the future -- in which case the force of gravity should everywhere also decline as a result.

Note that in scalar hierarchical systems (which the universe can be taken to be) changes and events proceed at faster rates at smaller scales (Salthe 1985). The process of equilibration would be this kind of change, and, indeed, we know equilibration experimentally only at molecular scales, where it proceeds rapidly enough to be observed by us. At our own scale equilibration is very much slower, and, as I have been saying, at the scale of cosmological systems it is exceedingly slow in comparison. This maps to the fact that the force of gravity is weaker the smaller the scale — so much so that equilibration can take place locally at these smaller scales relatively unhindered.

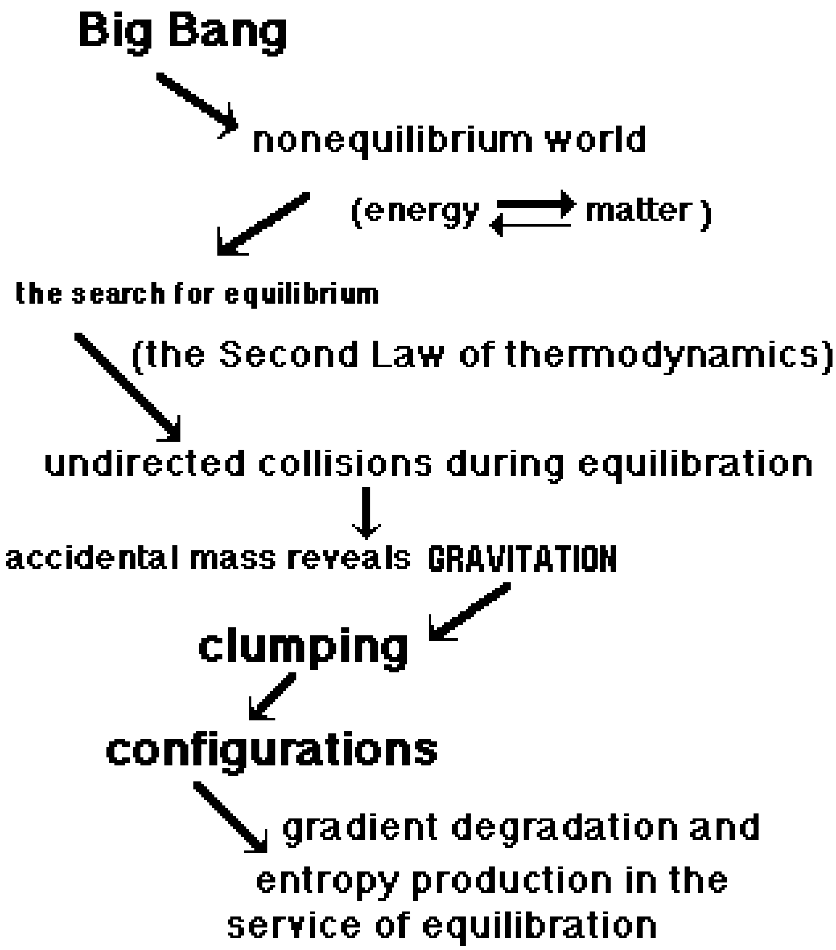

Figure 2: Basic events in the development of the universe.

So, we have matter and gravitating clumps of matter because the universe is out of equilibrium. This fact is, of course, the source of the Second Law of thermodynamics, which we can take to be the universe's striving to equilibrate. If, as some evidence indicates (Ostriker and Steinhardt 2001), the universal expansion continues to accelerate, the Second Law must be becoming ever more urgent and powerful. The universe, it turns out however, shows considerable ingenuity in furthering its need to equilibrate. The very clumps of matter can serve the Second Law in this nonequilibrium world — by facilitating entropy production by way of energy gradient degradation. Clumps of matter represent potential energy gradients of one kind or another. Because of the Second Law, these energy gradients are intrinsically unstable and the world acts spontaneously to demolish them in the service of equilibration (Schneider and Kay 1994). And the faster the degradation, the more entropy (as opposed to useful work, which embodies some of the energy in other clumps) is produced per unit time. Gradients would originally form just from gravitation and fluctuation-driven winds and waves. Some of them, just by chance, would come to be configured in such a way as to be able catalyze the degradation of other, more metastable clumps. Configuration, location and behavior are the key factors here. Even a slightly eccentric orbit can entrain a simple meteorite to serve the Second Law by smashing up other clumps. From that simple (almost non-) example we could move on to such systems as cyclonic storms, the ascendency increases of ecosystems (Ulanowicz 1986, 1997), and, by a long series of events, to the activities of living systems, whose destruction of potential energy gradients is entrained by the buildup of yet other gradients — in their own image (Figure 2).

In short, energy dissipation is the key process in understanding all local events in our universe. Natural philosophy received this insight already from Helmholtz back in the middle of the nineteenth century (Rabinbach 1990). But, as I said, catalyzing energy degradation requires particular relations between gradients and consumers. This fact brings information into our picture. The information is required to create energy availability in a degrading gradient — availability for work. Gradient destruction in the service of work is necessarily an informed process (Wicken 1987). For a consumer to line up with a gradient so as to set up exergy extraction, it needs to have a certain orientation and form with respect to that gradient. What is a consumer? It is a gradient feeding upon another one. But it is necessarily an informed gradient. The origin of definitive semiosis (the biosemiosis of Hoffmeyer 1993) lies in these relations, as noted already by von Uexküll in 1926 (Salthe 2001). So, what is information?

3 INFORMATION

Information would be needed to locate or characterize whatever is present in a system that is not at equilibrium, and, in the cosmological sense which we have been exploring, its measure would reflect the distance of that system from equilibrium (Layzer 1975). Thus, in a non-equilibrium situation one would need to construct a trajectory as well as coordinates, and in a far from equilibrium system, chaotic parameters would need to be added, while near equilibrium, coordinates might suffice. The more out of equilibrium a system is, the more information would be needed to characterize it; that is, the more information would be contextualizing events, and would be “missing” for an uninformed observer (figure 3).

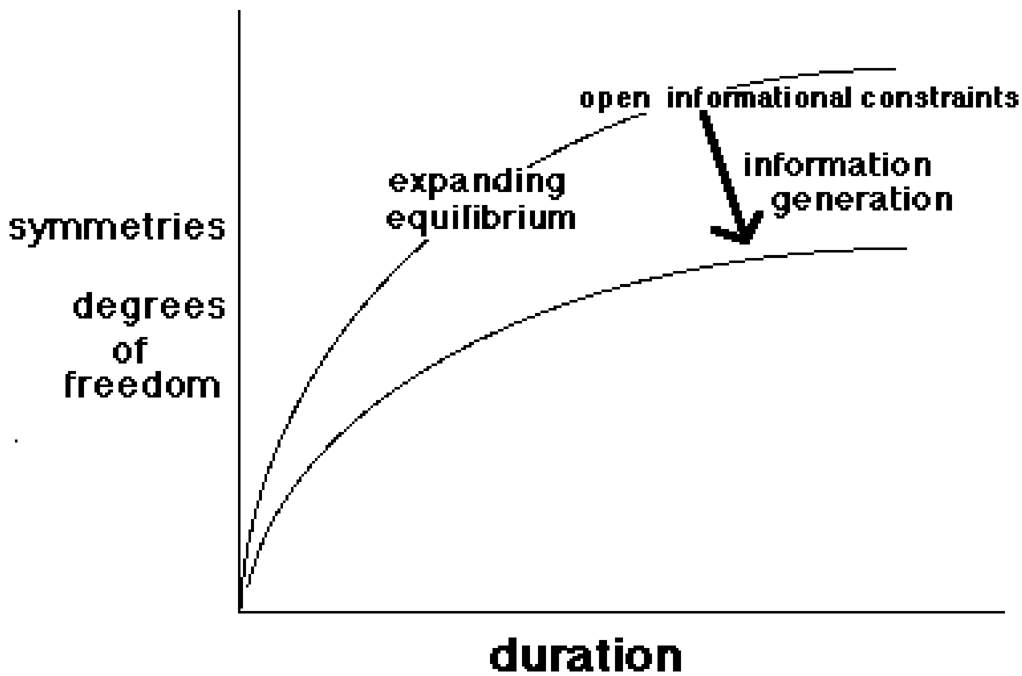

Figure 3: Changes in lack of information in an expanding system, or, the precipitation of information in an expanding or growing system.

Information is most generally just constraint — the constraints holding a system away from its maximum entropy, or greatest free energy, condition, where more possible states could be reached from any other without privileged sequence. In a developmental sense, information becomes embodied when open informational constraints get reduced, as degrees of freedom get fixed and symmetries broken (the negentropy principle of information: Brillouin, 1956; Collier 1996).

Informational constraints (symmetries, degrees of freedom) appear in a system as it grows, as when the situation arises where clumps of matter appear in the universe as it expands. These clumps are the informational resolution of that situation, marking its degree of lost equilibrium. With a nod to Charles Peirce, the laws of nature would represent symmetries broken very early in the history of the universe, and which have continued, as universal habits, to be preserved. So, information functionally is just configurations working as boundary conditions on a system seeking its lowest free energy state, including, in a cosmological sense, natural laws and conservation principles as information. [But, of course, not including these cosmic constraints in the context of distinguishing laws from local boundary conditions, where the laws are taken to be non-historical because unchanging at present (Pattee 1995)].

Note that, in this sense information is constraint that might have been different. It is preeminently historically acquired, a result of contingency. This principle can be sharpened in the digital context to: constraint that might have been different even with no difference in energy cost of acquisition. That is, information might have been different, given the conditions — it would be difference for free! And, therefore, it could be viewed as having been acquired as a result of creative action (Salthe 1993b). It is true that in any particular local situation (say, in a developing embryo) there would be constraints — laws and conservation rules, as well as (in this case) genetic information which were not acquired by this local system itself but by its ancestral systems. For this embryo itself, these rules would not be generated during its own individuation, but circumscribe its activities from its beginning. They would impose *developmental constraints*.

Development is just predictable directional change (Salthe 1993a), guided by stabilized constraints of any kind. These reliable rules are informational constraints functionally, and they were at one time acquired historically, but they were not acquired that way by any particular local system but rather by inheritance. For example, any communication is today bounded by the speed of light. Since it is not changing measurably at our time scale, this speed is not taken to be an historical constraint, but the present viewpoint presumes that it was acquired by the universe by way of historical accident in the past (and may even be continuing to change, at our scale, very slowly).

In a developmental sense, an immature system would be expected to have more open informational constraints than a more mature one. For one reason, it is growing more rapidly, and that growth generates informational constraints, and fixes some of them as well. Universal laws and conservation rules would have been acquired when the universe was more immature, and may be changing hardly at all any more. As a system senesces it would have fewer open informational constraints, and their fixation would be more reversible, i.e., not so tightly built into the system. This would be the source of whatever flexible behavior, or informational entropy, a senescent system might yet generate.

4 INFORMATIONAL ENTROPY

Information can change, and its relations can be altered, and (as systems grow) it can multiply —all leading to an increase in potential uncertainty in systems being constrained by it, or for an observer of such a system. This uncertainty refers to the many ways the information can mutate, or be recombined and concatenate, which necessarily increases as the amount of information increases (Collier 1986; Brooks and Wiley 1988). It refers as well to the multiple ways information can be expressed as behavior, which increases with development. All this uncertainty generates information capacity (information carrying capacity), variety, or the informational entropy, H, of Shannon and Weaver (1949) -- Collier and Hooker 1999) (figure 4).

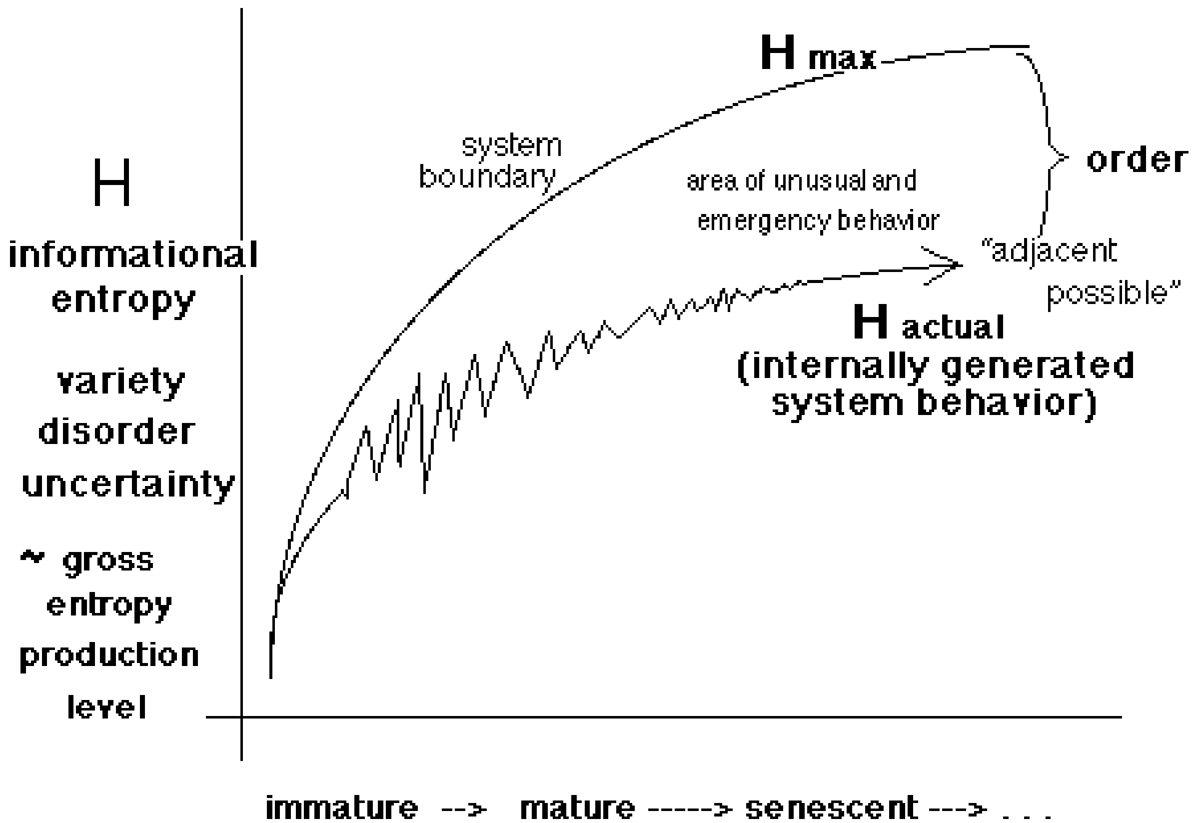

Figure 4: The infodynamics of a dynamic material system. Above Hmax the system would disintegrate. Order is interpreted as less than maximal disorder. Gross entropy production refers to physical entropy. [Modified and extended from Brooks and Wiley 1988.]

H marks a diversity of possible meanings, or behaviors mediating them, that can be generated from fixed informational arrays. In an expanding or growing system, mutational changes of all kinds (generated in any material system by friction and fluctuations) will tend to create new informational configurations as the system expands into its "adjacent possible" phase space (Brooks and Wiley 1988; Kauffman 2000), as afforded by environmental boundary conditions (Salthe 1985; Collier and Hooker 1999).

Many of these new configurational states will be unstable, non-fitting, or non-functional (as the case may be), and so the actual variety of a surviving system will be held down from its maximum possible. That is, if it continues to exist at all, it will be more orderly than it might be if more of its potential behavioral variety could be accessed. Here we can see how H easily maps to the disorder (S) of Boltzmann's interpretation of physical entropy (Boltzmann 1886; Brillouin, 1956). Indeed, as implied in Smith (2001), we might see that Boltzmann's S was the earliest formulation of an informational entropy; that is, a system that is able to access any of its possible configurations at any time would appear to be more disorderly to an observer than one that displayed more habits. For this reason, information increase in any actual material system implies increased *orderliness* even in the face of an increasing maximum number of possible informational configurations, including unstable ones, implied by possible permutations of its growing informational arrays (figure 4).

Order in this view is then, minimally, just less disorder than might be possible. Note that, in a growing system, even the functional, or actual, informational entropy will tend to increase as a result of mutational exploration, simply because new actual relations are being generated just by geometric extension and scale increase. A system could not both grow and maintain the same number of accessible states.

5 THE ORIGIN OF DIVERSITY

The first thermodynamic discovery, by Sadi Carnot, was that exergy extraction for doing work is never perfectly efficient (Heilbron 1981). So, even though energy gradients are all metastable during an accelerating universal expansion, their consumption in the service of building other gradients is always a challenge, and the newly made gradients will always be of lesser amount than those consumed. The universe, one might say, is wary of all forms, and so, niggardly about affording new ones. The general cause is that the material world is (as a sign of being out of equilibrium) characterized by friction and delay. Furthermore, the inefficiency of exergy extraction (dissipation in Second Law sense) increases with work effort. The more rapidly a gradient is consumed, the less of it can be put to any particular use. Any attempt to gobble it up results in the generation of new energy gradients that, if the Second Law efficiency is low, as it most usually is, leaves some disordered gradients of better quality than heat (this result signaling dissipation, then, in the First Law sense), and these might be available to other consumers. So, as a result of the Carnot / Clausius Second Law, secondary sources of exergy tend to multiply and get disseminated (Taborsky 2000).

Again, energy availability is a matter of relations between the configurations of consumers and gradients (— and, in passing, I note again that this signals the presence of semiosis). The configurations of any consumer, being finite, can only relate to limited kinds of gradient configurations. All consumers must be specialists to some degree. These configurations and their relations, are informational in nature. It seems clear from this perspective that physical entropy is just a measure of the derangement of gradient, of its disordering with respect to particular consumers; indeed, it is a measure of loss of informational connections. The amount of entropy produced during any exergy extraction is best measured by the amount of heat produced, this being the lowest grade of gradient (if it is gradient at all). So, physical entropy is derangement or, as Boltzmann modeled it, disorder. More precisely, we can say that it is the disorder produced during gradient derogation over and above the disordering generated on average by the temperature of a system. In any case, it represents a loss of informational connections.

Information, as part of energy gradients (that is, as embodied energy), is always unstable, generating the materials for information capacity, H. Mutation leads as well in some cases to new relations with other gradients, so consumers tend to diversify (Brooks and Wiley 1988). And, as consumers themselves become energy gradients for other consumers, there is a positive feedback here. H, as variety, can be a measure of the diversity of consumers-as-gradients in the sense that, with many kinds at hand, it becomes uncertain which might be encountered next at a given locale, or in movement away from it. The more diverse ecosystem can generate more informational entropy for an observer, or for a participant.

Individual consumers tend to grow as a result of energy assimilation. As such they expand the surface area of their contact with gradients, increasing their per unit time gradient consumption. As Swenson (1989) cast it in very general terms, "the time-dependent behavior will be such that the field will extend the space-time dimensions of its diffusive surfaces through the spontaneous emergence of new levels of dynamical behavior, progressively selecting its own accessible microstates so as to maximize the rate of its mass specific global diffusivity, subject to constraints". (In connection with Kauffman's proposed (2000) "Fourth Law" of thermodynamics, read 'work surface' here instead of 'diffusive surface'). By growing, dissipative structures may encounter new gradients. Overextended, they break up (eventually the source of reproduction in living ones), spreading to new locales, again meeting new gradients. I note here that each individual dissipative system eventually senesces, acquiring more internal constraints, and its mass-specific (OR VOLUME-SPECIFIC) rates of all activities then gradually diminish.

Each individual consumer undergoes a development, from immaturity to senescence (Salthe 1989; 1993a), which is imposed, in my view, by the material constraint of information overload, acquired through growth of informational constraints, and their fixation as a result of contingent encounters in the world. This leads to organizational overconnectivity, which leads in turn to functional under connectivity. Information growth tends also to reinforce established system habits, which material systems cannot transcend. The result is loss of adaptability, which sets a system up for recycling.

Thermodynamically, I think of senescence as signaling a switch from attraction by an entropy production / gradient destruction maximization, as in the Swenson - Kay - Kauffman view, to attraction by Prigogine's minimum entropy production regime (Kay 1984; Salthe 1993a). The gross energy throughput, as a result, levels off (Lotka 1922; Odum 1968). Prigogine's regime is a reasonable model only for senescent systems insofar as experiments demonstrating it do not grow or expand, but are fed a steady low level of energy input.

I would like to point out that Ulanowicz's (1986; 1997) ascendency is a good general measure of development as I view it here.

6 SUMMARY

Summarizing some points: the inefficiency of energy gradient utilization results in a multiplication of gradients; the mutative dissipation of embodied information generates new kinds of consumers. Together these forces generate an increasing diversity in the biosphere, which should continue as long as the universe keeps expanding, even though each individual dissipative structure eventually senesces, hobbled by information. As the universal expansion eventually slows, we can expect that it, too, will senesce. So, the world can be viewed as a dialectic between gravitation (the build-up of gradients, embodying information) and the Second Law (their destruction, using that information, leading to smaller gradients). In this perspective, life is a way of inserting smaller, more stable gradients into larger ones, generating a kind of friction, thereby plateauing the destruction of gradients (Lotka 1922), so that we don't burn oxidatively so much as we slowly dehydrogenate.

So, finally: why is there anything? Because the universe is expanding faster than it can equilibrate. Why are there so many kinds of things? Because the universe is trying to simultaneously destroy as many different energy gradients as possible in its attempt to equilibrate.

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