Entropy
ISSN 1099 - 4300
www.mdpi.org / entropy /

Letter to the Editor

The Spontaneous Origin of New Levels in a Scalar Hierarchy

Stanley N. Salthe

Biological Sciences, Binghamton University, New York, USA
Tel. 607-467-2623, ssalthe@binghamton.edu, http://www.nbi.dk/~natphil/salthe/
42 Laurel Bank Avenue, Deposit, New York 13754

Received: 18 March 2004 / Accepted: 2 June 2004 / Published 19 June, 2004

Abstract: Given a background of universal thermodynamic disequilibrium, I suggest that the interpolation of new levels in a material scale hierarchy is favored when the entropy production of a local region would be increased by such structural complexification. This would involve the separation by order of magnitude of the average dynamical rate of the new level compared to those of the resulting contiguous levels from which it became disentangled, thereby facilitating laminar flows. Here the Second Law of thermodynamics is understood as a final cause, which can be expressed in this creative way when the surrounding superstructure has a form allowing it to mediate this change (by, e.g., focusing kinetics, etc.), and given, as well, sufficiently differentiated local energy gradients to materially support the increased local dissipation.

Key words: Aristotelian causal categories, entropy production, finality, scalar hierarchy

Introduction

It is commonly supposed that the production of physical entropy in the world is something which could further only the global equilibration of the Universe as a whole, when viewed as an isolated system. Here I take a different view, and suggest how necessary increases in entropy production in nonequilibrium situations can be used to explain the origin of complexity locally, thereby finding the Second Law of thermodynamics to be a final cause of the origin of information because it provides the motivation for all dynamics in isolated, but non-equilibrated, systems.

This paper attempts in particular to relate the emergence of new levels in a scale hierarchy to the basic fact about our universe -- its expansion in the Big Bang. Since this task is undertaken in the framework of thermodynamics (the laws of which constrain all material phenomena), the emergence of new hierarchical levels is here being taken to be a fundamental, all permeating, process in the world.

The major background conception is the origin of gravitation and of the Second Law of thermodynamics as dual, simultaneously emergent, opposing consequences of the acceleration of Universal expansion. On the analogy of the precipitation of water droplets from vapor in an expanding cloud chamber, gravitation is seen to come into existence when matter precipitates from energy that has been left in radical disequilibrium -- literally left behind -- by the acceleration of Universal expansion. Matter, mass, form and organization, as signs of disequilibrium, are taken to be configurations of energy increasingly distant from thermodynamic equilibrium. The Second Law is then taken to be the Universe's tendency to equilibrate, and can be seen, seemingly paradoxically, to be implicated as a final cause in the generation of new forms, including new levels in a scale hierarchy.

Some preliminaries

It should be noted up front that this paper is in the style of ***Natural Philosophy*** -- discursive and widely ranging across fields of inquiry.

A ***Scale Hierarchy*** is a spatiotemporal organization of co-present systems having average dynamical rates of different orders of magnitude. Natural hierarchies are frequently nested, as with cells within organisms and chemical entities within cells, or tornadoes within thunderstorms. Each of the entities named exists at a different scalar level. Processes of interest would be located at a focal level, and would be bounded by a lower level which generates the focal level dynamics, and a higher level regulating those dynamics [1]. This paper is concerned with the origin of new levels as a general process anywhere in the material world.

Complexity has a number of different definitions. The organizational complexity represented by the scale hierarchy is that where several systems occupy one locale, but do not directly interact. Rather they transact indirectly by way of mutual constraints. For example, a larger scale system will impose boundary conditions upon the faster dynamics of lower scale systems. When the scales of the rate magnitudes get closer together short of allowing direct interaction, dynamical complexity such as chaos may be initiated.

Entropy, as used herein, refers to physical entropy -- the condition of disorder found among particles displaying heat energy.

The ***Second Law of thermodynamics*** has a number of appreciations. My take on it comes from ecology, where an emerging perspective understands it to be manifested in the instability of all energy gradients. This comes from the perspective of 'systems ecology', which models ecosystems as energy and matter transformations, beginning with solar energy, carbon dioxide and minerals, and, working its way through several 'trophic levels', eventually going back to the initial reactants again, and, of course, to heat energy on its way to the energy sink of space. Assuming the Universe to be an isolated system entails that the Second Law be viewed as its tendency to equilibrate. And so the instability of energy gradients is another aspect of this Universal tendency to equilibrate.

Exergy, is that portion of an energy gradient that actually gets used to power work.

Final causality is unfamiliar to most thinkers and scientists because it was dropped from the analytical canon early in the modern era. Some of us think that in the face of complexity, the entire suite of causal factors elaborated by Aristotle will need to be revived. These are: the synchronic pair: material cause (which proposes possibilities) and formal cause (which mediates some of these into effects), as well as the diachronic pair: efficient cause (which initiates or triggers effects -- pushes) and final cause (which calls for these effects -- pulls). Efficient cause was preserved in physics, while material cause continued to be used by chemists and biologists. Formal cause is implicitly used by all theorists, embodied in the organization of models and the configurations of equations.

Final cause, however, was more or less explicitly excluded from thought within the mechanistic philosophy of science as it has been in the modern era. It is that ***for which*** something happens, answering the question 'Why?" As an example, we can consider human purpose -- teleology. Inasmuch as, on materialist grounds, any property of a highly evolved system must have had precursors in the ancestral systems from which it evolved, we want to represent those precursors here. With respect to purpose, functionality in biological systems -- teleonomy -- has been widely accepted in this role. Teleology is, then, a kind of teleonomy, which would be the more generally present ground from which it could have developed. Then O'Grady and Brooks [2] proposed 'teleomaty' as the logical precursor of teleology. It identifies physical tendencies, like those modeled by variational principles, to be its source in abiotic systems. That is, function is taken to be a refinement, in more complex systems, of natural physical tendencies. So, logically, we have {{{teleological} teleonomic} teleomatic} -- {physical tendency {function {purpose}}} as our parsing of finality in this case.

Here I identify the Second Law as a final cause of energy transactions in any isolated system. Inasmuch as there is a well-known efficient causal mechanism of this law in the net diffusion of particles away from each other, resulting in their most likely configurations, it has been claimed that invoking final cause here is unnecessary. But analyzing a system using one causal mode does not logically exclude identifying other modes that must also be acting. Furthermore, identifying only a single causal mode would likely be deficient in the face of complex systems. Indeed, seeing diffusion as a ***means*** of achieving equilibration implicitly identifies the Second Law (the tendency toward equilibration) as separate from any means by which it might be brought about. Especially in the context of our contemporary knowledge of the efficient cause of the Universe's disequilibrium -- its accelerating expansion -- we can see that the Second Law answers the question 'why does diffusion occur at all?', which is separate from explaining how.

(1) Dynamical stability

Ulanowicz [3, 4] has constructed a dualistic metaphysic of centripetal versus centrifugal dynamics, while I have proposed a congruous one of collecting versus cascading processes [5]. Neither were explicitly connected to Big Bang cosmology, but the collecting of stuff is seen here to be afforded by the fact of the acceleration of Universal expansion [6, 7]. Under present conditions on Earth however, even though collecting is in this way afforded, it cannot occur without the concurrent dissipation of other material collections being used as energy gradients to power it. In that way new construction is consistent with the Second Law. On the other hand, cascading (e.g., evaporation, diffusion, burning) is spontaneous, and so is accompanied by loss of free energy. Collecting is parasitic upon energy dissipation, as when a centripetal / centrifugal system attaches to a cascading (or cascadable) gradient, often speeding up its dissipation, thereby increasing its own power (energy throughput) by siphoning off some of the available energy to serve as exergy in its work of self-collecting.

It is important to recognize the informational aspects of this scheme as well. As a system grows during collecting, it cascades into informational space, (a) generating a greater variety of configurations and behaviors (e.g., see the treatment of biological phylogeny and ontogeny by Brooks and Wiley [8], or of ecological ascendency by Ulanowicz [3, 4]), thereby (b) increasing the variety of different kinds of interaction of a system with its environment, as in growth of a nervous system. Continued growth also leads a system into susceptible contact with more and more powerful cascades that could destroy it. Note that, as a system grows, it develops -- eventually into senescence, a condition of relative rigidity and weaker intrinsic power that poises it for recycling [5]. So, system stability is dynamical, involving growth and development, is powered proximally by the centrifugal cascading of external energy gradients, and is afforded ultimately by the acceleration of Universal expansion.

(2) General thermodynamic viewpoint

I begin by noting that system appropriation of exergy for its growth, siphoned off from the cascading of other systems, is heavily taxed by the Second Law of thermodynamics. At typical work loads, about as much of an available energy gradient is dissipated as heat energy as is captured in work [9], including the work of self-organization [10]. Because of this large entropy tax, it is not an implausible view, given the extreme disequilibrium of the Universe, that entropy production acts as a final cause in the buildup of organized gradients, including biological systems. My perspective here [5, 14, 15, 16, 17] is related to that of Swenson [11, 12] and Schneider and Kay [13]. Because of the radical disequilibrium of the Universe, all gradients are unstable. Increases in the steepness of a gradient will tend to trigger the spontaneous organization of dissipative structures that will begin degrading it, or will attract already organized, free roaming dissipators, like organisms. The origin of life discourse needs to be nestled within this consideration as well. Whatever model of this process one espouses, that process necessarily had to have taken place within a larger scale dissipative structure whose entropy production was used to power it. This larger scale structure would also likely have imposed constraints that would have helped to guide Life's emergence, informing the system along with other boundary conditions generated by other larger scale processes and configurations. A prebiotic selection process would have been involved here, with -- in the present view -- forms that could mediate faster entropy production during their self-organization replacing earlier stages in the origin. A dissipative structure utilizes available energy to self-organize, the work of doing which produces entropy. In many cases (tornadoes, organisms) further work is done by the structure, creating traces of its presence in its environment. This activity ranges from the destruction of external forms unrelated to the gradient supplying available energy (as by a tornado), as well as the construction of the likes of footprints, tunnels, burrows, nests, dams -- the 'ecomass' of Wesley [18].

Note that the present perspective is not in conflict with kinetic models of the origin of life [e.g., 19] or of levels generally. Kinetic models focus upon material and efficient causes in an historical and local perspective, while the thermodynamic view focuses upon a final causality operative universally. Its perspective is that, given sufficient sustained energy gradient steepness, some form of organized system must evolve in order to mediate entropy production from that gradient, the supposition further being that, if the surrounding system survives long enough, some form of lifelike system will eventually emerge, elicited by the Second Law of thermodynamics acting as final cause.

(3) Hierarchies

I have noted [5, 20, 21] that there are formally two kinds of hierarchies to be found in science related texts -- the scalar hierarchy, [whole [part]], and the specification hierarchy, e.g., {physico-chemical system {biological system}}. Both are applicable as analytical formats to any material systems, and some analyses conflate them. (For a capsule image relating the two, see Figure 16 in Salthe, 1985). The current dynamical hierarchy movement is primarily oriented towards the scale hierarchy [e.g., 22], and this text will explore the origin of new levels in that perspective -- that of spatiotemporal scale.

As I pointed out in 1985, [1], one easily discerns hierarchies of dynamics in the natural world. In order to give a clear framework for this, we can look at an equation for some physical process. The form of the equation describes the consequences of activities at some level in focus. These focal level dynamics will be influenced -- controlled or regulated (not determined) -- by boundary conditions instituted by dynamics or arrangements at scales higher than focal level, and these are embodied as constants in the equation. As well, the focal dynamics will have been made possible by properties of the entities represented by the variables, which initiate them [1, pp. 103-111]. And so we have an irreducible triad of levels in describing any material system spatiotemporally [1].

For a relatively simple concrete example, take a vortex -- say, a tornado [23, 24]. We can begin with the large scale arrangement (formal cause) that imposes boundary conditions favorable to tornado development. A three-way meeting of warm and moist air, dry air, and cold air sets up the conditions -- like instabilities and lifting air -- necessary for the formation of thunderstorms. At a somewhat more local level, a wind shear can start a thunderstorm into rotation (efficient cause), generating a supercell with a well-defined mesocyclone circulation, which has a central updraft and a downdraft wrapping around it. This will move in a direction imposed by the large scale circulation patterns in a region, trailing an anvil cloud. Tornadoes may emerge in the advancing gust front where the downdraft gets sucked in close to the updraft. Low level winds veering with height seem to be crucial precursors (efficient causes) at the focal level -- the scale of tornado dynamics . But the downdraft could quell a nascent tornado if the local arrangement isn't just right, by cutting off the updraft. Initiating conditions (material causes) from the lower level here are primarily sharp temperature differences in the interacting air masses, generating the need for entropy production (final cause). The steeper the gradient, the more likely a convective structure will organize tending to dissipate it [13].

We could examine different kinds of systems, including more complicated ones, in the same triadic format. For example, an organism, or some organismic behavior, could be interpreted in this way. Or a city, or some urban process like garbage collection, could be handled within the same format. Indeed no material phenomenon could not be parsed in this way -- because all material phenomena exist at multiple scalar levels, and are as well nested within still larger scale systems [see 1 for further examples and discussion].

(i) Dynamical Separation

Material dynamics tend to be sticky and to mutually interfere, becoming chaotic. The result would be turbulence unless different dynamics can get to be separated into distinct levels. Turbulence is a kind of mesoscopic scale conduction, dissipating a gradient more slowly than would a more laminar energy flow. The orderly accumulation of stuff by dissipative structures and their constructions would be better facilitated by laminar flows, which would be enabled when dynamics are separated by roughly orders of magnitude rate differences. For example, pedestrians, cyclists and motorists have dynamics that are ***not*** separated by order of magnitude rate differences, and the chaos they would generate moving together is avoided by the configurations of roadbeds. In organisms, sufficient dynamical rate differences do characterize, e.g., metabolism as opposed to cellular dynamics like mitosis, as contrasted with whole organism dynamics like those involved in food processing, circulation and mating behaviors. Biological systems, like social ones, use configured arrangements (informed in this case by genetic information) to allow dynamics relatively little separated by scale to proceed simultaneously in close proximity.

The process of separation of increasingly definite different dynamics, however it is accomplished, accompanies development, which is most generally a process of elaboration from a relatively vague primordium toward an increasingly definite definitive system, typically accompanied by growth. The process of dynamical separation generally would move toward the dominance of dynamics separated by rates of about an order of magnitude difference. Dynamics separated to that degree (or by arrangements) can operate faster at their given scales than materially entangled ones, and so will commandeer most of an available energy gradient, impoverishing and starving out mutually interfering other potential dynamics. The result is a system where dynamics at different levels almost never interact, but transact indirectly by way of mutual constraint in the context of a global system [1]. (Even the process of generating a large text could be viewed in this way, with the interpolation of paragraphs, sections, chapters and so on, being required to elaborate an array of conceptual rhythms of different "scale".)

(ii) System Stability

Herbert Simon [25] suggested that separation into scalar levels is a spontaneous process that leads toward stability to perturbations in material systems -- toward dynamical stability. The spontaneity here relates, in my view, to seeking the fastest overall rate of entropy production consistent with a system's continued embodiment -- to what we could call streamlining. Conrad

[26] suggested that stability at any given level is fostered by adaptability at other levels, elaborating a hierarchical model based in Ashby's [27] principle of requisite variety. His suggestion amounts to the idea that no clearly defined laminar flows could be maintained at some level unless potential perturbations were being fielded at other levels. He used the example of biological functions at the organism level being afforded by variability at both the molecular (genomic) and population levels, so that some organismic function could continue to persist in the face of environmental change by fostering it from altered -- newly evolved -- phenotypic arrangements.

An important aspect of dynamical stability from Simon's point of view is the regulation of fast dynamics by slower ones, which must, then, be clearly independent of the faster. Stability is instituted because the regulator changes more slowly than the regulated. For example, the component with the slowest throughput will regulate the overall dynamical rate of an autocatalytic cycle. But, if it can be replaced by a faster component in the same role, it will be. Ulanowicz [3] posits that the cycle would reward the faster contender because it increases positive feedback within the cycle, thereby selecting it as a component. In my view this could be done only in the service of increasing overall entropy production. In this view, if the potential replacement would be more energy efficient, that replacement might not go ahead since that might not increase the overall rate of system entropy production, even though it fostered the cycle by increasing the positive feedback delimiting it. A related consideration would be whether the new, faster overall rate of the cycle would be better separated dynamically from other processes at different levels within the larger scale, embedding local system. If so, then the replacement would be favored. We can see from this perspective that not all tendencies to form organized systems that arise in Nature would get supported. That is, system stability requires a nice balance of kinetic rates at different levels such that overall entropy production will be maximized given the constraints. Dewar [28] gives a rigorous mathematical discussion of this perspective. Here the organization of a system could not be independent of its environment, reminding us again of an aspect of the extensional complexity [1] of material systems.

The constraints involved in reining in entropy production so that it is less than explosive reside in the organization of a system. If its entropy production were to increase beyond some level it could destroy a system's integrity, setting it up for dissipation by other energy consumers. That is, the so-called maximum entropy production principle [11, 12, 28] might, in connection with more highly organized systems, be better named the maximizing entropy production tendency. Biological systems, of course, support their continued stability by way of inherited internal information, which also allows considerable elaboration of form compared with abiotic dissipative structures. This elaboration, and the fact that they last longer for their size, makes biological systems especially sensitive to wear and disruption, and so, of course, their momentary rate of entropy production must be limited compared to their vaguer abiotic fellows. Yet the need to compete with others of their kind for resources, and the need to outreproduce them, as well as the vital need to heal and repair as quickly as possible, keeps them pushing the Universal entropy production project as well as they can.

From the developmental perspective it is clear that immature systems are more dynamically stable than senescent ones [5]. That is, the elaboration of form and the accompanying diminishment of mass-specific power during development places a system in increasing jeopardy with respect to perturbations. A relatively high mass-specific energy throughput would be required for effective recovery from perturbations. An immature system is, as it were, headstrong and relatively unstoppable, while a definitive system is more easily disrupted, partly because it ***is*** more definite, requiring more particular conditions to thrive, and partly because its reaction time is increasing as it grows. Immature systems, of course, always replace senescent ones -- in the present view because they can produce more specific entropy per unit of time because all their activity rates tend to be higher. One may note, as an example, that the history of Western society shows that it has continually increased its entropy production technologically during the time when it replaced other, "traditional" societies. Even while developing, it has remained more immature in this regard than those old cultures it coopted [see 16 and 17 for further discussion of this kind].

I have suggested [5] that the decline in specific power with development comes largely from information overload, causing an overconnectedness (impacting the dynamical separation of levels) tending to produce functional underconnectedness, characterized by lags in response time. (Information here is taken to be any definite configuration that could constrain entropy production.) Senescence in autocatalytic cycles would come, for example, from a continued incorporation of components, setting up parallel tracks for throughput. Each new component would be selected because it momentarily increases cycle stability to some particular perturbation as it occurs, but eventually so many parallel tracks would exist, as a kind of record of past perturbations, that the cycle has become unwieldy in respect to unexperienced, new sorts of fluctuations. In short, dynamical stability is transient and is gradually lost in all developing material systems. If it lasts long enough, a tornado, for example, gradually gets more elaborate, assuming a rope or snake form as it weakens. It has grown, increasing its surface area, and therefore its gross entropy production, but its volume specific production would presumably have diminished as it became more unwieldy, as shown in data from other dissipative structures.

Dynamical stability requires a reliable background to supply more or less predictable boundary conditions. These come largely from embedding, larger scale supersystems because they change more slowly than does the system (like the autocatalytic cycle above) at focal level. Some systems also have the ability to convert lower level behaviors into information embodying statistical moments that also change more slowly than system dynamics [29]. One can understand the evolution of organisms from clusters of cells as having been successful for this reason. This can be viewed as the invasion of environmental scales by the living system, made possible as it came to hold indirect representations of repetitive environmental conditions in its internal informational (DNA) record. The result would be to enhance the stability of living systems, which were originally just recursive chemical cycles, which later became confined within micellar structures. The organism can thus be viewed as the the result of the cell's extension of control over higher scalar levels closest to its own functional processes, helping to better guarantee some critical boundary conditions. More precisely, the organism is the living system's way of influencing some of the nearer larger scale levels that control or regulate it. Boundary conditions from these levels existed, and were used informationally by the living system before the advent of the organism (everything in evolution must have precursor!), but were more uncertain then. Involved here would be the notion of scalar levels as moderating mediators of cross scale transactions [30]. Relatively strong signals from more distant larger scale levels can damage a system to the extent of the dynamical distance between the levels. If a system can interpose a level between itself and higher scale sources of occasional perturbations, the latter could be moderated -- as when organismic skin protects cells from powerful ultraviolet signals originating at the scale of the solar system. These mediations can then evolve into system-controlled regulation from a captured higher scale (in this case reconstructed as skin). For another example, physiological changes are regulated by organismic needs such as hunger, sleep and fear, all of which require and elicit different cellular activities which can be influenced, as downward regulation, by hormones and nervous stimulation.

In the same way, the evolution of biological populations regulated environmental events that would otherwise have impacted isolated organisms. Population processes like reproduction can interpose altered organisms between the germ plasm and environmental events that could threaten it, as when reproduction in populations of water fleas and aphids produce different morphs under different conditions. As well, since biotal changes are regulated by seasonal patterns, arrangements at the ecosystem level can modulate the threat of, e.g., food shortage, as when different foods for a given species are produced in different seasons. This latter process requires considerations of coevolution, which can be as loose as when squirrels with less than perfect memory bury nuts which then carry on a new generation of trees. In some cases, a species can even harness environmental events in its favor, as when fire resistant plants living in xeric environments produce extremely flammable leaves, which fall, accumulate and eventually burn, discouraging competitor species from invading their local habitat.

An evolved larger scale system can become powerful in regulating its lower level components. For example, a subway system enforces certain routes of travel for many citizens. In turn, this is regulated by the work day, being used at a greater rate during rush hours. Statistical study of such a system will show that the mean number of users at various times of a routine day will be quite stable and predictable, and, indeed, would be a result of, or exemplify, city scale dynamics. We see here that macrosystemic statistical moments can function as constraints on the microsystemic behaviors of individuals, inculcating their cohesion [22, 31] -- e.g., most people do not go to work in the middle of the night! It is an interesting possibility from the present point of view that the power laws followed by so many different kinds of systems [e.g., 32, 33] might be the result of downward constraints exerted by encompassing supersystems.

(iii) Extensional Complexity of An Actual Case

For an example of extensional complexity, we can look at organic evolution [34]. Since changes in the gene pools of populations are of relatively large scale, the average rate of change of effective genetic information takes place much more slowly than the rates of cellular, or even of organismic dynamics, and require multiples of cell and organism generations. In turn, the average rates of genome dynamics in the cell are much faster than the cellular dynamics occurring at higher than genomic scale. Thus, the results of large scale gene pool dynamics -- the genetic information bearing upon cells and organisms -- can regulate middle scale cellular and organismic activities, while the cell itself organizes, regulates and deploys small scale genome dynamics. Relevant genomic processes here are the misrepair of damaged DNA or its miscopying during genome replication. Since resulting mutant information could kill a cell or organism, or defeat its successful reproduction, we see that it must be processes going on at the slower rates of cellular and organismic behaviors that actually present newly mutated genetic information to the population as altered behaviors at these scales. The gene pool does not directly "see" the genome, nor does the latter "see" the former. Mediation between them is carried by cellular and organismic behaviors -- in both directions. Simply, genomic processes could never be regulated by cells that were unsuccessful in projecting descendants into the future.

Note that this example shows us in detail just how living systems (which I take to be minimally represented in cells) go about invading larger scales -- by creating cohesive ecological and genealogical processes based in individual cell or organism behaviors, at the scale of populations, which have been created as well by individual reproduction. Biological populations are composed of representatives of various genotypes. What are selected by natural selection are not really individuals, but types (even though this is actually mediated by the failures of individuals). That is, biological populations in the genealogical realm (demes) are not really made up of individual cells or organisms, but of differentially represented genotypes. If reproduction were less than a certain degree accurate, there could be no definite types to compete for representation. The result would be a more chaotic evolutionary process. We can note that some turbulence is introduced into the evolutionary process even in its present highly developed state by weaknesses in the system like linkage disequilibrium [35], caused by the material stickiness of chromosomes at the level of cellular dynamics, but disordering and slowing down population fitness increase.

Genotypes are functionally determined by environmental selection pressures, but they could be more, or less, crisp. The more crisp they are (i.e., confined to relatively few, relatively easily recombined genetic loci), the more efficient would be the selection pressure. Efficiency here is the amount of gene frequency change per cost of selection in numbers of unsuccessful individuals required to be sacrificed in order to accomplish that change. The number of generations required for these changes could decrease as well. This, of course, is just an example where increasing organization results in increased efficiencies. If selection pressures are narrowly focused enough, and if genetic representations are crisp enough, we could have a highly organized evolutionary system, characterized by relatively "laminar flows" of population fitness increase. Presumably primordial selection pressures would have been relatively vague, while primitive genotypes were embodied as fuzzy classes, so that the mutual information of population and environment would have been relatively quite low. With increasing crispness of genotypes, the biological population gradually emerged as a bonafide new functional level, interposing mediation between environmental selection pressures and individual cells or organisms.

(4) The spontaneous origin of new levels

(i) Interpolation

The basic pattern of the emergence of new levels in scale hierarchies is interpolation between existing levels [1]. All scalar levels are bounded by others above and below, receiving regulation from those above and the generation of their behaviors from below, -- delivering what I call [1] the basic triadic system of scale hierarchies. The lowermost level of the triad proposes (materially causes), while the uppermost disposes (mediates what happens at the focal level). It is possible that primordially one might have to postulate just a pair of levels -- i.e., somethings somewhere [36], the somewhere being the Universe itself, the things being the simplest material entities. Between these levels, matter as we know it, mass and form, all eventually emerged along with Universal expansion.

One could visualize an endless bubbling up of possibilities as fluctuations from what might come to be the lowest level in a future triad of them after a focal level has emerged with the cohesion of some of those possibilities. Only those possibilities supported by boundary conditions from what would come to be the highest level of the triad could become stabilized for the duration of those boundary conditions -- or even beyond if they become supported by other forms of information (such as genes in cells) as well. In this way, focal level cohesion might evolve from being supported by continued proximate dynamical maintenance by boundary conditions to one involving internal information as well. Thus, organism level configurations eventually became stabilized by genetic representation, as well as by way of reproduction in populations, which projects kinds of organisms into the future. At first such configurations -- say, strings, balls or slime coatings of cells -- would have been selected dynamically by local conditions, perhaps only for the duration of seasons. A neat analogous example was generated when a university planner deliberately neglected to plan pathways between buildings, allowing the behaviors of students to show which routes were most needed and to what extent. Here the boundary conditions were the sequences and locations of college activities, while the lower level was formed by the ambulatory impulses and behavior of the students. Eventually the dynamical behaviors of the students became fixed as the informational constraints of roadways in the design.

(ii) Thermodynamic Considerations

Now I will suggest that a new level will become interposed between others when (a) the overall rate of entropy production of the local supersystem increases as a result, which can happen only if (b) the new dynamic can separate itself from existing dynamics at other levels, increasing the dissipation rate of the consumed gradients, and that this will only happen when there is an appropriate match of (c) boundary conditions and (d) initiating conditions as a precondition. As part of (d), there needs, of course, to be sufficient local energy gradient to afford the insertion of a new dynamic. In the Aristotelian causal scheme, (d) would be material causes, (c) the formal cause, (b) the efficient cause, and (a) the final cause of this event.

(a) Thermostatics

We can begin by considering classical thermostatics. If the dynamics of different scalar levels proceed at different rates (this being a major criterion for distinguishing scalar levels -- see above), and if we assume that the Universe is an isolated system, then different levels must be at different distances from thermodynamic equilibrium -- the condition of random dispersion of their substances. That is, large scale systems, changing relatively slowly, would, if beginning at a similar distance from equilibrium, take a very much longer clock time to get there at their scale than would small scale systems. "Change" here involves accelerations and decelerations, alterations of direction -- all the motions that the molecules of a gas would undergo as it moves toward global thermodynamic equilibrium. These random motions can be extrapolated to any scale whatever, even to systems that are highly organized. Consider again a city with its subway system. Taking an appropriate glimpse of this system at the equivalent scale to the one we take on a gas, means that all the intentional activities that usually occupy us would become submerged in a buzz of activities spanning the construction of the system to its destruction and dispersion. The informational constraints so obvious to us in the city might do no more here than alter the probability density function we would use to analyze the system statistically.

Now, using the classical equilibrium approach [37, 38], it can be seen that there would be no thermodynamic opposition to the formation of new levels generally because a new one would in principle be further from local thermodynamic equilibrium than the lower level which gave rise to it, but closer to its local equilibrium than the upper level that regulated its emergence. Therefore the interpolation of new levels would not change the total entropy of the global system.

For some, the viewpoint just stated would require further justification inasmuch as they would claim that thermodynamic equilibrium could only be reached at the molecular level or below. But the last phrase is hedging as well. Which level is it actually? It is clear that statistical dispersal, or disorder, can occur at any scale whatever. Only if we view the world of mass and form as epiphenomenal upon some microscopic level would it, in my view, make sense to obviate considerations of equilibration at all but the smallest scale. The question turns, I believe, upon whether or not higher scale dispersal may or may not be viewed as a step in the direction of microscopic dispersal. Most simply, if an iceberg breaks up, or if stones roll off a mountain in a landslide, it seems clear that their molecular constituents have been moved closer to atomic dispersion by the process of mass wasting [39]. Furthermore, many macroscopic objects are parts of functioning biological or sociopolitical systems. These systems and objects are actively maintained. If not, they will fall to pieces, with the pieces, again, being more likely to undergo further abrasion than when they were being maintained as part of an active system. For example, those made of iron will be better exposed to rusting. All corrosive forces are enabled by breakup into smaller pieces. Of course, counterexamples might be pointed to, but my point is that in general, and statistically, the breakup of larger objects into smaller ones will favor the further dispersal of the smaller ones, and so on. Furthermore -- quite obviously the "punch line", it seems to me -- microscopic constituents of macroscopic objects will never get to global equilibrium if they remain separated from others of their kind by being trapped within larger scale forms.

(b) Nonequilibrium Thermodynamics

Turning now to the local, nonequilibrium approach to thermodynamics, I have stated above the viewpoint taken here. The differentiation of levels can be viewed as the avoidance of frictional turbulence by way of the cleaning up of flows -- a streamlining of energy flows in order to reduce energy gradients as rapidly as possible in the direction of heat energy. Rapid dissipation into various kinds of fragments is not as likely to dissipate a gradient all the way to heat energy (true Second Law dissipation), and so might be called "First Law dissipation". But gradients are susceptible to it because of competition between consumers, with those degrading them most rapidly getting most of them, creating in the event new gradients of lesser quality than the original. To explain why this occurs we can invoke (a) the radical disequilibrium of the Universe, coupled with (b) the maximum entropy production principle (MEP) [11, 12, 28], suitably qualified as a maximizing tendency in more organized dissipative structures, as suggested above. Since what is involved here are changes (not just Newtonian dynamics), different levels would be characterized by roughly order of magnitude differences of acceleration, funded by different activation energies. The emergence of a new level, while not affecting the global system's entropy (see the thermostatic section above), would afford a greater overall rate of local entropy production because it will likely be tapping some new gradient(s), some of which would be those lesser quality gradients produced by competition for primary gradients, taking their dissipation further in the direction of heat energy, and therefore, of universal equilibration. (Here we see the thermodynamic rationale for ecosystem evolution.)

This approach allows us a certain ability to predict which new levels might be favored in a [larger scale [smaller scale]] system. Starting with levels [A [B [C]]]: will it be [A [X [B]]], or [B [X [C]]]? Other things being equal, it would be the latter because more lower scale processes would mean faster average local rates of true physical entropy production. Of course, again, this would depend as well upon whether the new level would increase the overall dissipation rate of the greater supersystem. (Note that I use 'dissipation' to refer to gradient degradation, regardless of how much of it gets to serve as any systems' exergy.)

The emergence of a new level might also be a result of increased entropy production. For some examples: (a) an iron ball rusts at its surface, giving rise to new opportunities for more iron atoms to get combined with oxygen. The result is a scaling, flaky kind of form encasing the ball at a scale greater than microscopic. Or, (b) a magma will cool into multiple minerals, generating larger than molecular inclusions. A more complex example, (c) would be when a tree forms a bark out of its cork cambium. Like animal skin, this provides a protective barrier between cells and various larger scale insults that might be visited upon them. Bark and skin both involve myriad greater than microscopic cracks and crevices -- larger than cellular scale forms of various kinds. Of course, such a process of interpolation of levels is going to be somewhat more precise when guided by genetic information, as in these biological examples, generating, e.g., the characteristically different barks of different species of trees.

We can examine a model system of autocatalytic cycles at a given locale that are partially separated from each other by way of different rates of acceleration, based on the masses of reactants and products. Each cycle will have co-opted local elements according to their scale (of mass/acceleration), all entrained by the overall rate of dissipation of the basic local gradient, but their separation by scale is not complete. A new level could be interpolated when the overall rate of dissipation can be increased, at least periodically, separating these still conflated potential levels. The lowermost relevant level will tend less to change its rate of dissipation because it would have been already closer to accelerating maximally at the current, slower overall cycling rate, but the potential higher level materially entangled with it might have its rate accelerated, and so (other things being equal) the dynamical distance between levels would increase. Some elements from both of the previously immanent cycles will be attracted by, and move into, the newly emerging cycle between them, delivering the streamlining effect. And, if the acceleration of the upper level cycle surmounts a larger activation energy, the gap between levels could increase even further.

Why should all this happen? Again, MEP -- The previous protocycles will now be more effective dissipators of their portions of the fundamental gradient because they have shed elements with mass/accelerations marginal for them, and the cycle at the new level will add its own dissipation to theirs as well. As a kind of conceptual corroboration of this view, I cite another way of seeing the same process. Kay et al [40] view the emergence of a new level as a "linearization" of dynamics, with nonlinearity being a hallmark of a system not well separated into levels. This nonlinearity is viewed as emerging when lower level influences increase their span, generating a positive feedback creating turbulence that could be negated by a negative feedback from a new level of constraint, reestablishing overall linear dynamics. Both this and the present perspective see the origin of a new level as a resolution of tension generated by less than smooth flows.

As an example of the present perspective, we could consider forest succession [13, 41]. Here we have developmental changes, starting from a disturbed area, going through the weedy, tangled bank of an old field with its extended ecotone, to a forest with its more neatly separated canopy, understory, and floor. During these changes the gross rate of energy throughput will gradually increase [42], with eventually a declining rate tracking onto an asymptote. The increasing volume of growing tissue will produce more entropy by way of metabolism, while dissipation to heat energy increases largely as a result of increasing leaf surface area, mediating increasing evapotranspiration. As the system matures, more of the increasing gross energy flow will be partitioned into dissipation, less into exergy used in the work of growth. During this development more species join the system, participating in -- and generating some of -- the increasing numbers of microhabitats, and this insertion of new species will be the major mode of dynamically separating the energy flows. This shows us the major role of biology in ecology.

This model requires a single basic gradient (here incident radiant energy from sun), which can be dissipated at different rates simultaneously according to an array of activation energies, mediated by different forms and behaviors. Gradient dissipation in any locale could be viewed as being driven by a single basic impetus, which may fluctuate somewhat. Primordially, smaller masses, or changes with faster rate constants, or funded in greater chemical affinities, can participate in energy consumption rates accelerated more by any given impetus (translated to power) than larger ones, or than changes with slower rate constants or lower affinities, thus at least partially separating levels initially. That is, the rate of work at upper levels would be less for a given impetus because the masses, or the friction, at the upper levels would be greater, delivering a slower time constant for higher level cyclic renewal. Higher levels, as we go up, would gradually approach isometric work. Thus, pulled by the dissipation of solar energy, the evaporation of water at some locale will proceed faster than some given chemical reaction, which will proceed faster than the generation of a concerted updraft. The primordial system would be a mixture of tendencies to change (different mass/accelerations or potential rate constants and chemical affinities) which under weaker impetus (therefore lower power) will not separate well into levels, and whose dynamics would then often be chaotic.

I speculate that the basic impetus (the propensity to change, or the origin and intensity of motion) is scaled by the rate of acceleration of Universal expansion, but that the power and the work driven by it may fluctuate locally, affording potential access to immanent levels, providing that the local situation can afford the required rates of dissipation -- that is, provided that it is not already maximally differentiated. As weight varies with mass (given the force of gravity), so power and rate of work would vary with effort (given the basic impetus). Faster rates of dissipation will be favored because the current radical Universal disequilibrium demands equilibration now, but increasing rates become opposed by the necessary embodiment of their mediators. That is, rates of gradient dissipation could only increase in hyperbolic fashion (which is what we see in the forest), restricting the ultimate differentiation of a system into a limited number of levels.

(5) Conclusion

The production of new levels in a scalar hierarchy is here viewed as the way a material system can streamline or linearize its overall energy gradient dissipation rates, this being mandated by the Second Law of thermodynamics which, because of the radical thermodynamic disequilibrium of the Universe, calls for the degradation of energy gradients and the production of physical entropy at the fastest rates possible. The very fastest rates conceivable are not materially possible because of the necessary embodiment of the energy consumers, which requires some portion of the dissipated gradients to be put to work creating and maintaining them. Presumably, without these, often very specialized, consumers, some energy gradients in the Universe would not get dissipated at all. Evolution, then, is the Universe's devious route to its own negation.

References

1. Salthe, S.N. ***Evolving Hierarchical Systems: Their Structure and Representation***; Columbia University Press: New York, 1985.
2. O'Grady, R.T.; Brooks, D.R. Teleology and biology; In ***Entropy, Information, and Evolution;*** Weber, B.H., Depew, D.J.; Smith, J.D., Eds.; MIT Press: Cambridge, MA., 1988; Chapter 14.
3. Ulanowicz, R.E. ***Growth and Development: Ecosystems Phenomenology;*** Springer-Verlag: New York, 1986.
4. Ulanowicz, R.E.. ***Ecology, The Ascendent Perspective;*** Columbia University Press: New York, 1997
5. Salthe, S.N. ***Development and Evolution: Complexity and Change in Biology;*** MIT Press: Cambridge, MA, 1993.
6. Ostriker, J.P.; Steinhardt, P.J. The quintessential Universe. ***Scientific American*** January 2001: 46-63.
7. Kirshner, R.P. ***The Extravagant Universe: Exploding Stars, Dark Energy, and the Accelerating Universe;*** Princeton University Press: Princeton, 2003.
8. Brooks, D.R.; Wiley, E.O. ***Evolution As Entropy: Towards a Unified Theory of Biology.***

Chicago: University of Chicago Press, 1988.
9. Odum, H.T. ***Systems Ecology: An Introduction.*** Wiley Interscience: New York, 1983.
10. Loewenstein, W.R. Two arrows from a mighty bow. In ***From Complexity to Life.*** Gregersen, N.H., Ed.; Oxford University Press: New York, 2003, Chapter 8.
11. Swenson, R. Emergent attractors and the law of maximum entropy production: foundations to a theory of general evolution. ***Systems Research*** 1989, 6, 187-198.
12. Swenson, R. Autocatakinetics, evolution, and the law of maximum entropy production. ***Advances in Human Ecology*** 1997, 6, 1-47.
13. Schneider E.D.; Kay, J.J. Life as a manifestation of the Second Law of thermodynamics. ***Mathematical and Computer Modelling*** 1994, 19, 25-48.
14. Salthe, S.N. Energy, development and semiosis. In ***Semiosis, Evolution, Energy: Towards a Reconception of the Sign;*** Taborsky, E., Ed. Shaker Verlag: Aachen, 2000, Chapter 14.
15. Salthe, S.N. Ecology and infodynamics: a review of R.E. Ulanowicz, 1997, *Ecology, The Ascendent Perspective*. ***Journal of Social and Evolutionary Systems*** 2000, 21, 223-237.
16. Salthe, S.N. An exercise in the natural philosophy of ecology. ***Ecological Modelling*** 2002, 158, 167-179.
17. Salthe, S.N. Infodynamics, a developmental framework for ecology/economics. ***Conservation Ecology*** 2003, 7, www.consecol.org/vol7/iss3/art3.
18. Wesley, J.P. ***Ecophysics, The Application of Physics to Ecology***. Charles C. Thomas: Springfield, IL , 1974.
19. Pross, A. The driving force for Life's emergence: kinetic and thermodynamic considerations. ***Journal of Theoretical Biology*** 2003, 220, 393-406.
20. Salthe, S.N. Notes toward a formal history of the levels concept. In ***Evolution of Social Behavior and Integrative Levels***; Greenberg, G.; Tobach, E. Eds. L. Erlbaum Associates: Hillside, N.J., 1988.
21. Salthe, S.N. Two forms of hierarchy theory in Western discourse. ***International Journal of General Systems*** 1991, 18, 251-264.
22. Collier, J.D.; Muller, S.J. 1998. The dynamical basis of emergence in natural hierarchies. In ***Emergence, Complexity, Hierarchy and Organization, Selected and Edited Papers;*** Farre, G. and Oksala, T. Eds. Finish Academy of Technology: Espoo, 1998.
23. Davies-Jones, R. Tornadoes. ***Scientific American*** August 1995: 48-57.
24. Edwards, R. ***The Online Tornado FAQ*** 2003. www.spc.noaa.gov/faq/tornado.
25. Simon, H. The architecture of complexity. ***Proceedings of the American Philosophical Society*** 1962, 106, 467- 482.
26. Conrad, M. ***Adaptability: The Significance of Variability from Molecule to Ecosystem***. Plenum: New York, 1983.
27. Ashby, C. R.. Requisite variety, and its implications for the control of complex systems. ***Cybernetica*** 1958, 1, 1-17.
28. Dewar, R. Information theory explanation of the fluctuation theorem, maximum entropy production, and self-organized criticality in non-equilibrium stationary states. ***Journal of Physics, A*** 2003, 36, 631-641.
29. Lemke, J.L. Opening up closure: semiotics across scales. ***Annals of the New York Academy***

of Sciences 2000, 901, 100-111.
30. Allen, T.F.H.; Starr, T. B. ***Hierarchy: Perspectives for Ecological Complexity***. University of Chicago Press: Chicago, 1982.
31. Collier, J.D. Information increase in biological systems: how does adaptation fit? In ***Evolutionary Systems: Biological and Epistemological Perspectives of Selection and Self-organization.*** Van de Vijver, G.; Salthe, S.N.; Delpos, M. Eds. Kluwer Academic: Dordrecht, 1998.
32. Axtell, R.L. Zipf distribution of U.S. firm sizes. ***Science*** 2001, 293, 1818-1820.
33. Zipf, G.K., 1949. ***Human Behavior and the Principle of Least Effort.*** Addison-Wesley: Boston, 1949.
34. Salthe, S.N. Naturalizing semiotics: an extended review of J. Hoffmeyer, 1996, *Signs of Meaning in the Universe.* ***Semiotica*** 1998, 120, 389-394.
35. Lewontin, R.C. ***The Genetic Basis of Evolutionary Change.*** Columbia University Press: New York, 1974.
36. Matsuno, K.; Salthe, S.N. The origin and development of time. ***International Journal of General Systems*** 2002, 31, 337-393.
37. Gladyshev, G.P. ***Thermodynamic Theory of the Evolution of Living Beings.*** Nova Science Publications: New York, 1997.
38. Gladyshev, G.P. The hierarchical equilibrium thermodynamics of living systems in action. ***Journal of Semiotics, Evolution, Energy and Development (SEED)*** 2002, 3, 42-59. http://www.library.utoronto.ca/see/pages
39. Pielou, E.C. ***The Energy of Nature.*** University of Chicago Press: Chicago, 2001.
40. Kay, J.J.; Allen, T.F.H.; Fraser, R.; Luvall, J.C.; Ulanowicz, R.E. Can we use energy based indicators to characterize and measure the status of ecosystems, human, disturbed and natural? ***Proceedings of The International Workshop: Advances in Energy Studies: Exploring Supplies, Constraints and Strategies. Porto Venere, Italy; 23-27 May, 2000***; 2001 pp.121-133.
41. Odum, E.P. The strategy of ecosystem development. ***Science*** 1969, 164, 262-270.
42. Odum, H.T.; Pinkerton, R.C. Time's speed regulator, the optimum efficiency for maximum output in physical and biological systems. ***American Scientist*** 1955, 43, 331-343.