for Symmetry, order, disorder and chaos (for October, ‘04)

Asymmetry and self-organization

Symmetry: Science and Art

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Abstract

I consider the self-organization of locales in an isolated system near thermodynamic equilibrium. The process of collecting versus that of cascading reflect a symmetry between the force of gravity and the strength of the Second Law -- an implicit conservation of global thermodynamic equilibrium. Collections near equilibrium are unstable, but can form out of local dissipation when this occurs in power law distributed bursts. Subsequent development, through the stages, immaturity -> maturity -> senescence, can extend into a long senescence via entrainment by a tree of potential developmental trajectories with common immature stages. Stabilized by this structure, a developing dissipative system then exchanges this possibility of entrainment by many different trajectories for commitment to fewer, more stable ones. This can continue because powerful fluctuations that could disrupt the system become rare as a locale equilibrates. Such development can occur only where higher scalar level boundary conditions provide a context, arising ultimately from some primordial asymmetry in the environing system. I end by considering implications of another symmetry, between diachronic and synchronic perspectives, where immaturity maps to relatively small scale, and senescence is relatively large scale. From any observational scale, dissipation appears to take place mainly at smaller scales because of its relative rapidity there.

1. Introduction

This paper is concerned with the opening and maintenance of open systems as a general problem, and, as a consequence is necessarily abstract (but not mathematical). The Second Law of thermodynamics is involved. Its vicar in respect to non-equilibrium, open systems is the necessity for positive local entropy production (Prigogine, 1955) to accompany the work of organization and maintenance. Failing this, there could be no open systems, no definite locales.

Since we know that artificially isolated systems equilibrate in the direction of uniform, symmetrical distributions of dust and energy, the fact that objects and asymmetries exist in our universe means that it must be far from thermodynamic equilibrium. It is sometimes claimed that, since an open system need not experience a change in entropy at all (Prigogine, 1955), the Second law does not apply there. Furthermore, if the surrounding system (the supersystem) containing an open system were itself taken to be open, then one might claim that there would be no need to consider the Second Law at all anywhere. With respect to a universe like ours (which is my model), however, we must assume it to be isolated. This assumption is imposed on us at bottom by the empirical fact of the instability of all energy gradients on Earth

(Schneider and Kay, 1994), and by inference, that of other objects in the detectable universe as well. All of these show the effect of universal isolation -- somewhere out there -- in their basic instability. Everything is susceptible to the breakdown of its order, and as well (Salthe, 1990a) to an increase of disorder -- partly as variety -- in its surroundings. I will consider open systems as locales (asymmetries) within an isolated supersystem that has not yet equilibrated. Symmetry is not easy to define. I use it in three ways below. First, as a constancy above change, then as spatiotemporal uniformity, then as codirectional change. I take symmetry generally to be an absence of difference (see also Petitjean, 2003).

Theoretical Orientation

A major dynamical concept here will be the opposition between the processes of collecting and cascading (Salthe, 1993b) (or between centrifugal versus centripetal flows; Ulanowicz, 1997). In thermodynamics discourse this is often characterized as competition between gravitation and spontaneous energy dispersal, the result of which is a tendency to minimize free energy (Müller, 2003). I will assume a certain stickiness of matter as the basis for collecting. This stickiness can be parsed, in the context of a rapidly expanding system like our Big Bang universe, as the symmetry breaking sequence: quantum decoherence -> strong forces -> chemical bonds -> gravitation -> selection -> organization. This sequence is increasingly energy demanding (dissipative), and some of that energy gets embodied in the resulting matter, masses and forms as metastable energy gradients. The tendency of local development shown in this sequence is opposed by an equal, opposed tendency for energy gradients everywhere to be dissipated, which is entrained -- increasingly strongly as the overall system continues to depart further from thermodynamic equilibrium -- by a simultaneously expanding universal energy sink. Collecting (and all material stickiness) expresses the fact that, because of its acceleration (Kirschner, 2003; Seife, 2004), the expansion of the global supersystem leaves it rapidly disequilibrating (Layzer, 1977; Frautschi, 1982; Landsberg, 1984). That is, materialization, gravitation and collecting are aspects of the cooling generated by accelerated expansion, while cascading (which also affords some collecting by way of producing accidental collisions) expresses the global supersystem's resulting tendency, expressed everywhere within it, to equilibrate. It seems to me that one can take the relationship between the magnitude of the force of gravitation (as a vicar for all stickiness), and the strength of the Second Law, to reflect a large scale symmetry -- the implicit, virtual conservation of global thermodynamic equilibrium.

I will examine a generic, classical world of the above kind, wherein locales are contextualized by global tendencies like conservation rules and the process of global equilibration. There will be clouds of chemically active particles dispersed locally in a sea of even more dispersed particles, with few macroscopic configurations persisting for long. These clouds I will take to be remnants of more condensed forms because the expansion of the system has been decelerating, weakening the local collecting tendency and, consequently, the strength of the opposing global tendency toward equilibration as well. It will be the task of this paper to elicit the self-organization of local forms within this scene. That is, we will start with the overall supersystem heading towards global thermodynamic equilibrium, and a local system will attempt to bootstrap itself out of this unfocusing nirvana. Insight gained into this situation may provide clues as to how symmetry breaking might be propagated out of a classical thermodynamic equilibrium itself -- or not.

The Second Law of thermodynamics is here being expressed in the dissipation of the clouds, which, in contrast to their less dense surroundings, remain potential energy gradients. They -- and the particles they are made of -- came into being in the first place because the global system had been expanding faster than it could equilibrate, but now the expansion has been decelerating. With deceleration, the distance between maximum and actual configurational entropy has everywhere been declining, as local embodied information has been losing its ability to restrain system configuration and behavior (Salthe, 1990b, 1993a). Since the global system is not yet at equilibrium, all condensations would still be intrinsically unstable, even though in the decelerating regime the global tendency to equilibrate has also weakened. So, in order to survive, such condensations would need to produce entropy (Prigogine, 1980), which is to say that they would have to sacrifice some of their own density, some of their own being itself. This might be accomplished non self-destructively by differentiation -- by subdividing locales within a cloud, one region of a locale then being free during its development to cannibalize the necessary dissipation of the material density of its other regions. Such subdivision would be fostered by the development of a part of a locale, as described below.

Collections of particles represent order as well as energy gradients. They generate asymmetries. Particular instances of order and asymmetry, as momentary configurations, exclude other possible arrangements in their locale, and so they express information, which I take to result from an elimination of possibilities (Brillouin, 1956). Clumps express, and are de facto, informational constraints, and, to the extent that they are held in some configuration, are in that place reduced to information neat. Unfixed, they would instead (given material finitude) express informational entropy as they resonate / mutate from one adjacent possible configuration to another. That is, each local condensation, to the extent that it has become somewhat organized, would generate a characteristic configurational / behavioral entropy if there is still energy flowing through it. So, condensations and clumps represent order in the sense that one collection of potential configurations (I will call it a metaconfiguration) has excluded others that might have been there instead, by having established its own informational hegemony. These locales also necessarily establish asymmetries with respect to any other locales in the universe. At thermodynamic equilibrium such an energy gradient / asymmetry might, as a very rare event, condense momentarily out of energetic fluctuations, but the information it expresses would be expected, as a rule, to be lost again when its toehold on the world is damped out at the urging of the Second Law -- that is, in concrete terms, because the haphazard behavior of its surroundings would not provide reliable enough support for it.

At equilibrium all condensations have broken down, their particles having dispersed. The situation has reached a global symmetry in that there is no greater likelihood of a fluctuated condensation appearing in one locale more than in any another. I will not consider a deeper symmetry between locales when particles themselves have been resorbed into their waves in the quantum vacuum because I do not believe that the deceleration of universal expansion leading to the situation under consideration here would be as steep as the original acceleration that led to particulate decoherence and its sequelia. In view of evidence from many kinds of growth and expansions in the material world (Salthe, 1993b), a systemic decline could never be as precipitous as the originating, immature, impetus. The canonical developmental trajectory would be: rapid rise during immaturity -> brief maturity only in particularly stable systems -> slowing decline into senescence (Salthe 1993b, where I advance this terminology for general use, and see below). That is, on principle given what little evidence we have, I view expansions as necessarily being informationally irreversible. We can call this pattern Minot's Law (Needham, 1964). Furthermore, current views of the Big Bang have an inflationary phase at or near the beginning, but no deflation is proposed at the end. A model of self-organization similar in this respect to my own has only an initial "blow-up regime" (Akhromeyeva et al, 1989), with no sudden collapse at the end.

So, we will be concerned with a situation not very far from thermodynamic equilibrium. Clearly there would be two versions of that situation, one immature, the other senescent. The first is located within a relatively small, dense, hot, rapidly expanding supersystem, the second in a vast expanse whose density is gradually thinning. The immature situation is generic because the immense power of expansion entrains all other motion, while the senescent situation is gradually becoming generic because its locales have been losing their historically collected individualities. While the initial nonequilibrium situation is dominated by the impetus of expansion, which co-opts all fluctuations, in the senescent scenario local fluctuations -- it may be sometimes expressing a locale's informational entropy -- gradually come to dominate the dynamics more and more. Such a system has developed from being primarily global toward being dissected into locales, with the locales at the same time fast fading away. Both extreme situations are relatively symmetrical, but in different ways. In the first no unique configurations / perspectives have yet appeared as the expansion is uniformly nonlocal; in the second they are eroding with dissipation of the energies binding them. Very close to equilibrium, symmetry would also be signaled by nearly Gaussian fluctuations around some average of energetic excursions in any local sector. We will be concerned with a time somewhat before that.

Some Further Preliminaries

Three conceptual tools to be used in this analysis should be introduced here. I have already mentioned one of them -- (1) The canonical series of stages in the universal developmental trajectory (Salthe, 1993b): immaturity -> maturity -> senescence. Immature systems are relatively small, simple, vaguely embodied locales experiencing powerfully accelerated expansion and development while becoming organized by strong intrinsic (per unit mass) energy flows. They are "sleek", with little behavioral variety, and "hot" -- energetically inefficient, producing relatively large amounts of physical entropy per amount of energy gradient dissipated in their rapid construction. These traits buffer them to an extent against being deranged by external perturbations, a stability that is supported as well by their vague -- therefore easily reconstituted -- embodiment. Being vaguely embodied, they are also informationally relatively generic, and so capable of developing in many directions. Highly evolved examples like the early embryos of living systems contain internally stored (genetic) information, as yet unexpressed. This information will harness their further developments in quite particular directions, so that the potentialities for evolution implicit in their actual informational genericity does not get a chance, in this case, to be expressed.

In comparison, senescent systems are relatively large and complicated, with diminishing intrinsic energy throughput. Having been moving in the direction of increasing their energy efficiency, they have been minimizing their entropy production as a result of matching their external energy dissipation to their average energy supply rate (Prigogine, 1955). Their complication of form has made them more sluggish in response and repair time. Having developed and grown, they also make large, relatively elaborate targets for disruptive forces, and so, with their declining intrinsic energy throughput, they are increasingly susceptible to being deeply damaged by environmental fluctuations. In more highly evolved forms like living systems, this weakness is further abetted by their having become definitive for their kind, and so they have little flexibility, becoming increasingly stereotyped in their responses. The ultimate condition of a senescent system, should it survive long enough by having a supportive environment, would be in my view the machine state (Salthe, 1993b).

A mature stage in between the immature and senescent ones is found only in more highly evolved and stabilized systems. This is the period when living systems reproduce. The system has grown and become definitive for its kind. It has fairly powerful intrinsic, and gross, energy throughputs to put in the service of healing, escaping dangers and reproducing. In my interpretation (Salthe, 1993b), the transition from this to senescence is mediated by a continual inbuilding of informational constraints and establishment of information, leading eventually to information overload, expressed partly in a structural overconnectedness leading to functional underconnectedness, with its attendant lags in response time.

I have also alluded above to: (2) the scalar hierarchy, as in [supersystem [system [subsystems]]]. The levels here are typically nested spatiotemporally, as suggested in this bracketed representation, as wholes and parts. The action being analyzed would always be the system's (at the focal level), to which its subsystems would be contributing potential transformations and possible directions of change -- that is, possibilities that the system might do -- which I have referred to (Salthe, 1985) as 'initiating conditions' for the system's dynamics. These lower level dynamics have the bottom-up role of generating system activities. The higher level supersystem, or system environment, has the top-down role of disposing what initiating conditions propose -- that is, of selecting, by way of imposing boundary conditions on its dynamics, what a system may do. The system is, in effect, a mutual construct of its initiating and boundary conditions (as in an organism being viewed as a dialog between its genome and encounters in its ecological niche). With the self-organization of the focal level system considered as well (Andrade, 2003), we have three levels as the minimum required for explicit consideration when analyzing such systems -- which, indeed, include all material systems. This structure also importantly requires that new levels originate by interpolation between two others (Salthe,1985; 2004).

Then I will be using (3), the Aristotelian causal categories as well. These comprise

(a) the synchronic pair: material cause and formal cause. Material causes, like the initiating conditions of the scale hierarchy, generate susceptibilities, making actions or events possible, while formal causes mediate these into effects, not unlike the role of a higher level in the scale hierarchy. The roles of formal causes could be said to be encompassed in the form of an equation describing a system, as well as in the values of its constant parameters. There are, further (b) the diachronic pair: efficient cause and final cause. Efficient causes include triggers, perturbations and pushes that initiate an action or event, while final causes are affordances and attractors that pull the resulting effects (being mediated by formal causes) in certain directions, or to certain ends. Both of these roles could also be associated with the higher level in the scalar hierarchy, with final causes being in particular associated with mini-max principles (like the Second Law) and conservation rules constraining the system being described by the equation. So it could be said that formal causes determine the means by which something can happen (which in effect defines that 'something'), while efficient cause determines when it happens, and final causes pull or bias the effects in certain directions.

The Aristotelian system is more general -- not as spatiotemporally specialized -- as the scale hierarchy. Thus, the realm of chemistry could be said to be a material cause of biology, which in turn imposes formal constraints upon the chemistry. Then biology could be said, in places, to be harnessed to the ends of sociocultural systems, as via the goals of agriculture. One might also attempt a scalar analysis here, in that chemistry is always of smaller scale, with more rapid dynamics, than biology -- that is, if one insists that biology is not present, as such, at the chemical level. But, indeed, we know that macromolecules embody both chemical and biological principles. Also with cultural control over agriculture, we might insist that a society is necessarily of larger scale than any collection of barnyard organisms or crops, but this is forgetting that biology exists at several scales, as in [population [organism [cell [macromolecule]]]]. I use scale concepts when I wish to emphasize order of magnitude differences in spatial scope or dynamical rates, as one does, e.g., in the macrosystem / microsystem distinction in statistical physics.

Symmetry Breaking

My inquiry can begin with a suggestion made by Lionel Johnson (1988). He considered a system of chemical reactions at thermodynamic equilibrium. Reciprocal reactions would be taking place, with small cycles forming randomly here and there, but not surviving for long. Considering energy sources available on Earth for the origin of life, he noted the intermittence of sunlight. An energy pulse, boosting a locale from equilibrium to near equilibrium conditions, can cause delays in reverse reactions. Such symmetry breaking delays to equilibration could be maintained if the pulse was reiterated regularly, as it would be by the diurnal alternation of light and dark. This could establish a near equilibrium minimum entropy production regime that might have the ability to evolve. He concluded that symmetry breaking requires near equilibrium conditions, supported by regularly repeated, low level energy inputs. Intermittent energy flows are requisite because, with continuous flows, as many protosystems would be disrupted before they could stabilize as were created.

But the system to be considered here is not yet at equilibrium, so there would still be available energy gradients. Local entropy production in a denser region would be speeded up by its energetic fluctuations being more Cauchy-like around some modal value instead of Gaussian, providing some -- intermittent and rare -- powerful fluctuations that could motivate, as efficient causes, symmetry breaks. These would generate instances of focused local impetus, like, for example, convections and/or linking chemical bonds. These would have a material cause in steadily produced simultaneous small fluctuations, some of which could happen to support each other by occurring in the same direction at the same time. These latter would serve as Part A of the (then potential, poised) symmetry break, while the boosting powerful impetus already referred to -- its efficient cause -- would supply Part B. So we have: a near equilibrium sea of fluctuations -> two or more moderate ones accidentally supporting each other -> get boosted by a rare large dissipation event. Note, however, that in order to continue further, these must be supported by some larger scale boundary conditions as well, as I will discuss below. The difference here from Johnson's scenario is only that externally imported light energy is replaced by dissipation of energies internal to a system not yet at equilibrium. The system generated by the symmetry break, after a rapid development will soon begin to senesce.

An entire locale will have been energetically activated by the symmetry break. It would be larger than the nascent protosystem, but equally activated energetically throughout. Persistence of a developmental trajectory tends to separate its immediate place of embodiment from the rest of its activated locale. This would be the acquisition of polarity by the locale (or a distinction made -- Varela, 1979), declaring the developing section to be the germ, while the rest of the energized locale is available to support it energetically, as a kind of protoendosperm.

Higher levels

Material systems display configurational entropy, with a characteristic suite of states, which can be exchanged by common weak fluctuations, by adaptabilities, or as part of development as well. Especially for the here-relevant immature stages, because their states are not as precisely specified, more than one developmental system could have the same, or very similar, states (as in different melodies sharing the same simple phrase). This would increase the chances of stability of a fluctuated protosystem at a locale because it will likely have connections to, and could be entrained by, more than one activated developmental system (a structure, or potential system of transformations), which I refer to as a developmental trajectory, mentioned above. Many of these trajectories (all members of the same metaconfiguration -- Figure 1) would be liminally activated by the appearance of a common characteristic, early successional configuration. This redundancy in several possible developmental trajectories reveals the presence of intrinsic -- in this case, implicit -- larger scale boundary conditions. A metaconfiguration of trajectories is a virtual higher scalar level context, an informational armature for, and a formal cause of, system development. Its states are developmental trajectories, providing adaptabilities at a developing locale because the dissipative structure undergoing development will be able to resonate between some of them, as described below.

Figure 1 here

So, what we have now is an equilibrating supersystem with one or more energized locales. Each of these is differentiated into a metaconfiguration of potential developmental trajectories, at least one of which is activated, and a supporting energy source in the nondeveloping remainder of the locale. Thus we have four levels in a scalar hierarchy, the level in focus being an activated locale (materially, a dissipative structure) entrained by a developmental trajectory. This trajectory is part of a metaconfiguration of potential trajectories. And all of this is located as well in a surrounding equilibrating supersystem (Figure 1). Both the metaconfiguration and the supersystem make up higher scalar level contexts for the trajectory, which itself entrains the dissipative structure, its material cause. The dissipative structure's material basis makes up a fifth, lower scalar level of molecules and chemical reactions, some in simple cyclic patterns.

Development

Development is fundamentally driven by a continual acquisition of information by a locale. Occasionally the intake of information triggers a reorganization, allowing the system to accommodate yet more new information. Each reorganization leads to the embodiment of a next developmental stage. Since later stages of developmental trajectories, being more informationally constrained, are more definitely embodied, so developing systems would acquire increasing internal stability, demonstrated by a decreasing configurational entropy. This increasing embodiment results in an increase in the free energy of the developing portion of a locale (accompanying a decline in its thermal energy), a process somewhat like the nativization of a protein (Brooks et al, 2001). Configurations can be maintained by lesser energy flows than those required to produce them. What happens here is an exchange of the immature possibility of getting entrained by many different developmental trajectories in a metaconfiguration for commitment to fewer and fewer, these requiring less and less energetic support. This decrease in range of activity can happen because the more powerful fluctuations that would rejuvenate (and indeed began) the system are becoming rarer as the supporting portion of the activated locale continues to equilibrate. So we get an increasingly more definite system developing on the material basis of continuing frictional dissipation of its larger locale. It is potentially entrained by ever-fewer developmental trajectories (Figure 1). The system is becoming more definite by way of discarding 'evolutionary potential' (Salthe, 1990b, 1993a, 1998); its asymmetry has been deepening. It is as well moving toward a minimum entropy production regime. It has, however, gained a repertoire of definite alternate configurations (its informational entropy) that can be used to buffer it somewhat from more common moderate thermal fluctuations. But these fluctuations too are becoming rarer because the energy gradient of the locale has been getting used up. So, initially the protosystem was supported by a redundancy of potential developmental trajectories, giving it early stability. This was exchanged for a more definite embodiment, more resistant to the increasingly fewer large fluctuations in its locale, but less resistant to even rarer greater fluctuations. The locale has senesced.

Further evolution of this developing system could be triggered occasionally by now very rare powerful enough fluctuations that happen not be strong enough to destroy it (which, like the one that started it on its way, are very rare now). These might change the direction of its development. This new direction could be one that would not have been available to the original impetus, being characteristic of a developmental trajectory requiring more elaborated form in order to access. This could signal an incipient ‘evolution of complexity’.

Asymmetry

So, a rare large fluctuation could potentially create a symmetry-breaking definite local, far-from-equilibrium system -- an emergent locale in a region that has previously been becoming increasingly ‘isolated’ and symmetrical. The asymmetry of definite locality is then a sign of away-from-equilibrium conditions having been instituted. Such a system develops by increasing its information content as it becomes more definite, more complicated, and increasingly individuated. But eventually the system will be ‘on the way out’ as its local energy gradients are getting exhausted. Here is where the larger scale connections of the developing system, via its more general formal connections to other developmental trajectories in the same metaconfiguration comes into play.

I need here to emphasize the idea that without a higher scalar level, or some other source of stable boundary conditions, nothing can be recorded / regarded as having happened, no locale established. to make this point sharply, note that we are dealing here with models, and that some models can be cast as equations. Most equations have constant parameters, and, without having definite values for these, no solution can be forthcoming. While this may seem to be a trivial argument, we need to emphasize that what I am producing here is a play of logic harnessed to the construction of a model. All of science is launched upon model building, and the only justification for models can be logical consistency. If, as realists, we insist that our models reflect conditions in the world, then a consequence of this line of reasoning would be that actual larger scale systems need to supply constraints before anything can happen at any given smaller scale (Salthe, 1985). This fact of the logical necessity for context is important for our deliberations here.

We can note that, if it has been self-organizing, a locale would necessarily be carrying its own internal record of this fact (Matsuno and Salthe, 2002). A developmental trajectory is itself a record. This record would be entirely implicit and consists in the fact that any stage of development will imply (i.e., material implication, or conceptual subordination) the previous stage. That is, just as biology implies the presence of chemistry, so a developmental stage necessarily implies the prior stage that gave rise to it. This is because a developmental trajectory can be parsed into a characteristic sequence of stages (Salthe, 1993b). A jump back to an earlier stage, would require a larger than average energetic boost, and could then result in a potential mutation to a coordinate developmental trajectory of the metaconfiguration that goes through that same earlier stage. This is because a suite of potential developmental trajectories make up a tree, branching from the most general / vaguer immature stages in its trunk (Figure 1). At some level of energies, such rejuvenations must happen fairly frequently, resulting in an activated tree, with tentacles like those of an octopus -- a metaconfiguration “feeling” its way forward by way of the tips of its potential trajectories taking turns being evoked / occupied as a developing dissipative structure resonates between them, avoiding inhibition of its development by being pulled in the direction of a configuration allowing an increased rate of energy dissipation (Salthe, 2004) when faced with increasing frictional opposition.

Rejuvenation of a dissipative structure jumping to an earlier stage in a developmental trajectory by way of experiencing a burst of energy throughput would not increase its vagueness. Instead, the trajectory would gain only in generality. Because information in the natural world involves material marks, developmental change is generally informationally irreversible, converting what was a primal vagueness into an increasingly general situation as more branches have become accessed by a metaconfiguration, even after they have been subsequently abandoned. Material marks tend to be permanent. Informational erasure would consume exceptionally large amounts of energy, tending to deplete the energy supplies of an activated locale, but, after a period of development would in any case be very rare.

Thermodynamically reversible changes would be possible laterally, from one trajectory to another accessible one in the same metaconfiguration. Such lateral movements of a dissipative structure could open up new opportunities for finding the best way forward. “Best” here would involve projection of development as far as possible into a future, and so would be a search for greater homeorhetic stability. Such opportunities would become increasingly restricted as a system senesces. So, even without experiencing an energetic boost, a developing system might still move laterally (in this case reversibly) from one entraining trajectory to another, possibly more stable one. And it could even be possible that it might switch entrainment from one metaconfiguration to another potential, on average more stable one -- one which, again, had not been accessible from earlier stages. That is, our developing impulse might fall under the influence of less energy demanding developmental trajectories. Yet senescence is the ultimate final stage, and eventually overtakes all developing systems. Here it emerges as there come to be fewer accessible adjacent possible trajectories available in the senescent condition. That is, the developing system has lost flexibility, as well as most of its evolutionary potential -- to say nothing about its depleted energy supplies.

Now, each developing tip of a metaconfiguration tree, when occupied by a dissipative structure, might be considered an agent, and their behavior together over some period of time during which they were each visited by the dissipative structure, would function as a microsystem, whose activities over a period of time could result in an emergent macrosystemic configuration that could help support continuance of development by way of its slower rates of change, consequent upon its being of larger scale than the developing dissipative structure. Different from the entraining metaconfiguration, an emergent higher scale structure might be thought of as being like an extended phenotype (Dawkins, 1982) for any single agent. That is, each agent would have the ability to invoke it -- and could be thought of as representing it. Functionally it would be an affordance (Gibson, 1966) for the senescent stages of the developmental trajectory. So the microsystem here would then have given rise to a macrosystem, it being then a sixth scalar level in the overall supersystem, and a third higher scale level enveloping the developmental trajectory (Figure 1). This could happen only if the encompassing supersystem was configured in such a way as to allow for it, as all levels in a scale hierarchy emerge in between existing ones (Salthe, 1985; 2004) only on that condition. Higher scalar level contexts formally have stabilizing / regulating effects on the systems from which they emerge (Salthe, 1985), and so this extended phenotype functions as an armature supporting the search of the metaconfiguration to discover the most stable senescent stages among its developmental trajectories. The effect of this search is for the extended phenotype to diminish in scope as the system senesces, increasing its asymmetry as its reach becomes more restricted. By now, the more immature stages at the base of the metaconfiguration of trajectories would no longer be accessible. The developing system will have lost its primal support in a redundancy of many developmental trajectories that earlier could have entrained it, but has gained a more stable supporting higher scalar level framework for its more restricted endeavors.

Well, we have been exploring self-organization in a supersystem near equilibrium. Consider what would be the case as the global system continues deceleration so that the global equilibrating tendency weakens. The system is cooling, and so its free energy gradients available for work are declining. Stickiness would also weaken in this situation. It seems clear that, after a certain degree of deceleration the above scenario would no longer be possible. Energy gradients would be lower, generating fewer powerful enough dissipative fluctuations to promote an immature system, these fluctuations around the declining average of energetic bursts having moved toward the Gaussian pattern. However, previously generated, now senescent developmental trajectories might continue to survive in this more benign environment. After a while, however, even the weaker energy flows required for repair would become so rare that these systems must gradually dissipate -- even if now very slowly -- as well.

Considering now classical thermodynamic equilibrium, this condition assumes either an unbounded environment into which the supersystem is diffusing, or a smooth, uniform boundary after equilibrium has been reached. Any heterogeneity whatever in this boundary could afford asymmetries, informational constraints that could function as frameworks for launching self-organization by way of supporting an emergent locale, making potential some metaconfigurations, as in the above scenario. Therefore, to preserve a symmetry break in a system at equilibrium would require a prior asymmetry in the environment of the sea of fluctuations which could support it -- before there can be something, there must have been something else! In the non-classical case, the required heterogeneity could arise via some measurement process. Nevertheless, in order for a nascent metaconfiguration to thrive, it would of course need sufficient available energy, and this becomes the major sticking point at equilibrium inasmuch as we no longer have power law distributed fluctuations, but rather, Gaussian, with a finite, “smoother”, energy density profile, and no really extreme values in a long tail that would be needed to provoke the initial symmetry breaks.

Finally, self-organization in far from equilibrium situations like our own environment does not pose any special problem -- aside from the question of how a system was able to get to that far-from-equilibrium condition to begin with.

Another Symmetry

Considering a scalar hierarchical situation, we might fractionate its energy flows, parsing them into different scalar levels. Thus, a coal seam in a mountain can be viewed as being very far away from heat energy. Small lumps of coal in a pile near a furnace, on the other hand, have been brought closer, given our presence, to final dissipation. In a sense these lumps are more entropic than the coal seam in the mountain. But if these lumps were to become scattered over a wide geographic area, the energy contained in them would have once again receded from heat energy, yet they would still be more entropic, because more enveloped in oxygen, than the coal seam. As the coal burns, heat energy is liberated and diffuses into the energy sink. In order for this to occur starting from the geological coal seam, processes at several scales must take place. Ignoring the energy used in these processes themselves, we can observe, for sake of the argument, only the dissipation of the coal seam.

From a given scale of observation, as one increases the observed scale (or the observer diminishes in scale with respect to an observed energy gradient), one would find the appearance of ever slower dissipative dynamics. Indeed, if we keep increasing the scale of the observed gradient away from that of the observer, its dissipation would gradually seem to approach thermodynamic reversibility in the limit. That is to say, faced with a mountain of coal, energy flows eroding it would appear to cease altogether if we observers were small enough -- as indeed we are! -- with respect to it. Looking the other way, as we observe smaller and smaller scales (or the observer grows in scale), dissipation rates would increase. Heat energy is what we would call the final condition at the lowest relevant level for any observer, no matter at what observational scale. So, that which is larger than observer formally has relatively slower dynamics of change, and what is smaller has relatively faster accelerations (Figure 2). In this view there would ontologically, or internally, be but a single rate of dissipation at all scales, but relative to the scale of observer dynamics it may be slower or faster at other scalar levels. Thus, for an observer the size of the solar system, the dissipation of a coal seam on Earth might be palpably detectable, or even visibly fast.

Figure 2 here

So, from any given observational scale, dissipation would seem to take place mainly in the lower levels (the traditional microsystem). This fractionation of dissipation rates is one aspect of the privileged governance by higher scalar level constraints. Higher levels in any hierarchy govern, regulate, control, contextualize, inform, harness and interpret lower levels; this is the top-down function in a hierarchy. But it is at focal level that dissipations are viewed as originating. At the observer's scale, things will tend to fall apart, but can be maintained or renewed by work, tapping manifest energy gradients like (in our own particular case) sugar, oil, wood. The process of falling apart involves actions and events pushing in any directions whatever, unregulated by recognized local finalities. This same undirectedness is what we take to occur at any scalar level, and is the sense of Boltzmann's disorder concept (Salthe, 2003). Such an undirected flow of energies at the lowest relevant level -- for us, approximately that of molecular bonds -- is what we at our scale call heat energy, that which is officially designated for calculating the amount of physical entropy in our manifest world. The energies producing dispersion at all higher levels are measured quantitatively only as reflected at this entrained lowest relevant level, allowing us to compare all activities viewed by us as events, whether fueled by sugar or gravitational potential energy, using a single criterion.

Our scenario in this paper -- a supersystem nearing global equilibrium, with therefore relatively slow local dissipation rates -- was being viewed above in a diachronic, developmental perspective. But in the present framework this can be translated into a synchronic one. As viewed by an observer at a given scale, slow dissipation rates would characterize larger scale systems. These, therefore, are isomorphic to rates in systems nearing equilibrium -- that is to say, that are senescing -- while smaller than observer's scale systems would, in contrast to observation rates, be dissipating rapidly, and so would be interpreted to be far from equilibrium, or, indeed, immature. A microscopic situation at equilibrium would still be showing fast rates of change, but to no avail; the equilibrium is palpable only at larger scale. Here we discover a symmetry between scale and developmental stage. So our original scenario can be taken to be formally of larger scale than our perspective as modelers. Diachronically, our observed system would have grown as it senesced; what has grown has become large. So we see that the system we considered throughout this paper was, relative to us, of large scale, and we found that self-organization might take place there. On the other hand, immature -- or constitutively small scale -- systems would be dissipating so furiously that nothing of any complication could survive in them for long (unless maturation could save them). This would be the realm of abiotic dissipative structures.

Abiotic dissipative structures are statutorily immature (e.g., simple, thermodynamically hot), therefore formally they must be of small scale. So the observers reference scale for the likes of tornadoes and river eddies, if they are constitutively of small scale, must be a much larger system -- say, for tornadoes, of the scale of the earth itself. But such systems never survive to grow very large in our earthly conditions. Hurricanes might ‘aspire’ to attain the size of the Red Spot on Jupiter, but in recent conditions of energy flows on Earth, no such development has been possible for them. Instead they senesce rapidly and, lacking sufficient support, fall apart. And as tornadoes grow they become unwieldy, flounder and fall apart. In earthly conditions it is living systems, supported by their internal information cache, that are constitutively mature, and so may develop beyond a mere vague immaturity. Given their ability to survive long enough to propagate themselves in a mature stage, their reference scale -- we may surmise -- must fairly match their own observational scale. We, indeed, are our own classic observers! Following this train of thought, we can posit that senescent systems, like the one considered in the bulk of this paper, must have a relatively small scale reference system (Figure 2) -- one which, in addition, would be mechanistic. That is to say, machines, in contrast to immature systems, which are of small scale with respect to a supporting reference, must be large compared to their reference scale. (I define machines as the most fully specified objects there can be -- Salthe, 1993b.) We can justly posit that the reference scale for machines would be molecular. There is little doubt that science discourse has characterized molecules as mechanistic, as tiny machines (see almost any page in the journals Science or Nature). That is how they function in our theoretical systems. Most of them (leaving aside radioactive forms) are not viewed as developing or evolving, and, indeed, they are frequently taken to be the basis of material systems for the very reason that they are putatively so unchanging and stable.

A final point relating to the switch from a diachronic to a synchronic interpretation of a system is that in the synchronic view, whatever system is in focus formally must have a larger scale system as context (Salthe, 1985), to supply boundary conditions allowing it to have reliable enough background in order to self-organize (see also Matsuno and Salthe, 1995). In line with this, we noted above the presence of our developing system within a surrounding supersystem, which gave it its final cause for development in the Second Law of thermodynamics. Then there was the metaconfiguration guiding its development, providing both redundancy in immature stages and opportunities for both stability and evolution in the later stages. As well, there was also a higher scale supporting system generated by the developing system itself. Then we noted that unless the surrounding supersystem also had some initial heterogeneity, no self-organization could begin to occur within it anyway. Here we can add that a way to prolong a system's tenure in the world is to observe it from a significantly smaller scale than its own dynamics.

Conclusions: In the logic of models, symmetry breaking leading to sustained self-organization requires, in addition to an intermittent energy source generating power law distributed fluctuations, one or more stabilizing boundary conditions from scales larger than that of the dissipative structure that is developing. These could arise out of the activities of the developing system, but ultimately would have to be founded in some asymmetry in the surrounding supersystem. Such asymmetries make non-equilibrium locales immanent within the supersystem. Each developmental trajectory ends in a terminal senescence, which can be prolonged even if depending upon a declining energy gradient by being observed from a lower scalar level.

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Figure Legends

Figure 1: The various scalar levels involved in the dynamics discussed in the text. The linked elipses making up the developmental trajectories are stages of development. Their relative sizes suggest magnitudes of unused evolutionary potential. All the trajectories, meeting in the earliest stages, make up a metaconfiguration.

Figure 2: Scale and relative entropy production.

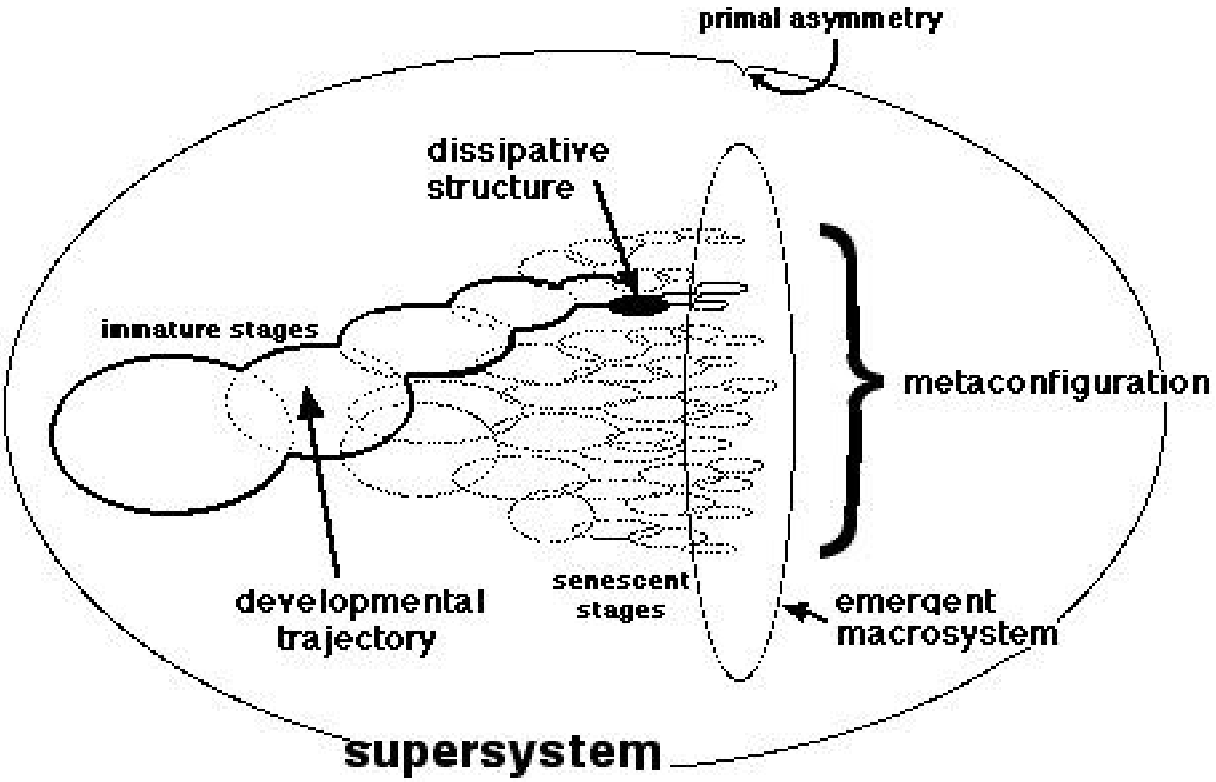
primal asymmetry
dissipative structure
immature stages
metaconfiguration
developmental trajectory
senescent stages
emergent macrosystem
supersystem

Figure 1

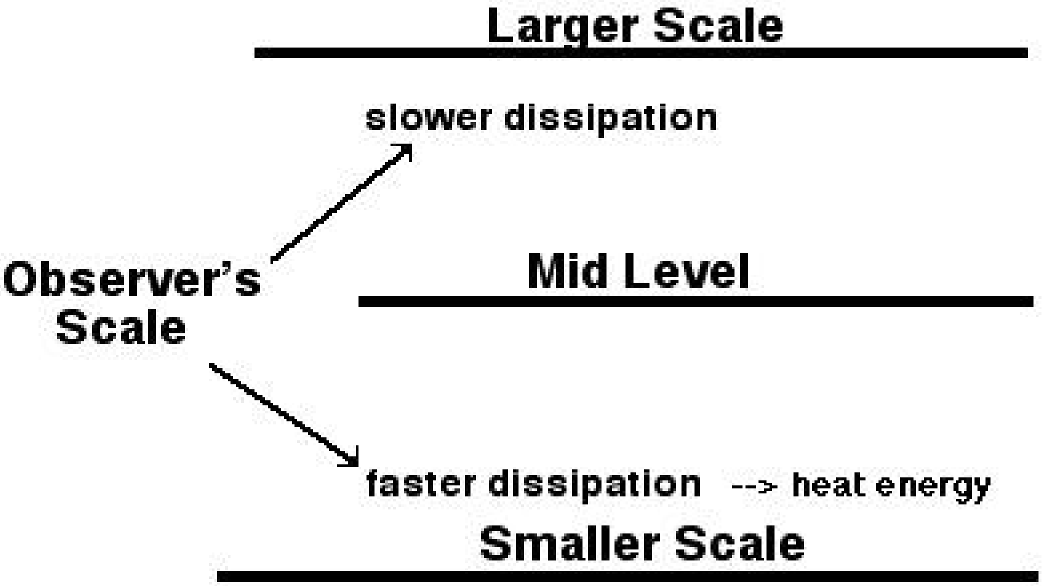
Larger Scale
slower dissipation
Observer's Scale
Mid Level
faster dissipation --> heat energy
Smaller Scale

Figure 2