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FORMAL CONSIDERATIONS ON THE ORIGIN OF LIFE

*You find in the very sands an anticipation
of the vegetable leaf
There is nothing inorganic.
H.D. Thoreau: Walden*

1. HIERARCHICAL STRUCTURE

It has often been proposed that the world has a fundamentally hierarchical structure (e.g., Alexander 1920; Shapeley 1958; Bonner 1969; Salthe 1985; Troncale 1985; Alvarez de Lorenzana 1993). The structure proposed is that of embedded parts and wholes, representable by scale-labelled classes called "levels", whose members are individual holons (part-wholes) of common scale. Scale can perhaps most easily be estimated from the magnitudes of the relaxation times of processes found at different levels. Size contributes as well in the sense that if something is small enough to be embedded in something else, it will be of smaller scale than the latter if their dynamics do not simply interact.

Because of these rate differences, entities found at each level are of characteristically different maturity (Margalef 1968) because it takes relatively longer to develop at higher levels of organization. As way of quickly grasping some essentials of the concept of maturity as used here, I will classify a few randomly chosen individuals. Immature individuals from different levels would include vortices in fluids (such as thunderstorms), icicles, geological formations. Somewhat more mature would be local ecosystems, embryos, social structures. Definitely at the mature end would be adult organisms, perhaps molecules and fundamental particles. Maturity refers to the most highly organized stage of development reached by any of these dynamic open systems during their development. The very largest individuals in the world are yet very immature and appear to us within them as unchanging, while a great many really tiny ones have already gone through their developmental trajectories, and are

going through them repeatedly, so that their most highly organized state is apparent to our experimental probes as a continual fabric. An implication of this perspective would be, for example, that protons are not very ancient as is currently thought, but are continually being destroyed and remade. Intermediate scale entities, like us, perceptibly traverse their developmental stages. Thus, the scale-defined classes represent radically different modal stages of maturity. At any given moment physical particles are mostly mature, while star systems are immature, and entities at the scale of organisms, say, icicles or

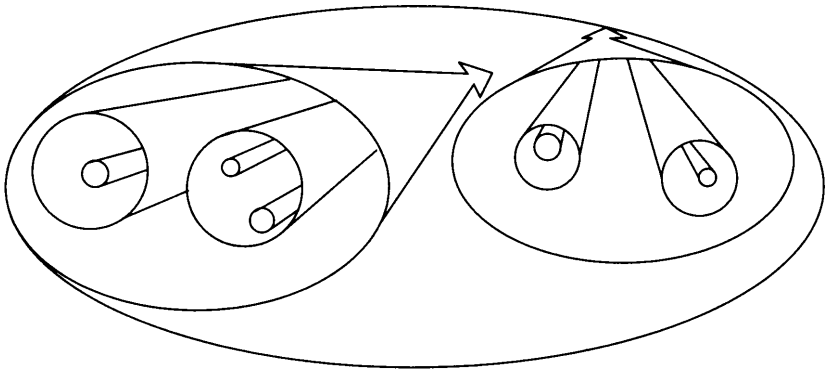


Fig. 1. Trajectories of different scale embedded within each other.

dust devils, occur at all stages because we observers share their scale.

Notice that this description indicates that the world is ordered in yet another way, separate from hierarchy. Most things in the world of every scale are developmental systems (hence the arrows symbolizing entities in figure 1). This means that they endure for a time and change in predictable ways, limiting the effects of perturbations to within a small range, if they survive them (Atlan 1981; Goodwin 1984; Williams 1985). Yet some perturbations leave their mark upon them, so that historical information also accumulates within them. For this reason, at least, individuals in the world are each unique, minimally in a small (perhaps for us undetectable) way. Physical particles do not appear this way to us because they are not with respect to the experimental criteria with which we detect them. Systems more highly organized than living ones may have their development curtailed by strong homeostatic capabilities. These would be machines. Entities of small scale relative to us have had lots of time to become so highly organized that developmental change hardly occurs in them. Among these might be found physical particles, perhaps mole-

cules – individuals so standardized by strong self-regulation that they do not seem to be developing at all. Their development in any case takes place so rapidly that whatever characteristics they have that differ in subsequent stages would be blurred for us by their molar effects. Machines produced by us as artifacts could be taken to be more highly organized than us in the sense of being more highly specified. Less is left open in their behavior, and a description of their ontogeny would have to include we organisms as part of the social system which is their womb.

At a certain scale – that which includes biological organisms – some sorts of individuals (living ones) incorporate a separate store of highly precise historical, linguistic information in their genetic apparatus. The degree of individuality achieved through this is orders of magnitude greater than that found in most other entities of whatever scale. This individuality is so great that it is preserved when these entities give rise to others, so that historical trajectories of this information are embodied in successive organisms replacing each other

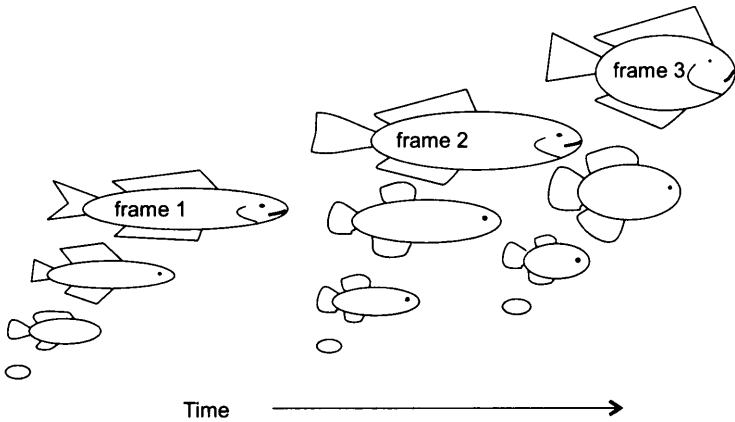


Fig. 2. A morphological trajectory of adult forms made up of sequences of individual ontogenetic trajectories. The latter show developmental changes, while the former show evolutionary changes. I am raising the possibility that the morphological trajectory simultaneously is a developmental trajectory at a higher scale.

in time, as in figure 2. This information is chunked to different degrees in genealogical entities of different scale, such as species, demes, genotypes. There is thus a hierarchy of genealogical entities paralleling those of developmental character with which they are associated. The latter dissipate some

of the energy flowing through them in replicating the unique historical information referred to here as genealogical information. The parallel hierarchy of developing entities has been called an "ecological or economic hierarchy" by N. Eldredge and S.N. Salthé (1984). Entities in the genealogical hierarchy evolve rather than develop inasmuch as the changes they do or do not record make up their sole significance, and they can become irreversibly altered by any of these changes without the ability to directly regulate away any of these alterations. Evolutionary change accumulates indefinitely (and as such touches scale only in a spatial sense) until the entity (lineage, species, genotype) carrying it becomes extinct. Associated economic-developmental systems can perhaps be taken to undergo an evolution as well if one compares successive ones (organisms, populations) as they replace each other over long periods of time, as the developmental trajectories in figure 2.

It is an interesting possibility that sequences of "time frames" of concrete individual organisms like those shown in figure 2, linked as in a film, actually do make up entities in their own right, separate from developing higher level economic entities (like the ecosystems and biogeographic regions of which they are parts), and separate also from standard genealogical entities (like genes, species and lineages) which are most of them characterized by the changing spatial extents and geographic locations of included species. What is shown in figure 2 is a sequence of *organisms*, and should not be taken to be a lineage. This problem has relevance to the origin of life since that usually is construed as a question of the origin of organismic organization. The criteria for discerning entities, discussed in Salthé (1985), are (1) distinctness from their environment; (2) limitation to a single scale range; (3) if with discernible parts, these covary over time.

Many planets scattered throughout the universe undoubtedly do not contain living systems. They nevertheless would show a hierarchy of developing ecological (energy dissipating) entities such as eddies, dust devils, thunderstorms, rock formations – for the most part of relatively ephemeral and uncomplicated form. In this paper the origin of life will be viewed as an interpolation of living systems within such systems. Thus, the presence of life does not in fact make the surface of a planet more complex [which is a function of the simultaneous occupation of given coordinates by physical systems that cannot interact because they are of different scale (Salthé 1985)]. It does, however, make a complex surface more complicated [which is a function of the stored information that supports the development of more highly specified (organized) forms of economic entities]. I suspect that a requisite degree of antecedent complexity is required before stable living systems can emerge (Cairns-Smith 1982).

2. ORGANISMS AND CELLS BEFORE LIFE: A REVIEW AND SOME COMMENTS

Sidney Fox and A.G. Cairns-Smith have for many years both been urging that the general organization of living systems preceded modern forms which utilize genetic information. Essentially this move attempts to emphasize the gradual emergence of living systems, making each step somewhat more easily visualized, and probably more easily mimicked in the laboratory. Genetic information in this view is assigned a role of permitting a vast leap in detailed specification of form and energy flow allocation, which may well have further permitted the emergence of previously dormant immanent potentialities (like intelligence). Indeed, in this view there is really no radically new property that appears with genetically informed life (Fox 1980, 1986), only a degree of complication that allows an immense intensification of uniqueness. [Philosophical attitudes related to this were previously expressed by, e.g., A.N. Whitehead (1929, 1933) and Sewall Wright (1964)]. Benchmarks in this version of the origin of life might include

- a cool dilute soup of organic chemistry;
- episodically "living" ponds utilizing inorganic catalysis (Ehrensverd 1960);
- clay organizations of biochemical activity (Cairns-Smith 1982);
- proteinoid microspheres of increasingly elaborate form and behavior (Fox and Dose 1972);
- eobionts with phospholipid membranes and mutually stabilizing proteins and nucleic acids.

The image of the origin of life generated by these scientists is that of a transfer of behavioral complexity from the environment to the first cells (Ehrensverd, Cairns-Smith), which rather suddenly appeared and then gradually became more complicated (Fox). In essence, pieces of the environment detach themselves from their surroundings, taking with them a selected biochemistry that allows them to continue to import environmental materials and to discard wastes. Once nucleic acid-guided protein synthesis has generated a precise control of uniqueness (Cairns-Smith's "genetic takeover" – perhaps the single most outstanding problem of general biology), the systems differentiate into various phyla exploring different ways of life. In all of this, immanent possibilities become embodied by the selective enhancement of certain biochemical pathways under the regulation of certain dissipative forms. The latter, as macrostructures, have not really been emphasized by these scientists to any significant degree, and I will undertake a sketch of their role in this paper. This is necessitated by the realization that the basic world structure is hierarchical (Salthe 1985; Corliss 1986).

Before leaving explicit consideration of this general research program, I would like to emphasize the requirement for hierarchical analysis by examining Sidney Fox's dialectic with his material (and often his critics) – because his laboratory was in fact the environment within which some microspheres have come into being. This is so even if some had also formed "naturally" well over three billion years ago, some of those being represented today by microfossils (Schopf and Walter 1983). In my "Evolving hierarchical system" (Salthe 1985) I note that three levels of organization (the "basic triadic systems") are minimally needed to represent any natural system – that in focus, the next level below, embodied by parts of the entities in focus, and a higher level representing the environment of the focal level entities. Processes generated by their lower level parts give rise to (or "initiate" focal level entities and their behavioral predispositions, while situations and events occurring at the higher level ("boundary conditions") control or regulate that behavior. The emergence of microspheres must follow this pattern as well. Inherent tendencies in amino acids, generated by their internal structure, result in various preferential linkages between them being possible. By surrounding them with certain environments, they are induced by Fox and his co-workers to engage in some of these behaviors, so that they form a proteinoid mass. Changing the boundary conditions, Fox can induce these to fuse, divide, incorporate materials and grow, etc. By diligently pursuing a program of providing the microspheres with various chemical inclusions (altering the initiating conditions within them) and with various environments (altering the boundary conditions impinging upon them) he has been able to make them mimic an astonishing range of behavior usually associated with living cells. By claiming that more than one combination of initiating and boundary conditions can give rise to the same results [a form of the systems concept of "equifinality" (von Bertalanffy 1968)], he has suggested that various properties of living system – even up to mind – are probably immanent in nature and were realized prior to the advent of nucleic acid-guided protein synthesis. Since many early microfossils look very like artificially fossilized microspheres (Francis et al. 1978), he has suggested that formation of these was in fact a stage in the generation of early living systems. The essence of the assertion here is that nature forms a system in which certain forms and behaviors are possible, and these will spontaneously occur given that they are released by appropriate configurations of higher and lower level causes. Some of the earlier moves in the direction of the origin of life would have required fairly generalized conditions, presumably easily reconstructed in a laboratory setting.

3. DISSIPATIVE FORM

The material world is molded by energy flow through thermodynamically open systems. This energy flow is dissipated in both heat and form. The forms generated depend upon the range of inner potentialities of the stuff being shaped and upon constraints imposed by surrounding boundary conditions, as well as upon the intensity of the energy flow itself, some forms not being achievable with a low intensity flow even if constraints would permit them to exist. The intensity of energy flow and the degree of complication of the constraints depend upon the relative maturity of the system involved. *Immature systems* are characterized by:

- relatively high intensity of energy flow (energy flow per unit matter),
- relatively small amounts of stored information (complication),
- relatively rapid change within the system (low internal stability),
- relatively high degree of stability to perturbations from the environment (easy recovery because of the intense energy flow).

These phenomenological laws have been distilled from R. Margalef (1968), A.I. Zotin (1972), J.P. Wesley (1974), A.I. Zotin and R.S. Zotina (1978). They reflect the necessity for an open system to move toward a minimum of entropy production as it approaches equilibrium (Prigogine 1955, 1980; Brooks & Wiley 1986). "Equilibrium" in this sense is not attained by any macroscopic system, but is approached as energy flow moves toward a low asymptote while stored macroscopic information (kinds and number of parts and/or the rules governing their behavior) simultaneously moves to an asymptotic maximum. [I am here assuming an isomorphism between thermodynamic entropy and informational entropy (Brillouin 1962) or, indeed, that there is a more general theory of which these are special cases].

That more general theory received its last general treatment at the hands of Charles S. Peirce at the turn of the century (see, e.g., Murphey 1967 for an introduction), but was further discussed in connection with developing biological systems by Paul A. Weiss (1973). In this theory, the world, and indeed any part of it, begins as a vague, unformed system, with much creative potentiality, and gradually differentiates into a more and more highly specified system with fewer and fewer degrees of freedom left over as more and more of its parts realize themselves as machinelike adaptations, as habits gradually replace uncertain moves and responses. A hierarchically organized system might look like figure 3. This classical developmental theory, however, does not include any discourse about rates, an aspect supplied by open system thermodynamics, as indicated above, which thus enriches the theory and also makes it more easily applicable to specific examples, as is appropriate in science.

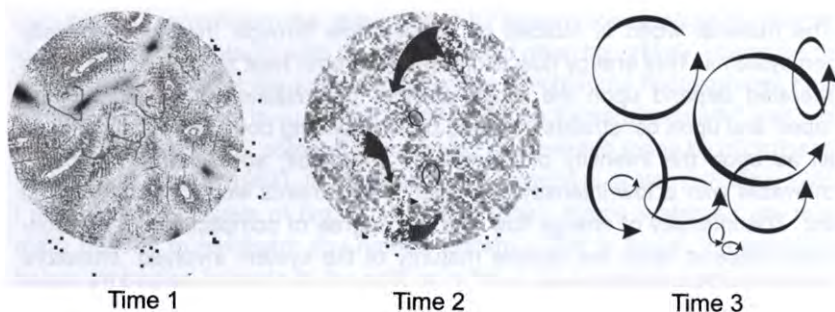


Fig. 3. A general picture of the development of a thermodynamically open system (adapted from Brooks & Wiley 1986).

As an example directed to the study of the origin of life, I will cite the emergence of the glycolytic cycle. Ch. Degani and M. Halmann (1967) found that glucose-6-phosphate in pure water decomposes spontaneously along several different lines. One of them was a rough adumbration of the glycolytic cycle. It is clear that, probably on the basis of "efficiency", living systems gradually teased forth the present glycolytic cycle by differential catalysis effected by genetically-coded enzymes, thus effectively suppressing all the other possible ways by which glucose might naturally be broken down. Hence, a vague possibility in the environment has been honed into a veritable biochemical machine within living cells. Since glucose-6-phosphate probably no longer occurs to any significant degree dispersed in the environment, this process is not even vaguely realized there; as living systems have become more complicated their environments have become simpler (Ehrensward 1960).

That would be true for microscopic (or lower level) aspects of the environment, but probably not for macroscopic ones. If anything, these will have increased in complication as a result of the development of living systems. A tropical rain forest embodies more complicated forms than does a prairie, while the latter has more stored information than a mud flat. "Information" as used here could be roughly measured by the number of statements it would take to describe a system (Chaitin 1975). Each statement would reflect one or more boundary conditions that might be imposed upon entities of smaller scale. While fewer in number, such dissipative forms would have been present in early "environments" as well. These would have included, as they still do today, various vortices in gases and fluids, like thunderstorms, eddies and

dust devils, as well as the rock formations and terrain irregularities that serve to elicit their formation.

Theories of the origin of life rarely mention these sources of organization for microscopic systems. Thus, water would tend to be channeled into stream beds. Deeper places in these would tend to form quieter pools with eddies. These could be the sites of Langmuir circulation such that globs of membranous structures made of phospholipid molecules would tend to form and sink to the bottom where they could coat clay formations containing a primitive metabolism. Such situations would be intermittently exposed to sunlight for only short periods of time because of overhanging ledges, thereby escaping dangerous amounts of solar radiations, which can break forms, as well as supply the energy for making them. The movement of the waters coming in from upstream carries in new reactants upon which metabolism depends as well as more clay particles, and also supplies a relatively gentle form of energy for mixing. We have the makings of a "living pond". Macroscopic arrangements of these kinds would have served the same function as Sidney Fox's laboratory serves today, and, indeed, the earliest microspheres had to have been elicited to form by just such macroscopic arrangements. Such arrangements, and sequences of them, would have been the sources of boundary conditions required for the early microscopic complications that everyone seems to agree would have been the beginnings of living systems. When in the nineteenth century it was realized that Friedrich Wöhler had synthesized urea in the laboratory, the idea of defining life as that which produced organic chemistry was dropped. It might have been noted that Wöhler and his laboratory was a (and part of a) living system! So, I would maintain, were the early streams and ponds. Organic chemistry is found, of course, in interstellar dust clouds, but these too must represent (or are the remains of) such macroscopic dissipative forms. I would think that a more powerful formulation would see it as if *the environment plus the chemical structures, clay and liquid crystalline forms, all together, made up the earliest living systems*. This was the major strength of Ehrenvärd's insight.

4. SELF-ORGANIZING TRAJECTORIES

We need now to focus upon particular dynamic systems rather than upon the constraints (higher and lower) that make them possible and regulate their behavior. As noted above, we find that there are two kinds of these among living systems (Eldrege & Salthe 1974) – the developmental/ecological and evolutionary/historical – that are intimately related by way of mutual constraint. Thus, populations, as economic-dynamic systems are informed by associated demes, which carry, in their genotypes, important genetic information concern-

ing the details of energy flow allocations. The populations allocate some of the energy flowing through them to the mating activities of *their* subsystems, the organisms that make them up. This results in the genetic information being replicated so that it can be retrieved by later populations, perhaps somewhat modified. Populations and their organisms develop and replace each other in time, demes and their genotypes may continue to evolve indefinitely, or may go extinct and be replaced by others.

The presence only of ecological/developmental systems can be projected back before the "origin of life". These are represented by macroscopic dissipative forms in any, even an abiotic, setting. In making this projection, it is most convenient to focus particularly upon entities at the same scale as organisms, since the latter (both single-celled and multicellular) appear to be the most highly specified (developed) kind of entities found among living systems. Yet we must realize that all other biological systems are necessarily associated with organisms – populations, ecosystems and so on – it is rare to find some without the others. Traditionally we have seen the origin of life as the origin of genealogical entities at the scale of genes, but this is a very narrow focus. In this paper I urge instead a more expansive view (see also the works of Fox and Cairns-Smith), one that I think will allow us ultimately to have a more precise perspective than the genetic that is being such a mystery to us at present.

First, we should note that entities of different scale will experience "coherent moments" (Salthe 1985) of different relative magnitudes. What this means to us here is, since organismic moments are enclosed within population-level ones, and these within ecosystemic ones, that proto-ecosystems must be thought to have begun before proto-populations and these before proto-organisms. Each consecutively higher level entity provides the context within which the next can emerge. Visually, one needs only to see a large vortical swirl differentiating by breaking up into several smaller ones (see figure 3). Since the rates at which events succeed each other at the smaller scale levels are relatively greater than that at the larger ones, lower level entities will tend to be more complicated than their environments. (That this doesn't *seem* to be the case below the level of organisms can initially be taken, as suggested above, to be an artifact of our own limited observational capacities).

Entities at any level can be viewed as self-organizing trajectories. Such trajectories through the material world, being thermodynamically open systems, show:

- (1) an increasing complication of systemic organization, in the pattern shown in figure 4,
- (2) a decreasing intensity of energy flow through them,

- (3) a related decreasing rate of internally driven change,
- (4) an increasing susceptibility to being severely perturbed or even destroyed by environmental fluctuations consequent to a decreasing homeostatic capacity following (2); self-organizing trajectories, however, go beyond these and also show
- (5) a (decreasing) capacity to incorporate significant historical information acquired from those perturbations not anticipated but survived (Atlan 1981); that is, they can be scarred or they can learn or they can evolve.

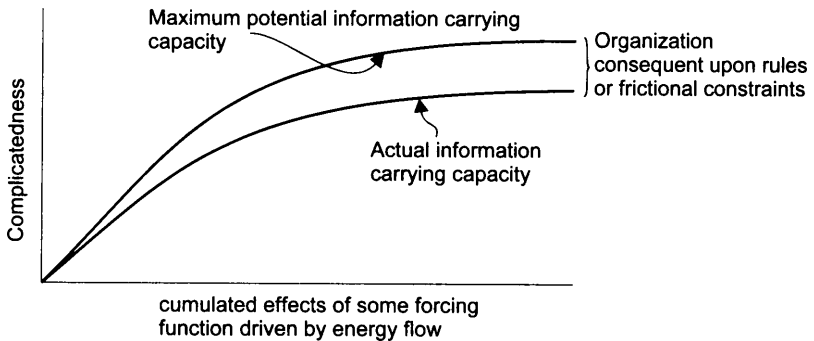


Fig. 4. A graph depicting some of the consequences of the development of a thermodynamically open system.

The latter ability has been intensified in living systems at the scale of organisms and larger by the acquisition of the organismic genetic apparatus. A major consequence of genes has been to facilitate evolution, the result of which has been to provide conditions intensifying (1), so that the economic activities of living systems have become separated into ever more finely dissected roles. Living systems at many levels of organization are further characterized by an immature period when they grow as well as differentiate.

Self-organizing trajectories begin as immature dynamic systems and increase their organization to varying degrees as they spin themselves out and mature. Being adaptable (Conrad 1983) they also incorporate information from the environment as a result of having survived unanticipated perturbations, and this information alters their detailed potentialities. They also may modify their environments to some extent, particularly when many of the same kind traverse it repeatedly. Benchmark stages known to be attained by self-organizing systems are shown as classes in figure 5. Self-organizing trajectories are shown as arrows in this diagram. All must begin at less highly speci-

fied stages, and some will work their way to more highly specified ones. Of course not all attain the most highly specified stage of autopoietic systems.

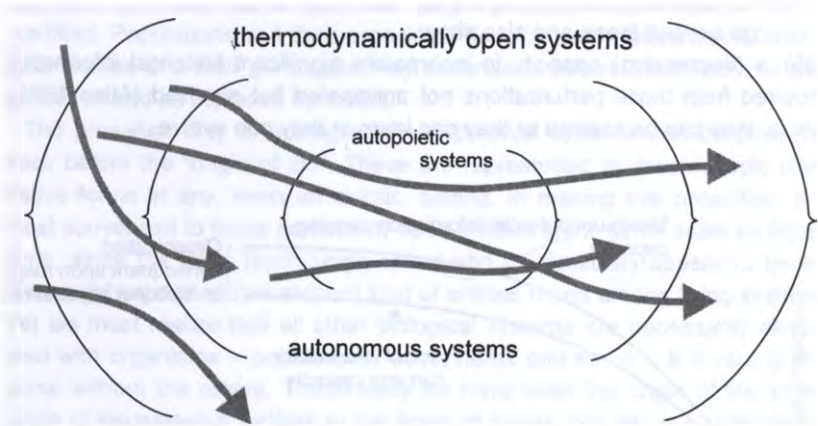


Fig. 5. Various states of different degree of specification open to physical systems represented as classes and subclasses, with self-organizing trajectories beginning at different degrees of specification and moving to more highly specified states during their development before returning to less highly specified states as they get recycled.

Only living systems, of those known to us, get so far. Thermodynamically open systems are those having an energy flow through them. Almost any natural dynamic system has memberships here, even the swirl of water in your flushing toilet or (Henshaw 1985) a drop of water on your windshield. Autonomous systems are those dynamic systems maintaining some kind of boundary, separating them much of the time from their environment (Varela 1979). Examples would be a particular stanza of a song, the Chicago Fire, Hurricane Alice, the Gulf Stream, the Pine Barrens of New Jersey, and the Mid-Atlantic Ridge. Perhaps the distinction between these two kinds is largely a matter of apparent stability to us, finite observers. Autopoietic systems are those autonomous ones that can make more of themselves, thus grow and in consequence reproduce (Varela 1979). Eobionts before the origin of the genetic code would be examples, also the "clay organisms" of Cairns-Smith (1982) and some of Fox's microspheres, perhaps also the "tenuous growth structures" of T.A. Witten and M.E. Cates (1986). Living systems are autopoietic ones made of proteins and nucleic acids, with the latter serving as a storage library for historical information of a linguistic character. These are the stages potentially attainable by self-organizing trajectories, which may be

either developmental and/or evolutionary. Machines may be the next most highly specified state (Weiss 1973; Wesley 1974).

5. AGENCY

In this section I will suggest that self-organizing trajectories, living or not, need to be further specified than they have traditionally been, as given above. To be able homeorhetically to reaccess a trajectory after perturbation requires that the self-organizing system has a viewpoint, a perspective preserved even in the face of thermodynamically necessary and historically contingent changes. That which does that and has this is an agent in the world. An agent is something that can personally act upon the world. It gradually acquires more and more personal uniqueness as it continues to survive and to incorporate the effects of perturbations it has met. Traditionally, agency has been attributed only to living or even conscious entities, but it is a quality separate from those. This quote from Hume (1739) suggests something of its nature in what is missing from it:

When I enter most intimately into what I call *myself* I always stumble on some particular perception or other, of heat or cold, light or shade, love or hatred, pain or pleasure. I never catch *myself* at any time without a perception, and never can observe anything but a perception.

Without this notion we could argue that as a tadpole becomes a frog it is becoming a new entity in the face of spatio-temporal continuity (and when is the change made exactly?) or that as species replace each other in a lineage we should keep changing its name because it is continually changing. (Note that it is being assumed throughout this paper that entities like ecosystems, species and lineages are individuals, not natural kinds or classes – see Hull 1978, Salthe 1985).

From the perspective of the origin of life, we need to set out what kinds of relevant agents there are. An organism represents but one kind. However, not *per se*, rather as part of an ontogenetic trajectory, such as suggested by the concatenation *ovum-embryo-tadpole-frog*, as suggested by Goethe and Richard Owen long ago (recall figure 2 above). The organism itself is an economic entity whose acts are confined to a given cogent moment of the existence of the population it is a part of (Salthe 1985). It is also a stage in a particular kind of self-organizing trajectory. Most obviously it is a stage in the ontogenetic trajectory that begins with the egg. But, as suggested above, it may also be taken to be a stage in the evolution of a kind-of-organismic-form, which may itself be taken to be an agent in the world (see Wake et al. 1983). Lack of recognition of this particular entity (similar in some ways to concepts in the \repu-

diated "idealistic morphology" of the nineteenth century) may have contributed, in evolutionary theory, to the alienation of that theory from studies of the origin of life. The "chronofauna" or "community type" (Olson 1966, 1983) or "community group" (Boucot 1975) is another self-organizing agent, represented at any moment in time by particular communities located at particular coordinates on the Earth's surface. A morphological lineage would be yet another, represented by coexisting sister species at any given moment in time wherever they are located. Spatio-temporal continuity in this case is not apparent to us because of the large scale of these entities. Thus, what we would see as a gradual movement to the northward of certain kinds of organisms in the fossil record, would take place in only a few moments at the scale of lineages, so that there would be fewer such moments than paleontological horizons in any given section.

In dealing with the origin of life, the self-organizing agents we have to deal with would be those that carry organismic form through time (a piece of one branch of which is shown in figure 2). And these would be made up of smaller scale ones – ontogenetic trajectories (also shown in figure 2) – just as lineages are made up of species, a kind of self-organizing agent in their own right, capable of spreading out in space and evolving in time. We could envisage self-organizing trajectories beginning with dissipative forms like dust devils and eddies, gradually acquiring more definition as they intensify their autonomy [note that in figure 5 above the classes are surely fuzzy sets (Negoita 1981) so that there can be degrees of membership]. Gradually they begin to increase their autopoietic capacities, and at some point they acquire nucleic acid record keeping. At this point we see the emergence of associated genealogical entities, like genes, genotypes, demes, species and monophyletic lineages. During its history, a trajectory carrying organismic form becomes more complicated because of the differentiation of its branches into further branches of different kinds, a process that is immensely enhanced by the origin of the genetic apparatus. That enhancement, however, because it leads to the storage of increasing amounts of information, also ushers in a senescent decrease in the rates of change within the trajectories, and also within the associated genealogical trajectories (see the phenomenological rules of thermodynamically open systems, above), so that the rates of evolution of both kinds slow down (Goodman 1978; Brooks & Wiley 1986).

In order to illustrate the kinds of primitive glimmers of agency that I have in mind, we can cast our minds back to prebiotic times and observe a windy valley. Occasionally dust devils spin up and move down the valley, regulated by its shapes so that many of them would show a meaningful average trajectory. Their aggregated activity itself modifies the substratum, revealing habitual

tracks of erosion. Occasionally one of these vortices emerges from the end of the valley propelled by stronger than average generating forces, and we see that it continues by inertia to make certain characteristic "gestures" resulting from its acquired structure. If we take statistics over many such cases we again find some average behaviors, but with much greater variance in the frequency distribution because the valley walls are no longer supporting their moves. During such short unsupported excursions the first tinges of agency would have appeared.

We can connect this illustration with more traditional versions of the early stages in the origin of life by noting that the dust devils could be, instead, eddies in a slow stream of water. These could carry reagents across a silted, muddy substratum covered by a layer of surface active clay material enclosing phosphates and iron-containing enzymes. This material was deposited on a substratum shaped by the eddies as well. It would be a long time before any intrinsic macroscopic motion would be acquired by descendant "living" systems, and they would consequently continue to be dependent upon macroscopic dissipative forms that are common in their environment, especially where these continue to move habitually over characteristic paths. Probably no activity found in living systems today (save templated protein synthesis) was not found less highly organized in these early, but much more splayed out systems. *The forces driving the eddies were part of the activity of those "living systems"*. Today's life forms are merely more compact at the organism level of scale, more clearly demarcated there from their environments.

The major new suggestion here is that we should pay as much attention to macroscopic factors involved in the origin of life as we have paid to the microscopic ones. Life is *not* quintessentially microscopic. Rather it is simultaneously realized at several levels of organization, and I am suggesting that it was so right from the beginning. As suggested by Hume's rumination above, that which self-organizes is not so easily located at any particular privileged level of organization.

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References

Alexander S. (1920), *Space, time and deity*, London: Macmillan.

Alvarez de Lorenzana J.M. (1993), *The constructive universe and the evolutionary systems framework*, appendix to: S.N. Salthe, *Development and evolution. Complexity and change in biology*, Cambridge MA: MIT Press.

- Atlan H. (1981), Hierarchical self-organization in living systems. in: M. Zeleny (ed.), A theory of living organization, New York: North Holland, Elsevier.
- Bertalanffy L. von (1968), General system theory, New York: Braziller.
- Bonner J.T. (1969), The scale of nature, New York: Pegasus.
- Boucot A.J. (1975), Evolution and extinction rate controls, Amsterdam: Elsevier.
- Brillouin L. (1962), Science and information theory, ed. 2, New York: Academic Press.
- Brooks D.R., Wiley E.D. (1986), Evolution as entropy. Toward a unified theory of biology, Chicago: University of Chicago Press.
- Cairns-Smith A.G. (1982), Genetic takeover and the mineral origins of life, Cambridge: Cambridge University Press.
- Chaitin G.J. (1975), Randomness and mathematical proof, "Scientific American" v. 232, no. 5, p. 47-50.
- Conrad M. (1983), Adaptability. The significance of variability from molecule to ecosystem, New York: Plenum.
- Corliss J.B. (1986), On the role of submarine hot springs on the Archean Earth, "Origins of Life", v. 16, no. 3-4, p. 192-193.
- Degani Ch., Halmann M. (1967), Biogenesis. Chemical evolution of carbohydrate metabolism, "Nature" v. 216, p. 1207.
- Ehrensverd C. (1960), Life. Origin and development, Chicago: University of Chicago Press.
- Elredge N., Salthe S.N. (1984), Hierarchy and evolution, "Oxford Survey of Evolutionary Biology" v. 1, p. 184-208.
- Fox S.W. (1980), The origins of behavior in macromolecules and protocells, "Comparative Biochemistry and Physiology" v. 67B, p. 423-436.
- Fox S.W. (1986), The evolutionary sequence. Origin and emergences, "American Biology Teacher" v. 48, p. 140-169.
- Fox S.W., Dose K. (1972), Molecular evolution and the origin of life, San Francisco: Freeman.
- Francis S., Margulis L., Barghoorn E.S. (1978), On the experimental silification of microorganisms. II. Implications for the appearance of eucaryotes in the fossil record, "Precambrian Research" v. 6, p. 65-106.

Goodman M. (1978), in: M. Goodman, R.E. Tashian, J.H. Tashian (eds.), *Molecular anthropology. Genes and proteins in the evolutionary ascent of the primates*, New York: Plenum.

Goodwin B.C. (1984), *Changing from an evolutionary to a generative paradigm in biology*, in : J.W. Pollard (ed.), *Evolutionary theory. Paths into the future*, New York: Wiley.

Henshaw P.F. (1985), "Proceedings of Social and General Systems Research" v. 1, p. 58-67.

Hull D.L. (1978), *A matter of individuality*, "Philosophy of Science" v. 45, no. 3, p. 335-360.

Hume D. (1739), *A treatise on human nature*, London.

Margalef R. (1968), *Perspectives in ecological theory*, Chicago: University of Chicago Press.

Murphey M.G. (1967), *Peirce, Charles Sanders*, in: *The encyclopedia of philosophy*, v. 6, New York: Macmillan.

Negoita C.V. (1981), *Fuzzy systems*, Tunbridge Wells: Abacus Press.

Olson E.C. (1966), *Community evolution and the origin of mammals*, "Ecology" v. 47, p. 291-302.

Olson E.C. (1983), *Evolution or coadaptation? Permian-carboniferous vertebrate chronofauna*, in: M.H. Nitecki (ed.), *Coevolution*, Chicago: University of Chicago Press.

Prigogine I. (1980), *From being to becoming. Time and complexity in the physical sciences*, San Francisco: Freeman.

Salthé S.N. (1985), *Evolving hierarchical systems. Their structure and representation*, New York: Columbia University Press.

Shapley H. (1958), *Of stars and men*, Boston: Beacon Press.

Troncale L. (1985), *On the possibility of empirical refinement of general systems isomorphisms*, "System Research" v. 2, p. 43-84.

Varela F.J. (1979), *Principles of biological autonomy*, New York: Elsevier.

Wake D.B., Roth G., Wake M.H. (1983), *On the problem of stasis in organismical evolution*, "Journal of Theoretical Biology" v. 101, no. 2, p. 211-224.

Weiss P.A. (1973), *The science of life. The living system*, Mount Kisco NY: Futura.

- Wesley J.P. (1974), *Ecophysics. The application of physics to ecology*, Springfield IL: Thomas.
- Whitehead A.N. (1929), *Process and reality. An essay in cosmology*, New York: Macmillan.
- Whitehead A.N. (1933), *Adventures of ideas*, New York: Macmillan.
- Williams G.C. (1985), A defense of reductionism in biology, "Oxford Survey of Evolutionary Biology" v. 2, p. 1-27.
- Witten T.A., Cates M.E. (1986), Tenuous structures from disorderly growth processes, "Science" v. 232, no. 4758, p. 1687-1612.
- Wright S. (1964), Biology and the philosophy of science, "The Monist" v. 48, p. 265-290.
- Zotin A.I. (1972), *Thermodynamic aspects of developmental biology*, Basel: Karger.
- Zotin A.I., Zotina R.S. (1978), Experimental basis for qualitative phenomenological theory of development in: I. Lamprecht, A.I. Zotin (eds.), *Thermodynamics of biological processes*, Berlin: W. de Gruyter, p. 61-84.