

Toward a Natural Philosophy of Macroevolution

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Abstract This paper understands macroevolution from a general perspective focused upon energy and thermodynamics. Its biological perspective is ecological, more particularly regarding energy flows. The basic image is the spontaneous dispersion of energy gradients, which, while microscopic, entrains and enables the hierarchical organization of material systems, including the living. The paper will deal with the philosophy of development (involving final cause), the dissipative structure concept, the maximum entropy production, and maximum power principles. The origin of life was the origin of detailed informational control of energy flows. Key processes in organic evolution relating to energy flows were the tendency to generate a plenitude of ecological niches, as well as the evolution of endothermy, involving increases in both the size and complexity of organisms. Organisms serve the universe by serving as exemplary channels speeding up the dissipation of energy gradients. In my perspective, the course of human evolution can be understood, not as being a goal of organic evolution as such, but as entrained by a universal development toward thermodynamic equilibration.

Keywords Development • Dissipative structure • Diversity • Ecological niche • Energy flow • Entropy production • Hierarchies-subsumptive • Compositional

1 Introduction

Natural philosophy is an attempt to construct a scientifically based ‘big picture’ understanding of the world. It attempts to synthesize understandings gathered from any and all of the specialized sciences. Its epitome was FWJ Schelling (1775–1854), with his global developmental model (Esposito 1977). Natural philosophy projects—both directly and indirectly—a culture’s vision of the universe,

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and suggests a role for humanity in that picture. Using the ethnographic definition of ‘myth’ as generative stories that are believed, we can see that natural philosophy elaborates a myth (Salthe 1992, 2004a), in effect directly challenging religious myths.

Natural philosophy lost its place as an avowed discipline around the end of the nineteenth century, when science began to become largely entrained into supporting engineering, medicine, and technological advance. Individuals, especially some philosophers (e.g., Peirce, Whitehead, Buchler, Bunge), continued to contribute to natural philosophy, while some scientists, capping off their careers, contributed as well (Duhem, Einstein, Elsasser, Monod). My own approach emphasizes thermodynamics as a unifying science in a world that is capable, as well, of being modeled using hierarchical structures (Salthe 2007, 2012). My objective with regard to natural philosophy is to display biological evolution as an aspect of cosmic evolution.

2 The Energy Flow Perspective

In a joint paper with Eldredge and Salthe (1984), I opted, as a materialist, to focus upon the energy connections in the world, as contrasted with the more idealistic information perspective that has dominated biology since the middle of the twentieth century. This necessarily means that my outlook was, and is, ‘ecological’ inasmuch as ecology is at base the study of energy flow relations taking place on earth between the influx of solar radiation and its reradiation into space (Lotka 1922; Kleidon 2010). This perspective was most fully presented by the Odum brothers, between Odum (1971) and Odum and Odum (2000). Of course, it is information that channels most energy flows in the world, but my focus is upon the flows rather than the informational constraints.

Information regulates the flows of energy everywhere that matter exists, either as spontaneous configurations (crystals, river drainage systems) or as organizations (dissipative structures including the living and machines) (Bejan and Lorente 2006, 2013; Bejan et al. 2008). Even when not guided by forms, energy will flow, as in diffusion and wave front spreading, and so it will have been taking place even before gravitating matter appeared in the universe. Energy flow is the change that is the source of all other changes, including biological evolution, as energy disperses away from regions of higher concentration (Annala 2010; Annala and Salthe 2010). Energy dispersion is everywhere spontaneous, and everything of interest in the world emerges from tapping into that dispersion, temporarily diverting some of it into forms of every kind, as demonstrated, for example, in the records of macroevolution. I note that energy dissipation is logically prior to its capture in events and by processes—that is, it is spontaneous, entraining everything that occurs.

What is energy? It is that which, when gathered together, emerges as matter and which scatters about when matter dissipates, which it tends to do. Everything

emerges from energy flow by tapping into that flow and extracting a small portion for work (the exergy), leaving the rest (heat energy) to disperse as entropy. Thus

$$\text{available energy} \rightarrow \text{exergy} + \text{entropy}.$$

Entropy can be visualized as undirected particle motion, causing particles to gradually disperse and slow down as their local situation cools. Heat is the rapid motion of locally concentrated particles. So energy is basically a microscopic concept, but its flow can result in organizing meso- and macroscopic forms at many scales, including living systems and their constructions (Gladyshev 2006; Salthe 2007).

3 The Larger Framework

What is needed here are a few lines to orient us in the bigger picture—which is required because energy is integral to that picture and because the big picture is naturally the focus of natural philosophy. Before there was gravitating matter in the universe, it is hypothesized in the big bang theory to have been energy in a universal quark-gluon ‘soup,’ followed by an expanding matter-radiation ‘soup,’ followed by the formation of stars and galaxies, pulled together by the gravitational attraction that was emergent with baryonic matter. In one galaxy, the sun and its planets formed. We can use a subsumptive, or specification, hierarchy (Salthe 2012) to make a general summary, modeling successive originations of modes of being, or integrative levels, as subclasses, as follows:

$$\{\text{physical realm} \rightarrow \{\text{chemical or material realm} \rightarrow \{\text{biological realm \{etc.\}}\}\}$$

displaying what one might call the really ‘mega’ aspects of macroevolution. From each realm that is more generally present in the universe (the outer brackets), more highly specified realms will have originated in particular locales by way of the addition of new informational constraints. The more primitive realms remain in place, making possible and supporting the more derived ones wherever these occur.

The biological realm may have emerged in only one locale in the universe. As a general scientific perspective, that seems rather unsatisfactory, and the discipline of the origin of life studies takes, the view that life is funded upon just another phase of matter, and so we should eventually be able to duplicate its origin in vitro. However, implicitly mitigating this view is our understanding of the elaborate mechanisms of the genetic system. It is this system that makes life possible. It is so complicated that no single spontaneous ‘origin’ as such seems plausible, but rather—given that this *was* a ‘spontaneous’ event—a long concatenation of happenstances in special, perhaps unique, environments (Salthe 2009). That is to say, here we are dealing with history. The origin of the genetic system is basically unknown, likely unknowable. It was, in effect, the origin of informational control, of machinery, and of digitality as well, and it requires a semiotic perspective to

understand it (Pattee 2007; Barbieri 2011). Prior to that origin, all energy utilization resulted only in mass action. After it, by way of the genetic apparatus, mass action supports a piecemeal linking of molecules in an orderly manner, resulting in the generation of highly specific catalysts (enzymes). This difference is physically enormous. Life adds to the list of constraints that could characterize a locale, informing activities that may take place there. These constraints include generally various boundary conditions—temperature, roughness, etc., as well as the chemical affordances. Genetics adds technique!

4 Subsumptive Logic and the Philosophy of Development

Subsumptive logic can be succinctly shown in the following hierarchy (Salthe 2012):

{physical world {chemical world {biological world {social world}}}}

In words, this might be summed up (paraphrasing G.G. Simpson) as ‘physics is the science that applies to everything, while biology is a realm to which all the sciences (to the left of it in the hierarchy) apply.’ Given a particular format like this, our ideas become entrained in certain directions. The logic of a phylogeny requires, if it is taken to provide a model of biological evolution, that refinement is the basic process at work through time. Materially, this means that new kinds are formed by way of the addition of new, modifying, informational constraints and new information (which may cause loss of form as well as its modification). Thus, reptiles are, logically, more highly specified amphibians and birds more highly specified reptiles—and so birds are also more highly specified amphibians. There can be nothing radically, *totally* new. Everything has a precursor; nothing can come from nothing. This is a materialist as well as a developmental principle. (This ‘developmental’ point is a challenge for evolutionary biology, which has denied any developmental tendencies in biological evolution.)

I have argued (Salthe 1993) that the basic logic of development *as a kind of change* is refinement and that evolution, as a kind of change (not as the label for that particular example, organic evolution), is without logic. By this, I mean that evolution is just the willy-nilly accumulation of marks from the effects of fortuitous encounters with unfamiliar situations. Darwinian adaptation is a purely opportunistic ‘grasping at straws’ and could never be planned logically. Note that any example of development will also ‘evolve’—that is, a developing system will *individuate* by accumulating accidental marks. In biology, these can sometimes be registered in the genetic system (Jorgensen 2011; Shapiro 2011) and may then be passed along as part of the, now changed, genetic heritage of a lineage.

This idea that development is fundamentally a process of restriction (or refinement) is not a claim that there can be nothing new in biological evolution (assuming here that evolution is basically a developmental process); any modification would trivially register something new. Locally, within an evolving clade, a

changed form could present the possibility of opening up new opportunities for resource exploitation. But each opening necessarily closes off other possibilities that might have been explored instead. This is better appreciated by stepping back and examining a larger chunk of a phylogeny. Thus, bird evolution has precluded the possibility of a fossorial life—despite some digging out of nests and the kakapo’s burrow. This adaptive zone is being explored in most regions by other vertebrate clades, such as amphibians (caecilians) and mammals (moles, mole rates, etc.). Thus, while the more detailed picture shows openings up into new Hutchinsonian niches (the niche of a given population, Salthe 2001), the larger picture shows a gradual closing off of lifeway possibilities (Eltonian niches—general life ways, like, say, the cat way of life) for each lineage. Then, local evolutionary openings are into increasingly more restricted (more highly specialized) possibilities (Fig. 1). As local diversity increases, global disparity increase stalls. This general pattern, like any, will have exceptions and would, of course, be nullified by catastrophic extinction events, which tend to ‘reset’ an evolving system. We humans appear to be one of these exceptions.

By mapping numbers of species to information theoretic concepts, Brooks and Wiley (1986) produced a general interpretation of biological evolution that is concordant with the present view. In their view—and the record shows that—the variety (informational or Shannon entropy) of biological kinds increased rapidly early in evolution, with a subsequent gradual decline in the origination of new kinds continuing onto an asymptotically declining future (Fig. 2; see also, e.g., Vermeij 1987, Fig. 13.1). Viewing the biosphere as a pool of informational variety, or

Fig. 1 General view of Hutchinsonian ecological niches through geological time, based on developmental logic

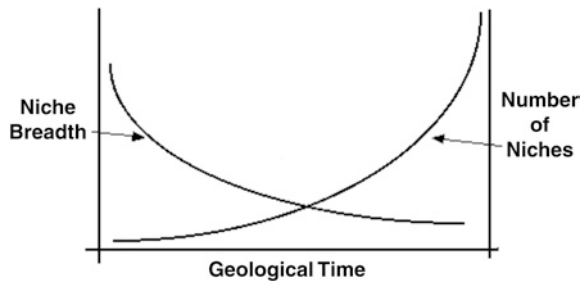
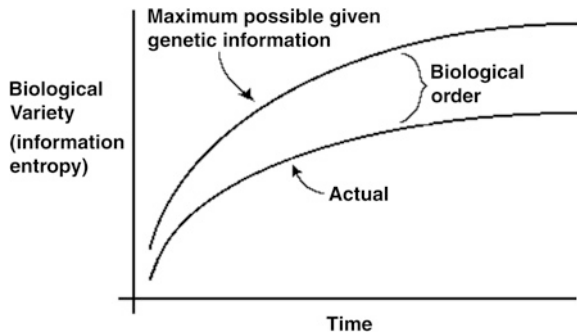


Fig. 2 The evolution of biological information, based on Brooks and Wiley (1986)



‘disorder,’ Brooks and Wiley represented generic and specific biological forms as embodying a degree of order compared to the informational disorder that would be the case if there were no individuated biological *kinds* and instead only masses of individuals of every possible form. That is, the order in biological kinds represents less disorder/variety than might be maximally possible given the coding possibilities of the genetic information held in living systems. Maximal disorder here is being conceived as the complete expression of all genetic information, while order would be represented by the larger than molecular bodies making up the various specific kinds of actual living things as based on the species-specific portions of genomes. Brooks and Wiley note that, overall, the variety of definable biological kinds has increased over time, expressing informational entropy increase.

From the ecological perspective, it is easily understood that variety of biological forms also represents a variety of Hutchinsonian ecological niches (Fig. 1). It also therefore reflects the variety of sources and modes of utilization of energy gradients. Biological variety can continue to increase over time in part because biological kinds themselves generate new ecological affordances. The ‘actual’ curve in Fig. 2 increases in a diminishing returns pattern. This rate of increase diminishes over time because, even though the universe appears to be expanding, the earth is finite. As well, the energy efficiency of the capture of incident solar energy by photosynthesis is quite low—around six percent—representing a kind of ‘rock-bottom’ constraint, and there is no reason to suppose that it could increase over time. As well, the more kinds that exist, the more will tend to go extinct at any time.

5 Dissipative Structures

The world in which evolution occurs is not at equilibrium in any aspect. This means that energy flows are maintained everywhere all the time. This might refer to the slow, steady expansion of a high-pressure region of the atmosphere driven by solar insolation or, more dynamically, the flow of ocean currents called for by the tendency for energy (here temperature differences) to even out. But, at smaller scales, everything dynamic, from thunderstorms to dust devils, from schools of fishes to individual organisms, are in more or less constant motion—in some cases with organisms, even (internally) while ‘at rest.’ These individuated active systems, from a flame to a hurricane, are examples of ‘dissipative structures’ (Prigogine and Nicolis 1977; Prigogine and Stengers 1984). Nothing that moves is not either a dissipative structure, or part of one, and often both, with one dissipative structure nested within another. Simple spontaneous types at meso- and macroscopic scales are waves, vortices, and branching tree forms like lightning. At the chemical scale, dissipative structures would be continually maintained exothermic pathways from substrates to end products, while endothermic reactions would be nested within exothermic ones.

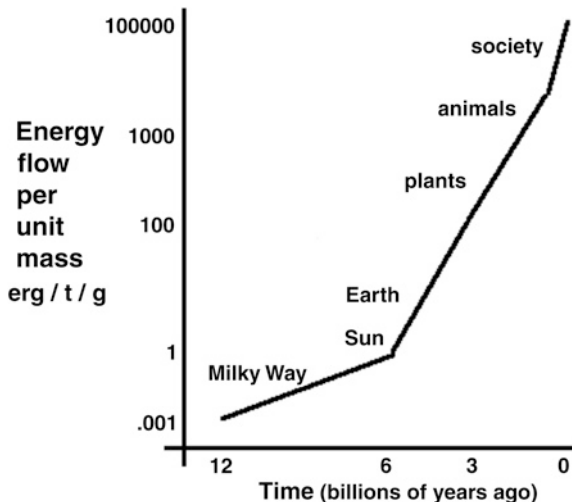
Dissipative structures appear when energy gradients become too steep to be significantly degraded by gradual heat conduction. At that point, they emerge as

convective forms of various kinds as allowed by local conditions (Schneider and Kay 1994; Salthe 2007). The processes of life's origination—that is, the origin of the genetic system—will necessarily have occurred within dissipative structures. Some of these dissipative structures will have developed later at several scales into living cells and organisms, being captured by 'genetic takeover' (Cairns-Smith 1993). The viewpoint of this paper is that living things as we know them are internally informed dissipative structures (Wicken 1987). This means that they are especially stable and can 'skate across' gaps in energy supply that would lead to the dispersion of abiotic dissipative structures. The energy supply for this stability is internally stored ATP, which would, of course, need to be regenerated. Living systems have internalized their primary energy source as well as the (genetic) source of their actual forms, which relate appropriately (adapt) to particular environments.

Current discussions of dissipative structures have been centering on the maximum entropy production principle (MEPP; e.g., Annala 2010; Kleidon 2010; Martyushev 2013). As I put it in 2010, 'an energy dissipative system that can assume several to many conformations will tend to take up one, or frequently return to one, that maximizes the entropy production from the energy gradients it is dissipating—to a degree consistent with the system's survival.' The latter qualification is required because literal maximization—an explosion!—would destroy the system. MEPP is a universal, global principle, on the reasonable supposition that our universe is a thermodynamically isolated system, thereby being subject to the second law of thermodynamics. How this cashes out locally is by way of the maximum energy dispersion principle (MEDP). Local energy dispersion will eventually result in the production of heat energy (entropy), but much of it immediately would be in the form of various waste products (imagine the feeding of a shark). In living systems, energy dispersion is produced by work; the faster/harder the work, the more of the supporting energy gradient gets dispersed as heat energy. Living systems are always, with intermittent rest periods, striving in one way or another; and while at rest, energy continues being used for healing. MEDP, then, refers to energy gradient dispersion by non-equilibrium systems such as organisms located within an out-of-equilibrium, thermodynamically isolated system (the universe) which elicits MEPP as an expression of its tendency toward thermodynamic equilibrium known as the second law of thermodynamics. Local MEDP serves global MEPP.

In the ultimate macroevolutionary perspective, Chaisson (2001, 2008, 2012) has shown that evolution (cosmic, biological, and technological) has produced systems that depend upon, and produce, greater and greater intensities of energy flows through them (Fig. 3). Energy throughput per unit mass is known as power. In dissipative structures, this power is the source of the energy (the exergy) that organizes and maintains them. In social systems, we are used to referring to this portion and that expended in various projects, as supporting 'work,' and I think we can safely refer to the portion used by living systems to maintain and reproduce themselves as work as well. I would further extend that usage to all dissipative structures (Salthe 2010a)—thus, tornadoes work hard at destroying houses.

Fig. 3 Energy flow intensity in selected entities through time. Redrawn from Chaisson (2012). erg/t/g is ergs per unit time per gram weight



An extremely curious fact about our world on earth is the constitutively poor energy efficiency of any effective work, which is never better, with significant loadings, than 50 % (Odum 1983). There has been no explanation of this known to me (Salthe 2003). However, if we consider ourselves, and all dissipative structures, to be part of the universe, we could see that all the multiple works manifesting this poor efficiency are activities *of the universe*, working through us, in its project of universal thermodynamic equilibration. This perspective (see also Martyushev 2013) is uncongenial to our fundamental cultural outlook of human individualism. On the template of the following subsumptive hierarchy (Salthe 2013), which would be in effect anywhere on earth:

{physical world {chemical world {biological world}}}

showing how some realms of nature, modeled as classes and subclasses, relate to each other logically, we have

{entropy production {free energy dissipation {work}}}

That is, work is a mode of free energy usage, which in turn is a mode of entropy production.

The line of reasoning in the previous paragraph is not ‘scientific.’ That is, it has no relation to the motivations for most scientific investigations or to the world view of the subsequent reports. It is concerned with the possible *meanings* of scientific knowledge, which is, in fact, the province of natural philosophy and of this paper.

We may ask: are species dissipative structures? No. What about populations? As parts of local ecosystems, possibly. Species cannot be said to be active agents in the ecological world. My current view is that species are essences, meaning that, as such, they have no dynamic ecological role, which is carried out instead, and not always identically, by local populations. Insofar as they are causal entities, species are coded scripts in DNA within cells. The essence of this would be that

small portion of the script carried by every member of the collection of organisms making up what we discern as a species *and* by no member of any other species. It could be just a few dozen kilobases, and it could be located in only one organism or free living cell of a species on the brink of extinction. Practically, it could never actually be identified. In short, species are constructs of the informational discipline, Systematic Biology. Populations, however, occupying actual space in time, and working Hutchinsonian niches, would be functioning parts of local ecosystems, where they transform energy in their position in a food chain and food web. But this sort of function—e.g., the ecological efficiency—is actually only the sum of the activities of the included organisms, which are the actual dissipative structures involved. However, it seems possible that a population’s relations to other local populations would be what allocates the characteristic number of individuals in that population. This would be a greater-than-organism function that effects the total energy transformations of that population, giving the population an actual ecological function of apportioning the energy throughput of a local ecosystem.

6 Senescence and Reproduction

All dissipative structures, if they survive assaults, develop through to senescence, which sets the stage for recycling. I have proposed (Salthe 1993) that development can be characterized by three general stages, as shown in Table 1.

Table 1 General stages of development

<i>Immature stage</i>
Relatively high energy density (per unit mass) flow rate
Relatively small size and/or gross matter and energy throughputs
Rate of increase of informational constraints relatively high, as part of high growth rate
Internal stability relatively low (it is changing fast), but dynamical stability (persistence) is high
Homeorhetic stability to same-scale perturbations relatively high
<i>Mature stage (only in relatively very stable systems)</i>
Declining energy density flow rate still sufficient for recovery from perturbations
Size and gross energy and matter throughput typical for the kind of system
Form is definitive for the kind of system
Internal stability adequate for system persistence
Homeostatic stability to same-scale perturbations adequate for recovery from insults
<i>Senescent stage</i>
Energy density flow rate gradually dropping below functional requirements
Gross matter and energy throughput high but its increase is decelerating
Form increasingly accumulates deforming marks as a result of encounters, as part of individuation
Internal stability of system becoming high to the point of inflexibility
Homeostatic stability to same-scale perturbations declining

Modified from Salthe (2010b), based on thermodynamic (Zotin 1972; Polentini 2013) and information theoretic criteria

Senescence is most often treated as a human disease, even though it is the natural culmination of all dissipative structures. Basically it results, in my perspective, from the inevitable taking on of new information (any modifications) after the definitive form of a kind of system has been achieved. Living systems have not been able to escape it. And so senescence is not a particular by-product of natural selection. It has had an enormous consequence. After the evolution—or was it the development? or might it even have been the incorporation?—of the genetic apparatus, the division of a (now living) cell entailed the multiplication of a particular identity. Protobiotic systems likely fragmented and spread over an abiotic ecosystem. Once the genetic system had made its appearance, fragments could take with them information that made their predecessor successful enough to grow enough under bearing conditions to fragment. This allowed them to split more readily when that was promoted by instability due to increasing size. Identity and its reproduction had been born. Before that, every piece of matter was different from all others; after that, we have definite kinds, enforced by genetic identity. Which living systems, after the origin of life, would inherit the earth? Those that could maintain a presence in the face of inevitable senescent decline and, as well, those that could utilize their energy sources faster than other competing kinds (Matsuno and Swenson 1999). This latter involved being able to respond successfully with an increased rate of energy acquisition when presented with larger energy sources to some extent even during senescent decline (Polentini 2013). Abiotic dissipative systems would do this spontaneously, but the more complicated living dissipative structures could be inhibited by their own delicate form to different degrees, giving rise to competition for moderate energy gradients. We now had particular kinds, in effect competing with other particular kinds, for energy. This situation placed a premium upon the ability to switch to new energy sources as those being utilized became depleted locally, driving the possibility of ‘speciation.’

7 Ecosystems as Energy Flow Pathways

Energy flows are everywhere in the universe and would have been happening on, and within, the primitive earth as well. The energy viewpoint is useful in allowing us to realize that there always have been ecosystems on the earth after it formed, perhaps at first only a single global one, with weather phenomena, orogenic activity, erosions, and so on (Kleidon 2010). Logically, we need to see protoliving systems emerging within, and getting intercalated into, preexisting liquid water flow systems. This would have been contextualized by the precipitation/evaporation cycle, where the emerging living systems likely were fostered within moderate flow eddies created and maintained within faster flowing hydrological systems that could deliver substrates. All of this will have been contextualized by local diurnal cycles produced by the spinning of the earth, allowing temporary survival (at night) of delicate forms at different scales, promoting further epigenesis. So the origin of life would have occurred within some abiotic dissipative structure(s) in

an abiotic ecosystem where the energy flows were moderate, as well as intermittent (Branscom and Russell 2013; Pross and Pascal 2013). In this sort of setting, we know pretty well how phospholipid membranes, microspheres, protobionts, and metabolism could have been produced spontaneously within increasingly lively ‘living ponds.’ With life being characterized as a system having propagation and interpretation (Pattee 2007), we can fairly well imagine crude forms of propagation going on, but biosemioticians would insist that interpretation became associated with the genetic apparatus, yet we have little idea about how this may have originated. (With this fact, I could assert that the energy perspective is actually on a sounder scientific basis than the alternative information perspective! Of course, both perspectives are required to understand living systems.)

The earth spins in a stream of electromagnetic radiation dissipated from the sun’s fusion dynamics. On earth, some of this energy (the sun’s entropy!) is further dissipated by the evaporation of water and the production of weather phenomena. This leads in turn to geophysical dissipation in the weathering of rocks and the production of dissipative structures such as drainage systems and ocean currents. I trace this particular dissipative pathway because it is solar radiation that is tapped also by most known current living systems, by way of photosynthesis. Living systems dissipate this energy gradually through food webs and beyond that by contributing to the mass wasting of rocks and the production of soils, as well as by plant transpiration, producing the humidity required by storms.

A given biotic storage of energy could be dissipated in many ways—action, predation, fire, floods, and ultimately by way of detritivory. Quoting my 2010 paper again, ‘an energy dissipative system that can assume several to many conformations will tend to take up one, or frequently return to one, that maximizes the entropy production from the energy gradients it is dissipating—to a degree consistent with the system’s survival.’ This is, again, MEPP, as carried out locally by way MEDP. So, at any locale, we can expect ‘things to happen’ that rapidly dissipate whatever energy gradients are present. This might at any moment call for a lightning strike, a predator’s strike, decay processes, and photosynthesis. On earth, biological systems have been entrained into this consequence of the second law of thermodynamics in a big way. It can be asserted that biological entities are almost always ‘striving.’ A major source of evidence for this viewpoint has been produced by Adrian Bejan as reported in numerous papers, in order to illustrate his ‘constructal theory.’ He has convincingly shown that all flow systems on earth, natural or manufactured, are formed so as to ‘develop the flow architecture that maximizes flow access under the constraints posed to the flow’ (Reis and Bejan 2006). This is exactly what would be predicted by the MEDP perspective. It has been noted that MEDP is often not a testable phenomenon in particular cases. Constructal form has however been amply demonstrated in many material systems, allowing plausible conjecture. I note here in passing that many adaptive scenarios in neo-Darwinian discourse are similarly hobbled by non-testability, with much less indirect evidence to back them up! In my 1975 paper (Salthe 1975) I cited references showing that natural selection functions more intensely during times of strenuous activity—which would, of course, be times of greatest entropy production.

The MEDP label has been objected to by noting that, for example, living systems do not literally maximize the energy flows through them, which would kill them. Instead, they optimize the energy flows, as discussed by Lotka (1922) and Odum and Pinkerton (1955), who dubbed this principle the ‘maximum power principle’ (MPP) (Salthe 2010a). Literal maximization anywhere would be explosive. In fact, dissipative structures generally intervene as a natural energy source increases before it can become explosive (Schneider and Kay 1994; Salthe 2007). Thus, while the expanding universe demands MEPP, this tends to be realized locally as MEDP, and this is further modulated in the more delicate living systems to MPP. The trade-off for the universe in the latter case is an increasing diversity of energy flows, producing some that might not occur at all abiotically. The predominant perspective on organismic energy use focuses upon energy efficiency, taking energy savings to be a major desideratum (e.g., Shepard et al. 2013). This is derived from the engineering mind-set, where energy supply is an important limitation. But organisms generally have reliable sources of energy within their niche spaces, as well as internal sources of energy such as ATP, both of which facts allow effective actions to trump energy savings as immediate goals. Excessive exertions might lead to death, but survivors are successful at—precisely—exertions. This means that energy efficiency would evolve within the overriding context of striving (Annala and Salthe 2010). The MEDP perspective is that energy efficiency would evolve mostly in order to promote striving. This would mean that, while effectiveness is the true focus of selection, efficiency increase during extreme activity could perhaps contribute to that effectiveness, but it would hardly count as a major focus of selection, except as weeding out really inefficient abnormalities.

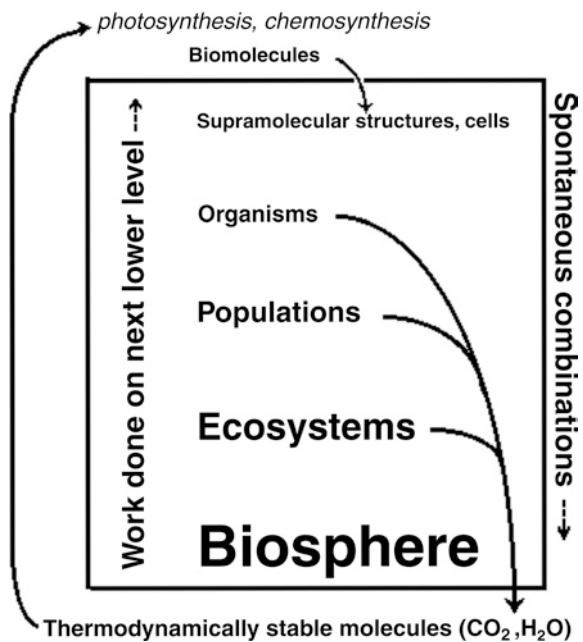
8 Biological Evolution

As Darwin pointed out, evolution can be visualized as producing a tree of biological forms (e.g., Rieppel), which can be modeled by a subsumptive hierarchy, `{{class {order {genus {}}}}}`. Each form comes out working its own ecological niche. From this, evolution can be viewed as an exploration of ways to degrade increasingly more particular energy gradients, creating a diversity, and increasing number, of energy sources. The big picture shows life beginning with chemosynthesis and/or photosynthesis, followed, in the animal branch, at length by the evolution of detritivores to utilize an increasing layer of dead biomass. The key idea here is that, given a significant energy source, sooner or later a dissipative system will emerge to disperse it. This led further to more macroscopic forms with mouths and digestive systems utilizing the dead organic mass more rapidly and converting some of it to a form more readily accessed by microorganisms as well. Eventually, some of these detritivores evolved the ability to prey on others of like kind, becoming carnivores. After a while, other detritivores acquired endosymbiont microbes that allowed them to explore herbivory, which led eventually to the establishment of the typical modern food chain with the addition of predation. And then, carnivores and herbivores began exploring increasingly more specialized ways of life.

With regard to MEDP, the evolution to carnivory and herbivory entailed more rapid energy conversions, with top carnivores, for example, tending to speed up local food chain transformations. Viewing populations as dissipative structures, predation dissipates prey energy faster than would slower microorganismic decay of individuals from prey populations. With animals, apex predation can also elicit faster prey reproduction, at earlier ages, since older individuals tend to be preferentially harvested. These effects have been observed in fisheries (e.g., Odum 1983). Herbivory and carnivory also entailed increased organismic striving (in plants for increased growth rates) as a functional requirement, and this entails more energy throughput and heat energy production. This leads us to note Van Valen’s (1973) Red Queen’s hypothesis, which energized and generalized its forerunner, Gause’s (1934) competitive exclusion principle. On the supposition that there are characteristic energy availabilities in a given habitat, if one population begins to reproduce more successfully, it will impact other populations working the same general Eltonian niche (syntopic species of woodland herbs in a forest, for example), requiring these to compensate in order to keep up. The result will also affect others in a food web, delivering a constant jockeying for energy between populations in a habitat.

Eventually, evolution resulted in a hierarchy of biological systems (e.g., Eldredge 1989) that can be modeled as a compositional hierarchy (wholes and parts, Salthe 2012). But how did it accomplish this? As it happens, nature is not intrinsically opposed to this structuring, which would in that case require specific kinds of work to create it. Gladyshev (2006) has shown that such a hierarchy is compatible, as a steady state, with the second law of thermodynamics and so can come about spontaneously (Fig. 4). This suggests that the abiotic ecosystem prior

Fig. 4 Steady-state thermodynamic relations among levels in the compositional hierarchy of biological systems on earth. Redrawn from Gladyshev (2006)



to the origin of life will already have self-assembled into such a structure in crude form; biological systems will then have come along and filled in the slots, as it were. Of course work needs to be done to keep any system going, but we need to understand in just what way the work is done to maintain the hierarchical form biologically. Figure 4 shows the biological hierarchy as a spontaneously achieved thermodynamic steady state resulting from self-assembly of the levels. Each level acts in its role as a higher level to the next lower level in a way that fosters the hierarchy as a quasi-stable, steady-state entity. The work that is done—in addition to the primal work of photosynthesis—is done by each level maintaining an environment that keeps eliciting the contributions of its next lower level. That is, it maintains a situation favorable to the activities of the next lower level. For example, the organism creates conditions that promote the activities of its incorporated cells. This work creates a top-down affordance inviting the continued bottom-up contributions of the next lower level that structurally makes possible its next higher level. The work accomplished at one level creates, at the next lower level, conditions that allow it—the higher level—to continue to emerge.

But the Gladyshev model is not complete. It is one thing to understand that a compositional hierarchy could be a thermodynamically secure structure—unlike a tall building, for example—but there is also the question of why it would continue to be thermodynamically favored once achieved. This question moves us from the classical thermodynamics informing Gladyshev to non-equilibrium thermodynamics. In that format, we can bring in MEPP. That is, I would posit that this hierarchical form is the one that elicits the most favorable kinds of flow structures throughout the hierarchy that promote the MPP overall and therefore maximizes as much as possible the system's global rate of entropy production (Salthe 2004b).

So, we have two basic thermodynamic principles working here. One is the classical Gibbs free energy perspective utilized by Gladyshev, stating that a system will spontaneously move to a least free (available, usable) energy configuration. The other is MEPP, stating that this will emerge in a non-equilibrium system as rapidly as possible. In living systems, the solar energy captured by photosynthesis is routed metabolically on its way toward ATP synthesis and the heat energy released from the cytochrome system. Living systems that did not sufficiently moderate the rate the energy dispersion through them burned out and went extinct.

Moving now from the more speculative to more solid evidence in favor of the idea that evolution has increased the rate of earth's energy flows/entropy production, we can recall Bejan's multiple evidences that facilitating energy flows acts as a final cause of any and all dynamic material structures, as well as Chaisson's more particular evidence (Fig. 3) that per unit mass energy flows have increased during evolution. But in my view, the clearest evidence for the influence of MEDP/MEPP in biological evolution is the convergent evolution of homeothermy (endothermy) in mammals and dinosaurs/birds. There are tendencies toward this in other phyla as well, for example, the endothermy of tunas and some other large, fast swimming predatory fishes. Even a plant has achieved it—the flower of the skunk cabbage, which stimulates beetle pollinator activity in cool weather. Behavioral homeothermy is another common tendency, as in lizards. Endothermy

requires significant amounts of energy dissipation and is a direct result of physical entropy (heat) production, with no other more elaborate product. It, and behavioral homeothermy, do nothing more than increase the rates of activity of the animals in question. Regardless of particular adaptations that may have been facilitated by homeothermy (such as living in colder climates), its ‘universal’ achievement is simply to directly increase the entropy production of an animal per second of life. Surely, a frog might be imagined to think, ‘What a waste of energy! Look at me—I get along quite well without it (even in Siberia)!’

9 Humanity’s Role in the Universe

Evolutionary Biology has not identified any goal of organic evolution. Neither increase in complexity, nor increase in consciousness has been accepted as biological evolution’s goal on earth. One may suspect that this may be an effect of the neo-Darwinian domination of evolutionary studies, where all effects are viewed as the results of local caprice, allowing no tendency to evolve out of anything beyond contingency, or to long survive environmental change if it did emerge. The concept of natural selection allows of no directional tendencies that are not merely local, provisional, and contingent. Even humanity is not viewed as occupying a privileged position at the top of a perceived chain of evolved forms—an image that in any case likely reflects rejected ancient religious opinion.

However, as alluded to above, there is a scientifically based concept of a universal goal of all events and actions—the dispersion of energy gradients toward a universal final state approaching thermodynamic equilibrium, where orderly fluctuations here and there will soon get damped out. This ‘heat death of the universe’ has had many objections on various grounds, but in the long run, it seems to me that it cannot be avoided given our current knowledge. This knowledge amounts to the empirically derived fact that entropy must increase if it changes in a thermodynamically isolated system. Since it is produced each time any action occurs—and copiously with significant work—we may reasonably infer that the universe, or our section of it, is a thermodynamically isolated system. Given that assumption, the second law of thermodynamics, perhaps second only to the law of gravitation, is the physical law most immediately impacting our lives—disorder threatens everywhere, and we must work harder than seems reasonable to achieve anything (Salthe 2003).

I have argued that the second law is a ‘natural’ example of final cause (e.g., Salthe 1993; Salthe and Fuhrman 2005). Directional tendencies in nature have been parsed (Mayr 1988) as:

{teleomaty {teleonomy {teleology}}}

or

{natural tendency {function {purpose}}}

on the template:

{physicochemical world {biological world {human socioeconomic world}}}

where each innermost subclass (or integrative level) is a more specific example of the next outermost class. Thus, e.g., purpose is a kind of function. The essential point is that all the labels in the second hierarchy here are end-directed. The second law of thermodynamics is a teleomatic principle, and thus

{entropy production {free energy decline {work {social projects}}}}

on the template:

{physical world {chemical world {biological world {socioeconomic world}}}}

As Lotka pointed out, some solar energy reradiation from earth's surface is delayed while being rerouted through living systems, but this has the 'universal' payoff of slowly undermining earth's gravitated mass by way of activities that stir up soils, undermine rocks, and spray water—slight events with slowly accumulating effects, adding to the much more powerful abiotic disturbances such as earthquakes and storms. Over geological time, events with slight effects gradually accumulate to global significance.

Spontaneous diffusion and mass wasting are insufficient to dissipate all energy gradients formed by gravitation and its sequelae. Dissipative structures such as storms speed things up in the presence of massively steeper energy gradients, but still many gradients will have been very slowly dispersed until life appeared: Thus, lichens speed up the mass wasting of rocks; microorganisms at work even in depths of earth's oceans and mantle produce corrosive chemistry and heat energy; tree roots and burrowers in the soils do so as well and open soils up for further chemical transformations. Microorganisms everywhere transform chemical gradients to simpler forms. (I can't resist an exception that 'proves the point'—bacterial action has resulted in the buildup of small gradients of gold, but subsequent human activities have torn apart many regions of the earth to collect it.) The role of biological diversity in this is clear; it increases the number of energy gradients being dissipated and works on some smaller and more cryptic energy gradients that are not touched significantly by abiotic dissipative structures.

Humanity's role regarding MEPP emerged significantly with industrialization, as visualized in Fig. 3. Human economies have added to all of the dissipative effects on earth's surface and, after the industrial revolution, have magnified some of them many fold, by way of various mining activities, modern travel and warfare. But, as Machu Picchu and China's buried terracotta army show, intense labor was not a consequence of the industrial evolution. Yet, after that direction was taken, hard labor was magnified manyfold and mechanized. Our current throwaway economy may be its crowning achievement. Warfare may have a special role in human entropy production. It is deplored by everyone, yet is indulged continually somewhere on earth's surface—taking a large-scale glimpse, it would be everywhere anytime. Entrainment by the second law can serve as an explanation for the paradoxical role of war as an attractor of human activity regardless

of everyone's voiced disapproval, working as a final cause of human activity. The second law would provide a very slight pull at any moment, but is always reliably beckoning so as to tip the scales of decision making in cases of uncertainty. Yet industrial activity may be an even greater, if somewhat more careful, producer of heat energy and debris. The keynote seems to be, Build → Destroy → Rebuild, with heat energy being the only definite result in the long run.

10 Conclusion

Have I, in this paper, reduced all the complexities of biology and sociology to physics? In one sense, yes. On the other hand, my perspective in this paper is that humanity is a part, or aspect, of the universe in addition to being the growing point of a lineage in a cladogram. We no longer can view ourselves as a goal of organic evolution. In the phylogenetic perspective, we are merely one more primate, while in the physical perspective, we have become mighty workers in the service of universal dissipation.

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