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A Hierarchical Framework for Levels of Reality: Understanding Through Representation

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Abstract Levels of reality reflect one kind of complexity, which can be modeled using a specification hierarchy. Levels emerged during the Big Bang, as physical degrees of freedom became increasingly fixed as the expanding universe developed, and new degrees of freedom associated with higher levels opened up locally, requiring new descriptive semantics. History became embodied in higher level entities, which are increasingly individuated, aggregate patterns of lower level entities. Development is an epigenetic trajectory from vaguer to more definite and individuated embodiment, punctuated by the emergence of new integrative levels. It is constrained by being subsumed by lower levels (e.g., physical dynamics) and may be guided by structural attractors as well as by internally stored information (e.g., genes) in the higher levels. I conjecture, on a thermodynamic basis, that the number of levels that become manifest in an expanding universe depends upon its rate of expansion.

Keywords Big Bang · Complexity · Convergent evolution · Development · Emergence · Hierarchies · Thermodynamics

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1 Introduction

Levels of reality is an ontological construction, based in scientific knowledge, that attempts to accommodate the fact of complexity, in the sense that the models of no single discourse can provide a satisfactory image of any aspect of the natural world (Rosen 1985). Scientific discourses have mostly not been pursued primarily for philosophical motives, but rather for various pragmatic ends. It then remained for philosophical work to try to gather into one framework information gained from the various sciences. After its beginnings with Aristotle, this work of Natural Philosophy was taken up again by the German Romantics of the nineteenth century, culminating in the thinking of E. W. J. von Schelling (Esposito 1977) and the American philosopher Charles Peirce (e.g., Esposito 1980; Hausman 1993). Beginning in the 1940s the specific integrative levels approach, which I will present here, emerged in a group associated with Needham (1943) and Feibleman (1959). (Some of my own previous work on this is to be found in Salthe 1988, 1993, 2002, 2008, 2009.) I am here deliberately ignoring the erstwhile ‘unity of the sciences’ approach (Neurath et al. 1955, 1970; see also Agazzi and Faye 2001) because it is basically a reductionist approach.

2 Complexity

Two forms of complexity have been modeled as hierarchies—extensional complexity as a compositional hierarchy, and intensional complexity as a subsumptive hierarchy (Salthe 1993, 2006). The former is the most commonly referred-to hierarchy in natural science, as well as in systems science and the complexity sciences. An application of this hierarchy to the natural world, for example would be:

$$[\text{ organism } [\text{ cell } [\text{ macromolecule }]]]$$

$$\text{interpreted as } [\text{higher level } [\text{lower level }]]$$

The key distinction between levels here is that the scale of their dynamical rates differs by about an order of magnitude (Salthe 1985, 2002), which is what keeps the levels functionally separate (Salthe 2004), and so I have been referring to this form as the ‘scale hierarchy’. Generally there are in this form more entities in lower levels relative to the higher.

What Poli (2001) refers to as ‘levels of reality’, however, requires the other sort of hierarchy to represent them, what I have called the ‘specification hierarchy’ (Salthe 1993, 2002). Intensional complexity exemplifies Rosen’s (1985) view that complexity refers to situations that cannot be satisfactorily described using only a single perspective or discourse. This hierarchy has a long pedigree in western discourse, going all the way back to roots in Plato (Salthe 1993), but has figured little as yet in modern natural science (Salthe 1988), where, in its most recent usage in that context, the levels were referred to as ‘integrative levels’. For example we have:

$$\{\text{ physical world } \{\text{material world } \{\text{biological world }\}\}\}$$
$$\text{interpreted as } \{\text{lower level } \{\text{higher level }\}\}$$

Here the biological world integrates (organizes) the other worlds, while the chemical world integrates the physical world under its rules (Polanyi 1968). The use of set theoretical brackets is exactly appropriate here, as the logic is that of subsumption. Thus, the lowest level, here the physical world, subsumes the other worlds in this hierarchy, while the chemical world subsumes the biological. Thus, e.g.,

$$\{\text{entropy production } \{\text{free energy expenditure } \{\text{metabolism } \{\text{cognition}\}\}\}\}$$

So the material world is one kind of physical world—i.e., some parts of the world are material, but there is more to the physical world than that (e.g., a quark–gluon plasma, or radiation in space). The material world is thus logically a refinement of the physical world, placing further specification upon its physical degrees of freedom (Fig. 1).

In both kinds of hierarchy, a higher level organizes, controls, regulates, harnesses, guides, interprets, constrains, limits, etc. the lower levels. In a compositional hierarchy this constraint imposition is non-transitive and so limited to the next lower level, while in a subsumption hierarchy upper level constraints are transitive down through all the integrative levels below the level where they originate.

In this paper I will be interpreting levels of reality as integrative levels in an intensionally complex world, and I will elaborate on the modeling consequences of the formal principles of the specification hierarchy in that endeavor.

3 Physical Background to Levels of Reality

The appropriate physical context for levels of reality is the Big Bang understanding of the development/evolution of the Universe. The levels unfold naturally in this context, with its causal chain: expansion of space → universal cooling → 'precipitation' of baryonic matter → gravitation forming masses → modulation to forms → development of organizations (e.g., Turner 2007). In this understanding, Universal expansion is the underlying cause of all there is. The changes here can be visualized as a process of coarse graining by way of phase transitions, and the resulting specification hierarchy could be presented like this:

$$\{\text{physical dynamics } \{\text{material connectivity } \{\text{biological form } \{\text{social organization}\}\}\}\}$$

Figure 1 displays ostensively the logic of the process of reality production as understood from the present perspective. Two points can be emphasized here: (a) local physical degrees of freedom in developing regions become increasingly fixed as the universe expands; (b) new degrees of freedom associated with new integrative levels open up locally in developing regions, and in their turn may also become fixed as the scale of developmental change increases. Note that in this view all levels were

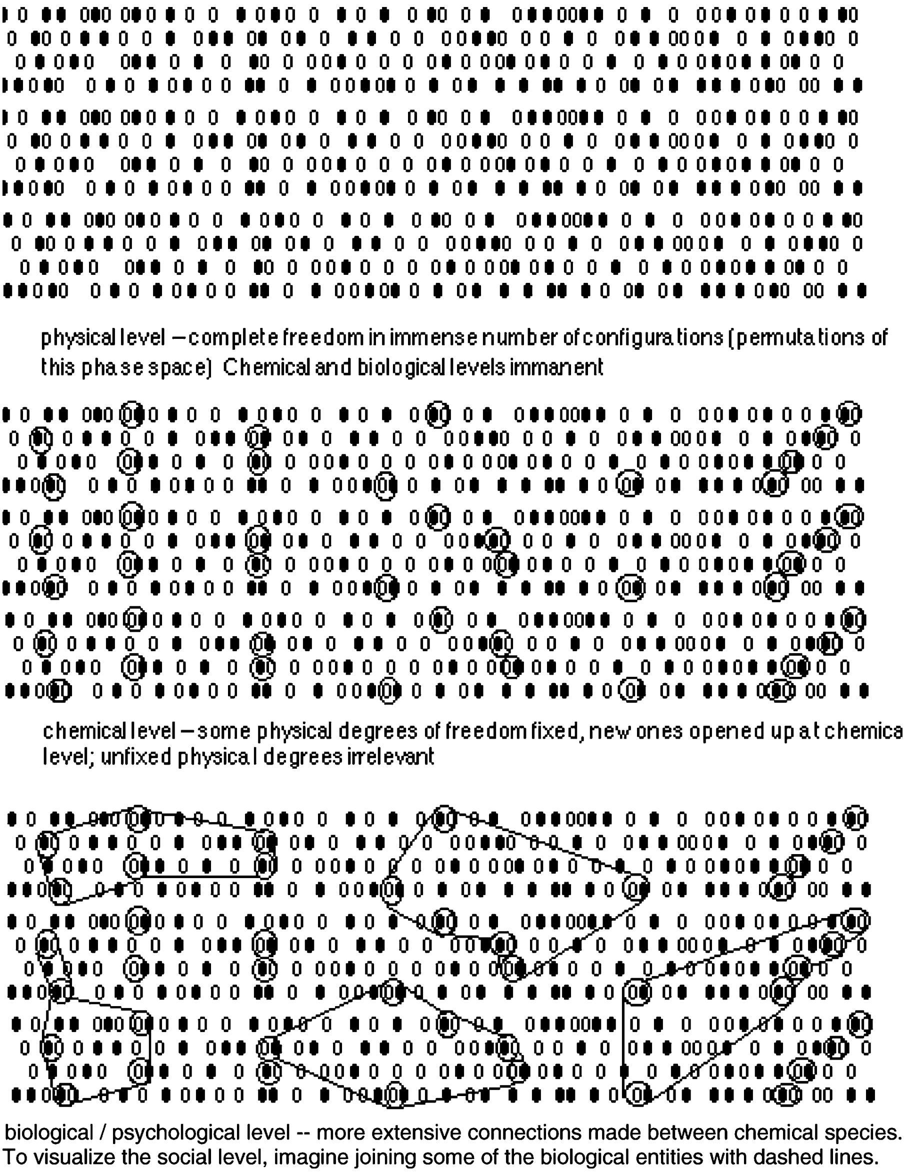

Fig. 1 A simplified representation of relations between levels of reality as they unfold in time from *top* to *bottom*

immanent initially in the primal physical level, but would have been only vaguely and fleetingly embodied back then. This is shown in Fig. 1 by using the same physical configuration of particles in all three panels. New types of individuals emerge by way of the fixation of open informational constraints, which in turn opens up more new informational constraints in new levels that had been only potential. The cooling of the universe makes possible, and calls forth, new kinds of individuals.

So we see that objects at different levels of reality have different spatiotemporal extents, with higher level objects being states of objects at lower levels. Thus, higher level entities are generally aggregate patterns of lower level entities.

As well, we can see that emergent forms partake of two temporal orders. From an external point of view, they are the result of the prior evolutionary/historical emergence of their kind during an earlier era in the course of the Big Bang. Internally, they emerge continually from moment to moment, being actively maintained by the forces of nature and the continued universal expansion. Also, in some cases, their maintenance is a consequence of being informed by historically acquired constraints such as, for examples, the atomic relations shown in the periodic table, and the genetic information held in biological systems.

The form of a subsumption hierarchy (not shown in my representations here) is that of a tree branching from its trunk in the lowest level—the level characterized by the most generally applicable predicates. This indicates that one cannot suppose that the sequences of emergences during universal expansion was determinate. Before any emergence there would have been a degree of equivocation as to what might appear. This is especially true of the higher levels of reality, where contingency plays an increasingly greater role. We could predict, no doubt, which chemical species would be capable of being formed under given conditions, but we would not be able to predict, for example, sea horses, orchids, or airplanes, in another universe. This is not to declare that, e.g., every sodium chloride ion pair is identical to every other one, but rather that what differences they may have do not play a role in the emergence of higher level forms as we apprehend them. These higher level forms, however, are very much embodiments of their history. Every tornado and hurricane is unique, as well as every biological species and individual. Presently we imagine that we can ignore hurricane uniqueness theoretically, but that remains to be seen (we do in fact name them as individuals).

Nevertheless, it seems reasonable to suppose that in other universal expansions, there would occur very similar overall emergences of levels of reality, with increasingly information rich individuals appearing in the upper levels, and with internal information accumulating within entities at the highest levels. This would likely be true to the degree that universal constants (e.g., universal expansion rates) had similar values to those characterizing our own universe. Otherwise we could not predict at all what might the case in other instances of universes.

In a related point, it seems reasonable to suggest that, as in the macrosystem/ microsystem model in statistical physics, there could be the possibility that the existence of the same higher level individual might admit several non-isomorphic decompositions in the lower levels. Certainly, for example, the chemical constituents of organisms are turning over continuously, and this example suggests that lower level replaceability would be more active the greater the distance in number of levels separating the ones being compared. Yet, we can note, social conventions can remain fairly stable even as persons directly entrained by them in the very next level below continue to be replaced by others. It is certainly the case that relative to other levels, entities at the higher levels must be changing more slowly than those involved in them at lower levels, allowing the upper level to generate constraining boundary conditions on lower level changes, giving higher levels regulatory powers over the lower.

In the larger arena of the emergence of levels of reality in general, these considerations seem to feed as well into the problem of the 'reproducibility of universes' (Lineweaver 2005). Providing that we could generalize our concepts of individuals at the different levels, it seems that reproducibility would be quite plausible. For example, in a general thermodynamic sense, birds in one universe could replace mammals in another. Obviously, given the importance of historicity in the higher levels, particular species could not be thought to be reproduced from universe to universe, and this leads Lineweaver to doubt universal reproducibility. Reproducibility could be expected only for generic forms and relations.

This line of thought connects as well with the evolutionary convergence found to have occurred among living things on Earth (Willey 1911; Conway Morris 2003). One's impression is that there seem to be structural attractors operating during evolution (as implied, e.g., in Goodwin 1991) along with the random changes dealt with by neoDarwinians. Evolutionary biologists, informed only by Darwin's 'descent with modification' model have largely ignored this phenomenon, which does not fit comfortably within the branching tree of life model used to show the 'adaptive radiation' of living things into a plenitude of ecological niches. But here we can also note, for example, the Mediterranean style vegetation pattern, which is found not only along Mediterranean shores, but also in the Andes, as well as in Australia, each with their own unique, but similar, species. At a smaller scale we have many examples of unrelated plants and animals adopting similar forms and behaviors, living similar lives in different ecosystems (Salthe 1972). A convenient simple physical model of a structural attractor would be the universal pattern of vortex flow in fluids forced by energy gradients great enough to push beyond conductive flows like diffusion (Lugt 1983). Given the differences in the fluids that can harbor vortices, and the scales at which they can occur, it seems reasonable to take the vortex as a structural attractor in our universe, and it can serve as an example of what I mean by the term 'structure'.

4 Development

In 1993 I proposed very general definitions of development and evolution, based on their usage in biology, where both terms have important currency. Development, I propose, is made up of predictable directional, or progressive, changes, while evolution (equating it with individuation) is the irreversible accumulation of historically acquired information. So, if universes are reproducible, their development would be describable in a series of developmental stages (as, for example, in Turner 2007, or, much more generally from a thermodynamic perspective, in Salthe 2007). It needs to be noted that developments are necessarily observer-dependent. Any collection of examples of some defined kind of change, as found, e.g., during the progress of tornadoes or the aging of cities, will be found to share some changes in common, and these will make up the basis for describing stages of development, thereby making up a suite of constitutive changes characterizing that kind of system. Of course, material systems are markable, and will acquire individuating marks as they continue to develop, or exist. As a result, all developing systems must necessarily individuate—i.e., evolve—as well as develop. It is interesting that the neoDarwinian hegemony in evolutionary biology does not allow phylogeny to be thought to have any developmental tendencies, thereby forestalling the possibility of discovering them.

The canonical developmental pattern begins in relative vagueness, which gradually becomes increasingly more definite as particular individuals emerge from it. Vagueness is a difficult concept to deal with. Logicians view it as a problem to be avoided (e.g., Keefe 2000), as they struggle for increasing explicitness, creating the likes of propositional calculus and predicate logic as ways to avoid it. Science has followed this explicit path as well, clearly for pragmatic (technological) reasons. But, for example, the modern poetry of the late nineteenth and early twentieth centuries cultivated a verbal vagueness, and founded its meanings in indirection while trying to linguistically capture the ineffable. Vagueness in the present context would be open potentiality. No material system can begin totally vague, and so the movement of development generally is toward increasing definiteness.

As shown in Fig. 1, the values of universal degrees of freedom become increasingly more definite (fixed) as levels of reality emerge. The top panel, representing the more primitive situation, is not fully vague because there are already definite particles. On the other hand, all material objects are to some degree vague, and so even the highest integrative level retains some vagueness. Consider the human body—the sketches and sculptures of Rodin show well how there is no one form that can represent a living body, except, perhaps, in the limit of some ideal 'physical instant'. I believe that the problem of complexity arises for science partly because the world is in some degree vague while scientific models are as fully explicit as possible. Physics has recently been confronting vagueness in the concept of quantum coherence, where it is beginning to look like an opportunity for its exploitation in computation.

Development implies and signifies knowability. Stages of development are guaranteed for particular living systems in published 'normal tables' of development. The question arises as to whether such stages are predictable because they are being controlled in some way. In biology, we suppose that genetic information is regulating developmental pathways, but dynamic abiotic systems undergo similar predictable developmental changes as well, which can be constructed as their averaged behaviors. I have proposed that all dissipative structures undergo a canonical developmental trajectory, from immaturity to senescence using informational and thermodynamic criteria (Salthe 1993). This is a consequence, first, of the Second Law of thermodynamics in its non-equilibrium vicar—the need to maximize entropy production locally (e.g., Lorenz 2002; Sharma and Annila 2007), entraining, and explaining, the rapid work of growth made by a new system during its immaturity. Then the susceptibility of matter to accumulating marks gradually kicks in, finally imposing the rigidity of senescence, by way generally of information overload. Because a mature system is already definitive, continued accumulation of marks of individuality eventually work as restrictive informational constraints, limiting system flexibility and the behavioral variety requisite for continued homeorhesis. This generates increasingly large perturbations to a system in response to environmental fluctuations, which finally defeat a system's adaptability.

This general developmental sequence can be viewed as the emergence of informational constraints, followed by their fixation (as diagrammed in the simple example in Fig. 1). At first this process must be guided by generic tendencies inherent in material forms (e.g., Goodwin 1991; Reid 2007), which could inform any material system. In the living, these become further refined by guidance from genetic information. Since genetic information represents preserved historically acquired information, we can see that historical contingency becomes increasingly important as a living system develops. Increasing historical importance during development applies as well to abiotic systems like tornadoes, which are each different according to the specific conditions in place when and where they are generated, some of which in this case are imposed at the time when the system is initiated and some of which do not come into play until the system is already formed. Of course, living systems also are modified by individual historical encounters after they have become definitive for their kind, thereby continuing their individuation. So the developmental pattern of constraint imposition runs from structural attractors to preserved historical information (e.g., genes) to new historical information imposed by current contingencies. Uniqueness accrues during development at all levels of reality, producing definable agents in many of them, but is greatly enhanced in functional importance in the living. Thus, we can see that knowability (predictability) is necessarily restricted to generic tendencies.

A word is in order here about generic tendencies that can be discerned in any changing material system. For a simple example we have the vortex found in all fluid systems when powered by an energy gradient above a certain threshold of steepness. This is entirely predictable for any fluid whatever given certain relations between energy gradient and fluid density and volume. This system is affected by large scale boundary conditions, as we can see in the effect of the Coriolis force upon vortices, be they toilet swirls or hurricanes. But this only determines their handedness, not the vortical form itself, which emerges from different material causes in the different systems. Physico-chemical tendencies like this are claimed to be important as well in the development of living systems (Goodwin 1991; Newman and Müller 2000; Reid 2007), and can mediate a degree of ‘developmental plasticity’ when confronted with genetic constraints to generate new forms in unusual environmental conditions (West-Eberhard 2003). As noted above, borrowing a term from dynamical systems, I refer to universal forms like vortices as ‘structural attractors’. They are physico-chemical tendencies or propensities, and continue to exert effects in the higher levels of reality, showing that the physical world really does subsume the biological/psychological and sociocultural worlds. For a simple example, the trajectories of vultures descending upon carrion are vortical (see many other examples in Lugt 1983).

5 The Specification Hierarchy

We can model levels of reality as intensional complexity by using the subsumption hierarchy format, which I refer to as the ‘specification hierarchy’ (see Sect. 2). I have previously referred to this form as a system of ‘levels of generality’ (Salthe 1985, 1988) because the attributes of the lowest level (here the physical) are found in all material systems, and so are more generally present in arbitrarily picked locales throughout the world. Some physical places are also material, involving or being composed of baryonic matter. And some of these are organized into biological forms, while some of these are also entrained into social structures. Thus:

$$\{\text{physical level } \{\text{material level } \{\text{biological level } \{\text{sociocultural level}\}\}\}\}$$

Logically, generality is constructed by comparison of observed particulars, searching for properties they have in common, and is therefore a product of inquiry rather than an actual property of the world. The Linnaean hierarchy of living things is a well known result of such taxonomic work. Darwin's insight was to realize that this branching tabulation of genera and species grouped by similarity could be thought of as representing a process of descent of the contemporary living forms at the ends of the branches from inferred ancestral forms that lived in the past. These would be located at the branching nodes, which converge through yet more remote ancestral forms to a common ancestor at the base of the tree.

However, if we contemplate such an evolution as an actual material process of change, we will realize (Peirce 1905), that we cannot begin with a common ancestor that actually had particular contemporary versions of commonly held properties which now differ in detail among its descendants. For example, some families of plants have floral parts in units of three, and some have them in units of four or five. What would be the common ancestral form? We must suppose that its condition with respect to existing descendants could not have been relatively general, but, rather, relatively vague. It would most likely have been in a variable or even indistinct condition, and so not fixed to any one distinct pattern. Thus, while we linguistically construct generality out of particulars, evolution would construct such particulars out of vague beginnings. This view is reinforced by observing the embryonic development of any kind of living thing. We will see that embryonic forms are more indistinct the earlier in development we make our observations, and, indeed, this realization formed part of Darwin's knowledge, since it had been described earlier by von Baer.

The general logic of a subsumption hierarchy is that new levels get added as a result of the acquisition of new information. It can be viewed as a process of qualification or refinement of previously established information, for example, as the physical degrees of freedom in Fig. 1 become increasingly fixed by more constraints emerging at higher levels of reality. At first his would involve the appearance of new regions which could become the sites of further distinctions. That is, potential informational constraints will emerge, perhaps as a result of growth. Later such regions will acquire more particular configurations, as informational constraints take on more definite, particular forms, thereby becoming fixed information. Thus, when petals developed in the reproductive parts of some ancient plants, they would have showed considerable informational variety in any given lineage. Later this entropy was reduced, differently in different descendant lineages, to information neat, and became the basis for new branches at a new level in our perceived phylogenetic tree of plants. In principle, as new distinctions become possible, opening new degrees of freedom, new branches would tend to get added in our constructed phylogenetic trees. So we can interpret the nodes of a phylogenetic tree as sites of the evolutionary emergence of new attributes, carrying new degrees of freedom for yet further evolutionary change.

We might note again here the gradual freezing out, in the higher levels, of the original physico-chemical degrees of freedom These, of course, would still be open and at large in regions of the universe that have not hosted the development of higher levels of reality. We need to see that the opening of new possibilities occurs within a process of the closing off of older ones. The new are hoisted upon, and hosted by, locally harnessed old degrees of freedom, as modeled in Fig. 1. So, while, e.g., language opens up untold possibilities for the construction of informational patterns, it at the same time must effectively close off other more intuitive modes of knowledge or, as well e.g., the standardization of metabolic chemistry must have diminished the possibility of certain unused chemical transformations that previously occurred along with the ones harnessed by life. The universal developmental process is, in the classical sense, 'epigenetic'—one of 'building upon'.

Referring to the discussion above under the Sect. 4, I note that my use here of "developmental" instead of 'evolutionary' is arguable, and represents a biased intuitive choice. It seems plausible to me that given another universe with our chemistry, very much the same mix of reactions would be chosen to energize higher level forms. Thus they would be predictable, and therefore 'developmental'. In any case, new levels of reality emerge along with new degrees of freedom generated by relationships launched upon the established configurations of older levels (Fig. 1).

This hierarchical model can be seen to be non-reductionist because individuals at the different levels are different in kind. For examples, molecules cannot run, and animals cannot get oxidized. But running can be reduced to oxidation because oxidation could support any kind of macroscopic activity made available at a higher level. However, one could not begin with oxidation and conceptually construct a system of levels that runs without arbitrarily adding constraints, which in nature would have been generated by some combination of system possibilities with environing contingencies. New semantics are required to describe new levels of reality. In this way we have different types of order at the different levels—indeed, new logical types (Salthe 1985).

However, one may be reluctant to understand the levels as being different categories. This is questionable in the specification hierarchy model because entities at different levels do share attributes from lower levels (e.g., biology can be seen as a particular kind of chemistry). The question, simply put, is whether a subset can be categorically different from its base set. I have (1985) tentatively suggested, no. We might consider the fact that fixed information is transferred from one level of reality to the next, from one medium to another (Fig. 1). What the fixed basis supports is determined within the emerging medium, top down. If something other than biology/psychology would appear in the lower panel of Fig. 1, a different collection of configurations would harness the lower level fixed constraints. Is there something beyond contingency and history involved here? For example, might structural attractors be involved—as they would be in any simulation? If the world is more unbounded than any simulation, then structures would be less likely to be involved. But when the world attains materiality, early in its development, this alone would diminish its wild possibilities to a great extent, and here we might find place for the formation of deep structures, as implicit attractors of future dynamics. These might be thought of biasing the changes between the middle and lower panels in Fig. 1.

Nevertheless, as the world system attains more levels of reality, historicity would become increasingly important, in the higher levels. Thus, if we would have another Big Bang, the details in the higher levels should be less and less ‘reproducible’ as we compare the worlds. This would be so even if, when the particulars are generalized to types, these worlds might be seen to reproduce each other. Uniqueness seems to accumulate as we ascend the hierarchy of levels of reality. This suggests that the range of choices increases in the higher level informational constraints. Thus, it seems plausible that the physics of a collection of worlds would be more alike than the biology in those worlds that get far enough in their development as to have biology, or its informational equivalent. And we could safely bet that in those worlds where language develops in some social organizations, these languages would most likely not be similar from one world to another.

6 Conjectures on the Physical Basis

Returning to the physical basis of reality, I make a conjecture and speculation that I think helps to fix the model of levels of reality discussed above. Starting with Einstein’s physical intuition that gravitation is none other than an example of acceleration, and combining this with the knowledge that the universal Big Bang expansion is currently accelerating, we can conjecture that the magnitude of the gravitational force is scaled by this acceleration. The gravitational force is the basic cause of the formation of clusters of matter in the universe, and is therefore a material cause of form, which is in turn a material cause of organization. Thus we can have a specification hierarchy:

$$\{\text{mass}\ \{\text{form}\ \{\text{organization}\}\}\}$$

That is, organization is a kind of form, while form is one possible condition of mass. This understanding also illuminates the cause of the Second Law of thermodynamics, since the above expanding scenario takes the universe further and further from thermodynamic equilibrium, thereby making the Second Law an increasingly powerful attractor as the universe departs increasingly from thermodynamic equilibrium. By this I mean that in the equation, $\mathrm{d}S \geq 0$ for local non-equilibrium systems (the entropy production of any locale must be greater than, or not less than, zero), the greater than increases for given work loads as universal acceleration continues to increase all gravitational energy gradients globally.

This perspective entails that entities at the higher levels of reality are required to serve the Second Law of thermodynamics as a prerequisite for their existence (Prigogine 1980). This they do because their local work, including that expended upon their continued existence in a non-equilibrium context, is taxed, at about 50% (Odum and Pinkerton 1955). That is, the efficiency of work by natural systems is not better than about 50% (and is overwhelmingly much less). And so, revising an above hierarchy:

$$\{\text{entropy production}\ \{\text{free energy expenditure}\ \{\text{metabolism}\ \{\text{cognition}\}\}\}\}$$

we can replace ‘cognition’ with the more general ‘work’. Physical entropy production subsumes all work. In this view, then, the gravitational force has afforded the continued development of material objects. Perhaps, then, the number of levels of reality in our world reflects the magnitude of acceleration of the Big Bang expansion.

It is curious, then, to consider what would happen if universal expansion were to decelerate. Then, e.g., we might conjecture that a sociocultural level might no longer be possible in this universe, as the levels of reality would be eliminated from the most complex downward, in reverse of their historical appearance. Things would no longer hang together as well as they do now, but also the Second Law will have weakened in consequence, delivering a curious enfeebled situation that is difficult to imagine. If it were to survive, society might not be so committed to action, conquest and discovery; and life would not be so 'driven' as it is now.

7 Summary

This paper is an exegesis of various concepts related to Fig. 1 concerning the idea of the development of the world that devolves from the general Big Bang model of the universe, using the subsumptive form of hierarchy (my 'specification hierarchy') as the major conceptual tool.

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