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■ *Research Paper*

Chaos and Chaos; Complexity and Hierarchy

Ron Cottam, Willy Ranson* and Roger Vounckx

The Living Systems Project, Department of Electronics and Informatics, Vrije Universiteit Brussel, Brussels, Belgium

We address the characteristic complexity of large multi-scale systems. Starting from the concept of perceptual scale, we present an ecosystemic model-hierarchy description, which we believe is more applicable to nature than conventional hierarchical representations. Such a hierarchy, or *holarchy*, may be ontological or epistemological, but either case presents a layered structure alternating between local scales and locally-scaled ecosystems that are characterized by scale-dependent chaotic properties. Unification of a hierarchical system implies the generation of a scale-independent property referred to as hyperscale, within which access to the different partially-isolated system scales is transparent. We propose that this framework can be used to characterize all Natural entities, from inorganic and organic to human organizations. We conclude with an examination of processes of emergence and its counterpart demergence. Copyright © 2014 John Wiley & Sons, Ltd.

Keywords chaos; perceptual scale; hierarchy; hyperscale; emergence; demergence

INTRODUCTION

Why is it that the performance of very large systems is often so difficult to exactly predict, even though the operation of their multiple sub-units may be eminently predictable? Is it possible in general to integrate such a collection of sub-units in an entirely logical manner, or is there some phenomenon which places the transition from *multiple* to *singular* representation beyond the obvious? How is it that an apparently clearly understandable simple system can perform in a completely unexpected manner, even within the constraints for which it was designed? In answering these questions, we will need to look closely at the characteristics of systems whose structure and operation depend on, but also transcend, the concepts of *scale* or descriptive *level*. Conventionally, these two—scale and level—have often been uniquely associated with structure and function, respectively [see e.g. (Crews and Young, 2013)], but we will present a general point of view within which structure and function are inseparable. We will draw much inspiration from Robert Rosen's (Rosen, 1991) 'modeling relation' between a 'real' Natural system and its formal representation [Figure 1, after Figure 3H.2 in (Rosen, 1991)], but in the case of multiscalar

*Correspondence to: Willy Ranson, IMEC vzw, Kapeldreef 75, 3001 Leuven, Belgium.
E-mail: life@etro.vub.ac.be

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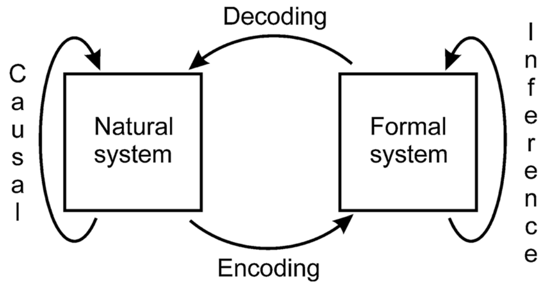

Figure 1 A representation of Rosen's modelling relation

systems, such a formal representation may simply be the real system viewed from a different scale. It is important to note, as we will describe, that the models and hierarchies we describe in this paper may well be ontologically real, or may be simply the useful figments of our imagination (we will use the term 'convenience' hierarchy in this case, for example), and it is important to try and distinguish between the two. Much is often made of phenomena of *self-organization*, but we will adopt a position from which organization is *always* related to a system's or sub-unit's environment, whether this is obvious or not in a particular case.

Our major aim in this paper is to present a scheme for the unification of multiple levels of system representation, whether this is related to inorganic, organic or Organizational[1] contexts; the view we will present is applicable to all of these, albeit in a manner which depends on their recognizable individual characteristics. We will clearly distinguish between systems that may be said to be hierarchical and those that may not and elaborate the general characteristics of hierarchy itself. A critical aspect is whether these multiple levels, or scales, are logically independent or not and whether they are real aspects of a system or conveniences as an aid to comprehension. Do hierarchies really exist in nature or are they merely mental conveniences? In any case, ontology is always a supposition. However, we believe that nature *does* create hierarchical systems, which we can model in a hierarchical manner. Consequently, the descriptions we will present apply equally to ontological and epistemological points of view.

We will find that complexity always plays a part in all large multi-scaled systems, whether we are aware of it or not. Talking about complexity makes no sense without models: creating models creates complexity. However, the complexity we will refer to is that described by Rosen (Rosen, 1991) rather than that associated by Kolmogorov with digital strings (Kolmogorov, 1998). Rosen has stated that

> A system is simple if all of its models are simulable. A system that is not simple, and that accordingly must have a nonsimulable model, is complex.

This implies that Rosennean complexity of this kind is in some way associated with logical incompleteness. Somewhat surprisingly, we can even find this in simple arithmetic. If we take the summation $1+2=3$, then there is at first sight no problem, but the 'equals' sign (=) is supposed to indicate a symmetrical 'left-to-right'/'right-to-left' operation, which is in fact not the case. Such an equation is hierarchical, and although we can straightforwardly derive the result '3' of summing '1 + 2', we cannot so easily go in the other direction. Our concluded '3' on the right-hand side could ambiguously originate from '1 + 2' (or '2 + 1'), '1 + 1 + 1' or even '3' on the left. Left-to-right is 'correctly' computable in Turing's terms, but right-to-left is not; even here, we can find Rosen's incomplete complexity! The situation is even worse if we attempt to apply this simple mathematics to a real situation: is the result of adding one apple to one apple just a single bigger apple? No, one apple plus one apple is always equal to one apple plus one apple.

We should distinguish between Rosennean complexity and that associated with digital strings that encode some aspect of nature. In that the latter does not suffer *per se* from logical incompleteness,[2] we would prefer to refer to it as *complication*, rather than complexity. Reference to Rosen's complexity immediately invokes the layman's description of *chaos*, but now we must

[1] We will use a capital letter, as in *Organization*, to distinguish between the relational 'organization' of any system and a *substantive* human 'Organization' in the business or industrial sense.

[2] While not forgetting Gödel's (Berto, 2010) conclusions.

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distinguish between this—which we will refer to as *chaos-L*—and the subject of the scientific study of *chaos theory* (Kellert, 1993)—which we will refer to as *chaos-S*. This latter, chaos-S, is in many ways the exact opposite of chaos-L, in that chaos-L implies an absence of order, whereas chaos-S describes a style *of* order. We shall see later that chaos-S *itself* effectively splits into two parts, one deterministic, one not, but for the present, we will content ourselves with our initial distinction of human and scientific descriptions. We can make sense of these opposite understandings of chaos-L and chaos-S by looking a little more into the latter. Chaos theory addresses situations where, although it is difficult to precisely determine a system's state at a given point in time, it is possible to see over *extended time* that the system's state approximates to one or more rather vaguely defined conditions, referred to as *attractors* (Milnor, 1985). Consequently, the distinction between chaos-L and chaos-S is one of perception rather than fact: the two are simply models at different levels of description—one (S) being more defined than the other (L).

This immediately injects into our considerations the idea that even conceptual descriptions exist within a framework of multiple scales or levels, and we are dragged into our stated area of *hierarchy*. A good example of this kind of conceptual hierarchy is given by the historical progression of descriptions of an atom, first conceived of in the period of the ancient Greek philosophers (Furley, 1987) and conventionally expanded into great and complex detail within quantum mechanics. Its initial evocation was one of a fundamental indivisible construction block for nature. Later, it was hypothesized that negative charges were distributed in a positively charged sphere [Thomson's 'plum-pudding' model (Thomson, 1904)]. Further experimentation and conceptualization resulted in a sun-and-planet model (Bohr, 1913), with electrons as planets orbiting the atom's nucleus as sun, and this has now been superseded by a quantum mechanical description, which attributes the electrons to probabilistic 'orbital clouds' in energetically-constrained shells around the nucleus (Liboff, 2002), and describes the nucleus itself as something of a 'liquid-drop' of protons and neutrons (von Weizsäcker, 1935).

Conventionally, we always tend to view the latest incarnation of a multiply-scaled modelling scheme as *the* correct model, but more realistically, any of them may be convenient and sufficient for a particular contextual purpose. A second excellent example of this kind of hierarchical modelling is provided by the electrical conductivity of a semiconductor (Azároff and Brophy, 1963) where the conventional electronics of silicon computer-chip manufacture has until recently depended on the sufficiency of description of an electron as a classical particle endowed with a number of quantum mechanical attributes (Sze, 1981), but which following progressive reduction in the size of the physical features of a chip is now forced to treat electrons as fully quantum mechanical entities (Klimeck, 2010). If we then move to electrical conduction in a physically less-symmetrical material like arsenic, we find that it is even no longer possible to maintain that the entities constituting an electric current in a magnetic field are always *either electrons* or *the holes* from which they may be absent (Jeavons and Saunders, 1968)!

The route we will take is one which begins from ideas of physical *scale*—as a replacement for *size* as a primary description—and progressively moves towards the integration of these ideas into more abstract domains. We will maintain that in any and all areas of study or description, these ideas can play a vital role in explaining the hierarchical properties of very large systems, and that in all cases, complexity enters into the picture. We will conclude that the natural hierarchies we describe appear to be a part of the reality of nature itself, and not merely a human formulation, which we superimpose on reality.

A PHILOSOPHICAL STARTING POINT

It has often been stated that things only exist as a consequence of their absence. This was formalized in the 20th century by Lupasco (Brenner, 2010) and has been expanded into a complete philosophical scheme by Brenner (Brenner,

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2008). Brenner's *Logic In Reality* (*LIR*) posits fundamental rules:

> LIR1: (Physical) Non-Identity: There is no A at a given time that is identical to A at another time. This formulation is essentially that of Leibniz.

and

> LIR2: Conditional Contradiction: A and non-A both exist at the same time, but only in the sense that when A is primarily actual, non-A is primarily potential, and vice versa, to a reciprocal extent.

The critical aspect here is the manner in which a new, higher-level representation can emerge from a pre-existing lower-level one. Our own point of view is based on a modification of Brenner's argument that

> LIR3: Included (Emergent) Middle: An included or additional third element … emerges from the point of maximum contradiction at which A and non-A are equally actualized and potentialized, but at a higher level of reality or complexity, at which the contradiction is resolved.

We would maintain that any entity emerges from its natural environment in the manner that an organism species can be said to co-evolve with a nascent natural niche, which it colonizes and adapts through its presence. If we artificially remove such a species from its natural environment, we are, however, *not* left with a 'hole' in the environment, which is the exact opposite of the species itself: a genotypic *bear*, for example, is not exactly the opposite of the consequent genotypic *bear-hole* (Kineman, 2009). This leads us to a possible re-identification of *A* and *non-A* in Brenner's philosophy: if *A* is an emerged entity, then *non-A* is the overall implication of its fully-fledged environment and not simply its formal opposite.

We will see this identification emerge (!) in the treatment we will present of multi-scale systems: it is an unavoidable characteristic of large Organizations, and is associated with the inevitable presence of complexity. For clarity, however, we will later need to distinguish between two kinds of emergences: ones which are apparently at the level of environment itself, and ones which appear to be at a higher level—although these are aspects of the same overall process, and, consequently, this is a conceptual rather than a fundamental distinction.

An important aspect of this ubiquitous reality of the included middle appears in the usual distinction between epistemology and ontology. Conventionally, these are considered to be entirely separate, but this is never the case. Different contexts indicate differences in the coupling between the two, but as in Brenner's (2008) conceptualization and our own treatment, their supposed relative independence provides the unattainable extremes of a dual system, where epistemology excludes ontology, and *vice versa*. More realistically, Scientific investigations *depend* on a presupposed ontology, and ontological structure and its supposition are related to the investigative methods available. Contextual effects may present more-or-less independent appearances of the two, but they remain always to some extent coupled as an included middle.

A CHARACTERIZATION OF SCALE

If we are to replace size by scale in our considerations, then we must be precise about their distinction. Matsuno (Matsuno, 2000) has described the interactions between entities as a *mutual measurement*, and we adopt this point of view in defining *perceptual scale*. In treating any entity or size-related or function-related group as a measuring instrument, we must take account of a *real* instrument's lack of infinite sensitivity. In practical terms, this is described as a measuring instrument's *bandwidth*—or, in our context, the range of sizes to which it is functionally sensitive.

Figure 2 indicates how this works for a multi-elemental-size multi-scale system, where each scale is characterized by its own size and its own particular size-perceptual bandwidth. As Figure 2(a) suggests, a system whose individual-scale bandwidths are large will not exhibit much in the way of scale-related effects—as in the case of a crystal, for example (Cottam and Saunders, 1973). However, if the size-perceptual bandwidths are small when compared with the system's entire range of sizes (Figure 2(b)), then

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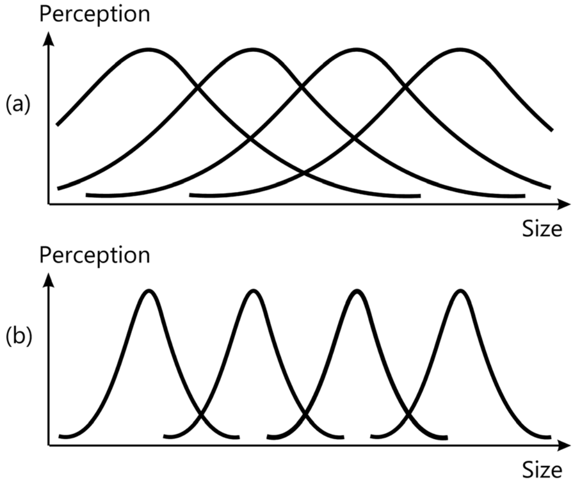

Figure 2 (a) Coupling between a number of scales of a system of wide perceptual bandwidths and (b) near-isolation of a number of scales of a system of narrow perceptual bandwidths

strong scale-related phenomena can be expected —as in the case of an organism.

Although we have indicated that scale plays an important role in the context of physically real size, analogous effects are obtained if we describe a system in terms of function rather than size. The traditional format of a large Organization was one of formal hierarchy, where different levels of organization were fixedly constrained to only functionally communicate in a limited manner across adjacent levels. More particularly, priority was clearly established 'from the top downwards', without great account being taken of influence 'from the bottom up'. This evolved towards the end of the 20th century to a model of more informal inter-level functional communication, resulting both in levels' extended cross-scale perceptual bandwidths and more top-down/bottom-up symmetry. In our investigation of hierarchy, we will need to take into account not only the perceptual bandwidths of individual scales but the way in which bandwidth limitation partially closes off different scales from each other,[3] resulting in the emergence of locally-scaled autonomies.

[3] This partial 'translucent' closing-off of scales, or of elements within scales, automatically incorporates *heterarchy* into our treatment of hierarchy.

THE DEVELOPMENT OF HIERARCHY

A primary characteristic of any defined collection of entities is the degree to which they are, or are not, integrated into a single system with uniquely system-dependent components. The principal distinguishing feature of such a single system, then, is its unification. Given, therefore, a multi-scale system, how are the scales integrated into a recognizable whole? The descriptive medium of this context is that of hierarchy, whether we are referring to inorganic entities, organic ones, or large human Organizations. We will adopt the pictorial device for a *model-hierarchy*, which is indicated in Figure 3: each level of the hierarchy corresponds to a scaled model of the complete system, which is being represented. In the light of currently developing views of physics and biology, and our earlier comment about late 20th century Organizational development, we intentionally represent a hierarchy from right-to-left, rather than top-to-down, to avoid any automatic presumption of top-down precedence. The vertical line-lengths in Figure 3 indicate the quantity of information required at each scale or level to characterize it as well as possible: describing a tree as 'a tree' requires less information than its description in terms of individual biological cells; representing an Organization as

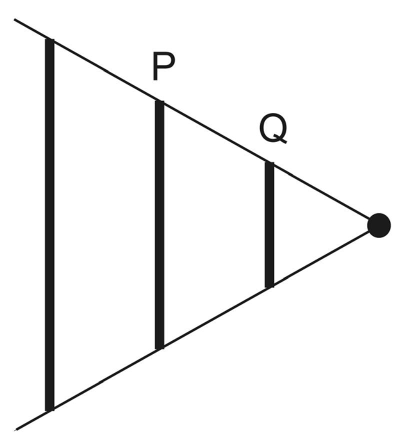

Figure 3 The imaginary pictorial representation of a model-hierarchy. The nominally highest level—corresponding to the simplest representation—is on the right-hand side. Vertical line lengths correspond to the relative quantity of information that would be required to describe the complete represented system at that scale

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its CEO requires less information than doing so in terms of all of the employees. So, the 'highest'—and therefore simplest—level of representation is on the right of Figure 3; the 'lowest'—most complicated—is on the left. Pattee (Pattee, 1973) has pointed out that the presence of hierarchical structure in a system implies that there is necessarily more than one valid systemic description available. If the basic system description is in terms of particle dynamics, for example, then a higher hierarchical level will be in terms of a statistical treatment of the dynamics, which subjugates the detail of individual particle properties. This supports our contention here that a *model*-based hierarchical description is the most essential representation of a (hierarchical) system.

It will be immediately evident that this hierarchical description is a *very* particular one, in that it identifies each and every individual scale as a *complete* representation of the entire entity, whether inorganic, organic or Organizational: it is in no way accidental that we referred to 'a tree's description *in terms of* individual biological cells' or to 'an Organization *as* its CEO'. This is a *model-hierarchy*, where each level is a scaled model of the *complete* entity under consideration, distributing autonomy and responsibility for the whole throughout the entire structure (Cottam *et al*., 1999). Pattee (Pattee, 1973) supports this recourse to model descriptions:

> … in hierarchical organizations we should overcome our traditional classical emphasis on the structural levels and recognize the essential role of the descriptive levels in maintaining and coordinating organization.

A major advantage of resorting to a model-based description is that structure and process can easily be integrated into a single representation of hierarchy. At first sight, this integration of structure and process into a single representation appears to contradict Pattee's (Pattee, 1973) view that

> … the relation between the structural and descriptive levels is the central problem that must be solved to have a theory of hierarchical control.

However, the problem still remains of how to construct the different levels of a representation to include all the necessary properties.

To see the importance of this conceptual modelling move, we must start by taking a couple of steps sideways, to look first at a conventional characterisation of hierarchy, and second at the distinction between contexts to which we can justifiably attribute hierarchy and those to which we *cannot*.

Salthe (Salthe, 1985; Salthe, 1993) has published extensively on the subject of hierarchy, concluding that there are only two acceptable forms: *compositional* hierarchy and *subsumptive* hierarchy (Salthe, 2012). An example of his *compositional* hierarchy could be the set of physical scales (atom, molecule. biomolecule. cell. organism and population) representing a living system (Salthe, 2012). This, unfortunately, takes no account of the organization at a particular scale, whether this is between biomolecules, cells… Consequently, it is unsuitable for the generic description of Natural entities, most particularly for entities whose character is as much based on internal organization as internal content, as for living organisms or human Organizations (see (Rosen, 1991) for Rosen's extensive considerations of relational biology). Compositional hierarchy appears to only be a dimensionally reduced form of the model-hierarchy we are describing. Salthe's *subsumptive* hierarchy could be (physical forces, chemical attractions and biological forms) (Salthe, 2012). However, he points out that for a subsumptive hierarchy

> control by the higher level … descends through all the levels simultaneously (Salthe, 2012),

which contradicts the conclusion we stated earlier with regard to inter-scale interactions in a hierarchy. Certainly, such an immediacy of cross-scale information transfer would not fit a conventional view of intra-Organizational communication, although current social media do to some small extent negate this objection, if at the same time they risk injecting instabilities. Consequently, we do not consider his subsumptive hierarchy to be an example of the generic model-hierarchy we are describing, and it again appears to be a dimensionally reduced form.

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Salthe's description of a structure where there is instantaneous top-down interaction corresponds to that of a class of system representation we would describe as a *convenience* hierarchy. This is where there is no real hierarchy at all, and all sizes or functions are 'transparently' accessible. Although examples of this kind of 'hierarchy as an aid to visualization or understanding' abound, the most illuminating instance is that of a digital computer. Here, there is complete logical transparency between all the 'definable' levels—bios, system, application, user interface… Any 'hierarchy' that exhibits such a logical transparency is no hierarchy at all, because it will collapse into a single level of organization (Cottam *et al*., 2005). This objection appears to apply to Salthe's subsumptive hierarchy, which then becomes a convenience hierarchy. For a digital computer, the conclusion is even more restrictive, in that the synchronizing clock signal also completely isolates each and every logical gate, reducing the computer's operations to those defined by its constructor or programmer and eliminating *any* other global effects or interactions. This makes a digital computer incapable of generating any of the informationally-integrative features of intelligence or consciousness (Schroeder, 2012; Tononi, 2004).

Unification of an entire hierarchical assembly will depend on communication and coordination between adjacent scales of its organization. If we wish to establish communication between, for example, scale P and scale Q in Figure 3, we will see the problem of '$1+2=3$' reoccurring: in an analogous manner, P contains far more information than does Q. Not only does this present us with the problem of how to compress P into Q, it leaves us in Q with insufficient information to precisely access or communicate with P. It also implies that in any multiple-level system of this kind, the individual Organizational levels or scales are necessarily separated by Rosennean complexity! Simon (Simon, 1996) has described hierarchies as *nearly decomposable systems*. Given a system that is decomposable, it would be possible to separate out exactly all of its components without there being any influence between them. Notably, for a decomposable multi-scale system, it would be possible to separate out exactly all of its different scales. However, such a logically consistent hierarchy would collapse into a single level (Cottam *et al*., 2005): a multi-scale decomposable system cannot exist, and, consequently, *all* real hierarchies are only partially decomposable. Simon (Simon, 1996) formulates his representation of hierarchy as a *nearly decomposable matrix* of intra-level and inter-level 'coefficients', where intra-scale properties and phenomena dominate inter-scale ones. Although there will *always* be a degree of complexity between the levels of a multi-scale system, the reality of system unification implies that this will never be so extreme as to completely eliminate inter-level communication. Inter-level complexity is particularly recognizable as a generic feature of hierarchical human Organizations whose effective unification then appears to require a degree of magic! However, natural entities or organisms *do* present a unified appearance, so how do *they* deal with their cross-scale accumulations of complexity?

If the different scales are associated with different kinds of phenomena, then the appropriate formalisms at the different scales may be *very* different, and our metaphor of '$1+2=3$' will then be far from sufficient: the '=' will most generally be replaced by a multiply fractal transfer function (Cottam *et al*., 2004). Natural (ontological) hierarchies and their (epistemological) representations share this common characteristic [we should remember that if inter-scale relationships are logically complete, then the scales will collapse into a single representation (Cottam *et al*., 2004)]. Individual scales tend—if not completely—towards simplicity or complication and not complexity, as this facilitates computation as a representation of internal processes. Complexity is consequently squeezed out of the scales into the inter-scale regions (Cottam *et al*., 2004). The implication is that the majority of complexity in a multi-scaled system or organism resides in the inter-scale regions. It has been shown in artificial environments that a system's internal complexity mirrors the degree of complexity of the environment (Auerbach and Bongard, 2014).

Referring once more to Brenner's *Logic In Reality* (Brenner, 2008), we find that the organization at a particular level of a system will be moderated by the constraints that are operational at that level. But where do those constraints

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originate? In Natural systems, local constraints are imposed by a system's environment. Is this so in human Organizations? Well, yes and no: some will indeed be environmental, but some are imposed from an abstract preferential point of view. And the constraints are most evident in the way they restrict a scale's interaction with its adjacent scales—*in the complex regions between scales*. This makes the complex regions analogues of an organism's environment, or ecosystem, in a manner that corresponds to von Uexküll's (von Uexküll, 1987) biosemiotic description of the constrained *umwelt* of a particular biological species.

HIERARCHICAL ECOSYSTEMIC STRUCTURE

Figure 4 illustrates the relationships between the extant scales of a system and the complex regions

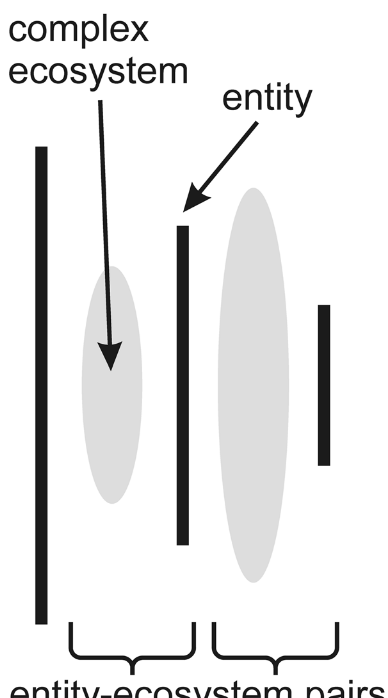

Figure 4 The relationships between the extant scales of a system and the complex regions between adjacent scales. The resulting entity-ecosystem pairs are indicated. Each entity-ecosystem pair describes the entire system as well as possible at that scale. Consequently, the more information that is included in the extant model, the less is attributable to its associated ecosystem, and vice versa

between adjacent scales (we have left out the extreme left and right-hand ends of the structure for a reason, which will later become evident). Each scale constitutes a more (to the left) or less (to the right) complicated model of the entire system itself. Different scales are described by differing degrees of information (Figure 3), and the sequence from left towards right of Figures 3 and 4 can be formulated as a progressive reduction in the degrees of freedom of the instantiated models. Each model corresponds to the emergence from its preceding more complicated model—to its left—of a specific scale of representation of the system. Its character is modulated and ultimately defined by the intermediate complex region through which it has emerged, and, consequently, this complex region has the character of its *ecosystem*, evaluated *at that scale*. The hierarchical scheme now consists of *entity-ecosystem* pairs (Cottam *et al*., 2000), as indicated in Figure 4. Each pair describes as far as is possible the entire system *at that scale*. At each scale, the more the information required to describe the extant model, the less is attributable to its associated complex region, and *vice versa*, in a manner related to the idea of *hidden variables* in quantum mechanics (Holland, 1993). Surprisingly, analogously to the relationship between the various extant scale models, the complex regions are *also* all correlated, and they make up a second *unified hierarchical structure* (Cottam *et al*., 2008), but one which is inverted in sense with respect to the first one (Figure 5).

The character of the complex inter-scale regions changes between the left and right of Figure 5. At the right-hand side the system is characterized by a very simple model. Consequently, its ecosystem—containing all of the remaining information required to describe the system—is very complex. We equate this complexity to one of two extreme forms of the Scientific *chaos-S* we referred to earlier, in that it represents a context within which causality is undefinable: *complex chaos*. At the left-hand side of Figure 5, the extant system model is very complicated, and the 'complex region' is very simplistically defined. Here, it equates to the generation of chaos from a simple equation: *deterministic chaos*. Intermediate complex regions exhibit intermediate forms of complexity or chaos.

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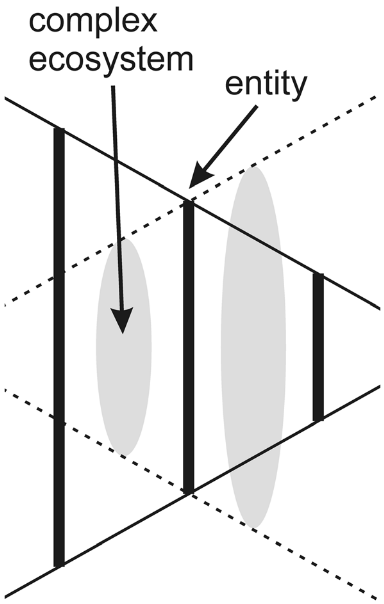

Figure 5 The complex inter-scale regions make up a second hierarchy opposed in sense to the first one

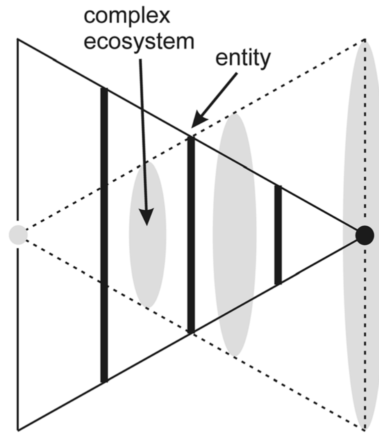

Figure 6 Combination of the dual hierarchy and our interpretation of part of Brenner's Logic In Reality (see, importantly, Footnote 4). At the left and right extremes of the representation, elements of the two hierarchies coincide, as exactly defined analogues of Brenner's opposite A and non-A, whereas in the intermediate region, there is an evolutionarily-based split between a local representational entity and its associated ecosystem

It is now possible to propose an extrapolated relationship between Brenner's (Brenner, 2008) *Logic In Reality* and our hierarchical scheme (Figure 6). We feel that Brenner's *LIR2* quoted earlier corresponds to a situation where it is possible to precisely define his *A* and *non-A*.[4] This would obtain at the extreme left and right-hand sides of our dual hierarchical scheme. Consequently, at these extremes, emerged model and ecosystem coincide. At the left-hand side, we find a model of pure nonlocality (Cottam *et al*., 1998) and of dimensionless particle; at the right-hand side, a model of pure isolated logic (Cottam *et al*., 2004) and infinitely-dimensioned wave. In between these two physically unattainable extremes lie the various extant models of the system and its ecosystem (Cottam *et al*., 2013), which emerge as *real* less-than-precisely-defined spatio-temporal variations of Brenner's *LIR3* between nonlocality and localization. Pattee (Pattee, 1973) mirrors this dual relationship

> On the one hand, there is the very simple quantum mechanical system for which we assume a complete dynamical description in time, but which exhibits a necessary indeterminism when we attempt to observe or control it. On the other hand, we have symbolic logical systems for which we assume precise deterministic operations under our control, but which exhibit incomplete and unpredictable behavior when we try to solve certain types of computational problems. We might say that sufficiently simple natural structures are predictable but uncontrollable, whereas sufficiently complex symbolic descriptions are controllable but unpredictable.

Tellingly, Pattee (Pattee, 1973) recounts, in agreement with the position we state here, that

> In contrast to systems theory, hierarchy theory must be formulated to describe at least two

[4] It should be noted that Brenner would not agree with this characterization: he would maintain that the extremes we refer to are simply the limits of classical logic or probability, and that they should be ignored. We agree with his conclusion as to their character, but do not feel that they can be ignored, as we consider them to be a necessary part of an extended interpretation of 'reality' itself. This corresponds to a view that both Plato and Aristotle were right, and that their points of view should be integrated to obtain a more complete picture.

[5] Pattee's requirement for the description of 'at least two levels at a time' is a restricted view of the situation. Salthe (Salthe, 1985; Salthe, 1993) insists that three levels are required for completeness, as there will be two pairs of relationships associated with any level we focus on: one from that 'below', and one from that 'above'. We would agree with Salthe.

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levels at a time,[5] it must optimize constraints for a given function, and it must allow interactions between alternative levels. Since there is no obvious way to extend the dynamical language to encompass these requirements, perhaps hierarchy theory will require a dualistic or parallel type of theory not unlike the wave-particle duality of quantum mechanics, here neither description alone is adequate, but where simultaneous use of both appears inconsistent.

FROM HIERARCHY TO HYPERSCALE

Let us perform a short taking-stock. The generic model-hierarchy we are describing consists of a number of differently characterized 'lowest' to 'highest' scales (or levels) of size or function, where adjacent model scales are separated by Rosennean complexity and individual scales are endowed with a degree of autonomy [see (Cottam *et al.*, 2003; Cottam *et al.*, 2004) for a more complete treatment of generic hierarchy]. Interactions between adjacent scales are 'translucent' through inter-scale complexity, and those between non-adjacent scales are through both the informational or functional moderation of intermediate scales *and* inter-scale complexity. Consequently, any and all inter-scale interactions are difficult if not impossible to locally qualify or quantify. We say *locally* qualify or quantify because the unification of a hierarchical system implies that these interactions *are* indeed characterized, even though this at first sight appears contradictory.

So, we are left with a quandary: in our generic model-hierarchy it is virtually impossible to locally qualify or quantify inter-scale interactions in an exact manner, but the complete assembly of scales is unified into an existent identifiable system. The clearest example of this phenomenon is that of an organism, which we will adopt as a limited metaphor for larger scale Organizations [see Miller (Miller, 1978) for the proposition that human Organizations can be considered as living systems]. It would be difficult to accept that a (multi-scale) organism does not exist! But it is the apparent *abstraction* of its unification, which we observe, and which somehow regulates interactions between its various Organizational scales (Cottam and Ranson, 2013). We find it necessary to attribute a character of *reality* to some kinds of abstraction, notably to those abstractions which are embodied—as is the system unification we are here referring to (Cottam and Ranson, 2013). The reader's attention is drawn to the philosophical implication of this projected conceptual move. Justification can be found in a combination of our arguments and Brenner's 'emergence from the contradiction of A and non-A' in his *LIR3* (cited earlier): reality emerges from *the concrete* and *the abstract* in opposition (note our earlier insistence that epistemology and ontology form a dual extreme system from which the included middle emergences as an embodiment. This can possibly give us a distinctive separation between what we have described as real and convenience hierarchies: in real hierarchies epistemology and ontology are coupled into an emerged middle; in convenience hierarchies, they are entirely separate. As Pattee (Pattee, 1973) points out, for a real hierarchy, this maintains

> … the essential Hertzian parallelism; i.e. the consequences of the description must describe the consequences of the natural events.

This, then, resolves our quandary: local inter-scale interactions can be modulated by the *real* higher-level abstraction of unification. This higher-level abstraction has a very special character, as it constitutes a *real* model of the entire translucent scale assembly, but one in which all of the scales can be accessed *as if* they were logically transparent: it is referred to as *hyperscale* (Cottam *et al.*, 2006),[6] as indicated in Figure 7. Hyperscale is the very nature of any and all

[5] Pattee's requirement for the description of 'at least two levels at a time' is a restricted view of the situation. Salthe (Salthe, 1985; Salthe, 1993) insists that three levels are required for completeness, as there will be two pairs of relationships associated with any level we focus on: one from that 'below', and one from that 'above'. We would agree with Salthe.

[6] It is tempting to draw a relationship between the inter-scale transparency of such a hyperscale representation and Salthe's (Salthe, 2012) submission that in a 'subsumption hierarchy' 'control by the higher level … descends through all the levels simultaneously.'

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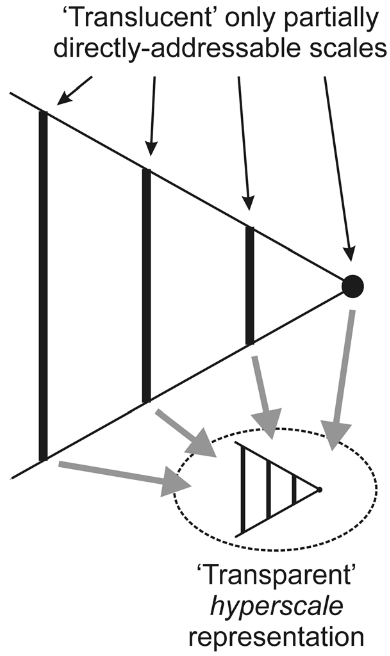

Figure 7 The emergence from a multi-scale hierarchy of the internally-transparent hyperscale representation of its real unification

unified entities we observe or refer to: of a crystal, an organism, an Organization. The multiplicity of complexities evoked by a multi-scale system is absorbed into an overall lack of precision and exactness in the simplified transparent hyperscalar definition of an entity. For a crystal, these complexities are limited in influence: description at the macroscopic level of the crystal is nearly [but not exactly (Cottam and Saunders, 1973)] the same as that at the microscopic level of its unit cell. For an organism, however, the situation is *radically* different, in that each scale's information content is drastically unlike that of any of the others. Human Organizations are to some extent logically built on the representation of humans by their simplified hyperscales, so although they may be complex, they will typically be less so than the internal organization of a single organism.

DISCUSSION

A complex system can be said to consist of a number of parts or sub-elements whose integration produces properties, which cannot be directly deduced or induced from those of its constituent parts. This closely resembles a definition of *Science*, where on the basis of integration of a number of (measured) pieces of information, a higher-level hypothesis is generated through *abduction*—or guesswork, as Peircian semiotics (Peirce, 1931-1958) would suggest. A system's complexity may vary between a pair of conceptual extremes: one of exhibiting Rosennean disorganization resulting from the less-than-correlated interaction of a large number of sub-elements; the other of an emergent organization, possibly even from a very small number of sub-elements. These two complexities correspond to the two variants of *chaos-S* we discover in the hierarchical formulation we have described—*complex chaos* and *deterministic chaos*, respectively. It will be clear not only that both of these may be observed in a single system, but that there may also be a number of intermediate conditions (see, for example, Figure 6). We pointed out earlier that it would be helpful to clearly distinguish between emergences, which are apparently at the level of environment itself, and ones which appear to be at a higher level. To this end, we will consider both *emergence* in a hierarchy and its converse, which we will refer to as *demergence*.

Emergence itself in a hierarchy is not the end of the matter. Pirsig (Pirsig, 1991) has neatly described the process of emergence of a new condition:

> A Dynamic advance is meaningless unless it can find some static pattern with which to protect itself from degeneration back to the conditions that existed before the advance was made. Evolution can't be a continuous forward movement. It must be a process of ratchet-like steps in which there is a Dynamic movement forward up some new incline and then, if the result looks successful, a static latching-on of the gain that has been made; then another Dynamic advance; then another static latch.

This is not unlike Deacon's (Deacon, 2012) proposition of *entropy ratcheting* in living systems. It suggests that emergence may be presaged by a number of smaller 'adjustments', which promote the ultimate 'latching' of a new condition. An excellent example of this process

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has been provided by Lohman (Lohman, 1992) in the field of artificial life. His experiment was to apply genetic algorithm techniques to the optimization of a seven-sided closed-loop structure over a large number of recursive generations. He found that his closed-loop structure underwent many small modifications over a very large number of evolutionary generations before finally, very quickly, flipping from a closed O-shape into a new open C-shape. This mirrors Pattee's (Pattee, 1973) statement that

> We have learned from our experience with building and managing complex organizations that when the complexity of any level grows beyond a certain range, function becomes impaired, operation becomes inefficient, and reliability declines. We know that ad hoc corrections and local improvements in efficiency can only go so far in correcting the problems, and that sooner or later we must face a total 'reorganization' of the system that must essentially alter the hierarchical control and levels structure.

In the context of our dual hierarchy, the process is even more complicated: Figure 8(a) indicates the sequence of operations that would take place, taking account of the partial inter-dependence and partial independence of the two hierarchies. Following Pirsig's 'pre-latching' effects, emergence from *J* to a new scale *K* can occur, under the partial influence of complexity *P*. This of necessity produces a new scaled environment *P*. Coherence of the second (ecosystemic) hierarchy is now disturbed, resulting in modification of the previously-scaled ecosystem *Q*, under the partial influence of scale *J*.[7] *J* is now in an altered environment, and it is forced to adapt, leading to a new cycle of $J \rightarrow K \rightarrow P \rightarrow Q \rightarrow J$, and so on iteratively. The consequent effect on *J* has been described as *slaving* by Haken (Haken, 1984), or *downward causation* by Salthe (Salthe, 1985). Ultimately, stabilization of *K* depends on convergence of this sequence; otherwise, *demergence* of the new condition will occur, as indicated in Figure 8(b). Partially *P*-complexity-mediated collapse of *K* back into *J* progressively results in modification of *Q*, and then in a partially *J*-scale-mediated modification of *P*—which will finally disappear at the end of this reverse cycling. It is important to note that Figures 8(a) and 8(b) are in no way exact replicas of the sequences: ultimately, it is impossible to draw them precisely, and the figures should just be used as rough guides. We should remember that information and previously-existing propensities are lost in the process of evolutionary up-scaling or latching (Root-Bernstein and Dillon, 1997):

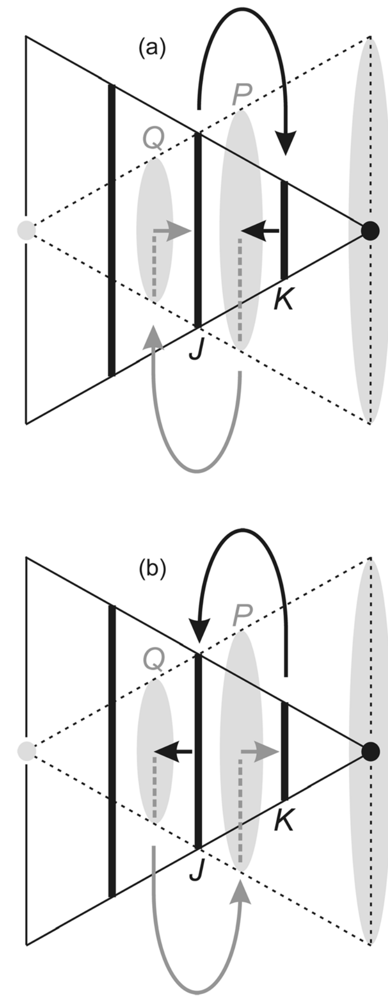

Figure 8 (a) The recursively looping emergent sequence in a Natural hierarchy—from J to K to P to Q to J and (b) the reverse looping demergent sequence—from K to J to Q to P to K. It is important to note that ultimately either of these processes would result in re-correlation of the entire structure, and not just the two levels indicated

[7] Ultimately, *all* the levels of the hierarchy will re-correlate, not just *Q*.

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at each step of sub-assembly, huge numbers of possibilities are eliminated.

Looking at the process of demergence more precisely, the new *J* resulting from collapse of *K* can therefore *not* be exactly the same as it was before, thus corresponding to a new emergence at the level of *J*'s environment.

CONCLUSION

We conclude that a model-hierarchical formulation of multi-scale systems can be effectively used to represent all large natural systems, from inorganic and organic to human Organizations. In all cases, we must take account of a system's environment, not only in general, but at each extant scale, where it operates as a *scaled ecosystem* for the locally-scaled representation of the entire system. This locally-scaled ecosystem can be associated with differing types of chaos, depending on its location in the overall scale framework. The most extensive system description is associated with the simplest type—*deterministic chaos*—whereas the simplest system representation is associated with the highest degree of ecosystemic Rosennean complexity we refer to as *complex chaos*.

We believe that related processes of *emergence* and *demergence* occur in *all* domains of nature, from inorganic through organic to Organizational contexts. The growth of a material's crystal structure from an fluctuatingly-cooling liquid resembles an emergent-demergent sequence, in that atoms provisionally attach themselves to the stabilizing crystal matrix, and either stay immobile there or re-enter the liquid phase, depending on temporal effects. The emergence of our metaphoric genotypic *bear* modifies not only the pre-existing nascent ecosystemic niche, but to some extent the entire ecosystem, as demonstrated by the lack of its exact correspondence to the allegorical genotypic *bear-hole*. Its local introduction followed by disappearance allows the local ecosystem to temporarily revert to an approximately previous state. The appearance of a directed task-force in a human Organization not only modifies its immediate environment, it also leaves its members changed following its dissolution. Above all, the temporary quasi-stabilization of an organism attained in achieving life eventually disintegrates leading to death.

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