

Toward bridging the gap between life and physics



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ABSTRACT

Examination of the scale properties of living organisms and the electronic configuration of crystalline structures suggests that related modeling may be used for both. This paper comments on individual and common properties of the two systems and draws a comparison between them. Both exhibit multiple 'scales' separated by complex or forbidden regions and a global 'overview' of their scale properties. We conclude that the analogy may provide a fruitful route toward extension of the modeling of both living organisms and electronic materials, by permitting bootstrapping cross-modeling between them.

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1. Introduction

The results of many and varied investigations over the last century have only gone to show that there is a wide gulf between our understandings of conventional physics and of living systems. Nowhere is this more obvious than in a comparison between the virtually universally accepted precise modeling of solid state physics and the multiplicity of unrelated or contradictory representations of living organisms. Most notable among the latter are Miller's (1978) eight levels of living-system complexity, from biological cells up to supranational organizations, and Rosen's (1991) radically different Metabolism and Repair (M, R) internalization of efficient cause. A major focus of our attention in this paper will be on the nature of *scale* – the way in which differently sized levels or groupings of a system's constituents may exhibit diverse properties. Unfortunately, while solid state physical modeling now primarily advances by incrementally addressing more and more detail, none of the currently available well-known models of organisms even reproduce all of the most salient features of a multi-scale living system. Miller's (1978) model, for example, provides no concrete representation of communication between his different levels; Rosen's (1991) takes no account at all of an organism's scaled differences in character.

A major distinguishing feature between the inorganic physical solid state and organisms is that, while inorganic physical materials exhibit a degree of difference in informational content across their scales, it is neither so complex nor functionally integrated as in living systems. By *scale* we will in general refer to more than just size. Differently sized sub-elements of a system relate in different perceptual ways to their surroundings – to their local *environment*. These surroundings may be common to the differently sized

sub-elements, but not all of their aspects will be relevant to each of atoms, molecules, biological cells, etc., in a way which is analogous to von Uexküll's (1987) biosemiotically differing *umwelt* for different biological species in one and the same natural environment. Difference in scale then corresponds to difference in environmental perception. This makes it possible to extend the idea of 'scale related to physical dimension' to 'scale related to organization or functional complexity', thus establishing scale as a property of cognitive activity, for example. A serious defect in the investigator's toolbox has always been the lack of a self-consistent study of scale in *natural* hierarchical structures – notably in organisms. By *hierarchy* we refer to situations in which there is more than one extant scale, and where these sub-elements are coupled together to form a unified whole. This clearly implies that there will be communication and interaction at least between adjacent scales to support the unification of the complete system in question – which identifies directly the nature of a *system*. Fortunately, a self-consistent study of scale in *natural* hierarchical structures is now available (Cottam et al., 2003, 2004a). Surprisingly, even simple crystalline materials show informational differences across scales. A case in point is the collection of zinc-blende structured crystals which comprise the chemical group IV, the III–V and the II–VI materials (Cottam and Saunders, 1973). However, this difference is only less than 1%, or a few %, while organisms exhibit radically different informational properties between adjacent scales, for example between tissues and their constituent cells.

We will present a generalized hierarchical representation of natural systems which is primarily based on structural scale (Anderson, 1972; Cottam et al., 2003, 2004a). We have earlier referred to the necessity for communication or interaction at *least* between adjacent scales of a unified system. An important characteristic of this representation is that different adjacent scales of the same system are coupled together through complex fractal interfaces (Cottam et al., 2004b). A basic difficulty encountered when moving from one structural scale up to a next higher one is

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that while information may be gained in the operation it is at the expense of a loss of information associated with the initial scale. An apposite analogy is the difficulty of actually carrying out the operation $1+2=3$, which is itself hierarchical in a similar manner: degrees of freedom are lost in the operation which yields the higher order '3'. This means that although it may be possible to upscale from '1+2' to '3' (which is, in mathematics, a prior definition by rule, not a punctual discovery), it is impossible to correctly return downscale (e.g. it is impossible from the resultant '3' to know if the lower scale constitutes '1+2', '2+1' or even '1+1+1'). This is the same problem that makes memory necessary in a Boolean computer, where the gates effectively 'throw away' information at each stage. In passing, it is instructive to note that the primary function of the clock in a Boolean computer is to eliminate any local-to-and-from-global communication, making the establishment in a Boolean computer of any phenomenon with global properties impossible – e.g. intelligence; consciousness.¹ This cautionary note should remind us that an abstract model is not subject to the same physical constraints as its phenomenological target. Most particularly, if we are to successfully model a system which exhibits hierarchical properties, we will need at least a hierarchical model to do so.

Our intention here is to provide sufficient description of both living systems and solid state physics to establish each of them as the other's analog. We will set up this analogous comparison in terms of their mutual hierarchical properties, leaving other more individual aspects for later consideration. An obvious initial criticism of this approach would be that the solid state physics of computational applications is dependent on the almost perfect long-range order of their constituent crystalline substrates, which is absent from living tissues. However, firstly many of the chemicals which make up biological tissues present an almost crystal-like appearance, for example the lipid *pdmpg* (Fig. 1). Secondly, it may be that the approximate spatial repetition of cells in tissue is just enough to provide long-range coupling. Thirdly, and most importantly, our aim is not to establish an exact equivalence between the two domains; it is to instigate bootstrapping cross-modeling between the two, as a way of improving both and addressing their future convergence and that of physical and biological modeling in general.

2. Living system scale and hierarchy

Scale is a tricky beast to deal with, the more so hierarchy. It is arguable that the nature of a *living system*² is very different from that normally attributed to a machine. We habitually attribute transparency to a machine's appearance and processes, assuming that the application of reductive analysis to these will result in comprehensive understanding of its structure and operation.³ Effectively, we view a machine as a complicated stable assembly of individually stable elements or sub-units. Such is far from being the case for a living system, where structure and operation depend fundamentally on the *relationships* between quasi-individual

¹ The clock in a digital computer imposes a waiting-time on all the individual processing gates to be certain that all of them have settled down before they are allowed to pass on their results to other gates. This *formally* eliminates any interactions which were not foreseen and planned (in principle!) by the computer designer or programmer: the only global character is that existing in the designer's or programmer's head – *not* in the computer itself. This apparently trivial argument *formally* eliminates any possibility of intra-digital-computer generation of *real* intelligence or consciousness.

² We will refer here to *living systems* rather than *organisms* to emphasize the multi-component *systemic* nature of life.

³ The reader should note that this is a somewhat abstract view of machines, which in reality are often far more unpredictable than we expect – usually at the worst possible moment!

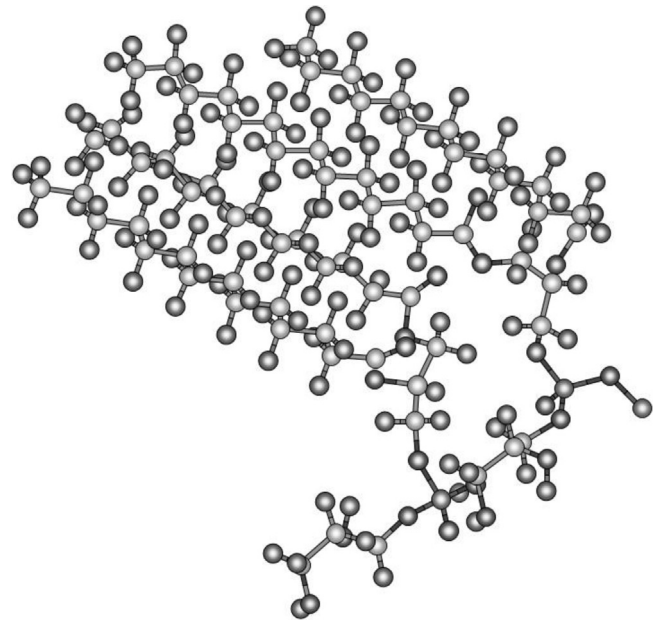


Fig. 1. The crystal-like atomic arrangement of the lipid *pdmpg*.

quasi-stable elements, and reductive analysis *destroys* the character of a system's being alive, rather than revealing it (Rosen, 1991).

Anderson (1972) has characterized in terms of symmetry-breaking the changes in character which may occur when a multi-elemental system is expanded. He points out that:

“The general rule . . . is that the (a) large system is less symmetrical than the underlying structure would suggest: symmetrical as it is, a crystal is less symmetrical than perfect homogeneity”;

and that:

“The essential idea is that in the so-called $N \rightarrow \infty$ limit of large systems (on our own, macroscopic scale) it is not only convenient but essential to realize that matter will undergo mathematically sharp, singular ‘phase transitions’ to states in which the microscopic symmetries, and even the microscopic equations of motion, are in a sense violated”.

Antoniou et al. (1997) have demonstrated that as a quantum system increases in size its *logical completeness* breaks down, leading to irreversibility.⁴ This kind of cohesive loss may be the general precursor of such a ‘phase transition’ which leads to the creation of a new system scale. The picture becomes less clear, however, if we attempt to distinguish between the developmental appearance of *phenotypic* scale and the evolutionary creation of *genotypic* scale. While the former would appear to correspond to this idea of a temporal expansion of system complication, resulting from cellular multiplication, and to that of cohesive breakdown leading to ‘phase transition’, the latter seems to be far more complicated. However, studies within both paleontology (e.g. Eldridge et al., 2005) and artificial genetic evolution (e.g. Lohman, 1992) suggest that critical ‘phase changes’ which lead to recognizably singular transformations of structure or character are preceded by a progressive buildup of detailed geographic or local incoherencies (c.f.

⁴ Gödel (Berto, 2010) has demonstrated that all formal systems are at least to some degree incomplete – implying non-self-consistency across their axioms. Antoniou et al.'s (1997) conclusion is that as a quantum system increases in size the self-consistency of its formal description progressively breaks down, leading to the necessity for probabilistic rather than deterministic description.

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