Organizing Relations and Emergence

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Abstract

Emergence is largely used as an explanation: such and such an object — ranging from atoms through multicellular organisms to consciousness — is an emergent property of some ensemble of parts. But this leaves an inadequate level of understanding, making the term a representation of something almost mystical. For emergence to be useful an understanding of the mechanisms of emergence must be brought out. This paper proposes a system of orders of organizing relations that are the means by which complex objects "emerge" from the interactions of their constituent parts.

Introduction

The term emergence has a somewhat equivocal press. For some it is an explanation for the appearance of wholes or coherent objects in any system of things or understandings; while for others it is either meaningless or, conversely, an invocation of something mystical. The term is applied to the appearance of novel, coherent objects that are not predictable from the isolated properties of the system's parts, functioning as a shorthand for the development of new levels in a hierarchy of organization of complex and adaptive entities. Novelty and coherence are the primary properties of emergent objects. Two questions arise here:

1. How can a new thing come into being if it cannot be predicted by the properties of the stuff that constitutes it? and

2. What confers coherence on something made up of many kinds of parts so that it has obvious existence as a whole thing?

Ultimately the question of emergence is the problem of how any kind of organized system can come into being. How can a collection of things self-organize? Where does the ordered arrangement of the parts, the thing's organization, come from? How can it self-regulate or maintain that organization in the face of the entropy in its environs? These questions apply particularly to biological entities.

Most authors on emergence seem to want to set up an understanding of emergence such that a bottom-up, micro-physical-properties basis for its explanation cannot operate and that only a non-reductionist consideration of the behaviors of objects should obtain. I want to explore this issue here and propose a way in which the explanatory value of emergence can be made consistent with a micro-physical causality understanding of the world. Thus, I will argue that the proper study of emergence is in the study of the organizing relations that operate to link the parts of an ensemble. Artificial Life, then, is the study of the organizing relations that produce the emergence of coherent entities in computational situations.

Kinds of Emergence

For most philosophers there are two kinds of emergence: ontological and representational (Searle 1992). Ontological emergence covers explanations for how objects and organisms can exist in the world given thermodynamics and a causally closed microphysics. Representational emergence covers the development of theories about the things which we are able to observe in the world. Cariani (1991) includes computational emergence, in which "complex global forms can arise from local computational interactions" (p.776) thus modelling similar processes to those which, in material systems, might produce actual emergent objects. It appears, for example, in work on cellular automata and in Holland's work on complex adaptive systems (CAS). Not only can cellular automata replicate themselves, but they produce "gliders", or coherent groupings of cells that emerge from a few explicitly specified rules. Holland probes the properties of CAS and argues that aggregation and self-maintenance are specifically relevant to the study of emergence. Aggregation is a function of organizational hierarchy, and self-maintenance involves the continued coherence of an aggregation despite the flow of resources through it and the perpetual turnover of its constituent parts (Holland 1995).

Here I will consider the emergence of *physical* objects and systems from the *matter* of their constituents, and its simulation in computational emergence, rather than dwell on representational emergence. One of the reasons emergence is adopted as an explanation is that it seems that there are numerous physical ensembles which do not predict the behaviors that these systems, when suitably constituted, may demonstrate. Any climb up the levels of the biological orders produces novel emergent systems, *e.g.* many behaviors of a cell are not predicted by the isolated properties of any of its macromolecular components. In fact many of the behaviors of those macromolecules don't even come into operation until they are integrated into a cell.

There are two flavours of ontological emergence:

Weak emergence, where an object having emergent properties is physically determined by the properties of its lower level constituents, yet would not exist as such without those emergent properties. (Collier 1998).

Radical emergence, where the emergent properties of the whole are *metaphysically incompatible* with the properties and relations of its parts, perhaps involving the appearance of a totally new (e.g. mental) stuff.

In the view canvassed here, the kinds of things that radical emergence is used to "explain" are accounted for in the roles of the feedback relations discussed in the *Taxonomy* section.

Characteristics of Emergent Objects

Emergence is best represented as a jump in hierarchical level of organizational structure of the parts of some system such that they become coherently organized and might be characterized as being something with a new name. The problem of emergence becomes the problem of whether it is meaningful to talk about hierarchical levels of organization in systems, how one might describe the boundaries between levels and how a collection of constituents can actually become a new level. These issues concern every level of science from the jump from quarks and gluons to nucleons and atoms in microphysics, to the difference between collections of organic molecules and cells, to the organization of individual humans into societies. Emergence thus becomes the question of organization and I will proffer a taxonomy of relations by which organization might arise in a collection of parts giving it integrity, coherence and the status of a whole. But we must first cover some of the properties of organized wholes that persuade us that they are emergent.

Emergent systems can be characterised as dynamical processes showing:

a: novelty — Instances of the first time some thing appears in the universe, or the emergence of something new with every instance of a particular organization of constituents (Bickhard 2000).

b: unpredictability — The unpredictability of the properties of something is at the very basis of calling it emergent (Broad 1925).

c: coherence, integrity — Objects that are "held together by causal interactions that constitute their organic unity . . . act[ing] coherently and resist[ing] internal and external fluctuations". (Collier 1998)

d: self-maintenance — Contingent stability with respect to variations in the environment. Self-maintenance is part of the cohesive nature of an emergent system (Collier 1998).

e: causal asymmetry — The emergence of "novel causal properties" is an essential criterion for emergence.

e:i) downward causation — Properties of the constituent sub-systems of an emergent system only revealed through its emergence.

e:ii) non-linearity — Step-functions, hysteresis and boundary development in far-from-equilibrium systems.

Suitable consideration of these integrative properties within levels of an organizational hierarchy, implies that al-though a full description of the processes involved in any particular emergence may be intractable, they are, in principle, precisely explainable in a reductionist procedure that acknowledges the organizational hierarchy of things. For example, in the deconstruction of vitalism as the principle that brought inanimate matter to life in biology, it was recognized that the organizing relations that had been attributed to some vitalistic (and radically non-reducible) principle were in fact the proper study of biology (Needham 1936). So by what mechanisms do these properties arise in making an ensemble of parts into an emergent whole?

Nature of Organizing Relations.

The organization of the constituents of a system is a result of the relations that operate in the physical world, or in the rules of procedure adopted for some computational simulation. Emergent objects depend on those *organizing relations* that can actually be operating in the physical world or in the rules of procedure adopted for some computational simulation. Explanations for emergences require description of the relations that link objects within some level of an integration and between hierarchical levels of order, but we need a definition of order. Von Foerster suggested that order allows us "to account for apparent relationships between elements of a set which would impose some constraints as to the possible arrangements of the elements of this system. As the organization of the system grows, more and more of these relations should become apparent". (von Foerster 1960, p.37). He then derives a relation between order and entropy such that for a system to be ordered it must carry less entropy than the maximum possible entropy of a set of the same elements not in any way so organized, i.e. a system wherein the elements are not in any relations (other than random spatial relations) with each other. So to produce order in a system it must possess relations among its elements which have the effect of *reducing the indistinguishability* of states of the system, thus organizing it. Whitehead defined relations as "abstractions from contrasts. A relation can be found in many contrasts; and when it is so found, it is said to relate the things contrasted". (Whitehead 1929, p.349) where a contrast is a difference between two perceptions such as the contrast between red and blue.

Now, if the system so organized becomes capable of some level of stability such that it develops constrained regions having boundaries and that for perturbations to its elements or its boundaries to be damaging they must be greater than a certain threshold, then that system can be said to be integrated (Ashby 1952). This integrity gives a system its emergent condition as a new order of object and we can then go on to describe various levels of order in which a set of integrated elements at one level become the parts which, in utilizing further kinds of organizing relations, constitute a new, higher level order. These organizing relations are complex networks of interactions among, for example, the physico-chemical and biochemical entities of biology or the neuro-anatomical structures of the brain or the individuals of a society.

Taxonomy of Organizing Relations

I offer here a taxonomy of the kinds of relations that could organize the parts of some ensemble into a coherent whole. The first and most prosaic are simple environmental relations which are the basic relations of arrangement or position such as shape, momentum, proximity (Searle 1992). They are not causal relations but the accidents of an object. They contribute to the emergence of an organized object through the opportunities they afford for other more interactive relations to operate.

Beyond environmental relations I want to draw out three orders of relations classified on the basis of their interactivity and thus on their organizational capacity.

First order: Feedforward relations: Where environmental relations have any emergent effect it will be through their enabling of local physical and chemical interactions. Feed-forward offers no situation in which the object takes into account the degree of impact of its relations with some other object affording it some kind of "information" by which it can regulate its action.

In ALife, rule-following is a feedforward process producing, *e.g.*, gliders in cellular automata. It includes sensing to find food, to gauge distance to neighbours, and other means of gathering environmental information. The rules in Reynolds' (1994) boids, each functioning in a feedforward only manner for each boid in a local region, allow a graded set of relationships throughout the larger global flock such that the autonomous behaviour of each boid produces an overall coherence in the flock.

The emission of signals may also be a feedforward only relation, but emission begs the question of to what end? Is it simply a marker, as with MacLennan's (1991) ants, or is it intentional behaviour leading to mutual interactions such as communication? Other feedforward relations include learning by repetition, or concentration gradient following in cellular development, but these may also be a function of third order mutualistic feedbacks.

Second order: circular causal Feedback relations: Feed-back is a function of sensing and enables an entity to regulate its behaviour. It arises when a signal emitted into the environment produces some impact back onto the originating entity and some aspect of that signal provides information to it about its ongoing presence in that environment. Feedback often involves learning when the individual modulates its own behaviour, by (1) emission of a signal for later reacquisition, or (2) alteration of a signal or marker by an individual for its own purposes. Relations between a system's internal self-regulation and its environment, afforded by feed-back, make the system possible, emerging from the soup as a distinct and distinguishable entity. All neural networks and classifier systems involve feedback learning via some path or another. The kind of feedback imposed by natural selection in a genetic algorithm (GA), is another example.

There are a number of different identifiable types of feed-back relations based either on the function of a comparison generating an error value (Wiener 1948) or on the re-entry of processed input (Edelman, 1989).

A: Feedback with error values:

1. Feedback in which a sample of the output is fed back into the input as a direct modulation of the input value. Negative feedback produces an inhibition of the system and helps a system survive perturbation. Positive feedback may cause a nonlinearity, producing hysteresis in a system, and may also induce resonance. There are well understood conditions under which this resonance can occur (*e.g.* feedback oscillators and resonant filters in electronics) yet it is a perfectly good example of a weak emergence.
2. Feedback in which several processing stages operate in a system so that its output is filtered or

otherwise modulated before it is returned to the input stage. These kind of feed-backs can provide emphasis of some particular aspect of the input and are probably involved in conscious attention in humans via the thalamo-cortical loop structure of the brain (Newman 1997).

3. Feedback with comparison to a norm or intended outcome, generating an error value which is returned to the input stage. This is the kind of control utilized in successive approximation processes like reaching for an object. Each stage of the articulation of the arm provides a fed back error value narrowing the discrepancy between current and intended position.

B: Feedback without error values:

1. Unguided learning: This is feedback where the output behaviour of some system becomes part of its input stream, but without comparison. It occurs when a known goal state is not available and the system has to make its own way, categorizing as it proceeds. In a constructivist interpretation of the world, our categorization of input stimuli cannot have developed in comparison with pre-existing norms but must have been made according to a series of recurrences of events reinforcing certain particular ways of viewing the situation.
2. Memory is possibly the most important consequence of feedback networks, particularly in biological and neural systems. Something very similar to short-term memory occurs with the propagation delay and resonance effects that a neural system will thus contain. It is very likely that re-entrant feedback produces that slightly smeared experience of the present that we have as part of our consciousness.
3. Self-reflection: Our ability to reflect on what is occurring in comparison to things which have been experienced previously, categorized and learned as history is a function of re-entrant processing coupled with memory and the error-value generating processes that allow us to evaluate the effectiveness of some act.

Feedback systems and the kinds of relations that are sensing and probing in environments where there are other entities of adequate complexity, may lead to mutualistic (or third order) relations and bring about communication. Any of these processes will indicate some sort of primitive intentionality in the system.

Third order: mutualistic feedback relations. Different entities in an environment emitting signals and responding to each other in natural or ALife systems can lead to cooperative behaviour and co-evolution (Jones 2000). Interdependence of metabolic regulation produces multi-celled organisms from a soup of single cells. Human interactions: learning, teaching and influencing each other, competing or cooperating are the processes that bind individuals into a society.

Communication can lead to a likely increase in the fitness of both the signalling and the responding groups. By emission of a signal individuals can assist each other to survive. (Koza 1991) describes an ant foraging GA in which ants search for food by moving, sensing and depositing pheromones. In Co-evolution each of a pair of algorithms acts as the environment for the other. One program tries to adapt to the "environment" created by the other, by testing the performance of the one program relative to the other and then vice versa. This is essentially a "biological arms race" where each species develops defences and attacks against the other.

Organisms gain their integrity, boundaries and self-maintenance through open-system behaviors such as ingest-ion and sensing, processes that are active in all biological systems. When a complex system has adequate organization there will be a massive array of internal and external feed-back relations. A state of organization is maintained by the exchange of energy with the environment, which helps to maintain the chemical metabolism of the membrane bounded system, but it also produces potentially deleterious metabolic waste products. Excretion of these wastes through the membrane completes a circular relationship with the environment. These wastes may be the basis for the development of mutualistic relations (Jones 2000; Pachepsky, Taylor, & Jones 2002). In humans, perceptions and productions are the primary elements of exchange with the environment that keep us integrated as conscious beings capable of interaction with other entities and processes in the world of matter and ideas.

Conclusion

In a sense Cariani (1991) quite correctly dismisses emergence, but in so doing he throws the baby out with the bath-water. The value of emergence is that it alerts us to situations in which explanations must include causal processes that are not usually recognized from within the purview of micro-physics. Reductive explanation is, in principle, possible for those objects that we commonly think of as emergent. Nevertheless such reduction obscures the forest not simply by a description of the trees but by the demand for a description of the quantum processes that make the atoms and then the molecules and then the amino-acids and the proteins and then the cells and so on up to the ecology of the forest. Strict reductionist explanation is thus rather wasted, tedious if not intractably difficult and not very useful. To completely explain some complex thing we must carry out a *series* of explanations, each of which amounts to a reduction of one level into the level of its constituents and their organizing relations. In turn the constituents have to be explained from within their own level, working down to the ultimate micro-physical components in a series of steps.

Emergence, as explanation, is a shorthand. Useful explanations of a system need to actively account for the role of the organizing relations among the parts at each sub-level. This has the great value of opening up mechanistic explanation, rendering it relevant in understanding the dynamics of process. As Holland comments: "When we can formulate macrolaws that describe the behaviors of emergent phenomena (for instance, the laws of chemical bonding) we gain greatly in comprehension, whether of a model universe or a real one". (Holland 1998, p.189).

The dynamics of organizing relations enable emergence, affording the emergent object the means by which it can self-organize, self-regulate and, within the biological levels, be alive. In the simulations of computational emergence we need to find means by which emergent objects at one level may become the constituents of a further emergence, by generating their own organizing relations, thus climbing multiple levels in the hierarchy of organization.

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