

Beyond Substance and Process: A New Framework for Emergence

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1 Introduction

We are interested in determining the conditions under which a spatially-extended finite system can support potentially unbounded emergence. This would afford emergentism the status of a universal phenomenon. It will be shown that this is possible if an infinite hierarchy of laws governing the behaviour of such a system is admitted. We postulate this as a necessary condition for open or unbounded emergence in spatially-extended finite systems. The ways in which we 'cut' this ontological hierarchy determine what are to count as the global 'physics' and local 'atoms' in our models of nature. Hence, we argue for an epistemology which is relativistic and motivated by intentional, i.e. conscious, concerns.

2 Background

The earliest articulation of the essence of emergence may well be the ancient Greek maxim "the whole is more than the sum of the parts". However, the first serious attempt at investigating the concept of emergence was not made until the middle of the nineteenth century when George Henry Lewes distinguished between resultants and emergents: in the former, the sequence of steps which produce a phenomenon are traceable while in the latter, they are not. Thus, Lewes could be interpreted as holding that emergence merely indicates the epistemological limitations of an observer. The concept was further described in C.Lloyd Morgan's *Emergent Evolution* (1923) and J.C.Smuts' *Holism and Evolution* (1926), but it was in Samuel Alexander's *Space, Time and Deity* (1920) that the first attempt at a comprehensive explanatory framework for emergence was made. Alexander identified emergence with the tendency for things to arrange themselves into new patterns which as organized wholes possess new types of structure and new 'qualities', i.e. properties. More recently, attempts have been made to define the concept in computational and information theoretical terms [Baa,93] [Dar,94].

3 The Emergent Theory of Mind (ETM)

The concept of emergence finds application in the context of the mind-body problem. Proponents of the emergent theory of mind (ETM), Searle [Sea,92] for example, follow Alexander by adopting an evolutionary perspective which holds that the mind (consciousness) emerges from the body (brain) as a consequence of bottom-up causal processes. The ETM describes the mind-body relation in terms of a two-level systemic hierarchy: the pattern of neuronal 'firings' in the brain (lower, local or substrate

level) gives rise to mental phenomena including the subjective experience of consciousness (higher, global or emergent level).

Proponents of the computational ETM (CETM) go further and assert that the formal aspect of bottom-up causation provides the necessary and sufficient conditions for the emergence of consciousness. This is consistent with functionalism which supports the possibility of artificial consciousness. Alexander's ontology is particularly appealing to proponents of the CETM because it maps isomorphically onto the class of mathematical formalisms known as cellular automata: on his view, space-time is the primordial ground of matter, life, mind etc. Cellular automata are highly suitable for representing space-time and pattern formation within a spatio-temporal framework.

4 Cellular Automata

A cellular automaton (CA) is a D -dimensional lattice of K cells where each cell is a finite state automaton defined by the triplet $\langle S, N_S, r \rangle$ where S is a set of states, N_S is a state-vector given by the states of cells in the neighbourhood of a central cell C , and $r: N_S \rightarrow S$ is a state-transition rule which is applied to each cell in parallel; hence, the global state of the lattice is updated at each time interval. An example of the space-time evolution of a 1-D CA from an initial state is shown in fig.1.

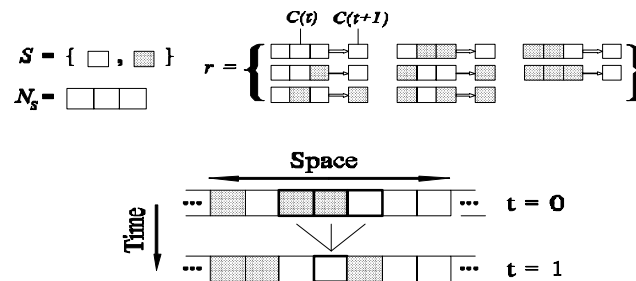


Figure 1 Space-time evolution of elementary 1-D CA

New kinds of functional behaviour, e.g. billiard-ball mechanics ('matter'), self-reproduction ('life'), and universal computation ('mind'), emerge as a consequence of the spatio-temporal dynamics of certain types of CA. Feedback between the dynamics of the global (emergent) level constraining the dynamics of the local (substrate) level which gives rise to the global dynamics provides for a kind of 'downwards causation'. The nature of this constraint is best understood in system dynamical terms, viz. trajectories (sequences of global system states), attractors (the end state or sequence of end states in a given trajectory), basins of attraction (the set of all trajectories converging on a given attractor). The existence of a set of basins of attraction, which constitutes the basin of attraction field, is a necessary

condition for emergence in CA. A state-space portrait of a basin of attraction field for a CA has a topology which is that of a 'landscape' of branching transient trees rooted on attractors; nodes represent states and arcs state-transitions.

5 Problems with Emergence in Cellular Automata

Cariani [Car,91] has argued that CA with finite lattices, finite states and finite rules have basin of attraction fields which are finite and hence, describable. He maintains that a result of this is that finite CA are examples of 'closed' systems supporting a finite or bounded potential for emergence. For CA of this type, what appears as emergence in fact indicates incomplete knowledge of the basin of attraction field at a particular instant in time by an observer. Once the field has been 'mapped', no further emergence is possible. CA with infinite lattices (but finite states and rules) have basin of attraction fields which are infinite and possibly non-describable. Consequently, some infinite lattice CA are examples of 'open' systems supporting an unbounded potential for emergence. Emergence as a *universal* phenomenon, unconstrained to only finitely many phenomenal levels, necessitates emergence without limit and infinite lattice CA meet this requirement. However, this scheme is inconsistent with current cosmological views regarding the closure, i.e. finitude, of the physical universe. An alternative scheme which meets the requirement for unbounded emergence and is consistent with the idea of a closed universe ('lattice' in the CA model) necessitates introducing the potential for openness via an extension of the standard CA definition.

6 Metarules

Metarule CAs introduce the required openness by postulating a hierarchy of CA rules. Each CA at a particular level in the hierarchy has a finite lattice, a finite number of states and a finite number of rules. However, there are two ways in which metarule CAs extend the standard CA definition:

- (1) rules at level p are states at level $p+1$ in the hierarchy, where $p \geq 0$.
- (2) initial conditions are independently specifiable at each level p in the metarule hierarchy.

The scheme may be expressed formally as follows:

Level 0 rule (r^0)

$$r^0 : N_{S^0} \rightarrow S^0, r^0 \in R^1$$

$$S^0 = \{s_i^0 / i = 0.. \alpha - 1, s_i^0 \in 0.. \alpha - 1, i \neq j \Rightarrow s_i^0 \neq s_j^0\}$$

Level 1 metarule (r^1)

$$r^1 : N_{R^1} \rightarrow R^1, r^1 \in R^2$$

$$R^1 = \{r_i^1 / i = 0.. \beta - 1, r_i^1 \in 0.. |S^0|^{N_{S^0}} - 1, i \neq j \Rightarrow r_i^1 \neq r_j^1\}$$

Level 2 metarule (r^2)

$$r^2 : N_{R^2} \rightarrow R^2, r^2 \in R^3$$

$$R^2 = \{r_i^1 / i = 0.. \gamma - 1, r_i^1 \in 0.. / R^1 / |R^1|^{|N_{R^1}|} - 1, i \neq j \Rightarrow r_i^1 \neq r_j^1\}$$

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Level m metarule (r^m)

$$r^m : N_{R^m} \rightarrow R^m, r^m \in R^{m+1}$$

$$R^m = \{r_i^{m-1} / i = 0.. \Omega - 1, r_i^{m-1} \in 0.. / R^{m-1} / |R^{m-1}|^{|N_{R^{m-1}}|} - 1, i \neq j \Rightarrow r_i^{m-1} \neq r_j^{m-1}\}$$

$$m \in \text{Nat}_+, m \geq 1, \alpha, \beta, \gamma, \Omega \in \text{Nat}_+$$

Rules r^p are numbered at each level p where $p \geq 0$ using the binary coding scheme described in [Wol,84].

The number of possible metarule configurations at level m in the metarule hierarchy is given by:

$$\prod_{k=1}^m \binom{|R^{m-k}|^{|R^{m-k}|^{|N_{R^{m-k}}|}}}{|R^m|} \binom{|R^m|^{|R^m|^{|N_{R^m}}|}}{m \in \text{Nat}_+, m \geq 1}$$

Example: $m = 1$ (single level of metarules)

$$|R^{m-1}| = |R^m| = 2, |N_{R^{m-1}}| = |N_{R^m}| = 3$$

i.e. a cell can be in one of two states with three contiguous cells comprising a cell neighbourhood. For such a CA with a single level of metarules, there are over 8 million possible metarule configurations to consider. Hence, empirical investigations have necessarily been restricted to small regions of the space of possible configurations.

7 Experiments

In our experiments, we used the classification scheme of Wolfram [Wol,84] which identifies four classes of CA behaviour: class I (fixed-point attractors), class II (cyclic attractors), class III (chaotic attractors), and class IV (complex attractors supporting universal construction and computation).

It has been shown that elementary 1-D CA, i.e. $|S|=2, |N|=3$ or binary automata with a neighbourhood of three cells, only support behaviour in classes I, II and III. However, it may be possible to generate class IV behaviour at the "edge of chaos" [Lan,91] by using rules which generate behaviours in classes II and III under a metarule scheme (Fig.2).

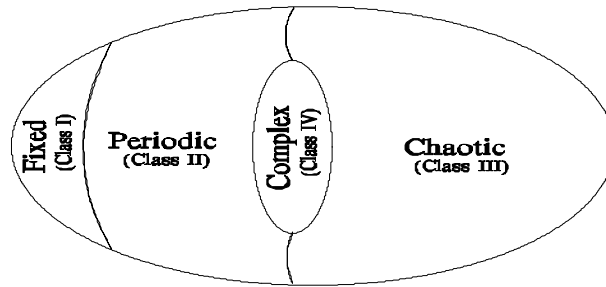


Figure 2 CA behaviour profile [Lan,91]

A small range of the possible metarule configuration space has been investigated in which $|S|=2$, $|N|=3$, $r^1=190$ and $R^1=(x,131)$ where $x \in \{18,22,54,60,86,90,101,102,109,120,124,129,134,135,146,150,151,165,193,195,225\}$. x generates class III behaviour and rule 131 generates class II behaviour.

Preliminary results indicate that incorporating a single level of metarules into a 1-D elementary CA may allow behaviour in class IV to be generated. Hence, universal computation, postulated as a necessary condition for mind in the CETM, is possible for elementary 1-D CA. Fig.3 is the space-time evolution for the metarule CA described above; Fig.4 is the space-time evolution of a 1-D CA (rule 906663673) generating class IV behaviour.

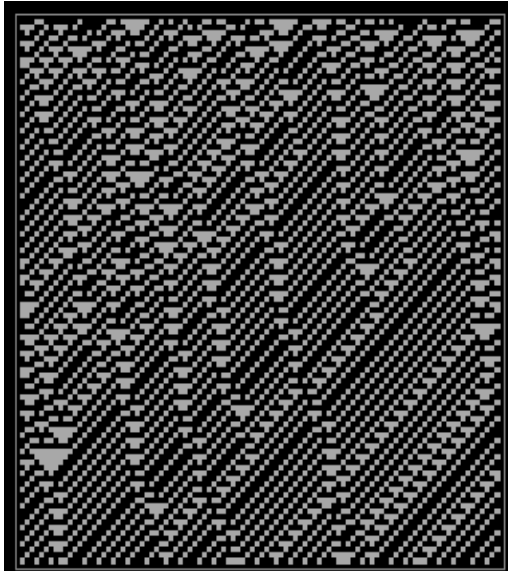


Figure 3 1-D CA with $|S|=2$, $|N|=3$

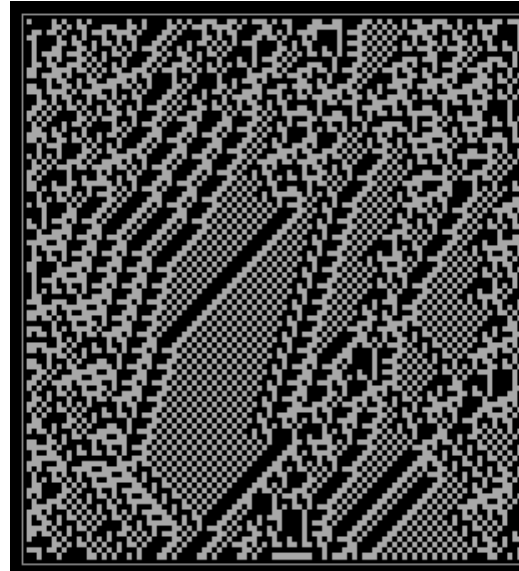


Figure 4 1-D CA with $|S|=2$, $|N|=5$

8 Beyond Substance and Process ...

One possible objection to this scheme is that it is ontologically dualistic at the lowest level in the hierarchy (states and rules) and ontologically monistic at all other levels (rules and metarules). This problem may be overcome by extending the framework to a bidirectionally-infinite hierarchy in which states at level m are rules at level $m-1$ and rules at level m are states at level $m+1$ where $-\infty \geq m \geq +\infty$. Such a framework replaces the dualistic ontology of state and rule, and their corresponding physical counterparts, substance and process, with a monistic ontology based on an instance of a more general kind.

$$\zeta^m : N_{H^m} \rightarrow H^m, \zeta^m \in H^{m+1}$$

$$H^m = \{\zeta_i^{m-1} / i = 0.. \Phi - 1, \zeta_i^{m-1} \in 0.. / H^{m-1} / |H^{m-1}| / |N_{H^{m-1}}| - 1, i \neq j \Rightarrow \zeta_i^{m-1} \neq \zeta_j^{m-1}\}$$

$$m \in \text{Nat}, \Phi \in \text{Nat}_+$$

9 Conclusions

An important epistemological result follows from adopting the hierarchy described above as the underlying ontology of nature. In the act of observation of a natural phenomenon, we 'cut' or identify as separate the levels in the hierarchy, thereby determining global physics (ζ^m) and local atomic substrate (ζ^{m-w} where w is the number of levels between cuts) (Fig.5).

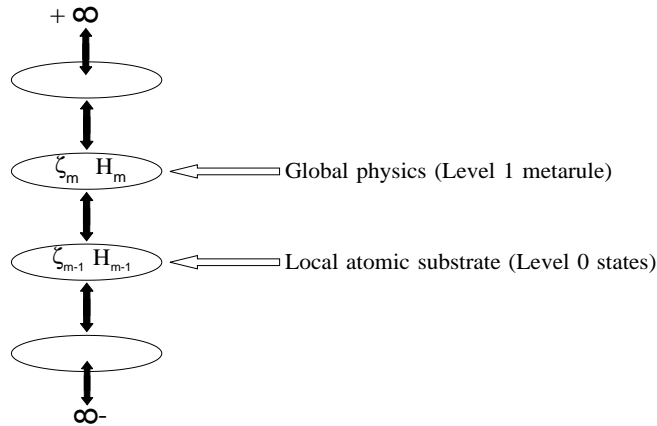


Figure 5 'Cutting' the hierarchy

Consequently, substrate-atomism is epistemologically-relativistic depending on where the cut is made in the hierarchy. The position of the cut affects (i) the extent to which emergence is possible, i.e. *emergence-relative-to-a-model* [Car,91], and (ii) the types of phenomena, i.e. behavioural classes, that can emerge given the global physics and atomic substrate. The idea of 'cutting' the world was anticipated in an earlier work by Spencer-Brown [Spe,69], viz. "a universe comes into being when a space is severed". However, the problem in that scheme and in the one presented here is the source or agency responsible for the cut. The fact that the problem of subjectivity remains [Nag,79] provides an indication as to where a possible solution may lie. We see the solution in an intentionalistic 'self-cutting' ontological hierarchy based on a variant of panexperientialism. Such a scheme allows for 'downwards causation' via what Polanyi [Pol,68] calls 'higher principles'. These are boundary conditions which are imposed in the selective act of cutting by an intentional observer, i.e. the subjective component of the hierarchy described above.

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