What Is Emergence?

or

The Blind Observer
And the Emergence of Adaptive Behaviour

or

Emergence: Enigma or Science
And the Emergence of Adaptive Behaviour

Simulation of Adaptive Behaviour
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Abstract
The aim of this paper is to examine the multifarious uses of the word "emergence" within numerous scientific and philosophical disciplines.

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11 An Introduction (394)

In ancient Greece, in around 350BC, Aristotle and his students wrote a treatise entitled Metaphysics; inside which, they recorded the observation that "*the whole is greater than the sum of its parts"*.

After two and a half thousand years of intellectual endeavour, this simple notion still lies at the heart of philosophical debate; yet it has, until recent years, remained steadfastly untouched by science.

Scientists, it seems, had been otherwise engaged with a reductionistic ontology (Capra 1996). Based on the ancient atomistic notions of Democritus and fuelled by Newtonian mechanics and the Cartesian worldview, science, dominated by physics, has regarded the whole as "reducible to" or "nothing more than" the sum of its constituent parts for some time.

However, over the last century the paradigm has begun to shift (Kuhn 1962). The subatomic world of the quantum has pulled away the stable platform upon which the atomic purists once stood. In its place, we are left with a new and unpredictable world of complex systems and thermodynamic flow (Schneider & Sagan 2005) and with it we are left with a new kind of science.

Aided by the exponential growth of computational power, scientists are now beginning to develop a general theory of these systems (Van Bertalanffy 1969); examining their nonlinear dynamics (Lorenz 1963; Feigenbaum 1978), their natural self-organisation (Maturana & Varella 1980; Prigogine 1981; Kauffmann 1993; Lovelock 1979) and, importantly, their hierarchy and hyper-structures (Mandelbrot 1977; Kauffman 1993; Baas 1994; Morowitz 2002).

The study of complex systems is slowly beginning to turn the old reductionist views on their heads. Rather than trying to describe wholes as collections of parts, scientists are now examining collections of parts only to discover strange and unexpected new wholes; properties, structures and behaviours observable in the whole system by not describable in the language of its individual parts. We are at last beginning to study the science of Aristotle's observation.

This non-reductive process is called emergence and in this paper we aim to bring together the recent and multifarious attempts at defining it as a legitimate field for scientific enquiry. We should head, however, the warnings of John Holland, in his ground-breaking book on the subject; "*despite its ubiquity and importance, emergence is an enigmatic, recondite topic, more wondered at than analysed … it is unlikely that a topic so complicated will submit weakly to concise definition*" (Holland 1998).

12 Dual Aspect Framework (124)

In discussing the reduction/emergence debate, Van Gulick (2001) makes the observation that speakers "*often talk past one another by failing to distinguish ontological from representational notions, especially in interdisciplinary settings that combine scientists and philosophers*". He extends this notion by distinguishing between the *metaphysical factors of emergence* (relations between real-world, physical, items) and *epistemological factors of emergence* (relations between our cognitive explanations, models and representations).

This important distinction can, we hope, be restated as highlighting the split between (i) the properties, patterns and behaviours observed within the whole (*structural emergence*) and (ii) the lack of description from within the formal language of the constituent parts *(representational novelty)*.

It is within this dual-aspect framework that we shall reposition some of the previous literature in the hope of adding clarity to the overall understanding of emergence.

13 Structural Emergence

Throughout the literature, commonality is found in the definition of emergence in terms of structure or pattern.

Crutchfield (1994) defines emergence as being "*generally understood to be a process that leads to the appearance of structure*"; Holland (1998) defines emergent phenomena as "*persistent patterns*"; Cariani (1997) states that "*emergence is the process by which new structures and functions come into being*"; and Baas (1997) refers to complex phenomena as "*higher-order structures*".

That which emerges is always measurable or observable structure or pattern.

Van Gulick (2001) concentrates his notions of metaphysical emergence on physical properties such as colour, mass, and temperature etc. But each of these can be restated in terms of observable or measurable structure.

More generally, the term emergence is used to describe behavioural aspects of complex systems (such as flocking, swarming etc). But again, these can be considered observable patterns or structures. A flock is only a flock because we observe the pattern of behaviour as "*different*" to a mere chaotic collection of birds.

(650 words)

14 Representational Novelty

Not describable in the language of its constituent parts.

- Van Gulick
    - Representational Emergence (it can't be represented in the frame work of its parts)
    - Predictive Emergence (it can't be explained or predicted from the features of the parts)
- BAAs
    - Deducible (specific value emergence?)
    - Observational (representational emergence?)
- Surprise (Sipper)
- Cariani – tackles emergence from a different angle. He sees it as the creation of novelty and therefore tries to define ways in which novelty can be created.
    - Combinatorial Novelty
    - Creative Novelty

(750 words)

15 The Observer

Problem of the Observer (the interpretation problem)
Intrinsic emergence (no external observer)
Adaptive emergence
(500 words)

16 Causal Efficacy

Strong Emergence (implies/requires downward causation)
Weak Emergence (epiphenomenal)
A third way (it all just happens man)
(**300 words**)

17 Emerging Frameworks

BAAs
Kubik
Edge of Chaos
(300 words)

18 Conclusions

Dunno yet

(300 words)

An important aspect of emergence which often leads to confusion within the literature regards the type of the emergent phenomena which is being described.

Cariani (1990) and Van Gulick (2001) both make distinctions between the material world (Cariani's *thermodynamic emergence* and Van Gulick's *metaphysical emergence*) and the representational world of models (Cariani's *computational emergence*[1] and *emergence relative to a model*, and Van Gulick's *epistemological emergence*). This distinction, although legitimate, fails to adequately categorise many of the other emergent phenomena made by other authors on the subject; and as Kubik (2003) also highlights "*the categorisation is not fine enough*". We therefore propose a slightly stricter categorisation of the types of emergent phenomena; namely, the property, form and function distinctions outlined below.

18.1 Emergent Properties

An example of an emergent property would be *colour*, *temperature or viscosity*. In this sense, it is a one-dimensional feature of the system at a particular moment in time. The term "property" must be considered as a finer grain to the wider "philosophical property" (which also encompasses shape, and perhaps computational function). Van Gulick (2001) seems also to concentrate his metaphysical emergence on this sub-class of philosophical property and produces a distinction of sub-categories which are worth examining below.

Specific Kind - the whole and its parts have properties of the same kind. For example, a bronze statue has a given mass, as do its molecules, but the mass of the whole has a different value to that of any of its components.

Modest Kind - the whole has features of a kind not found in any of its parts. For example, a piece of cloth has a purple hue, even though none of its molecules can be said to be purple.

Radical Kind - whole has features of a kind not found in any of its parts and the nature and existence of these is *not necessitated* by the features of the parts.

Although acting as a thought provoking sub-categorisation of properties, it is not felt that these act as a suitable sub-categorisation of emergence, or emergent properties. Firstly, in specific kind emergence, the whole appears exactly equal too the sum of its parts and is therefore at odds with the broader definitions of emergence in the literature. Secondly, regarding the existence of radical kind emergence, Van Gulick only sites consciounsness[2] as a possible example and he himself goes on to question the validity of its real-world

[1] Cariani's computational emergence is different to the form of emergent computations discussed by Forrest, Crutchfield as it describes any von Neuman style computation as an emergent property of the physical computation device (PC).

[2] Admittedly consciousness is generally the main subject in the philosophical debate on emergence

existence, describing its incompatibility with physicalism and the standard scientific world view. This leaves modest kind emergence as a sub-category of one which we can move up to become an adequate description of the main categorical notion of an *emergent property*.

18.2 Emergent Structures

An example of emergent form would be *pattern*, *structure* or *shape*. Although potentially dynamic, emergent form is generally a static feature; Holland (1998) describes "*emergent phenomena in generated systems [as], typically, persistent patterns with changing components*".

18.3 Emergent Behaviours

Computational / Behavioural

19 REFERENCES

Ablowitz R. (1939) "*The theory of emergence*", Philosophy of Science (6) pp. 1-16
Baas N.A. (1994) "*Emergence, hierarchies and hyperstructures*", Artificial Life III, SFI Studies in the Sciences of Complexity (17) pp. 515-537
Baas N.A., Emmeche C. (1997) "*On E*mergence and Explanation", Intellectica (25) pp. 67-83
Bedau M. A. (forthcoming) "*Downward Causation and the autonomy of weak emergence*", Principia, special issue on emergence
Bedau M.A. (1997) "*Weak Emergence*", in Philosophical Perspectives: Mind, causation and world (11) pp. 375-399
Berlekamp E. R., Conway J. H., Guy R. K. (1982) "*Winning Ways for Your Mathematical Plays, Vol. 2: Games in Particular*", Ch 25, London: Academic Press
Campbell R.J., Bickhard M.H. (2002) "*Physicalism, Emergence and Downward Causation*", unpublished www.lehigh.edu/~mhb0/physicalemergence.pdf
Capra F. (1996) "*The Web of Life: A new synthesis of mind and matter*", Harper Collins
Capra F. (2002) "*The Hidden Connections*", Harper Collins
Cariani P. (1997) "*Emergence of new signal-primitives in neural systems*", Intellectica (25) pp. 95-143
Cariani P. (1990) "*Emergence and Artificial Life*", Artificial Life II, SFI Studies in the Sciences of Complexity (10) pp. 775-798
Crutchfield J.P. (1994) "*Is anything ever new? Considering emergence*", Complexity: Metaphors, Models and Reality, Santa Fe Institute Studies in the Sciences of Complexity (19) pp. 479-497
Crutchfield J.P., Mitchell M. (1995) "*The Evolution of Emergent Computation*", Proceedings of the National Academy of Sciences, USA 92:23 10742-10746.
Emmeche C., Køppe S., Stjernfelt F. (1990) "*Levels, Emergence and three versions of downward causation*", in Downward Causation: Minds, Bodies and Matter: Aarhus University Press
Feigenbaum M. (1978) "*Quantitative Universality for a class of nonlinear transformations*", Journal of Statistical Physics (19) pp 25-52
Forrest S. (1990) "*Emergent computation: self-organizing, collective, and cooperative phenomena in natural and artificial computing networks.*", Physica D (42: 1-3) pp. 1-11
Holland J.H. (1998) "*Emergence: From Chaos to Order*", Oxford University Press
Johnson S. (2001) "*Emergence*", Penguin Press
Kauffman S. (1993) "*The Origins of Order*", Oxford University Press
Kubik A. (2003) "*Towards* a Formalization of Emergence", Artificial Life (9) pp. 41-65
Kuhn T. (1962) "*The Structure of Scientific Revolutions*", University of Chicago Press
Langton C.G. (1989), "*Artificial Life*", In Artificial Life. Addison-Wesley. pp. 1-47
Lorenz E. (1963) "*Deterministic nonperiodic flow*", Journal of the Atmospheric Sciences (20) pp 130-141
Langton C.G. (1990) "*Computation at the edge of chaos: Phase transitions and emergent computation*", Physica D vol. 42, pp. 12-37.
Lovelock J. (1979) "*Gaia: A new look at life on Earth*", Oxford University Press
Mandelbrot B. (1977) "*The Fractal Geometry of Nature*", New York: Freeman
Maturana H., Varela F. (1980) "*Autopoiesis and Cognition: The Realization of the Living",* Boston Studies in the Phil. of Science (42)
Mitchell M., Crutchfield J.P., Das R. (1997) "*Evolving Cellular Automata to Perform Computations*", working paper, SFI
Mitchell M., Hraber P.T., Crutchfield J.P. (1993) "*Revisiting the Edge of Chaos: Evolving Cellular Automata to Perform Computations*", Complex Systems 7, pp. 89-130.
Mitchell M. (1998) "*A Complex-Systems Perspective on the "Computation vs. Dynamics" Debate in Cognitive Science",* Twentieth Annual Conference of the Cognitive Science Society
Morgan C.L. (1923) "*Emergent Evolution*", Northgate and Williams
Morowitz H. (2002) "T*he Emergence of Everything: how the world became complex*", Oxford University Press
Pepper S. (1926) "*Emergence*", Journal of Philosophy (23) pp. 241-245
Prigogine I. (1967) "*Thermodynamics of irreversible process*", New York: John Wiley and Sons
Prigogine I., Stengers I. (1981) "*Order out of chaos: Man's new dialogue with nature*", New York: Bantam
Rockwell T. (1995) "*A Defence of Emergent Downward Causation*", unpublished http://www.california.com/~mcmf/causeweb.html
Ronald E.A., Sipper M., Capcarrérre M.S. (1999) "*Design, observation, surprise! A test of emergence*", Artificial Life (5) pp. 225-239
Schneider E.D., Sagan D. (2005) "*Into the cool: Energy flow, thermodynamics and life*", University of Chicago Press
Van Bertalanffy L. (1969) "*General System Theory: Foundations, Development, Applications*", New York: George Braziller
Van Gulick R. (2001) "*Reduction, Emergence and Other Recent Options on the Mind/Body Problem: A Philosophic Overview*", Journal of Consciousness Studies (8: 9-10) pp. 1-34
Waldrop M. (1992) "Complexity: The emerging science at the edge of order and chaos", Simon & Schuster
Wolfram S. (1984) "*Universality and complexity in cellular automata*", Physica D vol. 10
Wuensche A (1996) "*Attractor Basins of Discrete Networks*", unpublished D.Phil thesis, University of Sussex