# Demystifying Emergence
## Reviewing the state of the art in understanding, describing and modeling emergence

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Abstract: In an attempt to provide a working definition of a complex system, *emergence* is often chosen as its most distinguishing feature. This may be a circular definition, since the concept of emergence itself is undefined. Thus a number of established researchers have questioned whether emergence actually exists or whether the concept is needed at all in the description of Nature. Because of this, a group of researchers associated with CSIRO's Centre for Complex Systems Science in Australia saw the need to review the state of the art in understanding, defining, modelling and formally describing emergence. Our review was motivated by the publication of new approaches and new mathematical tools within the physics and mathematics community and growing interest in this subject in biology, ecology and philosophy.

Our approach was old-fashioned, aiming to probe the area with no premeditated outcome in mind. Because of the inherently interdisciplinary nature of the subject, we fostered communications between physicists, mathematicians, biologists, economists, information theorists, sociologists, ecologists and engineers. We organised 2 workshops involving CSIRO researchers, some DSTO colleagues and two invited, international guests: Daniel Polani and Cosma Shalizi. Amazingly, we soon discovered that this self-organised approach works: we learnt, we communicated, and we attracted more scientists along the way. Nine papers have been completed, several including original results.

In this short presentation, we summarize key outcomes of our 3-year Interaction Task on Emergence. For the most part, we confined our discussions to three issues:

- Relationship(s) between emergence, evolution, self-organisation and complexity;
- Relationship(s) between emergence and formal logic, computation and modeling;
- The role of scale and scope when studying emergence.

Some key outcomes were that:

- We proposed a set of concepts, with their information-theoretic interpretations, which can be used as a dictionary of Complex Systems Science discourse. Our hope is that this unifying, information-theoretic framework may facilitate consistent communications among practitioners and provide new insights (Prokopenko et al, 2008).
- Replacing the idea of *level* by a framework of *scope*, *resolution* and *state* would allow emergent properties to be determined by the relationship between the scope of macrostate and microstate descriptions. (Ryan, 2007)
- We explored whether what we intuitively define as strongly emergent systems may include processes which are not computable in a classical sense. We asked how incomputable processes would appear to an observer and then, via a thought experiment, show that they would display features normally defined as 'emergent' (Boschetti & Gray, 2007a)

- The analysis of emergent processes should address causal relationships and causal power, that is, it should account for what these processes 'do'. This led us to propose a 'Turing test for emergence' in which we ask whether a process empowered with autonomous, causal emergent properties (a human) can discriminate between another causal emergent process and a computer program. We suggest that the Complex System Science community could benefit from building more closely on the extensive experience accumulated along the difficult path followed by artificial intelligence (Boschetti & Gray, 2007b);
- Acknowledging that most complex problems are addressed via numerical computation, we consider the role of a modeler and ask what makes a problem complex. This led to viewing complexity as an 'inverse problem' and to a classification of complexity based on the level of human intervention required in its solution. This view is no more observer-independent, but instead accounts for both historical and cultural development (Boschetti et al, 2008).
- The critical phenomenon defining the transition from simple to complex classes of emergence may be the onset of self-organization, which is associated with non-equilibrium pattern formation (Halley & Winkler, 2008);
- The process of evolution is a candidate for generating dynamic emergence. We suggest that the relationship between selection, self-organization and emergence may become more apparent if we recognize that self-organization proposes what selection disposes (Batten, Salthe & Boschetti, 2008).

Relevant Papers:


- Prokopenko M, Boschetti F, Ryan A, 2008, An Information-Theoretic Primer on Complexity, Self-Organisation and Emergence, submitted to *Advances in Complex Systems.*
- Boschetti F, Gray R, 2007a, Emergence and Computability, *Emergence: Complexity and Organization*, 9 (1-2), 120-130.
- Boschetti F, Gray R, 2007b, A Turing test for Emergence, in M. Prokopenko (ed.), Advances in Applied Self-organizing Systems, Springer-Verlag, London, UK, 349-364.
- Boschetti F, Gray R, McDonald D, 2008, Complexity of a modelling exercise: a critique of the role of computer simulation in Complex System Science, in print, (available on line at the Journal site, http://www3.interscience.wiley.com/cgi-bin/fulltext/117922807/PDFSTART).
- Ryan, A., Emergence is coupled to scope, not level, *Complexity*, 13 (2), pp. 67-77, 2007.
- Halley J, Winkler D, Classification of emergence and its relation to self-organization, *Complexity*, accepted.
- Batten D, Salthe S, Boschetti F, Visions of evolution: self-organization proposes what selection disposes, submitted to *J. Biol. Theory*.
- Boschetti F, Prokopenko M, Macreadie I, Grisogono A. Defining and detecting emergence in complex networks, In volume 3684 of Lecture Notes in Computer Science, pages 573-580, 2005.