

The Vinod Wadhawan Blog

Celebrating the Spirit of Science and the Scientific Method

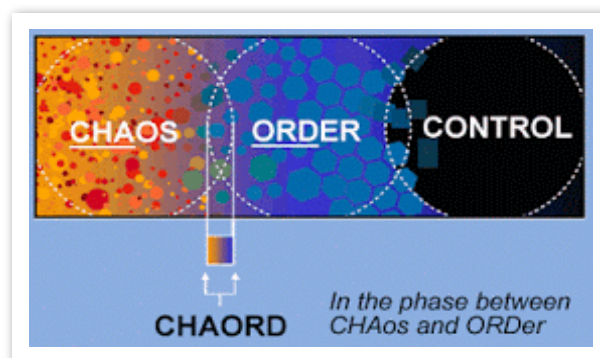
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Saturday, May 25, 2013

81. The Edge-of-Chaos Existence of Complex Adaptive Systems

Evolution thrives in systems with a bottom-up organization, which gives rise to flexibility. But at the same time, evolution has to channel the bottom-up approach in a way that doesn't destroy the organization. There has to be a hierarchy of control - with information flowing from the bottom up as well as from the top down. The dynamics of complexity at the edge of chaos seems to be ideal for this kind of behaviour (Doyne Farmer).

I introduced complex adaptive systems (CASs) in [Part 38](#). Then in [Part 80](#) I described Langton's work on them; in particular his introduction of the phrase 'edge of chaos' for the line in phase space that separates ordered behaviour from chaotic behaviour, with complex behaviour sandwiched between these two extremes. In 2-dimensional phase space we need a *line* to separate the two regimes. In 3-dimensional space we need a *plane* or a membrane (a 2-dimensional object) for effecting this separation. In n -dimensional phase space we need an $(n-1)$ -dimensional hyper-membrane for separating ordered behaviour from chaotic behaviour. The phrase 'edge of chaos' should be understood in this spirit.

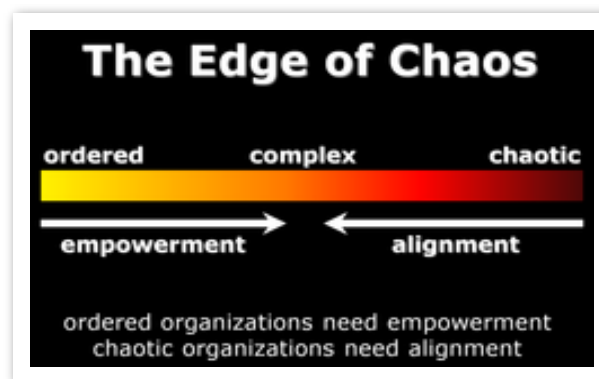


<http://www.innovativecommunities.org/how-we-work-together>

We have seen in [Part 68](#) that even a simple computational algorithm like the Game of Life is a universal computing device. The Game of Life is independent

of the computer used for running it, and exists in the Neumann universe, just as other Class 4 CA do. They are capable of information processing and data storage etc. They are a mixture of coherence and chaos. They have enough stability to store information, and enough fluidity to transmit signals over arbitrary distances in the Neumann universe.

There are many analogies, not only with computation, but with life, economies, and social systems also. After all, they are all just a series of computations. Life, for example, is nothing if it cannot process information. And it strikes a right balance between too static a behaviour and excessively chaotic or noisy behaviour.



<http://www.theidioticon.com/edge-of-chaos.html>

The occurrence of complex phase-transition-like behaviour in the edge-of-chaos domain is something very common in all branches of human knowledge. [Kauffman \(1969\)](#), for example, recognized it in genetic regulatory networks (cf. [Part 49](#)). In his work on such networks in the 1960s, he discovered that if the connections were too sparse, the network would just settle down to a 'dead' configuration and stay there. If the connections were too dense, there was a churning around in total chaos. Only for an optimum density of connections did the stable state cycles arise.

Similarly, in the mid-1980s, [Farmer, Packard and Kauffman \(1986\)](#) found in their autocatalytic-set model (cf. [Part 46](#)) that when parameters such as the supply of 'food' molecules, and the catalytic strength of the chemical reactions etc. were chosen arbitrarily, nothing much happened. Only for an optimum range of these parameters did a 'phase transition' to autocatalytic behaviour set in quickly.

Many more examples can be given ([Farmer et al. 1986](#)): Coevolutionary systems, economies, social systems, etc. A right balance of defence and combat in the coevolution of two antagonistic species ensures the survival and propagation of both. Similarly, the health of economies and social systems can be ensured only by a right mix of feedbacks and regulation on the one hand,

and plenty of flexibility and scope for creativity, innovation, and response to new conditions, on the other. The dynamics of complexity around the edge of chaos is ideally suited for evolution that does not destroy self-organization.

Based on the work of Kauffman, Langton, and many others, we can compile a number of analogies or correspondences from a variety of disciplines. The table below does just that. There is a gradation from (a) excessive order to (b) complex creativity and progress to (c) total anarchy and failure. In each case there is some kind of a ‘phase transition’ to the complexity regime as a function of some control parameter (e.g. temperature in the case of second-order phase transitions in crystals).

Cellular automata classes	1 & 2 → 4 → 3
Dynamical systems	Order → complexity regime → chaos
Matter	Solid → phase-transition regime → fluid
Computation	Halting → undecidability regime → nonhalting
Life	Too static → life / intelligence → too noisy
Genetic networks	No activity → stable-state cycles → chaotic activity
Autocatalytic sets of reactions	No autocatalysis → autocatalysis → no autocatalysis
Coevolution	No coevolution → coevolution → no coevolution
Economies, social systems	No creativity → health and happiness → anarchy

How do complex systems move towards the edge-of-chaos regime, and then manage to stay there? For complex adaptive systems (CAS), [Holland \(1975, 1995, 1998\)](#) provided *an* answer in terms of Darwinian evolution. Complex systems that are capable of sophisticated behaviour have an evolutionary advantage over systems that are too static and conservative or too turbulent. Therefore both the latter categories would tend to evolve towards the middle-course of complexity, if they are to survive at all. And once they are in that regime, any deviations or fluctuations would tend to be reversed by evolutionary factors.

The next question is: What do complex systems do when they are at the edge of chaos. [Holland's \(1998\)](#) assertion about the occurrence of ‘perpetual novelty’ in a CAS essentially amounts to saying that the system moves around in the edge-of-chaos membrane in phase space. But that is not all. The moving

around actually takes the system to states of higher and higher sophistication of structure and complexity. Learning and evolution not only take a CAS towards the edge-of-chaos membrane, they also make it move in this membrane towards states of higher complexity (Farmer *et al.* 1986 (cf. <https://en.wikipedia.org/wiki/Self-organization>). The ultimate reason for this, of course, is that the universe is ever expanding, and there is therefore a perpetual input of free energy or negative entropy into it.

Farmer gave the example of the autocatalytic set model (which he proposed along with Packard and Kauffman) to illustrate the point. When certain chemicals can collectively catalyze the formation of one another, their concentrations increase by a large factor spontaneously, far above the equilibrium values. This implies that the set of chemicals as a whole emerges as a new ‘individual’ in a far-from-equilibrium configuration. Such sets of chemicals can maintain and propagate themselves, *in spite of the fact that there is no genetic code involved*. In a set of experiments, Farmer and colleagues tested the autocatalytic model further by allowing occasionally for novel chemical reactions. Mostly such reactions caused the autocatalytic set to crash or fall apart, but the ones that crashed made way for a further evolutionary leap. New reaction pathways were triggered, and some variations got amplified and stabilized. Of course, the stability lasted only till the next crash. Thus a succession of autocatalytic metabolisms emerged. Apparently, *each level of emergence through evolution and adaptation sets the stage for the next level of emergence and organization*.

NB (4 December 2014):

For an update, please click [here](#).

Vinod Wadhawan at 9:31 AM

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About me



 **Vinod Wadhawan**

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I am a condensed-matter physicist. For the last few years I have been active spreading **the message of science and the scientific method**. In this context I have written over 30 articles at [Nirmukta.com](#). I am listed as an '**Enthusiastic Bright**' at the Brights Net.

Books written

1. **Introduction to Ferroic Materials** (2000)
2. **Smart Structures** (2007)
3. **Complexity Science** (2010)
- 3a. **Nauka złożoności. Trudne pytania, które zadajemy o sobie i o naszym Wszechświecie** (2010)
(Polish version of Book No. 3. Translation by Malgorzata Koraszewska.)
4. **Latent, Manifest, and Broken Symmetry** (2011)

I did editing work for the journal *Phase Transitions* (Taylor & Francis, U.K.) for 25 years, and took voluntary retirement from the task of **Associate Editor** in 2010.

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