Landscape data and complex adaptive system Earth

Holism in complexity and network science

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Landscape and its data can be viewed as interrelated components in the complex adaptive system, Earth. The Earth viewed from a holistic vantage point suggests a Gain sensibility, but I would suggest not in Lovelock's Gain sense as an organism, but rather in Margulis's sense as an ecosystem. An autonomous system, as proposed in Varela's interpretation of Gaia, with operational closure, that is a fully self-referential network that specifies its own identity and also specifies its response to emergent factors and events. A complex coadaptive network, coevolving in interaction with a wide range of networked systems, including information technology networks and the data that they generate. Data from emerging GIS developments, like all other data networks will play a role in the ongoing evolution of the complex adaptive system, Earth.

Why Gaia

Gaia is a dicey word. A word, that in scientific discourse, seems to have fallen a bit by the wayside. There is much up for debate concerning the Gaia hypothesis, particularly the notion that the biota manipulates its environment for the purpose of creating biologically favorable conditions for itself. However the one premise that is largely accepted – the biota has a substantial influence over certain aspects of the abiotic world – points to the holistic orientation of the Gaia hypothesis and it is this holistic orientation that I think is the Gaia hypothesis' major contribution to scienctific discourse.

Dr. James Lovelock, a British chemist specializing in atmospheric sciences, was a recognized scientist in his field in the 1960's when NASA and the Jet Propulsion Laboratory (JPL) asked him to participate in their project teams relating to the scientific search for the evidence of life on Mars. Lovelock predicted the absence of life on Mars based on analysis of the Martian atmosphere and its state of being in a chemically dead equilibrium. Noting that the Earth's atmosphere on the other hand is in a chemical state described as being far from equilibrium, Lovelock began to speculate about what was happening on the Earth which enabled the maintenance of the unlikely balance of atmospheric gases that make up the Earth's atmosphere. In explanation, Lovelock began to formulate his hypothesis that the planet had been transfigured and transformed by a self-

evolving and self-regulating system. In 1973, with American microbiologist Lynn Margulis, Lovelock formally proposed the idea of Gaia as a control system.

Lovelock's tendency toward the poetic seems to have contributed to the cooptation of the Gaia hypothesis by many far outside the scientific realm, who are attracted to its holistic orientation. Margulis who is in disagreement with Lovelock in his premise that the Earth is an organism, states: "Lovelock's position is to let the people believe that Earth is an organism, because if they think it is just a pile of rocks they kick it, ignore it, and mistreat it. If they think Earth is an organism, they'll tend to treat it with respect." (1) Lovelock's positioning for political aims might be considered unfortunate, because it's this holism, often misinterpreted in animistic terms, that is the paradigmatic contribution of Gaia. The premise of an interrelation between the biota and environment moves away from the one directional Darwinist notion of life adapting to environment, toward a holism that is also a primary factor in the fields of complexity and network science that were beginning to emerge during this same timeframe.

At the edge of chaos – the rise of complexity theory in evolutionary biology

William Thompson, the Director of the Lindisfarme Association, an interdisciplinary networking think tank, organized an international conference held in Perugia, Italy in 1988 called *Gaia 2: Emergence, the New Science of Becoming*. This conference brought together not only Lovelock and Margulis, but scientists like Varela, who brought to the conference an expansion of the discourse into the realms of the emerging fields of complexity and networks. As Thompson noted, "we are moving from lines of descent to patterns of reflexive self-reference or emergent patterns of circularity in the metadynamics of the system." (2) Someone who was not at the conference, but who could have contributed much to that discourse is Stuart Kauffman, a biologist who became deeply involved in the debates about complexity that were taking place at, what was during this same time period of the late 1980's, the recently founded Santa Fe Institute. The domain of complexity lies between order and disorder, or, as was coined by complexity scientist Chris Langton, "at the edge of chaos." Kauffman persuaded by the premise that life takes shape between too much and too little order endeavored into an examination of the precise dynamics of emergence.

As biologists such as Kauffman, who interprets the evolutionary process in terms of self-organizing systems, began to use complexity theory, there was a reaction from the neo-Darwinians such as Dawkins, who extends the theory of evolution to the level of genes. Dawkins maintains "A body is the genes' way of preserving genes unaltered." (3) For Dawkins what matters is the survival of the part rather than the whole. For neo-Darwinians the focus is on the elements that

make up the whole: the whole is the sum of its parts and the whole can be reduced to its essential elements without substantial loss. In response to the reductive excesses of neo-Darwinism, Kauffman argues for a combining of neo-Darwinism with an increasingly refined theory of complex self-organized adaptive systems: "the revolution in complex systems dynamics is now making it possible to hope that complex, self-organized systems, including those investigated by evolutionary biology, can be more closely linked to physics and chemistry without reductionism or vitalism." (4)

The underlying premise of Kauffman's view is that the emergence of order is spontaneous, but not random. In the early 1960's biologists Jacques Monod and Francois Jacob had discovered feedback mechanisms that function in a binary mode similar to computers are what regulate genes. Kauffman who saw this insight as pointing to a new research approach, was focused at the time on the problem of determining how the immense numbers of genes in the genome (approximately 100,000) could produce the comparatively speaking, very small number of different cell types necessary for life (250). With the potential activity states of the genes comprising the genome being 1030,000, Kauffman thought the chances of natural selection producing this small number of specifically required genes to be extremely improbable, if not impossible. Thinking of Monod's and Jacob's discovery of the feedback mechanisms by which genes switch on and off, he thought it possible to model genetic activity with Boolean networks. Kauffman speculated that the parallel distributed processes of Boolean networks could approximate genetic activity. In his research he found that Boolean networks, made up of a multiplicity of interconnected nodes, display the characteristics of emergent self-organizing systems. Kauffman found that when random inputs are applied to these networks, they tend to settle into regular patterns known as "state cycles" which serve as attractors in the system. Within certain parameters, Boolean networks produce emerging webs of self-sustaining patterns. Kauffman describes these webs within networks as "order for free."

Kauffman concludes that the principle of order for free provides an approach toward the explanation for the origin life as well as its development, arguing that life emerges in "autocatalytic sets". Autocatalytic sets possess the property whereby each member's formation is catalyzed by one or more members, so that its own high concentration is maintained. The set is collectively autocatalytic by virtue of reflexive catalysis among its members. In explaining the loops of autocatalytic sets, Kauffman points to Kant's understanding of the organism in relation to the concept of inner teleology:

> Immanuel Kant, writing more than two centuries ago, saw organisms as wholes. The whole existed by means of the parts; the part

existed because of and in order to sustain the whole. This holism has been stripped of a natural role in biology, replaced by the image of the genome as the central directing agency that commands the molecular dance. Yet an autocatalytic set of molecules is perhaps the simplest image we can have of Kant's holism. Catalytic closure ensures that the whole exists by means of the parts, and they are present both of and in order to sustain the whole. Autocatalytic sets exhibit the emergent property of holism. (5)

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Coevolution and fitness landscapes

The genome, Kauffman contends, is a complex adaptive system composed of "networks of genes and their products interacting with one another in enormous webs of regulatory circuitry." (6) Complex systems being adaptive, their evolution tends to be coevolution. When systems and networks adapt to systems and networks that are adapting to them, change is reciprocally related.

Developments, at both the individual and species level, take place in webs within networks that are transforming by adapting to each other. This process of coadaptation creates a dynamic of coordination between the parts and the whole within a system, establishing the type of niches similar to those found in an ecological system that form fitness landscapes, which Kauffman postulates are non-random. This non-randomness Kauffman argues is "critical to the evolutionary assembly of co"mplex organisms. We will find reasons to believe that it is not natural selection alone that shapes the biosphere. Evolution requires landscapes that are not random. The deepest source of such landscapes may be the kind of principles of self-organization that we seek. Here is one part of the marriage of self-organization and selection." (7)

Kauffman's argument that fitness landscapes are non-random comes out of his work on Boolean networks. Fitness landscapes of an individual or network develop in parallel with other fitness landscapes. These landscapes can be thought of as nodes in a web of landscapes that determine the parameters for each other: enabling the network to establish the conditions for development. The ecology of the whole network is transformed by a change in one niche or landscape. Kauffman argues that coadapting networks evolve to the verge of a self-organized threshold where minor changes in one landscape trigger a rush of changes that move out through the entire network. Because of the complexity of the web of landscapes, possibilities are limited within a given network. Networks

of fitness landscapes are inclined to settle into rhythms with cyclic patterns, functioning like attractors in dynamical systems. Functioning along a perimeter of divergence that is in constant flux, networks self-organize in somewhat stable patterns until another phase transition occurs. A bifurcation occurs resulting in the emergence of a new morphological type that remains relatively stable for a time, and then suddenly mutates or vanishes. Because this process is unpredictable by nature, it doesn't necessarily mean it is directionless. Instead of thinking of this process as teleological, self-organizing systems can be understood as following a teleonomic progression; a line of development that moves toward increasing complexity.

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Landscape and its data

What of the other landscapes – the material ones made of such things as dirt, rocks, and dust? Here we come full circle to the premise of the Gaia hypothesis that is widely agreed upon – the biota has a substantial influence over certain aspects of the abiotic world – and as argued in Kauffman's coadapting networks, vice versa. I would speculate further that both the data networks generated in relation to both the biotic and abiotic realms are also implicated in these coadapting networks.

It's interesting to note that in the field of physical geography, which is self-admittedly probably one of the most empirically oriented of the sciences, there is some discussion emerging concerning the use of complexity science in physical geography research approaches. The fields of biogeography and landscape ecology are the areas most oriented toward the applicability of complexity theory in research methodology. In his article, "Considering Complexity", biogeographer George Malanson suggests the science of complexity as a possible approach to the conflict that has emerged in physical geography between reductionism and holism, especially since the introduction of General Systems Theory, the scientific effort to identify structural, behavioral and developmental features common to particular classes of living organisms.

Malanson describes the "strong trend toward reductionism in physical geography over the past three decades…" which has lead to researchers tendency to "... simplify our research questions to conform to mathematically tractable domains…" (8) A primary argument of the paper is that most of the research in physical geography is related to place. Because "... the location of a place can be characterized by its spatial properties…" and "space can produce complexity in simple processes…" (9) there are nonlinearities created in geography associated with scale. Malanson views this as a prime area for applicability of

methodologies of complexity theory. He describes a key area for applications of complexity in biogeography as the analysis of ecotones (vegetation boundaries where plants are presumed to be near the edge of their physiological tolerance) related to the edge of a phase change, through the use of computer-simulation modeling developed out of GIS or remote-sensing technologies.

With the increasing use of GIS technologies in a wide variety of fields, including art, the data networks generated will disseminate into the expanding networks of information technology. I speculate these GIS generated data networks have the potential to act as bifurcations and coadaptive systems in relation to the landscape and the overall complex adaptive system earth.

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Notes

1) John Brockman, *The Third Culture: Beyond the Scientific Revolution* (Simon & Schuster, 1995).

2) William Irwin Thompson, *Gaia 2: Emergence: The New Science of Becoming* (Lindisfarne Press, 1991), 234.

3) Richard Dawkins, *The Selfish Gene* (Oxford University Press, 1989), 23.

4) David Deprew and Bruce Weber, *Darwinism Evolving: Systems Dynamics and the Genealogy of Natural Selection* (MIT Press, 1995), 399.

5) Stuart Kauffman, *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity* (Oxford University Press, 1995), 69.

6) *Ibid.*, 99.

7) *Ibid.*, 166.

8) George Malanson, *Considering Complexity – Annals of the Association of American Geographers*, vol. 89, no. 4 (Blackwell Publishers Inc, 1999), 747.

9) *Ibid.*, 748.

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