Monsters and Morphogenesis: On Differentiation, Hierarchy and Energy in Natural Systems

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The mythical monsters of the classical world were imaginary creatures, composed of parts of known animal and human forms. The sphinx, for example, had the head of a woman and the body of a lion, the centaur was a horse that had a human torso and head, and the chimera was a fire-breathing monster that had the head of a lion, the body of a goat and the tail of a serpent. The monsters of classical mythology were beings that united mankind and animals, but is not their cultural significance that I want to refer to, rather the fact that were composed of different parts in order to do something more than mortal humans could do. Monsters were aggregations of differences, and the union of these differences produced a higher functionality.

We describe a system as complex if it is made of several parts that are so thoroughly connected that the system cannot be broken down into elements or components without destroying it. As with the monsters of antiquity, the parts are simultaneously distinct, or different from each other, and at the same time they are connected. A system has more complexity the more parts it has, with more connections between them. An increase of differences is differentiation, an increase in the number or strength of connections between them is integration. For a system to be complex, both differentiation and integration are necessary. Complexity (1) theory focuses on the effects produced by the collective behavior of many simple units that interact with each other, such as atoms, molecules or cells. The complex is heterogeneous, with many varied parts that have multiple connections between them, and the different parts behave differently, although they are not independent. Recent developments in the mathematics of evolutionary biology extend the concept of a biological form or individual organism from an autonomous self-organised individual system, to a more complex meta-system with multiple hierarchies. The origin of the concept of a self-organising system lie in the intersection of biology and mathematics in the 1920's (2), but the recent focus on relations between multiple hierarchies stems from the recognition of the fact that individual organisms are not completely autonomous, but exist within higher level systems, which in turn are multiple and varied parallel systems that interact within populations, environments and ecologies.

Differentiation is a feature of all natural systems, between cells within biological tissues, between tissues, organs and structures within individual phenotypes or organisms, between individuals in populations, and between communities and species. Systems of energy flow control differentiation in each level of hierarchy. Living systems interact with the non-living world to form the ecosystem and this interaction is critical to the understanding of differentiation in the biota, as without environment there is no organism, and without organisms there is no environment.

Relationships between living organisms and the environment are vectored by energy and material flows, organised by trophic levels in a co-evolutionary process between living things and their physical and chemical environments. Analysis of energy flows and morphological differentiation, co-evolution, and speciation in ecological systems (3) offers the potential of developing a metabolic strategy for buildings and cities that recognises the dynamics of critical changes in the global environment.

The term differentiation has a specific meaning in biology, describing the process that takes place during the development of the embryo and leads to the formation of specialised cells, tissues, and organs. The mathematician and philosopher Whitehead (4) argued that process rather than substance is the fundamental constituent of the world, and that nature consists of patterns of activity interacting with each other. Natural systems are processes, and it is process that produces, elaborates and maintains the form or structure of all living things and of non-living things. Differentiation is a feature of all living things, between cells within biological tissue, between tissues, organs and structures within individual organisms, between individuals in populations, and between communities and species.

It might be thought that genetics and embryology take quite different approaches to differentiation, as they appear to have fundamentally different arguments. What is common to both systems of thought is differentiation. Genetics argues that all living things are the products of natural selection, operating on inherited small changes in the over many generations. It is these small changes (to the genome) that produce differentiation within populations, and drive evolution. Every reproductive cycle requires the organism to replicate its genetic material, and this process is susceptible to small copying errors, so that offspring are produced that are a little bit different from the parents. In the most extreme account, organisms are described (5) as a kind of temporary host for the genes, a mechanism for their perpetuation.

Darwin argued that just as humans breed livestock and vegetables by ‘unnatural’ selection, organising systematic changes in them, so wild organisms themselves are changed by natural selection (6). The mathematics of more recent evolutionary models developed by Heylighen (7) and Stewart (8) are based on differentiation or the distributed variation of different individuals within populations. Both individual organisms and the ecologies in which they exist are evolved by multiple parallel systems that interact with each other, and this interaction is what produces the self-organisation of the ecology as a whole. In this argument the morphogenetic differentiation of any single individual occurs at a relatively low hierarchical level in the meta–system of nature. What is considered significant is the differentiation of the population, how many individuals exhibit differences from the norm.

In more contemporary expressions organisms are described as members of a class of complex dynamic system with distinctive properties of order and form, and it is these characteristics of organisms that are drivers of evolution (9). The differentiated morphology of living organisms is determined not only by the genome, but also by the combination of the internal forces such as chemical activities and pressure in their cells, and of external environmental forces such as gravity; the effect of these natural forces is expressed in different ways depending on the size of the organism.

Energy is a critical factor in ecological differentiation. All biological organisms and many natural non-living systems are maintained by the flow of energy through the system. The pattern of energy flow is subject to many small variations, which is adjusted by ‘feedback‘ from the environment to maintain equilibrium, but occasionally there is such an amplification that the system must reorganize or collapse. The tendency of biological systems is towards ever increasing complexity, each reorganization being produced at the moment of the collapse in the equilibrium of a system. Evolutionary development in general emerges from energy flows in dynamic systems (10).

The evolutionary differentiation from unicellular organisms to more complex organisms may not have possible without the incorporation of energy producing systems into the larger organisms. There other common features, in addition to the genetic sequence, of organic energy systems. All organisms must not only produce energy, they must also transport it. The morphology of branching networks is found in all organisms of all species. It can be geometrically defined as a space-filling, fractal-like branching pattern (11) that reaches all parts of the organism, and the final unit of this branching pattern is always an identical size. There is a relationship between energy, lifespan and body mass; small organisms are typically more metabolically active than larger organisms, and the larger the organism, the slower the metabolism. Bigger organisms live longer and expend more energy than small organisms. Energy is the critical factor in biological differentiations of morphological and temporal scale.

The study of energy and differentiation in natural systems offers a new model for architecture that relates pattern and process, form and behaviour, design and construction that has a symbiotic relationship with the natural world. Architecture must make a positive contribution to the environment, and can do so by developing a metabolism for buildings and cities that extends far beyond the minimising environmental strategies of ‘sustainability’. In the natural sciences, metabolism refers to all energy transformations, the sum of the complex chemical and physical changes that take place within an organism and promote growth, sustain life, and enable the processes of living organisms. A model abstracted from complex natural systems must incorporate individual and groups of environmentally intelligent buildings, with interlinked systems of material and energy flows, organised to generate oxygen, sequester carbon, fix nitrogen, collect and purify water, acquire solar energy, and respond intelligently to impending climatic changes.

NOTAS

(1) Weaver, Warren, *Science and Complexity*, American Scientist, 36: 536 (1948).
(2) I have traced the conceptual origins to the intersection of ideas and techniques in the work of D'Arcy Thompson and Whitehead. Weinstock, Michael, *Morphogenesis and The Mathematics of Emergence*, in *Emergence- Morphogenetic Strategies for Design,* ed. Hensel, Menges and Weinstock, AD, Wiley-Academy, 2004.
(3) This text is a short outline of a larger study to be published in 2007, Weinstock, Michael, *The Architecture of Emergence - Algorithms, Energy and the Evolution of Form in Nature and Architecture,* Wiley Academy.
(4) Whitehead, Alfred North, *The Concept of Nature*, Cambridge University Press, 1920.
(5) Dawkins, Richard, *The Selfish Gene*, *The Extended Phenotype*, and *The Blind Watchmaker*, 1976/89, 1982,1986, Oxford University Press.
(6) Darwin, Charles, *On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life,* London, John Murray, 1859.
(7) Heylighen, Francis, *Self-Organisation, Emergence and the Architecture of Complexity,* Proceedings of 1st European Conference on System Science, 1989.
(8) Simon, H.A.,*The Architecture of Complexity,* Proceedings of the American Philosophical Society 106, reprinted in *The Sciences of the Artificial,* 3rd ed, MIT Press, 1996.
(9) Kauffman, Stuart, The Origins of Order – Self Organisation and Selection in Evolution, Oxford University Press (1993).
(10) Any physical system that can be described by mathematical tools or heuristic rules is regarded as a dynamic system. Dynamic System theory classifies systems by the mathematical tool rather the visible form of a system.
(11) Niklas, K. J. Plant Allometry: The Scaling of Form and Process, Univ. of Chicago Press, 1994.