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Self-Organization

The term *self-organization* refers to a spontaneous emergence of order in complex processes. The idea of an emergence of order has very old roots, but its importance as a scientific concept, and concomitantly its relevance for the ongoing science and religion debate, have only recently been recognized.

History of the idea

Though the idea of self-organization is often presented as a twentieth-century revolution in science, some of its basic notions are as old as human reflection on the origin of the world's orderliness. Many cosmogonic myths narrate the struggle between chaos and cosmos, and the emergence of order out of chaos.

In ancient philosophy, Heraclitus (c. 54080 B.C.E.), Aristotle (38422 B.C.E.), and Lucretius (c. 965 B.C.E.) attempt to rationally cope with nature's self-organization. In modern times, germs of the contemporary theory of self-organization are to be found in René Descartes (1596650), Gottfried Wilhelm Leibniz (1646716), and Immanuel Kant (1724804), who in his *Kritik der Urteilskraft* (*Critique of Judgment,* 1787) introduced the term *self-organization.* After Kant the idea of self-organization was a focal point in the philosophy of nature of Friedrich Schelling (1775854) and in the metaphysics of Alfred North Whitehead (1861947).

In scientific discourse, the concept of self-organization was introduced in 1947 by W. Ross Ashby, who elaborated on it in the context of cybernetics and systems theory. From the 1950s on, the scientific idea of self-organization was further developed by Heinz von Foerster (order from noise); Ilya Prigogine (dissipative structures); Hermann Haken (synergetics); Humberto Maturana and Francisco Varela (autopoiesis); Manfred Eigen (hypercycles); Norman Packard, Chris Langton, and Stuart Kauffman (the edge of chaos); Per Bak (self-organized criticality); and many others.

The scientific concept

Self-organization is the process of the spontaneous emergence and maintenance of order in a complex dynamic system. The capacity for self-organization enables the system to develop or change its internal structure spontaneously and adaptively in relation to its environment. The term *spontaneous* is meant to refer to the absence of control by an external or central agent. The global ordering results from interactions between the initially independent components of the system, all of which follow their own local laws. Thus, the development of the ordered structure takes place primarily in and through the system itself.

One of the fundamental traits that distinguish self-organizing systems from systems studied in more traditional cybernetics is the absence of centralized control. The "control" of the organization is typically distributed over the entire system. Because of this distributed character, such organization tends to be robust and to resist perturbations.

The internal and distributed "control" is often effected by circular or network relations between the components. Though the laws governing the global behavior are still imperfectly understood, the complex process is known to generally involve positive feedback loops alongside the "normal" negative feedback loops (known from standard cybernetic control systems). Negative feedback works to stabilize by reducing variations; positive feedback on the other hand amplifies the variations (e.g., autocatalytic processes). The interaction between these two forms of feedback may create a nonlinear dynamics, intricately developing itself until it reaches a stable situation, an *attractor.*

An attractor is a state, or set of states, toward which the system tends to evolve, and in which, when reached, it tends to stay. If the attractor contains an infinite number of states so that the system oscillates in an a-periodic way between them, the system is said to be chaotic An isolated system usually has a single, trivial, attractor: the equilibrium state with maximum entropy ("disorder"). A self-organizing system, conversely, evolves toward an ordered state. This may be an ordered equilibrium state (e.g., in crystallization), but in typical complex self-organizing systems (such as living organisms), it will be an ordered nonequilibrium (in those systems equilibrium means "death"). Such ordering processes may seem to contradict the entropy law of thermodynamics. This, however, is not the case, either because the systems involved are not at all thermodynamical (e.g., economies), orf thermodynamic considerations do applyecause these systems are thermodynamically open: Many of them import "order" from their environment (e.g., sunlight or food), and all of them export entropy to their environment (e.g., heat or waste).

Though self-organization eminently applies to living organisms, it is also seen in nonbiotic systems. Examples include crystallization, gravitational coalescence of cosmic dust to planets, the forming of galaxies, patterns in heated liquids, chemical compounds, living cells and organisms, the flocking of birds, evolution of life, ecosystems, brains and cognitive functions, artificial intelligence, and economies.

Relevance for religion and theology

In respect of religion, the idea of self-organization primarily presents a challenge because it suggests, as some physicists have been tempted to conclude, that the ability of cosmological, physical, chemical, and biological systems to organize themselves makes God as creator and director of the universe superfluous. Such conclusions may be premature, because many aspects of the theories about the origins of the universe and the origins of life are still highly hypothetical and uncertain; but, pointing to still existing gaps in those theories is not without danger for theology: Doing so may easily lead to a reintroduction of God as the filler of gaps. So, the real challenge for theology is to explore how the idea of God's agency with respect to the world, which is at the heart of the three monotheistic religions, can be related to the idea of nature's self-organization.

On the other hand, the idea of self-organization might give theology a chance to overcome its neglectver since theology's anthropological turnf nature as a theological issue. According to modern theological insights, God is involved in human actions, mentality, morality, freedom, and finality, all of which the dominant mechanistic worldview regards as typically uncharacteristic of nature. A nearly total gap in theology between nature and God is the result. However, a number of scientists who describe certain natural processes as self-organizing, claim that the introduction of the concept of self-organization signifies a shift with respect to the accepted mechanistic paradigm, in the sense that to some extent these nonhuman processes might also be characterized in terms of finality and freedom. This new, nonmechanistic, view of nature might help theology to explore new conceptualizations of

God's relationship to nature.

Apart from the question whether or not self-organization implies a paradigm shift, it is relevant to theology in another way. Studies of complex, dynamic, self-organizing systems involve themes such as order, chaos, waste and conservation, temporality, equilibrium, teleology, life and death, and consciousness, all of which also figure prominently in theological anthropology and in the religious interpretation of the world. It is therefore conceivable that the new insights arising from the study of complex, self-organizing systems may intensify and enrich the theological reflection on religiosity and religious interpretation.

See also AUTOPOIESIS; CHAOS THEORY; COMPLEXITY; EMERGENCE; ENTROPY

Bibliography

Ashby, W. Ross. "Principles of the Self-Organizing System." In *Principles of Self-Organization*: *Transactions of the University of Illinois Symposium on Self-Organization, June 8, 1961,* ed. Heinz von Foerster and George W. Zopf. Oxford: Pergamon Press, 1962.

Camazine, Scott; Deneubourg, Jean-Louis; Franks, Nigel R.; Sneyd, James; Theraulaz, Guy; and Bonabeau, Eric. *Self-Organization in Biological Systems.* Princeton, N.J., and Oxford, UK: Princeton University Press, 2001.

Capra, Fritjof. *The Web of Life: A New Scientific Understanding of Living Systems.* New York: Anchor, 1996.

Gregersen, Niels Henrik. "The Idea of Creation and the Theory of Autopoietic Processes." *Zygon* 33 (1998): 33367.

Kauffman, Stuart A. *At Home in the Universe: The Search for Laws of Self-Organization and Complexity.* London: Penguin, 1995.

Oomen, Palmyre M. F. "Divine 'Second Order' Design and Natural Self-Organization." *Studies in Science and Theology: Yearbook of the European Society for the Study of Science and Theology* 8 (2002): 36.

Paslack, Rainer. *Urgeschichte der Selbstorganisation: Zur Archäologie eines wissenschaflichen Paradigmas.* Braunschweig, Germany: Vieweg, 1991.

Schrödinger, Erwin. *What is Life?: The Physical Aspect of the Living Cell.* Cambridge, UK: Cambridge University Press, 1944.

Weber, Bruce H.; Depew, David J.; and Smith, James D., eds. *Entropy, Information, and Evolution: New Perspectives on Physical and Biological Evolution.* Cambridge, Mass.: MIT Press, 1990.

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