Topic Page: Chaos Theory

Summary Article: **Chaos Theory**
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CHAOS THEORY DERIVES from physics and mathematics, and is a form of systems theory that seeks to describe highly complex and disordered systems, such as the atmosphere; although some attempts have been made to apply chaos theory to both the social and ecological sciences. The theory states that complex and seemingly chaotic systems, whose structure cannot be described by linear mathematics, are actually underwritten by orderly processes, an idea that has been termed *deterministic chaos*. The theory utilizes nonlinear mathematics to describe these systems, and attempts to understand change in terms of the values that the variables take on, in contrast to the related complexity theory, which seeks to explain change in terms of variability from outside the system in question. In rejecting linearity, both chaos and complexity theory have replaced the classical notion of linear causation with the idea of *self-organization*, in which the individual components of the system are viewed as independent agents (as opposed to independent and dependent variables) that spontaneously rearrange themselves according to their individual properties and external conditions.

VARIOUS TYPES OF ATTRACTORS

A system, according to chaos theory, can exhibit either some pattern of stability or order according to some range of values that its variables can take, or be driven into chaotic behavior based on another set of values of the variables. That the chaotic behavior arises as a function of the defining equations and the values of its variables illustrates the idea of *deterministic chaos*. The set of values for the equation that produce stable results are termed *attractors*. A perfectly stable system that never varies from its steady state would have its equation graphed out such that it would be a point (the trajectory of values never deviates the initial values); such a set of values is termed a *point attractor*. A homeostatic system, one that deviates from its original state but that is brought back to its original state, has its trajectory of values following a toroidal trajectory, forming what is known as a *toroidal* or *doughnut attractor*. In illustrating the differences in explanatory power that chaos theory offers in explaining systems behavior, what is usually depicted is the *butterfly* or *Lorenz attractor*. With this attractor, a system will follow a toroidal path for a given set of values, but small variations can cause the system to shift into an alternative toroidal trajectory. That is, the equation describes a system with two homeostatic pathways possible, with small changes at a critical moment causing them to switch between stable trajectories. The resulting graphed trajectories appear to be two adjacent and linked *toroidal attractors*, vaguely resembling the wings of a butterfly, hence the name *butterfly attractor*. Higher order attractors, with three or more stable states, are possible as well. The set of values that drive the system into chaotic behavior are termed *strange attractors*. The trajectories followed by the equation under the conditions of strange attractors often exhibit recursive self-similarity (*fractal structure*).

THE BUTTERFLY EFFECT

Both attractors and *strange attractors* illustrate another important concept in chaos theory, this being *sensitivity to initial conditions*. Very minute changes in value for the variables could cause an orderly system to switch between stable states, as in a Lorenz attractor. Alternatively, these minute changes in values could drive the system into chaotic behavior, as in strange attractors. This idea of sensitivity to initial conditions has been popularized as the *butterfly effect*, which basically states that the minute turbulence produced by a butterfly flapping its wings in one location could make the difference between pleasant weather and violent storms elsewhere on the planet. *Sensitivity to initial conditions* is a concept that chaos theory shares with complexity theory; although the two differ, in that chaos theory views this sensitivity to be endogenous to the system, whereas complexity theory tends to stress the sensitivity of its component variables to exogenous noise. Chaos theory is broadly concerned with describing closed systems, whereas complexity theory tends to view systems more openly.

Chaos theory has found only limited application to ecological systems. Robert May is generally credited with first using nonlinear equations in an ecological context in 1974. He applied these nonlinear equations in describing the dynamics of population growth, using the growth rate, carrying capacity and population as the only variables. He discovered that by varying the growth rate, a variety of responses in the population could be attained, with stable populations occurring at low rates of growth, stable cycles of population levels occurring at moderate levels of growth (with periodicity of the cycles increasing as the growth rate increases), and finally with chaotic fluctuations occurring above a high threshold of the growth rate. That the equation can give various stable conditions or be driven into chaos due to sensitivity to one of its variables is consistent with chaos theory.

Damselfish Study

A study of fluctuating damselfish populations—a marine species that spawn on a monthly cycle and whose eggs hatch with the full moon—were found to fluctuate dramatically from month to month, and were not predictable in either linear or nonlinear population growth models according to standard population growth or predator-prey relationship models. Rather, researchers found that variations in exogenous factors such as winds and currents played a crucial role in the survival of damselfish hatchlings, and that when these were factored into the equations, the populations followed nonlinear dynamics. That is, the sensitivity driving chaotic fluctuations did not arise from the population variables themselves, as chaos theory would assert, but rather arose due to sensitivity to environmental noise (exogenous factors). These results are more in line with the predictions of complexity theory.

DETERMINISTIC CHAOS IN ECOLOGY

Subsequent research looking for deterministic chaos in ecological contexts typically focus on fluctuations in species composition, especially as situated in trophic structures. For instance, classic studies of snowshoe hare populations—which fluctuated in phase with the population of its predators, leading to the formalization of predator and prey relations—were re-examined in light of non-linear dynamics, and were found to vary according to both their food supply as well as to predator populations. Although *deterministic chaos* has been demonstrated in the laboratory setting for fluctuating populations, it has been more difficult to demonstrate in nature. This difficulty arises in no small part to a paucity of appropriate data; since a proper analysis would require monitoring the population of the species in question, its population of food species, population of predator species, and relevant environmental variables over a number of decades—and such extensive datasets are rare. Furthermore, natural systems appear to select for inhibitors; measured population growth rates are rarely high enough to initiate chaotic behavior in their descriptive equations.

The endogenous deterministic chaos predicted by chaos theory is characteristic of closed systems, and has largely only been demonstrated in laboratory settings. The climatic and atmospheric sciences have utilized chaos theory, however, since the atmosphere is largely a closed system when viewed as a whole. Although the social sciences have also begun to utilize both chaos and complexity theories, the area of human-environment interactions has largely been overlooked, but is an area that is drawing increasing attention from researchers.

SEE ALSO:
Butterfly Effect; Complexity Theory; Ecosystems.

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