THE THEORY OF CHAOS
Review Article

by

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REVIEW ARTICLE

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James Gleick, *Chaos: Making a New Science*, New York: Viking Penguin, 1987, pp. xi+354, U.S. $ 19.95.

So far, it has been a quiet revolution, and sometimes an enbittering struggle. For a time, journal editors refused to publish the research of its pioneers. Their work collided with the defenses of conservative thought: the dissertation committee's veto and the editor's rejection slip. The problems that concerned its proponents were simply not recognized as legitimate lines of inquiry.

As in any radical shift away from the prevailing and ingrained mindset, the major contributors to the theory of chaos have, almost without exception, encountered opposition, ridicule, and open hostility. With a stubborn tenacity, scientists outside this new discipline have gripped the handles, worn smooth by the familiarity of habit, of the more intuitive tools of tradition. As a result, theory of chaos had a turbulent beginning about ten years ago, when the new science began to attract serious interest.

Since then, interrelated discoveries, often mutually confirming, have occurred in a wide range of disciplines, from fluid mechanics and the physics of turbulence to mathematics, meteorology, chemistry, cardiology and immunology, cell growth and the biological architecture of organisms, human neuroscience, and artificial intelligence, some of the areas in which the main effects of theory of chaos have so far been felt.

In spite of its growing influence, the fact has been camouflaged that a deep-seated revision in scientific modes of thought is slowly taking place.

Theory of chaos seems to hold promise alongside other major breakthroughs in science: In different ways, all have exercized an *erosive* influence, cutting across the circular ruts of human intuition and common sense. Relativity laid to rest the Newtonian ideals of absolute space and time; quantum theory eliminated the dogma of an independent, objectively measurable reality; and now theory of chaos has departed from an ancient scientific tradition whose foundation was formed with the tools of linear mathematics.

Largely unrealized by scientists, the history of science has been constrained by the traditional models and the conceptual vocabulary offered by hard-edged geometry, well-defined set theory, and formal linearity. Theory of chaos punctures each of these presuppositions with a question mark. Physical reality has no crisp, hard edges; no physical object is a Euclidean triangle, not even a triangle stretched on a perfect sphere, for these are abstract constructs that can be made to fit physical reality only on a Procrustean bedframe.

> 'Clouds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth, nor does lightning travel in a straight line.'*

Physical, as well as psychological, reality is not well-defined; physical or imagined sets are often essentially vague or indeterminate; and the pristine linear equations with which it is convenient to model reality do not reflect its essentially rough-grained and yet indefinitely finely-detailed nature, predictively refractory and dynamically intertwined.

To rid itself of these inbuilt biases of an intractable tradition, theory of chaos has reached for a new basis: Fractal geometry, for example, more closely fits the indefinitely magnifiable rough structure of physical objects. Fuzzy sets more closely capture the way physical objects and events meld into one another. The computer-simulated behavior of nonlinear systems more closely resembles the dynamics of real events.

The central idea in theory of chaos has to do with the *iteration of nonlinear systems* – with mathematical expressions whose output can be fed back into them repeatedly. It was soon discovered that frequently from the simplest

* Benoît B. Mandelbrot, *The Fractal Geometry of Nature* (San Francisco: W.H. Freeman 1977), p. 1.

of such loops, intricate, endlessly proliferating patterns could be generated. They provided an image of order shading quickly into apparent chaos, of pattern giving way to seeming randomness. That comparatively simple functions when iterated could generate exquisite, endlessly evolving complexity was one surprise; another was the appearance of universal order within that complexity.

The practical interest in functions of this kind is that they frequently model the behavior of numerous and seemingly disparate physical processes that have long withstood linear understanding. They are as everyday as the weather, turbulence in fluids and gases, cardiac arrhythmias, fluctuations in commodity prices, or simply the apparent patternlessness of a dripping faucet.

The key technique in theory of chaos is to take a real-valued mathematical function, and iterate its values reflexively: that is, the behavior of a sequence of values $x, f(x), f(f(x)), f(f(f(x))), \ldots$, is studied, where f is a function that exhibits a cyclic or near-cyclic behavior as it is forced to take its own values in a self-referential manner. These functions make up the family of *nonmonotonic* functions. They are functions whose graphs are folded: When graphed, such a function's values move first in one direction, then in another.

The study of functions of this kind has led to some startling discoveries. They are only now coming to light, thanks to a style of mathematical exploration that is entirely new, made possible by digital computation. Experimental mathematics, assisted by computer simulation, has come into its own, and its use has made research in the theory of chaos possible.

The automatic iteration of nonlinear systems on a computer has brought to researchers in widely separated fields a surprisingly similar understanding of mathematical models for such things as planetary orbits, fluids, erratic eye-movements of schizophrenics, the weather, lasers, and population genetics. Again and again, such models have revealed previously unknown and counterintuitive properties of their peculiar feedback loops. It is here that the subject matter of theory of chaos lies.

As their values are recursively fed back into the functions themselves, unexpectedly universal structures have been discovered, structures that appear to be independent of the specific nature of the functions under iteration. Instead, what appears to be important is the fact of iteration or self-reference itself.

Theory of chaos is probably named inappropriately, but the terminology of chaos has proliferated, and is now unlikely to change: On the one hand, for example, Yale University physicist Roderick V. Jensen defines 'chaos' as 'the irregular, unpredictable behavior of deterministic nonlinear dynamical systems', yet on the other hand, mathematician John Hubbard considers the main discovery of theory of chaos to be the realization that simple processes can produce remarkable complexity *without* randomness. This is chaos divested of its fundamental meaning.

As one studies the literature of the theory of chaos, it soon becomes clear that the 'chaos' in the iterative unfolding of a nonlinear system is not really chaos at all, but refers instead to a peculiar kind of indefinitely ramifiable complexity of pattern and organization.

But by whatever name, the field astonishes by its brief history and rapid development. To the extent that theory of chaos models reality, nature appears to be constrained: Apparent disorder is channeled into patterns that may conceal universal principles of order.

In closing his book, Gleick quotes Goethe: "We have a right to expect from one who proposes to give us the history of any science, that he inform us of how the phenomena of which it treats were gradually known, and what was imagined, conjectured, assumed, or thought respecting them." From this perspective, Gleick has accomplished the task Goethe would desire. The book is carefully written, and offers a thorough compilation of history and information about this new and fascinating science, one that reveals the forefront of our efforts, once again, to extend the reflexive boundaries of our own understanding.

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