THE FASCINATING PHYSICS OF EVERYDAY COMPLEXITY, BEAUTIFULLY PORTRAYED

Chaos: Making a New Science

James Gleick
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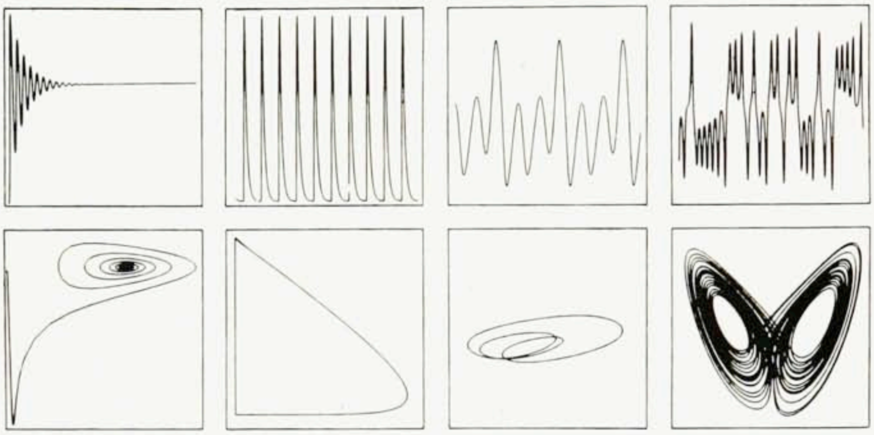

Road to chaos. A traditional time series (above) and trajectories in phase space (below) illustrate long-term behavior in a system. At left a system converges to a point in phase space, seen above as a steady state. The second pair shows periodic repetition or a cyclical orbit in phase space. The third pair shows a "period-three" waltz rhythm. The last pair shows chaotic behavior. (Reproduced from *Chaos* by permission of the publisher.)

About 20 years ago, researchers in a variety of fields, ranging from economics and biology to mathematics and physics, began to question the assumption that complex behavior springs from random and essentially inexplicable causes. Often they were working on unfashionable or interdisciplinary topics and their results were studiously ignored by more mainstream researchers. However, starting about 10 years ago, and largely due to the efforts of mathematicians and theoretical physicists, these disparate groups began to recognize that they were all pursuing fundamentally similar problems describable in terms of the same set of unifying concepts. James Gleick's fascinating book is a history of the development of these ideas, now known generically as chaos.

Gleick makes a convincing case that the theory of chaos has begun a revolution in our understanding of nature comparable to that engendered by quantum mechanics, with "sensitive dependence on initial conditions" playing the role of the uncertainty principle. However, though the initial inspiration for the two movements came at roughly the same time, they developed at different rates. At the turn of the century, the mathematician Henri Poincaré provided the basic formalism necessary to understand complexity. The biologist D'Arcy Thompson in his great book *On Growth and Form* (1917) proposed that, independent of detailed causes, systems tend to group themselves into broad classes whose behaviors should be explicable in terms of simple mathematical models. Alan Turing in 1952 claimed that morphogenesis and the formation of complex structures were legitimate subjects for physical inquiry. Nevertheless, for some 60 years mainstream physics focused on a reductionist understanding of the basic constituents of matter rather than on an understanding of complexity. Only recently, with the success of the theory of critical phenomena, has the more holistic approach become widely acceptable.

In Thompson's view the understanding of form is visual and metaphoric, often closer to the process by which an artist imposes meaning on nature than to traditional analytic techniques. Researchers on chaos have followed both approaches, some studying the behavior of bifurcations of differential equations, others turning to computational modeling and simulation. The legitimation of computer models as a vehicle for understanding is one of the hallmarks of chaos research.

The theory of chaos has had many successes in treating specific systems, but its most revolutionary contribution has been to effect a change in attitude. It has vastly increased the scope of subjects deemed suitable for investigation. One no longer dismisses complex and irregular behaviors as uninteresting or noisy; instead, one seeks for simple explanations. In this view the future of physics lies in the exploration of complex phenomena: the formation of patterns, the origin of turbulence, the functions of the brain and more. More traditional physicists may find the message threatening, but chaos presents the first real possibility that physics can be extended to the nonequilibrium complexity of the everyday world. One may draw an analogy between the development of chaos research and the birth of physics itself, in which seemingly disparate

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