BOOK REVIEWS

Aspirations in Santa Fe

Complexity: The Emerging Science at the Edge of Order and Chaos. M. MITCHELL WALDROP. Simon and Schuster, New York, 1992. 380 pp. $23.

Complexity: Life at the Edge of Chaos. ROGER LEWIN. Macmillan, New York, 1992. xii, 209 pp., illus., + plates. $22.

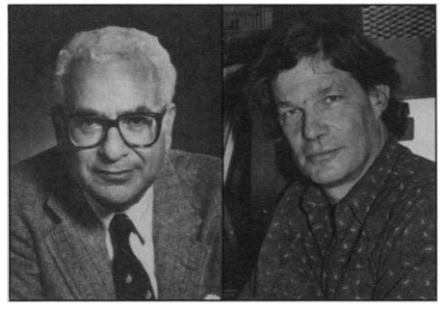
When the topic is complexity, it is only fitting that the reviewer must cope simultaneously with two books. Both of these two are extended essays in scientific journalism written by adepts of that field. And both arise from the aggregation, in the later 1980s, of a group of scientists, small in number but large in talent and in naive enthusiasm, to form the Santa Fe Institute. Do I mean "naive" in the pejorative sense of thinking big but not knowing what one is getting oneself into, or in the complimentary sense as referring to a quality that can be a driving force for innovation? Something of both, I think. I have strong views both positive and negative about aspects of what its proponents claim to be a new field of science with the name "complexity." But I must chiefly tell potential readers whether the books are adequate to let them make up their own minds.

Hero-worship of a few individuals is evident in both books. For the lay reader who wants to know what is going on in science but is not working in it, there is a missing perspective. When we consider, for instance, heroes of the sporting field, we can see their superhumanity rising out of the near-superhumanity of many other major-league players. We see them all, in the stadium or on the TV screen. But the other players in science are appreciated only by other scientists who read literature with hundreds of references, which journalistic books do not have. (Lewis Held's recent *Models for Embryonic Periodicity* references well some of the heroes of Waldrop's and Lewin's books, but among a total of 1021 references.)

Waldrop and Lewin both tend to paint a backdrop of stick-in-the-mud academia. Little hints point to this as a false perspective: one of the heroes was greatly stimulated by a stay at the venerable University of Oxford; another hesitated much whether to join the Santa Fe Institute full-time or go back to his university; two of them, on an examining committee, decided that a third of the heroes had not yet done enough for a Ph.D. These people are loyal members of the academic community, deriving stimulation from it and taking part in its proper conservatism.

Though both books are journalistic, they otherwise contrast in style and focus. For information about the Santa Fe Institute, how it was formed, who's involved, and whether it is likely to be ephemeral or long-lived, Waldrop's is the book. Its basis is a set of fairly detailed biographies of a few leading figures in the formation of the Institute. Brian Arthur, George Cowan, Stuart Kauffman, John Holland, and Chris Langton are successively treated in this way. As the old masters of portraiture used their anatomical knowledge of musculature, so Waldrop tries to get under the intellectual skin of his subjects and paint word-pictures of how their scientific thinking developed. This has led to several serially displayed portrayals of a rising wave of excitement in the mind of each scientist. To the reviewer who must read quickly and continuously, it is a voyage through a hurricane at sea, with each great wave leading only to the next. Readers who can take longer may fare better.

Throughout, and especially in the later chapters, these biographies are gradually woven into a frank account of the interactions leading to the formation of the Institute, involving these people and several others who are mentioned often but without set-piece biographies: Norman Packard, Doyne Farmer, the financier John Reed, and the Nobel prize winners Kenneth Arrow, Phil Anderson, and Murray Gell-Mann, perhaps the prime mover in the project. The title of the last chapter, "Work in progress," looks like a conventional coda for a Ph.D. thesis. But its last 25 pages, subtitled "the hair shirt," are almost as gripping as the end of a thriller. Problems of administrative and financial continuity are addressed in ways that keep one in suspense as to whether the institute will survive to the last page.



Left, "Murray Gell-Mann, California Institute of Technology: 'In biological evolution, experience of the past is compressed in the genetic message encoded in DNA. In the case of human societies, the schemata are institutions, customs, traditions, and myths. They are, in effect, kinds of cultural DNA.' " *Right*, "Stuart Kauffman, University of Pennsylvania: 'If the new science of Complexity succeeds, it will broker a marriage between self-organization and selection. It'll be a physics of biology.' " [From *Complexity: Life at the Edge of Chaos*]

I read Lewin's book second of the pair, and almost felt that I was watching the film of Waldrop's book. Some of the same people appear, but their biographies are treated by quick-flashback technique. Lewin is deeply moved by landscapes and evokes them well: Chaco Canyon, hedgerow-lined English country roads, a villa by Lake Como. His style has a *National Geographic* flavor, lively, colorful, informative, but often somewhat superficial, in contrast to Waldrop's fewer, longer, and deeper studies. But Lewin's larger cast of characters gives a more worldwide perspective. (His additional people include Brian Goodwin, John Maynard Smith, Jim Lovelock, David Raup, and Tom Ray.) Waldrop's book, regarded as a picture, is an American interior. Only the view through a window suggests that the people portrayed have come in from an outer world that is very important. But as a depiction of American science it is very good.

What is this field of complexity? It seems to mean the study of self-organization by nonlinear dynamics (including especially positive feedback) of phenomena as diverse as: economics in existing societies; the rise and fall of human societies; ecosystems and biological evolution; and biological development. The work focuses on phenomena currently beyond the scope of mathematical analysis, for which the principal studies must be computer experiments on the models, needing very large computations. Most of the Santa Fe people are definitely computer-crazy. Their work has revealed that some dynamic systems can display important self-organization in a region on the boundary between simple orderly behavior and deterministic chaos. This is "the edge of chaos," related to James Gleick's treatment of chaos and especially to Per Bak's "self-organizing criticality." To my mind, this concept is very promising for economics, societies, and evolution, which show both self-organization and a stochastic ten-

dency to unexpected trends. But biological development, such as the formation of all the precisely spatially organized structure of a human body, is surely in the deeps of the ordering realm, far from the edge of chaos. A dynamic model must work on diverse random input to give the same pattern every time. Embryology is also within the "hard science" realm of the repeatable experiment, whereas the other fields are historical science or, for economies and societies on the large scale in the here and now, observational science in which the systems cannot be duplicated for experiment. By contrast, for the developmental field, I am pleased to see in Lewin's book Brian Goodwin's example of *Acetabularia*. I work on the same organism and published a similar but different and therefore rival model of whorl formation three years before the Goodwin-Trainor model. I believe that the thing to do now is to get down to experiments that may determine which model is right, and I am trying. But I wonder whether some of the Santa Fe people might dismiss that step in the scientific enterprise as "reductionism," a word used as a term of abuse in Waldrop's book. It is a word that always baffles me when so used and that I see only as a swear-word and not as proper philosophy. Sometimes it is used in relation to taking things apart into little bits (like lots and lots of *Drosophila* genes), but sometimes for seeking simple principles. This dual usage obscures the proper distinction between the analytical (taking apart by detailed study) and the synthetic (putting together by unifying principles) aspects of science, its two complementary parts, which must always coexist in balance. Wild words downgrading Newton as the instigator of three centuries of reductionism in science (Waldrop's text and dustcover) would have been better omitted. We all say very silly things from time to time, but generally we try not to immortalize them.

Among the specific topics of complexity, Waldrop principally stresses economic theory. He sees the Santa Fe world through the eyes of Brian Arthur, the theorist of "increasing returns" or autocatalysis in economics. This is strategically good in writing for a non-scientific readership. The components of the system are people, industrial products, and money, things of which everyone has clear concepts. By contrast, as I heard another exponent of science for non-scientists, Jay Ingram, point out in a recent talk, most people have no clear grasp of such concepts as "molecule." Ecosystems are, I think, somewhere in between. Most people can well appreciate the units of which they are composed, biological organisms, but are much hazier about the interactions between them than about those in human economies and societies. Therefore, the concentration of Lewin's book on biological evolutionary theory is an inferior choice to Waldrop's for a popular introduction to complexity. But Lewin has a destination in mind: to discuss the relevance of computation to the problem of consciousness. He quotes diverse views, including that of Roger Penrose (*The Emperor's New Mind*), but with a clear bias toward people who would be ashamed to be regarded as other than materialists (the only alternative, apparently, being "mystics"). I am not a materialist. I do not believe consciousness and free will to be capable of explanation as among the material phenomena I study in science. To the extent that Lewin's book seems to prophesy conscious computers, I am a heretic reviewing a work of orthodoxy.

Left, "Chris Langton, Santa Fe Institute: 'The edge of chaos is where information gets its foot in the door of the physical world, where it gets the upper hand over energy.' " *Right*, "Doyne Farmer . . . and Norman Packard, Prediction Company: Farmer was Chris Langton's 'protector' at the Los Alamos National Laboratory; Packard: 'People don't like [progress in evolution] for sociological, not scientific, reasons. I don't impute a value judgement to computational superiority.' " [From *Complexity: Life at the Edge of Chaos*; Cary Herz]

These books portray significant and accomplished people with lively minds, who are well worth reading about. But the books contain rather too much ill-considered hype blazoning these people's work and their institute as the crucible of a new scientific revolution. This they are unlikely to be. From what other information I have on the Institute, I feel that this slant to the writing may only serve to embarrass its level-headed members. The work of Brian Arthur on economics has shown that self-organization can occur without a "master agent." The same is likely to be true of science on its vast modern scale. The Santa Fe Institute will probably remain a very good place to do some kinds of science, but it will not be a master agent. Complexity will make sure of that.

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Timepieces

Ivory Diptych Sundials, 1570–1750. STEVEN A. LLOYD. Harvard University Collection of Scientific Instruments, Cambridge, MA, 1992 (distributor, Harvard University Press, Cambridge). vi, 169 pp., illus. $50.

Until the invention of the mechanical clock in the late Middle Ages, timekeeping depended either on water clocks or on noticing the motions of celestial bodies, the sun during the daytime and the stars (and sometimes the moon) at night. A sundial allows us to follow the shadow of the sun on some surface in the course of the day, and by adding suitable markers on it for the hours, a fair degree of precision can be obtained for finding the time with respect to sunrise, noon, or sunset. The first phase in the history of sundials, in Egypt and Mesopotamia, is only partly known, and many problems of interpretation remain.

Beginning with the ancient Greeks, the story of sundials is very rich in detail, largely because of the survival of many examples and descriptions of them in literary works. In *Greek and Roman Sundials* (Yale University Press, 1976), Sharon Gibbs has described the dials known from classical antiquity: 98 with spherical, 109 with conical, 40 with planar, and six with cylindrical shadow-receiving surfaces. Earlier Derek Price (*Centaurus* **14**, 242–66 [1969]) catalogued a special class of these ancient instruments, portable sundials, and described the corpus of 11 specimens. In both of these studies the artifacts were compared with the written evidence on dialing, notably that found in Vitruvius's *De Architechtura* (early 1st century A.D.). Sundials continued to be made throughout the Middle Ages, and mathematical descriptions of them complement the extant examples. But by any standard the early modern period must be considered the high