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

point in the history of the sundial.

The book under review is a catalogue of a specific type of portable sundial from this period—those called "diptych" (meaning "folded in two"), in which two thin tablets are hinged together at one edge—that are made of ivory. Most such dials have a string gnomon between the two tablets that casts a shadow on the lower horizontal tablet to indicate local apparent solar time. Characteristically, a magnetic compass is included in the horizontal tablet to orient the dial correctly. This collection of 82 dials, now at Harvard, derives from Nuremberg (46 specimens), France (32 specimens), Flanders (one specimen), and Italy (three specimens).

For Nuremberg, there is a historical introduction by Penelope Gouk, based on her extensive research in the archives there as well as on published sources. The focus of her attention is the craft of "compass-maker," listed as a profession in the city's records as early as the 1480s. She skillfully places the manufacture of dials in its social and commercial context and remarks on the fruitful collaboration between scholars and craftsmen. As an example of the relationship to commerce, we are told of the increased availability of ivory, arriving from the coast of Africa at such Atlantic ports as Lisbon and Antwerp, and then transported to Nuremberg, in this period. For the other centers of production, there are essays by A. J. Turner. He tells us that, in contrast to the Nuremberg examples, the French dials are rarely dated and still more rarely signed, and little information about them is available. For Flanders, surprisingly, only six specimens are extant altogether, and they are dated between 1586 and 1599 (Harvard's dates from 1599).

The bulk of the book is devoted to a complete set of photographs of the dials in the Harvard collection as well as detailed descriptions of each of them by Steven A. Lloyd. In each case we are shown a photograph of the instrument in perspective and then photographs of both the inner and the outer faces of the tablets that are clear enough for the inscriptions to be quite legible. One set of faces, those of a Nuremberg dial of 1626 made by Hans Troschel (the younger), is displayed at right.

Some additional features of the book are worthy of mention, notably the facsimile of a short French text printed at Dieppe in 1653, "Usage de l'Orloge ou Cadran Azimuttal" ("Use of the Timepiece or Azimuth Dial"), with an English translation. There are also facsimiles of pages from various early publications on dialing, but they are not well integrated into the text. By and large, however, the relationship between the literary evidence and the artifacts is ignored. Similarly, the mathematical treatment of dialing is hardly mentioned (but is suggested by a figure reproduced in the appendixes from a French text of 1624), and the history of sundials deserves greater attention as well; we are told that a sundial with compass needle was made at Damascus in 1365/6 (long before the earliest European example) but are given no other information on sundials anywhere in the world before the 15th century. Such omissions would be accepted as normal practice in a straightforward catalogue, but the extra material that is included here leads the reader to expect more.

Within the limits set by the authors, they have succeeded admirably. We are presented with a beautiful and lavishly illustrated study that provides careful descriptions of an important set of scientific artifacts, together with some valuable essays on their social context.

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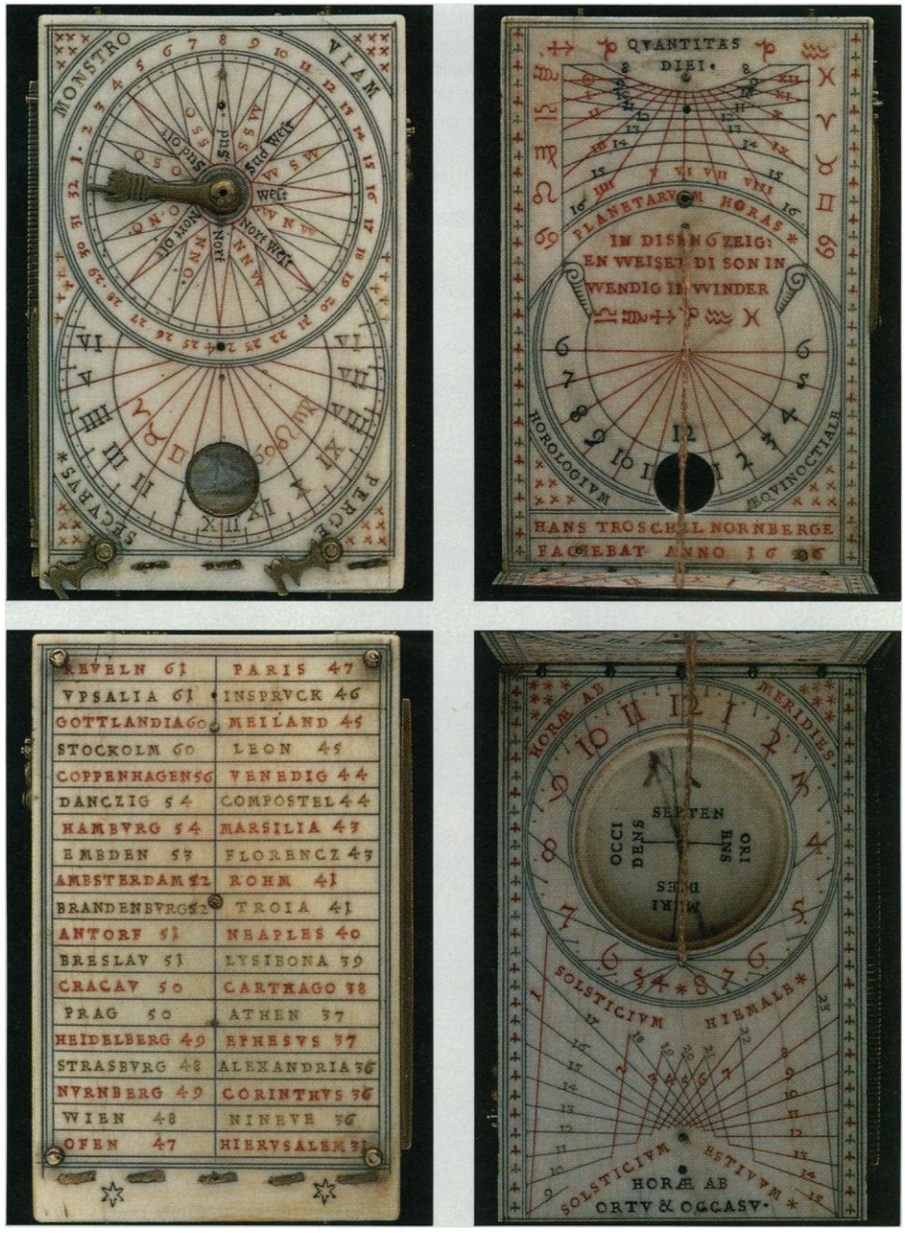

The four faces of a diptych sundial inscribed "Hans Troschel Nornberge faciebat anno 1626" ("made by Hans Troschel of Nuremberg in the year 1626"); outer faces at left; inner faces at right. The face at upper left is inscribed "Monstro viam perge securus" ("I show the way; proceed securely"). That at lower right is a horizontal dial with a scale for latitude 49 degrees, and its obverse, at left, gives the latitudes for 38 cities and includes the maker's mark, the six-pointed stars near the hinge. [Color reproductions of a dial depicted in *Ivory Diptych Sundials, 1570–1750*]