of Place is, I wanted it to continue following the disputes, Darwin or no Darwin. By this point in Browne's biography (as in his life), the country squire of Downe had become secondary to the debate that he launched a quarter century earlier.

BOOKS: DEVELOPMENT

What Is an Explanation?

Jonathan Slack

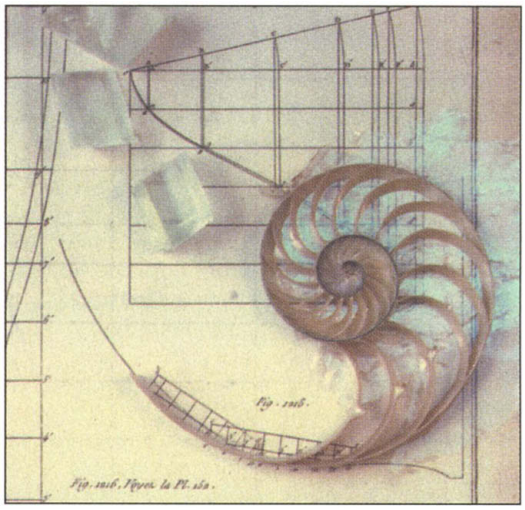
Inasmuch as there is a theoretical physics, why is there no theoretical biology? This is a question that has exercised many, from the London Theoretical Biology Club of the 1930s, through the influential symposia of Conrad Waddington in the 1960s, to today's theorists of computer-based "artifical life." Physicists traditionally feel that their science should represent an aspiration for all and that the separation of a distinct caste of theoreticians is a natural event in the development of any subject. Biology has not followed this pattern, probably because biology cannot choose its subject matter freely, but has to deal with actual life as it exists on Earth. In *Making Sense of Life*, Evelyn Fox Keller pointedly reminds us that, because of natural selection, "organisms solve the problems they face with little regard for elegance, efficiency or logical necessity."

Making Sense of Life Explaining Biological Development with Models, Metaphors, and Machines
by Evelyn Fox Keller
Harvard University Press, Cambridge, MA, 2002. 400 pp. $29.95, £20.50, €29.95. ISBN 0-674-00746-8.

Focused specifically on developmental biology, the book recounts various attempts to harness theoretical approaches to understanding the mysteries of embryonic development. Throughout, Keller tries to establish what has been considered a legitimate theoretical approach and what constitutes understanding in this area of research. A recurring theme is the arbitrariness of what we choose to regard as a proper explanation and the associated clash of cultures between mathematics and biology. In general, mathematicians value conceptual simplicity and the idealized model of a process, whereas biologists want to know how the specific system they are confronting actually works. Nicholas Rashevsky, a pioneer of theoretical biology in the 1940s and 1950s, seems to have encountered vituperative criticism for producing idealized models of processes that might exist, rather than applying quantitative treatment to actual processes in all their messy complexity. Keller herself is willing to adopt an historian's approach rather than that of a philosopher. She therefore recounts what has, in fact, been considered a valid type of explanation, instead of pontificating about what ought to be valid. This is a refreshing perspective, but perhaps it leans a little toward cultural relativism.

Oddly, the first case study in the book is not a theoretical one at all but a claimed creation of "artificial life," or at least something that might be considered a representation of the essence of life. This is the celebrated work of Stéphane Leduc around the end of the 19th century, in which simulacra of algae and colonial animals were produced by allowing crystals to "grow" in a strong solution of sodium silicate. As anyone knows who has ever made such a "chemical garden," the shapes that are produced can be quite remarkable, but few other than Leduc himself considered the inorganic growths to be a useful model for understanding any aspect of real life. Keller then discusses D'Arcy Thompson, but she does not explain why he is so much better known to the biological community than Leduc or Rashevsky, even though his ideas have similarly failed to be incorporated into any ongoing program of work.

Although Keller gives dynamical systems theory only a brief mention, she devotes much space to what some regard as the discrete equivalent, the class of models known as "cellular automata." This approach owes its origin to the work of von Neumann in the 1940s. After persisting for some decades in a half-forgotten byway, it has recently been revived and developed in different ways by Christopher Langton and Stephen Wolfram. Artificial life has been reborn in silico, this time not as messy flasks of actual sodium silicate but as computer-based cellular automata. Keller is very impressed by this, and she discusses at length whether a computer program is really life or simply a representation of life and whether it could be realized in a nonvirtual form. A more down-to-earth development of discrete mathematics is the use of formal logic to model genetic regulatory systems. Interestingly, it seems that physicists do not regard the representation of a gene by a logic circuit to be a "real model." To them, that is simply a formal restatement of the data, itself requiring explanation by a more abstract and general theory.



Olivia Parker's photograph *Marine II*.

With regard to the book's main theme, the nature of explanation, I found one of the clearest statements to come from the reviled Leduc. As a science develops, he once said, the first stage of explanation is a classification of the entities defined by the science; the second stage is an enquiry into their intrinsic mechanisms; and the final stage is the ability to synthesize them. So will the theory of cellular automata enable us to design and make new forms of life? Keller is aware that molecular biology currently creates new forms of life by rearranging preexisting components rather than by de novo design. She argues, however, that it is reasonable to expect a higher level of rational design in the future, and I agree with her. In this regard, the discrete mathematics of the cellular automaton is likely to prove a more appropriate tool than the differential equation.

Making Sense of Life does not include a discussion of what is really worrying many molecular biologists: the vast mass of genetic and molecular data that is being generated in the post-genomic era and the apparent impossibility of organizing all the material collected into any manageable type of explanation. But Keller has given us some food for thought. My own view tends towards coming off the relativistic fence and affirming that biology is now mature enough, by Leduc's criteria, to construe "explanation" as meaning "the ability to design" new types of organism—or at least to reprogram in specific ways the organisms we have. It is not very fashionable to quote Karl Marx now that his political program is so discredited, but the famous "11th Thesis on Feuerbach" does seem rather apposite to the future of biological explanation: "The philosophers have only interpreted the world in various ways; the point, however, is to change it."

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