COMPLEX SYSTEMS

An Informative Itinerary

Iain D. Couzin

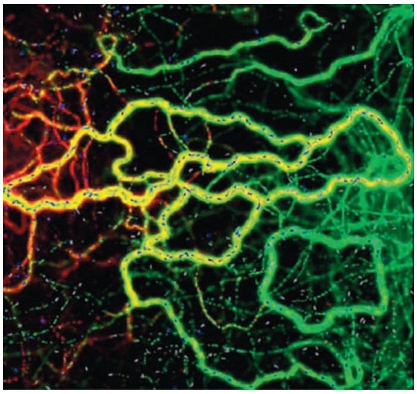
The "complexity barometer" is simple. Look carefully into a fellow scientist's eyes and say the words "Santa Fe Institute" (SFI). The response is remarkably binary: a rolling of the eyes and an exhalation of air (a sort of desperation) or an immediate glint of excitement at the prospect of discussing the home of complexity and the cascade of ideas that have been forthcoming from the institute. Its own Web site has a section titled "The edge of respectability"—echoing the phrase "the edge of chaos," coined by SFI physicist Doyne Farmer—which openly describes this position within the scientific community. Many complex systems, and perhaps the institute itself, the metaphor suggests, should be poised at a "critical" point between disorder and order, a region suggested to maximize information processing. This is itself one of the most interesting, yet controversial, concepts to have emerged from complexity research. And here lies one of the central challenges to those working in this community, to provide concepts that are sufficiently rigorous and well defined to be more than just a metaphor, to be useful.

Melanie Mitchell is well aware of this predicament as she takes us on a personal guided tour in *Complexity*. I emphasize personal because Mitchell (a computer scientist at Portland State University and SFI) uses her experience in evolutionary computation and artificial life to paint her picture of the history, and current state, of complexity research. Also, she writes in an unpretentious style with frequent entertaining and useful anecdotes that make one feel she is a trusted companion on the tour. Lastly, she focuses predominantly on computational aspects, with ecology, economics, and (perhaps surprisingly) neuroscience being notably less emphasized.

Almost immediately, Mitchell addresses the thorny issue of defining what is meant by a complex system: "a system in which large networks of components with no central control and simple rules of operation give rise to complex collective behavior, sophisticated information processing, and adaptation via learning or evolution." Like her, here I want to avoid the seemingly endless recursive discussions of what complexity is. However, given contemporary knowledge of biological organization (from neuronal circuits to flocking birds), it seems perhaps hasty to deemphasize the mutual presence of, and balance between, hierarchical and decentralized control and the role this can play in adaptive response.

Complexity
A Guided Tour
by Melanie Mitchell
Oxford University Press, New York, 2009.
365 pp. $29.95, £14.99.
ISBN 9780195124415.

Engagingly, Mitchell's tour offers the opportunity to touch on the history of many fundamental and transformative scientific discoveries, from those of information theory and quantum phenomena to that of dynamics. The book excels here; although the tour is fast paced, one doesn't feel that the guide is overly rushed. She captures the excitement of research and explains non-intuitive phenomena such as Maxwell's demon with clarity (and apparent effortlessness), making this an ideal guide for young scientists. Similarly, her summaries (although brisk) of entropy, information theory, and computation provide novice readers with a comprehensive overview.



Simulated foraging. A complex network formed by ants responding to their chemical trails and to contact with one another.

Mitchell shows, however, that relating these concepts to real adaptive systems is problematic. As she highlights, pure information theory, although conceptually appealing, often cannot apply directly to real biological systems. Literal measures such as Shannon entropy can equate increasing complexity with increasing randomness. While algorithmic information content and modifications thereof (such as Gell-Mann and Lloyd's "effective complexity") are meaningful, it is clear that no one quantitative measure of complexity has yet emerged as generically useful in complex systems research.

One theme running through the tour is that we may learn much about adaptive behavior in general from understanding the principles of computation in man-made systems such as Turing machines and cellular automata. In such systems, simple local rules of interaction can result in sophisticated patterns of activity. Those, in certain cases, have been shown to be capable of "universal computation" (computing anything that is computable). Mitchell correctly cautions that both the necessary starting conditions and the required computational time could be limiting factors in the application of these ideas to real information processing as in the brain. But their remarkable properties, and the means of their discovery, make for fascinating reading.

The connection of this type of computation to insights about biology, however, is occasionally frustrated by an oversimplistic representation of natural processes. For example, the author's imprecise description of evolutionary principles excludes important factors such as disease and predation pressures. Similarly, the description of ant colony behavior reads as a caricature, much as in decade-old complexity literature. Furthermore, I was surprised that Mitchell dismisses so readily "nonequilibrium, stability, bifurcation and symmetry breaking, and long-range order" as being "disparate concepts" that do little to explain complexity in nature. As highlighted in Philip Ball's recent series of books (*1*), those seem to be useful principles by which to understand biological self-organization, from how our heart beats to how ant colonies forage.

These issues aside, I thoroughly enjoyed Mitchell's tour of complexity. She proves an enthusiastic, sincere, and knowledgeable guide to ongoing debates in network theory, scaling, and artificial intelligence. As disciplinary boundaries fade and complexity science permeates the mainstream, she questions where we go from here. Throughout, she neither overemphasizes the progress made so far nor underestimates the important role that complexity research will have to play in addressing some of the most pressing scientific questions of our time. Thankfully, I think I'll be putting my complexity barometer to use for many years to come.

The reviewer is at the Department of Ecology and Evolutionary Biology and the Program in Applied and Computational Mathematics, Princeton University, Princeton, NJ 08544, USA. E-mail: icouzin@princeton.edu

References

1. P. Ball, *Nature's Patterns: A Tapestry in Three Parts* (Oxford Univ. Press, Oxford, 2009).

10.1126/science.1187332

Published by AAAS