COMPLEXITY

A Tree of Fireflies, a Flock of Boson Clouds

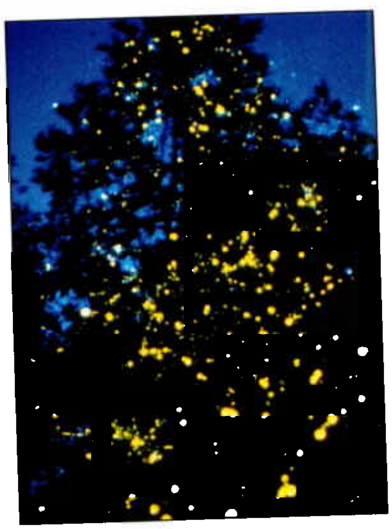
Nancy Kopell

Some twenty years ago I saw, or thought I saw, a synchronal or simultaneous flashing of fireflies. I could hardly believe my eyes, for such a thing to occur among insects is certainly contrary to all natural laws (*1*).

Philip Lawrence's comment, which opens the first chapter of *Sync*, appeared in 1917. Since then, the phenomena of synchronous oscillations have become more familiar, but no less surprising—or controversial. Applied mathematician Steven Strogatz now gives us a compulsively readable guided tour of many such phenomena: some from the inanimate world (lasers, chemical pattern formation, and electrical systems), others from biology (including "brain waves" and circadian sleep-wake cycles).

Strogatz's stories concern collections of things—neurons, bosons, fireflies, chemical reactants—that display periodic oscillations and whose elements have predictable phase relations, often synchrony in the strict sense (i.e., zero phase lags among components). Strogatz stresses the similarities among the behavior of these systems, as revealed by their mathematical descriptions. Throughout, the author mixes in accounts of his own trials and triumphs in addressing some mathematical issues related to synchrony. The result is a very personal book that might more accurately be subtitled "My excellent adventures in science." The history and scientific descriptions are freshest where Strogatz has been personally involved; my favorite is a wonderful chapter on sleep cycles, in which he discusses the sleep problems of his infant daughter, his thesis work, and a range of fascinating experimental studies.

The reviewer is at the Department of Mathematics and Statistics and the Center for BioDynamics, Boston University, 111 Cummington Street, Boston, MA 02215, USA. E-mail: nk@bu.edu



Flashing to the beat. Gathering in mangroves along tidal rivers in Malaysia, thousands of fireflies flash in unison.

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Strogatz's description of his own mathematical work gives a remarkably accurate (if sometimes breathless) sense of what it is like to work in the trenches of applied mathematics. There is the falling in love (or at least the obsession) with a question: "What was this fundamental puzzle.... It sounded extraordinary." There are the late-night insights and excitement: "My hand was sweating as I wrote down each new line of the calculation." And one feels the push and pull of collaboration. Strogatz makes the ideas accessible to a general audience (the book includes no equations), in a way that enables one to see the logical backbone of his arguments. One of the book's great pleasures is the stream of analogies that he comes up with to explain the science, both his own mathematics and some physical situations. He describes the simple mathematical model for pulse-coupled oscillators in terms of leaky toilets, and he compares a boson to the dirt cloud that surrounds Pigpen in the Peanuts comic strip.

Sync
The Emerging Science of Spontaneous Order
by Steven Strogatz
Theia (Hyperion), New York, 2003. 348 pp. $24.95, C$36.95. ISBN 0-7868-6844-9. Allen Lane (Penguin), London. 352 pp. £14.99. ISBN 0-7139-9621-8.

One of the book's themes is the hidden connections among phenomena that seem to belong to different worlds. In the chapter "Bridges," Strogatz shows that, at some level of description, a Josephson junction (two layers of superconductor separated by a very thin insulator through which the superconducting electrons can tunnel), a pendulum, and neural rhythms have dynamics that can be captured by the same sets of differential equations, the so-called Kuramoto model. But lurking behind this chapter is an unwritten one, about a central issue in mathematical modeling that bedevils attempts at such unification. Faced with overwhelming complexity of the unexplored kind, applied mathematicians often develop intuition by working out simple models that capture what seems to be essential to what has caught their interest. The Kuramoto model is such a description of synchrony: each oscillator is described by a phase on a circle, on which the movement would have uniform speed if there were no coupling and no perturbations. The coupling is of a very special type—the phase of the *i*th oscillator is continuously advanced or delayed, depending on the sines of the differences in phase between the *i*th oscillator and the others. As Strogatz tells us, the Kuramoto model "has always been a solution waiting for a problem." It did indeed find some physical applications, and the mathematics associated with it is, in any case, full of rich insights. But what can we deduce from that model about the behavior of fireflies or neurons?

Here we come to the distinction between "analogy" and "application." The Kuramoto model and the simple pulse-coupled oscillator model turn out to be quite fragile, in the sense that natural generalizations to other populations of oscillators behave very differently. This means one cannot expect the fact that the oscillators of those models must inevitably sync (if their natural frequencies are close enough) to imply that the same is true of fireflies. Nor can one conclude that the mechanics of synchronization in those models provide any details of the dynamics of the firefly synchronization. Indeed, before Strogatz related leaky toilets to fireflies, Bard Ermentrout (*2*) constructed a more physiologically supported model whose assumptions and predictions about firefly synchrony differ in critical ways from those of Strogatz's model. The latter produces behavior similar to that of fireflies, but does not provide anything like a mechanistic explanation. For that, one needs a model whose essential assumptions can be shown—or at least argued—to hold for the system in question. Though distinguishing between an analogy and an application is not always straightforward, it is important to try, if only to avoid seeming to sell more than is available to be delivered.

Another unwritten chapter is a more current look at how the science of sync has been "emerging" in biology. The omission is understandable, because much of the work of the last decade deals with complexity of the (partially) explored kind and has a different flavor. This work attempts to connect known and complicated facts to the synchronization behavior; the resulting models have more arcane biological details, and their predictions are not equivalent to those of the Kuramoto or the pulse-coupled models. Recent work emphasizes why at least some of those details matter and how they translate into the dynamics of the system. For example, there is now a growing zoo of variations on "brain waves," each with different dynamical patterns and likely different functions in the brain. But this story is changing almost daily, and perhaps it is not ready to be told with the grace and self-deprecating charm of *Sync*. In any case, we can be grateful for the stories Strogatz provides. They will enlighten and entertain many people, and perhaps inspire a few to look deeper.

References

1. P. Lawrence, *Science* **45**, 44 (1917).
2. G. B. Ermentrout, *J. Math. Biol.* **29**, 571 (1991).

HUMAN BEHAVIOR

The New Interactionism

Kevin N. Laland

The intellectual champions of nature and nurture have been battling it out for centuries in a struggle to understand the causes of human behavior. To 18th-century philosophers, such as Locke, Hume, and Mill, the human mind at birth is like an empty box, which is gradually filled as we experience the world. In the 19th century, Darwin helped shepherd in a new era of nativism by making a case for mental continuity between humans and animals and by documenting how we share with other species a variety of instincts and expressions. Before long, 20th-century psychologists were wallowing in a surfeit of human instincts. Yet in the absence of any understanding of their genetic, neural, or physiological bases, the term "instinct" possessed little explanatory power. Reaction against vague instinct-based theories, as well as to the abuses of eugenics, social Darwinism, and racist evolutionary anthropology, engendered a swing back to nurture, manifest in the learning theories of Pavlov, Watson, and Skinner and the extreme environmentalism of Mead's cultural anthropology. In turn, these excesses of nurture were criticized by ethologists, who tried (and failed) to resurrect a meaningful instinct concept.

Nature via Nurture
Genes, Experience, and What Makes Us Human
by Matt Ridley

HarperCollins, New York, 2003. 336 pp. $25.95. ISBN 0-06-000678-1. Fourth Estate, London. £18.99. ISBN 1-84115-745-7.

In recent decades, the nature-nurture debate has taken on a jaded appearance, as the swinging pendulum has been replaced by an insipid interactionism. Profound insights (e.g., Lehrman's finding that changes in a female dove's hormones are triggered by male courtship, or Garcia's experiments demonstrating that rats are predisposed to learn some associations more readily than others) served primarily to demonstrate that both internal and external causes were involved. Generations of students of human behavior have been frustrated with a politically correct interactionism that has little more to say than "It's more complicated than that!"

Against this background, Matt Ridley's *Nature via Nurture* is a breath of fresh air. In a whirlwind dash through the territory of the biological and social sciences, Ridley spells out how the monolithic forces of nature and nurture cooperate to produce complex behavior. Leaning heavily on insights engendered by the sequencing of the human genome and the advance of neuroscience, Ridley unveils the intricacies of gene operations. With wonderful clarity and the use of fascinating examples, he describes how genes are triggered into action by environmental events; how they switch other genes on and off; how they guide neurons to build brains; and how learning operates through gene expression. More so than any earlier writings, Ridley makes a compelling case for an explanatory interactionism.

The book also has its weaknesses. There is a lot of speculation; isolated examples are frequently presented as the rule; and Ridley is manifestly stronger on genetics than he is on learning and culture (for which precious few recent findings are presented). He also gives far too much credence to the doctrinal assertions of some behavior geneticists and evolutionary psychologists. For instance, many of Ridley's claims are based on studies that compare the correlation in psychological attributes among pairs of identical and fraternal twins. This comparison is used by behavior geneticists to estimate the heritability (h^2), the extent to which differences between individuals are down to their possessing different genes. Ridley asserts that these studies prove the "dramatically high heritability for personality." Unfortunately, twin studies are an imperfect method for estimating heritability, because they lack the resolution to tease apart genetic influences from a variety of subtle gene-environment

The reviewer, coauthor of *Sense and Nonsense: Evolutionary Perspectives on Human Behaviour*, is at the Centre for Social Learning and Cognitive Evolution, School of Biology, University of St. Andrews, Bute Medical Building, Queen's Terrace, St. Andrews, Fife KY16 9TS, Scotland. E-mail: knl1@st-andrews.ac.uk

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