BOOK REVIEWS

How Parts of the Brain Compute

The Computational Brain. PATRICIA S. CHURCHLAND and TERRENCE J. SEJNOWSKI. MIT Press, Cambridge, MA, 1992. xiv, 544 pp., illus. $39.95. Computational Neuroscience. A Bradford Book.

The last decade has seen a dramatic revival of a scientific quest that goes back centuries but that was especially active in the 1940s and the 1960s: the quest to understand the brain as a machine. More recent research with this goal has taken a number of forms: computational neuroscience seeks to analyze explicit biological data to determine just what sort of computer network the brain might be; connectionism (parallel and distributed processing) seeks to explain psychological phenomena with networks of processing units that are loosely modeled on properties of biological neurons but that are considered as conceptual rather than as biological units; engineers and computer scientists have used networks of quasi-neurons to approach such problems as pattern recognition, robot control, and medical diagnosis; and physicists and others have developed such approaches as statistical analysis of the properties of neural networks.

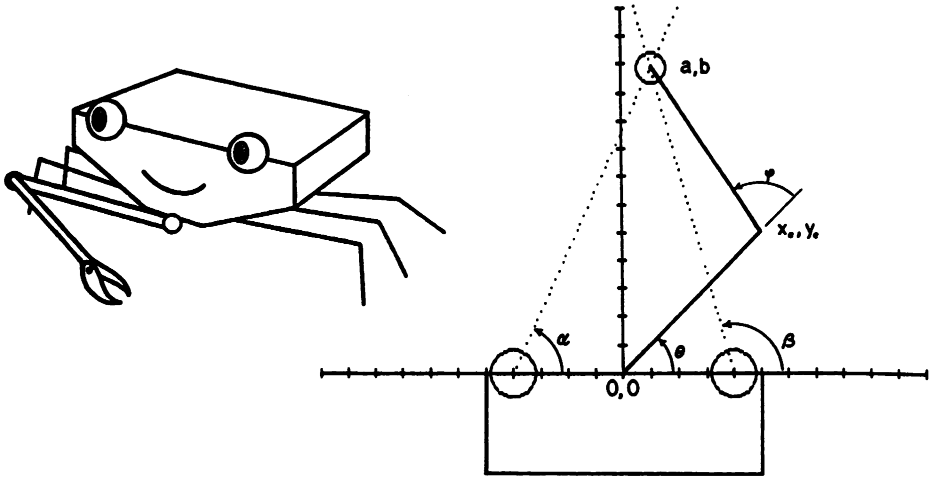
The Computational Brain treats the first of these themes. Regions of the brain—visual cortex, hippocampus, spinal cord, and so on—are surprisingly distinctive: they have different types of cells, different patterns of connectivity, and different relations with sensory inflow, other parts of the brain, and motor outflow. Thus computational neuroscience must model the brain as a network of specialized computers at a variety of levels including the "cooperative computation" that links various brain regions in subserving a variety of behaviors, the way in which the circuitry of a specific region fits it for certain tasks, and the intricate properties of individual neurons rooted in membrane biophysics and neurochemistry. The book focuses on the second of these, with some attention to the third.

The authors first introduce the structural levels of analysis of brains—systems, topographic maps, layers and columns, local networks, neurons, synapses, and molecules—and then list 13 useful "brain facts" that can guide analysis in their primary range from topographic maps to neurons. They then turn to a computational overview. Whereas "computational physics" is just physics studied with models implemented on current computing machines, "computational neuroscience" involves not only the study of brains with the use of computers but also the study of brains *as* computers. A computation is a function generated according to a rule, but the rule need not be a program for a serial computer. It can be provided by the processes of a neural network. The authors provide a lively survey of the computational style of a variety of neural network architectures: linear associators, Hopfield networks, Boltzmann machines, back-propagation networks, competitive learning networks, and recurrent networks. Here no attempt is made to relate the neurons to biology. By contrast, the models of (low-level) visual processing and of motor pattern generation presented later show how relatively simple models of neurons may be connected to yield biologically constrained circuits that replicate and explicate data on the function of specific regions of brains or other nervous systems. (Although most of the book looks at the human-like brains of such creatures as monkeys and cats, attention is also given to the rather different nervous systems of such invertebrates as the lobster and the leech.) It is only in the analysis of the synaptic plasticity that may underlie much of learning and memory that we are given an extended treatment of how the detailed study of synapses, membranes, and neurochemistry may extend our understanding of the properties of individual neurons. These choices are judicious. "The map is not the territory." A model is as successful for what it omits as for what it puts in. Details that are essential for some aspects of neural function only cloud our understanding of others.

	NECESSARY	NOT NECESSARY
SUFFICIENT	*PURE BOTTOM-UP*	*either TOP-DOWN or BOTTOM-UP*
NOT SUFFICIENT	*CO-EVOLUTION STRATEGY*	*PURE TOP-DOWN*

"Possible research strategies for trying to understand how the brain works as they divide on the question of the importance of cellular and molecular levels in theories of brain function. Some neuroscientists may prefer the pure bottom-up strategy; some psychologists and philosophers prefer the pure top-down strategy; probably no one falls into the upper right box, but we added it to round out the possibility-table; the co-evolutionary strategy (lower left) is the one adopted in this book." [From *The Computational Brain*]

Although its preface starts with the words "To understand how neurons give rise to a mental life . . ." and although the first author is best known for her book *Neurophilosophy* (MIT Press, 1986), which placed neuroscience and the philosophy of mind between the same covers, *The Computational Brain* does not address any of the grand issues of mental function, or even show how diverse parts of the brain function together. Rather, the book finds its rich subject matter in the study of single parts of the brain and in the construction of neural network models for limited visual, mnemonic, or motor functions. Chapter 6 shows how neuroscientists have come to understand the contributions that diverse regions of the mammalian brain make to vision and discusses how visual information may be coded in a distributed fashion in the brain, and then provides neural models (only weakly grounded in neural data) for perception of shape from shading, for stereo vision, and for hyperacuity. Chapter 7 focuses on the role of hippocampus in memory, starting with fascinating human data from the neurological clinic and Donald Hebb's seminal proposal that learning might result (in part) from strengthening of a synapse every time the two neurons it connects are active. This leads into a very long analysis of recent data from neurophysiology and neurochemistry that suggest that long-term potentiation of synapses in hippocampus may be a form of Hebbian learning, but with subtleties that are well outlined. The authors then provide a good perspective on a number of models of hippocampal circuitry, but with too little indication of their details. The chapter closes with a model of the formation of patterned connections in visual cortex and a general discussion of modularity in the brain. Chapter 8 approaches motor control through a computer model of how the leech bends its body, a connectionist model of the vestibulo-ocular reflex, an overview of a model of the control of visual pursuit, and a study of rhythm-generating circuitry in the spinal cord (but does not mention models of motor cortex, cerebellum, or saccadic eye movements). These models all use simplified neurons, but the chapter concludes with a useful review of more detailed prop-



Roger the Crab, representing a simplified problem of sensorimotor coordination for an arm. Roger is a computer simulation who has (mapped at right) "a pair of rotatable 'eyes' for detecting the presence of external stimuli and a single-jointed, extendable arm for making contact with what his eyes see in his impoverished 2-D space. Roger's sole task in his limited life is to detect stimuli and contact them with the tip of his hand. . . . Just as Roger has a 2-D 'visual' space in which the position of the target is represented, so he has a 2-D motor space in which his arm position can be represented. But, and this is crucial to understanding the problem of sensory-motor coordination in its most general aspect, *these two state spaces are very different.*" [From *The Computational Brain*; P. M. Churchland, *Mind* **95**, 279–309 (1986)]

erties that will surely play a role in further developments. The final chapter, "Concluding and beyond," disappoints since it all too briefly presents topics that can only be understood against a background of attempts made by the artificial intelligence community to build visual systems and control robots, a background outside the authors' focus.

This attractive and well-illustrated volume concludes with an appendix on anatomical and physiological techniques, a glossary, copious references, and a subject index, but lacks an author index (thus complicating the reviewer's task!). The book falls somewhere between a trade book and a textbook, with a style well suited for the *Scientific American* reader, as well as the active scientist, who may know something of either computer science or neuroscience but welcomes a crisp narrative that includes the necessary background from each discipline. As the authors disarmingly note in their preface, the book is focused on "research based in California, especially in San Diego." Actually, although the authors have used their local "networking" in the choice of models, they have made a thorough review of the global literature on the empirical results that ground these models, and the reader will be well rewarded who seeks to understand, from well-chosen examples, how to merge the analysis of neuroscientific data with the development of computational principles.

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HTSC for Newcomers

High Temperature Superconductivity. D. P. TUNSTALL and W. BARFORD, Eds. Hilger, Philadelphia, 1992 (distributor, American Institute of Physics, New York). xiv, 404 pp., illus. $130. From an institute, St. Andrews, U.K., June 1991.

It is six years since the now-famous paper of G. Bednorz and K. A. Müller appeared announcing to a then largely indifferent world the possibility of superconductivity in the Ba-La-Cu-O system at temperatures above 30 K. That was the event that ushered in the era of "high-temperature" superconductivity (HTSC). (HTSC is still a low-temperature phenomenon: the acknowledged world record is still about 125 K.) The saga of the announcement of both the unimpeachable confirmation and the extension of the results of Bednorz and Müller at the 1986 fall meeting of the Materials Research Society, followed by a rapidly growing frenzy of activity and publicity, marked by the famous (some say notorious) "Woodstock of Physics" 1987 March meeting of the American Physical Society, and culminating in the award of the Nobel prize in physics for 1987 to Bednorz and Müller has achieved mythical status. The totality of the scientific attention paid to the materials, mechanisms, and possible technological applications of HTSC has been overwhelming: Colin Gough of Birmingham University in England has estimated that about 20,000 publications on this topic appeared within less than five years following its discovery. (I leave it to the reader to guess what fraction of this flood of paper either has been read or is genuinely useful.)

The initial response of the popular press, incited by both the exuberance and some extravagant claims for revolutionary technological payoffs by scientists overjoyed by this new bauble (and potential funding gold mine), was one of wild enthusiasm. This was soon followed by equally unrealistic pessimism when the considerable difficulties in realizing the promise of the technological applications of these new materials became apparent, as well as the realization that even if some of these promised applications—in electric power transmission, microwave electronics, energy storage, and exquisitely sensitive magnetic field detection, for example—materialized, the economic and technological returns were neither going to come as soon nor be as large as the early enthusiasts had hoped. Now there is a more balanced and cautiously optimistic attitude about the time scale and magnitude of the arrival of HTSC technology. However, the extraordinary scientific significance of the discovery of the cuprate superconductors with high critical temperatures is even more apparent today than ever. A consensus on the mechanisms of superconductivity, and even a theory of the normal (resistive) metallic state, in these materials is still elusive, posing a worthy challenge to the best condensed-matter theorists of the day (at least three Nobel prize-winners in physics, Philip Anderson, Nevill Mott, and J. Robert Schrieffer, have been actively engaged in the lively debates), and the difficulties and opportunities posed by the understanding and control over multi-element compounds with complex structures, at the same time metallic, covalent, and ionic in character, will stimulate and frustrate materials scientists and solid-state chemists for decades. Thus it is likely that, far from merely being a "bandwagon phenomenon," the science and technology of HTSC will continue to attract new recruits to the ranks of researchers on this topic, the vagaries of funding and other market forces permitting.

The volume under review is aimed at such newcomers, intended as a broad survey of the current status of HTSC research, and consists of 11 chapters, ranging from an introduction to superconductivity, device applications, and current experimental problems to introductory descriptions of some of the most modern theories of electronic structure and superconductivity. The chapters grew out of lectures given at the 39th Scottish Universities Summer School of Physics and are pitched at a tutorial level suitable for graduate students and postdoctoral fellows in physics, chemistry, materi-