

## BOOK REVIEWS

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**Theoretical Neuroscience: Computational and Mathematical Modelling of Neural Systems.** Peter Dayan and L. F. Abbott. MIT Press, c/o Trilateral LLC, 100 Maple Ridge Drive, Cumberland, RI 02864-1769, USA. 2001. 460 pp. Price: US \$50.

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The metaphor of the brain as a computer is now firmly fixed even in the popular imagination, and this concept is at the heart of computational and theoretical neuroscience. The computational element comes in for two reasons, one philosophical and the other practical. The philosophical point is that most scientists now regard the brain as an organ whose purpose is information processing. Alan Turing showed that all computation is, ultimately, equivalent. Thus, the argument goes, the function of the brain should be considered from the viewpoint of computation. The practical point is that the brain is complex, and we need computational and theoretical tools to help us understand it.

The book under review by Dayan and Abbott is an outstanding introduction, both to the computational concepts as well as to the analytical tools.

The discipline of computational neuroscience became formalized about fifteen years ago with the establishment of CNS programmes at a few universities like Caltech and MIT. The field has blossomed since, in the quiet way that characterizes broad acceptance of approaches that were once esoteric. Most neuroscientists today would not find it unusual to see a detailed analysis of information representation in the fly visual system. Nor would they be surprised to hear predictions about the computational role of a cerebellar Purkinje made on the basis of a computer model. Even laymen no longer find the concept of human memory all that different from what goes on a computer's hard disk. These three topics – information, processing, and storage – are the three main subdivisions of the book. Needless to say, these topics are wide-open areas of current research.

How is information represented in the brain? This first question brings in issues of how individual cells convert information into trains of action potentials, how information is represented in many neurons in parallel, and how subsequent stages of neural processing decode the information. This is an area particularly prone to heavily mathematical analyses, and the authors wade in with gusto. Neurobiologists like to

remind the more enthusiastic exponents of Shannon information theory and Bayes' theorem that most neurons have not heard of either. Nevertheless, it is intriguing that information representation in the brain is often very efficient, and these mathematical treatments certainly set bounds to what the neurons must be able to do.

How do neurons process this information? The biophysical theory of single neurons is one of the most accurately predictive parts of modern biology. In principle, we know a great deal about how neurons sum, integrate, compare, fire periodically and generally compute. It is when these cells are wired together into networks that our understanding falls short. So it is with the book. The authors do a sound job of describing single-cell models using the standard building blocks: cable theory, Nernst equations, and Hodgkin-Huxley equations. They then discard much of this framework (with some justification) when considering network models. It is a simple fact that it is far easier to analyse neural networks using abstractions that throw away much timing information. There is perhaps a gap here when one refers back to the elaborate spike-train analysis from the first section. Such conceptual gaps are precisely where the field is most interesting.

How is information stored? Here again there is a wide gap in the field between good experimental and theoretical understanding at the single-cell level, and severe abstractions needed for networks. This section is perhaps the most difficult one in the book, but at the same time it is very useful as it brings together widely disparate threads of learning research. Suffice to say that there are many hints now about how neural circuits wire themselves up, how animals and networks go about learning things, and how abstract representations of natural input may form. All these phenomena are believed to arise from the cellular basis of learning, that is, from changes in efficiency of connections between neurons. But there are many unknowns. Especially in this section of the book, it would have been useful to get a perspective of the many fascinating questions as well as of the few glimpses we currently have to the answers.

In spite of the popular acceptance of its core ideas, computational neuroscience remains a difficult teaching discipline. This is not surprising. At a brief glance, it encompasses anatomy, cellular biophysics, electrical engineering, chemical signalling,

information and probability theory, computer programming, numerical analysis, and animal behaviour. This is a tall order for a textbook; yet Dayan and Abbott do an excellent job. They liberally supplement their very readable text with more technical appendices to every chapter, and they cite a website for further exercises. Specialized mathematical sub-topics are treated in a mathematical appendix to the book as a whole. The overall effect is to make the book approachable even for the undergraduate, yet sufficiently rigorous to be a reference for specialists in the area.

Most of the standard texts in the field of computational neuroscience are edited books containing chapters by different authors (e.g. refs 1–3). While these texts are excellent references for all researchers in the field, it is difficult for an edited compilation to bring in the coherence and linear progression of ideas that is necessary for a textbook. *Theoretical Neuroscience* is finally a book that might fit into this mould. It has been over four years in the writing, and that is a long time in this rapidly changing field. There are some topics that one would wish to see. Examples are a discussion of how the biophysics of single neurons leads to computation, and the role of biochemical signalling networks. There is little mention of central pattern generators. Most of all, as mentioned above, the book presents known topics in neuroscience with confidence, but does not emphasize what is still wonderful and mysterious. These gaps notwithstanding, this book would now be my first recommendation for students starting reading in the area. The book has the potential to become the standard textbook in its area, provided the authors have the stamina to keep editions coming to keep up with the developments in the field.

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1. Koch, C. and Segev, I. (eds), *Methods in Neuronal Modelling: From Synapses to Network*, MIT Press, 1998.
  2. Bower, J. M. and Beeman, D. (eds), *The Book of GENESIS: Exploring Realistic Neural Models with the General Neural Simulation System*, TELOS, 1998.
  3. De Schutter, E. (ed.), *Computational Neuroscience: Realistic Modelling for Experimentalists*, CRC Press, 2000.
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