nature neuroscience

Computational approaches to brain function

When Watson and Crick proposed their model for the double helical structure of DNA, they ended with the famous words, "It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material." Unfortunately, life is not always so simple, and in particular, the structure of the brain—with its 10^{10} neurons and 10^{14} synapses—seems unlikely to suggest the mechanism by which it gives rise to behavior. Clearly, some kind of theory is needed if the brain is ever to be understood.

Although most neuroscientists would accept this position, at least in principle, many experimentalists remain very skeptical of modeling studies. There are several reasons for this. Some people believe that understanding will emerge spontaneously in a 'bottom-up' fashion once sufficient data are available. Others feel that we do not yet know enough to build biologically realistic models, and that models that are unconstrained by data have no explanatory power. Finally, many experimentalists simply find theoretical models too abstract and arcane to be useful tools for thinking about their next experiment.

Ideally, of course, the two approaches should go hand-in-hand: models should be firmly grounded in experimental reality, and should in turn guide further experiments. Achieving this ideal in practice, however, is not easy. Theorists and experimentalists have different skills and speak different languages, and the problem is exacerbated by current publishing habits. Theorists often publish dense papers in specialist journals that experimentalists rarely read, while many general-interest journals take a stringent view of modeling studies—if a model does not make a testable prediction, it is not publishable, and if it does, the prediction should be tested. The reality, of course, is that not every paper makes predictions that are immediately testable; moreover, even when such predictions exist, it is rare to find the necessary combination of theoretical and experimental skills within the same laboratory. Clearly, the full potential of computational modeling will not be realized unless theorists and experimentalists can talk to each other.

Our aim in producing this special supplement is to help promote such a dialogue. The authors of the eight review articles that form the core of this collection were asked to focus on recent developments in fields where models and experiments have influenced each other. We also asked the authors to emphasize concepts rather than mathematical details, and to explain the achievements of their field in a way that will be accessible to a broad experimental readership.

There are many different views of what models should achieve, and that diversity is reflected here. Koch and Segev, for example, review information processing in single neurons, an area where modeling is well established and is grounded in detailed knowledge of the relevant biophysical mechanisms. At the other end of the spectrum, Dayan, Kakade and Montague discuss statistical models of learning, relating these to the phenomenon of attention at a level of abstraction that is still some distance from the underlying neural processes. Taking a very different approach, Medina and Mauk describe their attempts to build a simulation of the cerebellum based on its known circuitry. This agenda raises the interesting question of what constitutes 'understanding'—if you build a simulation of the brain based on known properties of its constituent elements and find that it behaves like a brain, does that tell you how the brain works?

These are controversial issues, and in a field so young, it is no surprise that a consensus has not yet emerged. Rather than attempting to smooth over these differences of opinion, we wanted to capture something of the debate. To do so, we have included six viewpoint pieces, some from pure theorists and some from experimentalists with a strong interest in computational modeling. The authors were asked to consider how theory has contributed to neuroscience, whether the interaction between theory and experiment has been effective, and how it might be improved. We hope readers will find the resulting diversity of views entertaining and thought-provoking.

To offset the emphasis on recency in the review articles, we have also included six history pieces, which illustrate how computational neuroscience has developed over the half-century since Hodgkin and Huxley first proposed their model for the propagation of action potentials. These pieces provide snapshots of some of the most influential ideas in the field, as well as more personal reflections on lessons to be drawn for the future.

We are grateful to four NIH institutes (NIMH, NINDS, NIAAA and NIDA) for their generous financial support of this supplement. We approached the NIH as a partner because they share with us a strong commitment to computational neuroscience and to promoting dialogue across disciplines. With their help, we are making this issue freely available both in print and on the web. Despite our common interests, however, responsibility for the editorial content (with the exception of the sponsors' foreword) rests entirely with *Nature Neuroscience*. We hope that this collection will reach a wide readership, and that experimentalists and theorists alike will find something of interest here.

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