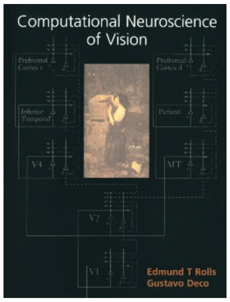
The roles of computation and experiment in neuroscience



Computational Neuroscience of Vision

by Edmund T. Rolls and Gustavo Deco
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Reviewed by Robert Shapley

It is hard to understand what the cerebral cortex is doing, because it is complex, diverse and large, and its properties change with experience. Perhaps we can make sense of single cells or small circumscribed neural networks, but that has not yet generalized to understanding the whole thing. It all depends on what you mean by 'understanding.' Most people would agree that it means, among other things, knowing what different cortical areas are doing in concert during a behavioral task like recognizing a face in the crowd or finding your way home.

Many scientists hope that mathematical analysis and modeling will help to solve this hard problem, based on the success of mathematics applied to other very hard problems, like fluid mechanics or astrophysics. Given the large number of neurons and connections in the cortex, and their diversity, computer simulations and mathematical analysis are likely to be needed to evaluate the functional consequences of discoveries about neurons at the cellular level. Theorists demand experimental data, lots of it—more than we have—to test their ideas. Then they make significant predictions that may require very difficult experiments for their validation. It is interesting that the experiments theory demands are often novel, and not what an experimental neuroscientist would have thought of on his or her own. For instance, theorists may demand to know the statistics of the distribution of a neuronal property like membrane conductance over an entire neuronal population, so they can develop a theory of population coding of a visual attribute. Because of theory's insights, the interplay between theory and experiment should lead to new kinds of advances.

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Edmund Rolls and Gustavo Deco offer the promise of theory to solve important problems in visual object recognition and selective attention in *Computational Neuroscience of Vision*. Indeed, they end the text with the promise, "Through neural computation, understanding." The theory is the analysis of neural networks with very specific architectures that the authors have designed to account for many different experiments. The book overflows with facts and ideas. Even the final chapter of the book, "Principles and Conclusions," has 31 headings and 20 pages of text.

Much of the book is written by Edmund Rolls, Professor of Experimental Psychology at the University of Oxford, who summarizes research from his laboratory on mechanisms of face and object recognition in macaque inferotemporal (IT) cortex, a high-level visual area. The result that provides a goal for theory is translation invariance of object (or face) specificity. Rolls' group finds that IT neurons have very large visual receptive fields, and that their selectivity for different stimuli is approximately the same (invariant) at different locations. Rolls presents his VisNet theory for how IT neurons could achieve this property: (1) a hierarchy of cortical areas from V1 to IT, each including local competition (via mutual inhibition); (2) localized feedforward convergence from one region in the hierarchy to the next higher region; (3) plasticity of IT corticocortical connections based on a modified Hebb-like learning rule. Although points 1 and 2 are common to many neural network models, the plasticity (point 3) in the VisNet model is unusual because it is based on the temporal trace or persistence of visual activity. However, there is a new wrinkle: recent experiments indicate that face recognition may not be translation-invariant in natural images. This new result may require a new theory that could depart considerably from VisNet.

In the rest of the book, Gustavo Deco, a theoretical physicist at Siemens Laboratories in Munich, Germany, describes a new model of visual attention. The model attempts to account for data suggesting biased competition between the neural representations of visual objects. The bias is, in part, set by visual attention. Deco offers a dynamical theory of top-down feedback from prefrontal cortex directly onto IT cortex, and then indirectly onto V1/V2, mediated through parietal cortex. The major novelty in the model is in the involvement of prefrontal cortex and the parietal–V1 path. The model accounts for many visual search data, and also for the pattern of fMRI imaging of human brain activity during attention-demanding tasks.

The density of experimental data in this book is impressive. The first three chapters are at an introductory textbook level. However, this weakness concerning early vision is counterbalanced by the book's strength in high-level vision and attention. Among many interesting results, there were two nuggets that could be of great importance for future theoretical efforts. One is the finding of the very large information capacity of a network of IT neurons based on the information carried by the number of the neurons' spikes within a fixed counting period. The spike count contains so much information that only a small increment could be gained by considering the temporal pattern in spike trains or the correlation between spike trains in different neurons. The second result is that IT neurons learn new patterns very quickly. This rapid learning can be seen not only in monkey IT, but also in human cortex homologous to IT, in fMRI experiments on visual learning.

This book presents material that specialists and graduate students in neuroscience need to know. It covers some of the same ground as the 1998 book, *Neural Networks and Brain Function* by Rolls and Alessandro Treves, but is more comprehensive. It could be useful in graduate courses on the neural basis of perception or in cognitive neuroscience. The authors' promise is kept; neural computation does lead to more understanding. Yet it is also clear that this is just the beginning.