Minding the microcircuits

Microcircuits: The Interface Between Neurons and Global Brain Function

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The MIT Press, 2006
472 pp, hardcover, $55.00
ISBN 0262072785

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An internet search for 'microcircuits' gives over half a million results, with this book topping the list. Why all the excitement? One reason is that most neuroscientists study microcircuits, broadly defined, making this volume of wide interest. The editors provide a flexible operational definition ('well-defined, fairly small entities of nerve cells') and outline their aim to provide a bridge from the genetic and molecular level to the behavioral and cognitive level not directly, but by understanding the intervening microcircuits.

The book consists of four sections that address microcircuits in the motor system, striatum, olfactory system and neocortex, and are arranged in chapters written by leading experts, which are followed by a group report. The first section covers collicular microcircuits for saccadic eye movements (Isa and Sparks) and vertebrate (Sillar and Grillner) and invertebrate (Pfluger and Buschges) locomotor microcircuits and highlights the fact that researchers have made a great deal of progress toward this general goal and that investigators in widely disparate systems speak the same language. The group report (Kiehn) is an elegant attempt at extracting common design principles in central pattern-generator microcircuits across motor systems that are adapted for many specific tasks. The argument, effectively supported by circuit schematics, is that central pattern generators involve a nearly universal 'kernel' that is composed of a small network of excitatory and inhibitory neurons. The basic microcircuit is then functionally adapted for specific tasks (for example, segmentally replicated and interconnected in locomotor systems, or pacemaker driven in brainstem respiratory centers). Neuromodulation is important for tuning the circuits' output.

These themes evolve and new ones are introduced in the striatal section, which takes readers through basic cell types, microcircuits and neuromodulation in the basal ganglia (Surmeier, Tepper and Plenz, Bergman, Kimura, Wickens). The group report (Bolam) discusses the canonical microcircuit, an interconnected group of medium spiny projection neurons, fast-spiking GABAergic interneurons and the giant cholinergic interneuron, collectively innervated by corticostriatal glutamatergic projections and dopaminergic projections from the substantia nigra. This architecture is proposed as a substrate for 'selection' between different cortical inputs via well-characterized ionic mechanisms mediating 'UP' and 'DOWN' states. Dopaminergic and cholinergic modulation, acting on the canonical microcircuit in the highly divergent and convergent system of cortical afferents, is proposed as a basis for reward-related plasticity.

The section on olfactory microcircuits revisits common principles across invertebrate and vertebrate systems in sensory coding and decoding. Chapters address population coding and network dynamics in insect olfactory pathways (Laurent), neuronal replacement in olfactory bulb (Lledo), molecular specification of connectivity in olfactory microcircuits (Mombaerts, Feinstein) and topographic aspects of olfactory circuits, maps and codes (Sachse, Galizia). The group report (Friedrich) focuses on formulating a canonical view of olfactory microcircuits, incorporating spatial and temporal aspects.

The neocortical section ranges widely, including interneuron diversity (DeFilipe *et al.*), cortical UP states, synfire chains and network dynamics (McCormick and Yuste), brain-wide dynamics relating to consciousness (Changeux and Michel), and computational approaches (Maass and Markram). The group report (Fregnac) examines the extent to which cortical circuits in different areas and species are canonical and how UP states relate to cortical microstates. The report assesses modularity (continuous versus clustered organization, in and across cortical areas), emphasizing the vertical and horizontal nature of columnar organization. The report also considers temporal aspects of information processing and 'noise' in cortical circuits: gain control, recurrent excitation and more. Boldly, the group considers how this might relate to what the neocortex does, finding merit for microcircuit mechanisms (synfire chains, UP states) in attention, perception and consciousness.

The book concisely explicates key themes in microcircuit research: spatial information coding, temporal information processing, excitatory-inhibitory interactions, modularity and modulation. Many chapters are refreshingly speculative, rising to the Dahlem conference series goal to transcend the format of most conference proceedings. Indeed, a particular strength of the book is that many authors explicitly list what they consider to be the key unanswered questions in their subfield. Much of the speculation is grounded in neural 'bedrock'—experimentally determined ionic and synaptic mechanisms underlying circuit organization. This book makes clear that behavior ultimately needs to be understood in terms of the functional organization of microcircuits.

For the future, two issues stand out to us. One is the need to be specific about the level of organization in identifying and analyzing microcircuits. Originally applied to local patterns of synaptic interaction and simple reflex pathways, the term is now applied at many levels, including intradendritic interactions, local synaptic connections, interlaminar connections and local circuits. Another issue is whether microcircuit modules in the cerebral cortex are diverse or stereotyped, and how this relates to higher cortical function. The many working hypotheses laid out in this volume will stimulate further research into such questions. ■

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