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Neuronal circuitry and population activity

Editorial overview

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Anthony Zador is Professor of Biology at Cold Spring Harbor Laboratory. His group combines physiological, molecular and computational approaches to study the cortical circuitry underlying processing in the auditory cortex, and how that circuitry is modulated by attention and disrupted in autism.

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Peter Mombaerts is a professor and the head of the Laboratory of Developmental Biology and Neurogenetics at The Rockefeller University, and is in transition to a position as the director of the Department of Molecular Neurogenetics at the Max Planck Institute of Biophysics, Frankfurt, Germany. His research interest is in the olfactory system of the mouse, particularly in axonal wiring and odorant receptor gene choice.

This issue is devoted to sensory systems, studied at the molecular, cellular, and systems level. Emphasis is placed on vertebrate, mostly mammalian, model systems.

Neuronal circuitry and population activity

Nirenberg and Victor consider the problem of how to infer computational and coding strategies from the spike trains recorded from large populations of neurons. Traditional methods relate sensory stimuli to neuronal responses one neuron at a time. With the advent of new techniques, it is now possible to record large data sets consisting of the spike trains of many neurons recorded simultaneously. However, exploiting the potential of these large data sets for studying neuronal interactions has turned out to be a formidable challenge for any but pairwise interactions. The authors review recent evidence that studying pairwise interactions is sufficient, at least in the retina.

Ohki and Reid review recent advances in understanding how the circuitry of visual cortex gives rise to the functional properties of neurons in visual cortex. Neurons in visual cortex are tuned for orientation. In some mammals, including the cat, neurons with similar tuning are organized into columns with single-cell precision, whereas in the rodent neurons are spatially dispersed. In spite of these differences, neurons in some rodents can show tuning as precise as that found in cats, indicating that orientation columns are not essential. Instead, it appears that cortical circuits are wired very precisely, and that in some cases nearby neurons may be part of distinct "subnetworks."

Brecht reviews the growing literature on the functional circuitry of the rodent barrel cortex. Over the past decade, the barrel cortex has emerged as perhaps the leading model system for studying cortical microcircuitry and plasticity. Through detailed quantitative analysis made possible by the application of electrophysiological and optical techniques, a detailed picture of barrel cortex circuitry is now emerging.

Sherman reviews the role of the thalamus in conveying information. The thalamus has traditionally been considered to act as a simple relay of information from the sensory periphery to the cortex. However, several lines of evidence suggest that thalamus may play an important role in conveying information from one cortical region to another. Thus intracortical communication may occur not only through direct thalamocortical connections, but also through a cortex-thalamus-cortex loop as well.

Neuronal adaptation

Wark and colleagues discuss the function of sensory adaptation. The authors start from Barlow's efficient coding hypothesis, according to which neural systems evolve the optimally efficient coding strategy to represent the stimuli they typically process. The authors then describe how sensory adaptation can be viewed as a consequence of Barlow's hypothesis in a world in which the statistics of sensory stimuli change. The authors show that formulating these ideas in a rigorous mathematical way leads to testable experimental predictions.

Benda and colleagues review new techniques for efficiently sampling receptive fields using online adaptive sampling of stimuli. They describe algorithms that allow for automatic generation of stimuli to explore a neuron's receptive field. These new approaches may allow researchers to characterize the properties of neurons in areas of the nervous system that are currently not at all well understood.

Fritz and colleagues review rapid adaptation in the auditory system caused by attention. Attention has long been known to modulate responses throughout the auditory system. The authors describe recent advances in the field, including both the interesting similarities with and differences from attentional modulation in the visual system.

Dahmen and King review adaptation in the auditory system on time scales longer than attention. They discuss how responses in the auditory system mature during development, and how they can be modified by experience and by damage to the auditory system. Perhaps less widely known than related work in the visual system, the literature on plasticity and learning in the auditory system offers several elegant examples of how the nervous system adapts to its environment over a wide range of time scales.

Nobre and colleagues review the effects of temporal expectation on neuronal activity. It has long been recognized that knowledge of when a stimulus will occur can exert a powerful effect on learning, reaction times, and other behavioral measures. More recently, progress has been made in understanding the neuronal substrates underlying this temporal expectation. These studies raise interesting questions about exactly how the brain represents time—where is the brain's clock? The authors evaluate evidence for both dedicated and distributed clocks.

Vision in humans

Kreiman reviews recent experiments in which neuronal activity in humans is studied at the single neuron level. Most data about activity in the human nervous system were obtained using non-invasive methods such as scalp electroencephalographic (EEG) recording and functional magnetic resonance imaging (fMRI). However in some cases it is possible to monitor single unit activity in humans. These studies reveal that individual neurons in the human can be surprisingly selective.

Conway and Livingstone show how insights from visual neuroscience can help us understand visual art. Artists intuitively know how to manipulate the gaze to achieve the effects they seek. In this fascinating review, the authors illustrate how some of these effects are achieved.

Sensory mechanisms in the periphery

The Zufalls challenge the long held notion of a dichotomy between 'general' odor perception by the main olfactory system, and 'pheromone' perception by the accessory olfactory/vomeronasal system. As is often the case, the reality is often more complicated than was thought initially. The peripheral olfactory system of the mouse continues to provide a surprising cellular and molecular diversity. The challenge ahead will be to integrate the various systems and subsystems.

Patapoutian and colleagues review the exciting recent developments in our understanding of the molecular basis of thermosensation (cold and warm) and the growing recognition of the sensory modality known as 'chemesthesis'. This chemical sense is distinct from taste and smell and is exemplified by the burning sensation caused by capsaicin, the hot ingredient in chili peppers. Thermosensation and chemesthesis appear to rely exclusively on members of a family of transmembrane proteins known as transient receptor potential (TRP) channels.

Ren and Gillespie review the biophysical evidence that is consistent and that is inconsistent with the cochlear amplifier hypothesis, which was proposed half a century ago to underly the concept of 'active' hearing. They conclude that the body of evidence is unconvincing, and propose instead a model of a cochlear transformer.