Cognitive neuroscience

Editorial Overview

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Brian Wandell's research is concerned with the acquisition and interpretation of images by human and electronic visual systems. In his visual neuroscience work, Wandell has used functional MRI to identify and measure the sizes and positions of visual areas in human and macaque, analyze color and motion responsivities in these areas, and learn more about plasticity of visual areas during development.

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Anthony Movshon's research is concerned with the way that the brain encodes and decodes visual information, and in the mechanisms that put that information to use in the control of behavior. His work centers on visual information processing by neuronal circuits in the cerebral cortex, especially those concerned with the form and motion of objects. He is also interested in the way that visual cortical circuits develop in normal and abnormal visual environments.

Introduction

Ulric Neisser's 1967 classic, *Cognitive Psychology*, both created and defined a field [1]. In the introduction to his book, Neisser writes of cognition as ''all processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used... such terms as sensation, perception, imagery, retention, recall, problem-solving, and thinking, among others, refer to hypothetical stages or aspects of cognition''. Neisser did not consider its neural basis to be especially relevant — he likened psychology to economics, both ''concerned with the interdependence among certain events rather than with their physical nature''.

Now, 36 years later, the subject of this issue is that portion of cognition that Neisser set aside, cognitive neuroscience. Interest in this new member of the family of cognitive sciences has grown spectacularly in the last decade or so, largely because of the development of new tools to probe the neural mechanisms of Neisser's 'hypothetical stages' of cognition. The growth of cognitive neuroscience represents a gigantic collective guess that Neisser was wrong, and that understanding cognition will be speeded by knowing how cognitive acts are computed and represented by the brain. Whether this approach will succeed is hard to say; but there is no doubt that this focus on specific mechanisms has brought together many formerly disparate parts of psychology through a common interest in the biological structures that mediate cognition.

Cognitive neuroscience is an enormously active field, brimming with creative ideas and experiments. As with many relatively new disciplines, there is no uniform view of what is and is not in its domain. Being unsure of where the boundaries lie, and being loath to miss something by an overly conservative definition of the field, we have taken a broad view. The reviews we have commissioned describe recent advances in understanding perception, decision-making, attention, language and action. The experimental methods involved include behavioral testing, single unit experiments, and a variety of neuroimaging methods. The theoretical methods involved include informal (qualitative) rules, quantitative formulae, and computer-based computational methods. In this issue, the vitality and diversity of cognitive neuroscience is on display.

As Kersten and Yuille observe, the biological sensory systems may be the most complex pattern recognition architecture known. Sensory systems incorporate knowledge of the likely stimuli with very simple processing elements to routinely arrive at simple, unambiguous interpretations of the retinal image data. Achieving such performance from ambiguous sensory information requires that the system incorporates properties of the physical world; Simoncelli, and Kersten and Yuille review recent advances in our understanding of the statistical properties of the visual world, and how this information may be effectively incorporated by visual pattern recognition algorithms. These reviews emphasize two aspects of pattern recognition — Bayesian inference and coding efficiency — and they review a series of advances in applying these methods over the past several years.

There is a strong presumption that the cortex includes computational mechanisms that are designed to apply these principles to the analysis of sensory signals. Human cortical responses to a wide variety of objects can be measured with unprecedented temporal and spatial precision under many different viewing conditions. In the domain of vision, Grill-Spector, Formisano and Goebel, and Yantis and Serences describe novel and important strides in our knowledge of activity within the human visual cortex. Grill-Spector describes recent advances in understanding the organization of human extrastriate visual pathways and the signals observed therein during simple object recognition. Formisano and Goebel illustrate a novel paradigm for improving the temporal resolution of human brain measurements using functional MRI. Yantis and Serences describe how attention is distributed during these recognition tasks. In the domain of hearing, Semple reviews new material on the general organization of cortical auditory processing and on the specific mechanisms that enable cortical networks to process complex sounds.

The collection of reviews shows that links between our understanding of pattern recognition performance and its neural basis remain quite tentative. One reason for this continuing distance between theory and measurement is that studies in neuroscience, both single unit and functional neuroimaging, often rely on manipulations of experimental parameters, such as attention or general category of visual stimulus, that can be easily controlled. It has been very impressive to learn that manipulations of attention or changes in coarse object categories give rise to powerful differences in the spatial distribution of cortical signals. Theoretical analysis, however, requires more clarification with respect to computational theories of object recognition, such as those that rely on Bayesian or efficiency principles.

The review by Miller and his colleagues bridges these areas, using pattern recognition to illuminate the formation of categorization and concepts. The ability to string together concepts and detect the rules that these high level abstractions obey is a key to intelligent behavior and essential for the development of language. The formation of categories and concepts is also central to the job of making decisions, and of selecting targets for organized behavior. Some of the most remarkable achievements in recent years have come in this area, and are described in the reviews by Schall and Assad. Schall details current thinking on the translation of information from active neurons into decisions about actions, and Assad considers the role of parietal cortex in the selection of targets for action. Lewis and Miall review a concept that is basic to all decisions and actions: time. They summarize evidence that different neural systems maintain separate representations of time.

All of our abilities to process information would count for little if we could not efficiently represent and then hold our percepts and decisions in memory, yet the puzzle of the basis of memory has remained one of the toughest neurobiological nuts to crack. Sanger describes the mathematical principles that have been used to describe the representation of mental information. Brody and his colleagues articulate a novel and provocative view of the way that specially configured networks of neurons might generate persistent activity, and they express this view as rigorous neural theory.

Perceiving and remembering would be of little value if we were incapable of acting. Usually, however, we conceive of internal models as being very important for understanding the external world. Interestingly, however, our reviews of action place an important emphasis on internal models for describing our own actions. Blakemore and Frith describe these internal models as a basis for the conscious experience of our own actions. Davidson and Wolpert discuss how these models are necessary to predict the consequences of our actions. By placing an emphasis on these internal models of action, they hope to describe how we learn to guide motor actions in uncertain environments. Sanes describes how those internal models, as instantiated in anatomical circuits, are modified by experience and use.

The connection between sensation and an important cognitive skill, reading, is explored by Ramus. He describes the current status of the hypothesis that there is a significant causal relationship between subtle sensory and motor disorders and developmental reading disability. As reading involves integrating signals between two sensory modalities, audition and vision, this important application of neuroscience again exposes a close relationship between concepts and the sensory elements of pattern recognition.

The tragedy of mental illness is one of the most compelling reasons to study the specific mechanisms of brain and thought. Ramus' description of the neural basis of reading is one example. Callicott's review of the neural basis of schizophrenia is another. In this review, we are reminded that functional neuroimaging must be considered together with other methods to uncover the nature and sources of brain differences that cause disease. Callicott uses functional neuroimaging to define a phenotype that connects schizophrenia and genomics. As in other domains of genomics, his review makes it plain that we must also understand the role of environmental influences in causing pathological changes in cognition and its underlying neural computation.

A collection of reviews gives us an opportunity to be impressed by the progress in cognitive neuroscience; it also gives us the opportunity to think about the impediments to progress. What data and tools are missing that might help the field advance more rapidly? Nichols and Newsome [2] wrote: ‘‘Computational theorists and psychologists have developed plausible models for many cognitive functions; our primary problem lies in acquiring and analyzing the neural data needed to evaluate these models’’. From the reviews in this issue, we wonder if this view is correct.

We suspect that the students reading these reviews will be impressed at the great array of experimental methods that are now available to probe animal and human brains. However, the ability to connect the different types of measurements through a coherent theory remains a daunting challenge. The computational language, whether it is Bayesian mathematics, neural networks, or the language of linear estimation theory, is not yet a powerful guide to designing experiments in electrophysiology, behavior, or neuroimaging. Consequently, many intriguing experiments stand on their own without a compelling theoretical mesh to connect them to other experiments, and certainly not to other experiments made using different techniques (e.g., behavior to neuroimaging to single unit). Our theories remain qualitative, and the connections between measurements and theory remain loose.

The exciting development, however, is that fields that were once widely separated, and sometimes even antagonistic, are now joined together. There is a vibrant and rapidly advancing field of cognitive neuroscience that is making great progress at simultaneously understanding behavior and brain. The field sits in the middle of many novel findings about the brain itself and many new discoveries about behavior. The bet that looking at the intersection of behavior and brain is the right way forward has been made and is being tested; we guess that Neisser will prove to have bet wrongly about the importance of understanding the brain to understanding cognition. The reviews in this issue offer you an opportunity to judge.

References

1. Neisser U: *Cognitive Psychology*. New York: Appleton-Century-Crofts; 1967.

2. Nichols MJ, Newsome WT: **The neurobiology of cognition**. *Nature* 1999, **402**:C35-38.