Department of Brain and Cognitive Sciences

Mission

The Department of Brain and Cognitive Sciences (BCS) has been driven for the 43 years of its existence by the mission of understanding how the brain works and how it gives rise to the mind. In the pursuit of this objective, BCS has created a diverse, multidisciplinary environment of interrelated areas and levels of investigation providing the greatest opportunities for significant insight into key questions. Today, BCS is the only department of its kind, balancing an extraordinary breadth of inquiry with the focus and exactitude required for field-leading research. BCS remains a unique department with a unique vision.

The Department is complemented and strengthened by its association with the Picower Institute for Learning and Memory and the McGovern Institute for Brain Research; 19 of 37 BCS primary faculty are also investigators in these centers. With the brain and cognitive sciences complex bringing researchers from all three entities together in the same building, BCS holds a special role, acting as an umbrella and providing the academic home for all teaching and research into the brain and mind at MIT.

Faculty

The BCS faculty are widely recognized as being among the leaders in their respective fields. There are 37 faculty with primary appointments in BCS; 9 of them also hold appointments in the Picower Institute for Learning and Memory and 10 in the McGovern Institute for Brain Research. Two faculty have dual appointments in the Harvard–MIT Division of Health Sciences and Technology; four are Howard Hughes Medical Institute investigators. The faculty is distinguished by its accomplishments and honors: 8 are members of the National Academy of Sciences, 3 of the Institute of Medicine, and 10 of the American Academy of Arts and Sciences.

Effective July 1, 2007, faculty members James DiCarlo and Joshua Tenenbaum were promoted to associate professor and Tenenbaum was also granted tenure. Over 2007–2008, Aude Oliva and Christopher Moore were promoted to associate professor without tenure, with their new appointments beginning on July 1, 2008. The Department also welcomed Professor Martha Constantine-Paton to its ranks when her primary appointment was transferred from the Department of Biology to BCS in September 2007.

The interdisciplinary nature of neuroscience and cognitive science is highlighted by the number of the joint appointments held by BCS faculty members as well as those granted to faculty of other departments. With the addition in the last year of Edward Boyden and Drazen Prelec, joint appointments in BCS number eight, with representation from the Department of Linguistics and Philosophy, Department of Mechanical Engineering, the Media Lab, Department of Nuclear Science and Engineering, Department of Biology, Department of Electrical Engineering and Computer Science, and the Sloan School of Management. BCS faculty members in turn hold joint appointments in many of these units as well as the Department of Physics, Computer Science and Artificial Intelligence Laboratory, and the Clinical Research Center.

Graduate Program

Nineteen graduate students joined the BCS graduate program in September 2007. Two of the new incoming students were funded by Presidential/Singleton Graduate Fellowships; nine were funded by Singleton Fellowships. Seven were supported by departmental National Institutes of Health (NIH) training grants, and one was funded by the Ida Green Fellowship administered by the Office of the Dean for Graduate Students.

During the past year, 11 students graduated with a doctorate, with eight of them assuming postdoctoral positions in universities or research institutions (four in BCS at MIT; two in the Psychology Department at Stanford University; one in the Psychology Department at the University of California, Los Angeles; one in the Psychology Department at the University of Massachusetts, Amherst). Of the remaining three, one is a Rowland Junior Fellow in the Rowland Institute at Harvard University, one is an assistant professor of psychology in the Department of Psychology at Carnegie Mellon University, and one is a senior scientist at Cenomed BioSciences.

Nine students were honored for excellence in undergraduate teaching and one was commended for continuing dedication to teaching.

Course 9 Major

For academic year 2008, BCS had a total of 159 undergraduates with 55 graduating seniors. Forty-nine freshmen joined the Department as new majors at the end of the 2008 spring term.

At the annual spring BCS Undergraduate Awards dinner, five seniors were honored for outstanding research, while 14 seniors were commended for outstanding academic records, leadership in the Department, or outstanding work in a particular course; an additional 13 juniors were also acknowledged for both research and academic accomplishments. Two of our students were awarded Fulbright Scholarships. Forty-three undergraduates had a perfect grade point average this past semester and were acknowledged by the Department for their achievements.

In the 2007–2008 academic year, Pawan Sinha and Aude Oliva received BCS Awards for Excellence in Undergraduate Advising and Teaching, respectively. And Oliva and Laura Schulz received the School of Science Prize for Excellence in Undergraduate Teaching.

Some Research Highlights

Richard Wurtman presented the results of a large-scale clinical trial on the use of a mixture of membrane phosphatide precursors as a treatment for early-stage Alzheimer's disease at the 2008 meeting of the Alzheimer's Association. Based on the results from 220 patients in 40 locations, the mixture was shown to be clinically effective and to cause minimum side effects. The treatment works by increasing the synthesis of synaptic membrane and, it appears, the number of synapses brain neurons make. The trial resulted from seven years of basic science studies in Wurtman's lab, all supported by the National Institute of Mental Health.

Peter Schiller's lab has been studying the feasibility of creating a prosthetic device for the blind. This work is carried out in both monkeys and humans. The work on monkeys examines the nature of visual percepts elicited by electrical stimulation of the primary visual cortex using individual electrodes as well as implanted arrays that may eventually be used effectively as a prosthetic device for the blind. The human work involves procedures that noninvasively mimic the images that would be created by the stimulation of implanted electrode arrays, and the effectiveness with which the images can provide shape and depth information is examined. The expectation is that these procedures will determine the optimal algorithm for the converting visual images into electrical stimulation.

In the past year, Carlos Lois and his lab have been studying the dynamics of migration of new neurons through the brain and have discovered that immature neurons move through the brain in nonlinear trajectories. In addition, migrating cells extend and retract processes in a highly dynamic manner in a search-like behavior. These findings suggest that new neurons probe the different elements of the circuit before they commit to integrating and making synapses in a particular target. In another line of research, they have developed genetic methods to modify the biophysical properties of neurons. Using these methods they have observed that neurons rendered hyperexcitable have the ability to compensate for excess electrical activity by reducing the frequency of the synaptic inputs they receive from other neurons present in the circuit.

Research in Tomaso Poggio's lab focuses on the problem of learning in both biological organisms and computers with a focus in three main areas: mathematics, engineering, and neuroscience of learning. Significant accomplishments in the past year include extending the model of the ventral stream of neocortex to incorporate neuroscience data on back-projections and controlling attention and eye movements, with preliminary results showing that this model can predict human eye movements in top-down tasks better than standard models of saliency. Further research in this area seeks to extend the model to the dorsal stream for the recognition of actions. The lab has also used the above system to phenotype mouse behavior, developing a vision system that eventually could become a useful tool for biologists.

Morgan Sheng and his lab have published several significant papers showing that phosphorylation of an abundant postsynaptic scaffold protein (PSD-95) controls synaptic strength; that an activity-inducible protein kinase causes degradation of its substrates, leading to synapse weakening and loss; and that genetically engineered mice lacking a postsynaptic scaffold protein implicated in human autism (Shank) have anatomical and behavioral features relevant to the human disorder.

Ann Graybiel's lab focuses on the habit system of the brain, which is affected by a number of neurologic and neuropsychiatric disorders including Parkinson's disease, Huntington's disease, and Tourette syndrome. In work with Japanese collaborators, they have shown that a loss of the neurotransmitter dopamine in portions of the basal ganglia explains the ability of L-dopa, the main pharmacologic therapy for Parkinson's, to also ameliorate the symptoms of dopa-responsive dystonia—an important step in understanding this disorder. New work led by Jill Crittenden has shown that two genes discovered in the lab with the help of David Housman from Biology are dysregulated in a model of Parkinson's in which dyskinesias are induced by prolonged use of L-dopa therapy. These findings are of great clinical interest. In recent studies of habit formation, the lab has found evidence of dual, coexisting representations of learned habits in the striatum of the basal ganglia. The fact that one representation has been shown to be quite fixed and stable while the other is more adaptable suggests that such coexisting representations may underlie the co-occurrence of cognitive flexibility and cognitive stability as we acquire and modify our habits.

Ruth Rosenholtz's research team has developed the first general model of visual crowding, a puzzling phenomenon most noticeable in peripheral vision. The new model has implications for the way people think about and study the neural computations underlying object recognition and pattern perception more generally. In addition, the model should have clinical significance, since crowding is considered an important aspect of conditions like amblyopia and dyslexia. For patients with macular degeneration, virtually all vision is crowded vision.

Martha Constantine-Paton's interest in developmental plasticity has led to a focus on two research programs this past year. The first is a continuation of a long-term interest in the molecular and cellular determinants of plasticity in the developing visual pathway. The second major effort has focused on the relative roles of the NR2 subunits (NR2A and NR2B) and L-type Ca^{++} channels and the erbB receptor tyrosine kinases in area CA1 of the hippocampus. This work suggests that these factors are most effective on long-term potentiation in ventral CA1 rather than the more commonly studied dorsal CA1 and are therefore of considerable interest in erbB receptor involvement in schizophrenia, because the ventral CA1 hippocampal projections are the major inputs to the limbic system and prefrontal cortex—brain areas whose function is believed to be disrupted in this major psychiatric illness.

Mary Potter has begun work to test a computational model of attention in collaboration with postdoctoral fellow Brad Wyble. The research focuses on the first 50–250 ms of visual processing in search tasks, when stimuli compete for processing. They have found evidence that selective search generates competition, whereas "whole report" minimizes competition. A recent study found that these two modes can be executed in parallel, contrary to previous assumptions.

Aude Oliva's research program seeks to understand and model the capacity and limits of the human brain for processing visual information, with the goal of developing more robust computational models of vision as well as rehabilitation strategies for the visually and cognitively impaired population. In her most recent work, she and her team have demonstrated a new bound to the capacity of the human brain at remembering information, offering hopes for developing novel rehabilitation tests for people with memory loss, as in Alzheimer's disease.

James DiCarlo's lab continues to focus on understanding the high-level neuronal representations that support the brain's remarkable ability to recognize objects under a very wide range of viewing conditions. In one line of work, they examine the role of real-world visual experience in constructing the neuronal representations that underlie this ability. One result is a novel form of rapid visual plasticity that may point to the brain's underlying solution to this problem. Further explorations in this area will involve both neurophysiology and computational modeling. The lab has also recently completed its first studies using functional magnetic resonance imaging (fMRI) in nonhuman primates to gain understanding of the spatial organization of shape information in high-level visual cortex. They have developed a novel high-resolution stereo x-ray method to study those fMRI-determined responses at the neuronal level.

Researchers in Edward Gibson's lab have discovered that there exist a language and culture without any words for counting (e.g., the number "one"). Their paper in the journal *Cognition* reported on work with a tribe from the Amazonian jungle, the Pirahã, that showed that this tribe has no counting words whatsoever. This result demonstrates that counting is a cultural invention, which is learned in other human cultures.

Mriganka Sur's laboratory uses cutting-edge technologies for imaging cells and molecules in the intact brain combined with novel probes to reveal mechanisms of cortical plasticity and discover the function of cortical cells and circuits. A major recent finding is that astrocytes—long thought to be support cells of the cortex—actually receive significant neuronal drive, have specific response properties, influence neuronal computations, and regulate blood flow into discrete regions of cortex thus enabling noninvasive brain imaging techniques such as fMRI.

Robert Desimone's lab is working to understand the neural basis of selective attention. One major hypothesis is that attended information is processed preferentially in the cortex because the neurons carrying the relevant information synchronize their activity. In the past year, the lab has made progress in identifying some of the key features of synchronized activity in the cortex, including the impact of synchrony on cross-neuron and cross-brain region interactions.

In the past year, Earl Miller's laboratory has made a number of discoveries using advanced multielectrode recording techniques. One important finding is that synchronization between spiking activity of individual neurons and oscillating activity of the neuron population may help encode the order of two objects held in working memory, as if different phases of the population oscillations provide different memory "slots" for the objects. They have also discovered the first direct neurophysiological evidence for a moving spotlight of attentional focus during searches of the visual environment. Further, the shifts in the attentional spotlight were synchronized with oscillations in population activity, suggesting a "clocking signal" that regulates attentional shifts. These findings provide insights into the neural bases of a fundamental cognitive function and provide new insight into how information may be encoded in the brain.

Suzanne Corkin's research continues its long-standing dedication to the study of brain–behavior relations in healthy aging and age-related degenerative diseases, such as Alzheimer's and Parkinson's. Using a variety of tools including tests that assess specific cognitive processes, structural MRI, fMRI, magnetoencephalography, and genotyping, Corkin's research team has found striking correlations between the integrity of white matter and scores on tests of long-term memory and executive function. A corresponding finding indicates no association between measures of gray matter (cortical thickness, cortical volume) and cognition. In Parkinson's, ongoing research examines how normal variation in genes that alter dopamine metabolism and dopamine receptor signaling modulates medication-induced side effects.

Selected Faculty Awards and Honors

Edward Adelson was named John and Dorothy Wilson professor.

Emery Brown received an NIH Director's Pioneer Award to develop a systems neuroscience approach to studying how anesthetic drugs act in the brain to create the state of general anesthesia. Brown was also elected to the Institute of Medicine and the Institute of Electrical and Electronics Engineers and was named a fellow of the American Association for the Advancement of Science.

Robert Desimone was named to the newly endowed Doris and Don Berkey professorship.

John Gabrieli and Nancy Kanwisher were awarded an $8.5 million Ellison Medical Foundation grant to study the brain basis of autism and dyslexia.

Ann M. Graybiel was selected by The Mental Health Research Association to receive its Distinguished Investigator Award. She also received an honorary doctorate at The Hebrew University in Jerusalem and an honorary doctorate in medicine at Queens University of Belfast, Northern Ireland.

Alan Jasanoff received an NIH Director's New Innovator Award in 2007 in support of his work to devise genetically controlled, noninvasive methods for measuring brain activity in animals.

Elly Nedivi received the Julie Martin Mid-Career Award in Aging Research from the Ellison Medical Foundation and the American Federation for Aging Research.

Rebecca Saxe received a 2007 John Merck Scholars Award in the Biology of Developmental Disabilities in Children. She also received the Cognitive Neuroscience Society Young Investigator Award.

Sebastian Seung was awarded the 2008 Ho-Am Prize in Engineering—a special award of the Samsung Welfare Foundation presented to ethnic Koreans and foreigners who have achieved world-class standards in creative research in the international academic world.

Peter Schiller was elected to both the American Academy of Sciences and the American Academy of Arts and Sciences.

Pawan Sinha was chosen to receive a James S. MacDonald Foundation Scholars Award.

Mriganka Sur was elected to the Third World Academy of Sciences and was named the inaugural holder of the Paul E. Newton professorship.

Joshua Tenenbaum was selected as a recipient of the 2008 American Psychological Association Distinguished Scientific Award for Early Career Contribution to Psychology. Further awards for Tenenbaum and his lab included 2007 Computational Modeling Prizes for Best Paper on Perception and Action as well as for Best Paper on Higher-Level Cognition.

Li-Huei Tsai was inducted into the Academia Sinica of the Republic of China.

Mriganka Sur
Department Head
Paul E. Newton Professor of Neuroscience

More information about the Department of Brain and Cognitive Sciences can be found at http://www.mit.edu/bcs/.