# Department of Brain and Cognitive Sciences

The mission of the Department of Brain and Cognitive Sciences (BCS) is to understand the brain and the mind and, ultimately, how the brain 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. In the past year, the BCS community has been strengthened by a growth in overall resources, record classes of graduate and undergraduate students, and the recognition of its peers. BCS today is a unique department with a unique vision, looking forward to continued scientific leadership and service to the Institute and to society.

Of 32 primary BCS faculty, 16 are also investigators in two neuroscience research centers—the McGovern Institute for Brain Research and the Picower Institute for Learning and Memory (PILM). As BCS is the umbrella organization for neuroscience and cognitive science at MIT, its faculty investigate the function of the brain at multiple levels of analysis, including molecules, neurons, networks of neurons, and modules of the mind. Investigators in the McGovern Institute seek to understand specific brain systems, including those for vision and movement, using approaches of brain imaging, systems neuroscience, and molecular neuroscience. Investigators in the Picower Institute seek to understand mechanisms of learning, memory, and brain plasticity using molecular and systems approaches. A new building housing all of neuroscience and cognitive science at MIT is scheduled to be completed in September 2005, bringing together the department and centers in one place in an unprecedented research, teaching, and training enterprise.

## Education

The department had a total of 133 undergraduates this year, with 51 graduating seniors—the largest class ever for BCS. At the annual spring BCS Undergraduate Awards dinner, seven majors were honored for outstanding academic records, performance in research, leadership in the department, or outstanding work in a particular course. In addition, Laurel Yong-Hwa Lee '05 was named a Rhodes scholar, was listed in *Glamour Magazine*'s "Top 10 College Women" in 2004, and made *USA Today*'s "All–USA College Academic Team." Swati Saini '05 was also listed in *Glamour Magazine*'s "Top 10 College Women" in 2004. Shijun 'Cindy' Xi '05 earned a Merage Fellowship in the spring of 2005.

The 15 graduate students who entered in fall 2004 were funded by Praecis Presidential Graduate Fellowships, Presidential Graduate Fellowships, a Dean's Fellowship, Picower-Leventhal Presidential Graduate Fellowships, the new Singleton Fellowships, and by departmental National Institutes of Health training grants. During this year, 11 students received PhDs; the majority of these students have gone on to postdoctoral positions in universities or research institutions. Four students were honored for excellence in undergraduate teaching, three students won awards for excellence in graduate teaching, and two were commended for continuing dedication to teaching. This year, a new teaching award was created—Team Award for Outstanding Teaching—which was given to two TA teams for two of the department's lab classes; a total of 11 students comprised these teams (6 in one, 5 in the other). Finally, one student received a BCS Special Award for Extraordinary Teaching Service.

## Faculty Highlights

- Edward Adelson won the Longuet-Higgins award for outstanding contributions to Computer Vision.
- Suzanne Corkin celebrated her 40th year at MIT in 2004.
- Ann Graybiel delivered the Plenary lecture at the Gordon Research Conference, won the Fondation IPSEN Neuronal Plasticity Prize in recognition of an outstanding contribution in the field of neuronal plasticity, and was awarded an honorary doctor of science degree by Tufts University.
- Neville Hogan was awarded an honorary doctorate by the Dublin Institute of Technology.
- Alan Jasanoff received the Raymond and Beverley Sackler Scholar Award to support research in his lab.
- Nancy Kanwisher was elected to the National Academy of Sciences.
- Troy Littleton was awarded the Fred and Carole Middleton career development professorship.
- Carlos Lois received the Ellison Foundation Young Investigator Award.
- Earl Miller was elected to the International Society for Behavioral Neuroscience and was the keynote speaker at both the 2005 Human Brain Mapping Meeting and the 2005 Motivational Neural Networks Meeting.
- Tomaso Poggio was a featured speaker at the Crick Memorial at the Salk Institute and keynote speaker at the SigGraph workshop, at the ETH 150th anniversary; and at the International Conference on Mathematical Harmonic Analysis (Hangzhou, China). He was also chairperson of the conference "Future of Information and Communication," Venice, 2005, and was named a member of the Scientific Advisory Board of the ISI Foundation (Turin, Italy) and of the Comitato di Esperti dell'ISICT (Genoa, Italy).
- Gerald Schneider was appointed honorary professor at the University of Hong Kong.
- Morgan Sheng was elected fellow of the American Association for the Advancement of Science.
- Sebastian Seung was promoted to full professor.
- Pawan Sinha was promoted to associate professor.
- Matthew Wilson was promoted to full professor.

## Research Advances

### Brain Mechanisms of Vision, Touch, and Movement

Edward Adelson's lab is looking at the gain control mechanisms that biological and machine vision systems can use for dealing with high dynamic range in images, such as when you have a mixture of bright illumination and shadow in the same image. They have an algorithm that models retinal and cortical gain control; it should have useful applications in digital video and photography. They are also studying the perception of material properties such as brightness and gloss and have found that certain textural statistics are diagnostic of these properties for complex surfaces. This allows them to build a computational system that can estimate the surface properties and that gives similar estimates to those given by human observers.

Neville Hogan's lab emphasizes how humans and robots control physical interaction. They have developed an Anklebot—a robotic device designed to help stroke patients regain movement in paralyzed ankles. MIT and the Baltimore Veterans Administration Medical Center will establish a center of excellence on task-oriented exercise and robotics in neurological diseases to further such work on lower extremity movement.

Nancy Kanwisher's lab has shown that brain reorganization occurs in people suffering from macular degeneration, a progressive visual disorder in which the center of the retina is damaged and sight is limited to peripheral vision. Their major finding is that the part of the brain that processes only central retinal visual information in people with normal sight reorganizes itself in people with macular degeneration to help process peripheral visual information. This suggests the possibility of developing new rehabilitative strategies to use these changes to compensate for loss of retinal function.

Mriganka Sur's lab studies the development, function, and disorders of the cerebral cortex. In the past year, the lab described a fundamental principle by which the visual cortex represents multiple features of visual images. They examined a mathematical principle called "dimension reduction," whereby several properties of neurons come to be systematically mapped on the two dimensions of the cortical sheet. The findings demonstrate that multiple maps of response features in the visual cortex are intertwined in highly specific relationships in such a way that at locations where one feature changes rapidly, other features change slowly, thereby maximizing coverage and continuity of representations.

Over the past year, Pawan Sinha's laboratory has made significant progress on the issue of how the brain learns to parse the visual world into distinct objects. Their recent experiments, undertaken as part of Project Prakash, have revealed some key strategies the visual system employs during the early stages of visual learning. These empirical findings have guided their design of Dylan, a computational model of unsupervised object discovery. Somewhat unexpectedly, this work has suggested important new ways of thinking about processing deficits in autism. As part of Project Prakash, Sinha's lab also provided ophthalmic screening to over 300 children in India, several of whom have been or will be provided free treatment for congenital blindness, which they otherwise could not afford.

### Learning and Memory

Ann Graybiel's lab conducts research on the "habit system" of the brain. New work has demonstrated through recording with many electrodes simultaneously what happens to brain activity in the basal ganglia as animals learn to perform a task that requires decision making and what happens when they forget and then relearn. The brain cells reorganize their activity patterns, new cells are recruited and then drop out, then come back. They believe these changes are fundamental fingerprints of learning in the brain's habit system. They have also discovered and cloned a gene that is critical for responses to addictive drugs such as amphetamines. This work is of direct relevance to the field of drug addiction and to seeking pharmaceutical reagents for this purpose.

In the last year, a surprising synergy between the different directions of research has emerged in Tomaso Poggio's lab. A theory of the feed forward path in the ventral stream of the visual cortex turned out to perform as well or better than state-of-the-art computer vision systems on difficult recognition problems of natural images. It also performs at the human level in rapid categorization tasks of natural images. The model is consistent with known (or predicted and then experimentally verified) physiological properties of cells in several cortical areas. Furthermore, the architecture assumed in their model has strong relations with key aspects of learning algorithms, as suggested by learning theory. The theory of the visual ventral stream is the main tool in their collaboration with several experimental labs at MIT, Harvard, Georgetown, CalTech, and Northwestern.

Using techniques that make it possible to measure the responses and interactions of large groups of neurons, Matthew Wilson's laboratory is studying how memories of personal experience are formed and used. This effort has led to the study of sleep and the dreaming life of rats, yielding surprising insights into the relationship between dreams and memory. Wilson's laboratory, in collaboration with the Tonegawa laboratory, demonstrated for the first time the role of circuits within the hippocampal area CA3 in mice in the formation of memories of novel events. These findings have implications for the formation of human memories. Recent experiments have also found that certain brain rhythms may serve to coordinate the functions of widely separated brain areas during memory-guided planning and decision making. This finding may lead to new methods of the diagnosis and treatment of a variety of neurological disorders, such as schizophrenia and autism, which may involve the disruption of communication between brain structures such as the hippocampus and prefrontal cortices.

### Brain Development and Plasticity

Mark Bear and his group have developed a theory about the mechanism controlling fragile X that may lead to its treatment in the near future. Their research shows that the critical brain protein that normally dampens signals from a brain-chemical receptor called MGluR is blocked by the Fragile X mutation, thus allowing some overactivity by the MGluR and eventual weakening of connections between cells, impairing brain development. Preliminary safety testing of MgluR–blocking drugs in cells and animals is being undertaken before any clinical trials can be conducted on humans.

Using the fruit fly *Drosophila* as a model, Troy Littleton's lab studies the alterations in neuron-to-neuron signaling and connections that underlie epilepsy, Huntington's disease, and other genetically complex disorders. The lab also studies how the connections among neurons change during learning and memory. They are seeking to elucidate the molecular mechanisms underlying synapse formation, function, and plasticity by combining molecular biology, protein biochemistry, electrophysiology, and imaging approaches with genetics. New research in the laboratory has identified a novel mechanism by which synaptic connections communicate. Although communication from the presynaptic neuron via calcium-dependent synaptic vesicle fusion has been well characterized, the lab has recently discovered a novel retrograde signaling pathway that is required for synapse-specific potentiation and growth at *Drosophila* glutamatergic neuromuscular junctions.

Earl Miller's lab found that the striatum—the input structure of the basal ganglia—showed more rapid change in the learning process than the more highly evolved prefrontal cortex. Their results suggest that the basal ganglia first identify the rule and then "train" the prefrontal cortex, which absorbs the lesson more slowly. Thus, primitive brain structures might be the engine driving even our most advanced high-level, intelligent learning abilities.

Elly Nedivi's group found that a plasticity gene and its growth-promoting protein, CPG15, could potentially be used to develop therapies for renewing damaged or diseased tissue. They identified a form of CPG15 that protects cortical neurons from apoptosis, or programmed cell death. Apoptosis is a normal and essential part of early development, when brain cells proliferate rapidly and some are killed off, but little is known about how apoptosis of growing neurons is regulated. The molecule is key to the survival of neural stem cells in early development.

Researchers in Morgan Sheng's lab found that a glutamate receptor designated GluR2 is in charge of directing postsynaptic glutamate receptors (i.e., AMPA receptors) from the cell surface to the inside of the cell. AMPA receptors allow information to flow between neurons, and when they are moved from the cell surface into the cell depths, synapses weaken. They determined how this movement is governed and explained how GluR2 works to alter the recycling and breakdown of AMPA receptors after they move to the internal region of the cells. Being able to manipulate GluR2 may make it possible to get more receptors to the surface of the synapse and ultimately boost brainpower in the hippocampus, where long-term memories are stored.

### Language and Cognition

In Mary Potter's lab, researchers discovered that the so-called attentional blink is caused by having to select one of several stimuli, not by the demands of consolidating memory for the selected item (as had been generally assumed). They also found that people have good memory for the gist of a pictured scene but relatively poor memory for spatial and visual information about the scene and that unusual pictures that people tend to email to each other are slightly harder to encode initially but are remembered longer than comparable but more ordinary pictures.

### New Undertakings and Ongoing Events

The Brain Development and Disorders Project, a collaboration between the department and Children's Hospital that began in October 2003, has continued to develop and has sponsored lectures and discussion groups. The laboratories of Ken Wexler, Pawan Sinha, and Emilio Bizzi have been involved in studying children with autism spectrum disorders (ASD) in collaboration with Dr. Leonard Rappaport of the Developmental Medicine Center at Children's Hospital. Mriganka Sur's laboratory is using animal models to study the function of genes implicated in ASD.

The Friday Colloquium continues as a much-anticipated end to the week in BCS, providing a rich forum for scientific collaboration and social interaction within the department. The student-organized lunch series, Brain Lunch and Cog Lunch, as well as the Visual Perception Series and the Plastic Lunch series organized by PILM, have expanded as they attract larger audiences.

**Mriganka Sur**
**Department Head**
**Sherman Fairchild Professor of Neuroscience**

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