Department of Brain and Cognitive Sciences

The collective quest of the people 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. 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. In addition, we have established an ongoing collaborative project with Children's Hospital to study autism spectrum disorders. BCS today is a unique department with a unique vision, looking forward to continued scientific leadership and service to the Institute and to society.

Sixteen BCS faculty members (of 29 primary faculty) are also investigators in two neuroscience research centers: the McGovern Institute for Brain Research and the Picower Center for Learning and Memory (PCLM). The core strength of BCS is investigating fundamental problems of the brain at multiple levels of analysis, including brain 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 Center seek to understand mechanisms of learning, memory, and brain plasticity using molecular and systems approaches. The new building for neuroscience and cognitive science, the brain and cognitive sciences project, which is scheduled for completion in 2005, will bring together the department and centers in one place in an unprecedented research, teaching, and training enterprise.

Education

The department had a total of 123 undergraduates this year, with 33 graduating seniors, who were replaced by 41 freshmen joining the department as new majors at the end of the 2003 spring term. At the annual spring BCS Undergraduate Awards dinner, seven majors were honored for outstanding scholarship or research—including a UNCF Merck Science Undergraduate Science Research Scholarship Award and a Barry Goldwater Scholarship—while six majors were commended for outstanding academic records, leadership in the department, or outstanding work in a particular course.

The sixteen graduate students who enrolled in fall 2003 were supported by MIT Presidential Graduate Fellowships, Dean's Fellowships, an NSF Fellowship, a GSO Ida Green Fellowship, a Praecis Presidential Graduate Fellowship, and departmental NIH training grants. Of the eight students receiving a PhD, four assumed postdoctoral positions, one is a lecturer in the Linguistics Department of the University of Southern California, one a junior fellow in the Laboratory for Developmental Studies of the Psychology Department at Harvard University, one a research scientist at the Max Planck Institute for Biological Cybernetics, and one is at the Computer Science and Artificial Intelligence Lab at MIT. The department also inaugurated Outstanding Thesis

Awards, which went to four graduates who received their doctorates in the past two years.

Faculty Highlights

- Mark Bear was elected fellow, American Association for the Advancement of Science (fall 2003) and fellow, American Academy of Arts and Sciences (spring 2004).
- Emilio Bizzi received a doctoral degree "honoris causa" in biomedical engineering from the University of Genoa, Italy.
- Ann Graybiel was awarded an honorary doctor of science from New York's Mount Sinai School of Medicine and also received the Radcliffe Alumnae Achievement Award and the National Parkinson Foundation "Women Leaders" Award.
- Neville Hogan received a silver medal from the Royal Academy of Medicine in Ireland.
- Nancy Kanwisher was awarded the Ellen Swallows Richards professorship.
- Carlos Lois received the Ellison Foundation Young Investigator Award (2004–2008).
- Earl Miller was named Picower professor of neuroscience.
- Elly Nedivi received the Dean's Award for Education and Student Advising.
- Tomaso Poggio was presented the Gabor Award by the International Neural Network Society.
- Mary Potter was elected a member of the Society of Experimental Psychologists, the oldest honorary society in psychology.
- Pawan Sinha received the Global Indus Technovator Award in October 2003 for Project Prakash and its contribution to basic science and children's health. He was also promoted to associate professor.
- Mriganka Sur was appointed to the Advisory Council of the National Eye Institute/NIH.
- Joshua Tenenbaum was awarded the Newton career development professorship.
- Matthew Wilson and Sebastian Seung were promoted to full professor.

Research Advances

Brain Mechanisms of Vision, Touch, and Movement

Emilio Bizzi's lab, which focuses on the study of the physiological mechanisms underlying motor learning and motor control, tested the hypothesis that linear combinations of muscle synergies represent a general mechanism for the construction of motor behaviors. They were able to demonstrate that the electromyographic patterns observed during different motor behaviors in the intact frog could be described with few time-varying muscle synergies. They have also been investigating how motor cortical cells control the muscle synergies of the arm and the hand. They demonstrated the feasibility of a remotely supervised, computer-enabled physical therapy device administered over high-speed telecommunications for patients recovering from stroke.

Peter Schiller's lab seeks to characterize the roles that various primate cortical visual areas play in the processing of visual information and in the selection of visual targets with saccadic eye movements. They showed how monkeys select visual targets with saccadic eye movements and what the time course is for saccade execution, and they demonstrated how the probability of target choice is affected by specific variables. Work has also continued on a study of the effects of electrical stimulation in V1 on saccadic eye movements. This research should have significant bearing on microstimulation prosthetics for the visually disadvantaged.

Christopher Moore's lab is studying the neural correlates of rapid changes in perceptual context and how rapid changes in neural organization support rapid changes in perceptual ability. Their model system is the sense of touch, and they use fMRI, optical imaging, and electrophysiological techniques in rodents, monkeys, and humans. They recently discovered that rats' facial whiskers—one of the most important model systems of sensory function—amplify vibrations in a way that parallels mechanisms of hearing.

Pawan Sinha's laboratory studies the basic neural mechanisms and computational principles that allow humans to visually recognize objects in the environment. This has direct implications for developing therapies for recognition disorders associated with neurological conditions such as autism. They have provided the first direct neurophysiological evidence of the use of contextual cues for high-level vision tasks. The results also bear upon their efforts to characterize visual impairments in autism. As part of Project Prakash, they worked with congenitally blind children in India, finding that children can learn to perform complex face detection tasks in as little as six weeks after sight onset following surgery. This experimental work is providing a foundation for a computational framework Sinha's lab is formulating to model the development of visual recognition skills in the human brain.

Edward Adelson's lab continues to work on the perception of material properties such as lightness, texture, gloss, and transparency. They have shown that image statistics, such as those derived from multiscale filter analysis, are very useful in estimating surface qualities in a machine vision setting and are important for human vision as well.

James DiCarlo's group continues to focus efforts on trying to understand the neuronal mechanisms that enable visual object recognition to tolerate real-world changes in object position, size, and clutter. They recently uncovered evidence from neuronal recordings in primates that strongly supports the hypothesis that the position tolerance of object recognition depends on visual experience.

Learning and Memory

Ann Graybiel's lab conducts an integrated research program to study the physiology and cellular signaling of cortico-basal ganglia circuits during the learning and the performance of behavioral sequences and habits. They discovered that large-scale changes occur in the patterns of neuronal activity in the striatum as animals learn and consolidate their learning in such tasks. Many of these plastic changes are reversed by episodes of extinction in which rewards are not available, while at least some changes can be reversed by reinstating the reward in reacquisition training. A central question addressed in their experiments is how the activity of neurons in cortico-basal ganglia loops changes during learning and what activity characterizes these neurons when animals have been trained to the point at which they carry out tasks in a highly automatic fashion.

Suzanne Corkin's lab uses behavioral, structural brain imaging (MRI) and functional brain imaging (fMRI) paradigms to address questions concerning the cognitive and neural basis of learning and memory in humans. Research topics include the dissociation between autobiographical and semantic retrieval in remote memory (i.e., memory for specific events versus facts), comparison of emotional memory in young versus older individuals, episodic retrieval in aging, the effect of divided attention on episodic memory, and analysis of the cognitive and neural components of working memory.

Mathew Wilson's lab 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 lab, 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, which has implications for the formation of human memories. The lab has also demonstrated the replay of memories for sequences of events during slow-wave sleep.

Richard Wurtman's lab previously showed that giving older people or rats citicoline could partially restore age-related memory losses and that in people this effect is mediated principally by an elevation in blood uridine levels. They have now shown that a different treatment that raises blood uridine levels in gerbils also improves their memory function and probably does so by promoting the synthesis of brain membranes. (This compound is UMP—uridine monophosphate—which, in small doses, is a normal constituent of infant formulas and is also found in human breast milk.)

William Quinn's lab demonstrated that long-term memory in Drosophila is separable into two independent components: anesthesia-resistant memory, which requires a functional *radish* gene, and protein-synthesis-dependent memory, which requires the transcription factor. They found that transformation of mutant *radish* flies with a wild-type CG15720 transgene restores substantially normal anesthesia-resistant memory after heat shock. The *radish* gene encodes a novel protein with suggestive sequence motifs.

Brain Development and Plasticity

Morgan Sheng's lab is interested in the molecular mechanisms by which synapses in the brain change their strength and connectivity in response to experience. In both the developing and mature brain, there is a regulated balance between elimination of old (poorly used) synapses and the formation of new connections between neurons. The molecular mechanisms underlying these processes are poorly understood. During the past year, the Sheng lab has discovered a novel way to eliminate synapses.

Mark Bear's lab has made significant progress elucidating the synaptic and molecular bases of receptive field plasticity in the visual cortex. One example is the striking loss of visual cortical responsiveness to an eye temporarily deprived of normal vision during a critical period of postnatal life. Bear has shown that this deprivation-induced synaptic depression is a consequence of residual retinal afferent activity that fails to correlate with evoked postsynaptic responses in the visual cortex. Bear's ultimate aim is to generate conditional mouse mutants and determine the molecular basis of the critical period.

Michale Fee's lab studies how the brain learns and generates complex sequential behaviors, with a focus on the songbird as a model system. Young songbirds learn their vocalization, a complex sequence of vocal/motor gestures, by listening to a tutor and then practicing their song for several months. They recently found neurons in the premotor song control circuit that generate only a single brief burst in the sequence and may form an explicit representation of time in the brain.

Using genetic technologies that allow researchers to manipulate the birth, death, and formation of newly generated neurons, Carlos Lois's lab explores neurogenesis—the ability of certain species to grow new brain cells in adulthood and integrate them into existing brain circuits. A long-term goal is to harness this regenerative ability to correct neurological defects from injury or disease. They use retroviruses to perform these genetic manipulations because of their ability to integrate permanently into the genome of target cells. They will now focus efforts on generating transgenic songbirds in order to study the physiological role of adult-born neurons.

Using molecular biology techniques, Elly Nedivi's lab pinpoints which of the brain's genes are involved in making memories and details how they work. This fundamental understanding may eventually help scientists design highly targeted drugs for disorders such as Alzheimer's disease. They are working on characterizing CPG15, a gene that may play a role in synaptic plasticity. The lab has shown that the soluble, secreted form of CPG15 is expressed in regions that are undergoing rapid proliferation and apoptosis in the embryonic brain and is the first identified survival factor expressed by undifferentiated neurons.

Mriganka Sur's laboratory studies how genes and activity interact during brain development. Mechanisms of development lead naturally to the study of developmental disorders of the brain. The Sur laboratory has started to examine the causes of autism by focusing on the genes and molecules responsible for the regional parcellation of the cerebral cortex into discrete processing areas and for synaptic plasticity in these areas; both of these features are implicated in autism.

Language and Cognition

A new project in Edward Gibson's lab investigates the relationship between the working memory resources that are used in online language processing tasks and working memory resources that are used in other cognitive processing tasks, such as doing arithmetic or remembering phone numbers. Another project focuses on the development of reading and language understanding in children in grades 6–11, ages 11–17, that is being conducted with cooperation from the Bedford schools.

Joshua Tenenbaum's group has been developing a new theoretical framework for understanding the interaction between Bayesian statistical learning and structured representations in the development of human knowledge. They have applied this framework to understanding how people learn and reason about biological, physical, and social systems, infer cause-effect relations, predict the future of uncertain events, and learn the meanings of words.

In Mary C. Potter's lab, researchers studied the perception of photographs presented for a 12th of a second and found that foreground objects interact with each other and with perception of the background setting. They also found that multiple pictures can be processed in parallel in a target search task, but memory for multiple pictures cannot be consolidated in parallel.

New Undertakings and Ongoing Events

The Brain Development and Disorders Project, a collaboration between the department and Children's Hospital, began in October 2003. The laboratories of Ken Wexler, Pawan Sinha, and Emilio Bizzi are 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 PCLM, 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 on the web at http://web.mit.edu/bcs/.