Department of Brain and Cognitive Sciences

The past year, 2005–2006, will undoubtedly be recorded as one of the most important in the Department's history. In December 2005, MIT opened the largest facility in the world dedicated to neuroscience and cognitive science, housing the Department of Brain and Cognitive Sciences (BCS), the McGovern Institute for Brain Research, and the Picower Institute for Learning and Memory (PILM). During this same period, BCS celebrated the 40th anniversary of the Department's graduate program. BCS also granted 36 BS degrees and 11 PhDs, welcomed three new faculty colleagues, and initiated a significant program in autism research.

Mission

The mission of the people of BCS continues to be what it was 40 years ago: to understand 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, which provide the greatest opportunities for significant insight into key questions. BCS remains a unique department with a unique vision.

The Department is complemented and strengthened by its association with PILM and the McGovern Institute for Brain Research; 18 of 36 BCS primary faculty are also investigators in those centers. With the new brain and cognitive sciences complex bringing researchers from all three entities together in the same building, BCS will play a special role, acting as an umbrella and providing the academic home for all teaching and research into the brain and mind at MIT.

Highlights and Ongoing Activities

Opening of Building 46

On December 2, 2005, Dana Mead, chair of the MIT Corporation, formally dedicated the new brain and cognitive sciences complex. Leaders and representatives from all of MIT and the surrounding community attended. The dedication ceremony accented a day of celebration of all BCS has accomplished and of what lies ahead. The morning's activities included a symposium featuring distinguished speakers spanning the breadth of the Department's history and intellectual endeavors. The first doctoral BCS graduates were recognized at the closing dinner, with two of the four pioneers in attendance to share memories from 40 years ago when they received their degrees.

Initiatives in Autism Research

With support from a $7.5 million grant from the New York-based Simons Foundation founded by James and Marilyn Simons, BCS researchers are undertaking an ambitious multifaceted approach to understanding the genetic, molecular, and behavioral aspects of autism. A number of unique projects by investigators Mriganka Sur, Mark Bear, John Gabrieli, Ann Graybiel, Pawan Sinha, and Susumu Tonegawa were begun, featuring collaborations between these research groups as well as with researchers at the Yale Child Study Center, the University of Sydney, Boston University, and Massachusetts

General Hospital. The grant also funds a new Boston-area seminar series on autism and developmental disorders hosted at MIT.

The Brain Development and Disorders Project, a collaboration between the Department and Children's Hospital begun in October 2003, continues to develop. The laboratories of Kenneth Wexler, Pawan Sinha, and Emilio Bizzi have been involved in studying children with autism spectrum disorders. The clinical research is conducted in collaboration with the Developmental Medicine Center at Children's Hospital. Continuing funding from the Anne and Paul Marcus Family Foundation has allowed this project to focus on understanding the neural and cognitive bases of these disorders.

Faculty Growth

The BCS faculty welcomed three new colleagues—all senior appointments whose contributions are both celebrated and anticipated. Li-Huei Tsai was appointed Picower professor of neuroscience in BCS and PILM. Emery Brown joined the faculty as professor of computational neuroscience with dual appointments in BCS and Health Sciences and Technology (HST). John Gabrieli was appointed professor of cognitive neuroscience with a dual BCS and HST appointment; in addition, Professor Gabrieli has been named an associate of the McGovern Institute, co-director of the Clinical Research Center, and director of the Martinos Imaging Center at MIT.

Pawan Sinha and Elly Nedivi were promoted to associate professor with tenure.

Other Events

Professor Mary Potter's nearly 40 years with BCS were celebrated at "Mollyfest," a symposium
hosted by former student and current faculty member Nancy Kanwisher. Many of Professor Potter's former BCS (or Department of Psychology) students and colleagues joined in acknowledging her many contributions as a researcher, a teacher, and a mentor.

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 Vision Seminar and the PILM-sponsored Plastic Lunch, have expanded as they have attracted larger audiences.

Education Highlights

During the past year, 11 students graduated with a doctorate, and eight of them assumed postdoctoral positions in universities or research institutions. Ten students were honored for excellence in undergraduate teaching and five students were commended for continuing dedication to teaching. The incoming graduate class numbered 12, a group notable for its strength in a year when the number of applications, while still high, retreated somewhat from recent record levels.

The department had 133 undergraduates this year, with 36 graduating seniors. Forty-nine freshmen joined the department as new majors at the end of the 2006 spring term, so the undergraduate program is entering the 2006–2007 academic year with 136 majors.

At the annual spring BCS Undergraduate Awards dinner, seven majors were honored for outstanding scholarship or research, and four majors were commended for outstanding academic records, leadership in the department, or outstanding work in a particular course; an additional six students received the Walle J.H. Nauta Award for Outstanding Research in Brain and Cognitive Sciences. In addition, the Department acknowledged 22 undergraduates who had perfect GPAs this past semester.

Faculty Awards and Honors

Edward Adelson was elected to the National Academy of Sciences. He also received the Longuet-Higgins Award for "outstanding contributions to computer vision that have withstood the test of time."

Emilio Bizzi was elected to the Institute of Medicine of the National Academies. He was also awarded the President of Italy's Gold Medal for achievements in science.

Emery Brown was elected fellow of the American Institute of Medical and Biological Engineering and fellow of the American Statistical Association.

James DiCarlo received the McKnight Scholar Award in Neuroscience and the Surdna Research Foundation Award.

Ann Graybiel received the IPSEN Neuronal Plasticity Prize "for outstanding work…in the domain of Motivation and Associative Learning." She also was awarded an honorary DSc from Tufts University and was presented with the first Harold S. Diamond Professorship by the National Parkinson Foundation.

Earl Miller was elected fellow of the American Association for the Advancement of Science.

Christopher Moore was awarded the Mitsui Career Development Chair.

Aude Oliva received a National Science Foundation CAREER Award.

Tomaso Poggio was named to the Scientific Advisory Board of the ISI Foundation (Turin, Italy) and of the Comitato di Esperti dell'ISICT (Genoa, Italy).

Morgan Sheng received the IPSEN Neuronal Plasticity Prize.

Mriganka Sur was elected fellow of the Royal Society.

Joshua Tenenbaum received the 2005 New Investigator Award from the Society for Mathematical Psychology.

The team of James DiCarlo, Christopher Moore, and senior research scientist Sonal Jhaveri received the School of Science Prize for Excellence in Undergraduate Teaching.

Research Advances

Brain Mechanism of Vision, Touch, and Movement

Edward Adelson's lab is looking at the gain control mechanisms that biological and machine vision systems can use to deal with high dynamic range in images, such as when there is 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, which allows them to build a computational system that can estimate the surface properties and which gives estimates similar to those given by human observers.

Emilio Bizzi has proposed that the central nervous system handles the daunting number of variables involved in a single movement by grouping sets of muscles and their innervating neurons into an integrated unit called a muscle synergy. In recent studies in frogs, Bizzi, Vincent Chi Kwan Cheung, a graduate student in the Harvard-MIT Division of Health Sciences and Technology, and collaborators found solid evidence for muscle synergies. They showed that grouping muscles in a small set of muscle synergies simplifies the central nervous system's control issues. The near autonomy of the muscle synergies makes it possible to control a large number of muscles with just a few signals generated in the areas of the central nervous system involved in programming voluntary movements. This simplifies the future design of neuroprosthetics.

Robert Desimone's lab has been working on defining how the brain focuses on a specific target when the object is in a chaotic or complicated scene. It appears that select brain cells may unite to accomplish this task. Brain cells specialized for a specific type of sensory signal—such as color—may be primed by a feature of the object and become more active than usual, and other cells, activated by other aspects of the object, such as shape, may join them. Lab members are trying to determine what mechanism is involved in making these activated cells act in concert to ensure that the brain avoids focusing on anything else in order to target the specific object. The synchronization of the individual neurons is of special interest to the group.

James DiCarlo's lab continues to focus on understanding the 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 are examining the role of visual experience in the real world in supporting this ability. Last year, they discovered that specific, subtle alterations in the visual world that are invisible to human subjects can alter a property of their visual recognition previously assumed to be rock solid—the ability to recognize objects in different positions. This year they completed a neurophysiology study, which revealed that related effects of visual experience are found in high-level neuronal patterns of activity in nonhuman primates. They are using neurophysiology and computational modeling for their research.

Nancy Kanwisher and her lab members Rebecca Frye Schwarzlose and Christopher Baker are using high-resolution functional magnetic resonance imaging (fMRI) scans to produce much more detailed images of the brain than were possible just a couple of years ago. The results provide some of the strongest evidence ever reported for extreme specialization within the brain. The study focuses on face recognition, long considered an example of brain specialization. At this higher resolution, they could clearly distinguish two neighboring regions. One was active primarily when people saw faces (not bodies), and the other was active when people saw bodies (not faces). This finding supports the original claim that the face area is in fact dedicated exclusively to face processing. The results further demonstrate a similar degree of specialization for the new "body region" next door.

Christopher Moore's lab has discovered an exquisite micromap in the brain. It is the size of the period at the end of this sentence, and it is in a most unexpected place—connected to the whiskers on a rat's face. On the basis of discoveries in primates and cats, scientists previously thought that highly refined maps representing the complexities of the external world were the exclusive domain of the visual cortex in mammals. This new map is a miniature schematic, representing the direction a whisker is moved when it brushes against an object. "This study is a great counterexample to the prevailing view that only the visual cortex has beautiful, overlapping, multiplexed maps," said Moore.

Mark Bear's group has found that neural activity in the brain's visual cortex—which for years was thought to have only one job, creating visual perceptions—can serve another purpose, that of connecting visual experience with nonvisual events. The study implies that sensory parts of the brain may be able to accomplish more complex tasks than was previously imagined. The findings have implications for understanding how our brains imbue sensory experience with behavioral meaning.

Learning and Memory

The 25 researchers in the Center for Biological and Computational Learning, under the leadership of Tomaso Poggio, examine the problem of learning, which they believe is at the core of the problem of understanding how the brain works and of synthesizing intelligence in machines. Their research effort is at three levels: theory (foundations of learning theory and development of learning algorithms), engineering applications (bioinformatics, with the Department of Biology; computer vision; trainable human–machine interfaces), and computational neuroscience (models of visual cortex underlying object recognition). In the past year, however, a surprising synergy between these different directions of research has emerged. A theory of the feed-forward path in the ventral stream of visual cortex turned out to perform as well as 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 to 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 (Desimone, DiCarlo, Oliva, Miller) and at Harvard, Georgetown, CalTech, and Northwestern universities.

After running a maze, rats mentally replay their actions, but they do it backward, like a film played in reverse. Matthew Wilson's lab reported that animals have complex dreams and are able to retain and recall long sequences of events while asleep. Like people, rats go through multiple stages of sleep, from slow-wave sleep to REM (rapid eye movement) sleep. They found that, during slow-wave sleep, animals replayed spatial experiences in the same order they were experienced. The latest results of experiments show that, after a spatial experience such as running laps on a track, the awake animal replays the memory so precisely that its recorded brain activity corresponds exactly to the places it has just been. However, to the researchers' surprise, the episode is replayed in time-reverse order, with the most recent locations first, proceeding sequentially back to the beginning of the task. Their work may lead to information useful for treating amnesia or Alzheimer's disease or for helping people to memorize more effectively.

Researchers in Richard Wurtman's lab will be involved in a large-scale, double-blind, placebo-controlled clinical trial, based on applying their findings on a possible treatment for early Alzheimer's disease. The study will involve perhaps 40 centers in five European countries. The basic findings underliying this test relate to a method for increasing the quantities of synaptic membranes in the brain by giving subjects several circulating compounds that the brain is unable to synthesize but that it requires for optimal membrane synthesis. (One of these compounds, uridine, is present in mother's milk but normally is not consumed beyond infancy in a manner that makes it available to the brain.) Their application to treating Alzheimer's disease is suggested by the decrease in the number of synapses—especially in the hippocampus and cortex—that is universally acknowledged as characterizing this disease. Animals that received the therapeutic mixture exhibited not only increases in the brain proteins and lipids that characterize synaptic membranes, but also, in an anatomic finding, dendritic spines, which are a progenitor of synapses.

Brain Development and Plasticity

Mriganka Sur's laboratory studies mechanisms of development and plasticity in the cerebral cortex. In the past year, the laboratory used gene discovery methods and genomics analyses to discover the role of a novel molecular pathway in activity-dependent plasticity in visual cortex. The laboratory used high-resolution imaging methods in vivo to discover subtle structural changes in synapses alongside functional rewiring of connections that accompany manipulations of activity. The group described novel dynamic changes in neuronal responses in early visual cortex influenced by the internal state in alert behaving animals. In a new set of studies that has tremendous potential for understanding and treating developmental disorders such as autism, the laboratory discovered the function of specific genes that have been linked to autism and mental retardation.

Carlos Lois's laboratory is interested in the assembly of neuronal circuits and the genetic control of brain development and function. They focus on the process of neuron replacement in the brains of adult vertebrates and seek to understand how new neurons incorporate into the circuits of the adult brain and their possible role in memory storage. The laboratory recently discovered that the time of birth of a class of neurons determines the types of contacts they establish in the brain, and they now plan to focus efforts on studying the mechanisms by which these neurons connect with each other in the brain. In addition, the laboratory is actively involved in creating technologies to genetically manipulate the development and function of neurons. Recently, they developed a transgenic technology based on enhancer trapping, in which a viral vector integrates into the cell's genome and recapitulates the expression pattern of the endogenous gene that is near its integration site. Using this method, they have generated transgenic lines of mice that display gene expression in selective cell types in the brain. This method provides an immediate readout of the spatial pattern of gene expression with single-cell resolution, and the transgenic mice carrying a particular enhancer probe can be used to regulate the expression of other genes of choice in a highly specific manner.

Elly Nedivi's lab has shown that structural remodeling of neurons does occur in mature brains. This finding means that one day it may be possible to grow new cells to replace those damaged by disease or spinal cord injury, such as the one that paralyzed the late actor Christopher Reeve. The study's coauthors (Nedivi; Peter T. So, an MIT professor of mechanical and biological engineering; BCS graduate student Wei-Chung Allen Lee; and Hayden Huang, a mechanical engineering research affiliate) used a method called two-photon imaging to track specific neurons over several weeks in the surface layers of the visual cortex in living mice. With the help of technology similar to magnetic resonance imaging (MRI), but at a much finer cellular resolution, the researchers were able to stitch together two-dimensional slices to create the first three-dimensional reconstruction of entire neurons in the adult cortex. Dendritic branch tips were measured over weeks to evaluate physical changes. "The scale of change is much smaller than what goes on during the critical period of development, but the fact that it goes on at all is earth-shattering," Nedivi said. She believes the results will force a change in the way researchers think about how the adult brain is hard-wired.

Experiments by Gerald Schneider and Rutledge Ellis-Behnke together with their collaborators at Hong Kong University have been very successful in a process they call nanoknitting, which used biodegradable nanofibers to reconnect a hamster's optic nerve that had been cut. The fibers seemed to create a scaffold that helped heal the brain tissue and let axons regrow. This technique could be useful in repairing damage that may occur during brain surgery or after trauma or stroke, though a cure would probably involve other factors as well.

Language and Cognition

Research in Aude Oliva's lab is concerned with computational visual cognition, which includes investigating visual cognition through its formal modeling. Their research encompasses empirical studies of human visual cognition with image processing methods and computational vision, with the aim of proposing artificial systems that encode and represent visual scenes and places as humans might do. A model is successful when, faced with the same task and the same visual input as a human, its behavior is indistinguishable from that of a human being (for example, it makes the same errors). In the lab, they first investigate the principles that build human scene understanding (using behavioral, eye tracking, cognitive neuroscience methods) and then they implement the human-like principles they found in computational models to evaluate their robustness.

Mary Potter's lab has continued making progress on studies of attentional fluctuation in target search versus whole report (the attentional blink and related effects) in collaboration with postdoc Mark Nieuwenstein, studies of picture perception under occlusion with postdoc Ming Meng, and studies of perception and memory for multiple pictures presented simultaneously

Even preschoolers approach the world much like scientists: they are convinced that perplexing and unpredictable events can be explained, according to a study by Laura Schulz. The way kids play and explore suggests that children believe cause-and-effect relationships in the world are governed by fundamental laws rather than by mysterious forces. "It's important to understand that kids are approaching the world with deep assumptions that affect their actions and their explanations and shape what they're able to learn next," Schulz said. "Kids' fundamental beliefs affect their learning. Their theoretical framework affects their understanding of evidence, just as it does for scientists."

Joshua Tenenbaum and former student Tom Griffiths have found evidence that people's intuitive predictions about the durations and magnitudes of everyday events can be explained as approximations to optimal Bayesian inferences. Most strikingly, people appear able to make Bayesian predictions under several very different kinds of prior distributions, and they implicitly estimate the form and shape of the distribution appropriate for a wide range of everyday events.

Mriganka Sur
Department Head
Sherman Fairchild Professor of Neuroscience

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