

Department of Brain and Cognitive Sciences

Mission

The Department of Brain and Cognitive Sciences (BCS) continues in its long-standing mission to understand the brain and, in doing so, to learn how it gives rise to the mind. Believing that such an understanding requires an approach that is simultaneously broad and deep, BCS seeks to create a diverse, multidisciplinary environment of interrelated areas and levels of investigation. BCS is a unique department—one of a very few that successfully balance the tension between the breadth needed to understand the brain in its totality and the focus required for field-leading research.

The department is complemented and strengthened by its association with the Picower Institute for Learning and Memory (PILM) and the McGovern Institute for Brain Research (MIBR); 21 of 39 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

BCS faculty are widely recognized as being among the leaders in their respective fields. Of 48 total faculty, 39 hold primary appointments in BCS, 9 of whom also hold appointments in PILM and 12 in MIBR. Two faculty have dual appointments in the Harvard-MIT Division of Health Sciences and Technology, 4 are Howard Hughes Medical Institute (HHMI) investigators, and 2 hold the special title of Institute Professor. 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 11 of the American Academy of Arts and Sciences.

Effective July 1, 2010, assistant professor Laura Schulz will be promoted to associate professor and awarded the Class of '43 career development chair. In June 2010, Guoping Feng joined the department as Poitras professor of neuroscience. He also holds an additional appointment in MIBR.

The interdisciplinary nature of neuroscience and cognitive science is highlighted by the number of the joint appointments held by BCS faculty as well as those granted to faculty of other departments. Joint appointments in BCS currently number nine with representation from Linguistics, Mechanical Engineering, the Media Lab, Nuclear Science and Engineering, Biology, Biological Engineering, Electrical Engineering and Computer Science, and the Sloan School of Management. BCS faculty in turn hold joint appointments in many of these units as well as in Physics, and the Computer Science and Artificial Intelligence Laboratory. In February 2010, the Clinical Research Center was incorporated into the department.

Graduate Program

Eleven students entered the BCS graduate program in fall 2009. Two of the incoming students were funded by Singleton Presidential Graduate Fellowships, three by Singleton Fellowships. Five were supported by departmental National Institutes of Health training grants, and one was funded by the Lord Foundation fellowship associated with the new molecular and cellular neuroscience interdepartmental graduate program.

In AY2010, 13 students graduated with the doctorate. Nine took postdoctoral positions in universities or research institutions (six in Brain and Cognitive Sciences at MIT, one at Stanford University, one at Novartis, one at Brigham and Women's Hospital/Harvard Medical School). The remaining five include the chief executive officer and cofounder of HeadLamp Research, and a visiting assistant professor at Duke University.

Eight students were honored for excellence in undergraduate teaching and one for excellence in graduate teaching; seven were commended for continued dedication to teaching.

The Course 9 Major

BCS currently has 156 undergraduates, with 38 graduating seniors. Fifty freshmen joined the department as new majors at the end of the spring 2010 term.

Nineteen students received outstanding research awards, and 27 students were recognized for outstanding academic work in the department. In addition, five BCS majors received Institute awards at this year's convocation: Albert G. Hill Prize to Asha Martin, Priscilla King Gray Award to Caroline Huang, Malcolm G. Kispert Award to Alexandra May, Frederick Gardiner Fassett, Jr. Award to Ryan Andrews, and the William L. Stewart, Jr. Award to Keri-Lee Garel.

Two of the three MIT Rhodes Scholars this year are BCS majors, and one student who minored in BCS received a Marshall Scholarship. Five majors were Burchard Scholars and three were inducted into Phi Beta Kappa.

Development Activities

BCS continues to build momentum in its development activities. In June 2010, Barbara Vejvoda joined the department as senior development officer—a new position for BCS. Barbara came to MIT with over 20 years of fundraising and marketing communications experience in higher education, healthcare, and nonprofit organizations. Barbara will be working closely with all BCS faculty and will also support PILM in its development efforts. Among the top development priorities going forward are fundraising for the department's disease-based initiatives as well as the cross-disciplinary MIT Intelligence Initiative.

Some Research Highlights

In AY2010, Edward Boyden's laboratory developed a new tool for the safe, effective, and powerful shutdown of neurons in the brain. Published in the January 7, 2010, issue of *Nature*, the Boyden lab performed a genomic screen of natural molecules from around the world, to find molecules that can convert light into electrical energy. Since the brain is an electrical device, such molecules allow us to shut down neurons in the brain for temporally precise periods of time. This reagent is already in widespread use in neuroscience, and may enable new kinds of therapy for epilepsy and other disorders where neurons are overactive. Preclinical safety and efficacy testing is ongoing at multiple BCS labs. The Boyden lab has since received funding from the government to pursue the use of these neural-silencing technologies to study—and perhaps treat—chronic pain, epilepsy, posttraumatic stress disorder, and other neurological and psychiatric disorders. The lab continues to explore genomic resources for finding new tools for science as well as discovering new principles for treating brain disorders.

Area schoolchildren recently got a whirlwind introduction to brain and cognitive science, thanks to the initiative of Ki Goosens, Museum of Science administrators, and a handful of BCS graduate students. In December, the museum participated in the HHMI lecture series, "Making Your Mind: Molecules, Motion, and Memory," by hosting a live webcast of talks from Columbia University professors Eric Kandel and Thomas Jessell. After each of the two lectures, Goosens followed up with live question and answer sessions, fielding questions from high school students, teachers, and general museum visitors about plasticity and learning. Her interaction with the Museum of Science is part of a broader movement in the department to engage with the Cambridge and Boston communities. Similar outreach efforts have been made by BCS students who are teaching short, free, high school-level courses through two MIT educational studies programs: the High School Studies Program and Splash.

Keeping track of time is essential to the formation of memories—as the brain processes inputs from visual, aural, and somatosensory systems, it must also record when each event occurred. But until recently, the hypothesis that the brain "time-stamps" events as they happen has remained unproven. A team led by BCS faculty member and Institute Professor Ann Graybiel reports in the November 10, 2009, issue of *Proceedings of the National Academy of Sciences (PNAS)* that it has found groups of neurons in the primate brain that code time with extreme precision. This kind of precise timing control is critical for everyday tasks such as driving a car or playing the piano, as well as keeping track of past events. Graybiel suggests that the new research could help patients with Parkinson's disease, who often behave as if the brain's timekeeping functions were impaired: they have trouble performing tasks that require accurate rhythm, such as dancing, and time appears to pass more slowly for them. Rhythmic stimuli, such as tapping, can help them to speak more clearly. Targeting the timekeeping neurons with neural prosthetic devices or drugs—possibly including the natural brain chemicals dopamine and serotonin—may help treat those Parkinson's symptoms.

In the past year, researchers in Earl Miller's laboratory discovered that individual neurons in the monkey prefrontal cortex can "multitask" and play a role in representing very different categories, e.g., cat v dog, sedan v sports car. At the same time, the

degree of multitasking depends on cognitive demands, namely the degree to which the different categories can be confused. This may explain why normal human cognition is so flexible, and so inflexible in diseases like autism. They also discovered that when monkeys hold two pictures “in mind” (i.e., in working memory) simultaneously, neural activity for the two pictures line up on different places of 32 Hz “brain waves” across the neuron population. This may explain our severe limitation in thinking multiple thoughts at the same time, and suggests that dysfunction of these mechanisms may contribute to the disordered thought seen in schizophrenia.

Tomaso Poggio’s laboratory has developed a new mathematical model to describe how the human brain visually identifies objects. The model accurately predicts human performance on certain visual perception tasks, which suggests that it is a good indication of what actually happens in the brain and that it could also help advance artificial intelligence research. In the future, the model could possibly be expanded so that, in the same way that it makes predictions about human eye movement, it could predict the cognitive deficits associated with disease.

Ruth Rosenholtz and her colleagues have developed a new model of peripheral vision, and have tested it on crowded letter recognition in the periphery. In addition to expanding our understanding of peripheral vision and mechanisms of vision more generally, these results bear directly on certain diseases of the visual system (e.g., age-related macular degeneration) in which patients are forced to use their peripheral vision. This work has been published in the *Journal of Vision*.

In AY2010, Sebastian Seung’s laboratory published and patented two new methods by which machines can learn to segment images: maximum affinity learning of image segmentation, and boundary learning by optimization of topological constraints. These are the first methods based on metrics of segmentation performance that strongly penalize topological errors and are insensitive to small differences in boundary locations. These methods produce segmentation algorithms that are significantly more accurate. They are being applied to find the shapes of neurons in electron microscopic images, a crucial task in the new field of connectomics.

In a paper published in the April 13, 2010, issue of *PNAS*, postdoctoral associate Liane Young and BCS professor Rebecca Saxe report that it is possible to affect a person’s ability to make moral judgments by interfering with activity in a specific region of the brain. Saxe has focused much of her research on the right temporo-parietal junction (RTPJ), which she has shown to be highly active when we think about other people’s intentions, thoughts, and beliefs. The ability to infer the intentions of others—frequently referred to as “theory of mind”—is necessary to constructing moral judgments, and Saxe and Young wanted to see what would happen were the RTPJ not functioning correctly. After reviewing the results of experiments, the researchers found that when the RTPJ was disrupted, subjects were more likely to judge failed attempts to harm as morally permissible. The conclusion was that transcranial magnetic stimulation interfered with subjects’ ability to interpret others’ intentions, forcing them to rely more on outcome information to make their judgments. Saxe believes that while understanding others’ intentions is critical to judging them, it is just one piece of the puzzle and her laboratory

is continuing its work to understand the processes and structures of the brain that are involved in moral judgment.

Mriganka Sur's laboratory uses cutting-edge technologies for imaging cells and molecules in the intact brain in order to reveal their roles in synaptic plasticity and cortical function. Combined with novel probes, these methods have revealed unexpected mechanisms of cortical plasticity, the role of specific cell classes in cortical circuits, and mechanisms of brain disorders. In the past year, his lab discovered the function of a key molecule, Arc, in regulating synaptic plasticity in visual cortex. Removing Arc renders the visual cortex impervious to the effects of visual experience or deprivation. Using specific transgenic mice, Sur's lab discovered that a crucial class of inhibitory neuron in visual cortex, which expresses parvalbumin and targets the soma of other neurons, has precise responses that help shape responses of their targets. By analyzing mice that are deficient in specific genes of autism and examining the effects on signaling molecules at synapses, his lab has proposed a therapeutic for Rett Syndrome that has entered clinical trials. This discovery points to an exciting breakthrough in autism research.

Li-Huei Tsai and Christopher Moore collaborated recently on a project that demonstrated the feasibility of inducing gamma oscillations by stimulating the brains of specially prepared mice with lasers. The results, which were published in *Nature*, have wide-ranging implications in terms of understanding brain function in both normal and disordered states. "We know that gamma oscillations are highly correlated with a number of processes that are needed to function normally in the world— perception, motor control, memory, attention," says Moore. "And we also know that certain disorders, such as schizophrenia, are highly correlated with abnormal gamma oscillations. We now have a way to look deeper into the circuits that produce these oscillations." Exercising control over the neurons that create the gamma oscillation was made possible by newly developed optogenetic techniques that allow for the selective expression of light-activated ion channels in specific classes of neurons.

A team led by Li-Huei Tsai has revealed that sirtuins can also boost memory and brainpower—a finding that could lead to new drugs for Alzheimer's disease and other neurological disorders. Sirtuins (the proteins produced by SIR or SIRT genes) have received much attention in recent years for their potential to boost life span, and for their link to resveratrol, a compound found in red wine that in animal studies has shown beneficial effects against cancer, heart disease, and inflammation. In 2007, Tsai and her colleagues showed that sirtuins protect neurons against neurodegeneration caused by disorders such as Alzheimer's. They also found that sirtuins improved learning and memory, but believed that might be simply a by-product of the neuronal protection. However, the results of Tsai's new study show that sirtuins promote learning and memory through a novel pathway, unrelated to their ability to shield neurons from damage. The team demonstrated that sirtuins enhance synaptic plasticity by manipulating tiny snippets of genetic material known as microRNA, which have recently been discovered to play an important role in regulating gene expression. Tsai and her colleagues are now studying the mechanism of SIRT1's actions in more detail, and are also investigating whether sirtuin genes other than SIRT1 influence memory and learning.

Selected Faculty Awards and Honors

Edward Adelson was elected to the American Academy of Arts and Sciences.

Suzanne Corkin discussed her decades-long work with the “pure amnesic” Henry Gustav Molaison on the *NOVA scienceNOW* program *How Memory Works*, which aired in August 2009.

Neville Hogan was the recipient of the 2009 Rufus T. Oldenburger Medal, from the American Society of Mechanical Engineers Dynamic Systems and Control Division. In addition, he was named the Sun Jae professor in the Department of Mechanical Engineering, 2009–2014.

Robert Desimone won the Helmholtz Award of the International Neural Network Society.

Yingxi Lin was named a John Merck Scholar. The award will support her research on activity-dependent regulation of inhibitory synapses and neural circuit plasticity, processes that are thought to be disrupted in a wide range of brain disorders.

Earl Miller received the MERIT Award from the National Institute of Mental Health.

Aude Oliva was elected a fellow of the Association for Psychological Science.

Tomaso Poggio was awarded the 2009 Okawa Prize, named an American Association for the Advancement of Science Fellow, and was the 2010 distinguished speaker for the Heller Lecture Series in Computational Neuroscience at the Hebrew University of Jerusalem, Israel.

To honor the contributions of Mary Potter to cognitive psychology and in anticipation of the celebration of the 50th anniversary of the Psychonomic Society, Women in Cognitive Science announced the Mary C. Potter Award to recognize an outstanding junior scientist.

Gerald Schneider received the BCS Award for Excellence in Undergraduate Teaching for 9.20 Animal Behavior and 9.14 Brain Structure and Its Origins.

Mriganka Sur was recognized as one of the 50 most notable alumni of the Indian Institute of Technology. During the year, he presented several keynote lectures worldwide, including the Nobel Conclave and Symposium hosted by the Indian Institute of Information Technology–Allahabad.

Li-Huei Tsai was awarded the 2010 Glenn Award for Research in Biological Mechanisms of Aging.

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://bcs.mit.edu/>.