Department of Brain and Cognitive Sciences

The Department of Brain and Cognitive Sciences (BCS) continues in its long-standing mission to understand how the brain gives rise to the mind. Because that 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 balances 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 and the McGovern Institute for Brain Research; 26 of 38 BCS primary faculty members 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.

Administration

After serving as department head for many years, Mriganka Sur stepped down from this post in February in order to assume the directorship of MIT's new Simons Center for the Social Brain.

James DiCarlo is now heading the department; he commenced his five-year term on March 1, 2012.

Matthew Wilson continued as the associate department head through June 30, 2012.

Pia Handsom became administrative officer on May 28, 2012.

Faculty

BCS faculty members are widely recognized as being among the leaders in their respective fields. Of 47 total faculty, 38 hold primary appointments in BCS and nine have primary appointments elsewhere. Of the 38 primary appointments, nine hold appointments in the Picower Institute for Learning and Memory and 13 hold appointments in the McGovern Institute for Brain Research. Two faculty members have joint appointments at the Broad Institute, two have a dual appointment in the Harvard-MIT Division of Health Sciences and Technology, three are Howard Hughes Medical Institute investigators, and two hold the special title of Institute Professor.

The interdisciplinary nature of neuroscience and cognitive science is highlighted by the number of BCS faculty with joint appointments, as well as the number of MIT faculty holding secondary appointments in BCS. The nine faculty members currently holding secondary appointments in BCS represent the following departments: Mechanical Engineering, Media Arts and Sciences (the Media Lab), Biology, Biological Engineering, Electrical Engineering and Computer Science, and the Sloan School of Management. BCS faculty members, in turn, hold secondary appointments in many of those departments as well as in Physics and in Linguistics and Philosophy (Linguistics section).

In January 2012, Kay Tye joined the department as an assistant professor based at the Picower Institute for Learning and Memory. In spring 2012, both Jim DiCarlo and Elly Nedivi were approved for promotion to professor, and Laura Schulz was approved for promotion to associate professor with tenure.

Professor Suzanne Corkin retired in June. Professor Corkin began her service to the department as a research associate in 1964 when BCS was the Department of Psychology. She was tenured in 1984 and promoted to professor in 1987.

Graduate Program

Eighteen graduate students entered in fall 2011. Incoming students were supported as follows:

- Fulbright Scholar award (one student)
- National Institutes of Health training grant (departmental) (five students)
- National Science Foundation Fellowship (one student)
- Norman B. Leventhal Fellowship (one student)
- Singleton Fellowship (eight students)
- Singleton Presidential Graduate Fellowship (one student)
- Ida M. Green Fellowship (through the Office of the Dean for Graduate Education) (one student)

This year, 13 students graduated with doctorates. Of those, nine accepted postdoctoral positions in universities or research institutions (at MIT; Harvard University; Brown University; University of Rochester; Harvard Medical School; University of Trento; and University of California, San Francisco School of Medicine), three accepted positions at organizations (as an analyst at QRM; a research scientist for the Agency for Science, Technology and Research; and a senior technical analyst at ChoiceStream), and one is a continuing medical student at Harvard.

Two students received their master's degree: one is an annotation contractor at Raytheon BBN Technologies and the other is a freelance content editor at Boundless Learning and a lab technician at MIT.

Three current students were honored for excellence in undergraduate teaching, one student was honored for excellence in graduate teaching, and one for continued dedication to teaching. Ten current students received team teaching awards for one of three classes: two neuroscience "wet" labs classes and Introduction to Neuroscience.

Undergraduate Program

BCS currently has 131 undergraduate students with 34 graduating seniors. Twenty-five freshmen joined the department as new majors at the end of the spring term.

Nine seniors and 21 underclassmen received outstanding research awards, and eight seniors and 19 underclassmen were recognized for outstanding academic work in the department. Two students were part of a team that received a teaching award for 9.01 Introduction to Neuroscience.

Four majors were Burchard Scholars, one student received a 2012–2013 Merck Engineering & Technology Fellowship Program Award, and one student received the 2012–2013 UNCF Merck Fellowship Award. One of our students has been selected as a Truman Scholar. Five of our seniors were selected to join Phi Beta Kappa.

Development Activities

The Department of Brain and Cognitive Sciences continues to enjoy the support of many friends and alumni, including some of the Institute's most generous and loyal donors. Our primary objective is to steward our current donors, making sure they are well informed and feel connected to the faculty, graduate students, and new department head, Jim DiCarlo. Professor DiCarlo has met individually with a number of donors, including Barrie Zesiger and Bill McClelland who have generously supported the department with $1 million and $500,000 dollar gifts. Professor DiCarlo acknowledged the passing of Angus MacDonald, one of the department's most vocal supporters. He has also reached out to a number of lower level donors to thank them for their support and to encourage continued engagement.

In learning how the brain works in both sickness and health, faculty in the department are understanding more and more about the development disorders affecting children, as well as the diseases of aging that impact our older alumni and friends. Many of our alumni affected by these disorders are encouraged by the department's research and are eager to support its efforts. Providing meaningful engagement opportunities for these potential new donors is our goal. We want to broaden the number of friends and alumni who will be willing to support collaborative neuroscience research at MIT.

In addition to the donors who support our disease-related research, we have actively been looking to increase the pipeline of people interested in supporting all areas of the department's research. In order to understand how the brain gives rise to the mind, we continue to look at ways to engage partners who join us on this journey of discovery by supporting our graduate students and by establishing flexible research funds that enable our faculty to pursue bold new ideas.

We have been working closely with the assistant dean for development in the School of Science who is collaborating with the central resource development operation to make sure our friends and alumni are aware of the department's activities and initiatives.

Selected Research Highlights

Edward Adelson and his colleagues carry out research directly related to the perception of surfaces, by both visual and tactile sensing. One topic they have been investigating is translucency perception, as part of a collaboration with researchers at Harvard and Cornell universities. They have a paper accepted at *ACM Transactions on Graphics*, and have just received a National Science Foundation grant to continue this research. They have also been working on computational models of shape perception. Adelson hds a paper accepted at the European Conference on Computer Vision, which describes a unified framework for understanding the perception of three-dimensional shapes from line drawings, shape-from-shading, and shape-from-texture. With support from a Google grant, Adelson and his colleagues continue to study the relationship between the visual and haptic perception of materials, especially fabrics. They are interested in the visuo-haptic aspects of soft materials such as food, and have received seed money from the MIT Intelligence Initiative to support a postdoctoral student pursuing that topic. Adelson's lab also continues to develop the GelSight tactile sensor. With it, lab members are developing techniques to estimate texture and hardness of soft materials, which could be useful in robotics as well as in diagnosis of medical conditions such as melanoma or breast cancer.

To understand how the human visual system accomplishes object recognition, we must understand how it determines that different images of the same object are equivalent. The ability to solve this "invariance problem" is what separates humans from machines and likely reflects deep cortical processing principles. James DiCarlo and colleagues have developed an animal model to study these principles by showing that neuronal populations in the high-level primate visual cortex have solved the invariance problem. In the past year, they extended their earlier discovery that the key neuronal population response properties can be built from unsupervised, natural visual experience. They have provided new constraints on underlying mechanisms by showing that these response properties are gradually improved along a series of visual areas, with precise balancing of two key types of operations in each area. They have recently developed models based on these neuronal populations that can quantitatively account for a wide range of human object recognition behavior.

Ted Gibson's research over the past year has been guided by the hypothesis that human language has evolved for communicative purposes. Although this hypothesis seems obvious, many prominent linguists, including MIT's Noam Chomsky, have argued that language is poorly designed for communication. Such a use, they say, is merely a byproduct of a system that probably evolved for other reasons—perhaps for structuring our own private thoughts. As evidence, these linguists point to the existence of ambiguity: in a system optimized for conveying information between a speaker and a listener, they argue, each word would have just one meaning, eliminating any chance of confusion or misunderstanding. In a recent paper published in the journal *Cognition*, graduate student Steve Piantadosi, postdoctoral student Hal Tily, and BCS professor Edward Gibson demonstrate that ambiguity actually makes language more efficient by allowing for the reuse of short, efficient sounds that listeners can easily disambiguate with the help of context. The critical insight was that because context usually disambiguates, it is efficient to re-use whatever words people find easiest to use. Thus short words (which are easier to process) end up being more ambiguous than longer words, exactly as the communicative theory predicts, a fact that the language-for-thought hypothesis does not explain. Other results from the Gibson lab in the past year also bolster the hypothesis that language has evolved for communicative purposes.

Ann Graybiel and her colleagues carry out research directly related to the range of clinical disorders associated with the basal ganglia, including motor disorders such as Parkinson's disease and neuropsychiatric disorders such as obsessive-compulsive disorder, anxiety disorders, and autism. They have found that two genes that they originally discovered are strongly dysregulated in relation to the motor problems that Parkinson's disease patients encounter when taking levodopa. These genes also are dysregulated in the striatum of Huntington's disease patients and in the striatum of mouse models of Huntington's disease. In a second project, Ken-ichi Amemori and Graybiel (*Nature Neuroscience*, 2012) have discovered a cortical site that controls anxiety-like behavior, a promising new lead for therapeutic work on depression and anxiety disorders. Graybiel and her colleagues are also working intensively on the basic science underlying how we make habits and why it is so hard to break them. They found that the "habit circuit" imprints a habit pattern of neuronal activity even more strongly than normal if a sensory cue to instruct which habitual behavior should be performed is given up front—a phenomenon familiar to anyone trying to make or kick a habit. They discovered that habits, under natural conditions and without instruction, develop to optimally efficient patterns—perhaps the good side of habit formation that makes habits so prevalent in our behavior.

Tomaso Poggio's lab, the Center for Biological and Computational Learning, is completing work on a major new theory of the ventral stream. At its core is the conjecture that the computational role of the ventral stream is to learn visual invariances from visual experience (during development), and to discount them for object recognition. The theory leads to several surprising predictions about the architecture of the ventral stream and the properties of its neurons. The MIT Intelligence Initiative, developed by the Poggio and the Josh Tenenbaum labs, recently obtained funding from SkTech and submitted a Science and Technology Center proposal to the National Science Foundation. After the first two screenings, they were notified of an upcoming site visit in September–October 2012.

Mary Potter's lab followed up the past year's discovery about the ability of viewers to detect a picture in a rapid sequence, presented as briefly as 13 milliseconds per picture, when given only a name such as "couple smiling." Potter's lab confirmed its earlier finding that this was possible even when the name was given immediately after the sequence (not before). Lab researchers showed, however, that a 5-second delay of the name after the sequence reduced the ability to report seeing the target, indicating that the information about what had been seen decayed quickly after such brief presentations.

A study from Rebecca Saxe's lab, published this year in the *Journal of Experimental Social Psychology*, tested the mechanisms of successful conflict resolution programs. Israelis and Palestinians participated in a brief online dyadic interaction: participants either described their own group's experience of the conflict (perspective-giving) or listened to the other side's experience (perspective-taking). Whereas Israeli participants showed the greatest improvement in attitudes to Palestinians following perspective-taking (a common activity in conflict resolution programs), Palestinians only showed improvements from perspective-giving. Similar results were observed in a study of white Americans and undocumented Mexican immigrants. These results demonstrate that scientific experiments, using randomized controlled designs and quantitative outcome measures, can be used to evaluate which aspects of conflict resolution programs are most effective for the different groups involved.

In a recent paper, "The truth, and the whole truth: children's sensitivity to sins of omission in pedagogical contexts and its effect on subsequent learning" (Hyowon Gweon & Schulz, under review) Schulz explains that "even very young children do not learn from agents indiscriminately; children selectively trust informants who have been accurate in the past. We show that by the age of six, children recognize sins of omission and adjust their exploratory behavior to compensate for under-informative testimony. Experiment 1 shows that, given identical demonstrations of a machine, six-year-olds rate an informant lower if the machine also had non-demonstrated functions. Experiment 2 shows that given identical demonstrations of a machine, children engage in more exploratory behavior when the informant previously committed a sin of omission. These results suggest that children selectively trust optimally informative agents and rationally resist learning from agents whose credibility is in doubt."

Mriganka Sur's laboratory developed a new technological platform for light-based circuit interrogation in the intact cortex which made it possible to activate single neurons and synapses and record the effects in connected neurons within a functioning circuit. Using this platform with genetically engineered mice, they revealed new computational roles for inhibitory neuron classes in the visual cortex: soma-targeting parvalbumin-expressing inhibitory neurons divide target cell responses and control response gain, whereas dendrite-targeting somatostatin-expressing inhibitory neurons subtract from target cell responses and control response selectivity. Because inhibition is profoundly important for a wide range of brain functions, these findings provide a crucial conceptual framework for understanding cortical circuits that underlie normal and abnormal information processing. In other findings, Sur's lab showed that cholinergic inputs influence long-term changes in cortical circuits through astrocytes, thereby pointing to a novel but fundamental mechanism of cortical wiring and plasticity.

Josh Tenenbaum's lab studies learning, reasoning, and perception in humans and machines, with the twin goals of understanding human intelligence in computational terms and bringing computers closer to human capacities. He and his collaborators have pioneered accounts of human intelligence based on inference in sophisticated probabilistic models. His current work focuses on understanding how people develop the ability to learn new concepts from very sparse data—how humans "learn to learn"—and on characterizing the nature and origins of people's intuitive theories about the physical and social worlds.

In clinical trials, a mixture developed by Dick Wurtman appears to help overcome loss of connections between brain cells. One trial of this Alzheimer's disease treatment has found that the nutrient cocktail can improve memory in patients with early Alzheimer's. The results confirm and expand the findings of an earlier trial of the nutritional supplement, which is designed to promote new connections between brain cells. The supplement mixture, known as Souvenaid, appears to stimulate growth of new synapses. "You want to improve the numbers of synapses, not by slowing their degradation—though of course you'd love to do that too—but rather by increasing the formation of the synapses," Wurtman says. To do that, Wurtman came up with a mixture of three naturally occurring dietary compounds: choline, uridine, and the omega-3 fatty acid DHA. Choline can be found in meats, nuts, and eggs; omega-3 fatty acids are found in a variety of sources, including fish, eggs, flaxseed, and meat from grass-fed animals. Uridine is produced by the liver and kidney, and is present in some foods as a component of RNA. These nutrients are precursors to the lipid molecules that, along with specific proteins, make up brain cell membranes, which form synapses. To be effective, all three precursors must be administered together. The new findings are encouraging. Plans for commercial release of the supplement are not finalized, according to Nutricia, the company testing and marketing Souvenaid, but it will likely first be available in Europe. Nutricia is the specialized health care division of the food company Danone, known as Dannon in the United States. A two-year trial involving patients who don't have Alzheimer's, but who are starting to show mild cognitive impairment, is now under way. If the drink seems to help, it could be used in people who test positive for very early signs of Alzheimer's, before symptoms appear, Wurtman says. Tests to determine these early signs, which include PET scanning of the hippocampus, are now rarely done because there are no good Alzheimer's treatments currently available.

Weifeng Xu's laboratory aims to elucidate the molecular mechanisms of activity-dependent modifications of neuronal properties (neural plasticity), including synaptic efficacy and neuronal excitability. This activity-dependent plasticity is essential for the immense computational power of the neuronal network for information processing and storage. Dysregulation of neuron excitability and synaptic efficacy is often manifested in neurological and psychiatric diseases and disorders, and is thought to underlie some of the cognitive impairment and dysfunction often seen in these illnesses. Two lines of research are conducted in the laboratory: 1) Using the molecular replacement approach, Xu's laboratory has discovered that the members of the postsynaptic scaffold PSD-MAGUKs family of proteins have overlapping yet distinct effects on basic properties of synaptic transmission including active synapse numbers, unitary synaptic strength, and activity-dependent regulation, suggesting an elaborated regulation of synaptic function orchestrated via PSD-MAGUK family proteins. This functional diversity may underlie their specific functional significance during development and experience-dependent plasticity. This work is currently in submission. 2) Calcium (Ca) and Ca-binding protein calmodulin (CaM) are important messengers mediating electrical signals to cellular signaling. Xu's laboratory has discovered that the levels of an apo-CaM binding protein (neurogranin) can be rapidly regulated by experience and neuronal activity, providing an experience-dependent regulation of calcium signaling in neurons at a very short time scale. Bidirectional manipulation of neurogranin levels using virus-mediated knockdown and overexpression lead to bidirectional change of neuronal excitability, suggesting this pathway may contribute to activity-dependent regulation and modulation of neuronal network activity. Ongoing research aims to further examine the functional implication of this rapid experience-dependent regulation of neurogranin levels in learning and in synaptic plasticity. The outcome of these studies will provide targets for pharmacological interventions for patients with neurodegenerative diseases and psychiatric disorders.

Selected Faculty Awards and Honors

Emery Brown was the 2011 recipient of the Jerome Sacks Award for Outstanding Cross-Disciplinary Work from the National Institute of Statistical Sciences.

Emery Brown and Matt Wilson were elected as fellows of the American Academy of Arts and Sciences.

John Gabrieli received the BCS Award for Excellence in Undergraduate Teaching for 9.00 Introduction to Psychology.

Edward Gibson and Emery Brown received BCS awards for Excellence in Undergraduate Advising.

Ann Graybiel will receive the Kavli Prize in Neuroscience, one of the highest honors in the field, in September 2012. She delivered a number of invited lectures in the US and abroad, including the Presidential Lecture at the annual meeting of the Society for Neuroscience in Washington, DC, and the Segerfalk Lecture at Lund University in Lund, Sweden.

Tomaso Poggio continues to be an honorary member of the Neuroscience Research Program, a member of the American Academy of Arts and Sciences, a Founding Fellow of the American Association of Artificial Intelligence, and a scientific board member of the Institute for Scientific Interchange (the MIT of Italy) and of the Institute of Science and Technology Austria (the MIT of Austria). He is one of the (computational) neuroscientists with the highest h-index (greater than 100 based on Google Scholar).

Laura Schulz received the Troland Award from the National Academy of Sciences, 2012.

Rebecca Saxe was selected by the World Economic Forum as a Young Global Leader.

Mriganka Sur was elected as a member of the Institute of Medicine of the National Academies, 2011. He also received the Distinguished Alumnus Award in the psychological sciences, Vanderbilt University, 2012.

Kay Tye received a Jeptha and Emily V. Wade Award from the MIT Research Support Committee.

Feng Zhang and Ed Boyden received the Perl/UNC Neuroscience Prize, shared with Karl Deisseroth of Stanford University. Feng Zhang was also named a Searle Scholar.

Matt Wilson was elected a fellow of the American Association for the Advancement of Science.

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