Department of Brain and Cognitive Sciences

Mission

The mission of the Department of Brain and Cognitive Sciences (BCS) is to understand how the brain gives rise to the mind. That is, the department aims to "reverse engineer the mechanisms of the mind." The unique vision of BCS is anchored in the idea that achieving this goal requires the synergy of multiple levels of analysis: characterization and investigation of human cognitive phenomena in both normal and disordered states; the neuronal circuits, algorithms, and representations in the brain that underlie those phenomena; and the cellular, molecular, and genetic mechanisms that develop, implement, and maintain those circuits. The department believes that building links among these levels—links often specified in the language of computation and engineering—is the way to achieve an accurate understanding of how the brain gives rise to the mind. The department also believes that this deep understanding is the key to ameliorating or eliminating disorders of the mind, building truly intelligent machines, and advancing education, among myriad other unpredictable world-changing impacts.

A unique and defining identity of BCS is that the department pursues all of these levels of analysis in an integrated and synergistic way. There are very few other departments in the world organized in the same manner as BCS—in most universities, the study of the brain (neuroscience) and the study of the mind (cognitive science) are housed in separate buildings, and often on separate campuses. At MIT, the Brain and Cognitive Sciences Complex, also known as Building 46, not only houses the BCS department and all of its primary faculty labs but also includes the space and facilities of the McGovern Institute for Brain Research (MIBR) and the Picower Institute for Learning and Memory (PILM), where many of the BCS faculty carry out their research. This combined strength puts us squarely at the forefront of the BCS mission.

Leadership

The department plays an important "umbrella" role in building and strengthening the brain and cognitive science community at MIT. The overall strategy of BCS, which focuses on bolstering the sub-communities that naturally cross cut the entirety of Building 46, has lowered the walls between the various units and created opportunities for the community to come together.

Building-wide leadership: The BCS Council includes Jim DiCarlo, BCS department head (chair); Professor Bob Desimone, director of MIBR; Professor Li-Huei Tsai, director of PILM; Professor Mriganka Sur, director of the Simons Center for the Social Brain; Tomaso Poggio, director of the Center for Brains, Minds and Machines (CBMM); and senior and junior faculty members spanning all areas of the department. The council meets monthly and serves as an advisory committee to ensure that departmental decisions are strongly informed and that all leaders in the building are comfortable and enthusiastic about those decisions.

BCS faculty leadership roles: The department would not be able to plan and execute its myriad functions without the support of the faculty, and the department continues to espouse a culture of shared effort. The following faculty have notably stepped up to continue and/or take on key leadership roles over the last four years:

- Professor Michale Fee (associate department head for education and chair of the BCS Education Committee)
- Professor Laura Schulz (undergraduate officer)
- Professor Matt Wilson (graduate officer and chair of the BCS Graduate Admissions Committee and BCS Graduate Affairs Committee)
- Professor Nancy Kanwisher (BCS space oversight)
- Associate Professor Alan Jasanoff (chair of the BCS Seminar Committee)
- Professor Pawan Sinha (chair of the BCS Diversity Committee)
- Professor Mark Bear (postdoctoral officer for the BCS community)

All primary BCS faculty actively serve on one or more of these standing committees.

Faculty

BCS faculty members are widely recognized as being among the leaders in their respective fields. Department faculty includes one Nobel Prize winner, 10 members of the National Academy of Sciences (including two emeritus members), five members of the National Academy of Medicine, 19 members of the American Academy of Arts and Sciences (including two emeritus members), one National Medal of Science awardee, one winner of the Kavli Prize, eight winners of the Troland Award from the National Academy of Sciences, and four recipients of the Society for Neuroscience Young Investigator Award.

The McGovern Institute for Brain Research and the Picower Institute for Learning and Memory are critical components of the BCS community: 24 of the 35 BCS primary faculty are also investigators in the McGovern and Picower Institutes. All 14 of the PILM investigators have either their primary (11) or secondary (three) appointments in BCS, and 15 of the 16 MIBR investigators have their primary (13) or secondary (two) appointments in the department.

Two BCS faculty members have core appointments at the Broad Institute, and one holds the special title of Institute Professor. The faculty members who held joint appointments this past year in BCS represent Chemical Engineering, Mechanical Engineering, the Media Laboratory, Biology, Biological Engineering, and the Sloan School of Management. BCS faculty members in turn hold secondary appointments in many of those departments, as well as in Linguistics and Philosophy and the Institute for Medical Engineering and Science.

Effective July 1, 2017, Laura Schulz was promoted to full professor.

Since 2017, BCS has successfully hired two new faculty members, one at the junior level (assistant professor) and one at the senior level (associate professor). Professor Michael Halassa, who began in spring 2018, has added strength to the systems neuroscience research area by helping to connect it to other areas of research. Professor Alexander

(Sasha) Rakhlin also began in spring 2018 and has helped strengthen the area of computation within the department. While BCS has made significant progress in hiring, the work is not done.

Development

While challenges remain, resource development efforts have resulted in significant success in promoting and supporting activities that benefit MIT's entire brain enterprise. Two new endowed BCS graduate fellowships, the Alder Fellowship and the Holubow Fellowship, were established in spring 2017, and BCS anticipates that a third graduate fellowship will become available by the end of 2018. The establishment of the John Jarve Endowed Professorship in Brain and Cognitive Sciences will also benefit MIT; the department selected Rebecca Saxe, an exceptional faculty member, as the inaugural Jarve Professor. In addition, BCS resource development efforts helped secure a $5 million gift to the School of Science to establish the John Jarve Research Seed Fund.

Significant efforts have also been dedicated to supporting the launch of MIT's Quest for Intelligence "Core," including extensive work to promote the value of the "science of intelligence" both externally and internally. Departmental resource development efforts have assisted with several major (more than $5 million) Quest for Intelligence gifts that will benefit MIT and BCS research. BCS development efforts facilitated pledges to the department totaling approximately $2.8 million in 2017 and $5.6 million (to date) in 2018 (not including Quest efforts), with about 60% of these funds placed into endowments. Of note, BCS has seen an approximate 42% increase in the number of donors in 2018 (relative to the preceding three-year average). While most of these gifts have been greater than $50,000, increased engagement with a broader pool is encouraging for the department's long-term prospects.

Quest for Intelligence

Jim DiCarlo worked closely with other departmental leaders (in particular Professor Poggio and Professor Josh Tenenbaum) and with Daniela Rus, director of MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL), to create an internal white paper of a vision based on MIT's history, unique strengths, and forward-looking opportunities. Poggio's leadership over the last 10 years in establishing the Center for Brains, Minds and Machines, a multi-institutional collaboration funded by the National Science Foundation (NSF), was particularly important in pulling an initial MIT community together. BCS was extremely pleased that the Institute leadership embraced the vision in the white paper as a key component of the forward-looking vision of MIT. In March 2018, MIT launched the Quest for Intelligence, an Institute-wide initiative to advance the science and engineering of both human and machine intelligence. The initiative is organized under two connected entities: "The Core" and "The Bridge."

The planned activities of The Core are highly aligned with one of the key forward-looking research directions of BCS: the natural science of intelligence. Accordingly, the department is very pleased that BCS will be strongly represented on the leadership team of The Core, with Jim DiCarlo as director, Josh Tenenbaum as one of the scientific directors, and Tommy Poggio as the founding scientific advisor. BCS is also pleased that this will be a strong partnership with engineering; for example, the other key leaders of The Core are Associate Director Daniela Rus (Department of Electrical Engineering and Computer Science [EECS]/CSAIL) as and Scientific Director Leslie Kaelbling (EECS/CSAIL). This provides an exceptional opportunity for BCS to benefit from philanthropic and corporate sponsorships raised through The Core, and BCS is very excited to be part of the epicenter of this increasingly important area as it aligns and strengthens the critical role of computation in its mission. In sum, BCS is enthusiastically embracing its important and natural role in the future of intelligence research and education at MIT.

Education and Training

BCS provides its students with an interdisciplinary curriculum designed to educate them and prepare them to be future scientific leaders. The department's intensive undergraduate program is a tiered system that builds on the expertise gained at each preceding level. Beginning with broad courses, students gain foundational knowledge of topics drawn from molecular, cellular, and systems neuroscience; cognitive and perceptual psychology; applied mathematics; computer science and artificial intelligence; linguistics; and philosophy of mind. These multiple tiered pathways through the undergraduate program are designed to prepare students for a range of possible career paths, including research, health care, and industry. The graduate program provides advanced instruction on topics and research methods in one (or more) of four themes: molecular and cellular neuroscience, systems neuroscience, cognitive science, and computation. Our faculty taught a total of 49 subjects in the BCS undergraduate and graduate curricula this past year.

This year, a new course was introduced to the undergraduate and graduate curriculum. The MIT/Massachusetts General Hospital (MGH) 9.900 Clinical Connection Module subject, led by Thomas Byrne, provides undergraduate and graduate students the opportunity to connect their core neuroscience training to clinical experience (e.g., pathogenesis, diagnosis) through seminars at MGH. BCS launched this program in September 2016 to add a clinical translation perspective to the department's existing graduate training mission, exposing students to bridge-building opportunities that can facilitate their research.

Undergraduate Program

BCS, now in the fifth year of its undergraduate curriculum redesign, has provided its students with opportunities to build a strong quantitative skill set and be rigorously exposed to an engineering-level description of neurons and neural circuits and the computations they carry out. All undergraduates in BCS learn elementary computer programming and statistics and take the foundational course (9.40) that covers quantitative and computational approaches to understanding the brain and behavior.

Students in the department are often quite accomplished and are recognized as such. In 2017–2018, two students were Burchand Scholars, one was a Fulbright Scholar, one was a Marshall Scholar, and another was a Mitchell Scholar.

Institute awards presented to undergraduates include the Walle J.H. Nauta Award for Outstanding Research in Brain and Cognitive Sciences (six) and the BCS Hans Lukas Teuber Award for Outstanding Academics (15).

Over the past year, 29 students graduated with degrees in brain and cognitive sciences.

Graduate Program

Student demand to enter the BCS graduate program is very high. However, due to funding limitations, the size of its graduate program has remained steady over the past five years at around 100 students (approximately 2.5 students per faculty member). Eighteen graduate students entered in fall 2018. Fifty-five percent of these students were female, 33% were international students, and 11% were under-represented minority students. Fourteen of the incoming students were funded by Singleton Presidential Graduate Fellowships, one by a Burnett Fellowship, one by a National Defense Science and Engineering Graduate Fellowship, and two by National Institutes of Health (NIH) training grant programs.

This year 12 students graduated with doctorate degrees. Institute awards over the past year include the Angus MacDonald Award for Excellence in Undergraduate Teaching (nine), the Walle Nauta Award for Continuing Dedication to Teaching (two), and the Walle Nauta Award for Excellence in Graduate Teaching (three).

Postdoctoral Program

The postdoctoral program continues to be a success, with 45% placement in faculty and other science-related positions. The changes in the BCS community standard postdoc annual stipend rate were fully implemented as of July 1, 2016. The rate is indexed at the NIH National Research Service Award level of 4 years of experience. With this policy, the department continues to pursue the goal of reducing the financial anxiety experienced by postdocs to allow them to focus on building their future careers by doing unfettered science during their postdoctoral training period.

BCS also recently spearheaded an initiative designed to gather data on training outcomes for Building 46 postdocs matriculating in the past decade. The initial results were quite encouraging, with two thirds of postdoctoral alumni moving directly from MIT into faculty and science-intensive positions, including positions in the pharmaceutical industry. BCS continues to collect and analyze this information within the department with the intention of publishing the findings in the near future.

Research

While there are many joint research priorities, a key priority this year was launching the Community Computational Core (CompCore) in order to provide in-house advanced computing capabilities to researchers in the BCS complex. CompCore has dedicated office space in Building 46 for engineering staff along with a common space and a meeting room equipped with a projection system. It will provide ongoing support, training, development, and guidance for BCS graduate students, researchers, and faculty and serve as a central point of contact for the OpenMind high-performance computing cluster (currently managed through MIBR, with plans for BCS to manage these services). CompCore will also provide machine learning specialization and development services, technical support for special projects, and resources to innovate current methods of data analysis, model building, and more.

MIBR recently established a marmoset colony in order to use this species as a platform for transgenic primate research, in particular for studying the neural basis of psychiatric disorders. This new program is being led by Professors Guoping Feng and Robert Desimone and also involves other collaborating groups. The colony currently occupies two dedicated housing rooms in the seventh-floor vivarium and four rooms recently renovated on the sixth floor for behavioral testing.

Our faculty continue to make significant contributions to their respective fields. Below is a selection of recent research highlights from members of the BCS community.

Professor Laura Schulz, who was promoted to full professor this year, published online findings in *Science* indicating that babies who watched an adult struggle at two different tasks before succeeding tried harder at their own difficult task than babies who saw an adult succeed effortlessly. This study suggests that infants can learn the value of effort after seeing just a couple of examples of adults trying hard, although the researchers have not studied how long the effect lasts. Although the study took place in a laboratory setting, the findings may offer some guidance for parents who hope to instill the value of effort in their children. This work was supported by the NSF Graduate Research Fellowship Program, CBMM, and the Simons Center for the Social Brain.

In a study published in *Neuron*, Professor Earl Miller (PILM) and his research team showed that the ability to categorize items based on straightforward resemblance or abstract similarity arises from the brain's use of distinct rhythms, at distinct times, in distinct parts of the prefrontal cortex. Humans have this capability whether the items appear patently similar, such as Fuji and McIntosh apples, or share a more abstract similarity, such as a screwdriver and a drill. According to Miller, the team's findings suggest a model of how the brain achieves category abstractions. By precisely illustrating the frequencies, locations, and timing of brain rhythms that govern categorization, the findings could advance the understanding of certain aspects of autism spectrum disorders.

A landmark 1995 study showed that children from higher-income families hear about 30 million more words during their first three years of life than children from lower-income families. This "30-million-word gap" correlates with significant differences in tests of vocabulary, language development, and reading comprehension. A study from the laboratory of Professor John Gabrieli (MIBR) revealed that back-and-forth conversations between adults and children are more critical to language development than the word gap. In a study of children between four and six years of age, the group found that differences in numbers of "conversational turns" accounted for many of the disparities in brain physiology and language skills observed among the children. This finding applied to children regardless of parental income or education.

Neurons in the brain communicate via rapid electrical impulses that enable the brain to coordinate behavior, sensation, thoughts, and emotion. Scientists who study this electrical activity usually measure these signals with electrodes inserted into the brain, a task that is notoriously difficult and time consuming. Professor Edward Boyden (MIBR) and his research group have developed a new approach: a light-sensitive protein that can be embedded into neuron membranes, where it emits a fluorescent signal that indicates the amount of voltage present in a particular cell. This could allow scientists to study how neurons behave, millisecond by millisecond, as the brain performs a particular function.

Catching a bouncing ball or hitting a ball with a racket requires estimating when the ball will arrive. Neuroscientists have long thought that the brain does this by calculating the speed of the moving object. However, a new study from the laboratory of Professor Mehrdad Jazayeri (MIBR) shows that the brain's approach is more complex. The group's results suggest that, in addition to tracking speed, the brain incorporates information about the rhythmic patterns of an object's movement: for example, how long it takes a ball to complete one bounce. They found that people make much more accurate estimates when they have access to information about both the speed of a moving object and the timing of its rhythmic patterns.

Humans use an ability known as "theory of mind" every time they make inferences about someone else's mental state: what the other person believes or wants or why the person is feeling happy, angry, or scared. Behavioral studies have suggested that children begin succeeding at a key measure of this ability, known as the false-belief task, at around the age of four. However, a new study from Professor Rebecca Saxe and her research group shows that the brain network that controls theory of mind is already formed in children as young as the age of three. This study is the first to use functional magnetic resonance imaging to scan the brains of young children as they perform a task requiring theory of mind—in this case, watching a short, animated movie involving social interactions between two characters.

In a new study of one of the most common genetic causes of autism, MIT researchers led by Professor Mriganka Sur (PILM), director of the Simons Center for the Social Brain at MIT, have identified a molecular mechanism that appears to undermine the ability of neurons in affected mice to properly incorporate changes driven by experience. The findings indicate that a particular gene, MVP, is likely consequential among people with 16p11.2 deletion syndrome. Accounting for up to 1% of autism cases, 16p11.2 deletion occurs among people who are missing a small region of DNA near the center of one copy of chromosome 16. For years, scientists have been working to determine exactly how the reduced presence of 29 protein-encoding genes leads to clinical symptoms of the syndrome such as autism-like behaviors, developmental delays, and intellectual disabilities.

Using a machine-learning system known as a deep neural network, Professor Josh McDermott and his research group have created the first model that can replicate human performance on auditory tasks such as identifying a musical genre. This model, which consists of many layers of information-processing units that can be trained on huge volumes of data to perform specific tasks, was used by the researchers to shed light on how the human brain may be performing the same tasks. The study also offers evidence that the human auditory cortex is arranged hierarchically, much like the visual cortex. In this type of arrangement, sensory information passes through successive stages of processing, with basic information processed earlier and more advanced features such as word meaning extracted in later stages.

A great deal of evidence suggests that it is more difficult to learn a new language as an adult than as a child, which has led scientists to propose that there is a critical period for language learning. However, the length of this period and its underlying causes remain unknown. A study conducted by Professor Josh Tenenbaum (CBMM) suggests that children remain skilled at learning the grammar of a new language much longer than expected, up to the age of 17 or 18. However, the study also showed that it is nearly impossible for people to achieve proficiency similar to that of a native speaker unless they start learning a language by the age of 10. The findings were based on an analysis of a grammar quiz taken by nearly 670,000 people, by far the largest data set that anyone has assembled for studying language-learning ability.

It is often said that experience is the best teacher, but the experiences of other people may be even better. If one saw a friend get chased by a neighborhood dog, for instance, one would learn to stay away from the dog without having to personally undergo that experience. According to Professor Kay Tye (PILM), this kind of learning, known as observational learning, offers a major evolutionary advantage. Tye and her colleagues at MIT have identified the brain circuit that is required for this type of learning: the anterior cingulate cortex, which transmits socially derived information to the basolateral amygdala, where it assigns predictive value to enable social cognition.

Selected Faculty Awards and Honors

Professor Tomaso Poggio received the Azriel Rosenfeld Lifetime Achievement Award at the 2017 International Conference on Computer Vision.

Three BCS faculty members were honored with awards from the NIH Common Fund’s High-Risk, High-Reward Research program: Professors Kay Tye and Feng Zhang received Pioneer Awards, and Professor Edward Boyden received the Transformative Research Award.

Professor Zhang also received the 2017 Albany Medical Center Prize in Medicine and Biomedical Research; was awarded the 2017 $500,000 Lemelson-MIT Prize, the largest cash prize for invention in the United States (in recognition of his work with CRISPR); and was named a laureate of the 2017 Blavatnik National Awards for Young Scientists. In addition, Zhang was a recipient of the 2018 Vilcek Prize, which honors the contributions of immigrants to the United States. Finally, Zhang was elected to the American Academy of Arts and Sciences and the National Academy of Sciences.

Mark Harnett received a major grant from the Dana Foundation. The grant, part of the David Mahoney Neuroimaging Program, will launch his project Imaging Synaptic Computations in Human Neural Circuitry.

Mehrdad Jazayeri was a 2017 McKnight Scholar Award recipient.

Michale Fee was the inaugural recipient of MIT’s Fundamental Science Investigator Award and was presented the McKnight Technological Innovations in Neuroscience Award.

Molly Potter received the Norman Anderson Lifetime Achievement Award from the Society of Experimental Psychologists.

Edward Boyden, Earl Miller, and Molly Potter were elected to the American Academy of Arts and Sciences.

Mriganka Sur received the Cortical Discoverer Prize from the Cajal Club, the oldest neuroscience society in the United States.

John Gabrieli was presented the Alice H. Garside Lifetime Achievement Award by the Massachusetts branch of the International Dyslexia Association.

Josh McDermott received a Troland Research Award from the National Academy of Sciences in recognition of his "groundbreaking discoveries about how people hear and interpret information from sound in order to make sense of the world around them." In addition, he received the BCS Award for Excellence in Undergraduate Advising.

Edward Boyden won the 2018 Gairdner International Award, Canada's most prestigious scientific prize, for his role in the discovery of light-gated ion channels and optogenetics, a technology to control brain activity with light. He was also named the inaugural Y. Eva Tan Professor in Neurotechnology.

Rebecca Saxe was a recipient of the MIT Committed to Caring Award, which recognizes faculty members who are nominated by graduate students as outstanding mentors. Also, she was named the inaugural John Jarve Professor in Brain and Cognitive Sciences.

Nancy Kanwisher received the 2018 Heineken Prize, the Netherlands' most prestigious scientific prize, for her work on the functional organization of the human brain. Kanwisher also received the 2018 Davida Teller Award, established to honor women vision scientists who have made exceptional contributions to the field of vision science and have a strong history of mentoring.

Emery Brown was inducted into the Florida Inventors Hall of Fame in recognition of his research advancing anesthesiology.

Ann Graybiel was a recipient of the 2018 Gruber Neuroscience Prize in recognition of her pioneering work in the structure, function, and organization of the basal ganglia.

Edward Boyden and Feng Zhang were named Howard Hughes Medical Institute investigators.

Steven Flavell was named the Lister Brothers Career Development Professor.

Elly Nedivi received the BCS Award for Excellence in Undergraduate Teaching.

Bob Desimone and Earl Miller received the BCS Award for Excellence in Graduate Teaching. Myriam Heiman received the BCS Award for Excellence in Graduate Mentoring.

Kay Tye received the BCS Award for Excellence in Postdoctoral Mentoring and was granted tenure as an associate professor in BCS.

James J. DiCarlo
Head
Peter de Florez Professor of Neuroscience