

Department of Brain and Cognitive Sciences

The mission of the [Department of Brain and Cognitive Sciences](#) (BCS) is to understand how the brain gives rise to the mind. BCS is a department with a unique vision, anchored in the idea that a deep understanding of the mind requires the synergy of multiple levels of analysis: the 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 and molecular mechanisms that implement, maintain, and potentially repair those circuits. The department also upholds a core value of MIT—that sufficient explanations of these processes must ultimately be rooted in the language of mathematics and computational theory.

A defining identity of the department is that all these levels of analysis are pursued in an integrated and synergistic way. Arguably, there is no other department in the world organized as BCS is—in most universities, the study of the brain (neuroscience) and the study of the mind (cognitive science) are housed in separate buildings, often on separate campuses. At MIT, Building 46, which houses the McGovern Institute for Brain Research (MIBR) and the Picower Institute for Learning and Memory (PILM), offers the opportunity to further the BCS mission, which spans research, teaching, and training in both neuroscience and cognitive science.

Today, BCS is a dynamic department that is on an overall upward trajectory in faculty, student, and financial indicators. In the latest quantitative assessment of doctoral programs published by the National Research Council in 2010, BCS placed first among 94 neuroscience doctoral programs in the US.

Leadership

On March 1, 2013, professor James DiCarlo completed his first year heading BCS. His top two priorities are to integrate the community of the brain science enterprise at MIT, and to revolutionize the department's educational programs. To ensure the guidance and representation of the entire departmental faculty and brain science enterprise, Professor DiCarlo created and chairs the BCS Council, which comprises the directors of MIBR (professor Robert Desimone), PILM (professor Li-Huei Tsai), and the Simons Center for the Social Brain and former BCS department head (professor Mriganka Sur), and representatives of the four areas of the department, including junior faculty.

Professor DiCarlo's top priority over the past year was the improvement of educational programs, particularly the undergraduate curriculum. To help lead this effort, he recruited professor Michale Fee as associate department head for education, professor Matthew Wilson as the graduate officer, and professor Laura Schulz as the undergraduate officer.

Professors DiCarlo and Fee put together the BCS Education Committee to build consensus of curriculum, provide an ongoing transparent process for teaching assignments and proposed course additions and changes, and implement improvements to the curriculum that had previously only been discussed. Professor Fee has led

this effort. Professor Schulz, who was recently named a MacVicar Fellow for her commitment to undergraduate education, has led the effort to build a stronger faculty culture of teaching.

Community

Strengthening community at all levels within BCS and its affiliated institutes has also been among the department's top priorities. The strategy is to strengthen subcommunities that horizontally integrate across the institutes in Building 46—faculty, postdoctoral researchers, graduate students, undergraduate students, and staff. More specifically, BCS aims to create an environment where each subcommunity is empowered and can flourish in directions that are percolated from its grassroots. At the faculty level, Professor DiCarlo created standing committees in the department and empowered each to take ownership of areas of importance to the BCS community. He invited all BCS faculty members to be part of at least one committee (but not more than two). These areas of importance are strategic planning (BCS Council), education (BCS Education Committee), graduate students (BCS Graduate Affairs Committee), hiring (BCS-led Search Committee), seminars (BCS Seminars Committee), junior faculty mentoring (BCS Junior Faculty Mentoring Committee), etc. These committees will report to the full faculty on a semiannual basis.

The department also worked to identify and empower leaders among various subcommunities (graduate students, undergraduates, postdoctoral researchers, and junior faculty) who can organize events and represent the concerns of those subcommunities to the department. A staff member was provided to give the groups access to departmental resources and to be a conduit for ideas from department leadership to be presented to each subcommunity. To date, particular progress has been made with the postdoctoral community. BCS senior lecturer Sonal Jhaveri has taken on the role of director of postdoctoral affairs for Building 46. With her support and that of other BCS staff, a postdoctoral association, which began within PILM, has expanded to serve postdoctoral researchers from BCS and all its affiliated institutes. Postdoctoral fellows Katie Harris and Daniel Bendor were selected for Infinite Kilometer awards by the School of Science for their work with the Building 46 postdoctoral community.

BCS is also striving to improve communications and deeper collegiality across the BCS community. It now has monthly BCS-wide faculty meetings and lunches. Professor DiCarlo sends a BCS-wide email at least once a month, highlighting recent awards, honors, and achievements of all members of the community. BCS headquarters communications staff also send a weekly email summarizing community-relevant information.

Faculty

BCS faculty members are widely recognized as leaders in their respective fields. Of 48 total faculty, 39 hold primary appointments in BCS and nine have primary appointments elsewhere. Of the 39 primary appointments, nine hold appointments in PILM, and 15 hold appointments in MIBR. Two faculty members have joint appointments at the Broad Institute and two at the Institute for Medical Engineering and Science, two are Howard Hughes Medical Institute investigators, and two hold the title of Institute Professor.

The interdisciplinary nature of neuroscience and cognitive science is highlighted by the number of BCS faculty with joint appointments. The nine faculty members who held secondary appointments this past year in BCS represent the departments of Mechanical Engineering, Biology, Biological Engineering, Electrical Engineering and Computer Science, as well as the Media Lab and the MIT Sloan School of Management. BCS faculty members in turn hold secondary appointments in many of those departments, as well as in the Physics and the Linguistics sections of the Department of Linguistics and Philosophy.

This past year, BCS recruited three outstanding junior faculty members: Josh McDermott, Mehrdad Jazayeri (MIBR), and Gloria Choi (MIBR).

Professor Peter Schiller retired in June. He began his service to the department as a postdoctoral associate in 1962, when BCS was the Department of Psychology. Professor Schiller was tenured in 1969 and promoted to full professor in 1971.

Graduate Program

Twenty-two graduate students entered in fall 2012. Two of the new incoming students were funded by Singleton Presidential Graduate Fellowships, six by Singleton Fellowships, two by special BCS donor awards (Jeffrey and Nancy Halis, and Al and Barrie Zesiger), and one by a special Office of the Dean for Graduate Education fellowship award. Seven were supported by a departmental National Institutes of Health (NIH) training grant, one was funded by a National Science Foundation Fellowship, one by a Samsung Fellowship, and two by Natural Sciences and Engineering Research Council of Canada fellowships.

During this year, 13 students graduated with doctorates: Ben Auerbach, Krista Ehinger, Hyowon Gweon, Mark Howe, Ni Ji, Li-Wei King, Stuart Layton, Retsina Meyer, David Osher, Zeynep Saygin, Susan Su, Nathaniel Twarog, and Veronica Weiner. Eight took postdoctoral positions in universities or research institutions (e.g., MIT, the University of Buffalo, and the Harvard Medical School), while another recent graduate took a senior analyst engineering position at BitSight Technologies.

Two students were honored for excellence in teaching: Simon Kornblith received the Walle Nauta Award for Excellence in Graduate Teaching, and Steve Ramirez received the Walle Nauta Award for Continuing Dedication to Teaching. Nine graduate students—Joseph Keller, Matthew Greene, Horng-An Edward Nieh, Gerald Pho, Laura Stoppel, Wilma Bainbridge, Sam Norman-Haignere, Julian Jara-Ettinger, and Kimberly Scott—received the Angus MacDonald Award for Excellence in Undergraduate Teaching.

Undergraduate Program

During AY2013, BCS had 116 undergraduates, with 43 graduating seniors: Hamsika Chandrasekar, Shivani Agarwal, Phyllis Yan, Elia Harmatz, Heather Acuff, Camila Caballero, Elizabeth Cain, Beverly Cope, Margaret Mary Cunniff, Jeremy Dalcin, Swethasri Dravida, Joy Ekuta, Margarita Esteban, Jenelle Feather, June Geng, Arooshi Kumar, Smriti Kumar, Allison Lee, Margaret Lee, Eugenia Luo, Carine Moezinia, Victoria Okuneye, Jessica Pourian, Elise Stave, Alissa Totman, Lily Tran, Huaiying Wang, Shawn Wen, Jeanne Yu, Fangheng Zhou, Kathryn Dere, Carolina Roque,

Adrienne Tran, Alireza Samiei, Jennifer Bustamante, Soraya Shehata, Claire O’Connell, Ian Cinnamon, Sahar Hakim-Hashemi, Catherine Olsson, Aparna Sud, Chelsi Green, and Connor Kirschbaum.

Three Course 9 majors were inducted into Phi Beta Kappa, and two undergraduate students—Heather Acuff and Hamsika Chandrasekar—received the Angus MacDonald Award for Excellence in Undergraduate Teaching.

Development Activities

BCS development efforts are now led by Elizabeth Chadis, assistant dean for development for the School of Science. BCS development officer and events coordinator departed from BCS; the department replaced the position with a new communications and development assistant, Rachel Traughber, who started her role in September 2012.

The BCS top fundraising priorities continue to include endowed and expendable fellowships for graduate students and postdoctoral associates, endowed career development chairs and professorships, and unrestricted research funds. BCS has had considerable success with its biannual Brains on Brains symposium, which was held this year on April 30. In a departure from past Brains on Brains symposia, two significant changes were made to the day’s organizational structure. First, the primary guest list was expanded to include all Institute leadership donors, not just those who had previously shown an interest in the department. Second, the content of the symposium was restructured to focus on the breadth of the department, from basic science to disease research. This strategy led to several new gifts for the department and helped identify a new group of constituents who are interested in the department’s work in both education and research.

Research Highlights

Edward Adelson

“Shapecollage” is a human-inspired learning-based system that extracts 3-D shape from 2-D photographs and line drawings. This is the first computational technique that can interpret line drawings of naturalistic shapes (as opposed to polyhedra). It treats photorealistic renderings and stylized line drawings using the same machinery, suggesting that human vision may also use the same machinery for these seemingly different kinds of images. The Adelson Lab has also described “Puffball,” which is a simple representation that converts 2-D curves (i.e., silhouettes) into inflated 3-D shapes, and captures a surprising amount of perceptual information with a very simple technique. Adelson Lab members continue to explore the tactile capabilities of GelSight, and have demonstrated its potential in detecting tumors (such as those in breast cancer or prostate cancer). They also made progress on material perception, including a learning-based system for classifying materials by visual appearance, and a perceptual space for capturing the appearance of transparency.

Marc Bear

Professor Bear's most important research accomplishment was the demonstration that it is possible to correct many aspects of fragile X syndrome (FXS) by pharmacological treatment, even when treatment is begun after symptom onset. FXS is the most common inherited cause of autism and intellectual disability. Several years ago, the Bear Lab proposed that symptoms of the disease arise from excessive protein synthesis stimulated by a neurotransmitter receptor called mGluR5. This year, the Bear Lab showed that chronic treatment with an mGluR5 inhibitor can actually reverse disease phenotypes in adult mice. The data indicate that many symptoms of FXS arise from an ongoing disruption of synaptic signaling, not an irreversible derailment of brain development.

Emilio Bizzi

During the last two years, the Bizzi Lab began investigating whether its work on muscle modules can lead to better rehabilitation methods. In collaboration with clinical neurologists in Venice, Italy, and at the Spaulding Rehabilitation Hospital, in Boston, Bizzi Lab members examined muscle activity in stroke patients as they performed different reaching movements. They selected patients with stroke damage in one cortical hemisphere only, so one arm was impaired while the other was unaffected. By comparing the activity patterns in the two arms, they showed that the same modules were present in both arms, but their activation and combination was disrupted specifically on the affected side. The work on this project involves tracking a group of stroke patients to evaluate how the activation of modules changes throughout the rehabilitation process. The Bizzi Lab will also be exploring whether or not some modules are more affected than others, and if so, how they can speed up a patient's recovery by focusing on the most affected modules. This could give a degree of specificity that has been missing in current rehabilitation therapy.

Edward Boyden

The Boyden Lab presented two longstanding holy grails in the field of optogenetics: noninvasive optogenetic neural silencing, and independent multicolor optogenetic stimulation of multiple populations; manuscripts on both topics are being written up now. The lab also presented a microfabricated 3-D infrastructure for whole-brain optogenetic neural control (*Optics Letters*, 2012) and is now implanting it into the brain. Boyden Lab also, in collaboration with the Forest Lab at the Georgia Institute of Technology, unveiled the first "in vivo robotics" invention, a robot that can automatically perform intracellular recording in the live mammalian brain. The group is now working towards the automation of neuroscience. This work was published in *Nature Methods*, May 2012. Finally, the Boyden Lab, working in collaboration with the Demirci Lab at Brigham and Women's Hospital, developed a 3-D brain culture system that enables cell bodies and pathways to be situated in 3-D, and also showed that it had normal cell types and properties. This technology will enable easy-to-use studies of human stem cell-derived neural networks, important for personalized medicine and studies of neural development.

Emery Brown

The Brown Lab had four significant research accomplishments this year. Burst suppression is a state of profound brain inactivation that occurs in deep states of general anesthesia, hypothermia, coma, and impaired brain development. Brown Lab members developed a precise physiologically-based mathematical description that shows that these states, which appear mechanistically unrelated, are controlled by metabolic activity regulating K⁺ dependent ATP channels on neurons in the brain (Ching, PNAS, 2012). By recording from human patients with electrodes implanted to undergo epilepsy surgery, they reported the first description of how neural activity within the human brain changes with induction of general anesthesia using propofol. With induction, incoherent slow oscillations immediately appear across the cortex limiting neural spiking to narrow time intervals. This slow-wave-mediated fragmentation of neural activity impedes intracortical communication and contributes to propofol-induced unconsciousness (Lewis, *Proceedings of the National Academy of Sciences [PNAS]*, 2012). Using a monkey model, the group developed a highly efficient brain machine interface for movement control that works by decoding the components of a sequential movement from distinct locations in working memory prior to their execution (Maryam Shanechi, et al., *Nature Neuroscience*, 2012).

Robert Desimone

The Desimone Lab made significant progress in establishing the mechanisms of selective attention in primates, and also made progress in establishing optogenetic techniques in primates. It published a peer-reviewed paper in the past year: Kyle Lepage, Georgie Gregoriou, Mark Kramer, Mikio Aio, Stephen Gotts, Uri Eden, and Robert Desimone: "A Procedure for Testing Across-condition Rhythmic Spike-field Association Change." *Journal of Neuroscience Methods*, 2013.

James DiCarlo

The DiCarlo Lab's highly active research remains focused on understanding the neural mechanisms underlying visual object perception. Specifically, DiCarlo Lab members seek to understand how sensory input is transformed by the brain from an initial representation (essentially a photograph on the retina) to new, remarkably powerful patterns of neural activity that can support our seemingly effortless ability to solve the computationally difficult problem of object recognition. Over the past year, they made three major advances. First, they discovered that patterns of neuronal activity in one part of the primate brain (inferior temporal cortex [IT]) can perfectly explain human object recognition abilities, suggesting that human and non-human primates share a common neural substrate for object perception. Second, they developed a new computational model that closely follows a significant problem in the field—the model can predict IT patterns of neural activity much more accurately than any previous model of visual processing. Third, they used the non-human primate to establish a new quantitative link between functional magnetic resonance imaging (fMRI) ("brain scan") measurements—as obtained in most human studies—and the underlying patterns of neural activity that process visual information. Taken together, they are closing in on building an end-to-end understanding of object perception—from the patterns of light striking the eye, to human perception of object identities in the world.

Guoping Feng

The Feng Lab, while using Shank3 mutant mice as a model for autism, identified important synaptic plasticity defects in the striatum that may be a pathological mechanism for autistic-like behaviors in these mice. Feng Lab members also developed transgenic mice that express calcium sensor GCaMP3 for imaging neuronal activity in living mouse brain, and using in vivo GCaMP3 imaging of neuronal activity in the mouse brain, they identified network activity defects in mouse models of autism, a potential common mechanism for autism.

John Gabrieli

The Gabrieli Lab developed a novel way to characterize localized human brain functions and optimize human performance. For the first time, Gabrieli Lab members used real-time fMRI to monitor functional states of particular regions of the human brain and to present information when an individual's brain state was optimal or suboptimal for learning or performance. They found that they could measure when the brain was ready to learn or when the brain was ready to be vigilant, and that people's learning and speed of performance were superior when information was presented during a period when particular brain regions were in particular states. These experiments showed for the first time that human performance could be enhanced by knowledge of dynamically changing states of function in particular brain regions.

In regard to neuropsychiatric disorders, the Gabrieli Lab's most important finding related to neuromarkers that predicted treatment efficacy in social anxiety disorder. For most psychiatric diseases, pharmacological or behavioral therapies are effective for about half of patients, but ineffective for the other half. Remarkably, there is almost no scientific knowledge about whether a particular patient is more or less likely to be helped by a particular treatment. Physicians have no evidence-based support for selecting one versus another treatment for patients, and patients often have to exhibit continued difficulty before another treatment option is attempted. Gabrieli Lab members hypothesize that brain measures prior to treatment might predict which patient will benefit from a particular treatment. In this study, they performed fMRI with patients prior to behavioral treatment (cognitive behavioral therapy), and showed that they could substantially improve predictions of treatment efficacy, above current practices, by using brain measures prior to treatment. They envision that such neuromarkers predicting response to treatment may allow patients and physicians to select a treatment most beneficial for each patient (personalized medicine).

Edward Gibson

Research in the Gibson Lab in the last few years has been focused on the idea that a primary function of human language is communication. Institute Professor Noam Chomsky has famously argued that this is a flawed hypothesis, because of the existence of such phenomena as ambiguity. Contrary to Professor Chomsky, the Gibson Lab applies information theory and communication theory in order to explain the typical usage of language in comprehension and production, together with the structure of languages themselves. Two recent results are: (1) ambiguity out of context is not only not a problem for an information-theoretic approach to language but it is a feature, and (2)

thinking of language as communication can explain aspects of the origin of word order across languages. Most human languages are either Subject-Verb-Object (SVO), like English, Spanish, and Chinese, or SOV, like Japanese, Turkish, and Hindi. The Gibson Lab proposes that the most basic word order is SOV and that this word order is retained as long as the language includes cues that dissociate the agent (subject) from the patient (object) when they are similar; one example of such a cue is case-marking, as is found in most SOV languages. When no such cue is part of the language, it proposes that the preferred word order is SVO, so as to keep the subject and object more recoverable in the face of noise in the channel, and the Gibson Lab provides several experiments in support of these claims, using evidence from a task where participants gesture event meanings (*MIT News*, 2012).

Ki Goosen

The hypothalamus-pituitary-adrenal (HPA) axis has come to dominate the world of stress research; hormones in this axis are thought to coordinate all bodily responses to stress. Despite the availability of numerous drugs that target these HPA stress hormones in humans, these drugs have virtually no clinical efficacy in treating stress-sensitive diseases such as post-traumatic stress disorder (PTSD). The Goosen Lab's most important discovery of the year was to show that ghrelin, a stress-sensitive molecule that underlies stress-related vulnerability to fear, is not a consequence of HPA axis activation. Ghrelin also does not stimulate the HPA axis; rather, ghrelin appears to mediate a stress pathway that operates in parallel to the HPA axis. This discovery represents a potentially important step towards novel targets for the treatment of stress-sensitive diseases.

Ann Graybiel

The Graybiel Lab made a number of major research accomplishments during the past year. In the area of habit learning—why do we do some things over and over again with scarcely a thought?—the Graybiel Lab discovered that optogenetic silencing of the infralimbic cortex, a prefrontal cortical region implicated in habit formation, turned off and on the expression of the acquired habitual behavior. These effects on behavior occurred within a few trials, with only less than 10 seconds of on-line inhibition. Remarkably, the same silencing that blocked the expression of the original habit led to its re-expression when given several days later, perhaps by suppressing the second habit. These findings demonstrate that semi-automatic, habitual behaviors are still under on-line cortical control and will have a major impact on both basic and clinical research, as disturbances in this balance, which lead to overly fixed or overly flexible behavior, are the basis of many neurologic and neuropsychiatric disorders (Kyle Smith, et al., *PNAS*, 2012). The findings also demonstrated that habit-related regions in the striatum (dorsolateral striatum) and prefrontal cortex (infralimbic cortex) exhibit a similar pattern of activity that marks the beginning and end of the entire behavioral action as animals learn a new habit. However, these two regions exhibit strikingly different dynamics of learning-related plasticity during acquisition, loss, and reinstatement of the habitual behavior. The findings suggest a dual-operator view of habits related to the dynamics of cortical and subcortical activity. In primate work on decision making, the Graybiel Lab identified a region in the primate prefrontal cortex in which neurons encoding negative emotional aspects outnumber those encoding positive ones. Remarkably, electrical stimulation in this striosome-projection region of macaque anterior cingulate cortex

induced negative value-based decision making in a task requiring monkeys to choose to accept or avoid a combination of “good” and “bad” outcomes. These changes in decision making were blocked or reversed by anxiolytic drugs. The findings suggest a new potential target for the treatment of anxiety and other emotion-related disorders (Ken-ichi Amemori and Ann Graybiel, *Nature Neuroscience*, 2012).

Myriam Heiman

This past year, the Heiman Lab completed several cell-type-specific studies of how disease-affected cells change in mouse models of Huntington’s disease, as well as how disease-affected cells change during the course of Parkinson’s disease, with and without therapeutic treatment. The results from these studies will be prepared for publication, and suggest cell-type-specific therapeutic targets that were previously unappreciated. In a series of pilot experiments, the Heiman Lab collected promising preliminary data related to building better models of human neurodegenerative disease by combining human-induced pluripotent stem cells, xenografting, and molecular labeling.

Neville Hogan

To date, the agility of human locomotion has eluded robots. The Hogan Lab has shown that key features of human locomotion require only simple sensory feedback—provided it is combined with appropriately controllable “shock-absorber” behavior in the legs. The Hogan Lab developed unique technology to measure the “shock-absorber” behavior in humans and new technology to measure comparable behavior in rats. The latter will enable extending these studies to persons with spinal cord injury to facilitate their recovery.

Nancy Kanwisher

The Kanwisher Lab discovered that Broca’s area, a brain region that has been debated for 150 years, in fact consists of two functionally very different subregions: one very specialized for language processing, and another broadly engaged in multiple cognitive demands. In another line of work, the Kanwisher Lab showed that a region on the lateral temporal lobe processes the pitch of a tone complex primarily using spectral (not temporal) cues to pitch, neatly fitting prior psychophysical work on pitch perception.

Troy Littleton

The Littleton Lab during the last year has revealed new insights into how synaptic connections form and function to transmit information within the brain. They have characterized the role of several key proteins, including synaptotagmin, complexin and synaptogyrin that form the molecular machinery that allows the presynaptic side of the synapse to release neurotransmitters and initiate neuronal signaling in the brain. They have also used *Drosophila* as a genetic system to model Huntington’s Disease (HD), an adult-onset neurodegenerative disorder resulting from an expansion of a polyglutamine (polyQ) track within the Huntingtin (Htt) protein. They have generated *Drosophila* HD transgenic models expressing fluorescently tagged wildtype and pathogenic Htt proteins that allow for in vivo imaging of Htt localization, axonal transport and aggregate formation in live animals. They have identified several pathologies associated with Htt polyQ expression in fly neurons, and have identified small molecules and genetic

interactors that can revert HD pathology in our system. They are also studying mutants of the *Drosophila* Htt homolog to define the normal function of Htt within neurons. Together, these approaches have advanced our understanding of HD pathophysiology and provided new insights into how synapses normally mediate communication between neurons.

Elly Nedivi

A key feature of the mammalian brain is its capacity to adapt in response to experience, in part by remodelling of synaptic connections between neurons. Excitatory synapse rearrangements have been monitored *in vivo* by observation of dendritic spine dynamics, but lack of a vital marker for inhibitory synapses has precluded their observation. The Nedivi Lab's developed a method to simultaneously monitor *in vivo* inhibitory synapse and dendritic spine dynamics across the entire dendritic arbor of pyramidal neurons in the adult mammalian cortex using large volume high-resolution dual color two-photon microscopy. They found that inhibitory synapses on dendritic shafts and spines differ in their distribution across the arbor and in their remodeling kinetics during normal and altered sensory experience. Further, they found inhibitory synapse and dendritic spine remodeling to be spatially clustered, and that clustering is influenced by sensory input. The Nedivi Lab's findings provide *in vivo* evidence for local coordination of inhibitory and excitatory synaptic rearrangements.

Tomaso Poggio

During this past year, the Poggio Lab released as open software the GURL system—a comprehensive toolbox for regularized machine learning applications. Poggio Lab members also extended an automatic phenotyping system to multiple mice, and they plan to release the associated software. In terms of pure scientific research, the two main accomplishments were the skeleton of a mathematical theory of the ventral stream based on invariance to affine transformations, and measuring with magnetoencephalography the timing of the onset of visual invariances in human visual cortex.

Mary Potter

Previously, the Potter Lab showed that observers can detect a verbally defined picture target (e.g., “people in a restaurant”) when viewing an uninterrupted stream of six pictures, all new to them, presented as briefly as 13.3 milliseconds per picture. Moreover, performance was also above chance when the name of the picture was presented immediately after the sequence, so that participants had to process and remember the pictures without knowing what they were looking for. To determine whether increasing the number of pictures per sequence would interfere with detection—at least in the condition requiring memory—the Potter Lab replicated the experiments using 12-picture sequences. It obtained the same results, even in the memory-recognition condition. The findings support a rapid feedforward model of visual comprehension in which the first few milliseconds of processing at each level in the visual system can be sufficient to activate a representation at the highest level, the level of meaning—whether the target meaning is specified in advance or only immediately after viewing.

Laura Schulz

As early as 18 months, infants can use the time and effort associated with achieving a goal-directed action to distinguish agents, and infants prefer more competent agents when asked to choose between a competent and an incompetent agent, each of whom acts as a moral bystander and refuses to engage in a helpful action. The Schulz Lab members find a sustained preference for the more competent agent until the age of three, when the preference is reversed. They argue that the ability to calculate the cost and benefits of goal-directed action originates in early childhood and plays a fundamental role in moral reasoning. Mental states, such as beliefs, desires, and intentions, are not directly observable and must be inferred. Computational and developmental evidence suggests that humans explain and predict mental states through the principle of rationality—the expectation that intentional actions are the product of an efficient plan to achieve desires, given one’s knowledge about the world. In a second study, they found that five- and six-year-olds are able to make judgments about competence when given information about the preferences of an agent and her behavior. Moreover, they find that children are able to design simple interventions to test an agent’s competence when given information about the agent’s preferences.

Sebastian Seung

The Seung Lab launched EyeWire, the first online community that mobilizes the public to participate in neuroscience research. EyeWriters map connections between retinal neurons by playing a game of coloring images from serial electron microscopy. By year-end, EyeWiring had registered more than 22,000 members. In a collaboration with Pavel Osten (Cold Spring Harbor Laboratory), Seung Lab members demonstrated the use of automated microscopy and image analysis to study structure and function of whole mouse brains. With Gordon Shepherd (Yale University), they used retrograde delivery of ChR2 via rabies virus to study the connectivity of motor cortical neurons. With Jeff Lichtman (Harvard University), they demonstrated marked elimination of branches and synapses at the mammalian neuromuscular junction shortly after birth.

Pawan Sinha

The Sinha Lab made headway along three related research avenues, corresponding to visual processing in three subject populations. First, working with normally developing adult individuals, Sinha Lab members were able to uncover systematic differences between the two cerebral hemispheres in terms of how they analyze images of faces. This was the first clear demonstration of hemispheric variations in high-level vision. Second, in their work with the newly sighted Prakash children, they found compelling evidence of rapid change in visual abilities as well as brain organization following sight surgery. These results also seeded computational work that seeks to develop machine vision systems capable of autonomous learning. Third, they formulated a hypothesis regarding causal factors for sensory processing (visual as well as auditory) deficits in autism. This hypothesis has proven very effective in guiding experiments, and pilot results were submitted for presentation at the International Meeting for Autism Research.

Mriganka Sur

The Sur Lab developed cutting-edge tools and used them to answer foundational questions about cortical development and function and how they go awry in brain disorders. In one study, Sur Lab members used a combination of very high resolution imaging of neuronal activity in space and time, and single cell stimulation in genetically engineered mice, to reveal computational principles of inhibitory neuron function in visual cortex. In another study, they showed that astrocytes receive cholinergic drive from the nucleus basalis and are critical for stimulus-specific neuronal plasticity in visual cortex. Since inhibitory networks and astrocytes are implicated in a variety of brain disorders, including autism and schizophrenia, these findings point to important ways by which cortical circuits are impacted in these disorders.

Josh Tenenbaum

The Tenenbaum Lab was able to build some of the first computational models that capture core domains of human common sense reasoning, such as intuitive physics and intuitive psychology, and that can explain how people construct these intuitive theories based on their experience in the world. This progress comes from being able to express intuitive theories as probabilistic programs, and to explain learning as a form of program induction or program synthesis. The Tenenbaum Lab has shown how these models can provide unprecedented quantitative fits to the common-sense inference and learning behavior of both infants and adults. The models have also enabled new, more human-like machine learning algorithms for data analysis and artificial intelligence (AI); as a testament to this progress, Professor Tenenbaum was invited to give keynote talks at both major AI conferences—the Association for the Advancement of Artificial Intelligence, and the International Joint Conferences on Artificial Intelligence—as well as at the more specialized conference on Uncertainty in AI (UAI). UAI also awarded its 2012 best student paper prize to a student in the Tenenbaum Lab for his work on a more human-like machine learning algorithm that automatically discovers the form of structure in matrix decompositions, a core aspect of data modeling that previously was strictly the province of human analysts and practitioners.

Kay Tye

Major depression is characterized by diverse debilitating symptoms, including hopelessness and anhedonia. Among many neural populations hypothesized to be relevant, dopamine neurons have been considered as potentially involved in the pathophysiology of these diverse symptoms, in part because certain antidepressant treatments, including medications and brain stimulation therapies, may (along with other effects) target aspects of the complex central nervous system dopamine system. But until now, it has not been possible to directly test this hypothesis, even in animal models, since existing therapeutic interventions do not provide specificity for dopamine neurons. The Tye Lab directly investigated the causal contributions of defined dopamine neurons to multidimensional depression-like phenotypes induced by chronic mild stress by integrating behavioral, optogenetic, and electrophysiological methods in freely-moving rodents. Tye Lab members found that bidirectional control (inhibition or excitation) of specified midbrain dopamine neurons immediately and bidirectionally modulated (induced or relieved) multiple unrelated depression symptoms caused by

chronic stress. In probing circuit implementation of these effects, they observed that optogenetic recruitment of these dopamine neurons potentially altered the neural encoding of depression-related behaviors in the downstream nucleus accumbens of freely-moving rodents, suggesting that depression symptoms could involve alterations in the neural encoding of action in limbic circuitry.

Weifeng Xu

The Xu Lab found that manipulating synaptic scaffold contents mainly influences the functional connection numbers rather than the strength of individual connection. This has great implication in how the neural circuit is maintained and modified during development, experience-dependent plasticity, and pathological conditions. The Xu Lab found that a small neuronal protein, neurogranin, is dynamically regulated by experience and neuronal activity. The activity-dependent regulation of neurogranin is fast, providing a novel mechanism of regulating neural plasticity by influencing calcium/calmodulin dynamics. Changes in neurogranin levels directly impact synaptic strength, neuronal excitability, and synaptic plasticity. This can serve as a master regulator for plasticity with defined temporal control, and facilitate learning and memory.

Feng Zhang

In the past year, Zhang Lab members made significant progress in advancing their ability to probe the role of genetics and epigenetics in brain function. First, they optimized the transcription activator-like effector (TALE) system to achieve efficient and precise targeting of the mammalian genome. Second, they applied TALEs to probe the causal role of gene mutations in brain disease. Third, they developed a system for using light to control gene expression in the brain. Fourth, they developed a novel RNA-guided genome editing technology. Ongoing efforts are focused on developing TALE and clustered regularly interspaced short palindromic repeats (CRISPR)-based genome editing technologies for in vivo applications in the brain, to accelerate the ability to probe the role of gene, genetic, and epigenetic processes in brain function and diseases.

Selected Faculty Awards and Honors

Professor Brown and senior research fellow Zhe Chen won third place in the Brain Corporation Prize in Computational Neuroscience for their *Scholarpedia* article “State space model.”

Professors Brown and Zhang were awarded High Risk–High Reward grants from NIH for their innovative research programs. Professor Brown will collaborate with Professors Wilson and Boyden, as well as Ken Solt, MD, of Massachusetts General Hospital, to redesign general anesthesia. Professor Zhang will probe neuropsychiatric diseases using targeted epigenome and genome engineering.

Professors Desimone, Boyden, Brown, and Seung were invited to the White House for President Obama’s announcement of the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative.

Professor Boyden was named as the 2013 recipient (along with five other researchers) of the Grete Lundbeck European Brain Research Prize, the largest monetary prize in neuroscience, for his role in the development of optogenetics. In connection with the

award, he was profiled by Cable News Network (CNN), *The New Yorker*, and *MIT News*. Professor Boyden was also awarded the A. F. Harvey Engineering Research Prize for his pioneering research contributions to the field of optogenetics.

Professor Emerita Sue Corkin received the Baltes Distinguished Research Achievement Award from the Division on Adult Development and Aging of the American Psychological Association. This award recognizes distinguished careers and outstanding contributions to the psychological science of aging.

Institute Professor Graybiel was invited to the White House to meet President Obama, in recognition of her Kavli Prize.

Professor Kanwisher received the BCS Award for Excellence in Undergraduate Teaching.

The newest BCS faculty-member, Professor McDermott, was selected for a James S. McDonnell Foundation Scholar Award in Understanding Human Cognition.

Professor Martha Constantine-Paton was elected to the American Academy of Arts and Sciences. She was also awarded the Society for Neuroscience's Mika Salpeter Lifetime Achievement Award, which recognizes individuals with outstanding career achievements in neuroscience who have also actively promoted the professional advancement of women in neuroscience. Professor Constantine-Paton received the Dean's Medal from the Tufts School of Arts and Sciences for her contributions to science; she is the fifth person to receive this award since its inception in 2005.

Professor Schulz was named a 2013 MacVicar Fellow, the highest honor awarded by MIT for excellence in undergraduate teaching. In addition to being a model teacher, Professor Schulz serves BCS as its undergraduate officer and a member of its Education Committee.

Professor Sinha was selected for a Presidential Early Career Award for Scientists and Engineers, the highest honor bestowed by the US government on science and engineering professionals in the early stages of their independent research careers.

Professor Sur received the BCS Award for Excellence in Undergraduate Advising.

Professor Tye was selected by the Esther A. and Joseph Klingenstein Fund to receive a Klingenstein Fellowship Award. She was also selected by MIT to receive the Whitehead Career Development Chair.

Professor Zhang was selected to receive a Vallee Foundation Young Investigator Award and was selected by MIT to receive the Keck Career Development Chair.

James J. DiCarlo
Department Head
Professor of Neuroscience
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