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. We are 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: 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. We also uphold a core value of MIT — that sufficient explanations of these processes must ultimately be rooted in the language of mathematics and computational theory.

A unique and defining identity of our department is that we pursue all these levels of analysis in an integrated and synergistic way. Arguably, no other department in the world is 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) as well as BCS, gives us the opportunity to continue to lead in our mission. The mission of BCS thus spans research, teaching, and training in both neuroscience and cognitive science.

Leadership

BCS has an important "umbrella" role to play in strengthening the Building 46 community. Because there is no silver bullet to creating stronger community, we are making efforts on many fronts. Our overall strategy is to focus on strengthening sub-communities that include members of groups throughout the entire building (especially faculty, graduate students, postdocs, and staff). This will continue to "lower the walls" between the various units in Building 46.

Building-wide leadership: The BCS Council includes 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 (SCSB); and senior and junior faculty members spanning all areas of the department. The BCS Council meets monthly to advise BCS on departmental decisions and ensure that all leaders in the building are comfortable with and enthusiastic about those decisions.

BCS faculty leadership roles: BCS would not be able to plan and execute the department's myriad missions without faculty support, and we continue to espouse a culture of shared effort across the faculty. The following faculty have notably stepped up to take on or continue leadership roles over the last two years:

- Michale Fee (associate department head for education and chair of the Education Committee)
- Laura Schulz (undergraduate officer)

- Matt Wilson (graduate officer and chair of the Graduate Admissions Committee and Graduate Affairs Committee)
- Nancy Kanwisher (BCS space czar and global chair of all BCS-related faculty searches, including those with possible appointments in MIBR or PILM)
- Alan Jasanoff (chair of the Seminar Committee)
- Sue Corkin (chair of the Junior Faculty Mentorship Committee)
- Pawan Sinha (chair of the Diversity Committee)

Nearly all BCS faculty now actively serve on one or more of these committees.

Community

Strengthening community at all levels within BCS and our affiliated institutes has been among our top priorities. Our strategy is to strengthen sub-communities that horizontally integrate across the institutes in Building 46 — faculty, postdocs, graduate students, undergraduate students, and staff. More specifically, we aim to create an environment that empowers sub-communities and allows them to flourish in directions that grow from their grass roots. One goal that has come to fruition this past year is the creation of standing committees at the faculty level. We also worked to identify and empower leaders among various sub-communities (graduate students, undergraduates, postdocs, and junior faculty) who help organize events and represent the concerns of those sub-communities to the department. The BCS headquarters staff has been instrumental in providing the committees with administrative support.

We have continued to make particular progress with the postdoc community, and we have identified graduate student representatives who want to help improve the graduate student experience. The plan is for those representatives to have a stronger voice in regard to decisions that might affect graduate students. Key opportunities we hope they will embrace are: 1) serving as a grad student rep on the BCS Education Committee (helping us to make decisions about the curriculum, lab rotations, qualifying exam process), 2) helping to plan career development events or programs (alumni networking, mock interviews), 3) planning social events for all students (thus spanning the entire department) with a dedicated budget from the department, and 4) outreach to the local community (science festivals) and undergraduates (a mentorship program).

We are also striving to improve communications and deepen collegiality across the BCS community. For example, we continue to have regular BCS-wide faculty meetings (once a month) and regular BCS-wide faculty lunches (one a month). DiCarlo continues to send a BCS-wide email at least once a month, highlighting recent awards, honors, and achievements of all the members of our community.

One of the most exciting new community events this year (June 1–2, 2014) was our first-ever building-wide overnight research retreat, jointly sponsored by BCS, MIBR, and PILM. All faculty, postdocs, graduate students, and research staff across Building 46, plus some outside Building 46, were invited. The retreat included research talks given by postdocs and senior graduate students selected from a range of labs across the entire building, a research poster session, and social time and events. By all accounts, the event was a huge success.

Faculty

BCS faculty members are widely recognized as leaders in their respective fields. Of 48 total faculty, 38 hold primary appointments in BCS, and 10 hold primary appointments elsewhere. Of the 38 primary appointments, nine hold appointments in PILM, and 16 hold appointments in MIBR. Two faculty members have joint appointments at the Broad Institute, two have joint appointments at the Institute for Medical Engineering & Science, two 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. The nine faculty members who held joint appointments this past year in BCS represent Mechanical Engineering, 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 the Linguistics section of Linguistics and Philosophy.

Graduate Program

Progress has also been made in planning improvements to the graduate curriculum. A meeting with a focus group of graduate students identified a number of important issues. It also revealed a broad consensus among the students that improving the "systems neuroscience" core course (9.011, currently taken by all BCS graduate students) should be a top priority moving forward, and we are working to address that.

Eleven graduate students entered in fall 2013. Two of the incoming students were funded by Singleton Presidential Graduate Fellowships, one by the Praecis Presidential Graduate Fellowship, one by the ASTAR fellowship, five by National Institutes of Health (NIH) training grant programs, one by a special BCS donor award, and one by a special Office of the Dean for Graduate Education fellowship award.

During this year, nine students graduated with doctorates: Aline Dorret Blunk, Paul L. Aparicio, Eric M Jonas, Joel Zaidspiner Leibo, Laura Lewis, Kartik Ramamoorthi, Nikhil Bhatla, Yarden Katz, and Michael Samuel Sidorov.

Nine students were awarded the Angus MacDonald Award for Excellence in Undergraduate Teaching. Stephen Allsop received the BCS Walle Nauta Award for Excellence in Graduate Teaching, and Laura Stoppel Ramirez received the BCS Walle Nauta Award for Continuing Dedication to Teaching.

Undergraduate Program

BCS continues to make progress in improving the undergraduate curriculum. All incoming students are now expected to take programming and statistics in their sophomore year, as well as 9.40, a new Tier 1 course on quantitative and computational approaches to neuroscience. Rolled out this past spring semester, 9.40 covers basic neuronal biophysics, quantitative approaches to describing and computing receptive fields, and mathematic treatments of simple feedforward and recurrent networks.

The course also gives the students familiarity with mathematical concepts such as correlation, convolution, Fourier series and spectral analysis, linear algebra and eigenvalue decomposition, principal components analysis, and singular value decomposition. Furthermore, the course emphasizes practical problem solving through MATLAB-based problem sets. Student evaluations indicated that the course was well received. Professor Michale Fee deserves kudos for his effort in rolling out this course. We are now adding and modifying several Tier 2 courses to take advantage of this new Tier 1 common foundation expected of all our students.

During AY14, BCS had 120 undergrads, with 44 graduating seniors: Eloho Fidelia Akpovi, George H. Bailey, Zuzanna Z. Balewski, Sean Batir, Sebastian K. Begg, Mika Braginsky, Luke A. Chellis, Emily K. Chen, Nora A. Darago, Christopher Delgado, Aliya P. Dincer, Salvador Esparza, Emilio A. Gonzalez, Heath P. Gould, David S. Han, Stephanie S. Holden, Da Sul Jin, Jaes C. Jones, Jared T. Katz, Nathaniel L. Kim, Jaclyn A. Konopka, Jiahao Liang, Jiayi K. Lin, Sarah R. Lund, Rebecca A. MacRae, Tomer R. Mangoubi, Christine J. Park, Joseph P. Perricone, Aviana L. Polsky, Lauren Quisenberry, Laya Rajan, Ricardo Reyna Fernandez, Christine K. Rogers, Elisabeth L. Rosen, Elise L. Ruan, Hannah F. Schiller, Katalina J. Sher, Harrison R. Siegel, Emad Taliep, Samuel B. Thacker, Natalia A. Velez-Alicea, William G. Watkins, Anjuli J Willmer, Yijing Xin.

Six Course 9 majors were inducted into Phi Beta Kappa, 10 received the BCS Hans Lukas Teuber Award for Outstanding Academics, and eight received the Walle J. H. Nauta Award for Outstanding Research in Brain & Cognitive Science.

Development Activities

BCS development efforts continue to be led by Elizabeth Chadis, assistant dean for development for the School of Science, and BCS senior communications and development assistant Rachel Traughber.

BCS's top fundraising priorities continue to include endowed and expendable fellowships for graduate students and postdocs, endowed career development chairs and professorships, and unrestricted research funds. While the department has several strong supporters of graduate students, we have been working to expand that giving through our new Champions of the Brain Fellows Society. This year, with the help of existing generous departmental supporters, we hosted our first annual Champions of the Brain Fellows dinner, created to recognize the generosity of those friends and alumni who make it possible for BCS graduate students to explore their scientific dreams. Our Champions include Gerald Burnett, Mark Gorenberg, Nancy and Jeffrey Halis, Anne and Paul Marcus, William McClelland, Janet and Shelly Razin, Mrs. Hubert Schoemaker, Caroline and Henry Singleton, Eugene Stark, Barbara Weedon, and Barrie HM and Al '51 Zesiger (our "Champions of the Champions"). This exciting, well-attended event was a tremendous way to demonstrate the importance of our graduate students to our mission and to immerse donors in the exciting research being carried out by their student fellows. It has already led to additional student support, and we plan to continue this annually.

Research Highlights

Edward Adelson

The Adelson Lab has made progress on three main fronts: 1. Visual perception of translucent materials: Many everyday materials, such as skin, food, wax, or marble, have some level of translucency. The physics of sub-surface scattering is complex, so they have sought simplified descriptors that capture the important visual qualities. The Adelson Lab has found a two-dimensional parameterization that captures the properties that are most important perceptually. 1: Subband manipulation of surface appearance: Photographers care greatly about the reflective qualities of surfaces. A portrait photographer may use face powder or broad lighting to reduce the specular reflections; a food photographer may spray an item to increase specular reflections. They have developed methods to control material appearance after the fact by image processing and perform a subband decomposition and then boost or reduce specific parts of the subband histograms. 2. Tactile sensing for robotic fingertips: a compact version of the elastomeric GelSight sensor that is small enough to attach to a robot gripper. With this sensor they can detect surface texture, force, shear, and slip. The Adelson Lab is collaborating with robotics researchers to exploit this technology in manipulation tasks.

Marc Bear

Bear's most important research accomplishment includes the publication of a study showing that lovastatin, a drug in widespread use to control high cholesterol, can correct the core pathophysiology in the mouse model of fragile X syndrome, the leading known inherited cause of intellectual disability and autism. The Bear Lab's previous work had implicated excessive cerebral protein synthesis downstream of an mGluR5-Ras-ERK signaling pathway as responsible for multiple signs (phenotypes) of the disease. Lovastatin is a mild inhibitor of Ras signaling, and remarkably this inhibition is sufficient to normalize protein synthesis and correct phenotypes including cortical hyperexcitability and seizures. In addition to their ongoing work on fragile X and autism, the Bear Lab continues to study experience-dependent visual cortical plasticity, and finds that many higher cognitive functions can be served by synaptic modification in the primary visual cortex (V1). One of these functions is learning to anticipate the timing of a reward after presentation of a visual cue. They discovered that this learning is possible in V1, even in a preparation where V1 is separated from the rest of the brain in vitro. This preparation gives them an unprecedented opportunity to study the mechanism of reward-dependent timing activity in the brain.

Emery Brown

Each day, nearly 60,000 patients receive general anesthesia. However, brain-state monitoring is not an accepted practice in anesthesia care, because markers that reliably track changes in level of consciousness under general anesthesia have yet to be defined. The Brown Lab has identified in humans specific behavioral and electrophysiological changes that mark the unconsciousness and the transitions between consciousness and unconsciousness induced by the widely used anesthetic propofol. Their results provide insights into the mechanisms of propofol-induced unconsciousness and establish electroencephalogram (EEG) signatures of this brain state that can be used to monitor the brain activity in patients receiving general anesthesia.

James DiCarlo

The DiCarlo Lab remains focused on understanding the neural mechanisms underlying visual object perception. Specifically, by studying neural activity in primate animal models, they seek to understand how sensory input is transformed by the human brain from an initial representation (essentially a photograph on the retina) to new and remarkably powerful patterns of neural activity that can support humans' seemingly effortless ability to solve the computationally difficult problem of object recognition. Over the past several years, the DiCarlo Lab has shown that patterns of neuronal activity in the inferior temporal cortex (IT) of the primate brain can explain human object-recognition abilities, suggesting that human and non-human primates share a common neural substrate for object perception. They have also developed and tested new computational models that can predict IT patterns of neural activity from visual images much more accurately than any previous model of visual processing, suggesting that these models are emulating the brain's computing strategy. Most recently, they have found that they can reliably perturb the IT neural activity patterns using new optogenetic methods that allow neurons to be controlled by light. These techniques are allowing them to strongly test predictions of the understanding they have helped to build, by asking how direct neural perturbations influence visual report, i.e., perception. The optogenetic techniques also open the door to future brain-machine interface possibilities, e.g., in the case of blindness due to retinal loss or degeneration. The DiCarlo Lab continues to close in on an end-to-end understanding of visual object perception — from the patterns of light striking the eye to human perception of object identities in the world.

Guoping Feng

The Feng Lab's research is focused on how defects in neuron-neuron communication contribute to psychiatric disorders such as obsessive-compulsive disorder and autism. Using mice as a model system, the Feng Lab discovered a new signaling mechanism leading to compulsive behavior in mice. This abnormal behavior can be rescued by correcting defects in this pathway. If confirmed in humans, this could become a drug target for developing treatment of obsessive-compulsive disorder. The Feng Lab has also developed new animal models for autism and schizophrenia and revealed specific circuit dysfunction in these models. These studies will advance understanding of the pathogenic mechanism of these debilitating disorders.

John Gabrieli

The Gabrieli Lab discovered a neuroanatomical difference in pre-reading kindergarteners that appears to predispose children toward typical or impaired (dyslexia) reading acquisition. This research involved a partnership with 19 diverse district, charter, and religious schools. At these schools, 1,433 children were screened on behavioral measures of language and other cognitive skills associated with learning to read. Then, 180 children came to MIT for neuroimaging and more extensive behavioral evaluation. The neuroimaging included diffusion tensor imaging (DTI), which provides measures of the size and nature of large white-matter pathways that connect relatively distant brain regions. Children whose behavioral scores revealed language weaknesses associated with risk for dyslexia had reduced volumes and organization of the left arcuate fasciculus, which connects the two regions most important for language in the human brain. Because these findings were made in children who had not yet received formal reading instruction, they could be interpreted as revealing a neuroanatomical cause (rather than a consequence) of dyslexia. These findings may help to more accurately identify children who are at true risk for dyslexia, and such identification could lead to early treatment that occurs prior to, instead of following, reading failure.

Edward Gibson

In the past year, the Gibson Lab has been investigating the hypothesis that human language is a rational inference system, and that furthermore it may have evolved for use in communication. To this end, the Gibson Lab showed that language comprehension appears to function as a noisy channel process, in line with communication theory. Several predictions of this way of thinking of language are true: (1) the more noise that is needed to edit from one alternative to another leads to lower likelihood that the alternative will be considered; (2) in the noise process, deletions are more likely than insertions; (3) increasing the noise increases the reliance on the prior (semantics); and (4) increasing the likelihood of implausible events decreases the reliance on the prior. Second, the Gibson Lab has shown that this way of thinking about language leads to a simple rethinking of the P600 from the event-related potentials literature. Although the P600 wave was originally proposed to be due to people's sensitivity to syntactic violations, the Gibson Lab showed that it can best be interpreted as sensitivity to an edit in the signal, in order to make it more easily interpretable. Third, thinking of language as communication can explain aspects of the origin of word order. Some recent evidence suggests that subject-object-verb (SOV) may be the default word order for human language. The Gibson Lab proposes that the high percentage of SVO languages cross-linguistically is due to communication pressures over a noisy channel. They provide several gesture experiments consistent with this hypothesis, and speculate how a noisy channel approach might explain several typical word-order patterns that occur in the world's languages.

Ki Goosens

The Goosens Lab recently demonstrated that chronic stress leads to vulnerability to excessive fear by enhancing signaling through a ghrelin–growth hormone axis. Perhaps even more important, they have shown that these hormones do not act through canonical stress pathways like the hypothalamus-pituitary-adrenal (HPA) axis, and instead appear to act in parallel to these other stress pathways. The Goosens Lab is the first to demonstrate a causal role for these hormones in adverse consequences of stress. They are also the first to argue for the existence of a second stress "axis." This is critical, because it provides a completely new set of targets in stress-sensitive mental illness.

Ann Graybiel

We all develop habits, and in some disorders, such as autism and obsessive-compulsive disorder, repetitive behaviors can become dominant. The Graybiel Lab has used the technique of optogenetics to examine the control pathways that underlie habits. They have discovered, in experiments on mice and rats, that specific brain circuits are involved in generating habits. By turning on and off these circuits, they can turn on and off normal habits and can turn off compulsive behavior. Again using rodents as experimental subjects, the lab discovered novel signaling involving the brain transmitter dopamine, known for its importance in Parkinson's disease and in neuropsychiatric disorders. These signals grow as the animals move to goals that yield reward, suggesting that they might drive motivated behaviors. Finally, the Graybiel Lab characterized the coordinated neural changes that occur when a Parkinson's-like state is induced in rodent models, and when the animals are given levo-dopa therapy, typically given to patients. They found a near-universal reorchestration of activity in the striatum of the basal ganglia and its recovery with levo-dopa.

Myriam Heiman

This past year the Heiman Lab: 1) discovered two neuronal-enriched factors that may contribute to cellular and organismal aging phenotypes; 2) demonstrated how the characteristics of one cell type (medium spiny neurons) make it more vulnerable to the mutant huntingtin protein in Huntington's disease; and 3) developed a new methodology that allows for "synthetic lethal" genetic screening in mouse brain, which the lab is currently applying to the study of Huntington's disease.

Mehrdad Jazayeri

This past year the Jazayeri Lab, a relatively new lab, has been in setup mode, but the group has achieved a few milestones: 1) They have adapted the intracellular recording technique, which has only been used in vitro and in small animal models, to the non-human primate model. 2) They have developed a head free training system for monkeys; three monkeys are at different stages of training, with one nearing electrophysiological recording. 3) Two ongoing human psychophysics experiments are probing the computational principles by which human subjects measure, produce, and memorize different time intervals.

Nancy Kanwisher

The Kanwisher Lab this past year conducted a study identifying a pitch-sensitive region in human auditory cortex, in collaboration with Joshua McDermott. This work is an exciting and new direction for the Kanwisher Lab. In addition, work being done with Ev Fedorenko and John Duncan shows that extensive regions of the frontal and parietal lobes are extremely domain-general, that is, they respond to any kind of cognitive load, independent of the nature of the task. This had been claimed before but never shown within individual subjects, as necessary to provide the strongest evidence for domain generality possible in humans.

Yingxi Lin

In the past year, the Lin Lab has been focusing on developing tools that allow for the identification and manipulation of ensembles of neurons as they participate in the processing of the influx of sensory information. This Robust Activity Marking (RAM) system is composed of two key elements: a generic activity-regulated promoter that is strongly activated by sensory stimulation, and a downstream effector gene to allow subsequent investigation and manipulation. The RAM system has the following properties: 1) low expression in basal conditions prior to a designated sensory stimulation; 2) strongly induced by neuronal activity during sensory experience to allow for strong labeling; 3) small size to be packaged into adeno-associated viruses (AAVs); and 4) a modular design so that the promoter and effector gene can easily be substituted to address specific experimental questions. Using the RAM system, they were able to identify unique electrophysiological properties of neuronal ensembles that are recruited to encode sensory information. An added advantage of the RAM system is that it can easily be applied to species other than the mouse, making it a valuable tool for the wider neuroscience community. The system has been successfully used in drosophila and rats.

Joshua McDermott

This past year the McDermott Lab, a relatively new lab, has been in setup mode, but the lab has achieved a few milestones. The lab started new research projects on reverberation, auditory attention, and biologically inspired source separation, all of which yielded promising results. They also collected pilot data for R01 submissions, submitted R01 and NSF grants (with another faculty member) to fund auditory fMRI research, and published the first paper from the McDermott Lab - an fMRI study of pitch-selective regions in human auditory cortex.

Earl Miller

The brain is highly rhythmic. The Miller Lab has been mounting evidence that the brain rhythms play a central role in communication within the brain. For example, in the past year, they have found that learning is accompanied by increased rhythmic synchrony between the prefrontal cortex (the brain's "executive") and subcortical structures important for memory. This includes the discovery that the learning of arbitrary associations (e.g., face-name) is guided by the prefrontal cortex and hippocampus signaling success or failure of learning via synchrony in different frequency bands (higher vs. lower, respectively). They have also found that the learning of new visual categories is accompanied by increased synchronization between the prefrontal cortex and striatum. The result is category-specific patterns of synchrony suggestive of rhythm-based neural ensembles for each category. The rhythms may allow the brain to exploit multifunction "mixed-selectivity" neurons in higher cortex by allowing those neurons to communicate different messages with different networks by virtue of whom they are synchronized with. In the past year, the Miller Lab published a paper showing that multifunction neurons are critical for cognition. They add computational horsepower to the brain by providing a multidimensional computational workspace.

Elly Nedivi

Clathrin-mediated endocytosis (CME) is one of several mechanisms for retrieving plasma membrane constituents and transmembrane proteins from the cell surface. At the synapse, CME of AMPA-type glutamate receptors (AMPARs) from the postsynaptic membrane is thought to be the substrate for various forms of plasticity. The cellular F-actin cytoskeleton has been implicated in CME, and is known to play a role in internalization of AMPAR and the control of synaptic strength. However, the mechanisms by which the F-actin cytoskeleton implements endocytosis, and the regulatory molecules involved, remain elusive.

AMPAR internalization is regulated by a number of genes, including Cpg2. The Nedivi Lab previously showed that the CPG2 protein regulates constitutive and activity-induced internalization of synaptic glutamate receptors. Structurally, CPG2 shows homology to F-actin-binding proteins. Given its role in glutamate receptor internalization and its potential to bind F-actin, the Nedivi Lab tested whether CPG2 constitutes a molecular link between CME and the cytoskeleton in dendritic spines. Their results identify CPG2 as essential for functional coupling of synaptic AMPAR CME with the spine cytoskeleton and as a key integration point for second messenger signaling with the synaptic endocytic process. Cpg2 has recently been identified as a risk gene for bipolar disorder.

Tomaso Poggio

The Poggio Lab's research is on the problem of learning in both biological organisms and computers. Their work thus spans three research directions: mathematics, engineering, and neuroscience of learning. In the latter direction, they are developing a broad theory that attempts to explain and predict cortical architecture and properties of neurons in different visual areas in the ventral stream.

The theory shows how a multilayer hierarchical architecture of dot-product modules can learn in an unsupervised way to be automatically invariant to transformations of a new object, achieving the goal of recognition with very few labeled examples. The theory should apply to a range of hierarchical architectures, such as visual cortex, HMAX (hierarchical model and x), and deep convolutional networks, and it may initiate a new phase in machine learning. The first phase, which played out during the last 20 years, led to a mature mathematical theory of supervised learning and a number of commercial applications. This first phase is characterized by n (number of labeled examples) approaching infinity: the more data the better. The second phase is about learning from very few labeled examples, similar to how children learn.

Mary Potter

The Potter Lab's prior work on the visual perception and understanding of rapidly presented picture sequences supported a rapid feedforward model of visual comprehension in which the first few ms of processing at each level in the visual system are 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. In the last year, the Potter Lab completed several other related studies. One supported a disputed claim that objects are initially perceived at a specific level (e.g., dog) rather than a more general level (animal). Another showed that targets in grayscale photographs were as readily detected as in color photographs, even with very brief presentations, but when filtered to include only low spatial frequencies, detection was poor (contrary to one prominent hypothesis). A third experiment found that delaying the target name reduced recall of the target after the sequence. A pilot study is under way (in collaboration with Kanwisher and Pantazis) to evaluate the use of MEG to investigate the time course of perception of rapid pictures.

Gerald Schneider

In 2013, Schneider completed a book to be published by the MIT Press early in 2014. Titled *Brain Structure and Its Origins: In Development and in Evolution of Behavior and the Mind,* the book includes reviews of Schneider's research findings with illustrations and new theoretical ideas. Schneider has also carried out new work on a project describing observations and analyses of effects of hypoglycemia on brain functions, some of which have never been described in scientific literature.

Laura Schulz

One of this year's highlights for the Schulz Lab is a methods project: an online interface for testing infants and children. The interface, called Lookit!, allows the lab to recruit participants online, collect behavioral data from participants' webcams (including infant looking time), and transmit the data securely back to MIT. This will allow the lab to efficiently collect samples that are both far bigger and far more diverse than previously possible. A research highlight is preliminary evidence suggesting that infants are, in some respects, like split-brain patients: they have difficulty integrating visual concepts across hemispheres. In one experiment, the Schulz Lab showed that infants successfully represent two identical shapes as "matching" when the shapes are presented in the same visual hemifield, but not when presented bilaterally. In a second experiment, they showed that infants represent 16 dots as 16 dots when the dots are in one hemifield but not when eight dots are in each hemifield. One interesting aspect of the study is that it provides a behavioral assay of infant neural development: the maturation of the corpus callosum.

Mriganka Sur

In the past year, the Sur Lab made important advances in three areas. First, they developed next-generation two-photon scanning methods for massive scale recording of the activity of identified single cortical neurons. They are using these methods for simultaneously imaging the activity of thousands of neurons from multiple cortical areas in awake behaving animals — such recordings are a cornerstone of the NIH BRAIN Initiative. Second, they demonstrated precise inhibitory-disinhibitory microcircuits in cerebral cortex by which neurotransmitters such as acetylcholine organize the temporal responses of neuronal populations and enhance information representation and coding during attention and arousal states. Third, they were involved in a clinical trial demonstrating safety and efficacy of a novel therapeutic for Rett Syndrome, a devastating disorder of brain development. The therapeutic, proposed by the Sur Lab in animal models, is the first mechanism-based therapeutic for Rett Syndrome.

Joshua Tenenbaum

The Tenenbaum Lab has extended and enriched their computational models of core domains of human common sense reasoning, intuitive physics, and intuitive psychology to include accounts of how people use their intuitive theories for action planning, for explaining the causes of events, and for evaluating the social and moral status of other people. The lab's progress has been enabled by the development of "probabilistic programming" tools that allow researchers to express intuitive theories as programs that describe the causal processes at work in the world, with random choices in the programs to capture points of uncertainty, and then to reason about these programs by Monte Carlo simulation. The Tenenbaum Lab has also developed and tested a new computational framework for Bayesian one-shot learning of probabilistic programs with "program-generating programs" — higher-order programs that generate lower-level programs — and applied this to learning concepts in both vision and speech domains. Finally, they have developed several new machine learning and perception algorithms inspired by human intelligence, including a computer vision system that works through inverting a simple model of the "graphics" process by which the three-dimensional world gives rise to the images we observe, and a system for automatic time-series analysis that can flexibly discover a wide range of structures in data and describe those structures in natural language; its output is a several-page paper describing the structure it discovers.

Kay Tye

In the past year, the Tye Lab has published two papers. The first study examined a specific population of synapses going from the basolateral amygdala (BLA) to the ventral hippocampus (vHPC) in anxiety-related behaviors. They established a causal role for this pathway by showing that activating BLA inputs to the vHPC increased anxiety-related behaviors, while inhibiting them decreased anxiety-related behaviors. They also dissected the local circuit mechanism and showed that this effect was mediated by monosynaptic, glutamatergic input to pyramidal neurons in vHPC CA1. In the second study, the Tye Lab showed that this same pathway also bidirectionally controlled social behavior. Together, these studies provide a possible explanation for the high rate of comorbidity for anxiety and autism, as a specific population of synapses can control both anxiety-related behaviors and social behavior.

Ken Wexler

One of the central questions of semantic and cognitive development has been how knowledge and computation of scalar implicatures develop. Collaborating with Raj Singh and Danny Fox, the Wexler Lab showed that the "grammatical" theory of scalar implicatures, coupled with the assumption that children don't do lexical substitutions in deriving implicatures, predicts, startlingly, that young children should treat "or" as "and." They have obtained clear experimental confirmation of this prediction. The results provide strong support for the grammatical theory of implicatures, the recursive nature of the system, and a particular theory of the development of implicatures, tying together linguistic theory and cognitive development. In addition, the Wexler Lab has shown, in an experimental study of passive development in Spanish, that children treat verbal passives as resultant-state passives in terms of their meaning — a prediction of Wexler's maturational theory of passive development that hadn't been tested in earlier work. The Wexler Lab also obtained several new results on grammar in autism spectrum disorder (ASD) and specific language impairment (SLI), for example, confirmation in the NIH BILD work that children make finiteness judgments as predicted. This sets the stage for imaging analyses.

Matthew Wilson

By simultaneously recording brain activity from areas involved in memory and action planning during spatial maze navigation, the Wilson Lab has gained new insights into the role of neural oscillations in memory-guided decision making. Their recently developed algorithms for real-time decoding of neural activity have provided new tools for the mapping and manipulation of memory processing in the brain.

Weifeng Xu

The Xu Lab studies how experience induces changes in neuronal properties (neural plasticity) important for information coding in the central nervous system. Using a combination of molecular, electrophysiological, and behavioral analyses in the rodent model system, the Xu Lab studies critical players in activity-dependent plasticity: scaffold proteins in the postsynaptic density and proteins important for modulating calcium dynamics. They discovered that different scaffold proteins influence synapses (mediating neuronal communication) differently in terms of dependency on activity, trafficking of the neurotransmitter receptors, evoked and spontaneous synaptic responses, and the kinetics of the synaptic currents. The lab has begun to map how scaffold proteins can influence different aspects of synaptic transmission and provide molecular substrates for synaptic diversity and specificity. In addition, they found that calcium signaling, an important secondary messenger system, in the neurons can be regulated via experience and activity-dependent translation of a small neuronal protein that intersects calcium signaling at the entry level. By manipulating the levels of this protein, they can shift the neurons' plasticity threshold and potency, and influence the animals' learning behavior. They believe this small protein is a master regulator for calcium signaling, and a critical positive feedback component in plasticity and learning.

Feng Zhang

In the past year, the Zhang Lab developed a new genome editing technology based on the Cas9 endonuclease from the bacterial adaptive immune system CRISPR. Main accomplishments were: 1) first demonstration of Cas9-mediated genome editing in eukaryotic cells; 2) characterization of the specificity of Cas9; 3) development of new strategies to improve specificity by over 1500X; and 4) development of a genome-scale CRISPR library for functional screening. The lab also extended the optogenetics toolbox to enable control of transcription and epigenetic states in cells, including neurons in the brain of awake behaving mice.

Selected Faculty Awards and Honors

Edward Adelson received the Helmholtz Prize in Computer Vision from the IEEE Computer Society.

Ed Boyden received a Pioneer Award for his project "Millisecond-Timescale Whole-Brain Neural Activity Mapping in Health and Disease," and a Transformative R01 Award for his project "Recording neural activities onto DNA." He was also promoted to associate professor with tenure.

Emery Brown was elected to the National Academy of Sciences.

Martha Constantine-Paton was elected to the American Academy of Arts and Sciences.

Alan Jasanoff and Ed Boyden launched a new Center for Neurobiological Engineering.

Yingxi Lin was awarded the BCS Award for Excellence in Undergraduate Teaching.

Joshua McDermott was awarded the BCS Award for Excellence in Undergraduate Advising.

Earl Miller was elected a distinguished member of the National Society of Collegiate Scholars.

Tomaso Poggio led in the establishment of A Center for Brains, Minds, and Machines: The Science and the Technology of Intelligence, supported by funding from the National Science Foundation.

Molly Potter received the Davida Teller Award from the Vision Sciences Society, given each year to an outstanding woman vision scientist with a strong history of mentoring.

Rebecca Saxe was awarded a Troland Research Award from the National Academy of Sciences, which recognizes "unusual achievement and further empirical research in psychology regarding the relationships of consciousness and the physical world."

Laura Schulz received the American Psychological Association Distinguished Scientific Award for Early Career Contribution to Psychology.

Joshua Tenenbaum was elected a fellow of the Cognitive Science Society and received the BCS Award for Excellence in Undergraduate Teaching.

Kay Tye was awarded the Director's New Innovator Award for her project "A Novel Strategy for Combating Obesity: Reprogramming Neural Circuits," and she was honored in the Office of the Dean for Graduate Education's "Commitment to Caring" program.

Feng Zhang was named one of Popular Science's yearly "Brilliant Ten" for his work on open-source genetic engineering techniques.

James J. DiCarlo, MD, PhD
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Professor of Neuroscience
Investigator, McGovern Institute