

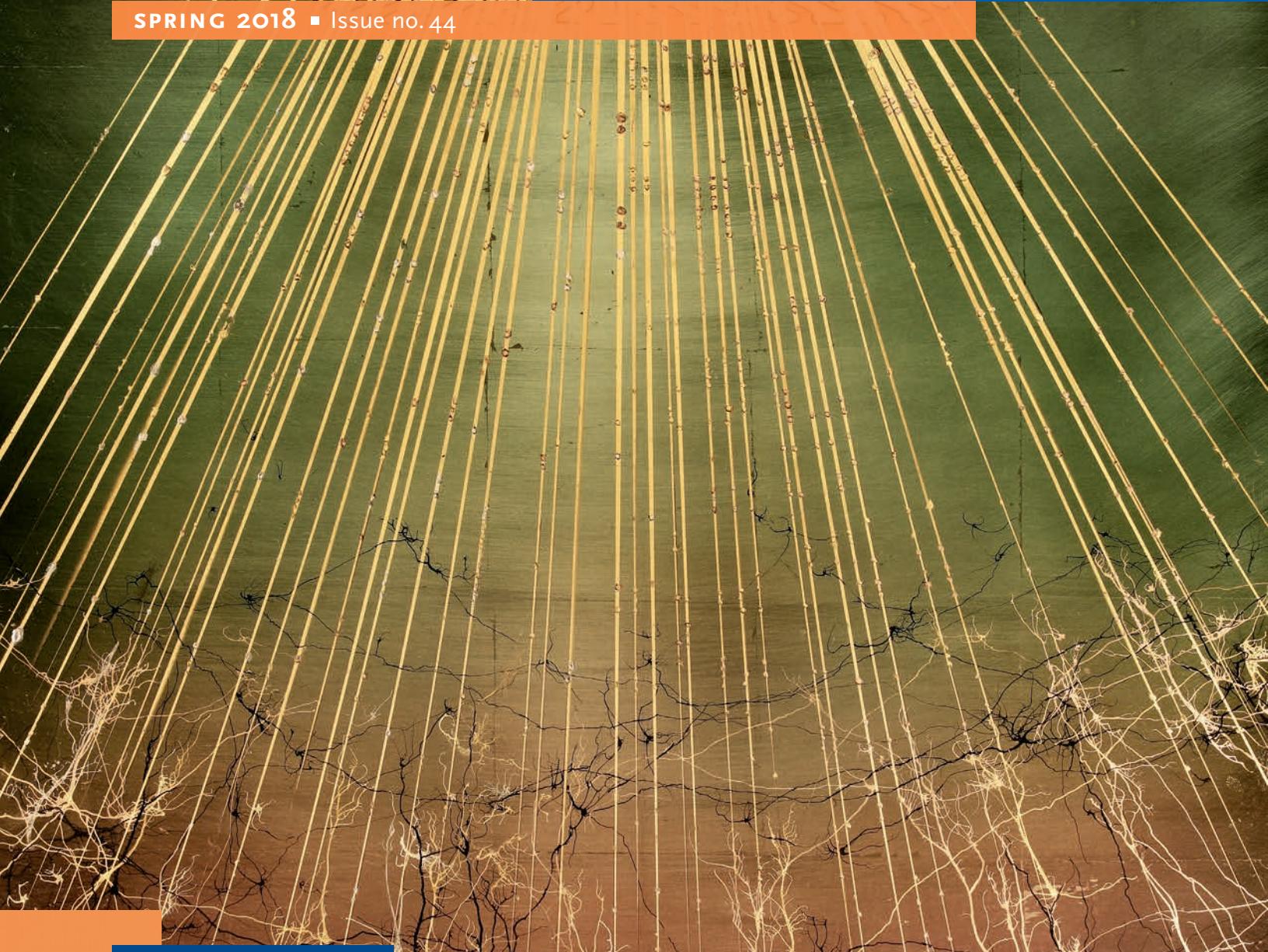


MCGOVERN INSTITUTE

FOR BRAIN RESEARCH AT MIT

Brain SCAN

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Engineering Intelligence

The Center for Brains, Minds and Machines is blending computation, neuroscience and cognition to build smarter machines and reveal the secrets of human intelligence.



FROM THE DIRECTOR

At a recent meeting with representatives from a major car company, I learned that great progress has been made on self-driving cars, but cars of the future will need to be “conscious,” or in possession of human-like intelligence. Autonomous cars can successfully navigate most highways, but they have difficulty understanding and predicting the actions of human drivers and pedestrians. For all the progress AI systems have made in fields like visual recognition and entertainment, AI systems still cannot match human intelligence in many areas, especially when they are faced with challenges that are unpredictable.

Five years ago, my colleague Tomaso Poggio established the Center for Brains, Minds and Machines (CBMM) here at the McGovern Institute, through a grant from the National Science Foundation. Its mission is to better understand the neural basis of intelligent behavior, which could lead to smarter machines in the future. This February, MIT announced a new institute-wide initiative called the MIT Intelligence Quest, or MIT IQ. Modeled in part on the success of CBMM, MIT IQ is an interdisciplinary effort to bridge human and machine intelligence research and to develop new applications. We look forward to being a part of this ambitious quest.

Finally, it is with great sadness that I share the passing of our longtime friend, Ted Poitras. Ted was a devoted supporter of McGovern research, and he and his wife, Kay, played a key role in supporting some of our major new initiatives. Ted will be greatly missed.

Bob Desimone, Director
Doris and Don Berkey Professor
of Neuroscience

On the cover: Artwork representing the brain's attempts to understand itself through neuroscientific study. Deciphering Spikes 22k, 21k, 18k, and 12k gold, ink, and dye on stainless steel—Greg Dunn, 2017



Photo: Kris Brewer

Now in its fifth year, the Center is gaining traction on arguably the greatest problem in science—understanding the human mind.

Go is an ancient board game that demands not only strategy and logic, but intuition, creativity, and subtlety—in other words, it’s a game of quintessentially human abilities. Or so it seemed, until Google’s DeepMind AI program, AlphaGo, roundly defeated the world’s top Go champion.

But ask it to read social cues or interpret what another person is thinking and it wouldn’t know where to start. It wouldn’t even understand that it didn’t know where to start. Outside of its game-playing milieu, AlphaGo is as smart as a rock.

“The problem of intelligence is the greatest problem in science,” says Tomaso Poggio, Eugene McDermott Professor of Brain and Cognitive Sciences at the McGovern Institute. One reason why? We still don’t really understand intelligence in ourselves.

Engineering Intelligence

The Center for Brains, Minds and Machines is blending computation, neuroscience and cognition to build smarter machines and reveal the secrets of human intelligence.

Right now, most advanced AI developments are led by industry giants like Facebook, Google, Tesla and Apple, with an emphasis on engineering and computation, and very little work in humans. That has yielded enormous breakthroughs including Siri and Alexa, ever-better autonomous cars and AlphaGo.

But as Poggio points out, the algorithms behind most of these incredible technologies come right out of past neuroscience research—deep learning networks and reinforcement learning. “So it’s a good bet,” Poggio says, “that one of the next breakthroughs will also come from neuroscience.”

Five years ago, Poggio and a host of researchers at MIT and beyond took that bet when they applied for and won a \$25 million Science and Technology Center award from the National Science Foundation to form the Center for Brains, Minds and Machines. The goal of the center was to take those computational approaches and blend them with basic, curiosity-driven research in neuroscience and cognition. They would knock down the divisions that traditionally separated these fields and not only unlock the

secrets of human intelligence and develop smarter AIs, but found an entire new field—the science and engineering of intelligence.

A Collaborative Foundation

CBMM is a sprawling research initiative headquartered at the McGovern Institute, encompassing faculty at Harvard, Johns Hopkins, Rockefeller and Stanford; over a dozen industry collaborators including Siemens, Google, Toyota, Microsoft, Schlumberger and IBM; and partner institutions such as Howard University, Wellesley College and the University of Puerto Rico. The effort has already churned out 397 publications, and has just been renewed for five more years and another \$25 million.

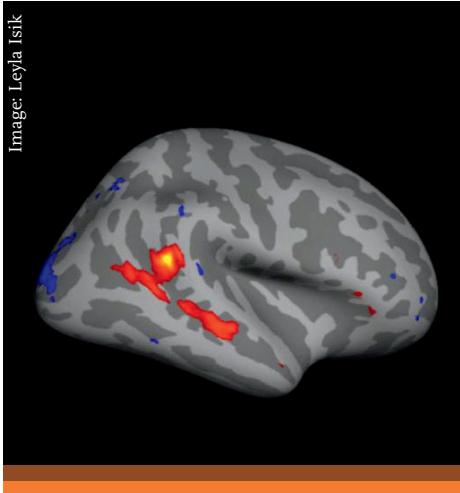
For the first few years, collaboration in such a complex center posed a challenge. Research efforts were still divided into traditional silos—one research thrust for cognitive science, another for computation, and so on. But as the center grew, colleagues found themselves talking more and a new common language emerged. Immersed in each other’s research, the divisions began to fade.

Photo: Lillie Paquette



Tomaso Poggio heads the Center for Brains, Minds and Machines at the McGovern Institute where Candace Ross (above, left) is a graduate student.

“It became more than just a center in name,” says Matthew Wilson, associate director of CBMM and the Sherman Fairchild Professor of Neuroscience at MIT’s Department of Brain and Cognitive Sciences (BCS). “It really was trying to drive a new way of thinking about research and motivating intellectual curiosity that was motivated by this shared vision that all the participants had.”



CBMM postdoc Leyla Isik (right) has identified a brain region that responds selectively to social interactions (shown in red, left).



Photo: Kris Brewer

New Questioning

Today, the center is structured around four interconnected modules grounded around the problem of visual intelligence—vision, because it is the most understood and easily traced of our senses. The first module, co-directed by Poggio himself, unravels the visual operations that begin within that first few milliseconds of visual recognition as information travels through the eye and to the visual cortex. Gabriel Kreiman, who studies visual comprehension at Harvard Medical School and Children's Hospital, leads the second module which takes on the subsequent events as the brain directs the eye where to go next, what it is seeing and what to pay attention to, and then integrates this information into a holistic picture of the world that we experience. His research questions have grown as a result of CBMM's cross-disciplinary influence.

Leyla Isik, a postdoc in Kreiman's lab, is now tackling one of his new research initiatives: social intelligence. "So much of what we do and see as humans are social interactions between people. But even the best machines have trouble with it," she explains.

To reveal the underlying computations of social intelligence, Isik is using data gathered from epilepsy patients as they watch full-length movies. (Certain epileptics spend several weeks before surgery with monitoring electrodes in their brains, providing a rare opportunity

for scientists to see inside the brain of a living, thinking human). Isik hopes to be able to pick out reliable patterns in their neural activity that indicate when the patient is processing certain social cues such as faces. "It's a pretty big challenge, so to start out we've tried to simplify the problem a little bit and just look at basic social visual phenomenon," she explains.

In true CBMM spirit, Isik is co-advised by another McGovern investigator, Nancy Kanwisher, who helps lead CBMM's third module with BCS Professor of Computational Cognitive Science, Josh Tenenbaum. That module picks up where the second leaves off, asking still deeper questions about how the brain understands complex scenes, and how infants and children develop the ability to piece together the physics and psychology of new events. In Kanwisher's lab, instead of a stimulus-heavy movie, Isik shows simple stick figures to subjects in an MRI scanner. She's looking for specific regions of the brain that engage only when the subjects view the "social interactions" between the figures.

"I like the approach of tackling this problem both from very controlled experiments as well as something that's much more naturalistic in terms of what people and machines would see," Isik explains.

Built-in Teamwork

Such complementary approaches are the norm at CBMM. Postdocs and graduate students are required to have at least two advisors in two different labs. The NSF

money is even assigned directly to postdoc and graduate student projects. This ensures that collaborations are baked into the center, Wilson explains. "If the idea is to create a new field in the science of intelligence, you can't continue to support work the way it was done in the old fields—you have to create a new model."

In other labs, students and postdocs blend imaging with cognitive science to understand how the brain represents physics—like the mass of an object it sees. Or they're combining human, primate, mouse and computational experiments to better understand how the living brain represents new objects it encounters, and then building algorithms to test the resulting theories.

Boris Katz's lab is in the fourth and final module, which focuses on figuring out how the brain's visual intelligence ties in to higher-level thinking, like goal planning, language, and abstract concepts. One project, led by MIT research scientist Andrei Barbu and Yen-Ling Kuo, in collaboration with Harvard cognitive scientist Liz Spelke, is attempting to uncover how humans and machines devise plans to navigate around complex and dangerous environments.

"CBMM gives us the opportunity to close the loop between machine learning, cognitive science and neuroscience," says Barbu. "The cognitive science informs better machine learning, which helps us understand how humans behave



The human brain perceives social abstractions—in this case, joke, scale, weight, noticing, not noticing—but even the best computers fail at this deceptively simple task.

and that in turn points the way toward understanding the structure of the brain. All of this feeds back into creating more capable machines.”

A New Field

Every summer, CBMM heads down to Woods Hole, Massachusetts, to deliver an intensive crash course on the science of intelligence to graduate students from across the country. It’s one of many education initiatives designed to spread CBMM’s approach and key to the goal of establishing a new field. The students who come to learn from these courses often find it as transformative as the CBMM faculty did when the center began.

Candace Ross was an undergraduate at Howard University when she got her first taste of CBMM at a summer course with Kreiman trying to model human memory in machine learning algorithms. “It was the best summer of my life,” she says. “There were so many concepts I didn’t know about and didn’t understand. We’d get back to the dorm at night and just sit around talking about science.”

Ross loved it so much that she spent a second summer at CBMM, and is now a third-year graduate student working with Katz and Barbu, teaching computers how to use vision and language to learn more like children. She’s since gone back to the summer programs, now as a teaching assistant.



CBMM Director Tomaso Poggio (second from left) with research leaders Jim DiCarlo, Boris Katz, Nancy Kanwisher and Rebecca Saxe at MIT's IQ launch in March.

“CBMM is a research center,” says Ellen Hildreth, a computer scientist at Wellesley College who coordinates CBMM’s education programs. “But it also fosters a strong commitment to education, and that effort is helping to create a community of researchers around this new field.”

Quest for Intelligence

CBMM has far to go in its mission to understand the mind, but there is good reason to believe that what CBMM started will continue well beyond the NSF-funded ten years.

This February, MIT announced a new institute-wide initiative called the MIT Intelligence Quest, or MIT IQ. It’s a massive interdisciplinary push to study human intelligence and create new tools

based on that knowledge. It is also, says McGovern Institute Director Robert Desimone, a sign of the institute’s faith in what CBMM itself has so far accomplished. “The fact that MIT has made this big commitment in this area is an endorsement of the kind of view we’ve been promoting through CBMM,” he says.

MIT IQ consists of two linked entities: “The Core” and “The Bridge.” CBMM is part of the Core, which will advance the science and engineering of both human and machine intelligence. “This combination is unique to MIT,” explains Poggio, “and is designed to win not only Turing but also Nobel prizes.”

And more than that, points out BCS Department Head Jim DiCarlo, it’s also a return to CBMM’s very first mission. Before CBMM began, Poggio and a few other MIT scientists had tested the waters with a small, Institute-funded collaboration called the Intelligence Initiative (I²), that welcomed all types of intelligence research—even business and organizational intelligence. MIT IQ re-opens that broader door. “In practice, we want to build a bigger tent now around the science of intelligence,” DiCarlo says.

For his part, Poggio finds the name particularly apt. “Because it is going to be a long-term quest,” he says. “Remember, if I’m right, this is the greatest problem in science. Understanding the mind is understanding the very tool we use to try to solve every other problem.” ■

Photo: Kris Brewer



CBMM summer students work with Boston Dynamics’ SpotMini, a quadruped robot engineered to have the dexterity of a human.

Ed Boyden Named Y. Eva Tan Professor in Neurotechnology



Eva Tan (left) and McGovern Investigator Ed Boyden (right).

McGovern Investigator Ed Boyden has been named the inaugural Y. Eva Tan Professor in Neurotechnology. The new professorship has been established at the McGovern Institute by K. Lisa Yang in honor of her daughter Y. Eva Tan.

"We are thrilled Lisa has made a generous investment in neurotechnology and the McGovern Institute by creating this new chair," says Bob Desimone, director of the McGovern Institute. "Ed's body of work has already transformed neuroscience and biomedicine, and this chair will help his team to further develop revolutionary tools that will have a profound impact on research worldwide."



In 2017, Yang co-founded the Hock E. Tan and K. Lisa Yang Center for Autism Research at the McGovern Institute. The Center catalyzes interdisciplinary and cutting-edge research into the genetic, biological, and brain bases of autism spectrum disorders.

"I am excited to further expand the Hock E. Tan and K. Lisa Yang Center for Autism Research and to support Ed and his team's critical work," Yang says. "Novel technology is the driving force behind much-needed breakthroughs in brain research—not just for individuals with autism, but for those living with all brain disorders. My daughter Eva and I are greatly pleased to recognize Ed's talent and to contribute towards his future successes."

Yang's daughter Eva Tan agrees. "I'm so pleased this professorship will have a significant and lasting impact on MIT's pioneering work in neurotechnology. My family and I have always believed that advances in technology are what make all scientific progress possible, and I'm overjoyed that we can help enable amazing discoveries in the Boyden Lab through Ed's appointment to this chair," Tan said.

Boyden has pioneered the development of many transformative technologies that image, record and manipulate complex systems, including optogenetics, expansion microscopy and robotic patch clamping. He has received numerous awards for this work, including the Breakthrough Prize in Life Sciences (2016), the BBVA Foundation Frontiers of Knowledge Award (2015), the Carnegie Prize in Mind and Body Sciences (2015), the Grete Lundbeck European Brain Prize (2013), and the Perl-UNC Neuroscience prize (2011). Boyden is an elected member of the American Academy of Arts and Sciences and the National Academy of Inventors.

"I deeply appreciate the honor that comes with being named the first Y. Eva Tan Professor in Neurotechnology. This is a tremendous recognition of not only my team's work, but the groundbreaking impact of the neurotechnology field," said Boyden. ■

McGovern Welcomes Sabbi Lall

We are delighted to announce that Sabbi Lall, PhD, will be joining the McGovern Institute as Director of Scientific Planning. Sabbi completed her doctorate in molecular biology at Oxford University in 1998 and brings a wealth of editorial experience to the position, including four years as Editor in Chief of *Cell Reports*. We look forward to welcoming Sabbi to the McGovern community this spring. ■

In Memory of Ted Poitras

We regret to note that Ted Poitras of Haines City, Florida, a longtime friend and generous supporter of the McGovern Institute, passed away in January. Ted was an enthusiastic supporter of our brain research programs, from novel methods for brain stimulation to the acquisition of a magnetoencephalography (MEG) scanner in 2011. Since its founding, the MEG lab has logged 2500 hours of scan time and generated more than 14 papers in high-profile journals such as *Science* and *Nature Neuroscience*. Ted is survived by many family members including his wife of 44 years, Kay Gleim Poitras;

daughters Julie, Jill and Jennifer; and brother Jim. Ted's enthusiasm for bold new research initiatives at the McGovern Institute will be greatly missed. ■



Kay and Ted Poitras (center) with Bob Desimone.

RESEARCH NEWS

Ed Boyden and colleagues at Paris Descartes University have developed a new optogenetic technique that sculpts light to target individual neurons, allowing them to be stimulated with precise timing within the living brain.

In a separate study, Boyden's lab developed a light-sensitive protein that can be embedded into neural membranes, where it emits a fluorescent signal that indicates how much voltage a particular cell is experiencing. This could allow scientists to study how neurons behave, millisecond by millisecond, as the brain performs a particular function.

The **Gabrieli** lab has found that conversation between an adult and a child appears to change the child's brain, and that this back-and-forth conversation is actually more critical to language development than the number of words a child hears during the first three years of life.

Ann Graybiel and colleagues have devised a miniaturized system that can deliver tiny quantities of medicine to brain regions as small as 1 cubic millimeter. This type of

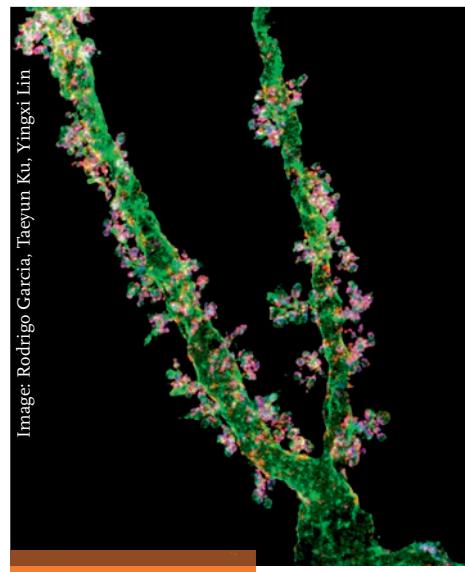
targeted dosing could make it possible to treat diseases that affect very specific brain circuits, without interfering with the normal function of the rest of the brain.

In a separate study, the Graybiel lab found that certain neurons in the brain are responsible for marking the beginning and end of a behavior as it becomes a habit.

Many researchers have argued for the existence of a centralized clock somewhere in the brain that keeps time for the entire brain. A new study from **Mehrdad Jazayeri**'s lab provides evidence for an alternative timekeeping system that relies on the neurons responsible for producing a specific action.

Feng Zhang's team, who first developed the CRISPR-based diagnostic tool called SHERLOCK, has greatly enhanced the tool's power, and has developed a miniature paper test that allows results to be seen with the naked eye. These advancements accelerate SHERLOCK's ability to quickly and precisely detect genetic signatures—including pathogens and tumor DNA—in samples.

Yingxi Lin has uncovered a cellular pathway that allows specific synapses to become stronger during memory formation. The findings provide the first glimpse of the molecular mechanism by which long-term memories are encoded in a region of the hippocampus called CA3. ■



New memories are encoded via synapses (cyan and pink) along the spines of large, branching dendrites (green) in the hippocampus.

AWARDS & HONORS



Photo: Justin Knight



Photo: Justin Knight



Photo: Donna Coverney

McGovern Investigators Feng Zhang, Nancy Kanwisher and Bob Desimone.

Feng Zhang has been awarded the Vilcek Prize for Creative Promise in Biomedical Science for his role in advancing optogenetics and developing molecular tools to edit the genome. The prize recognizes younger immigrants who have demonstrated exceptional promise early in their careers.

Nancy Kanwisher has won the Davida Teller Award, which honors female scientists who have made exceptional contributions to the field of vision science and have a strong history of mentoring.

Bob Desimone and Earl Miller have received the BCS Award for Excellence in Graduate Teaching. ■

EVENTS

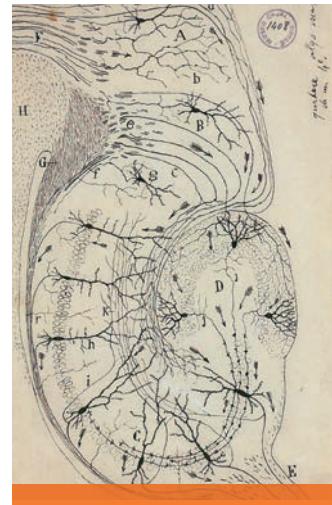
Photo: Bryce Vickmark; Photography



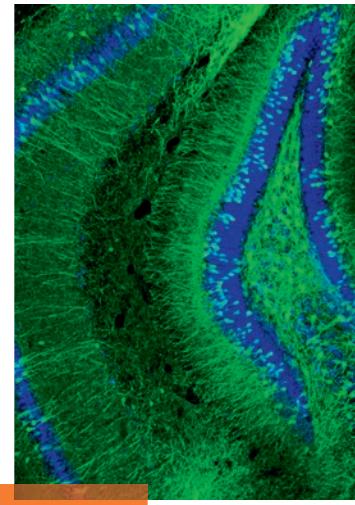
The Building 46 community gathers in the atrium for the annual holiday party.

Building 46 Holiday Party

On December 13, members of the McGovern Institute, Picower Institute and Department of Brain and Cognitive Sciences celebrated the holidays with a party in the atrium of Building 46. ■



Many neurons that Cajal illustrated in structures such as the hippocampus (left) can now be labeled using modern genetic methods (right).



Beautiful Brain Exhibit at MIT Museum

This spring, the MIT Museum will feature the drawings of Santiago Ramón y Cajal, a neuroscientist whose pioneering work detailing the microscopic structure of the brain earned him the Nobel Prize in 1906. *The Beautiful Brain: The Drawings of Santiago Ramón y Cajal* will include Cajal's drawings alongside a contemporary exhibition of neuroscience visualizations from the McGovern Institute and other MIT neuroscience labs. The exhibit is scheduled to open on May 3, 2018. ■



The McGovern Institute for Brain Research at MIT is led by a team of world-renowned neuroscientists committed to meeting two great challenges of modern science: understanding how the brain works and discovering new ways to prevent or treat brain disorders. The McGovern Institute was established in 2000 by Lore Harp McGovern and the late Patrick J. McGovern, with the goal of improving human welfare, communication and understanding through their support for neuroscience research. The director is Robert Desimone, who is the Doris and Don Berkey Professor of Neuroscience at MIT and former head of intramural research at the National Institute of Mental Health.

Further information is available at: <http://mcgovern.mit.edu>

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Writer: Shannon Fischer

Director of Development: Kara Flyg

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MC GOVERN INSTITUTE

FOR BRAIN RESEARCH AT MIT

Massachusetts Institute of Technology
77 Massachusetts Avenue 46-3160
Cambridge, MA 02139