Brain SCAN

McGOVERN INSTITUTE
FOR BRAIN RESEARCH AT MIT

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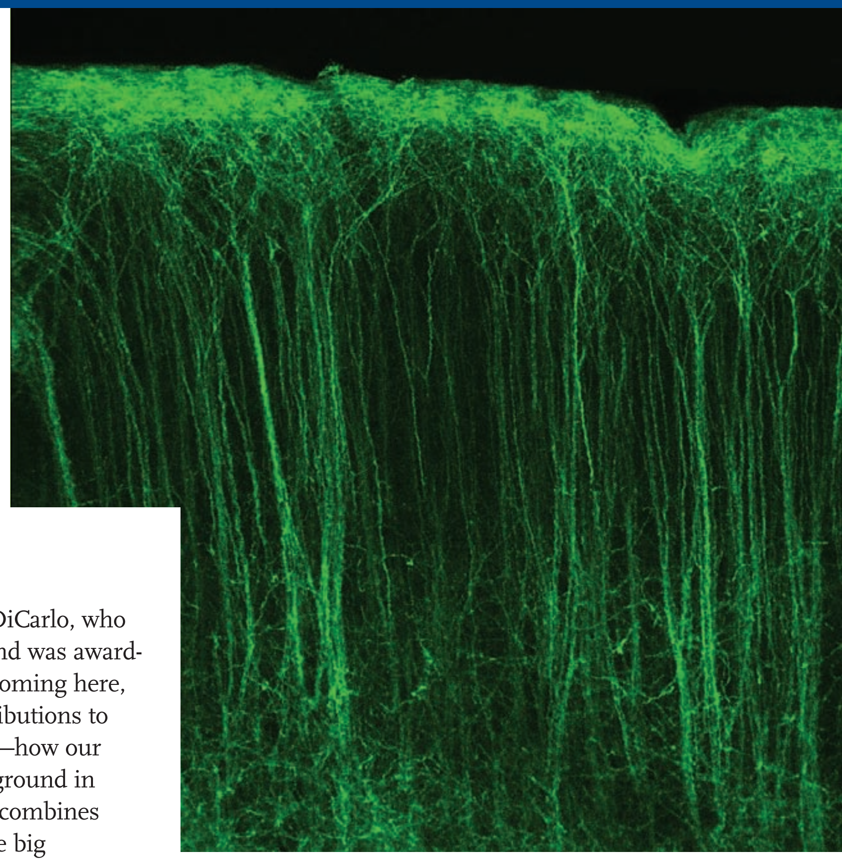


From the director

We celebrate the awarding of tenure to James DiCarlo, whose research on visual object recognition is shedding new light on some fundamental questions in neuroscience.

This issue of *Brain Scan* features James DiCarlo, who joined the McGovern Institute in 2002 and was awarded tenure at MIT earlier this year. Since coming here, Jim has made a series of important contributions to a fundamental question in neuroscience—how our brain recognizes objects. Jim has a background in engineering and medicine, and his work combines technical rigor with a willingness to tackle big questions. He has established strong multidisciplinary collaborations with McGovern colleagues, linking his work on monkeys to human neuroimaging and computational modeling of brain function. His work is also suggesting new approaches to computer vision, and may have implications for the development of human neural prosthetics. Jim has been a strong mentor to his lab colleagues, several of whom have already moved to start their own independent laboratories. We congratulate Jim on gaining tenure, and look forward to working with him in the years to come.

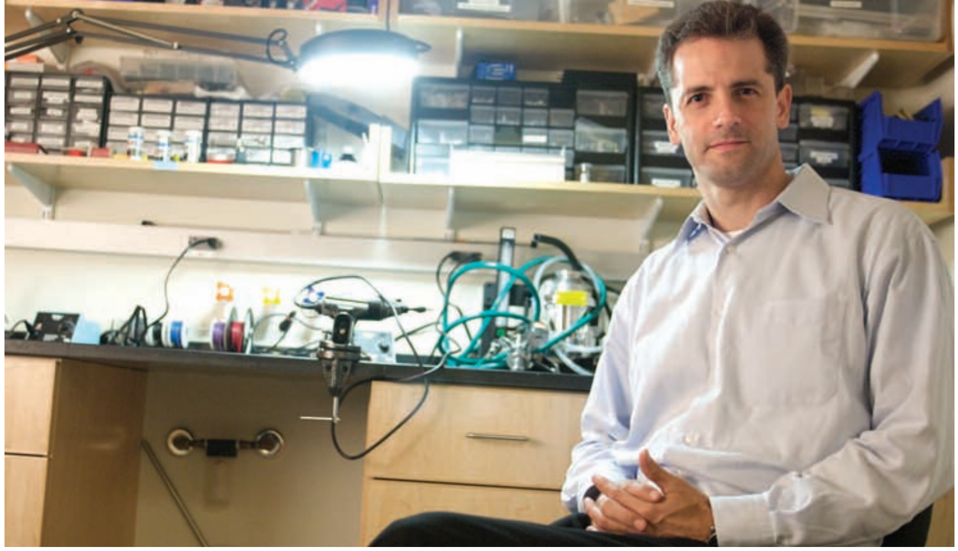
As we begin the new academic year, I have two additional important announcements. First, I am delighted to announce the appointment of a new faculty member, Guoping Feng, who is currently a professor at Duke University. Guoping is a pioneer in the study of synapses, and his work is shedding new light on how synaptic deficits may contribute to a range of psychiatric disorders. We are looking forward to welcoming him when he arrives at MIT in spring 2010.

Second, thanks to the generosity of our donors, we have now met our challenge grant to acquire a new magnetoencephalography (MEG) scanner. The machine has already been ordered, and will be installed early next year. I plan to use it in my own research, and I am excited about the many new projects that will be stimulated by this major new core facility within our Institute.

Bob Desimone, Director

Cover Image: Guoping Feng uses genetic technologies to control brain activity in mice. Shown here, cortical neurons expressing the light-sensitive protein channelrhodopsin-2.

Image courtesy Guoping Feng



James DiCarlo, newly tenured professor at the McGovern Institute.

Photo courtesy Kent Dayton

CRACKING THE CODE OF VISUAL OBJECT RECOGNITION

James DiCarlo wants to understand how the brain represents objects, and to reveal the computations that are the foundation of cognition.

Rock climbers call the hardest part of the climb the crux, and once they pass that obstacle they can see the way to the summit. James DiCarlo used to dedicate much of his free time to climbing rock faces. Now, as a newly tenured professor at the McGovern Institute, he is tackling what he considers the crux problem of systems neuroscience—object recognition. “Once we know how the brain transforms the pixels on our retina into pictures in our mind, we can start to understand how those representations form the basis for higher cognitive tasks such as memory, decisions, and long-term planning.”

The ease with which we recognize objects in the world around us belies the complexity of the underlying brain computations. Consider the game of chess. Distinguishing a king from a queen is easy, while winning a game seems hard. For computers, however, the reverse is true. Computers can now beat even the best human chess players, yet no computer vision system comes close to human performance in recognizing objects in the real world.

It makes sense that object recognition comes easily to us because the ability to recognize predators, food, or mates is essential for our survival. So the brain has evolved a system to perform these tasks quickly and automatically.

Says DiCarlo, “Object recognition is a ‘holy grail’ task for computer science, but our brains are so exquisitely capable of solving this task that we tend to take our object recognition abilities completely for granted.”

Science Imitating Fiction

As a teenager, DiCarlo loved science fiction stories about thinking machines, but he never dreamed he might contribute to building them. He planned to become a doctor and, as a biomedical engineering major at Northwestern University, he saw the possibility of building computational brain models with relevance to medicine. During his MD/PhD program at Johns Hopkins and a postdoctoral position at Baylor College of Medicine, he began focusing on how the brain recognizes patterns and transforms them into a neuronal code that represents objects.

Now, as a faculty member at McGovern Institute, DiCarlo is combining his engineering and neuroscience expertise to study this question in humans and experimental animals. For human studies, he often collaborates with McGovern colleague Nancy Kanwisher, an expert on human cognition and brain imaging.

He also works closely with computational scientist Tomaso Poggio to test computer models of how the visual system may actually perform object recognition.

"Object recognition is a big challenge, and we need to combine many different techniques to tackle it," he says. "Those interfaces are where the fun is—they are where the key discoveries will continue to occur."

DiCarlo also hopes that his work will help lay the foundation for new prosthetic devices to treat blindness or other sensory deficits. "If we can understand how the brain represents objects, then we have a better chance of recreating visual sensations in the brains of patients who have lost the ability to see."

Piecing it all Together

Much of DiCarlo's work involves studying macaque monkeys, whose visual abilities closely resemble those of humans. Previous studies found that the signals from the eyes travel to a succession of specialized brain regions that progressively and rapidly assemble the dots of light from the retina into lines, corners, shapes, and ultimately into complex objects. Object recognition is thought to happen in a region the size of a postage stamp, called the inferior temporal cortex (IT).

"I want to figure out how this small bit of tissue does this seemingly magical process of computing what's out there in the world," DiCarlo explains. "It's as if we have been given a highly sophisticated device from the future and we have the privilege of figuring out how it actually works."

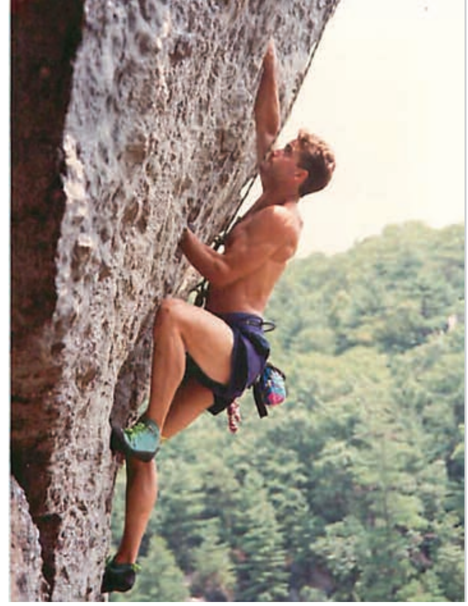
Fleeting Patterns and Stable Objects

To grasp the computational challenge of object recognition, consider what happens when we look at a familiar object, for example a dog. The dog may be facing us or in profile, nearby or far away, in sunshine or shadow, etc. Each variation in pose, position, or illumination produces a different pattern of light on the retina. So in essence, our visual system never sees the same image of the dog twice. Yet by the time the signals from the retina reach the IT cortex, the visual system has somehow determined that all of those different images originate from a dog.

This central problem of visual recognition is called invariance—the brain's ability to see beyond this variability and to recognize the constancy of the underlying object. How does the brain do it? One idea suggests that the brain has a built-in computational system that automatically generalizes knowledge about objects under a variety of viewing circumstances. An alternate theory, which DiCarlo finds more plausible, holds that the brain learns to solve this problem through its vast experience in the natural world.

Babies are confronted with new objects on a daily basis. DiCarlo wants to know how babies learn to recognize familiar objects, like a dog, despite variations in the dog's appearance.

Image courtesy istockphoto.com/palantir



Jim DiCarlo at Rocks State Park, Maryland, circa 1997.

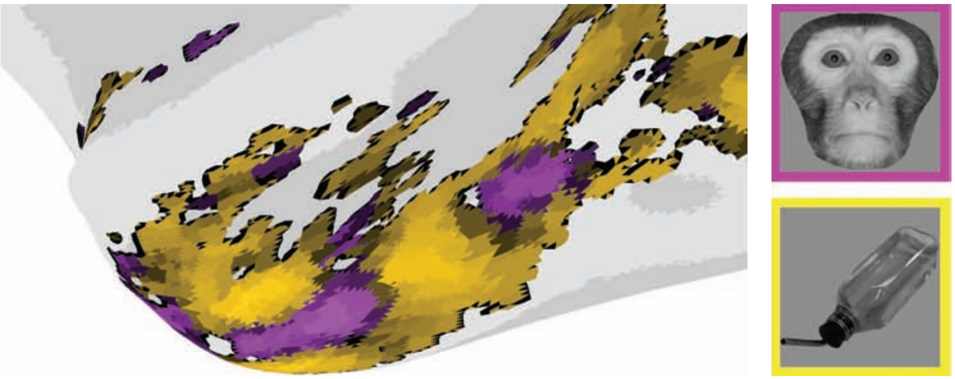
Learning like a Brain

In recent years, DiCarlo has been studying how the brain learns the most basic type of invariance—the ability to recognize an object independent of its position in the visual field. He thinks the key to position invariance may lie with natural visual experience, especially that resulting from eye movements.

"We move our eyes about three times per second, but physical objects seldom move that fast," he explains. "So it makes sense for a brain to assume that visual patterns that differ across successive eye movements often reflect the same object."

To test this hypothesis, DiCarlo and his colleagues tricked the brain by exposing subjects to an altered visual world that violates this assumption. As subjects looked at objects on computer screens, one object was swapped out and replaced by another. The object swaps were timed to occur at the split second when the eye moved. After two hours of this trickery, subjects began to confuse objects when asked to identify them at the "tricked" visual field positions. Their confusion implied that the invariance of object recognition involves learning, and that this learning continues even in adulthood.

DiCarlo wondered whether this behavioral result reflected how IT neurons themselves responded to the altered world. When his group conducted a similar experiment using recordings in monkeys, the neurons showed a strong learning effect that mirrored the human studies.



Functional magnetic resonance image (fMRI) of the inferior temporal cortex. Purple indicates regions of brain tissue that are more activated by human and monkey faces and yellow indicates regions that prefer non-face objects.

Image courtesy Hans Op de Beeck

"I was astonished at how easily we could manipulate the invariance properties of IT neurons. We did not expect that the proposed learning mechanism would operate so strongly and with such surprising rapidity in adulthood," says DiCarlo.

His group recently found that this type of learning occurs not only for object position, but also for object size, suggesting that they have tapped into a fundamental invariance-learning mechanism in the visual system. They are now conducting longer-term studies with large-scale recording arrays to see if this learning continues over weeks and months and not just hours.

Climbing Higher

"The discovery of how the brain uses visual experience to learn invariance provides a new foothold on the crux problem of object recognition," DiCarlo says. "Maybe now we can reach up to a new handhold and gain traction on other questions about the brain."

For example, as the father of two young children, DiCarlo wonders how babies learn to recognize the numerous novel objects that confront them daily. He plans to do developmental studies to look at how object recognition changes from birth through maturity.

He is also interested in how the brain deals with clutter in the visual world. "Computer models cannot handle multiple items, and clutter sometimes confuses even human observers," he says. "That's why it's sometimes hard to find the can-opener in the kitchen drawer. We're working on understanding how the brain copes with clutter because that will best reveal if we are on the right track."

DiCarlo plans to incorporate the new learning mechanism into large-scale computational models of the type pioneered by his McGovern colleague Tomaso Poggio. One key question will be whether such models perform as well as human observers when presented with challenges such as clutter. If so, DiCarlo may ultimately help create the brain-like machines he once dreamed about.

New Technologies Provide New Views

To reach these higher levels, DiCarlo often needs to tap into his engineering skills to stay on the ever-advancing edge of technology. "For example, we'd like to know whether neurons that represent related categories of objects, say knives and forks, are clustered together," he says. "Do these clusters change over time as we learn more about a particular category? But it's hard to answer those questions if you don't know exactly where your signals are coming from."

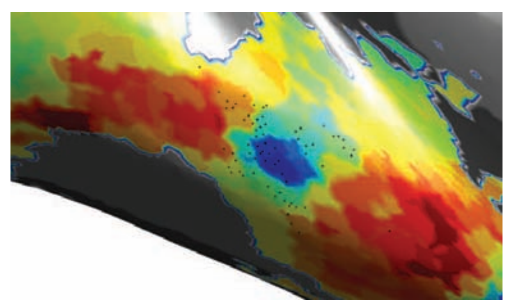
To provide that precision, his group has recently developed a novel x-ray-based imaging system that can co-register an unlimited number of neuronal recording sites onto the MRI image of a monkey brain. Much like a GPS system that links satellite images with street level photos, DiCarlo's new system will provide a clearer picture of the brain by identifying the neurons from which he is recording with pinpoint accuracy.

In addition to answering some basic questions about the brain, this technology may eventually help clinicians increase the accuracy of surgical planning, including the placement of implanted electrodes to treat Parkinson's disease and other disorders. It will also help neuroscientists to target new technologies such as optogenetic tools to learn more about brain function in health and disease.

Cracking the Code

DiCarlo believes that solving the problem of object recognition will ultimately reveal the perceptual building blocks that underlie higher brain functions. "I think the cortex of the brain discovered a way to extract general categories from specific examples," he says. "Then other, evolutionarily more recent, cortical regions hijacked these same computational processes to produce what we call cognition."

"Understanding the cortical computations that underlie object recognition will open the door to a deep understanding of human perception, cognition, and behavior," DiCarlo continues. "It will be as important to neuroscience as cracking the DNA code was to genetics." The view should be worth the climb. ■



DiCarlo's x-ray system allows electrode recording sites (black dots) to be mapped accurately onto the large-scale activity revealed by fMRI (colored regions).

Image courtesy Paul Aparicio

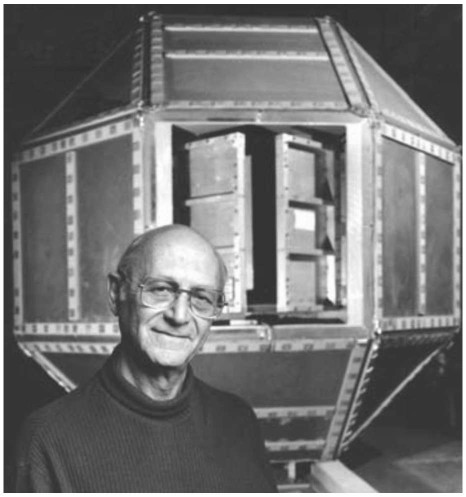
McGovern Institute Meets the MEG Challenge

We are very pleased to announce that the McGovern Institute will soon be adding magnetoencephalography (MEG) to its suite of neuroimaging technologies. Last year the Institute received a $2M challenge from an anonymous donor, and announced a campaign to raise matching funds (*Brain Scan*, Fall 2008). Now, through a combination of private donations, foundation grants, and public funds, we have met this challenge. Following an earlier commitment from Kay and Ted Poitras (*Brain Scan*, Summer 2009), the Institute has now received a major new commitment from Thomas F. Peterson, Jr. '57, a member of the McGovern Institute Leadership Board, along with grants from the National Science Foundation and the Simons Foundation. MEG is a safe and non-invasive brain imaging method that detects tiny magnetic signals at the surface of the head. It provides precise information about the timing of brain activity, and will complement the Institute's existing MRI-based imaging technologies. The new instrument will be housed in the Martinos Imaging Center. It will be open to users inside and outside MIT, and we anticipate that it will find many applications in basic and disease-oriented research. It will be one of only two MEG scanners in the Boston area (the other being at Massachusetts General Hospital, with whom we will collaborate closely to establish the new facility). It is particularly fitting that one of these scanners should be at MIT, since the MEG technology was pioneered by David Cohen in the 1960s while he was a member of MIT's Francis Bitter Magnet Laboratory (see photo).

Tom Peterson has been instrumental in helping the McGovern Institute acquire new technologies for brain research, including a two-photon microscope in Chris Moore's lab and now, a new MEG scanner for the Imaging Center.

Photo courtesy Tom Peterson

The first step in the installation of the new scanner will be the construction of a shielded room—three concentric layers of a special metal alloy that will protect the sensitive instrument from external sources of interference such as the nearby subway line. Site planning is already underway, and installation is scheduled for early 2010. We expect the scanner to be operational by next summer. ■



David Cohen, inventor of the MEG, stands in front of the original shielded room that he built at MIT's Francis Bitter National Magnet Laboratory in 1969.

Photo courtesy David Cohen

New EEG Booth Advances Dyslexia Studies

With the installation of a booth that dampens sound and blocks electrical/magnetic noise, the electroencephalography (EEG) lab at the Martinos Imaging Center is now running dyslexia studies with more accuracy than ever before. The booth provides cleaner EEG signals and it also allows dyslexia researchers in the Gabrieli lab to conduct event-related potential (ERP) studies, which provide accurate information about the timing of the brain's response to words that rhyme or repeat. "A deficit in phonological processing is thought to underlie dyslexia," explains Marianna Eddy, a postdoctoral associate in the Gabrieli lab, "so our ERP studies may reveal precisely when such a deficit occurs in the brain." ■

Electroencephalography (EEG) is a noninvasive method for measuring brain activity based on electrical recordings at the scalp.

Metcalfe Gift Supports Graduate Student Fellowships

Bob Metcalfe, '68, Leadership Board member emeritus, has made a gift in support of graduate student fellowships at the McGovern Institute. His gift was made in honor of his 40th reunion and of MIT's Campaign for Students. ■

Guoping Feng Appointed as New Faculty Member

The McGovern Institute is pleased to announce the appointment of its newest faculty member, Guoping Feng. A world leader in the study of synapses, Feng is currently an associate professor at Duke University and will become a McGovern Investigator and a tenured professor in MIT's Department of Brain and Cognitive Sciences. Feng's research focuses on the formation and function of synaptic connections and their disruption in mouse models of human brain disorders. He has developed a variety of genetic technologies to study the mechanisms underlying psychiatric diseases, including obsessive-compulsive disorder and bipolar disorder. "I'm very excited at the prospect of coming to MIT," says Feng. "There's no better place in the world to pursue the questions I'm most interested in." Feng will hold the Poitras Professorship of neuroscience, established by James W. Poitras '63 and Patricia Poitras to support psychiatric research at MIT. A full profile of Feng and his work will appear in a future issue of *Brain Scan*. ■

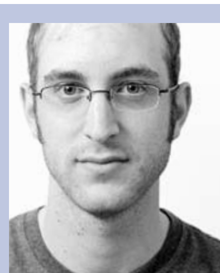
Guoping Feng, a world leader in the study of synapses, will join the McGovern Institute in spring 2010.

Photo courtesy Donna Coveney/MIT

Fellowships Awarded to Young Scientists

Paul Aparicio, a graduate student in Jim DiCarlo's lab, received the Sheldon Razin Fellowship for his work with functional magnetic resonance imaging (fMRI) and physiology in monkeys. Paul is working with a high-resolution x-ray system developed in DiCarlo's lab (see feature article) to map neurons within the temporal lobe that respond specifically to faces.

Paul Aparacio



Ethan Meyers

Photo courtesy Winston Chang

The Hubert Shoemaker Fellowship was awarded to Ethan Meyers in Tomaso Poggio's lab. Ethan has been developing methods to decode information from neurons in high level visual brain areas of macaque monkeys. Most research is focused on the activity of single neurons but the Shoemaker fellowship will allow Ethan to explore patterns of activity from multiple neurons. A major goal of Ethan's research is create a software toolbox will make it easy to analyze patterns in neurophysiological and fMRI data.

Yuri Matsumoto receiving season leader's jersey at the 2008 Eastern Collegiate Cycling Conference.

Photo courtesy MIT Cycling Team

Yuri Matsumoto in Alan Jasanoff's lab received the graduate student fellowship of the Friends of the McGovern Institute. Yuri is working on the creation of a protein that naturally forms magnetic nanoparticles inside cells. These nanoparticles are among the most potent and promising contrast agents for MRI. In her spare time, Yuri has also led the MIT cycling team to several championship victories. ■

In the News

John Gabrieli published a review of dyslexia research in the July 17 issue of *Science*. Gabrieli's review addressed the cognitive and brain bases of dyslexia, the best treatments for the disease, and the ways in which neuroscience may interact with education to help children with dyslexia.

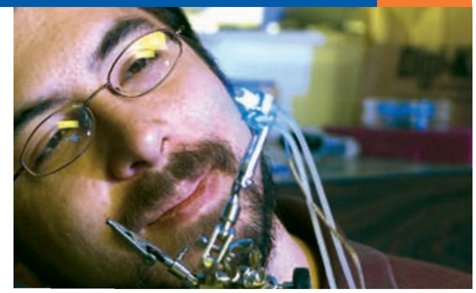
In July, *New Scientist* covered a study by **Nancy Kanwisher** in the *Journal of Neuroscience*, which found that the brain changes with unsuspected speed. Her findings suggest that the brain has a network of silent connections that underlie its plasticity.

U.S. News & World Report covered **Ann Graybiel**'s study in the *Proceedings of the National Academy of Sciences* which identified populations of neurons that code time in the primate brain. Understanding how these timing mechanisms work may facilitate the development of neural prosthetic devices for conditions such as Parkinson's disease.

Wired magazine and *Technology Review* featured **Ed Boyden**'s optogenetics research and explored how this novel technology is allowing scientists to tackle some fundamental questions about the brain. ■

MINT Program Supports New Optogenetic Technologies

The McGovern Institute Neurotechnology (MINT) program, established in 2006, is starting to bear fruit in the form of scientific publications. Ed Boyden, for example, has published several papers within the past year based on MINT-funded work, including the first demonstration of optogenetic technology in primates, in collaboration with Bob Desimone and Ann Graybiel. During the Society for Neuroscience meeting in Chicago in October, Boyden's lab also presented several recent findings, including the identification of a new light-sensitive inhibitor of neural activity that is likely to find many applications. In another MINT-supported collaboration, Boyden is now working with Clif Fonstad, a professor in MIT's Department of Electrical Engineering and Computer Science, to develop novel implantable devices that will combine optical activation and electrical recording within the brain. ■



Ed Boyden holding his most recent optogenetic device; an array of optical elements that can turn on and off individual neurons at sixteen different points with the brain.

EVENTS

Zack Lynch Discusses Neuro Revolution

Zack Lynch, a member of the McGovern Institute Leadership Board and founder of the Neurotechnology Industry Organization discussed his new book, *The Neuro Revolution: How Brain Science is Changing our World* to a packed auditorium at the McGovern Institute this July. "Lynch is passionate, knowledgeable and fully engaged with the world of neurotechnology," according to a review by *Publishers Weekly*, "and his overview makes absorbing material." ■

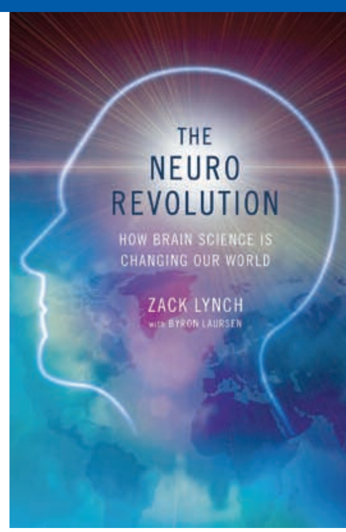


Image courtesy Zack Lynch

McGovern at Society for Neuroscience Conference

The McGovern Institute had a strong showing at this year's Society for Neuroscience Conference. More than 45 posters were presented by members of the Institute between October 17-21 in Chicago, Illinois. ■

Basal Ganglia Symposium Videos on MIT World

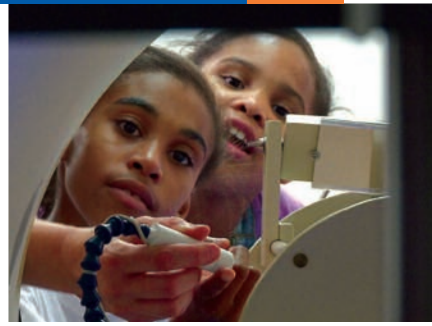
Eight lectures from the spring symposium, "Basal Ganglia in Health and Disease" (*Brain Scan*, Summer 2009) are now posted on the MIT World website. MIT World (mitworld.mit.edu) is a free site that provides on-demand video of significant public events at MIT. Since they were posted, the lectures have received more than 2500 hits. ■

Awards and Honors

Tomaso Poggio, a founding member of the McGovern Institute.

Photo courtesy Kent Dayton

Tomaso Poggio has been awarded the Okawa prize, presented annually by the Okawa Foundation to persons who have made outstanding contributions to research, technological development, and business management in the information and telecommunications fields. This September, Poggio also gave the William Benter Distinguished Lecture at the City University of Hong Kong and was invited to be a Distinguished Visitor to Singapore's Agency for Science, Technology, and Research (A*STAR). ■



Left: *A camera mounted to a jib captures students walking through the atrium;* top center: *Jane Pauley, member of the McGovern Institute Leadership Board;* top right: *two young study subjects explore the mock scanner;* bottom: *Ann Graybiel poses for a shot in her lab.*

McGovern Institute Video in Production

The McGovern Institute has hired John Rubin Productions, an Emmy-nominated science documentary production company, to produce a video about the Institute. The final video, which will run roughly 20 minutes in length, will provide an overview of the Institute that features a selection of our faculty members and their research. The video will also contain 15 additional 'Meet the Scientist' chapters that will allow viewers to explore the various labs in more depth. The video will be distributed on DVD and posted online this fall.

To celebrate and thank everyone who helped in the production of the video, the McGovern Institute will host a premiere party this winter that will be open to the public. Details will be posted on our website.

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 Patrick J. McGovern and Lore Harp McGovern, who are committed to improving human welfare, communication and understanding through their support for neuroscience research. The director is Robert Desimone, formerly the head of intramural research at the National Institute of Mental Health.

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

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