McGOVERN INSTITUTE

# BRAINSCAN

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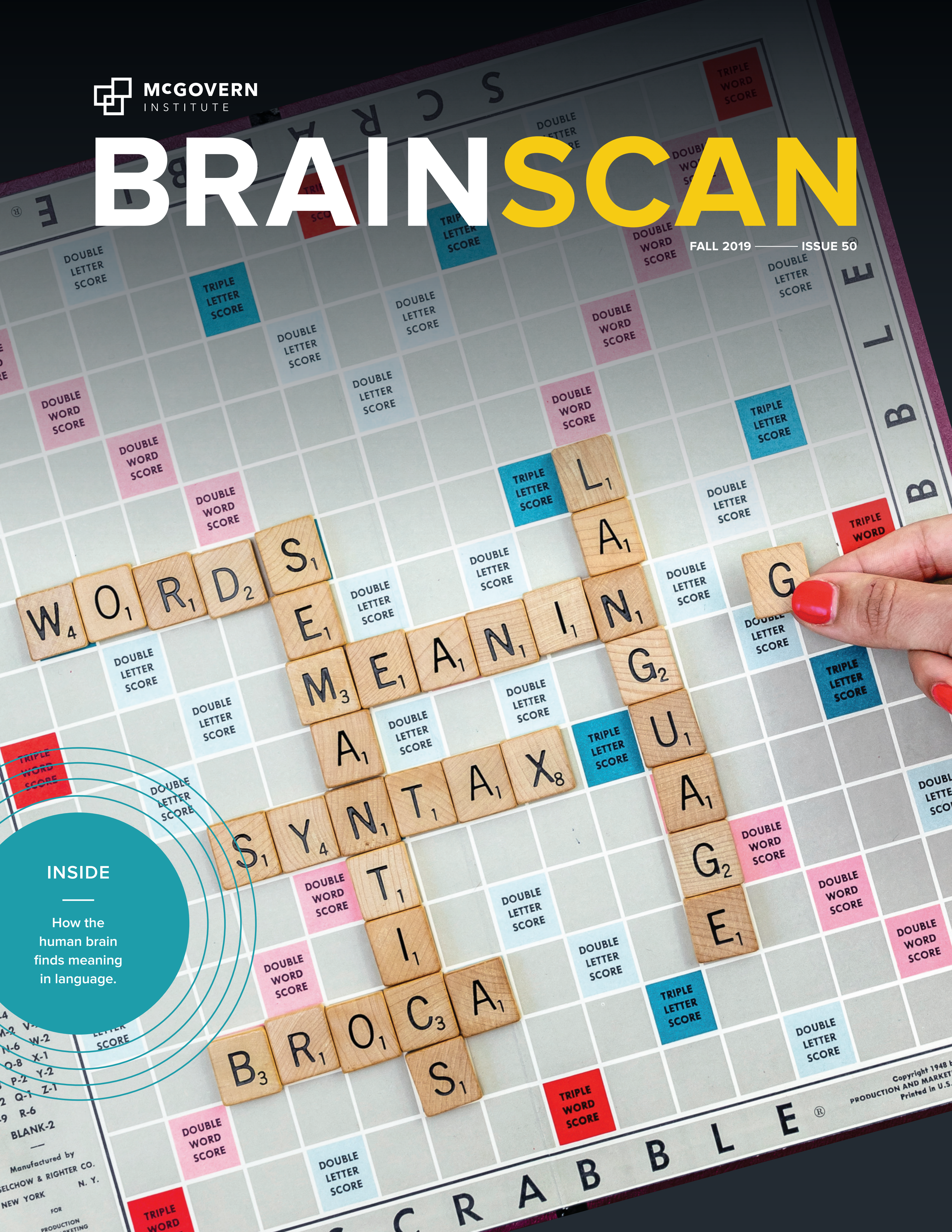



INSIDE

How the human brain finds meaning in language.

**McGOVERN MUSINGS**

***Perspectives from our community***

*I had long wanted to study the brain basis of language processing, but didn't have a strong enough background in language to do it well. So when Ev Fedorenko came to MIT and began working on this topic I was overjoyed.*

*What is so special about Ev's work is that it is tightly connected to the rich history of theoretical and behavioral work on language processing, yet at the same time she is constantly innovating on fMRI methods, making precise, quantitative, and replicable measurements from the brain's language system.*

*No one else working on the brain and language matches Ev's combination of theoretical depth and methodological innovation rigor.*

**NANCY KANWISHER**

*Founding Member, McGovern Institute*

**MIND YOUR LANGUAGE**

Ev Fedorenko has found that the language regions of the brain (shown in teal) are sensitive to both word meaning and sentence structure.


## The human brain is remarkably adept at finding meaning in words. Ev Fedorenko wants to know why.

Language is a uniquely human ability that allows us to build vibrant pictures of non-existent places (think Wonderland or Westeros). How does the brain build mental worlds from words? Can machines do the same? Can we recover this ability after brain injury? These questions require an understanding of how the brain processes language, a fascination for Ev Fedorenko.

"I've always been interested in language. Early on, I wanted to found a company that teaches kids languages that share structure — Spanish, French, Italian — in one go," says Fedorenko, an associate investigator at the McGovern Institute and an assistant professor in brain and cognitive sciences at MIT.

Her road to understanding how thoughts, ideas, emotions, and meaning can be delivered through sound and words became clear when she realized that language was accessible through cognitive neuroscience.

Early on, Fedorenko made a seminal finding that undermined dominant theories of the time. Scientists believed a single network was extracting meaning from all we experience: language, music, math, etc. Evolving separate networks for these functions seemed unlikely, as these capabilities arose recently in human evolution. But when Fedorenko examined brain activity in subjects while they read or heard sentences in the MRI, she found a network of brain regions that is indeed specialized for language.

"A lot of brain areas, like motor and social systems, were already in place when language emerged during human evolution," explains Fedorenko. "In some sense, the brain seemed fully occupied. But rather than co-opt these existing systems, the evolution of language in humans involved language carving out specific brain regions."

Different aspects of language recruit brain regions across the left

**Word Scramble**

The Fedorenko lab has shown that the brain finds meaning in a sentence, even when "local" words are swapped (2, 3). But when clusters of neighboring words are scrambled (4), the brain struggles to find its meaning.

hemisphere, including Broca's area and portions of the temporal lobe. Many believe that certain regions are involved in processing word meaning while others unpack the rules of language. Fedorenko and colleagues have however shown that the entire language network is selectively engaged in linguistic tasks, processing both the rules (syntax) and meaning (semantics) of language in the same brain areas.

## SEMANTIC ARGUMENT

Fedorenko's lab even challenges the prevailing view that syntax is core to language processing. By gradually degrading sentence structure through local word swaps (see figure), they found that language regions still respond strongly to these degraded sentences, deciphering meaning from them, even as syntax, or combinatorial rules, disappear.

"A lot of focus in language research has been on structure-building, or building a type of hierarchical graph of the words in a sentence. But actually the language system seems optimized and driven to find rich, representational meaning in a string of words processed together," explains Fedorenko.

## COMPUTING LANGUAGE

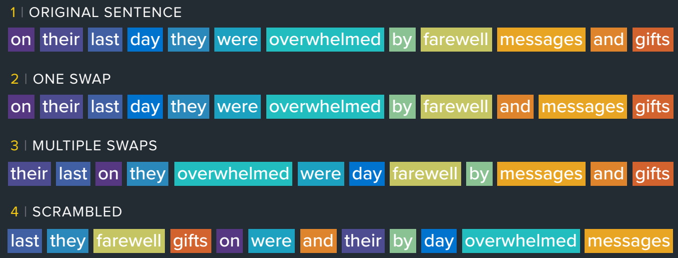
When asked about emerging areas of research, Fedorenko points to the data structures and algorithms underlying linguistic processing. Modern computational models can perform sophisticated tasks, including translation, ever more effectively. Consider Google translate. A decade ago, the system translated one word at a time with laughable results. Now, instead of treating words as providing context for each other, the latest artificial translation systems are performing more accurately. Understanding how they resolve meaning could be very revealing.

"Maybe we can link these models to human neural data to both get insights about linguistic computations in the human brain, and maybe help improve artificial systems by making them more human-like," says Fedorenko.

She is also trying to understand how the system breaks down, how it over-performs, and even more philosophical questions.

Can a person who loses language abilities (with aphasia, for example) recover—a very relevant question given the language-processing network occupies such specific brain regions. How are some unique people able to understand 10, 15 or even more languages? Do we need words to have thoughts?

Using a battery of approaches, Fedorenko seems poised to answer some of these questions.





Ev Fedorenko uses the widely translated book *Alice in Wonderland* to test brain responses to different languages.

# INVESTING IN THE FUTURE

**New research fellowships will support 12 McGovern graduate students for the 2019-2020 academic year.**

Each year, the McGovern Institute awards fellowships, generously provided by our supporters, to foster the research of exceptional graduate students in labs across the institute. This year's graduate fellows study a wide range of topics — from worm behavior to human emotion — and have equally diverse interests outside the lab.

**Daniel Oran**
Boyden Lab
*Builds optical devices that harness light to a degree never before possible*
**Superpower:** Sculpting with light

**Atharva Sahasrabudhe**
Anikeeva Lab
*Builds flexible probes that listen to and control the activity of neurons*
**Superpower:** Can speak and understand five languages

**Suzannah Fraker**
Halassa Lab
*Develops brain-inspired AI that can handle multiple tasks at once*
**Hobby:** Fusion dancing

**Tobias (Toby) Kaiser**
Feng Lab
*Explores how microglia — or immune cells — influence brain development*
**Hobby:** Kitesurfing

**Eghbal Hosseini**
Fedorenko Lab
*Develops computer models that can extract meaning from language*
**Favorite science-themed movie:** Interstellar

- Friends Fellow
- Janet and Sheldon (1959) Razin Fellow
- Lore Harp McGovern Fellow
- Tan-Yang Fellow

**Madeline (Maddie) Cusimano**
McDermott Lab
*Pushes the limits of AI to hear a pin drop within a tapestry of noise*
**Last great book I read:** Rumi's poetry

**Tzu-Hsuan (Maz) Ma**
Fiete Lab
*Analyzes specialized neurons that help us navigate the world around us*
**Hobby:** Origami

**Sean (Dae) Houlihan**
Saxe and Gabrieli Labs
*Unpacks how the brain reasons about emotion in ourselves and others*
**Famous person I'd like to meet:** Dalai Lama

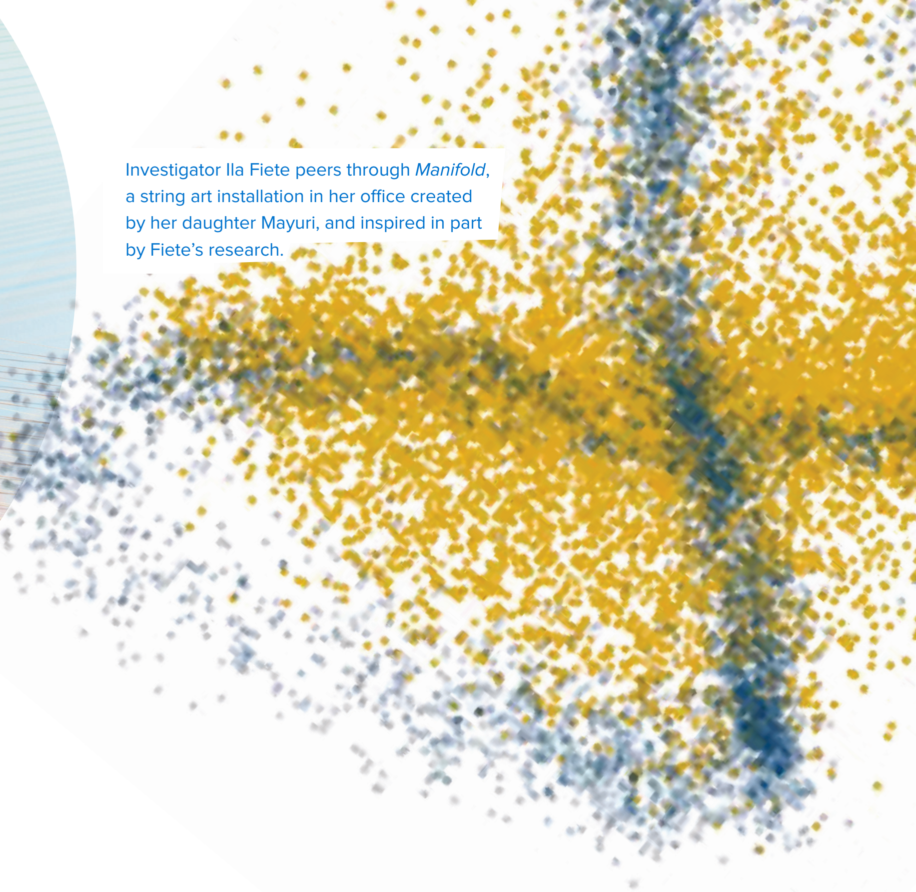
**Alim Ladha**
Zhang Lab
*Tinkers with CRISPR gene-editing tools to make them work efficiently in cells*
**Superpower:** Making the perfect cup of coffee

**Hyodong (Hyo) Lee**
DiCarlo Lab
*Sculpts brain-inspired neural networks*
**Dream Vacation Spot:** Bora Bora Island

**Marc-Joseph (MJ) Antonini**
Anikeeva Lab
*Makes flexible probes that deliver drugs to the brain with pinpoint accuracy*
**Superpower:** Transforming coffee into Matlab code

**Eugene Lee**
Horvitz Lab
*Probes the minds of worms to understand how humans learn*
**Dream Vacation Spot:** A real-life Jurassic Park

**Interested in supporting future fellows?**
Contact Kara Flyg (kflyg@mit.edu)



Investigator Ila Fiete peers through *Manifold*, a string art installation in her office created by her daughter Mayuri, and inspired in part by Fiete's research.

# Searching for Meaning

The world is constantly bombarding our senses with information, but the ways in which our brain extracts meaning from this information remains elusive. How do neurons transform raw visual input into a mental representation of an object — like a chair or a dog?

Ila Fiete has identified a brain circuit in mice that distills "high-dimensional" complex information about the environment into a simple abstract shape in the brain.

**"In the absence of this ring," Fiete explains, "we would be lost in the world."**

Fiete and her colleagues measured hours of neural activity from neurons in the anterodorsal thalamic nucleus (ADN) — a region believed to play a role in spatial navigation — as the animals moved freely around their environment. They mapped how the neurons in the ADN circuit fired as the animal's head changed direction. Together these data points formed a cloud in the shape of a simple and persistent ring (see above). This abstract compass represents the current direction of the head relative to the external world.

Fiete sees these analyses and related studies as fundamental to the future of neural decoding studies. With this approach, she explains, it is possible to extract abstract representations of the mind from the brain, potentially even thoughts and dreams.

## Symbolic Conversation

On a recent trans-Atlantic flight, McGovern postdoc Rachel Romeo harnessed her skills as a speech language pathologist to help a nonverbal boy diagnosed with autism to communicate using hand-drawn symbols.

Their story became a Twitter sensation.

**Rachel R. Romeo** @RachelRRomeo • Aug 28

This was the human desire for communication, pure and simple. To connect with another person and share a thought. Communication is a basic human right, and I was overjoyed to help someone find it. What a privilege and a gift.

293 5.8K 99K

NEUROTECHNOLOGY

## Drug Delivery

The **Anikeeva** lab has developed a system to deliver medical treatments that can be released at precise times, minimally-invasively, and that ultimately could also deliver those drugs to specifically targeted areas such as a specific group of neurons in the brain.

COGNITIVE NEUROSCIENCE

## Evaluating Mindfulness

Two new studies from the **Gabrieli** lab suggest that mindfulness — the practice of focusing one's awareness on the present moment — can enhance academic performance and mental health in middle schoolers. The researchers found that more mindfulness correlates with better academic performance, fewer suspensions from school, and less stress.

## Sound Bytes

A study out of the **McDermott** lab sheds light on how the brain accomplishes the task of extracting meaningful sounds from background noise — findings that could one day help to build artificial hearing systems and aid development of targeted hearing prosthetics.

## Awards

**ED BOYDEN** | 2019 Warren Alpert Prize, 2019 Croonian Medal and Lecture, 2019 Lennart Nilsson Award

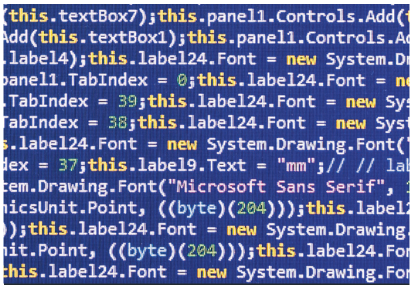
**MEHRDAD JAZAYERI** | 2019 MIT School of Science Teaching Prize for Graduate Education

GENOME ENGINEERING

## RESCUE

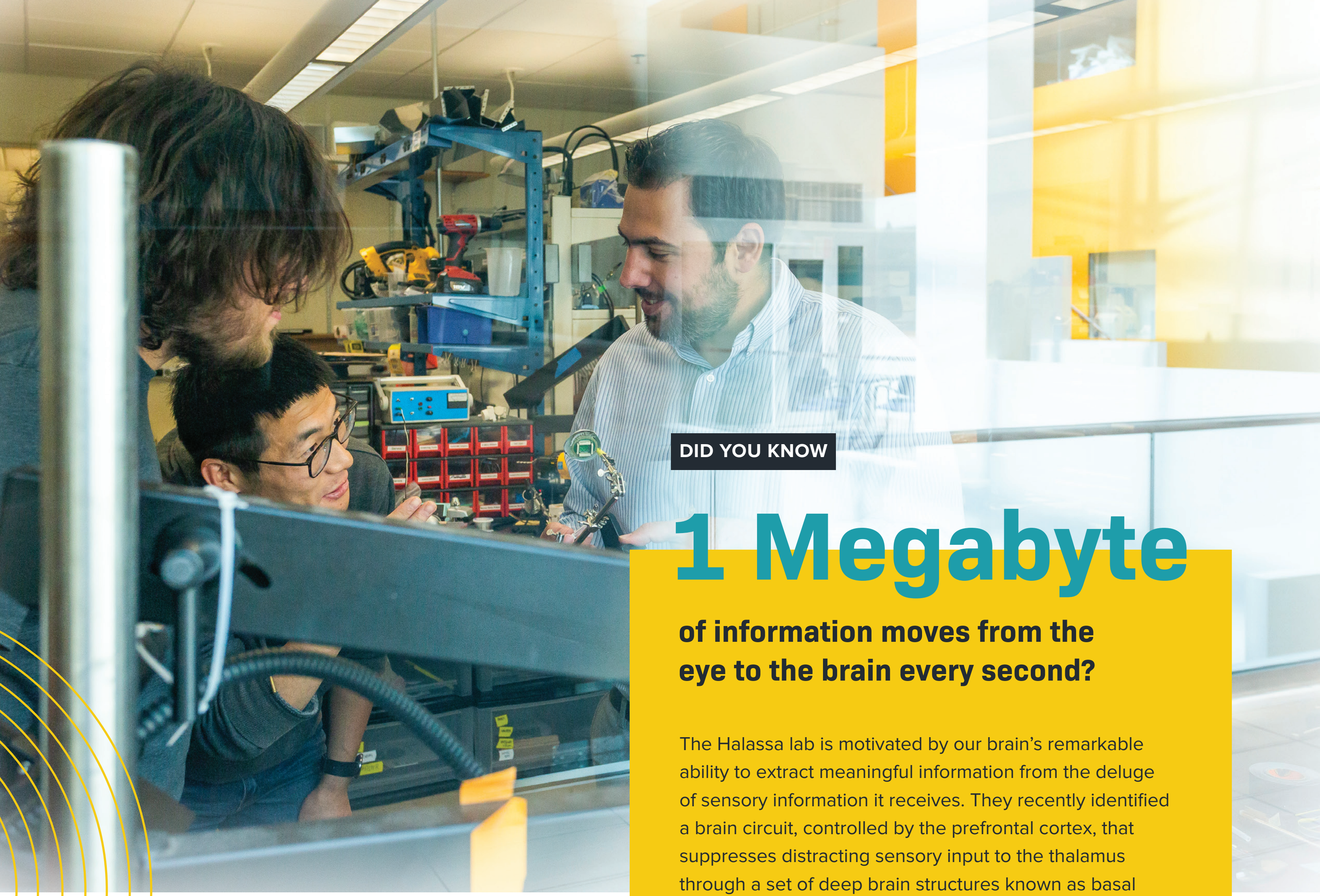
**Omar Abudayyeh** and **Jonathan Gootenberg**, together with **Feng Zhang**, have expanded the CRISPR toolkit to include a new RNA-editing method called RESCUE (RNA Editing for Specific C to U Exchange). RESCUE performs reversible RNA edits that were previously not possible. They introduced the Alzheimer's risk-associated *APOE4* RNA into cells, and showed that RESCUE can convert its signature C's to an *APOE2* sequence, essentially converting a risk to a non-risk variant. ●

The CRISPR family enzyme Cas13 at work. Cas13 (pink), is at the heart of the RESCUE platform, where it uses a special guide (red) to target RNAs in the cell (blue). Image: Stephen Dixon



## Coding Language

Fedorenko lab grad student Anna Ivanova has found that computer code engages "math and logic" brain regions as well as frontal brain regions linked to higher-level language processing.



DID YOU KNOW

# 1 Megabyte

## of information moves from the eye to the brain every second?

The Halassa lab is motivated by our brain's remarkable ability to extract meaningful information from the deluge of sensory information it receives. They recently identified a brain circuit, controlled by the prefrontal cortex, that suppresses distracting sensory input to the thalamus through a set of deep brain structures known as basal ganglia. Their discovery provides some of the first evidence that the basal ganglia, previously associated with motor control, may also play a role in controlling attention.

These findings are particularly intriguing since many ADHD medications work by increasing dopamine, and the basal ganglia have the highest concentration of dopamine receptors in the forebrain.

**Learn more about the Halassa lab:**
mcgovern.mit.edu/halassa

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