Massachusetts Institute of Technology
Summer 2019

Spectrum

TRAJECTORY

PLUS

CELEBRATING THE MIT STEPHEN A. SCHWARZMAN COLLEGE OF COMPUTING

P. 30

Left: Russell Pasetes 2020 shows off a project that creates public surround sound during celebration events for the MIT Stephen A. Schwarzman College of Computing (see page 30).

PHOTO: LILLIE PAQUETTE

Wide Angle

Subjects

SPECIAL SECTION

Trajectory

Breakthroughs and Insights

Inside the MIT Campaign for a Better World

FRONT COVER

ILLUSTRATION: STOLTZE DESIGN

BACK COVER

VIDEO: MELANIE GONICK/MIT

Changing Course, of Course

Since joining MIT's faculty nearly 40 years ago, I have witnessed a fascinating range of moments that shifted our trajectory in some fundamental way. Those I admired most strengthened our whole campus community while simultaneously extending its impact far from home.

With Project Athena in 1983, MIT revolutionized its own teaching and research environment with ubiquitous computing—and ended up driving technological advances with global impact, from the X Window system to Kerberos authentication. When women faculty in the School of Science documented serious inequities in their resources and lab space compared to their male colleagues, MIT made it public and changed course, setting a remarkable example for all of higher education and beyond. And with each of its major initiatives in digital learning, from MIT OpenCourseWare to MITx and edX, MIT has set out to reach a broader educational audience—and changed the game.

As you'll see in this issue of *Spectrum*, these big familiar examples speak to the same culture of bold experimentation that continually drives new thinking and new trajectories at MIT, from economics to architecture, management to materials science, music to mechanical engineering.

Looking ahead, the fall opening of the MIT Stephen A. Schwarzman College of Computing (see page 30) represents another thrilling shift in the Institute's trajectory—the most significant restructuring of MIT in nearly 70 years. By tapping into the power of computing to advance diverse fields of study and enriching computing with insights from disciplines across MIT, the college will play a vital role in MIT's work to invent the future—and continue to make a better world.

By the time you read this letter, a task force of faculty, students, and staff will have submitted ideas for the college's design, from organizational structure to faculty appointments to the social implications of computing. And in August, the college's inaugural dean, Daniel Huttenlocher SM '84, PhD '88, will arrive on campus and begin turning ideas into action.

Once again, we are charting a new path while staying true to our guiding mission.

Sincerely,

L. RAFAEL REIF

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Summer 2019

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Contact Us
617.253.2066
spectrum@mit.edu

spectrum.mit.edu
betterworld.mit.edu
giving.mit.edu/spectrum

Vice President for Resource Development
Julie A. Lucas

Executive Director of Communications and Events
Carrie Johnson

Director of Marketing and Communications
Aimée Jack

Editor-in-Chief
Tracey Lazos

Managing Editor
Kathryn O'Neill

Senior Creative Director
Barbara Malec

Creative Director
Elizabeth Connolly

Design
Stoltze Design

Contributing Designer
Niki Hinkle

Copy Editor
Evanthia Malliris

Spectrum Online
Stephanie Eich

The Office of Resource Development gratefully acknowledges the leadership of the MIT Corporation in the MIT Campaign for a Better World.

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1936

The boathouse opened in 1936 with 30 sailing dinghies thanks to alumni funding. In 1976, it was named for Walter Cromwell "Jack" Wood 1917, one of its founders and MIT's first sailing master.

"It's like riding a bike. Once you have the basic skills—which are taught in a lively, tippy dinghy—the sport is there for a lifetime of enjoyment."

Franny Charles, MIT Sailing Master

TECH DINGHY

The original "Tech Dinghy" was designed specifically for MIT by Professor George Owen (Class of 1894 and head of the Department of Naval Architecture) and made by the storied Herreshoff Yard in Bristol, Rhode Island, using lapstrake construction. Nathanael Greene Herreshoff, Class of 1870, a naval architect and steam engineer, and his brother, John Brown Herreshoff, a blind boat-builder, formed the Herreshoff Manufacturing Company in 1878.

BIRTHPLACE OF INTERCOLLEGIATE SAILING

MIT was the first university to recognize sailing as an official student activity, and the pavilion has become known as the birthplace of intercollegiate sailing. This pavilion is still home to the largest college recreational sailing program in the United States.

6th gen.

Today's sixth-generation Tech Dinghies maintain the same lines and weight as the originals. However, they are built combining resin-infused sandwich construction with a carbon fiber inner hull skin. Everyone who learns to sail at MIT starts out in a Tech Dinghy.

Summer Sail Days

Learn-to-Sail classes are offered free to all members of the MIT community, with more than 2,400 people participating every season.

"The foundation of the program is teaching basic skills, and there is a hardy core of volunteers who enjoy sharing their passion with newcomers almost every evening of the week," says Franny Charles, MIT's long-time sailing master.

MIT's recreational sailors also can procure a sailing card and use the fleet; more than 3,000 cards are issued annually. As a result, the MIT Jack Wood Sailing Pavilion on the Charles River is a hub of activity all summer long. The facility is open seven days a week from April 1 through November 15.

The fleet

A variety of sailboat types allows students to challenge themselves. MIT has more than 100 boats, including:

- **31** TECH DINGHIES
- **24** FIREFLIES
- **24** CLUB FLYING JUNIORS (used by the racing team)
- **6** 420s (also a racing boat)
- **6** GAFF-RIGGED CATBOATS
- **6** LASER CLASS OLYMPIC BOATS
- **1** FOILING CATAMARAN
- **1** FOILING MOTH CLASS SAILBOAT
- **1** 1902, MUSEUM-QUALITY, 51-FOOT HERRESHOFF SLOOP suitable for sailing around Massachusetts Bay
- **+** VARIOUS SAILBOARDS

PHOTO: M. SCOTT BRAUER

Tech Harmony

Students use programming to create new musical experiences

TITLE

21M.385 / 6.809: Interactive Music Systems

INSTRUCTOR

Eran Egozy ’95, MNG ’95
Professor of the Practice
in Music Technology

FROM THE CATALOG

Interactive Music Systems is a hands-on programming and design course that explores audio synthesis, musical structure, human-computer interaction, and visual presentation as the ingredients for the creation of engaging, real-time interactive musical experiences. These experiences allow users to connect with music more deeply than through passive listening. The most **successful ones** give users intuitive control, greater musical insight, and a deeper emotional response to the musical experience. Students learn about the principles, design considerations, and aesthetic qualities of interactive music systems by exploring topics such as music perception and audio synthesis, analysis and application of design elements in music games, music visualization, and **aesthetic cohesion**.

Successful commercial examples include games like Guitar Hero, Rock Band, and Fantasia: Music Evolved.

Venkatesh Sivaraman ’20: “You can design an instrument that requires a lot of effort but is really satisfying to play. And so the goal of our class and the projects we do is to lower that bar. But there’s also a sweet spot. It can’t be too easy.”

THE LECTURES

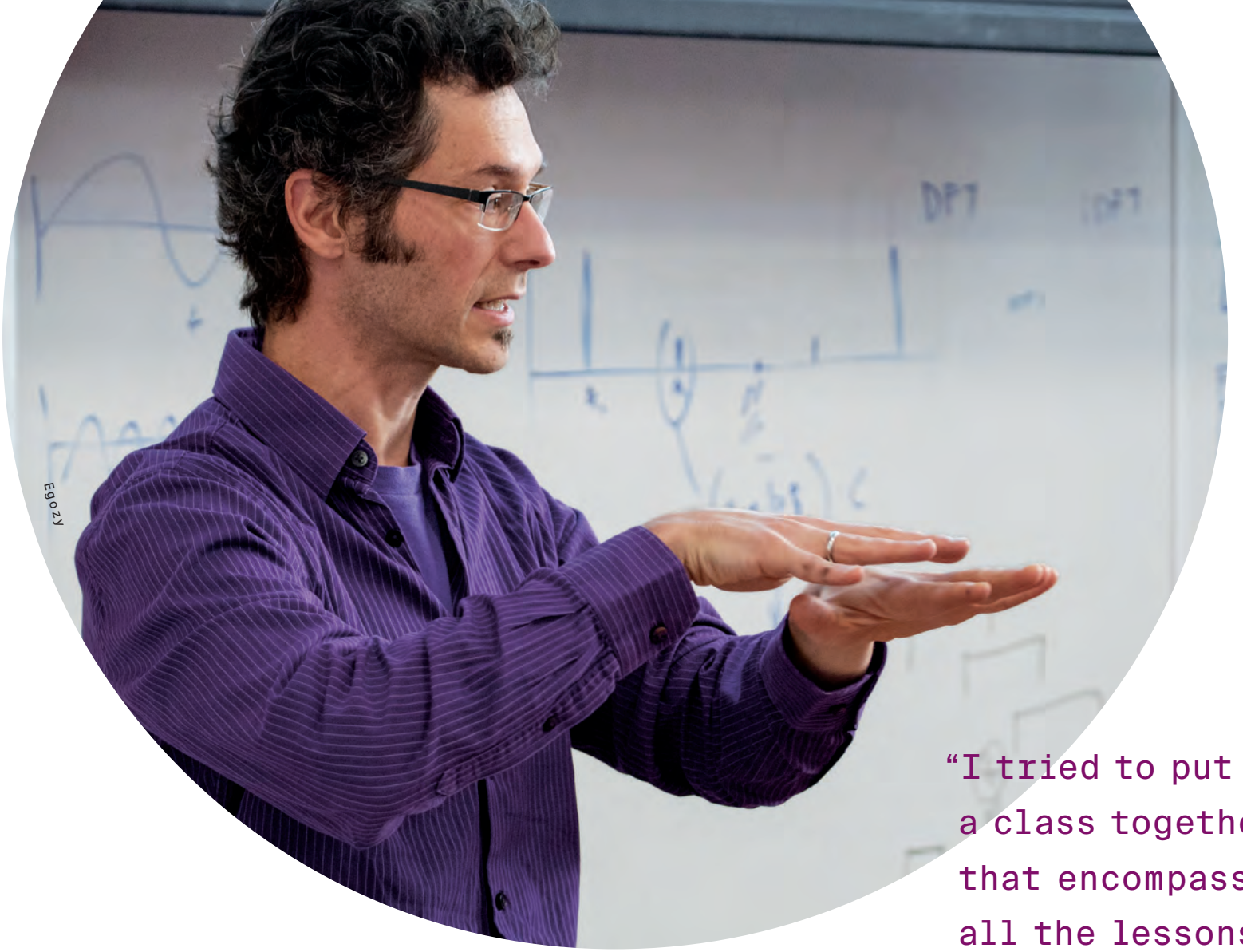
Interactive Music Systems has been offered every semester since spring 2015. The course (developed by Professor of the Practice Eran Egozy with support from Leslie Kaelbling, the Panasonic Professor of Computer Science and Engineering) **combines computation with music**, allowing students to apply what they’ve learned in their coding classes in a new and creative way. **Egozy’s career** creating wildly popular interactive music games gives students **unique and thorough insight** into what it takes to develop new musical experiences. Prerequisites include 21M.301 (Harmony and Counterpoint I) and 6.009 (Fundamentals of Programming), so all of the students have some degree of interest in the **unique combination of music and technology**. A student who took the class in the previous term serves as teaching assistant for the class.

Egozy: “There are lots of issues around music that lend themselves to notions of computation. The fact that there are structures and rules means that you can think about it computationally and you could write code or programs that do something with that music.”

Isabel Kaspriskie ’19: “Professor Egozy is both extremely supportive and encouraging, and he definitely imparts his years of experience to the class. The class has a great reputation, and the creative atmosphere there exceeded all of my expectations.”

Egozy is the cofounder of Harmonix Music Systems, which developed the video game franchises Guitar Hero and Rock Band. In 2008, Egozy and his cofounder, fellow MIT alumnus Alex Rigopulos ’92, SM ’94, were named to *Time*’s 2008 list of the 100 most influential people for their work on Rock Band.

Kaspriskie: “In my experience, the best scientists and engineers use creative processes in their technical work. So it makes sense to me that MIT should foster creative thinking both in STEM as well as the humanities.”



Janelle Sands '19 and Brice Huang '19 demonstrate their final project for Interactive Music Systems: Cello Hero, a gamified feedback tool for novice musicians.

PHOTO: ROSE LINCOLN

Every Monday, students meet for lectures on a variety of topics of music technology. Through these lectures and occasional analysis of popular musical games, students come to understand the many components of creating exciting interactive music systems. Occasional guest lectures from industry innovators expose the students to the breadth of opportunities available in the field.

THE PROJECTS

Wednesdays are reserved for **class assignments**: problem set demos where students show off the creative part of their assignment, an "exploration presentation" where students explain interesting interactive music systems already in existence, and a lab where students work out problems related to that week's lecture material. For the final project, students team up to **create their own interactive music experience**. Over the years, these have included an interactive guitar tutor and a side-scrolling video game that requires players to perform actions on the beat.

Interactive Music Systems is just one of several music technology classes enhancing MIT's already rich array of music offerings. As a result, students who come to MIT for an unparalleled technical education can enjoy **world-class training in the arts** as well.

—Stephanie M. McPherson SM '11

Egozy: "The course and assignments challenge students in two ways: first, they have to write the software to create a piece of music technology, and second, they have to use the system they just made in an interesting, creative way."

Kaspriskie: "My team is working on a visualizer [a feature that generates imagery for music] for Spotify."

Sivaraman: "We're planning to build an interactive music generation system using the Kinect [motion sensor], so that you can place objects in a virtual space and move them around to produce different kinds of music."

Emily Hu '20 (spring 2019 teaching assistant): "Music has always been pretty important to me because it's always been a way for me to make friends, connect with people. It's very universal. I really enjoy bringing that experience to other people as well—which is why this interactivity with music through technology is so interesting."

"I tried to put a class together that encompasses all the lessons that I've learned building a music game company," Egozy says.

PORTRAIT: JON SACHS (EGOZY)

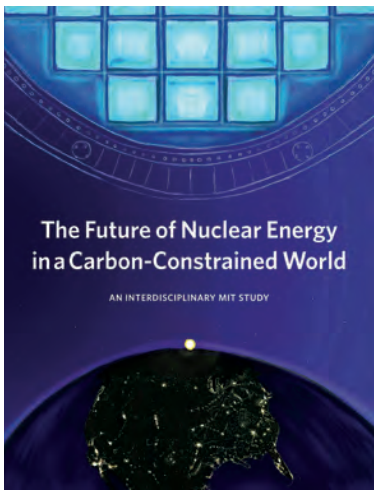
Paths of discovery cross every day at MIT, enabling community members to learn from each other, change course, come together again, and make progress. These interactions propel groundbreaking research and further personal development. Although it's not always clear where a path will lead in scholarship, or in life, MIT aims high, working to ensure that humanity's collective trajectory is pointed toward a brighter future.

Power Forward

MIT Energy Initiative plans for low-carbon future

Meeting the growing energy needs of our technological age while addressing global climate change is a daunting undertaking. That's why the MIT Energy Initiative (MITEI) continually draws together wide swaths of the Institute's intellectual, organizational, and policy resources to take on the challenge.

"MITEI has a mission of bringing together science, innovation, and policy to transform the world's energy systems," says Robert C. Armstrong, MITEI director and the Chevron Professor of Chemical Engineering. "Our goal is to reach across campus to get as many different disciplines as appropriate to work together and tackle these complex problems." MITEI works with almost 35% of the MIT faculty on its three major objectives: research, education, and public outreach.



Among its most visible projects is its series of "Future of…" studies, comprehensive multidisciplinary research reports that explore paths to meeting future energy demands under carbon dioxide emissions constraints. To date, MITEI has produced "Future of…" studies on energy sources such as solar, natural gas, coal, and geothermal, and on vital parts of the energy infrastructure, including the electric power grid and the nuclear fuel cycle.

The latest report is The Future of Nuclear Energy in a Carbon-Constrained World. This title neatly sums up the study's major point, which as study co-chair Jacopo Buongiorno PhD '01, TEPCO Professor and associate head of the Department of Nuclear Science and Engineering, explains, is that "nuclear can and should play a big role in decarbonizing the power sector."

The study points out that reaching this goal will require not just technical innovations, such as new reactor designs, but also updated policy and business models, regulations, and construction techniques.

Changing nuclear landscape

In some ways, the new study harkens back to The Future of Nuclear Power, a report released in 2003—even before MITEI was formally established in 2006 by MIT's then-president Susan Hockfield, professor of neuroscience. However, Buongiorno says, "The landscape for energy and nuclear in particular has changed dramatically since 2003."

Vast new natural gas resources have been tapped, and attention to climate change and the need for decarbonization have increased. The nuclear industry was hit hard by both the 2008 economic crisis and the 2011 nuclear accident in Fukushima, Japan.

Furthermore, emerging technologies continue to increase the value of nuclear energy in terms of decarbonization. Fourth-generation reactor designs are more efficient and more

The latest research from the MIT Energy Initiative outlines the value of including nuclear power in any plans to decarbonize the energy sector.

PHOTO: ZHONGGUO

accident-tolerant; today's small, modular reactors offer more flexibility and versatility than traditional large-scale nuclear plants. "If you sum these all up, we thought that it was a good time to take a fresh look at the prospects of nuclear," says Buongiorno.

Buongiorno points out, "We looked not just at electricity, but at the other energy applications of nuclear systems, for example, heat for industry or production of synthetic fuels or hydrogen—essentially a way to penetrate markets that are not traditional for nuclear. Nuclear traditionally has been used for power. But the idea here is to go after also the massive carbon emissions that are outside the electricity sector."

Such ideas capitalize on the fundamental function of a nuclear reactor: creating heat. Typically, plants create steam to turn turbines that generate electricity, but heat itself can also drive industrial processes—a concept made even more attractive by the higher operating temperatures available with advanced reactor designs.

In addition to exploring new technology, however, Buongiorno and his colleagues also examined the policy and economic issues that have stalled the growth of nuclear power. Their analysis shows that trying to meet energy needs solely through renewable sources will raise the cost of decarbonization while slowing its progress. The study makes the case that, ultimately, nuclear is an important avenue to a low-carbon future.

Armstrong

Buongiorno

"Nuclear traditionally has been used for power. But the idea here is to go after also the massive carbon emissions that are outside the electricity sector," says Buongiorno.

Worldwide audience

MITEI's "Future of…" reports have been well received, with impacts that reach beyond the expected audience of government policy makers and energy industry wonks. This latest effort has been no exception.

The report was released in September 2018 to what Buongiorno calls "an overwhelming reaction—the amount of attention exceeded my wildest expectations." Following the initial rollout of the study, Buongiorno and his colleagues embarked on what amounted to an "almost nonstop world tour" to present their findings—traveling from London, Paris, and Brussels to India, China, Japan, and Korea. The executive summary has been translated into six languages, and the entire report was translated into Chinese.

Such a globetrotting presentation, gathering reaction and feedback from scientists and policy makers around the world, highlights another difference between this study and the 2003 report. "That study had focused primarily on the United States and North America, with implications for the rest of the world," Armstrong says. "This most recent study has, by design, taken a global approach."

Despite all the positive reaction to the latest MITEI effort, Buongiorno admits that there's a difference between people paying attention and taking action. "It's hard to assess whether this is going to have a real impact," he observes. "Will people actually implement our recommendations or not? That remains to be seen."

However, some short-term impacts are already evident. "We've been invited to states in the US to talk about the value of the existing nuclear fleet," Buongiorno says, noting that the study provides useful information for decision makers charged with determining whether plants should be shut down or kept operating when their licenses expire.

Influential reports

Given the pattern set by previous MITEI efforts, it's also a safe bet that its long-term influence will be significant. Armstrong cites the 2011 Future of Natural Gas study as an example. "I think that one was particularly impactful," he says. "The report pointed out the likely possibilities that shale gas could remake the gas business in North America; it could revitalize the chemical industry by providing low-cost feedstocks; it could provide substantial new jobs in the natural gas sector; and it could potentially reshape the global gas business. We've actually seen that come to pass.

"We also pointed out that it had the potential at low cost, which we were projecting, to contribute significantly to meet the challenge of climate change. And that's also come to pass."

PORTRAITS: KELLEY TRAVERS, MITEI (ARMSTRONG); DIANA BOWEN (BUONGIORNO)

Unexpected and unconventional recommendations such as these are something of a hallmark of the "Future of…" studies, many of which have inspired new ways of thinking about old questions.

John Parsons, an economist at the MIT Sloan School of Management and co-chair of the nuclear study, points out that the new report, for example, contradicts the common belief that the main driver of cost for nuclear plants is the reactor itself and related systems. Actually, he explains, "The large cost of the power plant is in the civil engineering around the reactor, big civil structures, and in particular things like the containment building and the basemat, as well as the site preparation." He adds, "We identified ways to reduce these costs."

That sort of insight likely comes more naturally to an economist than a nuclear engineer—which is exactly why MITEI takes an interdisciplinary approach to energy research.

"In order to inform policy makers and thought leaders about the big challenges in meeting climate change and still providing more energy, we need to get all of those disciplines together," Armstrong says.

Armstrong believes that such a multidisciplinary effort is particularly at home at MIT. "That's part of the culture here, developed over many, many years. The faculty have a substantial trust and admiration for one another's capabilities and are happy to work together on these kinds of joint projects. It's hard to replicate that in other places," he says.

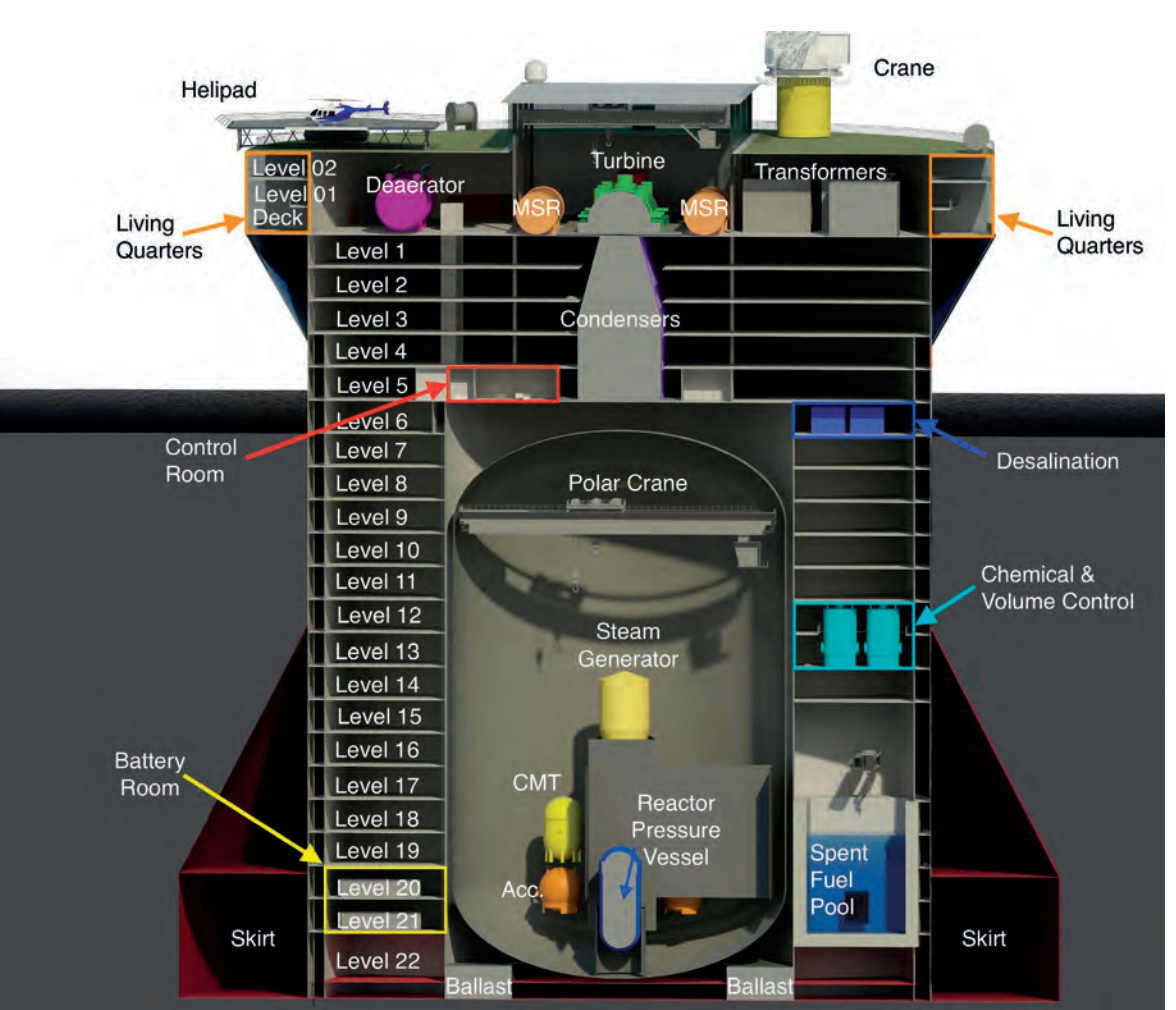
MITEI's work stands apart for other reasons too, according to Parsons. "There are three things. Number one is the attention to cutting-edge technological change. Number two is a lack of a bias toward one technology or another. Number three is a hard-nosed economic attitude. We're not sunny optimists," he says.

The next "Future of…" study is already well underway, focused on energy storage. "As we get more and more renewables in the electricity system, it becomes more apparent that there are substantial challenges from intermittency that are intrinsic to solar and wind," Armstrong explains.

The newest project emerged in part as a result of the 2015 Future of Solar Energy study. Says Armstrong, "One of the major conclusion areas was that we needed to prepare for large penetration of solar by developing appropriate storage technology." Following the successful pattern set by previous MITEI studies, the project brings specialists in different storage technologies together with experts in policy. The goal of the study, which Armstrong anticipates will take another two years, is to "help the public and policy makers understand what we need by way of storage technology to have a carbon-free world."

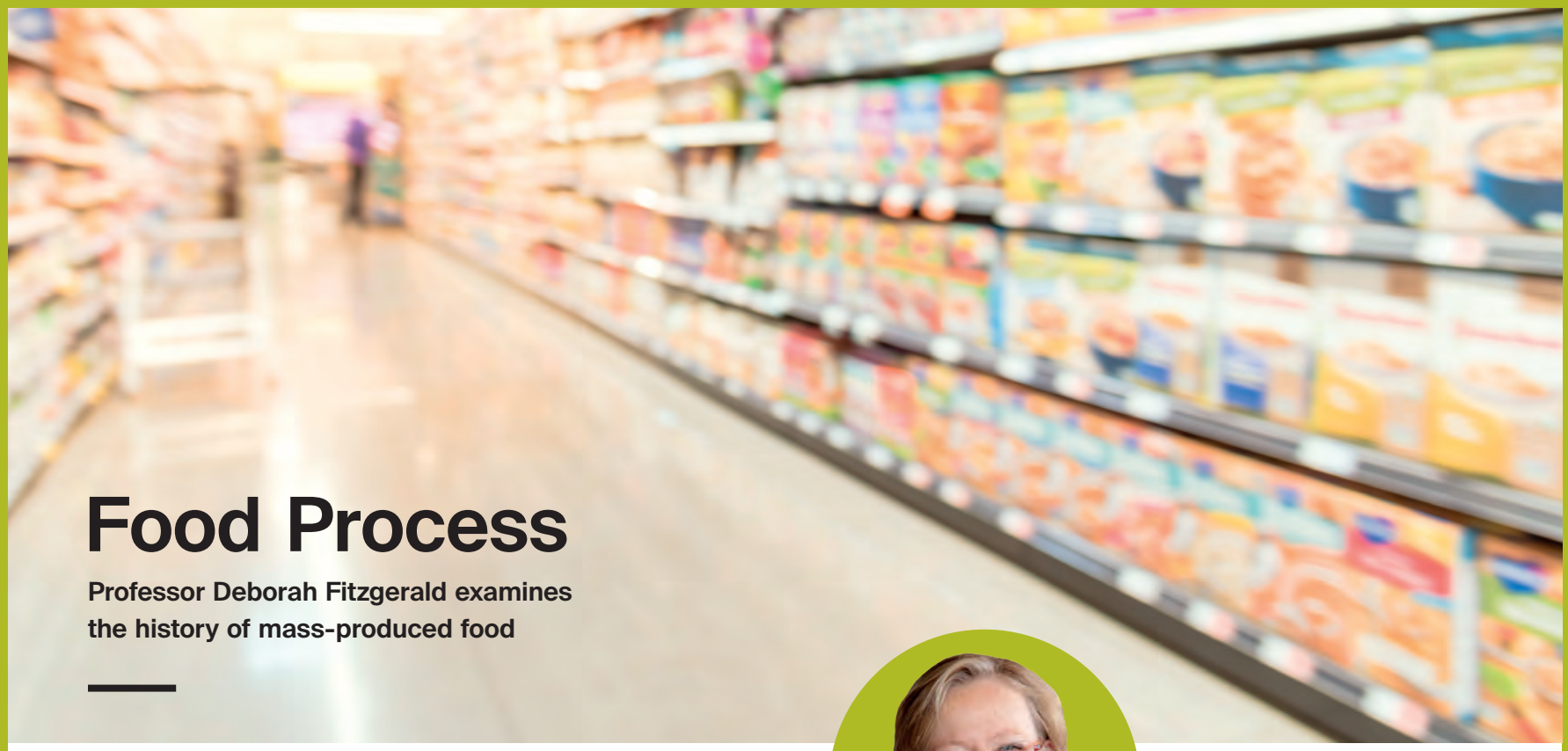
Whatever the results, chances are good the next report will reflect the attitude common to all the "Future of…" studies. As Parsons describes it: "We're sure there is some way to make the world better, but you really have to prove that you can do [something] with whatever technology and whatever economic paradigm you're proposing." It's a combination of being both visionary and yet completely practical, he says. —Mark Wolverton

Wolverton is a 2016–17 MIT Knight Science Journalism Fellow.



MITEI's latest report explores innovative ideas for nuclear power generation, such as siting reactors offshore. A detail of the design for such a plant is shown at left.

IMAGE: COURTESY OF MIT DEPARTMENT OF NUCLEAR SCIENCE AND ENGINEERING



Food Process

Professor Deborah Fitzgerald examines the history of mass-produced food

In a typical supermarket, all of the fresh food—fruits and vegetables, meats, dairy, and bread—line the perimeter of the store. The expansive middle, meanwhile, features aisle after aisle of processed foods. "It's all of these crazy crackers and chips, and stuff that didn't exist before," says Deborah Fitzgerald, the Leverett Howell and William King Cutten Professor of the History of Technology in the Program in Science, Technology, and Society at MIT. "I started wondering where it all came from. There had to be a driving force that made people think this was a great idea."

Acclaimed for her book *Every Farm a Factory* (Yale University Press, 2003), in which she explored the history of agricultural industrialization in the United States, Fitzgerald went on to spend nine years as Kenan Sahin Dean of MIT's School of Humanities, Arts, and Social Sciences. Now she is at work on a new book examining the origins of America's current supply of food products.

The story begins with World War II, when the country mobilized to feed 6 million soldiers stationed abroad in 23 different climatic regions. "All of the food they ate was made in America and shipped to wherever they were," Fitzgerald says. At the center was the US Army Quartermaster Corps, which exerted a profound, yet understudied, effect on the trajectory of our nation's agricultural system. "It was an amazing operation that has been written about very little."

The military solved its provisioning problems by working with food companies to create food described as "time-insensitive"—bland, processed meals that could withstand the rigors of overseas shipping and be carried by soldiers into battlefields anywhere. That meant heavily processed and preserved foods like cans of beef stew and chili con carne, "meat bars" (made of compressed and dehydrated meat), biscuits, cookies, and candy that could give soldiers energy and nutrients in a hurry.

To accommodate this rapid shift, the Quartermaster Corps requisitioned massive quantities of produce from distinct areas—fruits from California, dairy from Wisconsin and New York, grains from the Midwest—consolidating industries geographically. "Before the war, farmers grew a little bit of everything, but that became less realistic as the war developed," Fitzgerald says. "This big national crisis turned around the way agriculture was done."

After the war, those changes stuck. Midwest farmers, for example, suddenly found themselves with bumper crops of wheat and corn with no obvious civilian market. Food companies stepped in, creating new products to utilize the surplus. "They had to turn it into something—so welcome, Doritos!" Fitzgerald says. To make these processed foods more palatable to civilians, the companies tapped new technologies in coloring and spray-on flavor to create an amazing variety of foods—a trend that continues to fill the middle aisles of supermarkets today.

Fitzgerald says the story of 20th-century processed food is an intriguing lens through which to view the history of technology generally—especially in a place like MIT that has so much faith in the positive potential of technology.

"People tend to think that all of the things we are consuming were developed for a reason, and that's because they are better," says Fitzgerald, who has written an article on the history of processed foods for a forthcoming issue of *Osiris*, an annual journal dedicated to the history of science. "I want people to see the links between their experience and the larger cultural context," she says, explaining that she has found change comes most often in response to specific cultural and economic realities. "It's almost never because it was intrinsically better."

—Michael Blanding

> Groceries today are full of chips and other junk food. Fitzgerald found herself wondering where it all came from.

PHOTOS: TRONG NGUYEN (ABOVE); DONNA COVENEY / SHASS COMMUNICATIONS (INSET)

ET Genome

Team is developing genetic testing for life on Mars

Is there life on Mars?

The question is still open, though efforts to address it have run the gamut from the 1908 book *Mars as the Abode of Life*, in which astronomer Percival Lowell made his case for a lost Martian civilization, to the more than a dozen NASA missions that have explored the Red Planet.

Now, a team from MIT and Harvard is developing an instrument that could quickly provide convincing evidence of life on Mars, either at present or in its not-too-distant past.

Gary Ruvkun, a molecular biologist at Harvard Medical School and Massachusetts General Hospital (MGH), started thinking in the early 1990s about sending a robot to Mars that would look for DNA using polymerase chain reaction (PCR) technology. PCR is sensitive enough, in principle, to detect even a single genome. Furthermore, the detection of long, complex DNA molecules would strongly suggest biological origins—a prospect that could be verified by more detailed measurements.

Ruvkun and biologist Michael Finney PhD ’86 discussed the idea at a December 2000 Christmas party, and word subsequently reached Claude Canizares, MIT’s Bruno Rossi Professor of Physics. Canizares told Maria Zuber, a planetary scientist who now serves as MIT’s vice president for research, saying it sounded “kind of crazy.” But Zuber was intrigued. She soon contacted Ruvkun, telling him, “I want to work with you.” The Search for Extraterrestrial Genomes (SETG) project was thereby launched, with Ruvkun and Zuber as principal investigators.

A key advantage of their strategy, explains Zuber, the E. A. Griswold Professor of Geophysics, “is that if you’re looking for DNA-based life, you know exactly what to look for. So that ought to be one of the first things you do when searching for life beyond Earth.”

MIT research scientist Christopher Carr ’99, SM ’01, ScD ’05, SETG’s science principal investigator, agrees with this reasoning for starting with “life as we know it” before undertaking a more general search for the unknown. “If you lose your keys in a parking lot at night,” he says, “it makes sense to look under the streetlights first if you think you might have dropped them there.” But there are other arguments to be made for the approach.

“If there’s life on Mars, there’s a good chance it’s related to us,” Carr says.

All known life forms are based on DNA and RNA, polymeric molecules that are capable of storing information. The basic ingredients for these polymers, and for life in general, can be found throughout our solar system.

What's more, Earth and Mars have exchanged surface and subsurface rocks: roughly 4 billion years ago, during the Late Heavy Bombardment period that followed the formation of the planets, countless meteoroids shot from one nascent planet to the other. A significant fraction of those objects, moreover, did not experience sterilizing heat during launch or atmospheric entry. Thanks to all this material exchange, Carr says, "if there's life on Mars, there's a good chance it's related to us"—meaning it would have DNA or RNA, which is exactly what he and his colleagues hope to find out.

The SETG team is assembling and testing an autonomous device hardy enough to perform in situ DNA and RNA sequencing on the surface of Mars, or in other extraterrestrial venues, working from samples delivered by a rover vehicle's robotic arm. Their plan has evolved from PCR to single molecule DNA sequencing—and the model of device currently in favor is Oxford Nanopore Technologies' MinION.

About the size of a granola bar and weighing just a few ounces, MinION has sequenced entire genomes while proving itself in numerous harsh environments, including on board the International Space Station and under water. Although other researchers carried out the space station testing, SETG researchers have operated the sequencer successfully in volcanic craters in the Argentinean Andes and on Devon Island in the Canadian High Arctic, a location that's served as a Mars analog for scientists since around 2000.

MIT researchers have used volcanic locations, such as this acidic stream in the Andes, as Mars analogs to test their DNA sequencer.

PHOTO: C.E. CARR

In May 2018, Zuber and MIT postdoc Noelle Bryan took the MinION onto a reduced-gravity aircraft (the "Vomit Comet") where sequencing reads were obtained under zero gravity and Mars gravity (0.376 g) conditions.

In further tests, Carr used a vacuum chamber in the SETG MGH lab to simulate Mars temperatures and pressures. So far, the sequencing technique has performed well under those conditions too. The SETG team has demonstrated all steps of the process, and they're currently working to produce a fully automated "end-to-end-validated instrument" that can operate under Mars-like conditions. Reaching this critical step, Carr says, "would give us confidence that this could become a flight-ready instrument."

"We won't be ready for the Mars 2020 Rover mission," adds Zuber, but that will not be their last chance, as launch opportunities for reaching the Red Planet come every two years. After some technical progress on their end, plus luck in their bidding to get into space, the SETG researchers just might realize the "crazy" vision Ruvkun conceived more than a quarter century ago. —Steve Nadis

Nadis is a 1997–98 MIT Knight Science Journalism Fellow.

A Major Expansion for the Green Building

Rising nearly 300 feet from the ground, the Cecil and Ida Green Building, aka Building 54, stands out as not only the tallest building on MIT's campus but also (until recently) the tallest building in Cambridge, Massachusetts. Yet it's not obvious from the outside what actually goes on within this imposing 55-year-old structure designed by the late I.M. Pei '40.

People on campus tours often hear about the annual pumpkin drop or about instances when students have commandeered the Green Building's LED-equipped windows to play giant games of Tetris. But not everyone learns about the groundbreaking work carried out inside—such as the development of chaos theory, seismic tomography, numerical weather prediction, climate modeling, and far-reaching NASA missions.

This is the headquarters of MIT's Department of Earth, Atmospheric and Planetary Sciences (EAPS), and plans are now underway to give Building 54 a major facelift, including a new LEED-certified addition that will offer a window into the important work taking place inside.

The $60 million upgrade will allow construction of an Earth and Environment Pavilion designed to be a vital center for environmental and climate research on MIT's campus. With assistance from the Institute and generous private donors—including John H. Carlson; George Elbaum '59, SM '63, PhD '67; Fred A. Middleton Jr. '71; Neil Pappalardo '64; and Shell—EAPS recently passed the midway point on its $30 million fundraising campaign for the new pavilion and other improvements to the Green Building, such as a renovated lecture hall (54-100) to be renamed the Shell Auditorium.

The project will yield about 12,000 square feet of additional space, providing new meeting places, classrooms, and study areas.

The enlarged and revamped Green Building is expected to help EAPS attract and retain top faculty and students. But the more ambitious objective is to enhance the research undertaken within the department by co-locating EAPS and the MIT-Woods Hole Oceanographic Institution Joint Program with the MIT Environmental Solutions Initiative, affording greater opportunities for interaction and the cross-pollination of ideas.

Artist's rendering of the Green Building with the planned Earth and Environment Pavilion.

CONCEPTUAL RENDERING: ELLENZWEIG

From Vision to World Wide Web

An excerpt from Nick Montfort's *The Future*

"The future is not something to be predicted, but to be made," MIT professor of digital media Nick Montfort writes in *The Future* (The MIT Press, 2017), a book that examines concepts of the future through the work of writers, artists, inventors, and designers. In Chapter 6, "Pre-Invention of the Web," Montfort reveals how visionary work by Vannevar Bush, MIT's first dean of engineering; MIT Professor Tim Berners-Lee; and two other pioneers, Douglas Engelbart and Ted Nelson, came together to shape the World Wide Web. This excerpt centers on Berners-Lee's contributions.

Probably even more familiar to us today than the Interstate Highway Network, which was formed, post-Futurama, beginning in the 1950s, is our World Wide Web, a global information system that is now accessible instantly not only at workstations and notebook computers, but also on phones. This system carries a tremendous number of commercial interactions along with an unprecedented store of information, and it also has a recognized inventor. Tim Berners-Lee proposed this system early in 1989 and implemented enough of the system to load the first Web page later that year. He did have support from others on the project, including Robert Cailliau, but Berners-Lee's work and vision were at the core of the Web, and he is its first author.

The World Wide Web (and the future-making work that preceded it) holds several important lessons for future-makers. As is particularly clear in considering Douglas Engelbart's work and his predecessor hypertext system, an effective vision of the future is one that is engaged with society and builds on personal experience. Engelbart's vision, like Ted Nelson's concept of hypertext, involved higher-level concepts connected to specific, concrete ideas and examples. An effective vision is one that can scale up to widespread use and to new types of use, for instance, by groups of collaborators. Such a vision can draw on utopian modes of thinking and description, and can be exhibited directly as well as described and discussed in writing. And as for the Web itself, related to and in contrast to Vannevar Bush's early system and some of [Ted] Nelson's rich concepts of hypertext, this system took root because it was simple enough to be adopted, and because it was open and available to everyone.

Berners-Lee dedicated the Web to everyone in the world, asking for no royalties, filing for no patents, and ensuring that Web technologies would be unencumbered and free for anyone to use. Instead of becoming a monopolistic system limited to those in wealthy countries with financial resources, the Web—even if aspects of it present problems at times—has, as advertised, become remarkably worldwide and open to all sorts of businesses, universities, organizations, and individuals....

Berners-Lee and his collaborators didn't make up every concept that is the foundation of the Web—they were aware, directly and indirectly, of existing hypertext ideas. The success of the World Wide Web is surely due to two specific factors beyond determination and cleverness:

First, the Web is a simple system, much less powerful than Nelson would like. Not only does it lack built-in support for specific types of hypertext such as stretchtext, it also doesn't even have two-way links. A central registry could provide for such links, as well as transclusion [*Ed. note: an advanced form of hypertextual quotation*] with appropriate payments for authors. But the Web doesn't require any central authority—or, at least, it requires only the hierarchical aspects of the underlying Internet that were already there. The Web would be much less useful without the ultimately centralized Domain Name Service (DNS) that resolves verbal names such as "mit.edu" into numeric addresses. But this system was developed in the 1980s, and predates the Web. Once you can convert your domain names into addresses, your requests only need to route through the Internet to locate a Web server and retrieve information from it. A person who wants to set up a new Web server can just set one up without any interaction with a central registry. In the worst case, dealing with a central authority just means the equivalent of registering a new domain.

Letting people know...that the new server is there is helpful, of course, and in the 1990s a new type of business emerged to help people locate Web resources—including hand-made directories (Yahoo!, Open Directory) and search engines (AltaVista, Google). Such services work to patch up the decentralized Web and allow the discovery of Web resources that would otherwise be obscure. But the Web didn't need to have them in place at the very beginning. They could, and did, grow up afterward. The Web, as it first existed, was a very simple hypertext system. It didn't attempt to solve every problem with an elaborate initial design.

Second, the standards of the Web were offered to everyone rather than being restricted by patents or copyrights. Berners-Lee insisted that the Web not be encumbered, and there are concrete reasons this may have helped the system to succeed. For instance, one of the Web's early competitors, Gopher, offered generally similar ways to traverse hypertext

PORTRAIT: COURTESY OF NICK MONTFORT

resources online and began gaining traction in 1991. Gopher was more limited in some ways, because of its strongly hierarchical format, but also offered some features that the early Web lacked. While not the only factor that led the Web to prevail, Gopher was dealt a blow in early 1993, when its owner, the University of Minnesota, said that it would charge to license its Gopher server, the dominant one. The choice in the early 1990s between a clearly free and open technology and one that might face further restrictions helped to make one of them—the Web—look like a better choice.

... [P]ioneer Ted Nelson isn't a full-on fan of the World Wide Web, even though this famous system has broadened access to some forms of hypertext. He writes, "Trying to fix HTML is like trying to graft arms and legs onto hamburger.... EMBEDDED MARKUP IS A CANCER." He continues, "HTML is precisely what we were trying to PREVENT—ever-breaking links, links going outward only, quotes you can't follow to their origins, no version management, no rights management." Without knowing about Nelson's contributions to hypertext and computing, this may seem like pure negativity; if one knows just a little about history, it may seem like sour grapes. I tend to think that this perspective comes from a different view of what the future could have been. It has particular virtues, but was also complex, more difficult to implement, and required a centralized system for rights management. On the one hand, a wider array of features didn't mean, by itself, that Nelson's system was better. On the other hand, the Web, however successful it has been, is not beyond critique.

As far as future-making is concerned, these are the two, clear lessons from the early success of the Web:

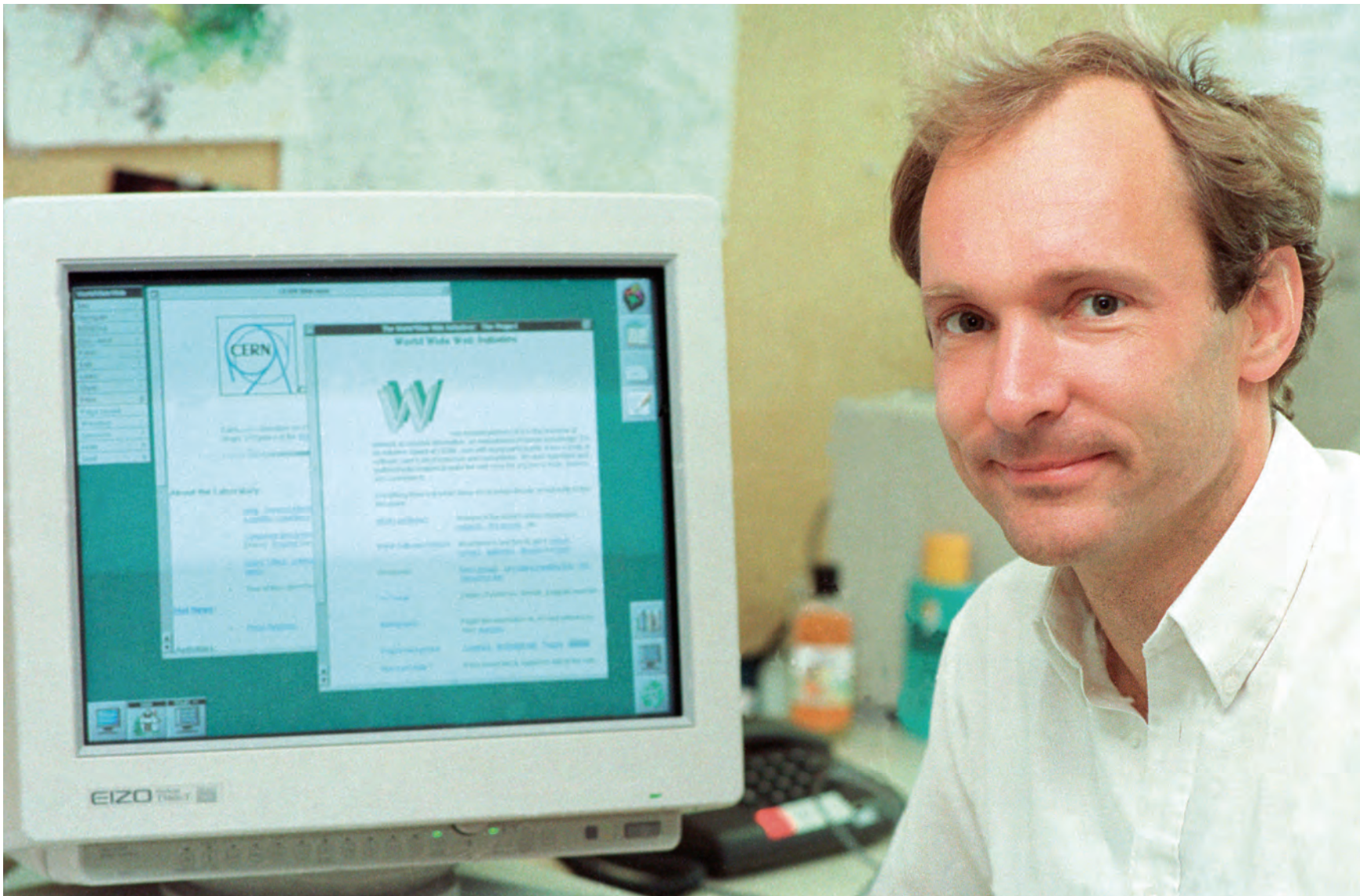
- The right level of simplicity/complexity is important, even if it means removing some of the features of a vision, and of a systematic future, that other future-makers really love. A vision has to be understood and accepted, and one that is too complex to understand or implement has little chance.

- Openness, an ability to be shared, and freedom to study and build on a system are really important to whether or not people choose to adopt and further develop new ideas and systems.

"Tim Berners-Lee insisted that the Web not be encumbered, and there are concrete reasons this may have helped the system to succeed."

The visionary work of MIT Professor Tim Berners-Lee (pictured in July 1994) in inventing the World Wide Web is highlighted in *The Future* by Nick Montfort.

PHOTO: ©CERN



Reinventing Jobs

Researchers measure the suitability of machine learning in the workplace

How will automation affect employment? Which tasks could be enhanced by machine learning and which might render human labor obsolete? Erik Brynjolfsson PhD ’91, director of the MIT Initiative on the Digital Economy, postdoctoral researcher Daniel Rock SM ’16, PhD ’19, and Tom Mitchell at Carnegie Mellon University have found some answers to these questions using a suitability for machine learning (SML) rubric.

While the media might foretell a future overtaken by robots with vast swaths of the workforce displaced from their jobs, that won’t happen anytime soon, Brynjolfsson says. The team’s rubric serves as a guide to which jobs or occupations could be reorganized—not eliminated.

“We’re very far from what researchers call artificial general intelligence, where AI can do the full spectrum of things that humans can do, like the Hollywood robots HAL or the Terminator. There’s almost no occupation where machine learning just runs the table and can do everything,” says Brynjolfsson, the Schussel Family Professor of Management Science.

The pair started by working with a team of machine learning experts to create a 23-question rubric that could differentiate between tasks that were suitable for machine learning versus those that weren’t. They then applied the rubric to the O*NET OnLine network data set, a resource that covers 964 occupations mapped to 2,069 direct work activities shared across occupations. One by one, they applied the questions to each job—Does this task require complex, abstract reasoning? Does it require wide-ranging conversational interaction?—and then used a human intelligence task crowdsourcing platform to score each job based on its suitability for machine learning.

“This rubric gives a map of where human labor will be more valuable, versus where machines will be increasingly able to do things,” Brynjolfsson says.

In most cases, Brynjolfsson says that machine learning will only affect parts of jobs. This means the task of leaders will be to redesign and reengineer jobs, not simply eliminate them. He calls this the “reinvention” of jobs.

“Most occupations consist of a couple of dozen or more distinct tasks. For instance, there are 27 distinct tasks that a radiologist needs to do. One of them is reading medical images. But there are other things that they have to do, like counsel patients, coordinate care with other doctors, and so forth,” he explains.

So, while a robot might be able to read images, could it deliver a compassionate diagnosis? Probably not.

In that vein, low-SML tasks often involve “empathy, human relations, persuasion, teamwork, care, and comforting,” says Brynjolfsson. “We’re deeply wired to connect to other humans, so compared to machines, we have a comparative advantage in connecting to other humans.”

Humans are also better at creativity than robots (for now), as well as at tasks that involve manual dexterity. Hence, jobs such as massage therapy and archaeology have low SML scores, whereas mechanical drafters and credit authorizers—jobs that require repetition and routinization—yield higher ones.

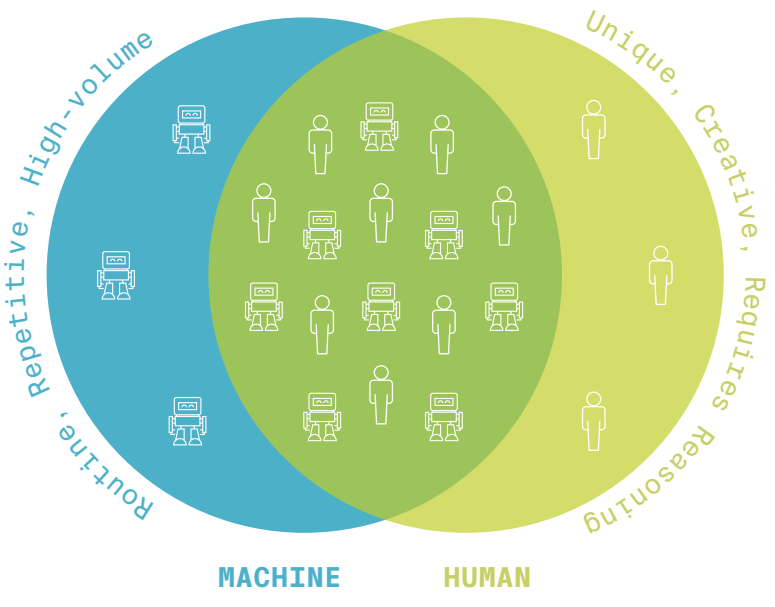
He says that the rubric will help leaders decide how to retrain their workforce and determine which skills to invest in heavily. Ultimately, he says, organizations and employees who achieve a symbiotic relationship with machines will thrive.

“People who will be most successful will be [those] who can leverage machine learning systems by combining human and machine insights,” Brynjolfsson says.

For instance, a computer might help a radiologist scan images more quickly, leaving time for the doctor to see more patients. The sooner society realizes this kind of benefit, the better, Brynjolfsson says. He points to electricity in the 1890s and the early 1900s. A game-changing innovation to be sure—yet the resulting productivity surge didn’t happen until the 1920s. Why? Nobody knew how to reorganize their workforce to embrace the budding technology.

The same holds true with reorganization today.

“How do we change our business processes, how do we change our skills, how do we change the products and services we deliver to take advantage of this?” he asks. “That’s harder. That requires a lot of creativity and entrepreneurship. But I hope it will happen faster than 30 years this time around. In fact, I’m sure it will.” —Kara Baskin



Researchers studying how machine learning will impact future employment have found that, in most occupations, humans and machines will need to work together because they provide different skills.

ILLUSTRATION: NIKI HINKLE

PORTRAITS: EVGENIA ELISEEVA (BRYNJOLFSSON); COURTESY OF DANIEL ROCK (ROCK)

Labor Intensive

Jason Jackson connects urban planning, future of work

Gig economy platforms are disrupting established industries in cities all over the world. But these successes are due less to revolutionary technology than to finding the fault lines in the existing labor market, according to Jason Jackson PhD '13, the Ford Career Development Assistant Professor in Political Economy and Urban Planning in the MIT Department of Urban Studies and Planning.

"The technological changes we observe are less driving these changes and more revealing the underlying cleavages," says Jackson, who serves on the MIT Task Force on the Work of the Future, an Institute-wide effort to understand and shape the way technology is changing jobs.

Jackson is helping the task force complete a global study of the subject in part because he believes it's critical that urban planners play a role in restructuring work. "It will become increasingly impossible for policy makers and planners to ignore these sorts of developments," he says.

Jackson

"Are people participating in the gig economy because they want to make extra money to spend for fun—or are they forced into it?" Jackson asks.

Winners and losers

Jackson's research focuses on ride-hailing apps—the poster child for the disruption of established industries. But even outlining clear winners and losers in the taxi industry is complex, he says, citing a 2013 investigation by the *Boston Globe* highlighting the fraud and worker abuse rampant in the legacy taxi industry. So, while taxi drivers have seen major income losses, the picture for the labor market as a whole is much more complicated.

"Perhaps as many as 35 to 40 million people in the United States have taken part as providers in some part of the gig economy, of which the platform economy is a rapidly growing part," Jackson says. "That's in a rich country with a labor force of about 160 million."

The interesting—and hard—question is: Why? The rise of the gig or platform economy coincides with the fallout from the 2008 financial crisis, when unemployment and general economic precariousness ratcheted up around the country.

"Those two things are likely related," Jackson says. "We have to see it through the lens of structural unemployment and underemployment, that is, the extent to which people who have jobs don't make enough in their jobs, don't make a living wage. Are people participating in the gig economy because they want to make extra money to spend for fun—or are they forced into it because of background conditions related to their lives and livelihoods?"

In some ways, the gig economy takes us back to a time when everyone had to fend for him- or herself, but with an important distinction. Instead of a handful of loosely organized independent entrepreneurs—informal cabs, for example—now there are multibillion-dollar global corporations controlling the platforms and the payment methods as well as lobbying governments and determining the rules of engagement, Jackson says.

Figuring out exactly how this changes the employment landscape is one of Jackson's research interests—and a central question for the Task Force on the Work of the Future.

Urban vanguard

While labor market changes are not exclusively an urban phenomenon, they are more visible in big cities, says Jackson. Cities have been at the forefront of efforts to address both the underlying structural causes of the gig economy's success as well as efforts to accommodate gig platforms in a way that is equitable and fair.

Cities have tools, Jackson explains, including taxes and incentives that can influence where companies set up shop, support alternative business arrangements like co-ops, and increase the minimum wage. His hope, as an urban planner and as part of the task force, is to encourage cities everywhere to be more forward-thinking about regulation while taking a labor-centric approach to policy and planning.

"The extent to which existing technologies and the technologies of the future are able to transform cities, urban life, and urban labor markets is a function of the ways that planners and urban politicians respond," Jackson says.

—Emily Omier

PHOTO: M. SCOTT BRAUER

Building Bridges

Caitlin Mueller uses digital tools to link architecture, engineering

Digital design tools date back to the very origins of the computer. While earning his PhD at MIT in the early 1960s, Ivan Sutherland PhD '63 developed Sketchpad, a computer program that allowed users to create images on a screen using a light pen instead of code.

"He really explored this idea of how the computer would change the way we can think and design and create," explains Caitlin Mueller, associate professor in the Building Technology Program at MIT, where she leads the Digital Structures research group. "Unfortunately, after that piece of work, it became more commonplace for both architects and engineers to think of the computer as replicating analog methods." In other words, engineers use computers for calculations, and architects use them for drafting.

Mueller's goal is to employ machine learning to support the design process from both an architectural and engineering perspective. By creating software that generates design alternatives and simulates their performance, she hopes to qualitatively change how buildings are conceived and built. A big part of that is encouraging architects and engineers to work together—every step of the way.

In the traditional building process, a client hires an architect and provides a set of specifications—X square feet, X number of rooms, etc. After finalizing the design, the architect hires an engineer, who typically looks at the design and says the building can be constructed using X amount of steel, for example. There's often little back and forth.

Engineers generally don't offer large-scale design suggestions in order to, for example, save a substantial amount of steel. As a result, buildings that look great can often prove expensive to build and operate.

That is a wasted opportunity, Mueller says, arguing that engineers should be an integral part of the process from the beginning. The tools she creates make it easier for architects and engineers to work together to find design solutions and assess how changes can influence metrics ranging from the energy needed to heat a building to the cost of labor in construction.

Clients can also evaluate in real time how different designs affect costs, impact the environment, and influence factors such as occupant comfort—giving them better information on which to base decisions. Architects and engineers can further employ Mueller's tools to ensure that, as designs are changed, a building continues to meet both a client's requirements, such as number of rooms, and safety regulations, such as required number of egresses.

The tools even work well on less traditional structures. Recently, Mueller's research team used them to design a community garden trellis system in Somerville, Massachusetts, using wood from culled urban trees. "We generated interesting forms by discerning the intrinsic geometry of the trees' branches to arrange them in structures that used the material efficiently and effectively," Mueller says. "We would never have been able to understand how to use this complex geometry or the structural behavior of these forms without the tools we're developing."

Bringing architecture and engineering together, and considering engineering problems during the design process, will ultimately lead to buildings that are more cost-effective, more environmentally friendly, and cheaper to build and operate, Mueller says.

"People have long been lamenting the fact that architects and engineers don't work together," Mueller says. "Today, both because of the sustainability imperative that's so serious and the abilities these new tools open up for us, I think in the next 5 or 10 years we're going to see a big shift in the types of tools companies use." —Emily Omier

Caitlin Mueller uses robotic 3-D printing to test architectural designs for non-standard elements, such as these culled tree limbs used to build a trellis.

PHOTO: ALAN SILFEN (MUELLER)

PHOTO: COURTESY OF CAITLIN MUELLER (TREE LIMBS)

Academic Turn

Math's challenges take undergrad in a new direction

Alula Hunsen '21, still remembers the moment his academic trajectory at MIT changed. He was taking the final exam for a differential equations class at the end of his first year, furiously working through problem after problem, when he had a realization. "It was a really hard exam, but I was really enjoying myself," he recalls. "I was just so confused as to what was happening because I had never engaged with anything in that way."

Hunsen arrived at MIT with a plan to major in bioengineering, a choice that felt obvious having grown up with parents who were organic chemists, and after having enjoyed advanced biology in high school. "I felt like that was the area where I could best succeed," he explains.

However, Hunsen, who is supported by a scholarship from the Thomas A. Pappas Charitable Foundation, found himself struggling to connect with the content in his introductory biology and chemistry classes at MIT. "I understood what was happening, but I didn't understand how we build up to the level at which they were teaching the subject, so I felt really detached from the material," he says.

In Hunsen's introductory math class, however, he was immediately attracted to the stepwise manner in which the material built from

Hunsen

> "I got over my fear of math by realizing that I could take it a step at a time," Hunsen says.

established principles to interesting abstractions. "I found myself being challenged in a way that I really appreciated," he recalls.

Still, Hunsen felt intimidated by the prospect of switching his major to math—that is, until the next semester when he took a differential equations class with Bjorn Poonen, the Claude Shannon Professor of Mathematics, whom Hunsen describes as a math legend. By the time finals rolled around that spring, Hunsen was sold. "I got over my fear of math by realizing that I could take it a step at a time, and that I didn't need to do that major in any way but the way that I wanted to do it," he explains. "I kind of removed the artificial pressure I put on myself and just went for it."

Now Hunsen is considering another adjustment to his trajectory: a double major in math and economics, which would allow him to continue engaging with the aspects of math he likes, while also applying math to real-world situations. "I enjoy the abstractness of math, but economics has given me a framework for understanding what's going on in the world around me. I can immediately see what I would do with an economics degree," Hunsen says. After MIT, Hunsen envisions pursuing economics in an academic or a government policy setting.

Hunsen's desire to understand topics from the ground up also extends to articles he writes for MIT's student-run magazine *Infinite*. A recent story explored the relationship between music and fashion: "I wanted to build the history and the background of how black music has influenced streetwear, and how that has existed for the length of streetwear and black music's existence," Hunsen says. He has also published opinion pieces about social justice issues such as prison reform in the *Tech*.

In his free time, Hunsen can often be found falling into deep reading rabbit holes online. "It's fairly random—I follow a bunch of news media sites on social media, and whatever they post, I'll follow that to the article and fall into a hole from there," he says. For example, Hunsen recently parsed Ta-Nehisi Coates's "The Case for Reparations" in the *Atlantic*, using the article's citations to find books and papers on sociology and African-American studies.

What motivates Hunsen to keep exploring new paths? "On some level it's just as simple as doing what I like to do and knowing that I'm going to be able to continue doing it even more." —Catherine C. Caruso SM '16

PHOTO: KEN RICHARDSON

A Helping Hand

MIT's entrepreneurial ecosystem boosts sensor tech startup

In 2004, Professor Edward "Ted" Adelson was focused on a successful career studying human and artificial vision.

Then he had children.

"I thought I'd be fascinated watching them discover the world through sight," says Adelson, the John J. and Dorothy Wilson Professor of Vision Science in the Department of Brain and Cognitive Sciences at MIT. "But what I actually found most fascinating was how they explored the world through touch."

That fascination led Adelson to invent a touch-based technology: a sort of artificial finger consisting of a gel-based skin covering an internal camera. The device could chart surface topographies through physical contact—creating something like sight through touch. That technology is now the lifeblood of GelSight, the startup that Adelson founded in 2011 along with two MIT colleagues.

Originally "a solution in search of a problem," as Adelson describes it, GelSight now produces bench-based and handheld sensors deployed for quality control in industries such as aerospace and consumer electronics. The company is also pursuing other commercial applications. Based not far from MIT in Waltham, Massachusetts, GelSight is closing its second round of financing and appears poised for profitability.

On the surface, GelSight's story reads like another MIT cradle-to-corporation fairy tale. But the team's odyssey from concept to company was filled with complex passages the founders were ill-prepared to navigate.

"We were academics," Adelson recalls. "We had this technology and thought it would be easy to transform it into a profitable enterprise. We learned very quickly that the technical invention is the easiest part for people like us. Developing a product and building a company is way harder. That requires the effort and expertise of many smart people who must work a very long time. Fortunately, we had great connections available to us through the MIT community. The resources we were able to tap into at MIT were essential in creating and sustaining GelSight."

Cofounders meet on campus

Adelson's first collaborator in developing the underlying technology was Kimo Johnson, who joined his laboratory as a postdoc in 2008. "Ted had invented this material that could make very precise measurements in 3-D," says Johnson, CEO and cofounder of GelSight. "We published several papers on the technology as academics tend to do. But we also made videos and posted them on YouTube. The response was amazing. My inbox was flooded with emails asking about potential applications. That was when we realized we should form a company."

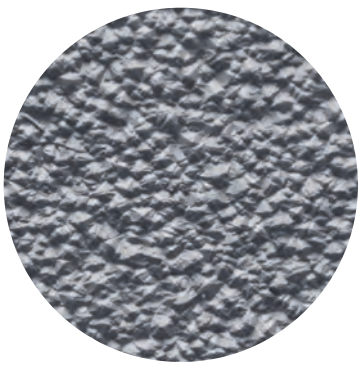
As a first step, Johnson collaborated with students in a course called iTeams at the MIT Sloan School of Management to draft a hypothetical business plan built around GelSight technology. The plan proposed a potential application in the inspection of helicopter blades. That exercise helped him understand how valuable a handheld device that employed GelSight technology could be to professionals who inspect and repair critical surfaces. "This was another piece of information that encouraged us to move forward," says Johnson.

Adelson and Johnson met GelSight's third cofounder in 2010 at an on-campus seminar on imaging and computer vision. János Rohály, a former MIT research scientist, had founded Brontes Technologies in 2004. That startup, which applied computer vision in dentistry, was acquired in 2006 by 3M. It was the incarnation of every MIT startup's dream.

"After my talk, Ted and Kimo introduced themselves and told me about GelSight," recalls Rohály, who is now CTO of GelSight. "I was captivated by their technology

GelSight Mobile, the company's handheld instrument, visualizes and measures the 3-D topography of surfaces such as, from left, fabric, diamond, and hair. The image at bottom, of a cartridge case, was also made using GelSight technology.

IMAGES: COURTESY OF GELSIGHT



"MIT gives you a tremendous boost...especially with investors. If you are from MIT or have technology invented at MIT, people are interested in seeing that technology," Rohály says.

and invited them to make a presentation to my colleagues at Brontes. A little later I realized I was losing sleep fantasizing about their technology. In 2011, when they formed the company, they reached out to me. I had the entrepreneurial experience and the knowledge of the MIT network that could help them. And I joined the team."

Tapping MIT's broad network

With Rohály on board, the GelSight team turned to MIT's teeming startup network for help plotting its next crucial steps. "MIT sits in the middle of the Boston-area startup ecosystem," says Adelson. "This ecosystem is populated with technologists, investors, business people, lawyers, and other professionals. Together they form a vibrant group of people who are constantly networking, sharing ideas, and encouraging each other.

That energy and activity is critical to launch a startup company. It was for us."

The MIT ecosystem delivered in a big way for GelSight. The company's founding trio received consistent support and encouragement from the MIT Venture Mentoring Service (VMS), which provided business advice, financial guidance, and introductions to potential manufacturing partners, customers, and investors. (VMS will be celebrating its 20th anniversary in 2020.)

"Neither Ted nor I had the slightest business experience," says Johnson. "At the Venture Mentoring Service, we could rely on seasoned entrepreneurs who were ready to share their experience and expertise with us. There are so many challenges a fledgling company faces. Negotiating contracts, for example. It takes an experienced entrepreneur to know where to make concessions and where to push back. We got that and much more from the Venture Mentoring Service. In the early days, they almost served as a board of directors for us."

GelSight got another big boost when their technology was featured in a 2011 MIT News article. "That article generated an enormous amount of interest," says Johnson. "There are so many subscribers across so many industries. And MIT News gets copied on so many technical news sites. In fact, it was that article that connected us to a person in business development, who in turn connected us to our biggest consumer electronics customer."

GelSight's founders also made critical connections through the MIT Deshpande Center for Technological Innovation and the MIT Technology Licensing Office. The MIT Industrial Liaison Program put the young company in touch with a series of potential customers, including Boeing. "In our first years, we essentially bootstrapped the company, selling benchtop systems to customers in industries including cosmetics, abrasives, and aerospace," says Johnson. "These were mostly connections we'd made through MIT. And they were enough to keep us going and slowly growing."

Unlike many startups, which seek rapid growth and an early sale, GelSight has plotted a more gradual growth curve. In 2014, thanks to a connection obtained through the MIT network, the company received an inquiry from a China-based manufacturer of smartphones. That company had a slew of complex measurement problems they thought they might resolve with GelSight's capacity to measure surface topography. That sale—GelSight's first large-volume order—changed both the company's manufacturing practices and its focus.

"Up until that point, we'd been selling single systems to R&D laboratories," says Johnson. "This sale showed us that our real value would be in quality control. We shifted toward process development and systems for mass production and inspection."

Buoyed by the China sale, GelSight held its first round of financing in 2015. Capital infusions came from Omega Funds—a Boston-based venture capital firm that specializes in biotechnology and medical device companies—and Ping Fu, a technology innovator and investor Rohály knew from his days at Brontes. Both Fu and Omega Funds managing director Richard Lim sit on GelSight's board of directors.

Rohály credits MIT for much of the success in GelSight's first round of financing. "MIT gives you a tremendous boost when you approach people," says Rohály. "Just the name alone. This is true not only in technology circles, but also in business circles. Especially with investors. If you are from MIT or have technology invented at MIT, people are interested in seeing that technology."

He also credits MIT and its ecosystem for sustaining the GelSight enterprise through all phases of its development. "There is a can-do attitude among MIT people that I have rarely seen elsewhere," he says. "They can attend to any problem at any level and have the confidence in their ability to solve it. Too many times, in other venues, I've seen people stumble before problems because they don't trust their ability to solve them. That doesn't exist at MIT. When there's a problem, [MIT people] say great, let's start working on it."

"The technical invention is the easiest part for people like us. Developing a product and building a company is way harder," Adelson says.


Adelson


Johnson


Rohály

In the past few years, GelSight has hit several important milestones. In 2017, the company successfully deployed its technologies at mass production and inspection facilities. The following year, GelSight was selected to provide surface inspection technology for the manufacturing operations of a top aerospace company. This too has helped GelSight gain credibility with investors. "Until recently, investors would ask us whether people would actually buy our products," says Johnson. "Now, when we have major companies selecting our technology to inspect their flagship products, that's validation."

In 2019, the cofounders say GelSight plans to step off the brakes and hit the gas. Over the past few years, the company has spent significant time and resources resolving scientific questions about the technology to ensure it can be produced on a broader scale. Now GelSight is working to close its second round of financing. This new capital will enable the company to ramp up manufacturing and accelerate its business plan.

"We've been extremely attentive to managing cash flow and operations," says Rohály. "And we've found a nice sweet spot in aerospace and electronics. We're also continuing to push for customers in new spaces. The amazing thing is that 90 percent of our current customers come from inbound interest, from customers reaching out to us and asking us to solve their problems."

The GelSight team still seeks advice from partners in MIT's entrepreneurial ecosystem. But now the company's leaders also offer insight and advice to other MIT inventors seeking to bring laboratory creations to market. "We're very much a part of the broad MIT network," says Johnson. "We've learned firsthand how much can be gained by experienced professionals sharing their knowledge within a larger community. Now we're in a position to give back to the community that has helped us so much." —Ken Shulman

PHOTOS: COURTESY OF GELSIGHT

What steps can researchers take to boost impact?

Martha Gray reveals lessons from MIT linQ initiative

Real-world impact is a major goal for many graduate students and postdocs at MIT. Helping young researchers reach that goal is the idea behind MIT linQ, says Martha Gray SM '81, PhD '86, the J.W. Kieckhefer Professor of Health Sciences and Technology and a professor of electrical engineering and computer science. The initiative's three programs—Catalyst, IMPACT, and IDEA² Global—match early career biomedical researchers with interdisciplinary mentors from universities, medicine, business, and industry to help them orient their research toward application. *Spectrum* asked Gray, director of MIT linQ, how the initiative works and what it has to teach all scientists. —Alice Waugh

How do the linQ programs work?

MG: The overarching objective is to change how people think and work so we can accelerate and heighten the impact of their research on health. Whether the fellows are just starting on a project or heavily involved in one, we ask them to consider: What do you do, and why is it important? Who's going to care, why are they going to care, and how is it going to ultimately benefit other researchers or patients? In Catalyst, a multiyear program, the fellows start from the very beginning: They conceive and execute new research projects with the potential for specific impacts. In IMPACT and IDEA² Global, each a semester in length, fellows start with existing projects and more deeply explore potential impacts. IMPACT is geared for Boston-area biomedical researchers. IDEA² Global works with teams of innovators from around the world.

In all programs, participants work iteratively, supported by regular mentoring. All participants are required to talk with people who are not normally in their "inner circle," including experts and stakeholders. For most trainees, this experience is very different from what happens in a traditional research lab, where they interact with others who share similar conceptual frameworks.

How does this approach change the trajectory of their work?

MG: In Catalyst, fellows usually end up working in areas unrelated to their prior work. This happens because they focus on impact, not area, and are not constrained by a specific lab or institution. In IMPACT, we find that many of the trainees rethink the direction of their research, and in some cases actually alter their research path, despite the fact that most of these projects are already peer-reviewed, funded, and ongoing. For example, an IMPACT fellow was designing a diagnostic test based on a molecular pathway that she discovered to be involved in Lyme disease. By talking to others as part of the process, she figured out that using the same pathway as the basis for a new therapeutic drug would address a more pressing clinical need, and she was successful in securing new grant funding based on this.

What's the most valuable takeaway from linQ for early researchers?

MG: They're able to critically assess what happens beyond the particular science they're doing now and think ahead to what would this mean in 3, 5, or 10 years—and ask if that's the kind of significance they want. It also gets them out of their comfort zone in terms of how they communicate their work and with whom they communicate. That is a really important professional skill.

What have you and other linQ mentors learned?

MG: We've discovered that having a real mix of individuals work together makes them unconstrained about the kinds of problems they consider, how they think about the problems, and directions they go. I think this lack of constraint is really empowering. The other really interesting thing is what the faculty mentors themselves gain—we call it 360-degree learning. Many of them report to us anecdotally that they do things differently in their labs as a result of participating.

Professor Martha Gray mentors MIT linQ participants.

PHOTO: KEN RICHARDSON

Going for the Gut

Team preserves human microbiome diversity

In a tiny Malay village near an ancient tropical rain forest, MIT postdocs Mathieu Groussin and Mathilde Poyet were explaining through an interpreter that they wanted members of the Batek tribe to donate some poop.

The villagers laughed. When they stopped laughing, they described how their toileting—which did not involve any actual toilets—took place privately, deep within the forest.

Groussin, Poyet and MIT professor and biological engineer Eric Alm had traveled to Malaysia in March as part of a worldwide mission to preserve the biodiversity of human gut microbes. It was crucial to include hunter-gatherers like the Batek, because their diets and microbiomes are strikingly different from those of city dwellers.

But this indigenous tribe 500 kilometers from Kuala Lumpur did not routinely encounter requests for stool samples. And now their modesty was posing a dilemma to the team's first Asian trip.

Tiny chemical factories

The human microbiome is made up of single-celled bacteria with hard-to-pronounce names like *Akkermansia muciniphila*, *Faecalibacterium prausnitzii*, and *Parabacteroides goldsteinii*. They live in our bodies in numbers that rival those of all our other cells combined, and they work so seamlessly with everything else that they have been likened to a separate organ. Each individual's microbiome is unique, but researchers are becoming aware of differences among populations that appear tied to not only diet, but also to vaccinations, antibiotics, and exposure to environmental chemicals.

To researchers, some of the most interesting bacteria are the 1,000-plus species inhabiting the gut. These aid in digestion, immune function, and eradicating free radicals (atoms linked to aging and disease). There is growing evidence that the influence of gut microbiota extends as far as the brain and nervous system.

"Bacteria are tiny chemical factories that have evolved for millions of years to interface with human beings," says Alm, co-director of MIT's Center for Microbiome Informatics and Therapeutics (CMIT) and professor of biological engineering and civil and environmental engineering. "The likelihood that one of these bacteria in any human population, industrialized or non-industrialized, makes some compound that

Microbiome researchers, from left, Mathieu Groussin, Mathilde Poyet, and Eric Alm process a human stool sample in Malaysia. Samples are kept frozen in a biobank, inset.

PHOTOS: CHRISTOPHER CORZETT (RIGHT); MATHILDE POYET (INSET)

is important for human health is probably much higher than finding a random [therapeutic] plant in a forest."

CMIT was launched in 2014 to explore the microbiome's potentially life-changing effects on human health and its role in the diagnosis, treatment, and prevention of disease. The microbiome has its own physiology, which, if altered, could compromise or—researchers hope—improve the health of the host.

"It's possible that a lot of the rapid rates of increase in diseases such as inflammatory gut disease, obesity, diabetes, and cardiovascular and autoimmune disease are associated with the microbiome," Alm says. "Is it because our microbiome is changing? And if that's true, what are we going to do about it?"

Research center launch

When MIT electrical engineering alumnus Neil Rasmussen '76, SM '80, and Anna Winter Rasmussen's child developed ulcerative colitis at age seven, they were faced with treatments involving aggressive drugs or surgery. Anna Rasmussen was typically rebuffed when she asked physicians whether her child's illness—an autoimmune disorder with symptoms such as bloody diarrhea and belly pain—might be meliorated through diet. Yet since the 1960s, there have been a handful of health practitioners who have reported that limiting the complex carbohydrates on which certain bacteria feed seems to help patients. "It was only in this sort of alternative medical universe that people were taking diet seriously," Anna Rasmussen says.

Slowly, that began to change. By 2013, when Neil Rasmussen was scouting Boston hospitals for microbiome-related research that might help his child, he found himself back at his alma mater. The Broad Institute of MIT and Harvard was using cutting-edge techniques to sequence ever-increasing species of gut bacteria. And there was Alm, a civil engineer studying bacteria that ingest environmental toxins to help clean up oil spills. Alm was also deeply interested in the human microbiome, as were dozens of others in fields ranging from math to microbiology. But there was no central focus for microbiome research at MIT.

"It's a gigantic computational and analytics problem to just understand the gene expressions between all these crazy things that live in us and on us," Rasmussen says. "It seemed like it was a thing MIT should be doing."

In 2014, the Neil and Anna Rasmussen Foundation funded the launch of the Center for Microbiome Informatics and Therapeutics as a partnership between MIT and Massachusetts General Hospital, which has access to patients for clinical trials. "It's part of our goal to produce really top-level researchers," Neil Rasmussen says. "We're pulling brilliant people into the field."

Fort Knox of bacteria

Soon after Groussin and Poyet completed PhDs in evolutionary biology at the same university in France (Poyet concentrated on ecology and evolution; Groussin on microbiology and genomics), they came to MIT to join Alm in investigating how human microorganisms interact with one another and with their environment.

"One of the surprising things had been that you could go anywhere in the US and compare gut bacteria to that of people living in Germany or even China who are very different genetically, very different in terms of diet, and nonetheless you'd see the same bacteria," Alm says. "So we started to think these are the human-associated bacteria.

"Then we started to look at non-industrialized countries. When you get to people who are living a lifestyle that is more like the lifestyle all of our ancestors led, their microbiomes are totally different."

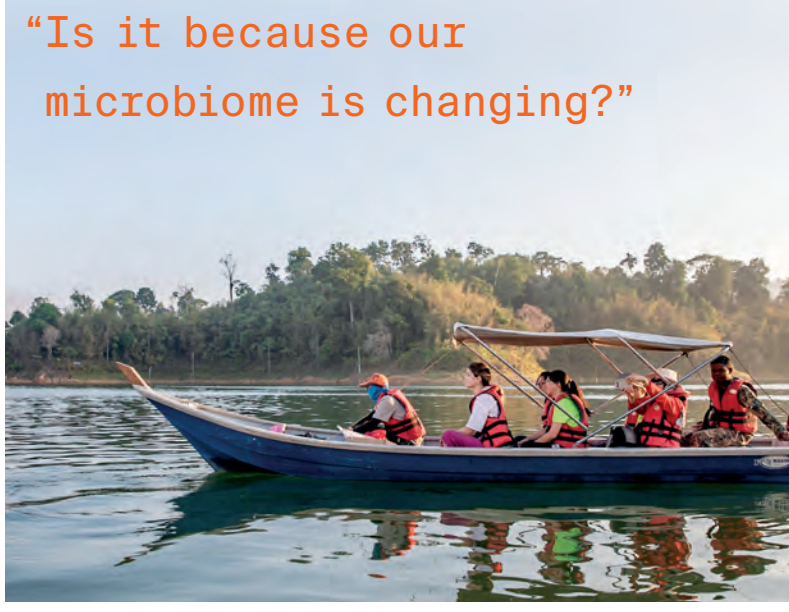
Bacteria have evolved to coexist with humans. To adapt quickly to changes in their environment, gut microbiota harbor a vast number of genes they trade among themselves. The less gut bacterial diversity, Alm says, the higher the rate of gene exchange—possibly an evolutionary survival mechanism in the presence of an enemy like antibiotics, which kill off healthy microbes along with dangerous bacteria. "We don't yet know what the implications of that are," Alm says.

Urbanization and industrialization, Poyet says, are leading to an alarming loss of microbiome biodiversity, wiping out strains that could play crucial roles in human health. At the same time, advances in anaerobic culturing methods and gene sequencing now allow a vast majority of human gut bacterial species to be cultured, characterized, and preserved indefinitely.

What if, Poyet and Groussin wondered, they gathered up all the separate and distinct bacteria that make up colonies within the guts of different urban and rural populations around the world?

"It's possible that a lot of the rapid rates of increase in diseases... are associated with the microbiome," Alm says.

"Is it because our microbiome is changing?"



The microbiome team travels to work in a remote Jahai village in Royal Belum State Park, Malaysia.

PHOTO: CHRISTOPHER CORZETT

In a third-floor laboratory run by the MIT Department of Biological Engineering at 500 Technology Square, an icy mist fills the air as Poyet opens one of two industrial-sized freezers set to a chilly -80°C. She pulls out a lunch-box-sized tray packed with dozens of tiny test tubes, each labeled with a donor's identifier. The repository is part of an ambitious, multilocation global network of similar biobanks protecting potentially useful microbes from extinction: a Fort Knox of bacteria.

Alm, Groussin, Poyet, and postdoctoral fellow Ainara Sistiaga launched the Global Microbiome Conservancy through CMIT in 2016. Over the past three years, in collaboration with scientists worldwide, they've collected more than 700 stool samples from different groups, including indigenous peoples: the Inuit in the Canadian Arctic; the Sami in Finland; the Beti and Baka in Cameroon; the Datoga and Hadza in Tanzania; and others in Ghana, Nigeria, and Rwanda. Participants can opt to receive an analysis of their own gut microbiome.

In the lab, Poyet slips her hands into rubber gloves in the plexiglass confines of an oxygen-free chamber—some bacteria die when exposed to oxygen—and picks up a glass petri dish. She points to dots ("This one looks like a little sun") amid brown splotches covering the plate's surface: colonies of different gut bacteria within the fecal sample. Painstakingly, she isolates each strain of bacteria and cultures it, maps its genomes, and fashions experiments to elucidate its unique structures and attributes. A portion of each original sample is stowed in the deep freeze.

The conservancy aims to collect 100,000 strains within the next three years from both urban and rural populations, including indigenous peoples. Alm predicts that in the coming decades, researchers will plumb these donated bacteria for hidden superpowers. A specific species might—as the Rasmussens hope—counter the effects of inflammatory bowel disease such as ulcerative colitis.

If a stool donor from Rwanda happens to have a specific bacteria or genetic component that turns out to be beneficial, the sample is traceable back to that person, who conserves ownership of donated samples and bacteria. "Discoveries may be made," Alm says. "They may lead to therapeutics, and so could be profitable. If a company wants to make a drug by capturing one of those strains as a probiotic, a new agreement will have to be made, and those profits will have to be shared with the people who donated the materials."

Above: Mathilde Poyet, left, works with local collaborators to introduce the mission of the Global Microbiome Conservancy to Batek villagers.

PHOTO: CHRISTOPHER CORZETT

Below: Poyet cultures gut bacteria in one of the anaerobic chambers in the Alm lab.

PHOTO: JUSTIN KNIGHT PHOTOGRAPHY

Rain forest sample

In Malaysia, collaborators from the University of Malaya helped Poyet and Groussin explain the project to the Batek villagers. They provided the big picture, and then it was time for what Poyet calls the tricky step: distributing blue plastic collection bowls. "The first day, they all said, I haven't eaten. There's no poop there," Alm recalls. "Then after a while they said, 'Well, we really don't want to poop in the bowl.'"

"Thanks to insights from our local collaborators, we anticipated this. But it was the first time we faced a cultural barrier where we had people saying they were not very comfortable with the collection material we provided," Groussin says. "Obviously, it's really different from what they are used to."

In the end, Alm, Poyet and Groussin worked it out with the tribespeople who were interested in participating. "Just do whatever you normally do and tell us where it is," they told the villagers. When the researchers ventured out, they spotted blue bowls scattered like Easter eggs amid the dense vegetation. They adjusted their collection protocol to avoid contamination from environmental sources.

As deforestation and development eat away at the rain forest, the Batek, mainland Malaysia's last nomadic clan, may choose to switch to "city" foods such as rice instead of forest-scavenged cassava root. Meanwhile, potentially life-enhancing bacteria associated with their age-old lifestyle will live on in tiny glass tubes. —Deborah Halber

App Magic

Jessica Van Brummelen finds purpose in software development

At age 6, when Jessica Van Brummelen was growing up in the mountains of British Columbia, she built a robotic dog. Or rather, a kid's version of a robotic dog—a cardboard box filled with loose screws, bolts, and circuit boards. She drew a pair of eyes, gave the box a good shake, and "hoped it would magically become a dog."

Her early interest in engineering, which was celebrated at home as she taught herself 3-D modeling and computer illustration, was seen differently by her peers. "I was bullied a lot. The girls said, 'You're that weirdo who doesn't like to play with dolls.'" It was isolating, and Van Brummelen hid that side of herself in public. In 11th grade, she enrolled in her school's woodworking class. When she walked in the door and saw a sea of teenage boys, she dropped the course.

Once she got to college at the University of British Columbia's Okanagan campus, however, she found herself among peers passionate about all sorts of things. "That freed me to be who I was," she says. And so, when she entered a 3-D modeling class, she let herself fall in love with the material. She soon switched her major from science to engineering, a decision that would lead her to a graduate program at MIT in the Computer Science and Artificial Intelligence Lab.

Van Brummelen works with Hal Abelson PhD '73, the Class of 1922 Professor of Computer Science and Engineering. Her current research revolves around the capabilities and ethics of conversational artificial intelligence—devices like Alexa and Google Home that rely on voice commands to direct a computer. "There's all this AI technology out there," she explains, "but lots of people don't know what it can do." Van Brummelen focuses her research on empowering young people to understand what's behind the algorithms "to help make a better future."

> "There's all this AI technology out there," Van Brummelen explains, "but lots of people don't know what it can do."

To date, she's run six workshops teaching Boston-area high school students how to use App Inventor, a program maintained by MIT that's intended to democratize software development. She built an easy-to-use interface and back end so that students can program Alexa to do something socially useful. One team of students developed a memory aid for people who have trouble recalling words. Another got Alexa to type responses, making it useful for the hearing impaired.

Van Brummelen gets especially jazzed when she notices girls and young women in her workshops. "Seeing that girls are engaged as they create these apps has been really exciting," she says, noting that MIT has been a special place for her to offer the kind of support to young women that she would have treasured herself years ago. "I can help students feel OK with being who they are as they pursue their interests and passions without being afraid of others' judgment," she says.

It's a trajectory made possible by the Jacobs Presidential Fellowship, a grant given to at least 15 graduate students in the School of Engineering each year. The funding stems from a $30 million gift provided by Irwin SM '57, ScD '59 and Joan Jacobs that's intended to help recruit stellar students to MIT from across the globe. Van Brummelen says that the fellowship has given her a lot of freedom. "I could do basically any kind of research I was interested in. So, I'm very, very thankful for that," she says.

Van Brummelen has come a long way from trying to transform a cardboard box into a dog. Today, she's doing something arguably more magical—helping transform young women and men into visionaries and innovators. "It's not technology itself that changes the world," she says. "Rather, it's what we *do* with technology that changes the world." —Ari Daniel PhD '08

Jessica Van Brummelen assists a high school student during an App Inventor workshop.

PHOTO: SARAH BASTILLE

LEWIS "LEW" '65 AND CONSTANCE "CONNEE" COUNTS

Intellectual, Professional, and Personal Support

As an undergraduate, Lew Counts '65 experienced a phenomenon not uncommon among MIT students: The field that held his interest most strongly hadn't been invented yet. For him, it was integrated circuits. "So, how is it that I had a successful career in integrated circuits?" he says, laughing. "The answer is a solid basic preparation in physics, chemistry, and mathematics from MIT."

Alongside the academics, Lew says, life-changing mentorship and connections stemmed from his time at MIT. Shortly after graduating, these connections led to his meeting Ray Stata '57, SM '58. Stata had cofounded Analog Devices, and Lew spent the majority of his career working there. "I took the job with Ray after he told me about his vision of working in integrated circuits, which was a crazy idea at the time," Lew says. Fortunately, Lew has a philosophy reflective of the climate of innovation at MIT: "If it doesn't sound like a crazy idea, it probably isn't worth it."

Lew met his spouse, Connee, while he was at MIT and she was at Radcliffe College. From their combined life experience, they both believe that the inspiration that leads to world-changing breakthroughs is often intertwined with a person's overall well-being. "MIT opened up a world to me, intellectually, professionally, and personally," Lew says, naming James Roberge '60, SM '62, ScD '66 as an important mentor. Roberge, who was a doctoral student when Lew worked in his lab, went on to become an influential MIT professor.

"With our support to MIT and other organizations, we're interested in opening doors, offering new opportunities, and trying to level the playing field," says Connee Counts.

In recent years, the Counts have increased their giving to the Institute, inspired by President L. Rafael Reif's mission to bolster programs that support "mind, hand, and heart" at MIT. They particularly support the Office of Engineering Outreach Programs (OEOP), which facilitates science and engineering experiences for middle- and high-school students. OEOP programs are free for all qualifying students and range from immersive six-week academic experiences to Saturday seminars that give students a taste of the rigorous MIT curriculum and campus life.

The Counts are involved with a variety of philanthropic organizations as volunteers and financial supporters, but a common thread runs through their giving: the goal of creating equity and increasing access to education, particularly through programs like OEOP. "We're conscious of the enormous inequality that we currently have in our society, which results in an achievement gap for students," says Connee. "With our support to MIT and other organizations, we're interested in opening doors, offering new opportunities, and trying to level the playing field."

Connee's background in education, which includes a doctorate from Harvard, and Lew's engineering experience fuel their mutual passion for supporting STEM and liberal arts education. For that reason, one way the Counts support MIT is through scholarships. "There are a lot of talented students in the world, and to an amazing extent the reputation of a school depends on the quality of the students—and other top schools are also trying to recruit them," Lew says. Connee adds, "It's not just important to bring them here—it's also important to support them while they're here at MIT."

It is MIT's efforts to make sure that all qualified students can enroll and thrive at the Institute that has made the Counts such ardent supporters. "MIT's leaders in recent years have put a strong emphasis on educating the whole person, as well as on academic excellence," says Lew. "Our goal is for students to feel well prepared in terms of their intellectual abilities and their interest in engaging with society so they can help change the world for the better."

—Joelle Carson

PHOTO: SARAH BASTILLE

“When I look at what education did for me and the doors it opened, I think it’s important to offer others the same access,” Fadel says.

HALA FADEL MBA ’01

Creating Opportunity

Hala Fadel MBA ’01 is one of the most influential figures in the Arab region’s growing innovation economy.

“The MIT Sloan School of Management has a very special place among the universities I’ve attended,” she explains, “because it has a combination of three things that have changed my life.” These elements are the pervasive “entrepreneurial spirit” of the entire MIT campus, MIT Sloan’s unparalleled “platform for networking” with individuals from across the globe, and the Institute’s commitment to service. A founding partner at Leap Ventures, a venture capital investment firm based in Beirut and Dubai, Fadel is dedicated to developing successful entrepreneurs and fostering the conditions that allow them to thrive. That passion was sparked by her experience at MIT Sloan and has grown through her many leadership roles at MIT, which include founder and chair of the MIT Enterprise Forum of the pan-Arab region, and MIT Sloan Executive Board member for the Middle East and Europe. This spring, she accepted the Institute’s most prestigious volunteer appointment when she joined the MIT Corporation.

Among top-tier MBA programs, Fadel believes that MIT Sloan is distinguished by its rare combination of “creativity, openness, and entrepreneurship,” reinforced by the scientific rigor that is in “the DNA of MIT.” These strengths enable the school to prepare business leaders who “understand technology, science, and the importance of rigorous processes in an organization, and at the same time are open and entrepreneurial and flexible enough to reinvent business.”

“Entrepreneurship all around the world is about solving problems,” she observes. While the Arab region has many challenges common to emerging markets, such as education, energy, and water, it also faces developed-market problems such as cybersecurity. These challenges are opportunities for entrepreneurs, Fadel says, but lack of practical support, and the fact that the entrepreneurial mind-set is not yet as familiar in the Arab world as in other regions, present barriers. The MIT Enterprise Forum’s startup competition for the pan-Arab region, which Fadel helped to create, is “a lifeline for many people who think differently.” A recent impact report on the competition’s first 12 years shows a thriving culture of entrepreneurship taking root.

“We receive about 10,000 applications every year, from 20 Arab countries,” Fadel says, proudly. “The competition has contributed to the creation of 14,000 jobs and about $500 million to the GDP of the region.” The number of female participants has increased 15-fold, with 51% of competing teams now women-led.

In her professional life and in her philanthropy, Fadel aims to create opportunity. “When I look at what education did for me and the doors it opened, I think it’s important to offer others the same access.” Her support for the Institute includes graduate fellowships at MIT Sloan and the new MIT Refugee Action Hub (ReACT). While most refugee initiatives focus on basic needs such as food and medicine, ReACT taps the potential of exceptionally gifted learners in displaced populations through MIT’s online MicroMasters programs. As a donor, Fadel is inspired by the opportunity to create a pathway for bright and ambitious individuals within refugee populations to “the world of better education and excellent science and technology.” This work, says Fadel, is a powerful example of a core MIT message: “You can be the brightest anywhere.”

Ultimately, Fadel’s passion for education is rooted in family. She and her husband, Robert Fadel, have three children; the eldest will begin college this fall. All parents, she believes, are “a university before the actual university,” whose curriculum includes instilling values, nurturing learning, and “creating curious people.”

In each aspect of her life, including her MIT leadership, Hala Fadel is guided by a belief in education’s power to inspire—and transform. For people in every region, she says, education offers a “path to fulfilling your potential and becoming who you are.” —Kris Willcox

PHOTO: M. SCOTT BRAUER

Hello World, Hello MIT

A three-day celebration of the MIT Stephen A. Schwarzman College of Computing—a bold endeavor to create the future of computing and artificial intelligence education and research with a deep concern for societal impact—drew experts on artificial intelligence, machine learning, ethics, education, and more to campus in February for a three-day celebration.

Headliners for the events, held February 26–28, included Massachusetts Governor Charlie Baker, *New York Times* columnist and author Tom L. Friedman, and Eric Schmidt, the former CEO of Google and a visiting innovation fellow at MIT. Martin Schmidt SM '83, PhD '88, MIT provost and Ray and Maria Stata Professor of Electrical Engineering and Computer Science, and Anantha Chandrakasan, dean of the MIT School of Engineering and Vannevar Bush Professor of Electrical Engineering and Computer Science, cochaired the event's planning committee.

Created with a $350 million foundational gift from Stephen A. Schwarzman, the chairman, chief executive officer, and cofounder of the asset management firm Blackstone, the college is at the vanguard of MIT's $1 billion commitment to address the global opportunities and challenges presented by the ubiquity of computing and the rise of artificial intelligence. Schwarzman discussed his aspirations for the college during a moderated discussion with MIT President L. Rafael Reif.

The college is set to open in September 2019, and by 2022 it will take up residence in a new building not far from the Kendall Square innovation district. Before long, the college is expected to be humming with the activity of 50 new faculty members conducting pioneering research on computing and at the nexus of computing and diverse disciplines—as well as exploring the social and ethical implications of that research.

"There is no more important opportunity or challenge facing our nation than to responsibly harness the power of artificial intelligence so that we remain competitive globally and achieve breakthroughs that will improve our entire society," Schwarzman said. "The technology is going to affect the whole world, and we have to get it right."

Schwarzman and Reif

"As computing reshapes our world, MIT intends to help make sure it does so for the good of all. In keeping with the scope of this challenge, we are reshaping MIT. The MIT Stephen A. Schwarzman College of Computing will constitute both a global center for computing research and education, and an intellectual foundry for powerful new AI tools."
L. Rafael Reif, MIT President

Schmidt

Chandrakasan

Nobles

"Technologists themselves must much more deeply understand what they are doing, how they are deeply changing human life."
Melissa Nobles, Kenan Sahin Dean of the MIT School of Humanities, Arts, and Social Sciences and Professor of Political Science

From "Conversation Pieces: MIT Perspectives on Ethics, Computing, and AI," a compendium of thought pieces published by the MIT School of Humanities, Arts, and Social Sciences.

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Alumnus Named First Dean

The first dean of the MIT Stephen A. Schwarzman College of Computing, Daniel Huttenlocher SM ’84, PhD ’88, returns to MIT with widely published scholarship in computer science as well as a strongly interdisciplinary approach to computing.

A member of Cornell’s computer science faculty since 1988, Huttenlocher has served since 2012 as the founding dean of Cornell Tech, a graduate school in New York City that focuses on digital technology and its economic and societal impacts. Previously, he helped create and then led Cornell’s Faculty of Computing and Information Science.

Huttenlocher also has an industry background, having served for 12 years as a scientist at Xerox’s Palo Alto Research Center before leaving to cofound a financial technology company in 2000. He currently chairs the board of the John D. and Catherine T. MacArthur Foundation, and sits on the boards of directors of Amazon and Corning.

“The Institute plays a unique role in American and global higher education, and it’s exciting to be coming back to the place where I did my formative research work,” Huttenlocher says. “I’ve learned a lot from MIT, and the world has changed a lot. If I can help contribute to the ways MIT wants to change in this new world, that is an amazing honor.”

Bloomberg

MIT professor Neri Oxman (left)...introduced her concept of “mothering nature by design” with materials like shrimp shells and melanin. MIT’s Vivienne Sze (right) said she’s looking into an at-home diagnostic tool for Alzheimer’s based on eye movements recorded on a mobile phone.

MARCH 1, 2019

@MassGovernor

Congratulations to @MIT on the launch of the new Schwarzman College of Computing, which will explore the long-term impact of advances in AI and computing. Massachusetts continues to lead the nation as a home for innovation and pioneering research. #MITComputing

FEBRUARY 28, 2019

@fahadpunjwani

So excited about #MIT Schwarzman College of Computing #MITComputing. I graduated too early. @MIT, can I be a student again?

FEBRUARY 28, 2019

@R_D

Toward the next giant leap... @MIT Schwarzman School of Computing #HelloWorld

FEBRUARY 28, 2019

Boston Globe

The robot sprang into the air, executed a perfect somersault, and landed on its feet. It was a pretty good trick to kick off a three-day celebration of the school’s new Schwarzman College of Computing, a $1 billion project to integrate computer science into every university department, from genetics to political science, and of course robotics.

FEBRUARY 26, 2019

Inside Philanthropy

The announcement of any $1 billion commitment is pretty significant, but it’s even more so, considering MIT officials say this one will allow a historic reshaping of the school.... MIT’s decision shows just how much artificial intelligence and computing have become a part of our vision of the future.

OCTOBER 23, 2018

“What’s really driving me is that artificial intelligence, quantum computing, machine learning, robotics—all of these new technologies are going to change the world. It’s happening already and it’s profound.”
Stephen A. Schwarzman, CNBC interview, February 28

PHOTOS: LILLIE PAQUETTE (SCHMIDT, OXMAN, SZE, @MASSGOVERNOR); ROSE LINCOLN (CHANDRAKASAN, NOBLES, SCHWARZMAN AND REIF, HUTTENLOCHER); R. DAVID EDELMAN (@R_D)

DAY 1 FEBRUARY 26

Explore: The Student Experience

A visitor to the student expo tries on the Thinking Cap designed by Nataliya Kosmyna (left), a postdoctoral fellow in the MIT Media Lab.

PHOTO: ROSE LINCOLN

Lead developer Benjamin Katz, a technical associate in MIT's Department of Mechanical Engineering, demonstrates the backflipping mini cheetah robot.

PHOTO: LILLIE PAQUETTE

A somersaulting mini cheetah robot and a project dubbed the Thinking Cap were among the highlights of Explore: The Student Experience, an exposition of projects that transformed the student street area of the Stata Center into a computing fairground on Day 1 of the MIT Schwarzman College of Computing celebration.

The showcase demonstrated many of the pioneering ways MIT students are harnessing the power of artificial intelligence and machine learning to solve real-world problems.

The robotic cheetah, for example, could one day carry out tasks in environments that would be dangerous or inaccessible for humans. The Thinking Cap, a wearable device that detects brain activity and provides feedback, is envisioned as a way to build self-esteem and improve academic performance.

"Computing tools and infrastructure have gotten to a place where students can outperform professional researchers," said Hal Abelson PhD '73, the Class of 1922 Professor of Computer Science and Engineering, who attended the exposition. "It's just an amazing time."

"We hope to integrate computing with just about every other subject at MIT so that students leave here with the knowledge and resources to be wise, ethically and technologically competent citizens and professionals. This is a very serious assignment, one that could have global consequences."

Susan S. Silbey, former Chair of the MIT Faculty, Leon and Anne Goldberg Professor of Humanities, Sociology, and Anthropology, and Professor of Behavioral and Policy Sciences

"Feeding 22 million children in a free and reduced lunch program is a big data problem, more important than self-driving cars, and it's the kind of computing I think we should do on inequality and poverty."

Megan Smith '86, SM '88, former US Chief Technology Officer and Founder and Chief Executive Officer of shift7

DAY 2 FEBRUARY 27

Teach: The Academic Symposium

The expanding role of computer science education—in disciplines from engineering to the arts to health to the environment—took center stage during a series of academic discussions held on Day 2 of the celebration of the MIT Schwarzman College of Computing.

MIT Provost and Ray and Maria Stata Professor of Electrical Engineering and Computer Science Martin Schmidt SM '83, PhD '88, speaking to a gathering of reporters, underscored that awareness of the societal impact of current and future advances in computing "should shape how the research is performed." The day ended with a fireside chat that brought together six MIT professors who have received the esteemed A.M. Turing Award, often described as "the Nobel Prize for computing."

Panelists emphasized the importance of integrating skills and knowledge from other fields with computer science to ensure that ethical, political, and social implications of technology are fundamental to the education of computer scientists.

"The future of the humanities depends on our ability to bring in computational resources, and the ability of computer science to effect societal change depends on bringing humanities to the table," said Michael Scott Cuthbert, associate professor of music and the director of digital humanities at MIT. "I think both futures at MIT are very bright."

MIT Provost Martin Schmidt SM '83, PhD '88 discusses the vision for the college with reporters.

PHOTO: JOHN GILLOOLY

PORTRAITS: LILLIE PAQUETTE (SILBEY); ROSE LINCOLN (SMITH)

The panel discussion on ethics and AI featured, from left: Ursula Burns, executive chairman and CEO, VEON, Ltd.; Jennifer Chayes, technical fellow and managing director, Microsoft Research New England, New York City, and Montreal; Ash Carter, director of the Belfer Center for Science and International Affairs, Harvard Kennedy School, and former US secretary of defense; Darren Walker, president, Ford Foundation; Megan Smith, founder and CEO of shift7 and former US chief technology officer; and Joi Ito, director, MIT Media Lab.

PHOTOS: ROSE LINCOLN

DAY 3 FEBRUARY 28

Celebrate: The College

Visions of the future shone bright as the celebration for the MIT Schwarzman College of Computing culminated in a community-wide symposium at Kresge Auditorium.

"My hope is that, in 2030, we'll look back on now as the beginning of a revolution that freed our minds the way the Industrial Revolution freed our hands," said Drew Houston '05, cofounder of Dropbox.

Darren Walker, president of the Ford Foundation, predicted, "What MIT is doing will set the pace for every other university that wants to be relevant in the future."

Ursula Burns, executive chairman and chief executive officer of VEON, Ltd., remarked, "It's not just about getting a whole bunch of computer scientists writing new programs; it is about making the world a better place."

Burns, Walker, and Houston were just 3 of more than 30 speakers who addressed topics ranging from innovation in the medical sciences to computing and the financial ecosystem.

One recurring theme: how the new college will rigorously address and incorporate research and teaching on the societal implications of computing. To illuminate MIT's approach to this topic, the MIT School of Humanities, Arts, and Social Sciences produced a compendium of short articles titled "Conversation Pieces: MIT Perspectives on Ethics, Computing, and AI," which was handed out at the event.

Humans "have never been more godlike," said *New York Times* columnist Thomas L. Friedman, noting that ethical approaches will therefore be "essential." Friedman moderated two panel discussions at the event.

Many speakers cautioned that the speed of technical innovation poses a serious challenge to the control of societal transformations that are already under way. Nevertheless, the tone of the day was aspirational. "There's no reason why computers can't think like we [do] and can't be ethical and moral like we aspire to be," asserted Ford Professor of Engineering Patrick H. Winston '65, SM '67, PhD '70.

"It is time to educate a new generation of technologists in the public interest," MIT President L. Rafael Reif said. "I'm optimistic that the MIT Schwarzman College of Computing is the right place for that job."

PHOTO: LILLIE PAQUETTE

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Friday, November 8, 2019
Queen Elizabeth II Centre

INNOVATION AND ENTREPRENEURSHIP
Westchester/ Fairfield
Thursday, February 27, 2020
Location to be announced

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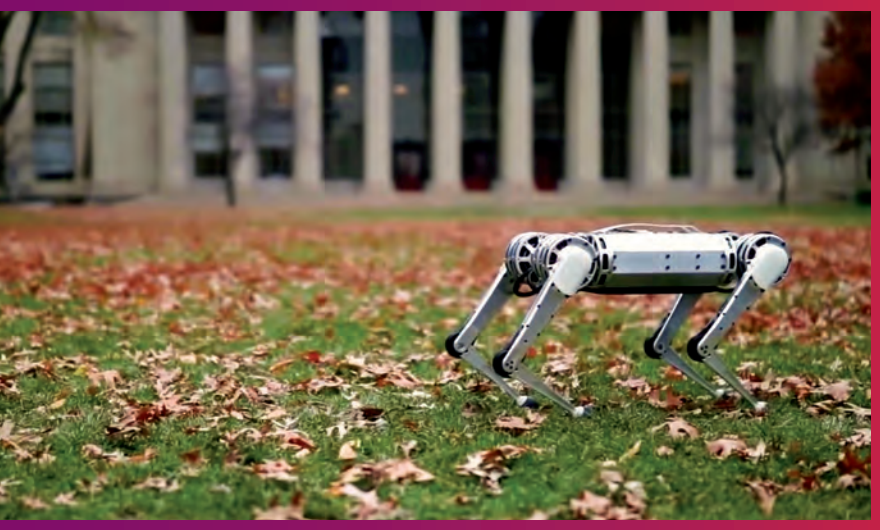

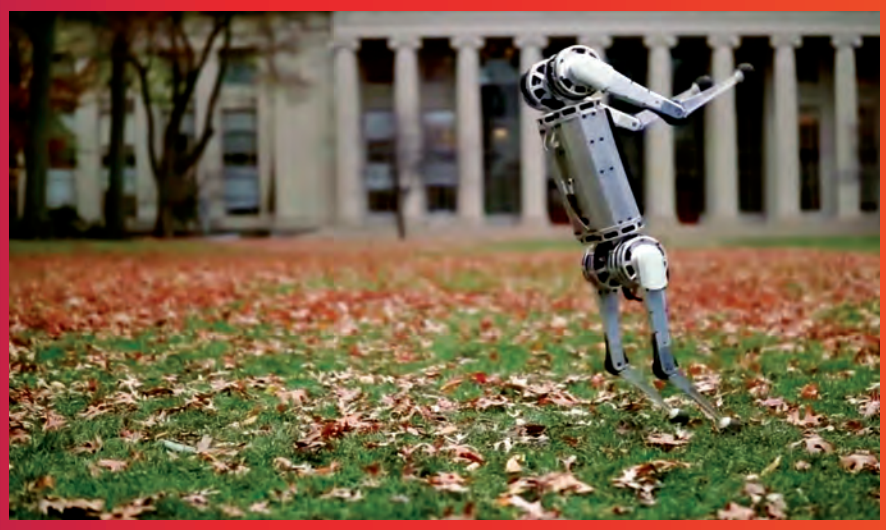

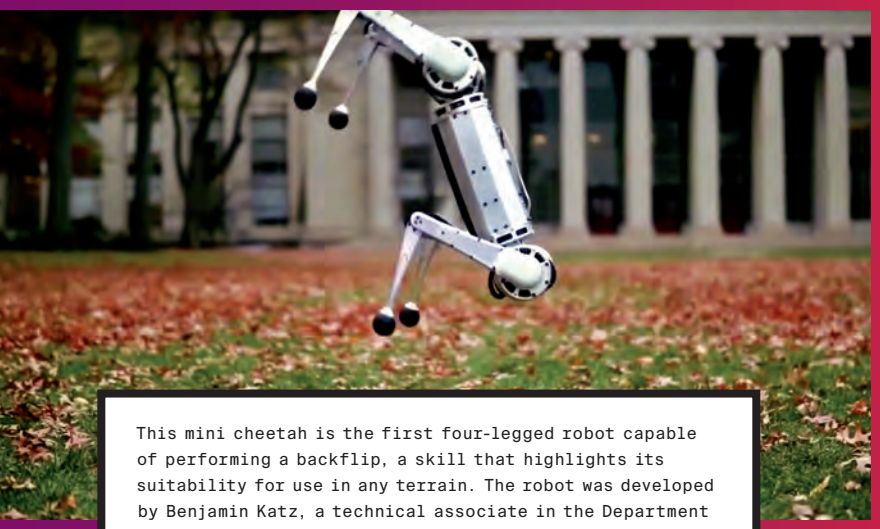

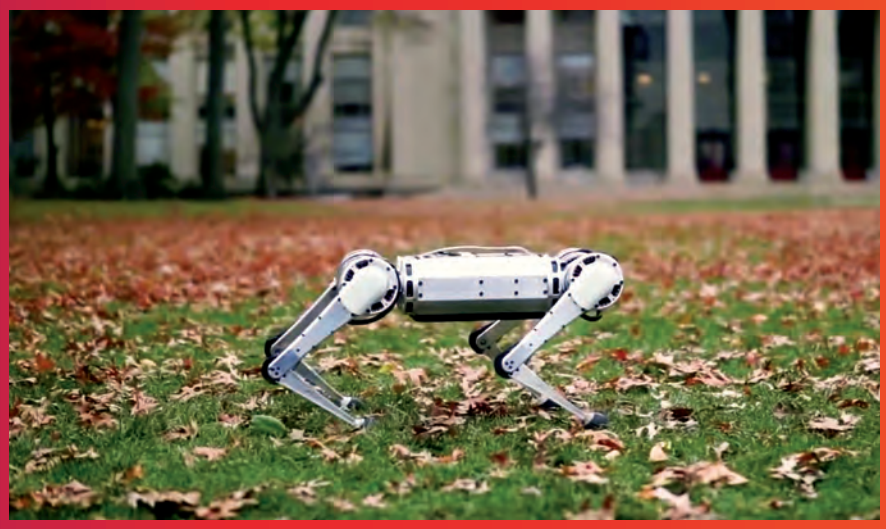

This mini cheetah is the first four-legged robot capable of performing a backflip, a skill that highlights its suitability for use in any terrain. The robot was developed by Benjamin Katz, a technical associate in the Department of Mechanical Engineering (MechE), and Jared Di Carlo '19 from the Department of Electrical Engineering and Computer Science, working with Associate Professor Sangbae Kim of MechE. The robot's abilities were demonstrated during the launch of the MIT Stephen A. Schwarzman College of Computing in February. See story on page 32.

WATCH THE VIDEO
spectrum.mit.edu/cheetah

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