Science AT MIT

Winter 2025 | Published twice yearly

GROWTH OF AI

Science's role in Artificial Intelligence

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MIT School of Science

TABLE OF CONTENTS

Letter from the Dean

Hello, my dear fellow alumni and friends,

In this issue, we take an in-depth look at artificial intelligence through the lens of fundamental scientific research. At a place like MIT, it's no surprise that we are global leaders in understanding how to both develop AI systems and use them in our research. What might be more surprising is that researchers in the School of Science, not just the MIT Schwarzman College of Computing or the School of Engineering, are leading the way. Page 4 provides you with a primer about what we mean when we, as scientists, use the term AI.

Those of you who joined our breakfast talk this past October were treated to a lecture by Professor Jesse Thaler about AI and physics. Jesse is a theoretical particle physicist who fuses techniques from quantum field theory and machine learning to address outstanding questions in fundamental physics. His research is focused on maximizing the discovery potential of the Large Hadron Collider (LHC) through novel theoretical frameworks and data analysis techniques. He is an expert in jets, which are collimated sprays of particles that are copiously produced in particle collisions at the LHC.

In addition, Jesse is the inaugural director of the Institute for Artificial Intelligence and Fundamental Interactions (IAIFI), which is housed within our Laboratory for Nuclear Science. Supported by a grant from the National Science Foundation, IAIFI is the intellectual home of more than 25 physics and AI senior researchers at MIT, Harvard, Northeastern, and Tufts universities. Read more about how Jesse became a convert to AI in physics research on page 13.

On page 8, you'll read about IAIFI postdoc fellow Jessie Micallef who uses advanced machine learning techniques and foundational particle physics theory in their work to better understand "ghost particles" or neutrinos. We have based our own School of Science postdoc fellowship on IAIFI's prestigious program with the goal of attracting and retaining the best talent among researchers who see scientific pursuits as inherently interdisciplinary.

Interdisciplinarity is the heart of Professor Kaiming He's vision for the future. The College of Computing hired He to sit at the intersection of science, computing, AI, and engineering. This is what the College allows MIT to do — to bring computation to every aspect of the research we undertake here: from expansive questions about the universe's formation to applied questions about protein folding and therapeutics.

On page 22, you can read about Professor Danna Freedman's work, sponsored by the U.S. Department of Energy, using an AI model to help reveal the structure of different materials. By analyzing X-ray crystallography data, the model could help researchers develop new materials for many applications, including batteries and magnets.

And lest you think the entire issue is about AI, turn to page 20 to learn more about how our climate science efforts are proceeding. Read an interview with Professor Ronald Prinn, a longtime leader in the field of climate science who has just handed the torch to Professor Noelle Selin to lead MIT's endeavors. Noelle and researchers at the Center for Sustainability Science and Strategy, housed within the School of Science, will work hand in glove with the MIT Climate Project to ensure that science is the basis for progress, and equity is the goal for implementation.

Also newly at the helm of MIT's efforts in translational research is Alex Shalek, director of the Institute for Medical Engineering and Science (see page 17). Alex and others in his orbits — including MIT's Koch Institute for Integrative Cancer Research; the Ragon Institute of Mass General, MIT, and Harvard; the Broad Institute of MIT and Harvard; Mass General Brigham; and Harvard Medical School — will be critical players in our newly launched collaborative focused on life sciences.

MIT's Health and Life Sciences Collaborative is based on the work of a report Dean Anantha Chandrakasan and I commissioned called the Vision to Integrate, Translate, and Advance the Life Sciences (VITALS). Last month saw the launch of this exciting new MIT collaborative that will provide a basis for engagement with hospitals, biotech, and pharmaceutical companies — yes, in the Kendall Square Innovation Hub — but also beyond our Cambridge borders.

I hope some of you will join me in the spring for a breakfast talk focused on the next steps for this important collaborative. As always, I hope you will come to campus soon to celebrate these initiatives and achievements with us in person!

With my very best wishes,

Dean Nergis Mavalvala PhD '97

Illustration: Ellen Weinstein

Researchers explore mutual benefits of AI and science

MIT scientists are leveraging advances in computing to answer increasingly complex questions while contributing to the next generation of artificial intelligence tools

Leah Campbell | MIT School of Science

ChatGPT's launch in 2022 brought artificial intelligence into the mainstream. But the vast and rapidly evolving set of tools encompassed under the AI umbrella began transforming health care, transportation, and more, long before that — thanks, in part, to the efforts of MIT researchers.

Across the Institute, researchers are using AI to build advanced robots, predict group decisions, and identify anomalies in unwieldy datasets. Biologists are using AI to annotate medical scans. Chemists are using it to interpret the structure and function of molecules. Cognitive scientists are using large language models, a type of AI trained on text, to understand the basis of human language. And that's just the beginning.

But the integration of science and AI is a two-way process. Scientists are utilizing these tools to digest large datasets and ask increasingly complex questions, but they're also leveraging fundamental scientific concepts to build more interpretable and efficient AI for a range of applications.

> **"If one can express scientific problems in the abstract language of computation, one can blur the boundaries between disciplines and leverage AI advances to tackle problems across both AI and science."**

James DiCarlo, Peter de Florez Professor of Neuroscience and Director of the Quest for Intelligence.

The National Academies described it as the "symbiotic relationship" between research and AI in a recent neuroscience workshop report.

That symbiotic relationship is driving questions around behavior, vision, language development, and more as part of the MIT Quest for Intelligence, directed by James DiCarlo, Peter de Florez Professor of Neuroscience.

"The unique thing we are doing is that the engineering systems that we are developing are aiming to be *both* the next generation of AI models *and* the next generation of scientific models of brain function," DiCarlo says.

Machine learning, a subset of AI where algorithms learn — even in the absence of encoded instructions — was largely inspired by the brain's neural networks and is useful for processing data and for exploratory research on the basis of natural intelligence.

DiCarlo's lab, for example, uses machine learning to understand how humans create and interpret visual images. They're building artificial networks that replicate the brain's architecture to study the mechanisms behind visual representation while applying that research to produce AI tools that can effectively perform visual tasks. One day, those discoveries could inform the development of brain-machine interfaces to restore lost vision.

"Before recent AI methods and tools were available, we didn't even have approximate computational models of brain sensory systems," DiCarlo says. "Modern machine learning methods are now producing the leading scientific models of brain function."

AI methods are also being applied in fields that have long relied on computational methods. Noelle Selin, professor in the Institute for Data, Systems, and Society and the Department of Earth, Atmospheric and Planetary Sciences, models trends in air pollution and climate change to inform decision making. AI is enabling scientists like Selin to make more accurate projections and better account for climate variability and societal interactions in those models.

The new Center for Sustainability Science and Strategy, directed by Selin (see page 18), also aims to incorporate AI into existing MIT-based tools like its Integrated Global Systems Modeling framework, which provides information on combined risks from social and environmental hazards.

"The real promise and impact of AI tools and methods is just beginning to be applied in climate modeling and sustainability science," Selin says.

In addition, AI could provide a valuable "productivity boost," Selin says, by making it easier to process the vast amounts of data — tens of millions of iPhones worth — output by climate models.

"The Climate Grand Challenge I co-lead, Bringing Computation to the Climate Challenge, is attempting to harness AI and other techniques to make climate models faster, easier to run, and more useful to those who historically haven't been able to do the months-long simulations required," she says.

Noelle Selin, professor in the Institute for Data, Systems, and Society and the Department of Earth, Atmospheric and Planetary Sciences.

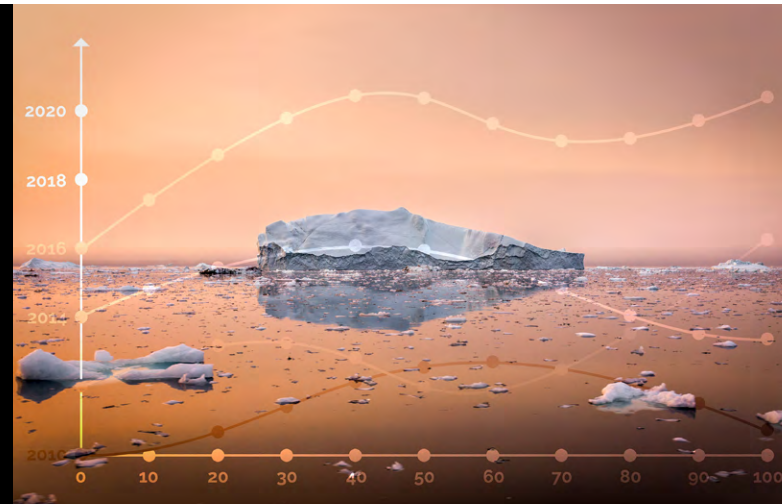


Image: MIT News, stock image

That efficiency boost is likewise enabling physicists to process extensive datasets from experiments and to undertake computationally-intensive theoretical calculations based on the fundamental laws of physics.

Professor of physics Jesse Thaler points out, though, that his field has long employed AI. The seminal discovery of the Higgs boson in 2012, for example, was facilitated by combining several machine learning algorithms to interpret data from the Large Hadron Collider. Physicists rely on AI to make real-time processing decisions about the significant amounts of information particle colliders generate, and Thaler is using it to study the sprays of particles produced by those colliders.

As director, Thaler has framed the NSF Institute for Artificial Intelligence and Fundamental Interactions (IAIFI) around combining the physics tradition of "deep thinking" with the "deep learning" of AI, using neural networks to simulate the brain's decision-making power, to enable "deeper understanding."

"The real promise and impact of AI tools and methods is just beginning to be applied."

Jesse Thaler, professor in the Department of Physics and director of the NSF Institute for Artificial Intelligence and Fundamental Interactions.

IAIFI researchers are utilizing AI tools to address fundamental physics problems, like the nature of dark matter, and to improve operation of large-scale experiments, like the LIGO gravitational wave observatory. But they're also applying physics principles, like diffusion and space-time symmetries, to improve AI for applications from materials discovery to video processing.

"Instead of treating AI like some inscrutable black box, we can bake physical principles into the AI, to make it 'think like a physicist,'" he says. "At the same time, I've learned more about how to 'think like a machine' and leverage the power of computers to solve complex optimization problems whose solutions could not be obtained through traditional techniques."

That process, he says, often goes both ways, where "AI for physics and physics for AI come together in a virtuous cycle of innovation," a model that scientists across MIT are replicating.

"By using the language of AI, I often find it easier to talk to scientists in other domains," Thaler says. "If one can express scientific problems in the abstract language of computation, one can blur the boundaries between disciplines and leverage AI advances to tackle problems across both AI and science."

Illustration: Ellen Weinstein

New perspectives on old questions: AI meets particle physics

A belief in the power of programming to revolutionize particle physics brought Jessie Micallef to IAIFI, a Boston-area research consortium applying cutting-edge technologies to physics data

Alison Gold | School of Science

Photo: Steph Stevens

With machine learning, physicists like Jessie Micallef are examining the universe's most minuscule particles with unprecedented efficiency and power in hopes of unlocking new insights about the forces governing our universe.

"We're moving from a phase of exploring ways that we can use AI and ways that can help us improve our measurements, to actually regularly doing that," Micallef said. "That's going to be a really exciting phase."

Micallef is a fellow at the National Science Foundation's AI Institute for Artificial Intelligence and Fundamental Interactions (IAIFI), a collaboration of MIT, Harvard, Northeastern, and Tufts experts applying artificial intelligence to physics research. Through IAIFI, Micallef collaborates with researchers across partner institutions and a tight-knit community of early-career fellows examining everything from astrophysics to particle interactions.

Micallef studies the neutrino, an abundant subatomic particle that remains elusive to scientists. “While I’m trying to measure a small particle, we have these huge questions that I can help to answer,” Micallef says.

Gaining momentum

Micallef didn’t set out to become a physicist. At their high school in Michigan, they completed three years of both chemistry and physics through the International Baccalaureate program. They entered the University of Michigan to study chemistry.

“Chemistry came a little bit more naturally for me,” Micallef says. Their plans changed when, in their first college physics course, they used programming to model and visualize the effects of forces like gravity. Within weeks, they switched their major to physics.

“Using programming to see invisible physics made it exciting and accessible,” Micallef says. “I decided that studying physics was worth the challenge, exciting, and I was going to put my time into it.”

After declaring their major, Micallef quickly began exploring physics research opportunities. They learned about the field of high-energy physics, where teams of hundreds or even thousands of scientists all collaborate to observe particle interactions. This led them to an internship at Lawrence Berkeley National Lab, which is where they first learned about neutrinos.

Searching for ghost particles

Neutrinos are nearly massless, carry no electrical charge, and rarely interact with other particles, making them difficult to observe and study. They are even invisible to particle detectors. Scientists can only observe neutrinos by spotting the particles created when they interact. Neutrinos are sometimes referred to as “ghost particles.”

“We don’t know a lot of things about neutrinos still,” Micallef says. “And then the more we find out, the more interesting they become.”

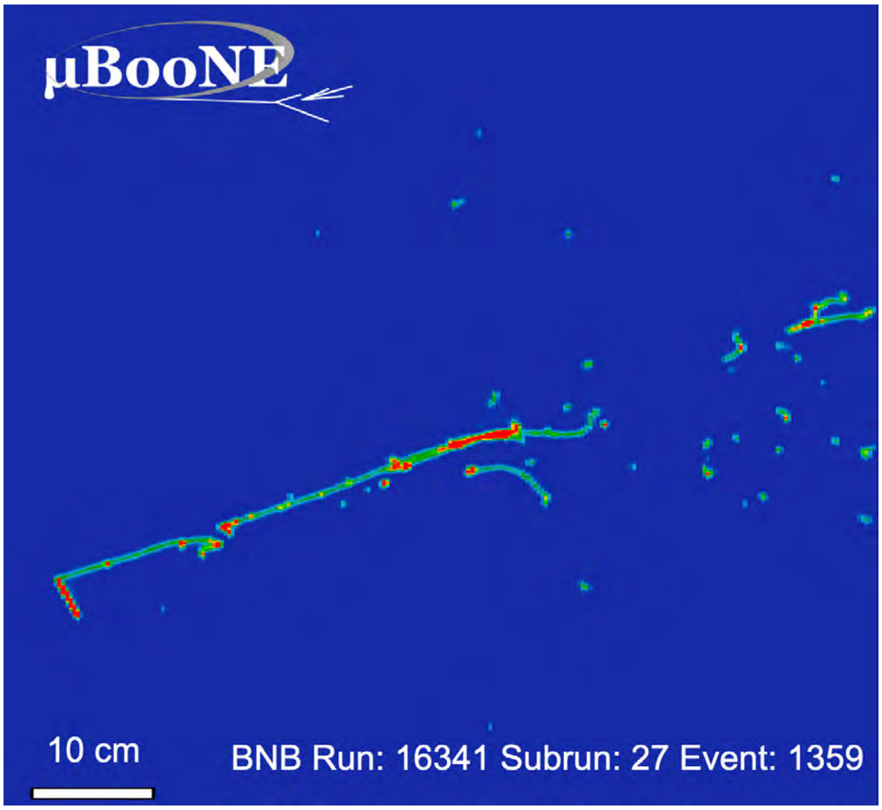
Neutrinos are produced when atomic nuclei interact, which occurs naturally in space at high-energy locations like the Sun. They can also be generated at particle accelerators.

While pursuing their PhD at Michigan State University, Micallef primarily worked with data produced at IceCube, a neutrino observatory located at the South Pole which images interactions from neutrinos produced in space. Now, they contribute to MicroBooNE and DUNE, which are accelerator-based detectors at Fermilab in Batavia, Illinois.

“As a prospective mentor, I read Jessie’s application, and was really impressed by what they had done before in the context of IceCube,” says Taritree Wongjirad, an assistant professor of physics and astronomy at Tufts University and Micallef’s IAIFI mentor. “Jessie also had a very clear vision about how to apply machine learning to projects involving accelerator neutrinos to help us achieve our goals.”

Wongjirad, a former MIT Pappalardo Fellow in Physics, is one of a growing number of neutrino physicists integrating machine learning into their work.

Jessie Micallef in front of the MINERvA detector in one of Fermilab’s accelerator neutrino beams. *Photo courtesy of Jessie Micallef*



A neutrino data image from the MicroBooNE detector. The neutrino comes from the left side of the image and interacts at the apex of the visible lines. From that interaction, a proton emerges (seen in the short stub of mostly red pixels on the bottom track) and an electron (messier and longer shower signature in the upper part). *Image: MicroBooNE Collaboration*

"Really precise measurements"

"What we're trying to figure out by studying the neutrino is why the rules that we've established to characterize particle physics do not perfectly describe what we actually end up seeing," Micallef says.

The universe's creation should have resulted in equal amounts of matter and antimatter. Yet physicists see stable matter in the observable universe, without any pockets of antimatter.

The Standard Model of particle physics, a set of widely accepted rules that explain most physics observations, is constantly being refined. While the Standard Model predicts neutrinos to be massless, in 2015, the Nobel Prize in physics was awarded to researchers who confirmed they do have mass. Micallef says that knowing neutrinos have mass now opens the possibility for them to have other interesting properties, such as neutrinos and antineutrinos behaving differently. This difference could help explain the matter/antimatter imbalance in the universe.

Traditionally, to spot and study neutrino interactions, physicists have relied on complex, time-consuming computational programs to examine millions of particles from detector images. Now, researchers including Micallef are building and deploying machine learning tools that sift through these images much more quickly, analyzing each pixel by pixel to categorize interactions and highlight images of interest.

"There are many particles that can come out of a neutrino interaction, such as electrons and protons," says Micallef. "We use these tools to tell us what particles have left a signature in our detector, kind of like using machine learning to tell you if the image has a cat or a dog, but we ask it if it's an electron or proton."

Major advances in machine learning have coincided with progress in accelerator and detector technology.

"In neutrino physics, we're starting to get really precise measurements, which can give us a clear idea of how our observations align with the Standard Model," Micallef says.

Building connections in science

As Micallef charts a new course at the intersection of machine learning and particle physics, they are also encouraging the next generation to pursue their scientific passions.

"As a collaborator in my group, Jessie was very quick to work with the students and help mentor them," says Wongjirad. "Jessie is very good at bringing in different people and forming groups to accomplish something that will have a good payoff."

Throughout graduate school, Micallef regularly volunteered at events and conferences for undergraduate women in physics. They also started a public outreach project called "Portrait of a Scientist." At conferences and meetings, Micallef asks scientists to fill out and pose for a photo with a sign reading "I am a ______ and I also _______." Researchers have shared wide-ranging personal interests, from raising chickens to knitting. Micallef assembles these images into collages posted online and on social media to showcase diversity in science. Eventually, they hope to share the collages in classrooms.

"Confidence is such a big thing that can steer people away from any field," Micallef says. "So many women in physics helped instill confidence in me. I wanted to give back as I've gotten later into my career."

Creating a common language

New faculty member Kaiming He discusses AI's role in lowering barriers between scientific fields and fostering collaboration across scientific disciplines

Kaitlin Provencher | School of Science

A lot has changed in the 15 years since Kaiming He was a PhD student.

"When you are in your PhD stage, there is a high wall between different disciplines and subjects, and there was even a high wall within computer science," He says. "The guy sitting next to me could be doing things that I completely couldn't understand."

In the seven months since he joined MIT's Schwarzman College of Computing as the Douglas Ross (1954) Career Development Professor of Software Technology in the Department of Electrical Engineering and Computer Science (EECS), He says he is experiencing something that in his opinion is "very rare in human scientific history," — a lowering of the walls that expands across different scientific disciplines.

"There is no way I could ever understand high energy physics, chemistry, or the frontier of biology research, but now we are seeing something that can help us to break these walls," He says, "and that is the creation of a common language that has been found in AI."

Kaiming He is a professor in the MIT Schwarzman College of Computing and a proponent of the integration of science research and AI.
Photo: Steph Stevens

Building the AI bridge

According to He, this shift began in 2012 in the wake of the "deep learning revolution," a point when it was realized that this set of machine learning methods based on neural networks was so powerful that it could be put to greater use.

"At this point computer vision — helping computers to see and perceive the world as if they are human beings — began growing very rapidly because as it turns out you can apply this same methodology to many different problems and many different areas," says He. "So the computer vision community quickly grew really large because these different subtopics were now able to speak a common language and share a common set of tools."

From there, He says the trend began to expand to other areas of computer science, including natural language processing, speech recognition, and robotics, creating the foundation for ChatGPT and other progress toward artificial general intelligence.

"All of this has happened over the last decade, leading us to a new emerging trend that I am really looking forward to and that is watching AI methodology propagate other scientific disciplines," says He.

One of the most famous examples, He says, is AlphaFold, an artificial intelligence program developed by Google DeepMind, which performs predictions of protein structure.

"It's a very different scientific discipline, a very different problem, but people are also using the same set of AI tools, the same methodology to solve these problems," He says, "and I think that is just the beginning."

> "I am really looking forward to . . . watching AI methodology propagate other scientific disciplines."

The future of AI in science

Since coming to MIT in February, He says he has talked to professors in almost every department. Some days he finds himself in conversation with two or more professors from very different backgrounds.

"I certainly don't fully understand their area of research but they will just introduce some context and then we can start to talk about deep learning, machine learning, [and] neural network models in their problems," He says. "In this sense, these AI tools are like a common language between these scientific areas: the machine learning tools translate their terminology and concepts into terms that I can understand, and then I can learn their problems and share my experience, and sometimes propose solutions or opportunities for them to explore."

Expanding to different scientific disciplines has significant potential, from using video analysis to predict weather and climate trends to expediting the research cycle and reducing costs in relation to new drug discovery.

While AI tools provide a clear benefit to the work of He's scientist colleagues, He also notes the reciprocal effect they can and have had on the creation and advancement of AI.

"Scientists provide new problems and challenges that help us continue to evolve these tools," says He. "But it is also important to remember that many of today's AI tools stem from earlier scientific areas — for example, artificial neural networks were inspired by biological observations; diffusion models for image generation were motivated from the physics term."

"Science and AI are not isolated subjects. We have been approaching the same goal from different perspectives, and now we are getting together."

And what better place for them to come together than MIT.

"It is not surprising that MIT can see this change earlier than many other places," He says. "[The Schwarzman College of Computing] created an environment that connects different people and lets them sit together, talk together, work together, exchange their ideas, while speaking the same language — and I'm seeing this begin to happen."

In terms of when the walls will fully lower, He notes that this is a long-term investment that won't happen overnight.

"Decades ago, computers were considered high tech and you needed specific knowledge to understand them, but now everyone is using a computer," He says. "I expect in 10 or more years, everyone will be using some kind of AI in some way for their research — it's just their basic tools, their basic language, and they can use AI to solve their problems."

How I learned to stop worrying and love AI

Jesse Feiman | School of Science

Jesse Thaler, director of IAIFI and professor of physics, talks about how he came to understand and promote the use of AI in science.

Alumni and friends of the School of Science gathered on the clear and chilly morning of Oct. 16, 2024 to join Dean Nergis Mavalvala for a lecture by professor of physics Jesse Thaler. Professor Thaler is director of the Institute for Artificial Intelligence and Fundamental Interactions, or IAIFI, one of the inaugural NSF artificial intelligence research institutes. In his talk, "Deep Learning + Deep Thinking = Deeper Understanding," Thaler discussed the significant advantages machine learning offers to solving problems faced across the field of physics, and he explained the efforts undertaken within IAIFI to foster interdisciplinary collaboration between researchers in AI and physics.

After thanking Dean Mavalvala, Professor Thaler began the morning by testifying, relating to the audience the story of his transformation "from an AI curmudgeon to an AI evangelist." In 2017, he was confronted by Patrick Komiske and Eric Metodiev, two MIT graduate students who were using machine learning in their doctoral research to discriminate between quarks and gluons, subatomic particles that cannot be detected in isolation. At the time, Thaler was also working on the problem of distinguishing quarks from gluons and had found some success with his own human-derived techniques. He was skeptical that AI's capacity for "deep learning" could surpass the "deep thinking" of a human being, and he challenged

Gayatri Pradhan, MBA ’06, and her two daughters listen to the School of Science breakfast talk given by Professor Jesse Thaler on Oct. 16, 2024.

> “Deep learning is all the more powerful when combined with deep thinking.”

Komiske and Metodiev to explain “what they even mean[t] by quarks and gluons?!” The students’ PhD work convinced Thaler that the combination of AI computation and rigorous human decision making could chart a principled path toward distinguishing between quarks and gluons. He learned the lesson that research into the quark–gluon problem was improved by the use of machine learning, which both contributed to his AI conversion and demonstrated that other questions might benefit from similar attention.

Thaler described IAIFI, which formed in 2020, as a group “dedicated to combining the deep learning revolution in artificial intelligence with deep thinking in physics, in order to try to gain a deeper understanding of physical systems and machine intelligence.” A collaboration between MIT, Harvard, Northeastern, and Tufts, IAIFI is dedicated to enabling breakthrough discoveries in physics and to the development of approaches to AI that incorporate first principles from fundamental physics. The institute seeks to cultivate pioneering research, to empower the next generation of talent working in AI physics, and to build a dynamic, interdisciplinary community. Its faculty, postdocs, and students bring together first principles from fundamental physics, rich datasets, and exciting discovery opportunities at the intersection of AI and theoretical physics, experimental physics, astrophysics, and other subfields. Additionally, researchers are innovating AI technology by infusing machine learning systems with physics principles.

Because AI-physics is a novel and collaborative endeavor, Thaler explained, IAIFI makes a priority of developing new talent and cultivating connections between the two fields. The institute’s postdoctoral fellowship program, which just welcomed its fourth cohort, has brought researchers from across the globe to MIT. Through coursework and an interdisciplinary PhD in physics, statistics, and data science, faculty within IAIFI are exposing more scientists to their new techniques and enticing others to follow their new approach to fundamental scientific research. Through summer school courses, workshops, colloquia, and informal gatherings, IAIFI provides opportunities for its participants to share their work and ideas in order to advance physics research and galvanize AI innovation by fusing deep thinking with deep learning.

According to Thaler, the future of AI and science is the future of science. Machine learning technology has only recently advanced to the point where it is of benefit to fundamental science. As projects in IAIFI progress, generative AI takes a larger role and impacts how physicists conceptualize and carry out computations. He ended with the notion that “deep learning is all the more powerful when combined with deep thinking.” Professor Thaler took questions from an enthusiastic crowd and lingered with guests at the conclusion of the breakfast.

Pursuing the secrets of a stealthy parasite

By unraveling the genetic pathways that help *Toxoplasma gondii* persist in human cells, Sebastian Lourido hopes to find new ways to treat toxoplasmosis

Anne Trafton | MIT News

Toxoplasma gondii (T. gondii), the parasite that causes toxoplasmosis, is believed to infect as much as one-third of the world's population. Many of those people have no symptoms, but the parasite can remain dormant for years and later reawaken to cause disease in anyone who becomes immunocompromised.

Why this single-celled parasite is so widespread, and what triggers it to reemerge, are questions that intrigue Sebastian Lourido, an associate professor of biology at MIT and member of the Whitehead Institute for Biomedical Research. In his lab, research is unraveling the genetic pathways that help to keep the parasite in a dormant state, and the factors that lead it to burst free from that state.

"One of the missions of my lab to improve our ability to manipulate the parasite genome, and to do that at a scale that allows us to ask questions about the functions of many genes, or even the entire genome, in a variety of contexts," Lourido says.

There are drugs that can treat the acute symptoms of toxoplasma infection, which include headache, fever, and

"One of the missions of my lab to improve our ability to manipulate the parasite genome," Sebastian Lourido says. *Photo: Jodi Hilton*

inflammation of the heart and lungs. However, once the parasite enters the dormant stage, those drugs don't affect it. Lourido hopes that his lab's work will lead to potential new treatments for this stage, as well as drugs that could combat similar parasites, such as a tickborne parasite known as babesia, which is becoming more common in New England.

"There are a lot of people who are affected by these parasites, and parasitology often doesn't get the attention that it deserves at the highest levels of research. It's really important to bring the latest scientific advances, the latest tools, and the latest concepts to the field of parasitology," Lourido says.

A fascination with microbiology

As a child in Cali, Colombia, Lourido was enthralled by what he could see through the microscopes at his mother's medical genetics lab at the University of Valle del Cauca. His father ran the family's farm and also worked in government, at one point serving as interim governor of the state.

"From my mom, I was exposed to the ideas of gene expression and the influence of genetics on biology, and I think that really sparked an early interest in understanding biology at a fundamental level," Lourido says. "On the other hand, my dad was in agriculture, and so there were other influences there around how the environment shapes biology."

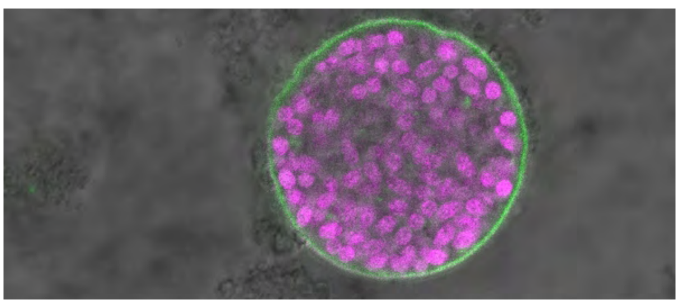
Lourido decided to go to college in the United States, in part because at the time, in the early 2000s, Colombia was experiencing a surge in violence. He was also drawn to the idea of attending a liberal arts college, where he could study both science and art. He ended up going to Tulane University, where he double-majored in fine arts and cell and molecular biology.

As an artist, Lourido focused on printmaking and painting. One area he especially enjoyed was stone lithography, which involves etching images on large blocks of limestone with oil-based inks, treating the images with chemicals, and then transferring the images onto paper using a large press.

"I ended up doing a lot of printmaking, which I think attracted me because it felt like a mode of expression that leveraged different techniques and technical elements," he says.

At the same time, he worked in a biology lab that studied daphnia, tiny crustaceans found in fresh water that have helped scientists learn about how organisms can develop new traits in response to changes to their environment. As an undergraduate, he helped develop ways to use viruses to introduce new genes into daphnia. By the time he graduated from Tulane, Lourido had decided to go into science rather than art.

"I had really fallen in love with lab science as an undergrad. I loved the freedom and the creativity that came from it, the ability to work in teams and to build on ideas, to not have to completely reinvent the entire system, but really be able to develop it over a longer period of time," he says.



Experiments identified one gene, which the researchers named Bradyzoite-Formation Deficient 1 (BFD1), as the only gene both sufficient and necessary to prevent the transition from tachyzoite to bradyzoite stages of *T. gondii* infection. The findings may inform research into potential therapies for toxoplasmosis, or even a vaccine. *Image: Ben Waldman*

After graduating from college, Lourido spent two years in Germany, working at the Max Planck Institute for Infection Biology. In Arturo Zychlinksy's lab, Lourido studied two bacteria known as shigella and salmonella, which can cause severe illnesses, including diarrhea. His studies there helped to reveal how these bacteria get into cells and how they modify the host cells' own pathways to help them replicate inside cells.

As a graduate student at Washington University in St. Louis, Missouri, Lourido worked in several labs focusing on different aspects of microbiology, including virology and bacteriology, but eventually ended up working with David Sibley, a prominent researcher specializing in toxoplasma.

"I had not thought much about toxoplasma before going to graduate school," Lourido recalls. "I was pretty unaware of parasitology in general, despite some undergrad courses, which honestly very superficially treated the subject. What I liked about it was here was a system where we knew so little — organisms that are so different from the textbook models of eukaryotic cells."

Toxoplasma gondii belongs to a group of parasites known as apicomplexans — a type of protozoans that can cause a variety of diseases. After infecting a human host, *Toxoplasma gondii* can hide from the immune system for decades, usually in cysts found in the brain or muscles. Lourido found the organism especially intriguing because as a 17-year-old, he had been diagnosed with toxoplasmosis. His only symptom was swollen glands, but doctors found that his blood contained antibodies against toxoplasma.

"It is really fascinating that in all of these people, about a quarter to a third of the world's population, the parasite persists. Chances are I still have live parasites somewhere in my body, and if I became immunocompromised, it would become a big problem. They would start replicating in an uncontrolled fashion," he says.

A transformative approach

One of the challenges in studying toxoplasma is that the organism's genetics are very different from those of either bacteria or other eukaryotes such as yeast and mammals. That makes it harder to study parasitic gene functions by mutating or knocking out the genes.

Because of that difficulty, it took Lourido his entire graduate career to study the functions of just a couple of toxoplasma genes. After finishing his PhD, he started his own lab as a fellow at the Whitehead Institute and began working on ways to study the toxoplasma genome at a larger scale, using the CRISPR genome-editing technique.

With CRISPR, scientists can systematically knock out every gene in the genome and then study how each missing gene affects parasite function and survival.

"Through the adaptation of CRISPR to toxoplasma, we've been able to survey the entire parasite genome. That has been transformative," says Lourido, who became a Whitehead member and MIT faculty member in 2017. "Since its original application in 2016, we've been able to uncover mechanisms of drug resistance and susceptibility, trace metabolic pathways, and explore many other aspects of parasite biology."

Using CRISPR-based screens, Lourido's lab has identified a regulatory gene called BFD1 that appears to drive the expression of genes that the parasite needs for long-term survival within a host. His lab has also revealed many of the molecular steps required for the parasite to shift between active and dormant states.

"We're actively working to understand how environmental inputs end up guiding the parasite in one direction or another," Lourido says. "They seem to preferentially go into those chronic stages in certain cells like neurons or muscle cells, and they proliferate more exuberantly in the acute phase when nutrient conditions are appropriate or when there are low levels of immunity in the host."

Alex Shalek named director of the Institute for Medical Engineering and Science

Taking a cross-disciplinary approach to understand human diseases

Mary Beth Gallagher | School of Engineering

Alex K. Shalek, the J. W. Kieckhefer Professor in the MIT Institute for Medical Engineering and Sciences (IMES) and Department of Chemistry, has been named the new director of IMES, effective Aug. 1, 2024.

Photo: Justin Knight

"Professor Shalek's substantial contributions to the scientific community as a researcher and educator have been exemplary. His extensive network across MIT, Harvard, and Mass General Brigham will be a tremendous asset as director of IMES," says Anantha Chandrakasan, chief innovation and strategy officer, dean of the School of Engineering, and the Vannevar Bush Professor of Electrical Engineering and Computer Science. "He will undoubtedly be an excellent leader, bringing his innovative approach and collaborative spirit to this new role."

Shalek is a core member of IMES, a professor of chemistry, and holds several leadership positions, including director of the Health Innovation Hub. He is also an extramural member of MIT's Koch Institute for Integrative Cancer Research; a member of the Ragon Institute of Mass General, MIT, and Harvard; an institute member of the Broad Institute of MIT and Harvard; an assistant in immunology at Mass General Brigham; and an instructor in health sciences and technology at Harvard Medical School.

The Shalek Lab's research seeks to uncover how communities of cells work together within human tissues to support health, and how they become dysregulated in disease. By developing and applying innovative experimental and computational technologies, they are shedding light on a wide range of human health conditions.

Shalek and his team use a cross-disciplinary approach that combines genomics, chemical biology, and nanotechnology to develop platforms to profile and control cells and their interactions. Collaborating with researchers across the globe, they apply these tools to study human diseases in great detail. Their goal is to connect what occurs at a cellular level with what medical professionals observe in patients, paving the way for more precise ways to prevent and treat diseases.

Over the course of his career, Shalek's groundbreaking research has earned him widespread recognition and numerous awards and honors. These include an NIH New Innovator Award, a Beckman Young Investigator Award, a Searle Scholar Award, a Pew-Stewart Scholar Award, an Alfred P. Sloan Research Fellowship in Chemistry, and an Avant-Garde (DP1 Pioneer) Award. Shalek has also been celebrated for his dedication as a faculty member, educator, and mentor. He was awarded the 2019–20 Harold E. Edgerton Faculty Achievement Award at MIT and the 2020 HMS Young Mentor Award.

Shalek received his bachelor's degree in chemical physics from Columbia University and his master's and PhD in chemical physics from Harvard University. Prior to joining MIT's faculty in 2014, he was a postdoc at the Broad Institute.

Shalek succeeds Elazer Edelman, the Edward J. Poitras Professor in Medical Engineering and Science, who has led IMES since April 2018.

"I am grateful to Professor Edelman for his incredible leadership and service to IMES over the past six years," says Chandrakasan. "His contributions to IMES have been invaluable, and we are thankful for his dedication and vision during his tenure as director."

MIT School of Science launches Center for Sustainability Science and Strategy

New center taps Institute-wide expertise to address and respond to sustainability challenges

Mark Dwortzan | MIT Center for Sustainability Science and Strategy

The MIT School of Science is launching a center to advance knowledge and computational capabilities in the field of sustainability science, and support decision makers in government, industry, and civil society to achieve sustainable development goals. Aligned with the Climate Project at MIT, researchers at the MIT Center for Sustainability Science and Strategy will develop and apply expertise from across the Institute to improve understanding of sustainability challenges, and thereby provide actionable knowledge and insight to inform strategies for improving human well-being for current and future generations.

Noelle Selin, professor at MIT's Institute for Data, Systems and Society and the Department of Earth, Atmospheric and Planetary Sciences, will serve as the center's inaugural faculty director. C. Adam Schlosser and Sergey Paltsev, senior research scientists at MIT, will serve as deputy directors, with Anne Slinn as executive director.

Incorporating and succeeding both the Center for Global Change Science and Joint Program on the Science and Policy of Global Change while adding new capabilities, the center aims to produce leading-edge research to help guide societal transitions toward a more sustainable

Noelle Selin, professor at MIT's Institute for Data, Systems and Society and the Department of Earth, Atmospheric and Planetary Sciences, serves as the inaugural faculty director for the new MIT Center for Sustainability Science and Strategy. *Photo: M. Scott Brauer*

future. Drawing on the long history of MIT's efforts to address global change and its integrated environmental and human dimensions, the center is well-positioned to lead burgeoning global efforts to advance the field of sustainability science, which seeks to understand nature-society systems in their full complexity. This understanding is designed to be relevant and actionable for decision makers in government, industry, and civil society in their efforts to develop viable pathways to improve quality of life for multiple stakeholders.

"As critical challenges such as climate, health, energy, and food security increasingly affect people's lives around the world, decision makers need a better understanding of the earth in its full complexity — and that includes people, technologies, and institutions as well as environmental processes," says Selin. "Better knowledge of these systems and how they interact can lead to more effective strategies that avoid unintended consequences and ensure an improved quality of life for all."

Advancing knowledge, computational capability, and decision support

To produce more precise and comprehensive knowledge of sustainability challenges and guide decision makers to formulate more effective strategies, the center has set the following goals:

Advance fundamental understanding of the complex interconnected physical and socio-economic systems that affect human well-being. As new policies and technologies are developed amid climate and other global changes, they interact with environmental processes and institutions in ways that can alter the earth's critical life-support systems. Fundamental mechanisms that determine many of these systems' behaviors, including those related to interacting climate, water, food, and socio-economic systems, remain largely unknown and poorly quantified. Better understanding can help society mitigate the risks of abrupt changes and "tipping points" in these systems.

Develop, establish, and disseminate new computational tools toward better understanding earth systems, including both environmental and human dimensions. The center's work will integrate modeling and data analysis across disciplines in an era of increasing volumes of observational data. MIT multisystem models and data products will provide robust information to inform decision making and shape the next generation of sustainability science and strategy.

Produce actionable science that supports equity and justice within and across generations. The center's research will be designed to inform action associated with measurable outcomes aligned with supporting human well-being across generations. This requires engaging a broad range of stakeholders, including not only nations and companies, but also nongovernmental organizations and communities that take action to promote sustainable development — with special attention to those who have historically borne the brunt of environmental injustice.

"The center's work will advance fundamental understanding in sustainability science, leverage leading-edge computing and data, and promote engagement and impact," says Selin. "Our researchers will help lead scientists and strategists across the globe who share MIT's commitment to mobilizing knowledge to inform action toward a more sustainable world."

Building a better world at MIT

Building on existing MIT capabilities in sustainability science and strategy, the center aims to focus research, education, and outreach under a theme that reflects a comprehensive state of the field and international research directions, fostering a dynamic community of students, researchers, and faculty; raise the visibility of sustainability science at MIT, emphasizing links between science and action, in the context of existing Institute goals and other efforts on climate and sustainability, and in a way that reflects the vital contributions of a range of natural and social science disciplines to understanding human-environment systems; and re-emphasize MIT's long-standing expertise in integrated systems modeling while leveraging the Institute's concurrent leading-edge strengths in data and computing, establishing leadership that harnesses recent innovations, including those in machine learning and artificial intelligence, toward addressing the science challenges of global change and sustainability.

"The Center for Sustainability Science and Strategy will provide the necessary synergy for our MIT researchers to develop, deploy, and scale up serious solutions to climate change and other critical sustainability challenges," says Nergis Mavalvala, the Curtis and Kathleen Marble Professor of Astrophysics and dean of the MIT School of Science. "With Professor Selin at its helm, the center will also ensure that these solutions are created in concert with the people who are directly affected now and in the future."

The center builds on more than three decades of achievements by the Center for Global Change Science and the Joint Program on the Science and Policy of Global Change, both of which were directed or co-directed by professor of atmospheric science Ronald Prinn.

The past, present, and future of sustainability science

Professor Ronald Prinn reflects on how far sustainability has come as a discipline, and where it all began at MIT

Kaitlin Provencher | School of Science

It was 1978, over a decade before the word "sustainable" would infiltrate environmental nomenclature, and Ronald Prinn, MIT professor of atmospheric science, had just founded the Advanced Global Atmospheric Gases Experiment (AGAGE). Today, AGAGE provides real-time measurements for well over 50 environmentally harmful trace gases, enabling us to determine emissions at the country level, a key element in verifying national adherence to the Montreal Protocol and the Paris Accord. This, Prinn says, started him thinking about doing science that informed decision making.

Much like global interest in sustainability, Prinn's interest and involvement continued to grow into what would become three decades worth of achievements in sustainability science. The Center for Global Change Science (CGCS) and Joint Program on the Science and Policy Global Change, respectively founded and co-founded by Prinn, have recently joined forces to create the MIT School of Science's new Center for Sustainability Science and Strategy (CS3), led by former CGCS postdoc turned MIT professor, Noelle Selin.

As he prepares to pass the torch, Prinn reflects on how far sustainability has come, and where it all began.

Q: Tell us about the motivation for the MIT centers you helped to found around sustainability.

A: In 1990 after I founded the Center for Global Change Science, I also co-founded the Joint Program on the Science and Policy Global Change with a very important partner, [Henry] "Jake" Jacoby. He's now retired, but at that point he was a professor in the MIT Sloan School of Management. Together, we determined that in order to answer questions related to what we now call sustainability of human activities, you need to combine the natural and social sciences involved in these processes. Based on this, we decided to make a joint program between the CGCS and a center that he directed, the Center for Energy and Environmental Policy Research.

It was called the "joint program" and was joint for two reasons — not only were two centers joining, but two disciplines were joining. It was not about simply doing the same science. It was about bringing a team of people together that could tackle these coupled issues of environment, human development, and economy. We were the first group in the world to fully integrate these elements together.

Q: What has been your most impactful contribution and what effect did it have on the greater public's overall understanding?

A: Our biggest contribution is the development, and more importantly, the application of the Integrated Global System Modeling (IGSM) framework, looking at human development in both developing countries and developed countries that had a significant impact on the way people thought about climate issues. With IGSM, we were able to look at the interactions among human and natural components, studying the feedbacks and impacts that

Ronald Prinn speaks at the 45th anniversary of the Advanced Global Atmospheric Gases Experiment in 2023. *Photo: Kathy Thompson*

"Sustainability is not just climate or air pollution; it's got to do with human impacts in general," says Prinn, outgoing co-founder of the Center for Global Change Science and Joint Program on the Science and Policy Global Change.

climate change had on human systems; like how it would alter agriculture and other land activities, how it would alter things we derive from the ocean, and so on.

Policies were being developed largely by economists or climate scientists working independently, and we started showing how the real answers and analysis required a coupling of all of these components. We showed, and I think convincingly, that what people used to study independently, must be coupled together, because the impacts of climate change and air pollution affected so many things.

To address the value of policy, despite the uncertainty in climate projections, we ran multiple runs of the IGSM with and without policy, with different choices for uncertain IGSM variables. For public communication, around 2005, we introduced our signature Greenhouse Gamble interactive visualization tools; these have been renewed over time as science and policies evolved.

Q: What can MIT provide now at this critical juncture in understanding climate change and its impact?

A: We need to further push the boundaries of integrated global system modeling to ensure full sustainability of human activity and all of its beneficial dimensions, which is the exciting focus that the CS3 is designed to address. We need to focus on sustainability as a central core element and use it to not just analyze existing policies but to propose new ones. Sustainability is not just climate or air pollution; it's got to do with human impacts in general. Human health is central to sustainability, and equally important to equity. We need to expand the capability for credibly assessing what the impact policies have not just on developed countries, but on developing countries, taking into account that many places around the world are at artisanal levels of their economies. They cannot be blamed for anything that is changing climate and causing air pollution and other detrimental things that are currently going on. They need our help. That's what sustainability is in its full dimensions.

Our capabilities are evolving toward a modeling system so detailed that we can find out detrimental things about policies even at local levels before investing in changing infrastructure. This is going to require collaboration among even more disciplines and creating a seamless connection between research and decision making; not just for policies enacted in the public sector, but also for decisions that are made in the private sector.

AI model can reveal the structures of crystalline materials

By analyzing X-ray crystallography data, the model could help researchers develop new materials for many applications, including batteries and magnets

Anne Trafton | MIT News

For more than 100 years, scientists have been using X-ray crystallography to determine the structure of crystalline materials such as metals, rocks, and ceramics.

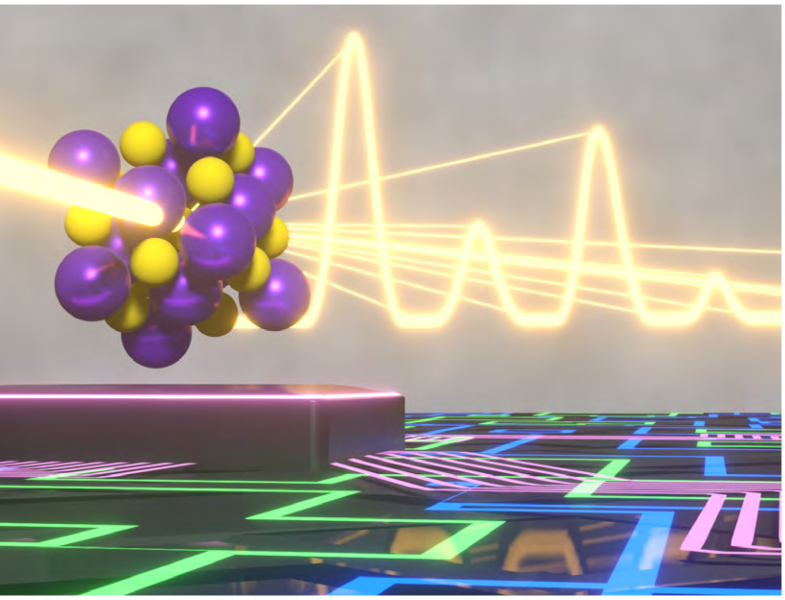
This technique works best when the crystal is intact, but in many cases, scientists have only a powdered version of the material, which contains random fragments of the crystal. This makes it more challenging to piece together the overall structure.

MIT chemists have now come up with a new generative AI model that can make it much easier to determine the structures of these powdered crystals. The prediction model could help researchers characterize materials for use in batteries, magnets, and many other applications.

"Structure is the first thing that you need to know for any material. It's important for superconductivity, it's important for magnets, it's important for knowing what photovoltaic you created. It's important for any application that you can think of which is materials-centric," says Danna Freedman, the Frederick George Keyes Professor of Chemistry at MIT.

Freedman and Jure Leskovec, a professor of computer science at Stanford University, are the senior authors of the new study, which appears in the *Journal of the American Chemical Society*. MIT graduate student Eric Riesel and Yale University undergraduate Tsach Mackey are the lead authors of the paper.

■ MIT chemistry professor Danna Freedman designs qubits for quantum computation. *Photo: M. Scott Brauer*



MIT researchers have created a computational model that can use powder X-ray crystallography data to predict the structure of crystalline materials. *Image: Eric Riesel*

Distinctive patterns

Crystalline materials, which include metals and most other inorganic solid materials, are made of lattices that consist of many identical, repeating units. These units can be thought of as "boxes" with a distinctive shape and size, with atoms arranged precisely within them.

When X-rays are beamed at these lattices, they diffract off atoms with different angles and intensities, revealing information about the positions of the atoms and the bonds between them. Since the early 1900s, this technique has been used to analyze materials, including biological molecules that have a crystalline structure, such as DNA and some proteins.

For materials that exist only as a powdered crystal, solving these structures becomes much more difficult because the fragments don't carry the full 3D structure of the original crystal.

"The precise lattice still exists, because what we call a powder is really a collection of microcrystals. So, you have the same lattice as a large crystal, but they're in a fully randomized orientation," Freedman says.

For thousands of these materials, X-ray diffraction patterns exist but remain unsolved. To try to crack the structures of these materials, Freedman and her colleagues trained a machine learning model on data from a database called the Materials Project, which contains more than 150,000 materials. First, they fed tens of thousands of these materials into an existing model that can simulate what the X-ray diffraction patterns would look like. Then, they used those patterns to train their AI model, which they call Crystalyze, to predict structures based on the X-ray patterns.

The model breaks the process of predicting structures into several subtasks. First, it determines the size and shape of the lattice "box" and which atoms will go into it. Then, it predicts the arrangement of atoms within the box. For each diffraction pattern, the model generates several possible structures, which can be tested by feeding the structures into a model that determines diffraction patterns for a given structure.

"Our model is generative AI, meaning that it generates something that it hasn't seen before, and that allows us to generate several different guesses," Riesel says. "We can make a hundred guesses, and then we can predict what the powder pattern should look like for our guesses. And then if the input looks exactly like the output, then we know we got it right."

Solving unknown structures

The researchers tested the model on several thousand simulated diffraction patterns from the Materials Project. They also tested it on more than 100 experimental diffraction patterns from the RRUFF database, which contains powdered X-ray diffraction data for nearly 14,000 natural crystalline minerals, that they had held out of the training data. On these data, the model was accurate about 67 percent of the time. Then, they began testing the model on diffraction patterns that hadn't been solved before. These data came from the Powder Diffraction File, which contains diffraction data for more than 400,000 solved and unsolved materials.

Using their model, the researchers came up with structures for more than 100 of these previously unsolved patterns. They also used their model to discover structures for three materials that Freedman's lab created by forcing elements that do not react at atmospheric pressure to form compounds under high pressure. This approach can be used to generate new materials that have radically different crystal structures and physical properties, even though their chemical composition is the same.

Graphite and diamond — both made of pure carbon — are examples of such materials. The materials that Freedman has developed, which each contain bismuth and one other element, could be useful in the design of new materials for permanent magnets.

"We found a lot of new materials from existing data, and most importantly, solved three unknown structures from our lab that comprise the first new binary phases of those combinations of elements," Freedman says.

Being able to determine the structures of powdered crystalline materials could help researchers working in nearly any materials-related field, according to the MIT team, which has posted a web interface for the model at crystalyze.org.

The research was funded by the U.S. Department of Energy and the National Science Foundation.

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At a symposium of the Simons Center for the Social Brain held on Nov. 15, 2024, faculty and postdoctoral fellows showcased their latest efforts to improve understanding of the autistic brain. Following the lightning talks and panel discussions, an art gallery featured pieces from UnrulyArt, a program founded by Professor Pawan Sinha to include children with disabilities or cognitive, social, or behavioral impairments in art creation. Read more at picower.mit.edu.