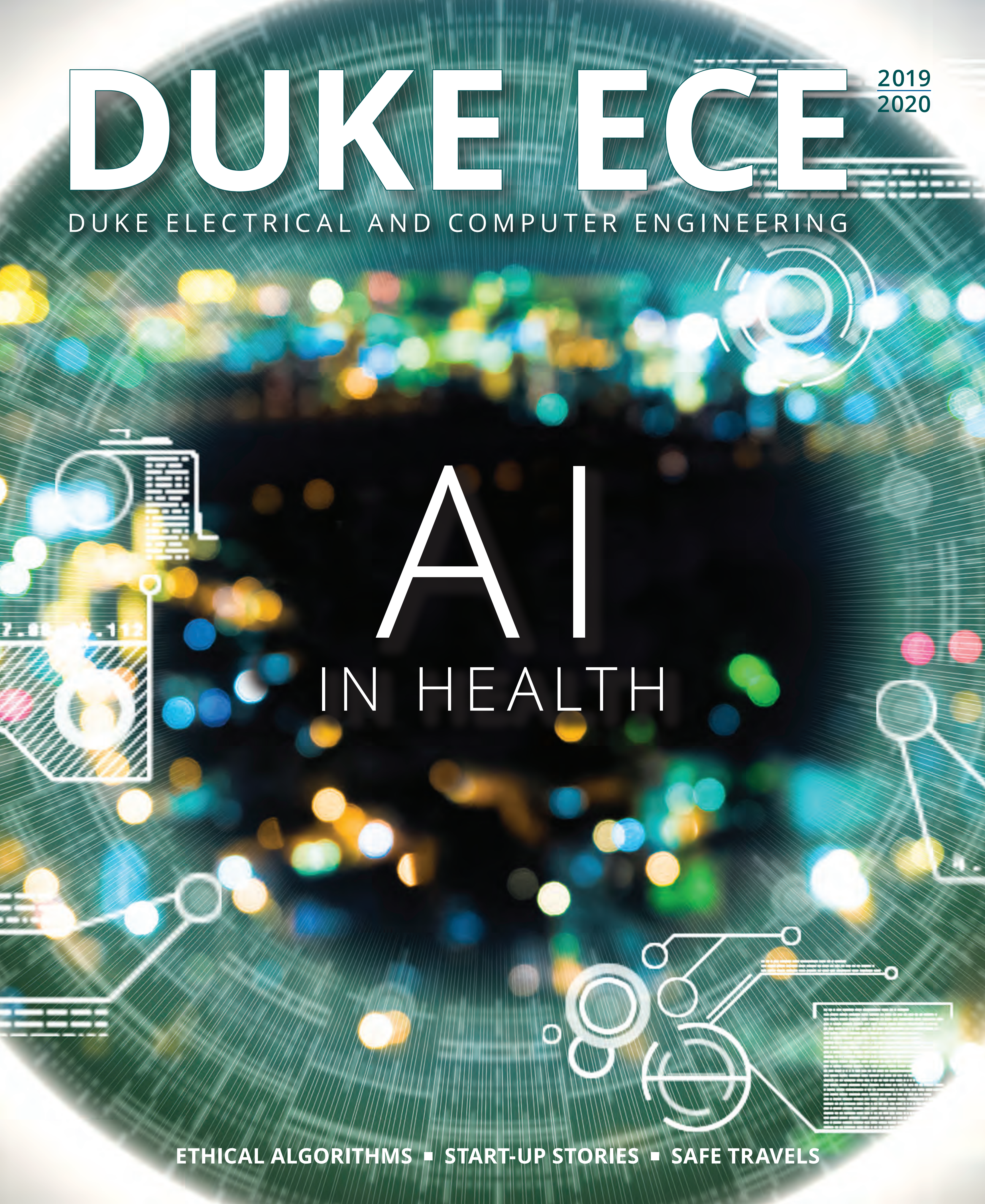
DUKE ECE

2019
2020

DUKE ELECTRICAL AND COMPUTER ENGINEERING



AI IN HEALTH

ETHICAL ALGORITHMS ▪ START-UP STORIES ▪ SAFE TRAVELS

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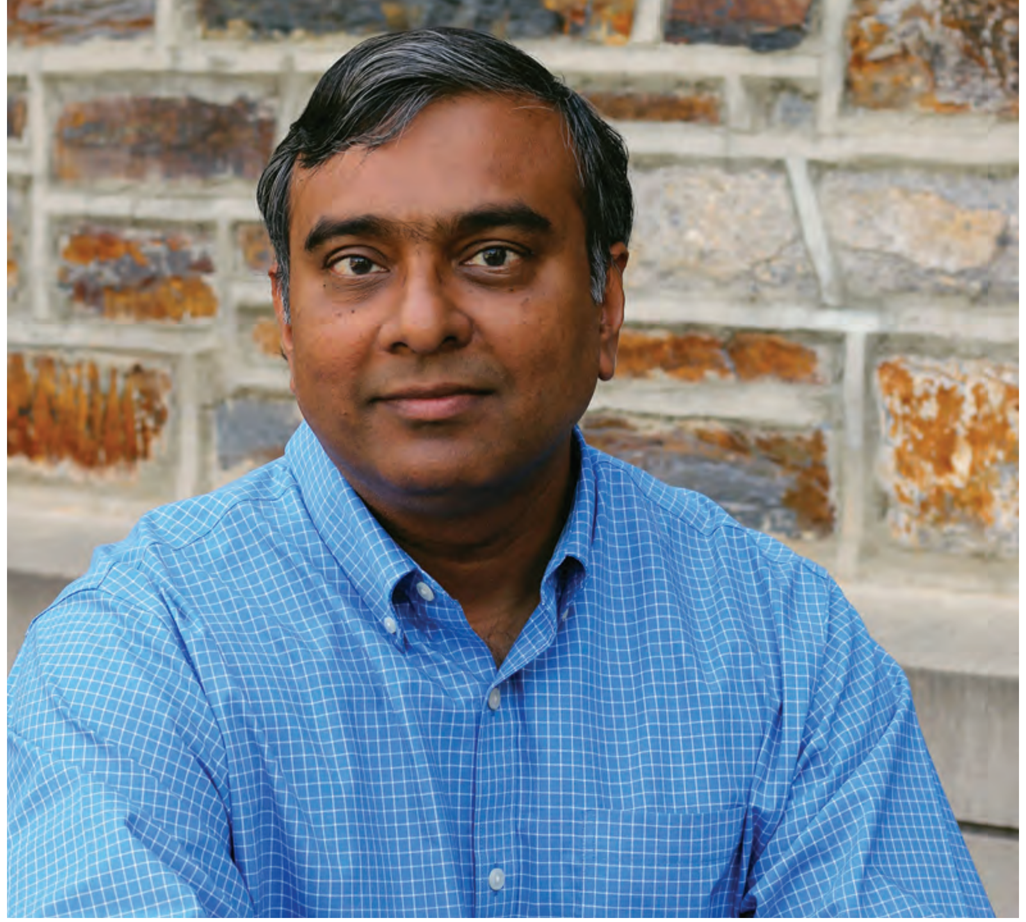


Dear colleagues and friends,

I often think about the dramatic advances we've made in our field over the last 20 or so years. Cast your own mind back to 1995, when we saw a semi-autonomous car steer itself across the country, coast to coast. The next year, the U.S. government put out its first public call for research proposals in quantum information processing. And in 1997, IBM's Deep Blue computer finally defeated the reigning World Chess Champion.

Could any of us have imagined that electrical and computer engineering would have evolved so far, so quickly?

Now, Duke ECE has constructed a thriving quantum information community, and a quantum research group that has captured $15 million in funding in the last two years. We're also pioneering new ways to apply machine learning and AI in service to society—with efficient and accurate security screening, responsibly developed algorithms, and deep new insights into human health through big data. And we remain deeply committed to engaging our students in tackling these tough, exciting challenges—by retooling the way our engineers learn about foundational topics like programming and data, and cultivating the design skills and entrepreneurial confidence needed to make real strides.

I invite you to read about these initiatives, and more, in this issue.

Krishnendu Chakrabarty
John Cocke Professor and Chair ■ Duke Electrical and Computer Engineering

ECE STATS

18 IEEE FELLOWS (THAT'S 50% OF OUR TENURED & TENURE-TRACK FACULTY)

$35 MILLION IN NEW RESEARCH AWARDS FOR FY19

67% GROWTH IN PHD STUDENTS & **203%** INCREASE IN MS STUDENTS

MATRICULATING IN THE PAST 5 YEARS—WITH NEW MASTER'S TRACKS IN SOFTWARE ENGINEERING, MACHINE LEARNING & MORE

#1 (TIE) IN U.S. FACULTY RESEARCH PRODUCTIVITY IN COMPUTER ENGINEERING

&

#5 (TIE) IN ELECTRICAL ENGINEERING IN U.S. FACULTY SCHOLARLY PRODUCTIVITY

(FUNDAMENTAL DATA: ACADEMIC ANALYTICS)

5 MAJOR EXTERNALLY FUNDED RESEARCH PROGRAMS*

- ACOUSTIC METAMATERIALS
- QUANTUM COMPUTING (2)
- WATER, SANITATION & HYGIENE
- COMPUTATIONAL METHANE SENSING

*$1M PER YEAR FOR 3+ YEARS

93% of 2019 Duke ECE seniors seeking employment had job offers before graduation.

At the Crossroads of Innovation & Collaboration

When we dreamed of a new engineering building, we envisioned a space that would maximize opportunities for students to explore, experiment and design—a transformative space that would facilitate collaboration on aspirational new projects with the potential to truly change the world.

Our new 150,000-square-foot building, which will open its doors wide to the Duke community in Fall 2020, will help turn these lofty ideas into reality.

Our new building is located at the very heart of Duke University, with the Schools of Engineering, Medicine, and Arts & Sciences within arm's reach.

The new building will expand current engineering student classroom, lab and program space by nearly 50 percent. Two floors will be focused on active student learning, with flexible teaching spaces and design labs as well as the 200-seat Jerry C. and Beverly A. Wilkinson Auditorium. Specialized educational centers are focused on Engineering Innovation and Student Entrepreneurship, and a 2,000-square-foot Learning Commons is dedicated to nurturing teaching excellence and the student experience.

Heating and cooling delivered through "chilled beams" and lab exhaust systems modeled in a wind tunnel for optimal efficiency are just a couple of the ways the building was designed for sustainability.

Three floors are designated as collaborative research 'neighborhoods' where students and faculty will come together to work on issues of

- **Environment**
- **Health**
- **Computing**, with a special emphasis on AI in health

AI IN HEALTH

Machine learning algorithms in Duke University's Department of Electrical and Computer Engineering were initially deployed in search of landmines. Over the past two decades, they've evolved to generate stunning insights into human health.

In the late 1990s, Larry Carin and Leslie Collins—both just beginning their tenures in Duke's Department of Electrical and Computer Engineering—began teaching computers how to spot buried landmines. The two worked together with a team of researchers for several years developing "active learning" algorithms to optimize their mine-hunting software.

It didn't take long for those early image-processing strategies to move from their military roots to the medical realm.

Researchers at the University of Pennsylvania soon added Carin's active-learning algorithms to software they were developing to help doctors classify cancerous cells. While the software already worked reasonably well, the new algorithms made it more accurate and more consistent. The enhanced toolkit also reduced the time physicians had to spend labeling cell samples to train the system, because the algorithm automatically selected the best examples.

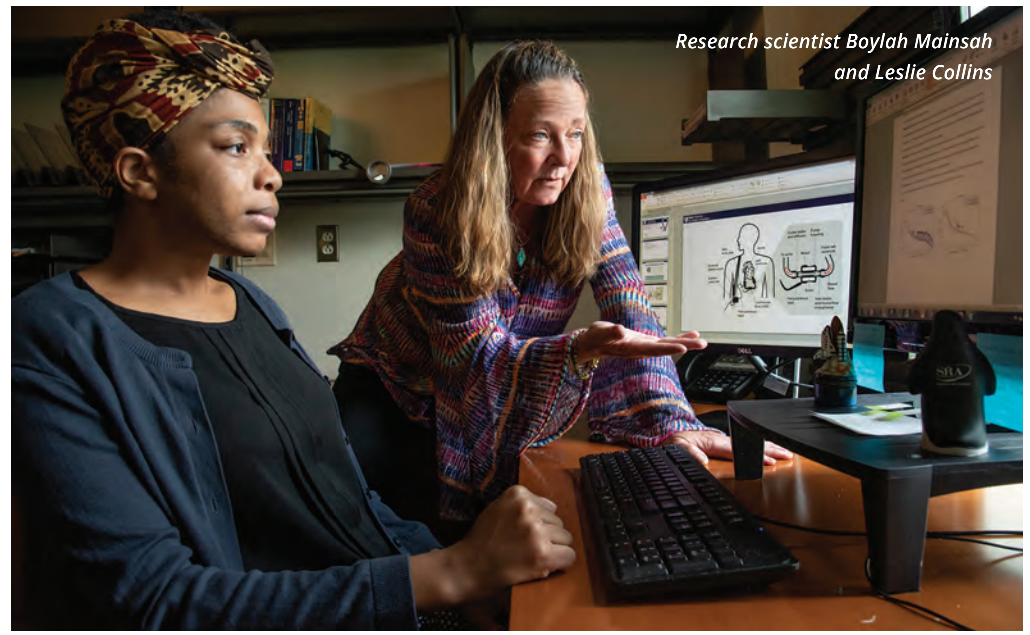
It was just one of many early successes that hinted at the revolution to come.

"The power of deep-learning image analysis has become increasingly clear over the last several years, and image analysis is very important to many aspects of health care," said Carin, now the James L. Meriam Professor of Electrical and Computer Engineering and vice president for research at Duke. "With examples in radiology, pathology, dermatology, cardiology and more, the analysis of health-sensing data with machine learning will be transformative in the coming years."

Carin should know. He is now leading one research project to autonomously spot cancerous cells in digitized slides of thyroid biopsies and another to detect early signs of Alzheimer's disease through retinal scans.

But he's hardly alone.

Over the past several years, Duke has hired a string of machine learning experts and launched several ambitious projects to tie Duke Health and Duke Engineering closer together. With a growing array of computer engineering faculty partnering with colleagues in the nearby medical school, and a new campus-wide initiative focused on AI solutions for health care, Duke ECE is playing a major role in the university's commitment to leverage machine learning to impact human health.


Research scientist Boylah Mainsah and Leslie Collins

Sensing for Sound

While Leslie Collins continued her work on detecting landmines well into the 2010s, she has also led several projects that applied machine learning concepts directly to health care. The earliest example—which continues to this day—is using machine learning to improve cochlear implants.

Cochlear implants are prosthetic devices that deliver direct electrical stimulation to auditory nerve fibers, at least partially restoring normal hearing in deaf individuals. Duke ECE alumnus Blake Wilson developed the sound-processing strategies used in most modern cochlear implants, which have to date helped hundreds of thousands of adults and children worldwide.

Using machine learning, Collins's laboratory is exploring how the spacing between electrodes and the timing of their interactions affects the user's experience. The new signal coding techniques should provide either more natural neural responses, or a more complete


Leslie Collins


Vahid Tarokh

representation of the acoustic signal, which may improve speech recognition for individuals with cochlear implants.

In another project involving acoustic signals, Collins and colleagues in the School of Medicine are using digital stethoscopes and machine learning to listen for complications with left ventricular assist devices (LVADs), which are mechanical heart pumps that prolong the life of patients with advanced heart failures.

Collins is also using machine learning to decode P300 brain waves to allow patients who are neurologically "locked in" to communicate through a brain-computer interface using electroencephalography (EEG) data. While initial proofs-of-concept have already been successful, the laboratory is working to make the system faster and more robust before seeking a commercialized version of the technology. Her laboratory is also using EEG data in an attempt to autonomously monitor the brain function of patients who have sustained brain injuries to guide early management and provide a foundation for a more accurate prognosis and trajectory of recovery.

If successful, the machine learning techniques will not only construct a classification system based on features of the ultrasound signal, they will be able to reconstruct the audio waveform to predict the shape of the blood vessel.

In another project focusing on waveforms, Vahid Tarokh, the Rhodes Family Professor of Electrical and Computer Engineering at Duke, is working to automatically diagnose peripheral artery disease. A narrowing of the peripheral arteries serving the legs, stomach, arms and head, the disease causes muscle pains and cramping that can become debilitating.

Currently, the disease is diagnosed using audio ultrasound and a trained ear. Collaborating with Wilkins Aquino, the Anderson-Rupp Professor of Mechanical Engineering and Materials Science, and Leila Mureebe, associate professor of surgery at Duke, Tarokh is working to replace the trained ear with a trained computer. If successful, the machine learning techniques will not only construct a classification system based on features of the ultrasound signal, they will be able to reconstruct the audio waveform to predict the shape of the blood vessel.

Tarokh is also working with Sina Farsiu, the Paul Ruffin Scarborough Associate Professor of Engineering, to improve treatment of diabetic macular edema—a leading cause of blindness in working-age Americans.

The first treatment most patients receive for this disease is called anti-VEGF. Besides being expensive and requiring regular injections into the eye, the drug doesn't work for everyone. If the patient doesn't respond after months of invasive, inconvenient treatments, the doctor will try a different approach. And it will continue like that until a treatment succeeds or the patient goes blind.

The researchers have, however, developed an artificial intelligence system that can predict which patients will respond to anti-VEGF treatment. If successful in retrospective studies and large-scale clinical studies, the system could greatly reduce the cost and save many eyes from going blind.

Algorithms for Autism

Another machine-learning expert who entered the field through image processing—including developing image compression techniques used in the Mars Rover missions—Guillermo Sapiro, the James B. Duke Professor of Electrical and Computer Engineering, is also turning attention to problems in health care.

With collaborators in the School of Medicine, including Geraldine Dawson, director of the Duke Center for Autism and Brain Development, Sapiro is developing an app to screen for autism spectrum disorder (ASD). Now in clinical studies, the app uses a smartphone's or tablet's 'selfie' camera to record young children's reactions while they watch movies designed to elicit autism risk behaviors, such as patterns of emotion and attention, on the device's screen.

The videos are sent to the study's servers, where automatic behavioral coding software tracks the movement of video landmarks on the

child's face to quantify emotions and attention. For example, in response to a short movie of bubbles floating across the screen, the algorithm looks for movements of facial muscles that indicate interest and joy.

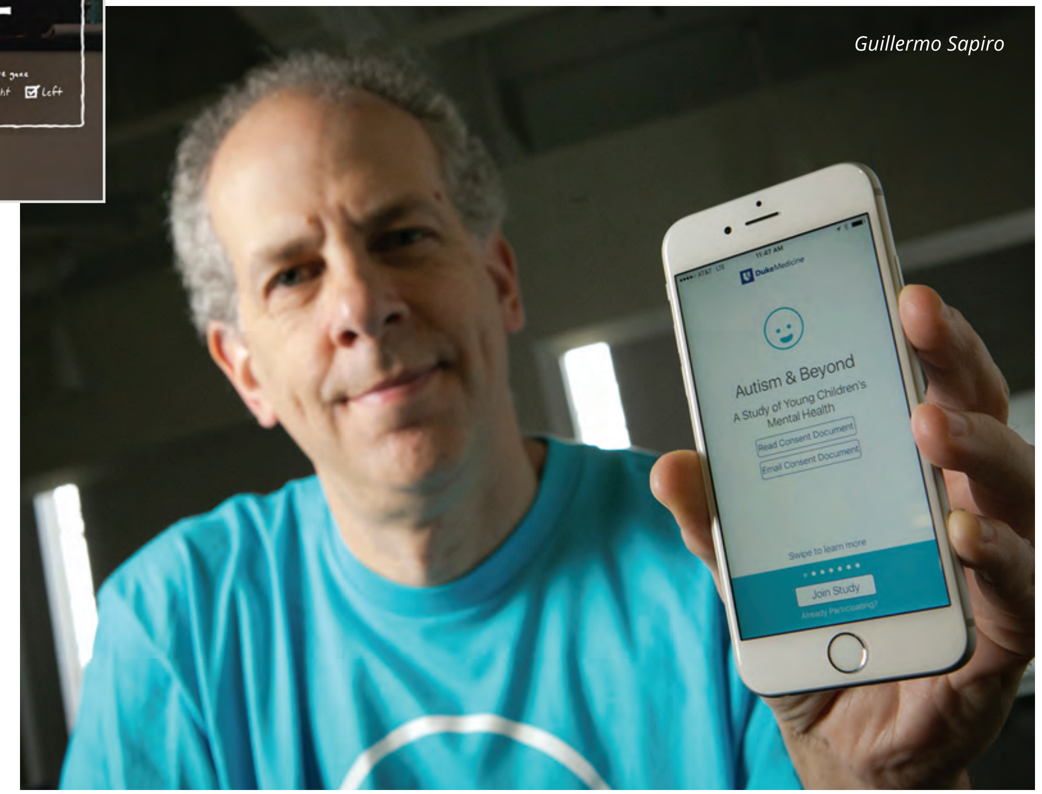
Sapiro is building machine-learning algorithms that connect these fleeting facial and eye movements to potential signs of ASD. His group is also using cloud computing tools to develop new machine learning algorithms for privacy filters for the images and videos they collect.

"We're trying to tackle the challenge of extracting the information we need from a person's face while simultaneously implementing filters to block information users might not want to share," said Sapiro. "We're also working to make our algorithms become better over time with each user and make them scalable and more user-friendly."

With the app showing promising early results, Sapiro is now beginning a project with Nancy Zucker, director of the Duke Center for Eating Disorders, to help children with severe eating disorders. Many children too young to worry about obesity or understand anorexia simply won't eat, or won't eat a varied enough diet to receive all the nutrients they require.

Sapiro and Zucker plan to create a machine learning program to help characterize the disease as well as compile information from thousands of families facing these challenges to help find solutions. For example, the algorithm could help find foods similar in texture and taste to things the children will eat that will best help round out their diet.

Another new project just starting to take shape has Sapiro working with colleagues across Duke, including Dennis Turner, professor of neurosurgery; Warren Grill, the Edmund T. Pratt, Jr. School Professor of Biomedical Engineering; John Pearson, assistant professor of biostatistics and bioinformatics; and Kyle Mitchell, assistant professor of neurology, to create a system for measuring behaviors and movements for people using deep brain stimulation implants to



Guillermo Sapiro

control neuromuscular diseases such as Parkinson's. The goal is to provide clinicians a clearer view into how well the technology is working for each patient so that they might fine-tune the device's parameters.

"It's like when the noise your car has been making for a week suddenly stops when you get it to the mechanic," said Sapiro. "Doctors are currently only seeing a snapshot of their patients' symptoms while they're in the clinic. We want to create a system that provides the doctors with a much more complete view of how the therapy is working on a day-to-day basis."

"We're trying to tackle the challenge of extracting the information we need from a person's face while simultaneously implementing filters to block information users might not want to share."

—GUILLERMO SAPIRO

Revealing Patterns in Health Records

While devices such as OCT scanners, ultrasound machines and smartphone cameras are creating massive amounts of data for computers to learn from, so is the growing use of electric medical records. The difference is that rather than already being bunched together in a nice, tight package, these data are spread out across multiple systems and multiple doctors.

Although Larry Carin's expertise in machine learning first took root in spotting potential explosives, he's now leading projects to spot potentially explosive health problems by creating a cohesive view across the diaspora of medical data.

"The most complex patients are being seen by several doctors with several specialties, and these at-risk patients are the so-called 'elephants in the room,'" said Carin. "Any one doctor generally only gets to touch a small piece of the elephant and doesn't see that there's an elephant in the room. Machine learning systems don't have that limitation. They can see the entire clinical record from all of the doctors and glean insights that that individual doctors can't."

Along with Ricardo Henao, assistant professor

Over the past five years, Larry Carin has been the single most published researcher at the world's leading machine learning conference, NeurIPS.

"We're going to make it easier for people to simply 'flip the switch' and plug into the data science flowing through Duke, no matter what appliance or application they're using."

—LARRY CARIN

of biostatistics and bioinformatics and electrical and computer engineering, Carin is building a system to help spot these elephants.

One of the most expensive and dangerous trips to the hospital a person can take is an unplanned one. By using machine learning to analyze electronic health records and claims data, Carin and Henao seek to predict which patients are most at risk for complications that could require emergency care in the next six months. Once flagged, care managers can look over their medical records and find appropriate interventions—thereby lowering health care costs while improving patient outcomes.

"It's really about engaging with individuals to help them avoid health complications in the first place," said Henao. "But to do that, you first need a machine learning model that says from these 50,000 people, these are the 200 that you really need to pay attention to."

AI & Health: The Future at Duke

The kinds of grassroots collaborations that have sprung up across Duke over the years are now being actively cultivated, with plans underway to turbo-charge efforts to develop AI-driven solutions to challenges in health care. A new initiative co-led by Carin and Robert Califf, Duke Health's vice chancellor for health data science, will connect the Schools of Engineering and Medicine and Trinity College of Arts & Sciences with units such as the Duke Global Health Institute and the Duke-Margolis Center for Health Policy to leverage machine learning to improve both individual and population health through education, research and patient-care projects.

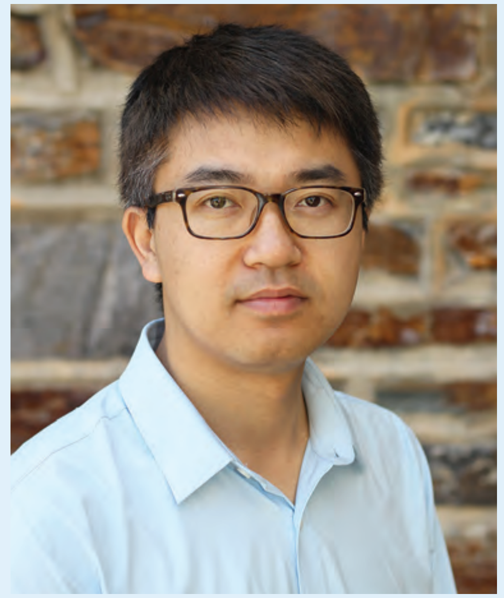
Learning Health Units centered around specialties such as heart, cancer and pediatrics will embed data scientists in the clinical setting, where they will work with clinicians to record, analyze and learn from their troves of medical data to predict and prevent complications and streamline care delivery.

Duke's +Data Science program will offer educational programming—including its popular Machine Learning Summer and Winter Schools (plus.datascience.duke.edu)—to help develop data analysis skills in clinicians, researchers, faculty and students university-wide. And with a new hub for AI in health opening on the fifth floor of the new Engineering Building (see page 3), Duke also plans to recruit exceptional new talent to add to the ranks of its faculty developing innovations in artificial intelligence—including the world-class team in Duke ECE.

"People have said that artificial intelligence will constitute the fourth industrial revolution and that data is like the electricity of the industrial revolution," said Carin. "We think of this project as the electric company. We don't own data science. We don't own health data science. But we are going to facilitate it and foster it. We're going to make it easier for people to simply 'flip the switch' and plug into the data science flowing through Duke, no matter what appliance or application they're using." ■

MEET ECE'S NEWEST STARS

Three new faculty members joined Duke ECE in 2019: **Neil Gong, Genevieve Lipp, and Lisa Wu Wills.** Each, in their unique way, will strengthen ECE's portfolio of groundbreaking research and its innovative hands-on curriculum.



Neil Gong

ASSISTANT PROFESSOR OF ELECTRICAL AND COMPUTER ENGINEERING

An expert in digital security technologies, Gong explores privacy and security issues related to machine learning and artificial intelligence. He is focused on predicting how malicious actors might misuse machine learning techniques to attack computer and network systems, and on studying the vulnerabilities of machine learning itself in order to build secure and privacy-preserving machine learning. He's also working to find ways of keeping medical data secure during machine learning research projects designed to improve patient health—an area of great interest for Duke, which is a leader in the field of AI in health.

Genevieve Lipp

ASSISTANT PROFESSOR OF THE PRACTICE OF ELECTRICAL AND COMPUTER ENGINEERING AND MECHANICAL ENGINEERING AND MATERIALS SCIENCE

Lipp's specialty is showing non-computer engineering students the most sound and effective approaches to programming. Some of Lipp's future classes will emphasize new applications for programming, including assignments on financial models like equities and bonds, and will be co-listed with Duke Engineering's new Financial Technology (FinTech) master's program (meng.duke.edu/fintech). Lipp is also engaged in innovation and research in engineering education, including online education.

Lisa Wu Wills

ASSISTANT PROFESSOR OF COMPUTER SCIENCE AND ELECTRICAL AND COMPUTER ENGINEERING

Wills specializes in computer architecture and microarchitecture, systems, accelerators, and Big Data. Her group, the APEX Lab @ Duke, aims to provide scientists and industry partners with computing systems that accelerate research analysis by orders of magnitude, through the design and deployment of custom hardware. As a first order of business, Wills has organized a Fall 2019 bootcamp for computer scientists and engineers interested in learning to design their own hardware using Chisel, an open-source hardware construction language.

ETHICAL ALGORITHMS

How do we balance the potentially transformative benefits of new technology against the risks?

Nearly forty thousand people lost their lives in car crashes last year in the U.S. alone. We can only presume that many of those fatalities were owed to our uniquely human frailties: distracted driving, driving under the influence, or plain inexperience. It makes sense to get human drivers off the roads as quickly as possible, and let machines do the driving.

That's one argument, anyway. There's also a compelling argument to stop and consider the ethical issues that this new technology surfaces. Whether it's self-driving cars or a selfie-sharing app with questionable privacy protections, the rush to deliver innovations to market often brushes ethical considerations aside—but several Duke ECE professors are pushing back.

Duke ECE professor Missy Cummings is a former Navy fighter pilot who now directs the Humans and Autonomy Lab, or HAL. Her research focuses on maximizing human and machine cooperation for optimal performance and outcomes, and she is an outspoken "techno-realist" when it comes to the idea that we're nearly ready for highly autonomous cars to hit the roads.

"Driverless cars could dramatically reduce roadway deaths, but currently, computer vision systems on these cars are extremely brittle, and not ready for unsupervised driving," said Cummings. "We know that long shadows, low sun angles, and even a quarter-inch of snow can cause these systems to fail, sometimes in catastrophic ways—so we are still 10 or more years away from achieving full driverless capabilities."

Manufacturers have spent around $80 billion on autonomous vehicle research and development to date. The size of that investment comes with pressure of equal magnitude; the investments need to pay off, and there is a clear interest in hustling the technology to an eager market. Yet, the shortcomings of current AV systems are well documented. They are vulnerable to hackers. They are not good at tasks of inference—for example, knowing that a ball that rolls into the road will probably be followed by a child chasing it. These types of knowledge and skill errors, noted Cummings, would cause a human driver to fail a driver's license test—but no equivalent "computer vision" test currently exists that examines the reasoning abilities of driverless cars.

> **"We know that long shadows, low sun angles, and even a quarter-inch of snow can cause these systems to fail…"**
>
> —MISSY CUMMINGS

Despite the dubious capabilities of autonomous systems and the lack of processes for testing and certifying highly autonomous vehicles, however, they have already taken to our roads—in what are essentially large-scale experiments involving the public without its explicit consent.

Cummings said that wanting to achieve fully autonomous vehicles is necessary to making the incremental improvements that will get us there, eventually. But pushing the technology out into the world before it can be effectively regulated, she warned, is both irresponsible and dangerous.

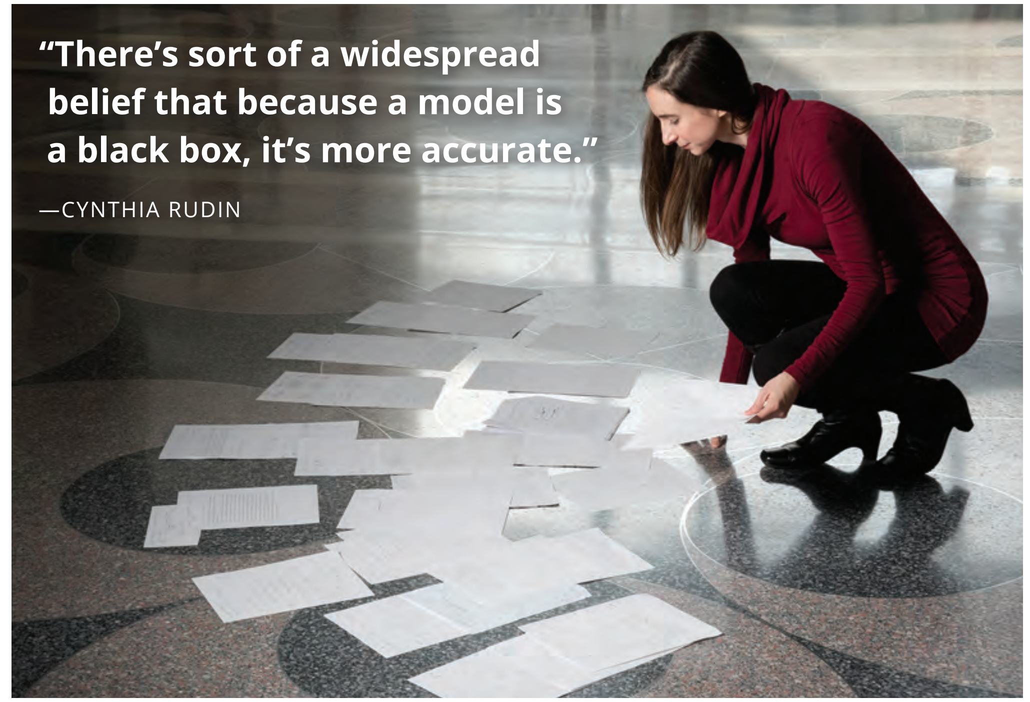
It's a problem that extends far beyond the AV sector.

Professor Cynthia Rudin runs Duke's Prediction and Analysis Lab, and she is a machine learning expert—specifically, she is an expert at building interpretable machine learning algorithms, in a world increasingly obsessed with black box models.

"A black box predictive model is a model that's too complicated for a human to understand, or a formula that's proprietary, meaning it's hidden by a company," said Rudin. Black box algorithms are commonly used in low-stakes applications like retail, where your age, income, occupation, purchase history, and a hundred other bits of data inform the decision of whether to show you an advertisement for airline tickets or vitamins.

More problematic are black box models used in high-stakes decisions, like evaluating credit risk and setting parole. Those decisions can profoundly affect people's lives, stressed Rudin, and it's difficult for someone who has been denied parole to challenge the decision if it's impossible to see how the decision was reached.

Missy Cummings



> **"There's sort of a widespread belief that because a model is a black box, it's more accurate."**
>
> —CYNTHIA RUDIN

Rudin's lab specializes in developing simple, interpretable models that are more accurate than the black box models currently used by the justice system. According to Rudin, you don't even need a calculator to compute them.

"There's sort of a widespread belief that because a model is a black box, it's more accurate," said Rudin. "And that, as far as I can tell, is wrong. I've worked on many different applications—in medical care, in energy, in credit risk, in criminal recidivism—and we've never found an application where we really need a black box. We can always use an interpretable model for a high-stakes decision problem."

The enthusiasm for black box models, said Rudin, should be tempered by careful consideration of the possible ramifications.

"Often the academic community doesn't train computer scientists in the right topics," said Rudin. "We don't train them in basic statistics, for instance. We don't train them in ethics. So they develop this technology without worrying about what it's used for. And that's a problem."

This year, Duke Engineering established the Lane Family Ethics in Technology Program, which will embed ethics education across the engineering and computer science curricula. The program supports faculty-led course content, extracurricular activities and an annual symposium focused on ethics in technology.

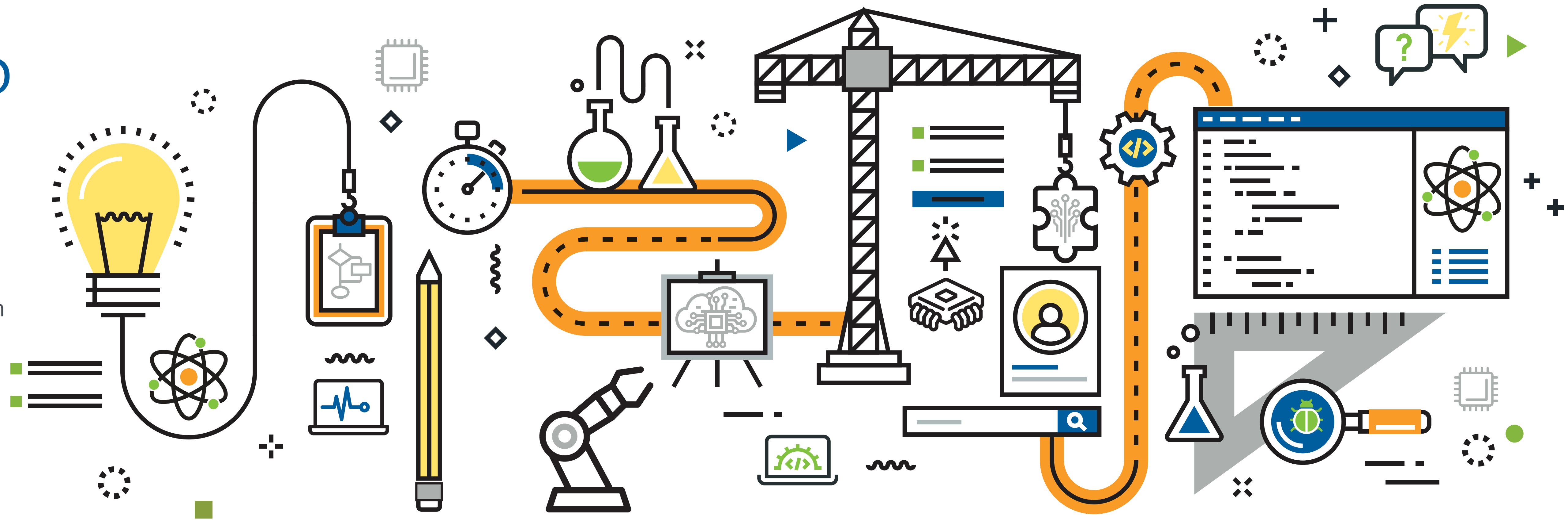
Stacy Tantum, the Bell-Rhodes Associate Professor of the Practice of Electrical and Computer Engineering, will lead one of the program's first courses this fall. Tantum will work with Amber Díaz Pearson, a research scholar at Duke's Kenan Institute for Ethics, to integrate ethics-focused modules into ECE 580, Introduction to Machine Learning.

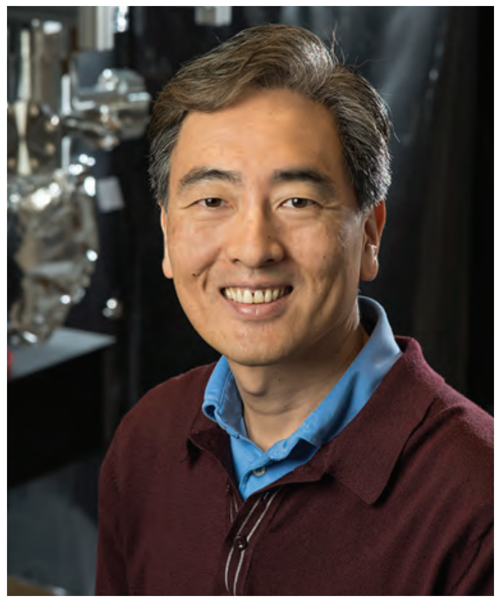
Three elements of ethical algorithm development will be emphasized in the course, said Tantum. First is *transparency*, or why others should be able to easily evaluate all aspects of algorithm design, from the input training data and algorithmic assumptions, to the selection of algorithmic parameters, to the process by which predicted performance is evaluated. Second is *algorithmic bias*—the conditions that are likely to result in bias, but which are often overlooked, or deemed unimportant. And third is *unintended use-cases* of algorithms—the potential pitfalls of re-purposing algorithms for use-cases other than those for which they were designed.

"Our goal is to lead students to incorporate ethical considerations as a natural part of algorithm development, not an afterthought to be considered only after an unintended or unanticipated consequence arises," said Tantum. ■

START-UP STORIES

Eighteen spinoffs—and counting!—have grown from Duke ECE's pioneering research in quantum computing, metamaterials, advanced sensing, robotics, and more. Meet a few of our entrepreneurs.





A Super Position

Quantum binary digits, or qubits, are the superheroes of computing, and their superpowers lie in their beyond-binary abilities and secret correlations among them. Unlike traditional bits, which represent a piece of information as either a 0 or a 1, qubits can represent both simultaneously, in a so-called superposition state. Qubits can also contain strong, fundamental ties among them, known as entanglement. When combined, these superpowers allow quantum computers to solve some complex problems with a speed unmatched by any traditional computers today—or, for that matter, at any time in the predictable future.

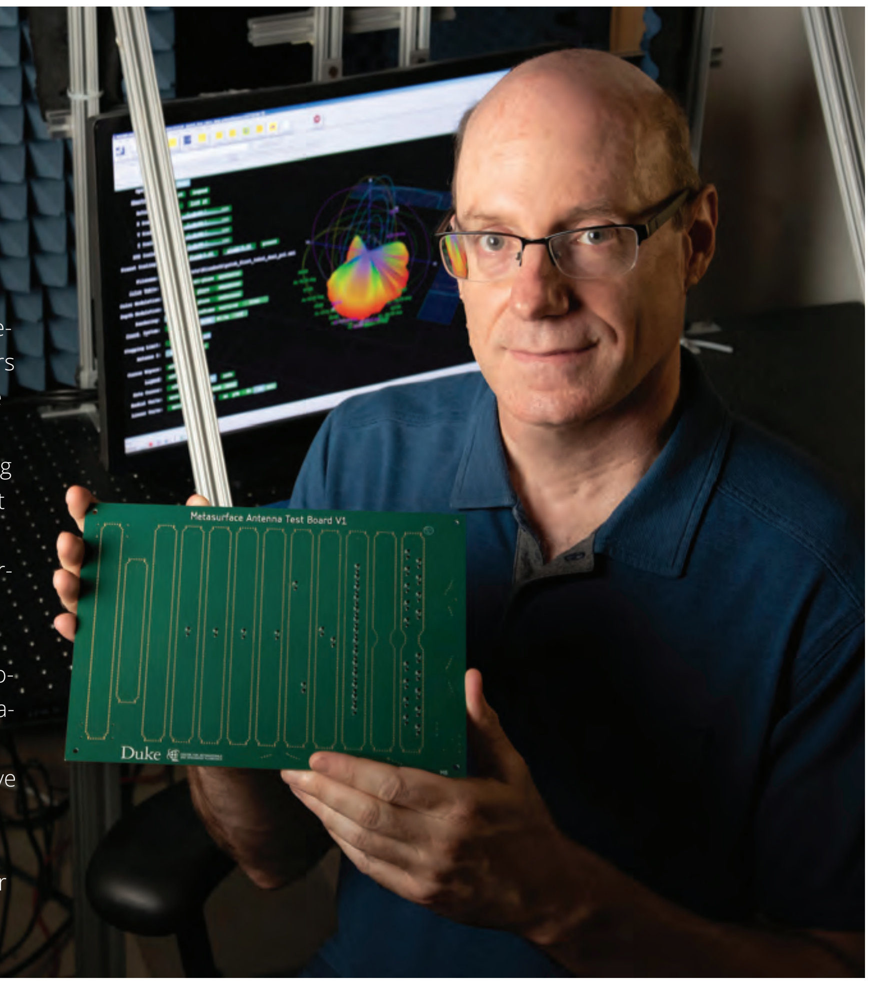
Companies really want quantum computers, and therefore really want to partner with quantum scientists. For Duke Engineering's Jungsang Kim, it's a super position to be in. IonQ, Inc., the company Kim co-founded with the University of Maryland's Chris Monroe in 2015, has captured $22 million in funding to date: $2 million in seed funding from New Enterprise Associates (NEA), and an additional $20 million in funding from GV (formerly Google Ventures), Amazon Web Services, and NEA. The funding allowed IonQ to scale its team up to 37 employees and build two of the most accurate quantum computers in existence in two short years.

"The future of quantum computing as an industry is somewhat uncertain," said Kim. "Since quantum computers have never existed, there are no existing companies whose market is built on quantum computers." He said that the situation is not dissimilar from the days when first digital computers were built in the 1940s. Those computers were built to tackle specific problems of interest to the government, but when their capabilities became more widely available, new industries flourished in ways that no one expected—and would continue to thrive over the seven decades that followed.

> **"This could be a once-in-a-lifetime type of opportunity to shape the future of quantum computing technology."**

"It is extremely exciting to be in the driver's seat in defining what the future industry of quantum computing is going to look like," said Kim. "This could be a once-in-a-lifetime type of opportunity to shape the future of quantum computing technology. And," he added, "we are always looking for enthusiastic young minds to join us in our journey."

The Serial Entrepreneur



Metamaterials are artificially structured materials whose electromagnetic properties can be tailored and tuned in novel ways—but the term "metamaterials" is more of a design approach than a class of devices or components, according to David Smith, the James B. Duke Professor of Electrical and Computer Engineering and Director of the Center for Metamaterials and Integrated Plasmonics at Duke. In Smith's lab, engineers learn to control and manipulate the flow of light and other wave excitations. Their work has led to unbelievable discoveries, like electromagnetic cloaking devices that "hide" objects by rerouting waves around them, and satellite communication terminals that electronically acquire, steer and lock waves to satellites.

In the young field of metamaterials, opportunities to commercialize the technologies abound. In 2012, communications company Kymeta spun off from research performed in Smith's lab. Smith co-founded Evolv Technology the following year, Echodyne Corporation in 2014, Pivotal Commware in 2015, and Metacept in 2018—all metamaterials-based ventures, running from security imaging to antenna design. Two other spinoffs, Lumotive and Carillon, have launched from Smith's lab since 2017.

"What has been so compelling—almost addictive—about metamaterials is the ability to exert unprecedented control over the properties of a material or other device," said Smith.

Joseph Andrews (left) with Aaron Franklin, the James L. and Elizabeth M. Vincent Associate Professor

Getting Your Hands Dirty

A week into his PhD work at Duke, Joseph Andrews found himself behind a local mechanic's shop, hacking apart discarded tires with a grinding saw—a far cry from what he imagined he'd be doing as a student in professor Aaron Franklin's nanotechnology research lab.

Though not the most glamorous, Andrews's project—developing printed electronic sensors to measure automobile tire tread—not only funded his space in the lab, but eventually led to multiple patents and a funded startup company.

According to Andrews, their invention is pretty simple. It's a capacitor-based device, which means it measures electrical energy between a pair of electrodes. As the thickness of the material between two electrodes changes, the electric field is also altered, leading to a measurable change in capacitance.

Andrews started with a parallel plate capacitor that used two plates—one in the wheel well and one inside the tire—to measure the material between them. "Of course I was doing good experiments, and moving the plates farther and farther apart until the wheel well plate was removed completely," said Andrews. "When I did, I got a measurement from a single side, which I didn't think was possible." This discovery led to the demonstration of a sensor that can be fully contained within a tire and capable of measuring changes in the tire's tread thickness.

This kind of capacitance uses electrical field lines that arc, called cross-capacitance. It's commonly used with technology like touchscreens, but Andrews was the first to apply it toward measuring the thickness of a material. The end product, a sensor with an electrode made using materials such as carbon nanotubes, spun off into a tire sensor company named Tyrata that secured $4.5 million in series A funding last year to develop the demonstrated sensor into a viable product.

A week into his PhD work at Duke, Joseph Andrews found himself behind a local mechanic's shop, hacking apart discarded tires with a grinding saw.

For Andrews, it means a credit as lead inventor on several U.S. and international patents. Hopefully, for the rest of us, it will mean the end of jamming pennies into our tire treads to check for wear.

Entrepreneur-in-Residence

Vamsee Pamula co-founded his first company, Advanced Liquid Logic, as an ECE postdoctoral researcher in Lord-Chandran Professor of Engineering Richard Fair's microfluidics lab. Working alongside Fair, fellow postdoc Michael Pollack PhD '01, and Richard West BSE '79, Pamula grew the fledgling lab-on-a-chip company to a 90-employee enterprise over the next nine years, before selling it to genomics giant Illumina in 2013 for nearly $100 million. Pamula and West launched a second company, Baebies, the very same day, capitalizing upon digital microfluidics and other technologies to deliver rapid testing for newborns—testing for several rare diseases using a single drop of blood, and allowing doctors to quickly begin interventions.

Vamsee Pamula

The extra "e" in Baebies, said Pamula, is for "everyone," signifying that every baby deserves a healthy start. The spelling is a constant reminder of their mission, and who they chose to serve.

In 2019, ECE brought Pamula back to Duke as its first entrepreneur-in-residence. Pamula visits the department monthly to spend time with ECE students and faculty who are interested in starting their own businesses, offering advice in areas including idea development, securing intellectual property, and commercialization of research.

Call It Kismet

Professor of electrical and computer engineering Daniel Sorin jokes that a computer architect and a roboticist must have never sat down to lunch together before he and George Konidaris did. If they had, they would have soon discovered that they were perfectly suited to start a robotic motion planning company, and gotten a jump on the competition.

"I met George at the State of the School address. He seemed to be doing interesting work, so we went to lunch," Sorin recalled. "He was talking about open problems in his field, and one was motion planning, or how to quickly move a robot from Point A to Point B without hitting stuff."

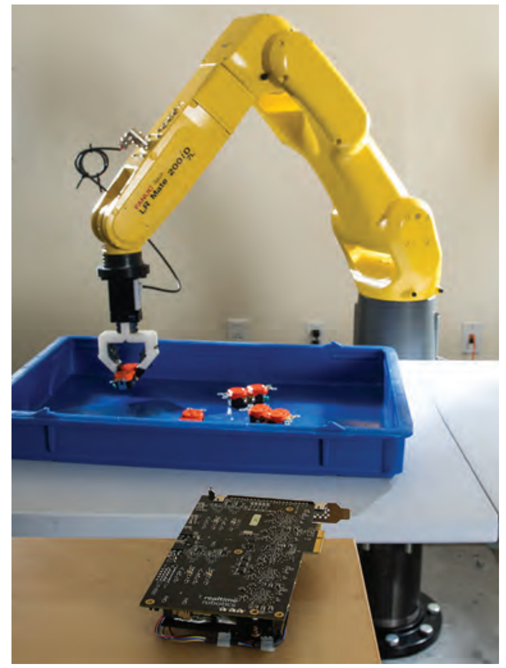
Sorin told Konidaris that in his own field, computer architecture, the goal was to improve upon processes that were slow, but important enough that they warranted specially designed hardware.

"Five years ago I knew zero about robotics... I'm now the co-founder of a robotics company."

"We looked at each other and thought, 'Hm, I wonder if anyone has tried this fusion before,'" said Sorin. They quickly determined that no one had.

From there, the pieces seemed to magically fall into place. Two excellent students—ECE PhD candidate Sean Murray and Will Floyd-Jones, an undergraduate double-majoring in ECE and computer science—were looking for projects, and Sorin brought them on board. "But all of us—two academics and two students—we knew nothing about business," admitted Sorin.

Serendipitously, Duke Engineering had just named alumnus and entrepreneur Bill Walker as the school's first Mattson Family Director of Entrepreneurial Ventures. "Bill very patiently answered a bazillion questions we had," said Sorin. "Then we were looking for a CEO, and Bill introduced us to Peter Howard. We knew immediately that he was our guy. All these wonderfully timed occurrences got us off the ground and helped us build our team."



↑ Founders (left to right), Sean Murray, Will Floyd-Jones, Daniel Sorin and George Konidaris at the Realtime HQ in Boston.

← Realtime's RapidPlan MPA processor (front) is used to control robots, such as this Fanuc in the background.

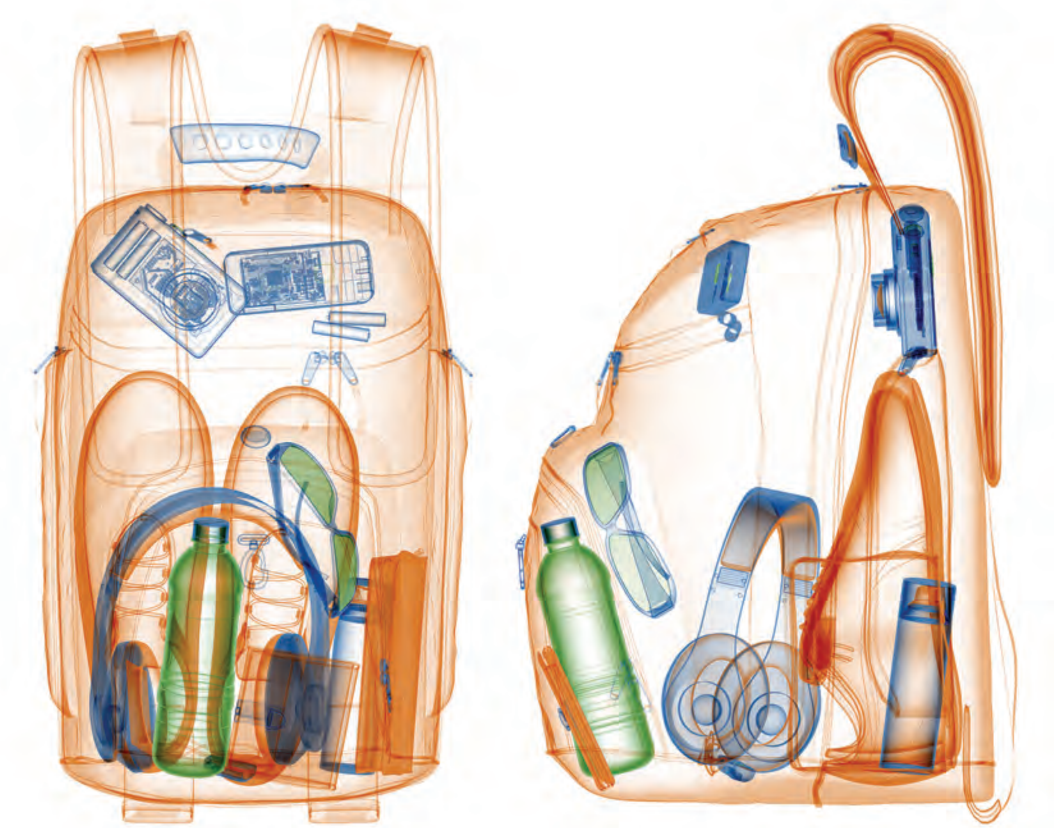
The team officially incorporated Realtime Robotics in 2016, to develop special-purpose hardware and software that helps machines move through unstructured or dynamic environments like factories and city streets.

Since that time, Realtime has raised funding from key investors including Toyota AI Ventures, SPARX Group and Scrum Ventures. Realtime has grown to over 30 employees in their Boston-based headquarters. They've won R&D projects and sold many processors, known as the RapidPlan MPA, with Fortune 50 customers proving out the technology. This year, Realtime seeks to close Series A funding and will further develop RapidPlan.

"Five years ago I knew zero about robotics," said Sorin. "Thanks to this series of happy coincidences, I'm now the co-founder of a robotics company." ■

SAFE TRAVELS

Tactical sporks. Million-volt tasers disguised as lipsticks. Suitcases packed with fireworks.



Stock image

Every day, TSA agents intercept a baffling assortment of weird and dangerous items that passengers try to smuggle onto planes. Most often, they catch the contraband with X-ray imaging. But anyone who has ever flown for business is familiar with the limitations of that process: X-rays have trouble passing through metal objects like laptops, which is why travelers must remove their laptops from their luggage and send them through the conveyor in a separate bin.

ECE associate professor Michael Gehm said that over the next few years, airports will begin using computerized tomography—analogous to CT scanners used in hospitals—to get 3D X-ray visuals on a bag's contents. But even these CT images cannot always easily distinguish among similar liquids, which leaves the problem of determining whether a bottle is full of shampoo or something more sinister.

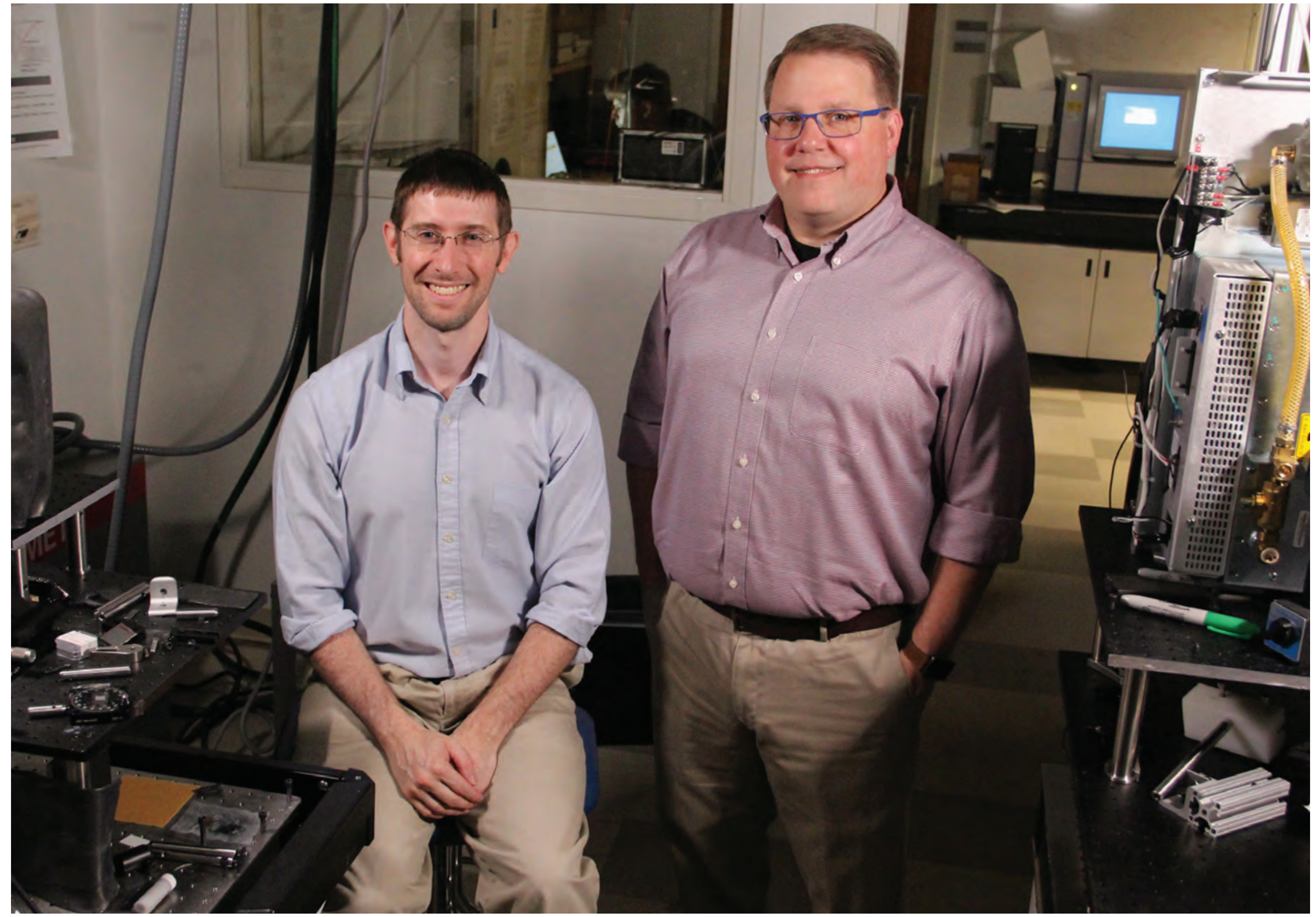
"You really need some additional information," said Joel Greenberg, an associate research professor in Gehm's lab and the principal investigator on a new government-funded $5.8 million aviation security project. "Instead of measuring only the X-rays that go straight through an object, we also want to measure the scattered X-rays—the ones that go in, interact with the material in the bag, and bounce off."

"The way in which they interact gives you identification at the molecular level," added Gehm. "You get the unique fingerprint of the material in the bag."

That interaction is called X-ray diffraction, and it has been studied for more than 100 years. While the physics is not new, stressed Greenberg, the technique is difficult to implement because of the very weak signal that is produced.

"If you were taking a photograph in the dark, you could open up your shutter for a long time and eventually capture enough light to illuminate the subject of the photo," explained Gehm. "If you use a quick shutter speed, your image will be dark. It's the same principle—we have a weak process that doesn't give us many photons to measure."

With the length of the lines at airport security checkpoints, creating long exposures isn't an option. "You have to capture the image quickly to keep the lines moving," said Gehm.



Principal investigator and associate research professor Joel Greenberg (left) and associate professor Michael Gehm (right) are driving a new $5.83 million airport security project.

The pair is designing an X-ray system that combines transmission imaging and X-ray diffraction tomography to get information faster. But making decisions about the system design—how many sensors and/or sources, what types, and what configurations—can become prohibitively expensive if a prototype has to be built before any real testing can occur. Having the ability to do an initial round of virtual testing allows researchers to quickly and inexpensively zero in on a promising system configuration.

Instead, the team developed a mathematical tool that simulates detector performance, source performance, and geometry, and gives them the ability to analyze which configurations show the most promise before building them. "We're attacking it using the simulation tool and information theory, and getting diffraction measurements faster, to relieve some of the practical pressures," said Gehm.

Greenberg and Gehm have brought in collaborators with highly specialized expertise to augment their work, including Duke radiology professor Anuj Kapadia and the University of Arizona's Amit Ashok, a professor of optical sciences.

"Quicker lines at airport security and getting to hold on to your water bottle would be nice benefits," said Greenberg, "but better detection of current and emerging threats is paramount." ■

"Quicker lines at airport security and getting to hold on to your water bottle would be nice benefits, but better detection of current and emerging threats is paramount."

— JOEL GREENBERG

Big Data at Duke

Data+ and Code+ are 10-week summer research experiences presented by the Rhodes Information Initiative at Duke, an initiative focused on unlocking the potential of Big Data. Data+ and Code+ challenge Duke undergraduates to tackle real-world challenges in small, interdisciplinary project teams. In 2019, Data+ teams used data-driven approaches to help understand evictions in Durham County, developed algorithms to recognize human emotions in audio speech samples, and even extracted information from basketball videos to analyze the efficiency, strength, and leadership of individual athletes. Code+ teams, led by Duke IT professionals and faculty, focused on programming-intensive challenges like building wayfinding apps that incorporated augmented reality content and improving personal security and privacy on residential networks.

Blue Devil Ocean Engineering

Bigger is better, where engineering challenges are concerned. That's according to ECE faculty members Martin Brooke and Tyler Bletsch, who align their engineering design classes with contests that offer huge payoffs, both figurative and literal. For the past several years, Brooke and Bletsch advised Blue Devil Ocean Engineering, a team of students competing in the Shell Ocean Discovery XPRIZE. The international "moon shot" contest offered a $7 million reward for the team that delivered technology to autonomously map the ocean floor.

As word of mouth traveled, Blue Devil Ocean Engineering grew to around 60 students, including members of a high school robotics team and visiting undergraduates seeking summer research experiences at Duke. "Intrinsic motivation is hard to create in academic environments, but this program was able to generate it," said Brooke, "There were no tests and no lectures. We just expected results."

The team successfully developed an aerial drone capable of launching diving SONAR pods from the surface of the deep ocean, earning a semi-finalist position in the competition and a $100,000 prize.

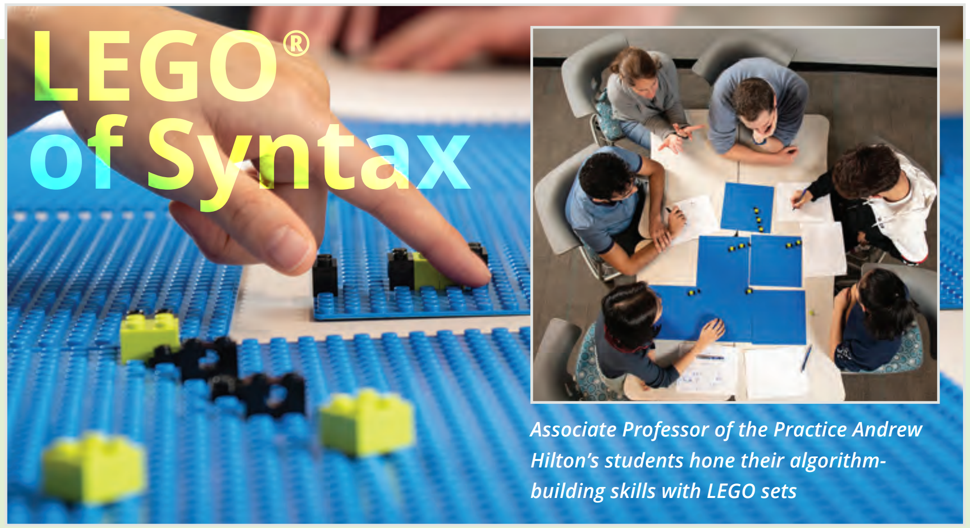
Tyler Bletsch (left) and Martin Brooke (second from left) led a Duke team competing in the $7 million Shell Ocean Discovery XPRIZE

Programming from the Deep End

Graduate students in Ric Telford's software engineering course designed a software system for Tyrata, a sensor technology company.

When Ric Telford retired from IBM, he didn't want to spend his days playing golf. Instead, he joined Duke Engineering as an Executive-in-Residence, mentoring and instructing engineering students who are just starting to build their own careers. Telford's graduate-level software engineering students design real products for real clients, working in teams to push out deliverables in sprints.

"The trajectory of improvement is very steep," said Telford. "In Sprint 1, there's not a lot of function. In Sprint 2, they're getting their feet under them and delivering code. But by Sprint 3, they're innovating and creating things the client hasn't even asked for."



Associate Professor of the Practice Andrew Hilton's students hone their algorithm-building skills with LEGO sets

Expert programmer Andrew Hilton likes to ask his graduate students to write instructions for one another using LEGO sets, in an exercise designed to illustrate how algorithms should also be written.

"Many students get hung up on syntax—where a semi-colon goes, for example—because they think that is the key to programming. While syntax is important, it isn't really the key skill," said Hilton, and added that people hit the same road block regardless of the language they're using.

"We have to write correct English sentences in order to write an article or book, but that's not the really key part—the key part is figuring out what to write. In programming, the 'what to write' is the algorithm. This exercise decouples thinking about the algorithm from anything related to the syntax of a particular language."

SENSOR Saturday Academy

The path to a research career revealed itself to Adrienne Stiff-Roberts during a Saturday Academy enrichment program offered by Saint Augustine's University in Raleigh, NC that she attended in middle school. "I knew I was going to college, and I knew how I was going to college," said Stiff-Roberts.

Now a renowned materials scientist and the Jeffrey N. Vinik Professor in ECE, Stiff-Roberts leads the SENSOR Saturday Academy at Duke, which fosters engineering design skills in underrepresented minority eighth-graders in Durham. Over the course of 13 Saturdays, the students learn the electrical engineering and materials science skills needed to understand devices used to measure water quality—skills they use to test water from the local Eno River, and determine whether the river is safe to swim in.

The program has graduated around 100 students to date; its first cohort, just entering college, includes at least three aspiring engineers and one forensic psychologist-to-be. Stiff-Roberts said the students' parents credit SENSOR Saturday Academy with helping the young scientists develop a STEM focus early and maintain it throughout high school.

Bull City Classrooms

Don't think you can make much of a difference in two hours? Try volunteering in sprints! It's been a successful strategy for Bull City Classrooms, started in 2018 by PhD candidate Anish Simhal, who studies computer vision and neuroscience. Simhal organizes squads of volunteers—many of them engineering students—for two-hour "blitzes" at elementary schools around Durham. The squads of twenty or more people pick up litter, scrape and repaint picnic tables, organize school supplies, and even plant flowers to brighten outdoor landscapes.

"We believe education is one of the most important facets of a growing community and that our teachers are overworked and underpaid," says Simhal. "We can't solve the latter of the two, but we can help with the first."

Girls STEM Day at Duke

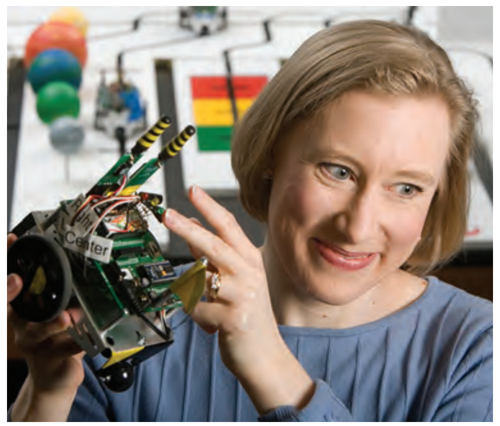
This year, more than 140 girls seamlessly transitioned from extracting DNA from wheat germ, to concocting super-shiny lip balms, to building robots with LEGO Mindstorm EV3 kits and then programming them to perform routine tasks. A special program for their parents featured high school and college counselors' advice on supporting their daughters' STEM endeavors and exploring career options.

Nan Jokerst, ECE professor and associate dean of strategic initiatives for Duke Engineering, is a co-lead for Triangle Women in STEM, the organization of professional women that hosted the event. As the girls tackled each of their challenges, they were able to draw on the knowledge and experience of more than 100 TriWiSTEM volunteer mentors, who represented 41 companies and institutions in the Triangle region. From the event, two strong messages emerged: that STEM is well within the reach of girls, and that they are not alone in their pursuits.

Hands-on workshops and chats with role models drew 140 future female scientists, engineers, technologists, and mathematicians to Girls STEM Day at Duke.

HIGHLIGHTS 2018 2019

EXCELLENCE IN TEACHING



Lisa G. Huettel

IEEE Undergraduate Teaching Award

This international award, given yearly, honors a single individual's inspirational teaching of undergraduate students in IEEE's fields of interest.

Vahid Tarokh

Member, National Academy of Engineering

Vahid Tarokh, who joined Duke Engineering in 2018 as the Rhodes Family Professor of Electrical and Computer Engineering, was recently elected to the National Academy of Engineering (NAE), one of the highest professional distinctions for engineers.

Tarokh, who holds appointments in the departments of Electrical and Computer Engineering, Computer Science, and Mathematics at Duke, is one of the world's most cited researchers in computer science and lauded for his singular contributions to signal processing; notably, he helped invent the algorithms called space-time codes that most modern cellular phones use to transmit data, and performed foundational work on distributed communications.

As a member of NAE, Tarokh will support the academy's mission of providing engineering leadership in service to the nation. He joins more than 2,500 peer-elected members and foreign members in the NAE, which serves as an advisor to the federal government and conducts independent studies to examine important topics in engineering and technology.

Ingrid Daubechies

North American Laureate, L'Oréal-UNESCO For Women in Science Award

What do MP3s and mammograms have in common? Wavelets—the mathematical building blocks that extract the essential elements of images or signals without degrading their quality.

Ingrid Daubechies, the James B. Duke Professor of Mathematics and Electrical and Computer Engineering, is a pioneer of wavelet theory. The former MacArthur fellow was the first female recipient of the William Benter Prize in Mathematics, the first female recipient of the National Academy of Sciences Award in Mathematics, and was the first woman to be president of the International Mathematics Union.

This year, she was named a laureate of the L'Oreal-UNESCO For Women in Science award for North America, receiving a 100,000-euro grant in recognition of her exceptional contributions to her field.

"In math, we always seek to understand magical things," said Daubechies. "I hope that my work will also be instrumental in helping people see that mathematics is everywhere."

PROFESSIONAL SOCIETY RECOGNITION

Kenneth Brown

Fellow, American Physical Society

Krishnendu Chakrabarty

Fellow, American Association for the Advancement of Science; IEEE Bob Madge Innovation Award

Yiran Chen

Distinguished Member, Association for Computing Machinery

Hai "Helen" Li

Fellow, Institute of Electrical and Electronics Engineers (IEEE)

Willie Padilla

Fellow, American Physical Society

Cynthia Rudin

Fellow, American Statistical Association and the Institute of Mathematical Statistics

UNIVERSITY HONORS

Qing Huo Liu

Distinguished Alumni Award (University of Illinois Department of Electrical & Computer Engineering)

Adrienne Stiff-Roberts

Bass Society of Fellows for Excellence in Teaching & Research (Duke University)

Blake Wilson

BSE '74 PhD '15
Distinguished Alumni Award (Duke University)




HIGHLY CITED RESEARCHERS

Clockwise from top left: **Steven Cummer, Willie Padilla, Guillermo Sapiro, David Smith**

Top 1% of Highly Cited Researchers, Clarivate Analytics

Guillermo Sapiro

"Test of Time" Award (recognizing the 2009 paper "Online Dictionary Learning for Sparse Coding" for lasting impact), 2019 International Conference on Machine Learning

EARLY CAREER AWARDS

Miroslav Pajic

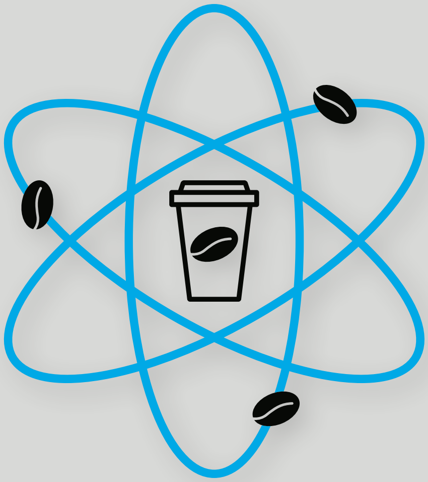
Early Career Award, Association for Computing Machinery Special Interest Group on Embedded Systems

IEEE Technical Committee on Cyber-Physical Systems (TCCPS) Early Career Award

Duke | ELECTRICAL & COMPUTER ENGINEERING

Duke University
Pratt School of Engineering
305 Teer Engineering Building, Box 90271
Durham, NC 27708

In 2019, Duke's $15 million Software-Tailored Architectures for Quantum Co-Design (STAQ) program held its first Quantum Ideas Summer School, a week-long exploration of quantum topics.



We're creating a quantum community.

With support from the Kavli Foundation, quantum information enthusiasts at Duke are connecting with the help of a powerful catalyst—coffee. Duke ECE professor Kenneth Brown organizes weekly coffees where students and faculty—regardless of their fields of study or levels of experience—can discuss the frontiers of quantum information science, develop strategies for grant proposals and help define Duke's effort in the National Quantum Initiative.

It's just one of the unique ways we're building collaborations and expanding horizons. **Learn more inside.**