FALL 2019

ELECTRICAL AND COMPUTER ENGINEERING

UNIVERSITY OF WISCONSIN-MADISON

LEADING INNOVATIONS IN TECHNOLOGY AND INSPIRING FUTURE LEADERS

CHAIR'S MESSAGE

Hello from Madison!

As you're reading this newsletter, we're well into the fall semester for the 2019-2020 academic year! It was a busy summer for the department, as our students and faculty traveled across the nation and all around the world, sharing the outstanding research from UW-Madison ECE. Be sure to look at the back cover of this newsletter to learn about some of the inspiring work our students are doing, including Ashray Manur's efforts to bring reliable electricity to rural India and Ashkat Khanna's Wisconsin Idea fellowship for outreach to middle school students in our home state.

Students in ECE are ready to lead, and our alumni continue to make us proud with their achievements. This year, for the annual Engineers' Day we are honoring two alumni who used their ECE degrees as a launchpad to outstanding careers. Our distinguished achievement awardee, Cynthia Bachman, vice president of engineering and product development at Kohler Company, has helped teams to usher hundreds of ideas from early concepts to production products and she's worked with the Bill & Melinda Gates Foundation on projects to solve the world's grand challenges. Early career achievement awardee Navrina Singh has served as the principal/director product manager for Microsoft AI, where she led a team responsible for building virtual agents (chatbots). Singh was recognized as a 2017 young global leader by the World Economic Forum for her work in emerging technology, entrepreneurship, STEM education and diversity and inclusion. We're so proud to call these outstanding engineers Badgers!

You may have seen the news that Madison experienced a massive power outage due to a transformer fire at the end of July. The blackout in Madison occurred mere weeks after a similar disaster in Midtown Manhattan. As I'm sure you're aware, ECE is home to world-class research in power electronics and power systems engineering, and several of our faculty are leading the charge to make the power grid more reliable and less vulnerable to disruptions like the blackouts. Coincidentally, two of our power engineering faculty members, Giri Venkataramanan and Line Roald, were in New York mere days before the power went out, as they are working on an exciting project to help the metropolis incorporate more renewable energy into its electric system.

Closer to home, we hosted teams of students from around the world for the 2019 IEEE International Future Energy Challenge. The students built electric drive bicycles and raced them around Engineering Mall. It was a fantastic event, especially because incoming freshmen in the new ECE summer early start program had the opportunity to shadow the competitors, getting firsthand experience with engineering within the first days of their undergraduate journeys—one of many opportunities for our students to learn by doing, which is a central tenet of our department.

We're also excited about the stratospheric growth of the accelerated master's degree program in signal processing and machine learning. Now in its third year, enrollment has spiked to 22 students, a nearly eightfold increase since the first cohort in 2017. Members of this year's incoming class are showcased on the front cover. Be sure to read about what some of those first students have gone on to do since completing their degrees.

Our faculty also continues to grow, and we were thrilled to welcome two new assistant professors to ECE in August. Coming to us after a stint in Korea for his postdoctoral research is Kangwook Lee, an expert in coding theory and machine learning. And joining us from MIT is Chu Ma, who develops acoustic sensing systems for biomedical applications. We cannot wait to see what these talented young researchers accomplish as they get their labs going. We will be welcoming several more new faculty over the coming year.

We've also created a new position of a full-time teaching professor to help accommodate the growth of the accelerated master's program in signal processing and machine learning. We're delighted to welcome Matt Malloy onboard as the program director and adjunct assistant professor. Matt is familiar with ECE, having spent time here as a PhD student and postdoctoral scholar.

The growth of our ECE family is a testament to the importance of electrical and computer engineering for solving the 21st century's most pressing problems. Our faculty and grad students are on the cutting edge of everything from sustainability to biomedicine, artificial intelligence and communications. Be sure to look over some of the outstanding research advances coming from ECE in the pages of this issue.

I hope you're having a wonderful autumn, and I encourage you to stay connected with the department or drop by campus for a visit if you're in the Madison area.

ON, WISCONSIN!

Susan C. Hagness
Philip Dunham Reed Professor and Chair
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Congratulations Engineers' Day award recipients!

Navrina Singh
- Global product and tech executive with leading roles at Microsoft, Qualcomm

Cynthia Bachmann
- Vice president of engineering and product development at Kohler Company

OUR COMPUTER ENGINEERS CREATE WORLD'S GREENEST SUPERCOMPUTER

UW-Madison computer engineers have designed and built the world's most energy-efficient supercomputer, earning the top ranking on the Green Graph 500 list.

Topping the Green Graph 500 list is an achievement that establishes UW-Madison as a major player in the field of high-performance computing. The certification builds on established practices from the U.S. Environmental Protection Agency Energy Star, and is backed by a steering committee composed of more than 50 international experts from academia, industry and national laboratories.

> **"The components are new, the ways we hooked things up are new, and the ways we mapped the software onto the hardware are new."**
>
> **— Jing Li**

Developed as a complement to the Graph 500, which is a benchmark to evaluate performance for one of the most difficult problems in data-intensive computing, the Green Graph 500 measures how much electricity a supercomputer consumes as it grinds through the immensely challenging set of calculations.

"We are very proud," says Assistant Professor Jing Li, who led the supercomputer's creation. "Historically, the top has always been IBM or national labs."

Achieving greater computational power per watt of electricity consumed will help enable faster computers with smaller ecological footprints—a win-win for human users and the planet.

Most supercomputers gobble tremendous amounts of electricity to perform their calculations. For example, "Summit" at Oak Ridge National Laboratory—the most powerful machine in the world—peaks out at roughly the same amount of power consumption as 7,000 homes.

Supercomputers excel at running conventional, linear programs. But there's another class of problems that is far more challenging. Those are called graphing algorithms.

"Graphs are very difficult for a traditional computer," says Li. "All the general tricks we know don't work."

Yet graphs are the best way to represent numerous important phenomena for our daily lives—for example, interpersonal connections among a social network, the electricity grid for a major city, or the interstate highway system.

Because there are several possible paths to connect individual nodes (think six degrees of Kevin Bacon), it's nearly impossible to predict the most efficient way for a computer to map out a graph. Most computers end up wasting processing power by scattering closely connected nodes in far-flung locations across their memory.

That's why Li and her student, Jialiang Zhang, took a unique approach.

"The components are new, the ways we hooked things up are new, and the ways we mapped the software onto the hardware are new," says Li.

Li and Zhang devised a new method of data analysis that allowed their computer to store and map graphs more efficiently. Then, taking a top-down approach, they built hardware that could handle the demanding software needs.

The design is patented, and they're currently working to scale up the system to tackle larger and even more complex datasets than the Green Graph 500.

With unique upgrades, one-of-a-kind ECE facility forges a path toward fusion

On the first floor of Engineering Hall, a 20-ton slightly deformed donut-helix-shaped machine forms the containment vessel for an experiment that could bring humanity one step closer toward harnessing fusion energy.

The donut, which is known as the Helically Symmetric eXperiment, or HSX, currently is the only device of its type in the world.

And now, with a $1.64 million upgrade to its heating system, a new microwave tube, and power supply improvements, the HSX will be able to wrangle plasma of a higher energy level than ever before.

"This is a really exciting pathway toward fusion that builds on the strength we have here," says Professor David Anderson.

With the upgrades, the HSX will triple the density of plasma that can be contained in its interior and boost its power by a factor of five.

Additionally, its new diamond-windowed microwave tube, donated by Germany's Max Planck Institute, will allow the HSX to sustain pulses for 10 times longer.

Those longer pulses with higher powers and densities will allow the HSX to answer many open questions about plasma confinement, turbulence and power control at the edge of a hot ionized gas.

"This will take us to the next level," says Anderson. "The HSX is at the top end of a university-scale experiment. It is in the parameter ranges of major national and international fusion experiments."

Yet Anderson and colleagues already have their sights set on building an even bigger and better machine.

"Our hope is that this is really a stepping stone," says Anderson. "We don't want the HSX experiment to go on forever. The goal is to corroborate key design precepts for the next step and then move forward."

Kangwook Lee uses deep learning to solve its own problems

An artificial intelligence system is a highly complex operation with numerous interdependent constituents where one straggler can slow down the entire system.

And concepts from information theory and coding can help solve the straggler problem for large-scale machine learning systems.

Kangwook Lee, a new assistant professor, dove into that notion during his PhD research at the University of California, Berkeley. In doing so, he bridged the gap between two traditionally separate communities: information theory and machine learning.

"The existing solutions weren't good enough," says Lee. "We realized information theory and coding can develop a much more efficient solution for the straggler problem."

A paper describing those solutions, which Lee co-authored with assistant professor Dimitris Papailiopoulos (who was, at the time, a postdoctoral scholar at UC Berkeley) went on to become one of the top-five most-accessed publications in *IEEE Transactions on Information Theory*.

Yet, even though Lee's work sparked vibrant discussion, he's been frustrated at the slow pace of progress.

"There's a huge gap between what we want to do and what's been accomplished," says Lee. "To be honest, I think it's time to forget about the small problems."

That's one of Lee's goals for his research at UW-Madison.

During his postdoctoral work at the Korea Advanced Institute of Science and Technology (KAIST), Lee immersed himself in deep learning. His time at KAIST also satisfied the mandatory military service requirement for all adult Korean men.

Even though much of Lee's time in the Korean military was spent in the lab, he still completed the four-week boot camp required for all service members.

After three years in Korea, Lee is eager to reunite with friends and colleagues. In addition to working (and hanging out) with Papailiopoulos at UC Berkely, Lee was in the same cohort as Assistant Professor Varun Jog.

"Varun was one of my best friends since the beginning of graduate school," says Lee. "While I was in Korea, I saw my friends being successful at UW-Madison," says Lee. "I could see that the College of Engineering is a good research environment and a good place for assistant professors to learn and grow."

Chu Ma has an ear for interdisciplinary acoustics research

Sound waves can enable us to see things that would otherwise be invisible.

And that's thanks to acoustics, which is key in the sensing technology sonar as well as ultrasound scanners.

"Ultrasound has become one of the most important imaging and diagnosing methods in biomedicine," says Chu Ma, who joined the department as an assistant professor in fall 2019.

Even astronauts aboard the International Space Station use ultrasound; the technology is the only method that is sufficiently small, portable and safe to bring up into near-earth orbit and produces a real-time image that can be transmitted to doctors on earth.

Acoustics is also opening up new frontiers in treatment.

"Acoustics can be used to manipulate cells and tissues in the human body," says Ma. "There are so many useful applications being developed for cancer treatment and drug delivery."

Ma works primarily on acoustic sensing, the technology behind ultrasound. Her research draws from physics, materials science, electronics and information engineering and she also works closely with clinicians and biological engineers.

That's why UW-Madison's low barriers to working across traditionally disparate fields attracted Ma to the College of Engineering. As a fellow of the Grainger Institute for Engineering, she'll also have ample opportunities.

"My research is very interdisciplinary, and UW-Madison makes interdisciplinary collaboration very easy," says Ma.

During her PhD work at the Massachusetts Institute of Technology, Ma developed an acoustic sensing system able to detect objects smaller than the diffraction limit, based on 3D printed metamaterials with advanced capabilities.

She also worked to develop custom-tunable metamaterials based on flexible hydrogels that could be manipulated in real time, substantially improving the signal-to-noise ratio.

At UW-Madison, Ma plans to continue her work on metamaterials and acoustic sensing. She's looking forward to lending her expertise to projects that need reliable methods for noninvasive medical imaging, such as Biomedical Engineering Professor Justin Williams' work on neural prosthetics.

"They need a reliable way to image the interface between implants and neurons," says Ma. "Ultrasonic imaging is an ideal technique to track the junction."

Matt Malloy brings real-world experience to teaching machine learning and data science

Machine learning techniques enable computers to perform astonishing feats and big data is part of what has allowed the enormous advancements in artificial intelligence in recent years.

Matt Malloy, newly hired as assistant adjunct professor, once worked behind the scenes to develop some important and widely used tools for parsing meaningful information from massive internet datasets.

One of those tools helped enable the sometimes-uncanny accuracy of targeted ads. Malloy and colleagues at the analytics company comScore described the dataset in the 2016 paper, "Internet device graphs" and more recently in 2019 in a paper titled "Graphing crumbling cookies."

"My work in industry involved developing cutting-edge machine learning techniques and implementing them at internet scale," says Malloy. "We worked on both the tools to collect and gather information, and the algorithms that make inference on those massive datasets."

Malloy brings a unique blend of industry and academic experience to his new role in the ECE department.

"I've wanted to come back to academia for quite some time" he says.

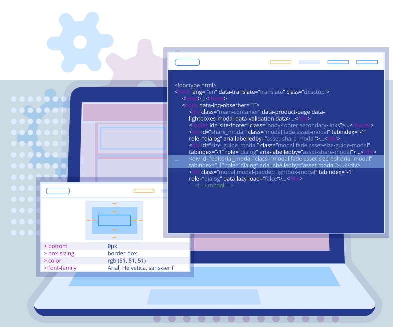
After receiving his undergraduate degree at UW-Madison in 2004, he completed a master of science degree in electrical engineering at Stanford University before working at the multinational telecommunications company Motorola for three years. Malloy returned to UW-Madison for his PhD (which he finished in 2013) and then spent one year as a postdoctoral scholar. For the past five years, he's been working in industry as director and principal data scientist at Comscore.

In his new position with ECE, Malloy will shift his focus to education. He's leading a full docket of electrical and computer engineering courses, as well as taking over as program director for the department's popular new accelerated master's degree program in signal processing and machine learning.

Malloy cut his teeth on teaching during his time as a postdoc. The course videos he created as the instructor of the ECE 203 class, *Signals, Information, and Computation*, have been viewed more than 31,000 times since 2014.

Malloy eagerly embraces educational innovation and his teaching philosophy is grounded in keeping students engaged and excited.

"Engineering students need to develop a keen mathematical sense," says Malloy. "Not just in academia but in industry, as well. Engineers need to be able to break down and solve any problems they encounter."



ARTIFICIAL INTELLIGENCE, FOR REAL-WORLD SUCCESS

Now in its third year, the ECE department's accelerated master's degree program in signal processing and machine learning has experienced explosive growth.

Since the program's first year, 2017-2018, which saw three students complete their degrees, enrollment has ballooned to more than 20.

"There's huge interest in the signal processing and machine learning area, and students can get the degree on an attractive timeline," says Matt Malloy, the program's director.

With its focus on quantitative thinking, problem solving and computer programming, the accelerated program positions graduates well for a variety of pursuits. The program differs from a traditional thesis-based master's degree, swapping independent research for accelerated coursework and a summer practicum.

That hands-on experience is part of what makes the degree so attractive to employers.

"My company felt that skills in machine learning would be a valuable investment," says Geoffrey Lau, who completed the program in 2018.

Lau's employer, ST Electronics in Singapore, covered his tuition and expenses for the year he spent in Madison.

Lau returned to Singapore after completing his degree, but one of his colleagues, Weijie (Winston) Chen was so taken with the summer practicum experience that he decided to stay in Madison and pursue a PhD under the mentorship of Alan McMillan, a professor of radiology.

In McMillan's group, Chen is working on similar problems that he encountered during the summer practicum, combining machine learning with medicine to make diagnostic imaging more accurate.

As the program continues to grow, Malloy hopes to add even more classes and incorporate open-source software tools into the majority of the coursework.

And even though a degree in machine learning can take students around the world in a wide variety of careers, graduates from the program will be Badgers for life.

"One of the reasons why I loved UW-Madison is the very strong school spirit," says Lau. "I was recently visiting New York City with a friend, and two people called out 'Go Badgers!' after seeing us in our UW-Madison t-shirts. We were a little taken aback, but it was a warm feeling to know that fellow schoolmates around the country considered us family."

FROM THE BIG RED TO THE BIG APPLE:

Line Roald lights the way toward reliable renewable power

During summer 2019, blackouts struck both Madison and Midtown Manhattan in New York, leaving thousands of people in each city without power for hours on end.

Both outages were set off by small-scale accidents that spiraled into major catastrophes; in New York, a transformer fire around West 64th Street darkened the lights in Times Square, the Theater District and the Upper West Side, whereas an explosion at a substation along Madison's East Washington Avenue left 12,000 people in and around the city's downtown without electricity for the better part of a day.

Assistant Professor Line Roald is working to forecast disruptions before they happen, and in the process, help the power grid become more resilient.

With support from the U.S. Department of Energy, Roald is developing new methods based on mathematical optimization that will help reliably deliver power, even when a catastrophe occurs.

"There's evidence the frequency of high-impact events like wildfires, floods and heat waves is increasing with climate change," she says.

And disasters aren't the only unpredictable factors with potential to disrupt the power grid. Renewable energy adds even more uncertainty.

That's why another one of Roald's ongoing projects aims to help our power delivery system accommodate the inherent variability that comes with adding renewable energy into the grid.

Our modern grid usually distributes electricity in the form of so-called "three-phase power," which is why transmission lines usually have a trio of wires strung from pole to pole.

Large motors take advantage of three-phase power to generate a rotating electric field. That's why farmers and manufacturers often need to draw on three-phase power. When the current or voltage in one of the phases is out of balance with the others, motors and transformers may overheat and vibrate excessively.

When an energy grid incorporates renewable power, unbalances are expected to become more likely.

"It's an important problem for agriculture," says Roald. "Unbalanced voltage can cause motors to fail prematurely, and incur high cost for the customers."

Big cities like New York must also manage uncertainty when adding electricity from renewable sources. In July 2019, Roald and Professor Giri Venkataramanan traveled to New York to meet with representatives from the New York Power Authority. As it turned out, the timing was serendipitous.

"We got back from New York just hours before the blackout," says Roald. "It really drove home the importance of this research."

SIMPLE 'SMART' GLASS REVEALS THE FUTURE OF ARTIFICIAL VISION

From left to right, Zongfu Yu, Ang Chen and Erfan Khoram developed the concept for a "smart" piece of glass that recognizes images without any external power or circuits. *Photo: Sam Million-Weaver.*

The sophisticated technology that powers face recognition in many modern smartphones someday could receive a high-tech upgrade that sounds—and looks—surprisingly low-tech.

This window to the future is none other than a piece of glass.

"We're using optics to condense the normal setup of cameras, sensors and deep neural networks into a single piece of thin glass," says Associate Professor Zongfu Yu.

It's an advance that could open new frontiers for low-power electronics.

"This is completely different from the typical route to machine vision," says Yu.

Tiny strategically placed bubbles and impurities embedded within small squares of glass could bend light in specific ways to differentiate among different images.

For their proof of concept, the engineers devised a method to make glass pieces that identified handwritten numbers.

"The fact that we were able to get this complex behavior with such a simple structure was really something," says Erfan Khoram, a graduate student in Yu's lab.

The computation is completely passive and intrinsic to the material, meaning one piece of image-recognition glass could be used hundreds of thousands of times.

"We could potentially use the glass as a biometric lock, tuned to recognize only one person's face" says Yu. "Once built, it would last forever without needing power or internet, meaning it could keep something safe for you even after thousands of years."

Additionally, it works at literally the speed of light, because the glass distinguishes among different images by distorting light waves.

In the future, the researchers plan to determine if their approach works for more complex tasks, such as facial recognition.

"We're always thinking about how we provide vision for machines in the future, and imagining application specific, mission-driven technologies." says Yu. "This changes almost everything about how we design machine vision."

Velten earns NSF CAREER Award to develop better cameras for capturing fluorescence

Invisible to human eyes, light emanating from everyday objects reveals a treasure trove of information.

And Assistant Professor Andreas Velten has a plan to create specialized cameras that can selectively capture unseen signals without becoming overwhelmed by a massive abundance of data.

"There's a very limited amount of data that is necessary for identification," says Velten. "The amount of data you need to capture depends on what you need to know."

Supported by a prestigious CAREER Award from the National Science Foundation, Velten is working to develop specialized cameras for fluorescence, which is the phenomenon by which objects absorb energy from the ambient illumination in their environment and then emit light of a different wavelength.

Almost every material has its own unique fluorescence signature—absorbing and emitting light at specific wavelengths and for unique lengths of time. That means cancer cells fluoresce differently than normal tissues, minerals glow differently than the soil that surrounds them, and diseased crops emit light differently than healthy plants.

"Fluorescence increases the dimension of the color space, so you can tell a lot more about what you're looking at," says Velten.

But those extra dimensions mean more information for cameras to capture on top of the visible details in an image.

That's a staggering amount of data, most of which isn't relevant to the task at hand.

That's why Velten aims to create cameras that can be more selective and ignore the irrelevant portions of an image. Depending on the application, that might mean measuring fluorescence in just a few pixels and for very specific combinations of wavelengths and decay times out of a complex scene.

The cameras will deploy adjustable filters and internal mirrors to pick up only the components that matter. For a given task, optimization algorithms will help narrow in on the essential pixels and identify what parts of an image may be ignored.

In addition to developing the cameras, Velten hopes to open people's eyes to the hidden fluorescence that surrounds them in their daily lives. He plans to set up an exploration lab in the lobby of the Discovery Building where people can sip fluorescent cocktails, see glowing rocks and find tiny beads buried in sand.

"I think it's a nice way to show what fluorescence really is," says Velten. "You can make things very visible that otherwise would be hard to find."

Kim earns NSF CAREER Award: Energy savings through approximation

Battery life is a big problem for our small handheld devices.

It's not just phones and wearables that greedily gobble power. Gadgets like medical implants, factory controllers and the antilock brakes in our cars all operate on limited energy budgets. All are examples of embedded systems, which, unlike general purpose computers, are designed to perform specific tasks.

An innovative strategy to reduce power usage by embedded systems while still maintaining acceptable levels of performance has earned Assistant Professor Younghyun Kim a prestigious CAREER Award from the National Science Foundation.

Kim's plan hinges on "approximate computing," which has been gaining traction in recent years as performance improvements have come up against the limits of advancements in semiconductor technology.

"There are many scenarios, for example, in machine learning, where we don't necessarily need precise results for intermediate computations," says Kim. "So, can we reduce the precision and do more computing for the same amount of effort?"

In some applications, just a 5-percent drop in accuracy can offer up to 50 times the energy savings compared to fully perfect computation. Most engineers apply approximate computing to a rather limited set of hardware, namely, only the processor cores that do the actual computing.

But embedded systems usually consist of several components working together, such as sensors and actuators and communication interfaces, which is why Kim plans to deploy approximation much more broadly.

It's relatively uncharted territory, and the effects of approximation on an entire embedded system might very well be greater than the sum of its slight less precise parts.

"Data flows from one component to another," says Kim. "How the approximate data is transferred and what's the implication to the overall quality is not well studied."

That's why Kim will take a holistic approach.

"You can't just brute-force design the system," says Kim. "We need a tool or a methodology to maximize energy efficiency and quality."

Importantly, Kim's modeling places the considerations of the eventual human users of embedded systems front and center.

"Human perception is not perfect and it tolerates error," says Kim. "We're including humans in our modeling to determine how approximation affects human perceptions, so we can generate the optimal system."

Online and accelerated master's programs

An engineering master's degree from UW-Madison gives you the credentials to get ahead. Find a program that fits your goals and lifestyle.

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STUDENT NEWS

Elektrifi, a UW–Madison spinoff founded by ECE PhD student **Ashray Manur**, is working on a project to implement "smart" microgrids—small, independent electricity networks that integrate communication and computing systems with traditional electricity infrastructure, serving just a few users, and often powered by renewable energy sources—in Mavinahalli, India, and other developing regions around the world.

The project is a collaboration between UW-Madison and a partner university in India, the National Institute of Engineering. It was spearheaded by Professor Giri Venkataramanan, and the core team includes Maitreyee Marathe, an incoming PhD student at UW-Madison in Venkataramanan's lab, and Abhishek Ramachandra, an undergraduate student at the National Institute of Engineering in India.

Each year, UW-Madison's Morgridge Center for Public Service supports undergraduate projects that address relevant issues in local or global communities through the fellowships. Computer engineering major **Akshat Khanna** won a fellowship to work with students at Madison's Black Hawk Middle School to build and maintain an indoor, self-sustaining vertical aquaponics system. Khanna and project partner Lillian Zander, an environmental science major, will analyze active learning's influence on STEM literacy in students for the project, which also won an American Family Insurance social entrepreneurship award. Their faculty advisor is Lesley Sager, a faculty associate in the UW-Madison School of Human Ecology.

We're celebrating 8 NSF CAREER Award recipients in two years!

Read about our two newest NSF CAREER Award recipients on page 7 of this newsletter and on our website!

2019: Younghyun Kim | Dimitris Papailiopoulos | Andreas Velten

2018: Mikhail Kats | Laurent Lessard | Jing Li
Po-Ling Loh | Zongfu Yu