Cornell Engineering

Electrical and Computer Engineering

ECE CONNECTIONS

2020/2021

LEARNING FROM ROBOTS

HOW ROBOTICS IS DRIVING NEW RESEARCH INTO FOUNDATIONAL ASPECTS OF ECE

Page 14

DIRECTOR'S REFLECTIONS: ALYSSA APSEL

It's certainly been a strange year. Like many of you, I have spent most of my adult life optimizing and organizing every facet of my work and personal activities around a set of expectations that have been more or less decimated in the past year. The pandemic has demanded a level of flexibility that most of us never knew we were capable of, while making any previous sense of control seem downright comical. And yet we have done it, and there is light at the end of the tunnel.

Articles abound discussing all the subtle and obvious ways that the last year has been an inflection point. With its compilation of physical isolation, social unrest, political instability, public health breakdown and more, so many people have experienced this past year in so many different ways that are going to forever shape our collective futures. I acknowledge that all of these factors are important, and also that I will not wade into any of it here. Instead, I will ask our alumni, students and faculty to think about the role of technology, engineering and education in the last year and the future to come.

We relied heavily on technology in the past year. During a time of isolation, technology connected us. Our collective Zoom experience has taught us that an awful lot of work can be done remotely with a good internet connection. It has now become difficult to argue that an internet connection is not essential infrastructure, requiring greater investment and innovation.

The pandemic has also been very good for robots. When the risks of hazardous human contact increased, the idea of having a robot deliver food or assist doctors seemed less preposterous. Factory automation has also accelerated, pushing the need for integration of more and better sensors as well as greater machine intelligence, all of which are explored as a theme of this issue.

Here at home, the faculty of Cornell ECE has done amazing work in making classes, office hours and (most impressively) laboratories work remotely. Faculty meeting participation has increased. Our sincere and genuine commitment to collegiality, cooperation and teamwork has served us well. The strategic investments we've made in robotics, artificial intelligence and machine learning also seem to be well placed in the current landscape.

But tech cannot solve everything. It is interesting to note that many countries with high states of "digital advancement" such as the U.K. and the U.S. fared worse both economically and in terms of public health outcomes than economies such as Vietnam and Indonesia with less tech preparedness. Trust in the government and willingness of the citizenry to act for the greater good played an even greater role than technology. Moreover, the emotional toll of a year physically disconnected is only beginning to become apparent.

All in all, the challenging experience of this year of pandemic has compelled us to consider the evolving role of engineering education, and to ask the question of how we produce future leaders. Witnessing how our community has responded to this challenge with creativity, enthusiasm and compassion, I am confident we are on the right path.

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HOW WILL YOU MAKE AN IMPACT?

Nobody knows better the impact a gift can make than a former Cornell student. You walked these halls, you studied in these classrooms, you worked in these labs. You've seen the names on the signs and plaques that remind us of the contributions people have made to the educational experience and research excellence in Electrical and Computer Engineering. How will you make an impact?

Graduate Student Support

Research funding for our faculty often requires matching funds for graduate student support. These graduate students are the future leaders of our technology economy, critical to our research and teaching efforts. Providing one-year fellowships would enable all graduate students to have a funded first year and enable us to attract and recruit top students to our program.

Infrastructure Projects

Phillips Hall was built in 1955 with three floors of identically sized offices. We need to make the research laboratory infrastructure in ECE facilities more compatible with modern research practices by providing chilled water, EM interference control, building vibration noise control and liquid Helium recycling. We need a complete overhaul of the building's ventilation and air handling capabilities.

Robotics Lab

Robotics is a top priority for the future of the school. We want to build out the Rhodes Hall Robotics Lab into a unified robotics space on the third and fourth floors. Support for our growing robotics program will ensure our students have the resources needed to excel in this challenging interdisciplinary field.

Graduate Student Seminars: Electronic Devices Society and ECE Colloquium Series

These events regularly bring our faculty and students together to stay on top of developments inside and outside of our field and create a continued sense of community across the school.

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Visit ece.cornell.edu/ece/alumni

INSIDE THIS ISSUE

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Cover image supplied by Ken Ho '21, a software rendering of his micro-robots. Read more about his work on Page 25.

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NSF backs project to create next-gen wireless devices

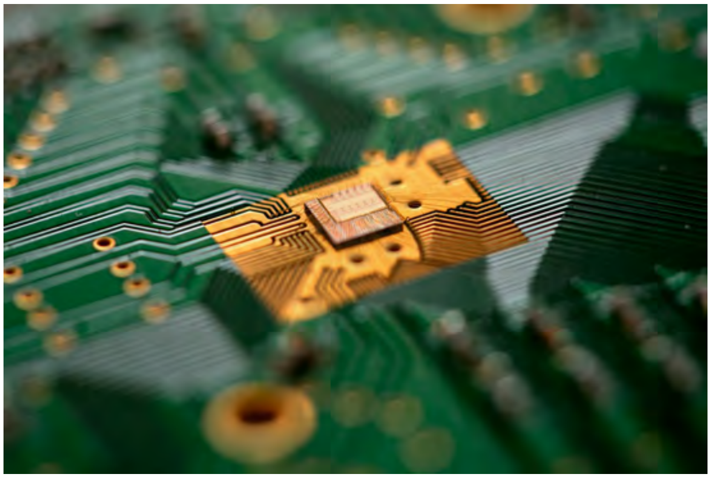
Amal El-Ghazaly and Alyosha Molnar, from the School of Electrical and Computer Engineering (ECE), have received an $880,000 grant from the National Science Foundation (NSF) to design a new class of radio devices capable of operating across a large portion of the growing wireless spectrum, while adaptively suppressing interferences.

"The electromagnetic spectrum has a lot of different frequencies that are accessible for communication," said El-Ghazaly, an assistant professor of ECE. "But there are so many more users than there are frequencies."

To meet growing demand for wireless services in the U.S., the Federal Communications Commission has periodically made an ever-widening range of frequencies in the electromagnetic spectrum available for unlicensed usage. This creates opportunities for innovation in the way devices like cellphones and computers use the spectrum for various types of communications.

As the usable spectrum becomes more congested, wireless devices may be forced to share frequency bands or use frequencies tightly packed together, leading to interference. New wireless systems must become more robust against interference to take advantage of the increased bandwidth.

To spur innovation among researchers, the NSF created the Spectrum and Wireless Innovation enabled by Future Technologies (SWIFT) program. SWIFT is looking for innovations in transmitters, receivers and spectrum coexistence, which refers to two or more applications using the same frequency band at the same time without adversely affecting one another. Spectrum coexistence has received less attention from researchers.



A mobile phone chip developed by Al Molnar, associate professor of electrical and computer engineering. Photo by Jason Koski/Cornell University

El-Ghazaly and Molnar, along with Bernd-Peter Paris, associate professor of electrical and computer engineering at George Mason University, have a unique approach to coexistence in their SWIFT-funded project: Use the entire range of frequencies and apply adaptive, tunable filtering to reject any interference. Their project is titled "Adaptive Interference Rejection with Synthetic Channel Diversity."

The team will develop a radio receiver architecture capable of operating across a large portion of the wireless spectrum while suppressing interferences as they arise. A new algorithm will allow the receiver to adaptively adjust its interference response as needed using digital signal processing.

"Your cell phone has certain bands it can use and some it can't," said Molnar, an associate professor of ECE. "For any given band you want to use, you need a filter that's engineered to just let that band through and block everything else."

But those filters are fixed, or only very weakly changeable, he said, when you build the device.

"You can't really use the spectrum efficiently because you have to commit in advance [to] which bands you want to use," said Molnar. "The approach we're taking is, rather than building these very narrow filters that only pass certain things, we're going to pass everything through."

But when a device receives all the frequencies, it's also taking in a lot of interference, overwhelming the receiver. The key: designing a device to enhance the signal in the frequency you want to receive and suppress interference at others. Such a device could take in a much wider band but also be able to filter out interference to focus on the desired signal.

"Any sort of band-limiting filter needs to have at least a couple of different components," El-Ghazaly said. "When the components are tunable, we're able to slightly change the values of the inductor and the capacitor so that we can adjust the network as needed to be optimal for each new set of signals and interferences coming in."

The algorithm analyzes the signals and calculates how to tune each of the values in real time, to get the best possible signal.

This type of device would remain usable even as the spectral environment changes. As regulators make additional bands available, such devices would already be capable of utilizing them. Likewise, bands that are in use only in certain locations, or at certain times of day, would become available.

"If you are near a satellite station during certain times of day when the satellite is overhead, you can't use that band," Molnar said. "That only happens a few times a day in certain locations, but the rest of the country is blocked from that band."

With his team's new adaptive architecture, those frequencies could become usable. The new receiver will be dynamic and tunable, the researchers said, responding in real time to whatever bandwidth is available and unconstrained by its own hardware.

The project includes plans to educate and train rising engineers, at both the graduate and undergraduate levels, to think holistically about the components and operation of wireless systems and design robust receivers for the future.

Some of the initial concepts foundational to this project were funded by the Semiconductor Research Corporation, through the Joint University Microelectronics Program.

Cornell researchers will use AI to develop next generation food systems

Cornell researchers are part of a multi-university team awarded $20 million by the National Science Foundation to establish an institute focused on enabling next-generation food systems through the integration of artificial intelligence technologies.

The AI Institute for Next Generation Food Systems, established in partnership with the U.S. Department of Agriculture and the National Institute of Food and Agriculture, aims to meet growing food supply demands by using AI and bioinformatics to increase efficiencies across the entire food production system, from growing crops through consumption.

Qing Zhao, the Joseph C. Ford Professor of Engineering, is leading the Cornell team, with co-principal investigators Jayadev Acharya, assistant professor of electrical and computer engineering; Martin Wiedmann, professor in the Department of Food Science; and Renata Ivanek, associate professor in the College of Veterinary Medicine.

"While we have witnessed great leaps in AI innovations in recent years, food systems present unique challenges in the application and adoption of AI," said Zhao. "Food systems are highly diverse, and data collection can be costly and subject to long delays due to the innate growth cycle of crops."

"More importantly, due to the primary tie between human and food, the adoption of AI solutions in food systems needs to be particularly mindful of ethical and socioeconomic consequences in terms of safety, fairness and equality, and impact on farm labor,"

The Pounder Heritage Vegetable Garden at Cornell Botanic Gardens. Photo by Lindsay France (UREL)

Zhao explained. "This research institute will serve as a national nexus for collaborative efforts to address these unique challenges."

The project will help food producers by allowing them to optimize plant traits for yield, crop quality and disease resistance through advances in molecular breeding. The researchers also hope to minimize resource consumption and waste by developing agriculture-specific AI applications, sensing platforms and robotics. Consumers will benefit from enhancements to food safety and new tools which could provide real-time meal evaluations to guide personal health decisions.

The award is part of a larger investment announced last month which will grant a total of $140 million to fund seven complementary AI research institutes across the nation. These new institutes will accelerate AI research that holds the potential for further economic impact and improvements in quality of life in a range of fields.

"AI will serve as both the enabling technology and the connective tissue that brings together these elements and catalyzes this transformation to a safer, fairer and more efficient food system for the next generation," said Ilias Tagkopoulos, professor in the UC Davis Department of Computer Science and Genome Center, and director of the new institute.

The overall mission of the center is to optimize global food production, quality and security. In addition to the scientific and technical objectives, the institute's charter includes a major emphasis on inclusive education and outreach approaches to build a diverse, next-generation workforce.

Researchers create 'beautiful marriage' of quantum enemies

by Syl Kacapyr

Using nitride-based materials, Cornell researchers created a material structure that simultaneously exhibits superconductivity – in which electrical resistance vanishes completely – and the quantum Hall effect, which produces resistance with extreme precision when a magnetic field is applied.

"This is a beautiful marriage of the two things we know, at the microscale, that give electrons the most startling quantum properties," said Debdeep Jena, the David E. Burr Professor of Engineering in the School of Electrical and Computer Engineering and Department of Materials Science and Engineering. Jena led the research, published Feb. 19 in Science Advances, with doctoral student Phillip Dang and research associate Guru Khalsa, the paper's senior authors.

The two physical properties are rarely seen simultaneously because magnetism is like kryptonite for superconducting materials, according to Jena.

"Magnetic fields destroy superconductivity, but the quantum Hall effect only shows up in semiconductors at large magnetic fields, so you're having to play with these two extremes," Jena said. "Researchers in the past few years have been trying to identify materials which show both properties with mixed success."

The research is the latest validation from the Jena-Xing Lab that nitride materials may have more to offer science than previously thought. Nitrides have traditionally been used for manufacturing LEDs and transistors for products like smartphones and home lighting, giving them a reputation as an industrial class of materials that has been overlooked for quantum computation and cryogenic electronics.

Doctoral students Phillip Dang (left) and Reet Chaudhuri at the National High Magnetic Field Laboratory, where measurements were made on a material structure that concurrently has superconductivity and the quantum Hall effect.

"The material itself is not as perfect as silicon, meaning it has a lot more defects," said co-author Huili Grace Xing, the William L. Quackenbush Professor of Electrical and Computer Engineering and of Materials Science and Engineering. "But because of its robustness, this material has thrown pleasant surprises to the research community more than once despite its extremely large irregularities in structure. There may be a path forward for us to truly integrate different modalities of quantum computing – computation, memory, communication."

Such integration could help to condense the size of quantum computers and other next-generation electronics, just as classical computers have shrunk from warehouse to pocket size.

"We're wondering what this sort of material platform can enable because we see that it's checking off a lot of boxes," said Jena, who added that new physical phenomena and technological applications could emerge with further research. "It has a superconductor, a semiconductor, a filter material – it has all kinds of other components, but we haven't put them all together. We've just discovered they can coexist."

For this research, the team began engineering epitaxial nitride heterostructures – atomically thin layers of gallium nitride and niobium nitride – and searching for conditions in which magnetic fields and temperatures in the layers would retain their respective quantum Hall and superconducting properties.

They eventually discovered a small window in which the properties were observed simultaneously, thanks to advances in the quality of the materials and structures produced in close collaboration with colleagues at the Naval Research Laboratory.

"The quality of the niobium-nitride superconductor was improved enough that it can survive higher magnetic fields, and simultaneously we had to improve the quality of the gallium-nitride semiconductor enough that it could exhibit the quantum Hall effect at lower magnetic fields," Dang said. "And that's what will really allow for potential new physics to be seen at low temperature."

The structure is the first to lay the groundwork for the use of nitride semiconductors and superconductors in topological quantum computing, in which the movement of electrons must be resilient to the material defects typically seen in nitrides.

"What we've shown is that the ingredients you need to make this topological phase can be in the same structure," Khalsa said. "I think the flexibility of the nitrides really opens up new possibilities and ways to explore topological states of matter."

Co-authors of the paper include Professor David Muller of Applied and Engineering Physics and researchers from the U.S. Naval Research Laboratory, the National High Magnetic Field Laboratory, and semiconductor company Qorvo.

The research was funded by the Office of Naval Research and the National Science Foundation.

New paper demonstrates effectiveness of measuring full blood pressures without an arm cuff

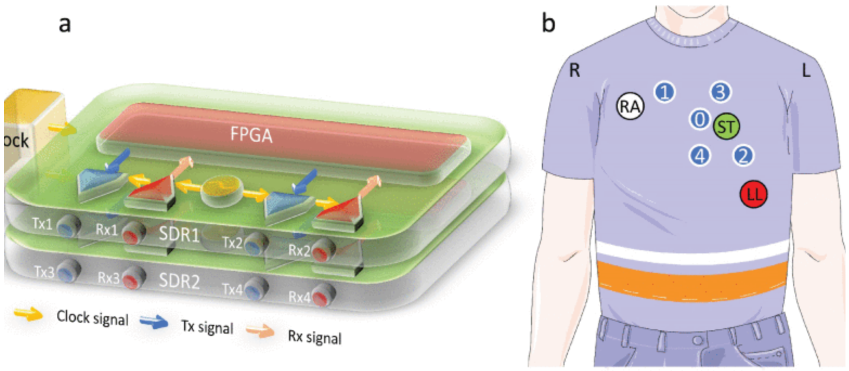


Figure 1 from the paper. The multi-point RF system for near-field coherent sensing (NCS). (a) Electronic hardware: The cardio reader constructed by two SDRs and an external reference clock source for synchronization. (b) Body placement: The location of the sensing points.

New research published in IEEE Access debuts a novel radio-frequency heartbeat sensor based on multi-point near-field observation via sensing antennas positioned outside clothing and over the heart.

Professor Edwin Kan, along with Xiaonan Hui and Thomas Conroy, both Ph.D. students in Kan's research group, are the authors of the paper titled "Multi-Point Near-Field RF Sensing of Blood Pressures and Heartbeat Dynamics."

"Blood pressures measured by an arm or wrist will give you 'brachial pressures' instead of the central pressure," Kan explained. "Brachial pressures can be similar if the cuff is maintained at the height of the heart, but it is an indirect measurement together with the arm condition."

Cuff-based measurements provide an estimate of an average blood pressure over a number of heartbeats, while the Kan group's RF-based method gives an estimate for every heartbeat.

Patients in hospital whose blood pressure needs to be periodically checked will often have their rest interrupted by cuff-based measurements. The new method can be done over clothing, without rolling up sleeves or putting on a Velcro wrap, and without disturbing the patient.

The RF method also collects data that an arm-cuff cannot provide.

"The heartbeat has two circulations," Kan said. "One goes through most of the body (systemic circulation) and the other through the lungs (pulmonary circulation). Therefore, the heartbeat contains four pressure points in the central blood pressures: systolic and diastolic pressures in systemic and pulmonary circulation. The arm cuff provides no information about pulmonary circulation."

Pulmonary artery hypertension (PAH), one of the pre-existing conditions that increases COVID-19 fatality risk, currently has to be measured using catheters or estimation from ultrasound imaging. Measuring pulmonary blood pressures using a far less invasive method has become even more important today.

"Additionally, blood pressure variations (like heart rate variation, HRV) per heartbeat are indicators for stress and wellness states, which is not possible in cuff-based measurements," Kan said.

If sensors can be integrated into garments, healthcare professionals could receive continuous monitoring of at-risk patients' complete blood pressure data in the coming era of telemedicine.

Creating "one-way lanes" for light in plasmonic structures

A new paper by ECE Assistant Professor Francesco Monticone explains the conditions necessary to realize unidirectional propagation of light in plasmonic structures.

The paper, titled "A truly one-way lane for surface plasmon polaritons," is published in Nature Photonics, the premiere journal of optoelectronics, laser science, imaging and communications in the field of photonics.

While conventional photonic devices are typically made with dielectric materials such as glass, plasmonic devices take advantage of the optical properties of metals. The field of plasmonics is sometimes referred to as "metal optics."

"The advantage of plasmonic devices," Monticone said, "is the possibility to squeeze and confine light to dimensions much smaller than its wavelength, dimensions that start becoming comparable with the size of modern nano-electronic devices."

The realization of ultra-small one-way waveguides carrying light in a preferential direction, without back-scattering light in the opposite direction, would open new opportunities to control and route light at the nanoscale, enhancing its interactions with new opto-electronic materials and nano-electronic devices.

Monticone's paper discusses the challenges that arise when attempting to create "one-way lanes" for light in plasmonic structures, in which wave propagation is allowed in one direction, but forbidden in the opposite direction.

"Light has a tendency to propagate symmetrically in opposite directions," said Monticone. "Breaking this symmetry, known as Lorentz reciprocity, is challenging. It requires "biasing" a system with certain external quantities, such as a static magnetic field."

Strong forms of nonreciprocity, in particular the unidirectionality explored in this new paper, are even more difficult to produce, but create opportunities for the development of novel devices. Some devices and functionalities can only be created with unidirectional light, such as on-chip optical isolators used to protect a light source (for example, a laser cavity) from back-reflections, and on-chip optical circulators able to route signals in a specific direction depending on the input channel.

Exploring the theoretical limits of metalenses

A new paper published in Optica, "Focusing on bandwidth: achromatic metalens limits," details the finding of some fundamental limits on so-called "metalenses," ultra-thin flat lenses which have shown great promise in their ability to function as ultracompact optical systems for focusing and imaging.

Federico Presutti, Ph.D. student in applied engineering and physics, and Francesco Monticone, ECE assistant professor are the paper's authors.

"Think of any optical system with lenses for focusing and imaging: a camera, microscope, a lens antenna," Monticone said. "All these lenses could in principle be replaced by ultra-thin flat structures —metalenses — with huge savings in terms of size, weight and cost of fabrication."

The paper's theoretical results will allow research groups working on metasurfaces to assess and compare the performance of different devices, and may offer fundamental insight into how to design better achromatic broadband metalenses for different applications.

"Typically, different colors are focused at different points, leading to what are known as chromatic aberrations," Monticone explained. "Our results determine the maximum range of colors that can be focused by the metalens at the same focal point."

A lens with chromatic aberrations does not focus all colors to the same point, leading to noticeable blurring and rainbow effects in images. Super-achromatic lenses could be replaced with thin metalenses, which allow more freedom to directly control how different colors interact with the structure.

There are, however, limits to how well metalenses can eliminate chromatic aberrations having to do with their thickness and refractive-index contrast. This paper establishes these limits for the first time.

Dozens of academic research groups in the U.S. alone are working in this area, a field also known as "flat optics." Startup companies, often spin-offs from academic research, as well as larger corporations are showing increased interest in applications of metalens technology due to the material and cost savings.

Some are working on compact imaging optics for consumer electronics such as cellphone cameras or for medical devices like optical endoscopes. Others are creating compact lenses with an ultra-wide field of view for applications in augmented and virtual reality.

Student team eyes next steps for ventilator designed in a bedroom lab


Landon Ivy in his home lab from the video he made detailing the project.

Cornell ECE Ph.D. student Landon Ivy assembled a team to work on a new project: produce a safe, simple and reliable ICU mechanical ventilator.

Landon Ivy started his Ph.D. work with Professor Amit Lal's SonicMEMS Lab, developing new processes for micro electrostatic linear actuators which will eventually drive the locomotion of a microbot. He had cultivated an affinity for working on hardware during his undergraduate studies, and when he got to Cornell he spent as much time as he could in the Cornell NanoScale Facility (CNF).

Then the pandemic forced Ivy along with all of his SonicMEMS Lab colleagues off campus. "A few days later, Dr. Lal got the word that there would be a ventilator shortage, so he encouraged the group to brainstorm," Ivy said. Since he wouldn't be able to resume work in the CNF for the foreseeable future, Ivy assembled a team to work on a new project: produce a safe, simple and reliable ICU mechanical ventilator.

"I had never produced any medical equipment before," Ivy said. "I took a bunch of clinician training classes online and read through a couple of textbooks on ventilator design." User manuals from existing ventilators were also helpful, he said.

Typically, ventilators are made almost entirely of custom parts, some of which are sourced from various vendors around the world. That's one reason why companies had such a hard time ramping up ventilator production as the pandemic began, and why most ventilators are quite expensive ($25 to $50 thousand for a high-end ICU ventilator).

"My goal was to make an emergency response ventilator capable of safely ventilating a COVID-19-induced ARDS patient using inexpensive and readily available components," Ivy said. He wanted to use parts that could be quickly and easily sourced and assembled by people with limited funds. The final version cost only $2750 to make.

Ivy detailed the ventilator project and construction in a video produced in his home lab—his bedroom.

"The patient circuit is a single-limb which is optimized for cleanliness," he said. "The inspiration line doesn't get contaminated during expiration like in a dual-limb ventilator."

He used a non-rebreathing valve normally used for a bag valve mask (sometimes known by the proprietary name Ambu bag, a hand-held breathing-assistance device) to further isolate the patient from contaminating the rest of the system. "This is something I haven't seen on any other ventilator," Ivy said.

The ventilator's modularity, that it can function as a transport or an ICU ventilator, running with a desktop or laptop, is one of the key innovations of Ivy's design. By running multiple instances of the clinician software, a single tablet or computer can govern multiple ventilators remotely, so nurses can monitor many patients without having to enter their rooms.

Ivy hopes that the progress and findings he was able to demonstrate with his home build might garner the support necessary for animal testing, or at the very least lead to further innovations within the health science community.

Watch the video on the CornellECE YouTube channel at **youtube.com/c/CornellECE**

MEET ECE'S NEW ASSOCIATE DIRECTOR

Professor Aaron Wagner has been named Associate Director of the School of Electrical and Computer Engineering and will serve a term of three years. Wagner joined Cornell ECE as an assistant professor in 2006 and was elevated to professor in July 2018.

Wagner's research work has focused on information theory, especially data compression and leakage in side channels. Now he is excited to take on the task of helping to strengthen the undergraduate curriculum in ECE.

"I'm thrilled to have Aaron in this role," said Alyssa Apsel, director of Cornell ECE. "He has already been a catalyst in modernizing our curriculum in a way that will make us a leader among ECE departments. This position is the perfect platform for him to continue driving us to provide the best possible program for our students."

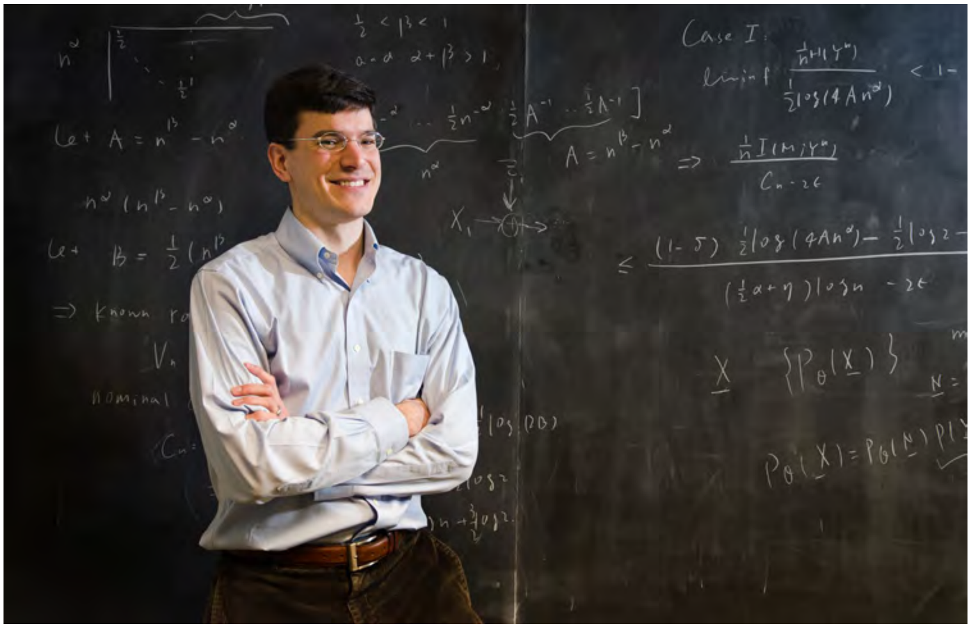
"I'm excited," Wagner said. "I enjoy teaching and I enjoy thinking about the curriculum and our student experience, and how all these things can be improved. That's one of the main functions of the job."

In practice if not in name, the role of associate director in ECE shares responsibilities that other organizations might classify as Director of Undergraduate Studies, overseeing the undergraduate program and, in particular, working to shape the sequence of courses students take to fulfill the requirements of an ECE major. Periodic reexamination of graduation requirements helps ensure that Cornell ECE is preparing students for emerging areas of engineering research and industry careers.

The associate director also looks at enrollment trends, working to understand how and why students decide to affiliate with ECE. Wagner sees reaching out to underrepresented groups and further improving the diversity of the ECE student body as a priority.

Wagner anticipates some changes to the sequence of required courses, noting that it might be time to revisit some prevailing assumptions and reconsider the role of some courses in the department and even the College of Engineering.

"We have to reevaluate these things from time to time," Wagner said. "Some aspects of the curriculum have been static for so long, we take them for granted. The prospect of rethinking everything is exciting."



"I'd like to understand what drives our enrollment," Wagner said. "What causes enrollment numbers to fluctuate? It's not entirely clear. I don't want to assume anything. Our undergraduate program is in great shape overall, but there is also plenty to do. How do you decide what to prioritize? I think it's important for me to hear from students."

Wagner's love of teaching is a good fit for this new role, and he expressed great enthusiasm at the prospect of helping shape ECE education. "It's a chance to define the field for the next generation of students," he said. "To me, that is deeply exciting."

TWO ECE FACULTY RECEIVE NSF CAREER AWARDS

Ziv Goldfeld, assistant professor of electrical and computer engineering, recently received a U.S. National Science Foundation Early Career Development Award from the Division of Computing and Communication Foundations (CCF). The award supports his research proposal "Smooth statistical distances for a scalable learning theory" for a five-year period from 2021 through 2026 with a total amount of $641,761.

"The smooth statistical distances framework, around which the proposal was written, is something I have been developing for the past year and a half since joining Cornell," Goldfeld said. "I think it holds great promise to progress our theoretical understanding of modern machine learning."

Professor Alyssa Apsel, director of the School of Electrical and Computer Engineering, expressed appreciation of and support for Goldfeld's work. "This project will develop a novel framework for high-dimensional inference based on smooth statistical distances, that gives rise to a scalable generalization and sample complexity theory for modern machine learning methods. We are excited to celebrate another great achievement among our faculty."

Ultimately, Goldfeld's project will promote the wide deployment of machine learning technologies with invaluable

societal benefits, from better healthcare to safer roads and improved crisis management. The project's educational component will nurture the next generation of scientists with an emphasis on increasing participation of women, who remain largely underrepresented in theoretical STEM disciplines.

"Receiving the CAREER award for it is a tremendous honor and a vote of confidence in those ideas, which means a lot to me," Goldfeld said."

Kirstin Petersen, assistant professor of electrical and computer engineering, received a U.S. National Science Foundation Early Career Development Award from the Division of Computer and Network Systems (CNS). The award supports her research proposal "Environmentally-Mediated Coordination in Natural and Robot Swarms" for a five-year period from 2021 through 2026 with a total amount of $520,490.

"Our project looks beyond robots working in parallel and towards actual swarm intelligence leveraging both explicit and implicit computation through software, morphology and embodiment into a shared environment," Petersen said. "This type of distributed coordination has many facets and is still poorly understood."

Petersen's work will result in a model of swarms in dynamic environments that act to integrate, diffuse, decay, and filter information derived from characterization of a biological model system, as well as practical robot experiments.

Professor Alyssa Apsel, director of the School of Electrical and Computer Engineering, described the scope of the project in a congratulatory message. "Kirstin's project will extend the concept of bio-inspired multi-robot systems operating in static environments to include dynamic environments, along with ways

to deal with errors and hardware reliability. We are excited to celebrate another great achievement among our faculty."

The CAREER award is the National Science Foundation's most prestigious award in support of early-career faculty who have the potential to serve as academic role models in research and education and to lead advances in the mission of their department or organization.

NEW FACULTY

FARRELL HELBLING

There was no single person or event that started Farrell Helbling on the path to her new position as an assistant professor in Cornell ECE. Though when she thinks about that path now, a particular television show plays a part. "When I was a kid, my Dad and I would watch Star Trek: The Next Generation," says Helbling. "And for the longest time I would say 'Okay, when I get older I am going to work in one of those starships.' It wasn't until I was five that my Dad told me starships like that aren't real." But by then it was too late—Helbling was headed for a STEM field.

Helbling, who went to high school on Cape Cod, chose to attend Smith College in Northampton, Massachusetts for her undergraduate studies. Helbling thrived at Smith, earning a B.S. in Engineering Science with highest departmental honors. She spent a year abroad in the UK, had a research field experience on Norway's Svalbard Island well north of the Arctic Circle, and in her senior year had a major role in a research project that used RC aircraft to measure air samples at various altitudes. "The engineering program at Smith is almost entirely practical," says Helbling. "There are still classes and lectures, but the focus is often on applying the things we are learning and I loved that."

As Helbling began to think about what to do after graduating from Smith, she had conversations with her advisor and other professors. "I have always liked teaching and academia," says Helbling, "but because I was at Smith I did not have a very good understanding of exactly what grad school entailed. I started talking to my advisors and I said 'I love doing independent research. If one day I wanted to be a professor, what are the steps I would have to take to do that?'" She understood quickly that a graduate degree would be essential.

Helbling spoke with Harvard roboticist and professor Robert Wood and quickly found that his RoboBee project was exactly what she was looking for. "We were very much on the same page with what he wanted to do with RoboBee and the ideas that I had for the RoboBee," says Helbling. The RoboBee is the smallest fabricated device modeled on an insect to achieve flight. The goal of the RoboBee project is to make a swarm of these devices fully autonomous and capable of carrying out assigned tasks.

"RESEARCHERS WILL USE THE PLATFORM TO POSE AND ANSWER QUESTIONS I MIGHT NOT HAVE THOUGHT OF."

At the time, the RoboBee required a tether and was incapable of sensing itself and its surroundings. So Helbling dove into the questions of which additional sensors it would need. In her 8 years at Harvard, as both a Ph.D. student and then a Post-Doctoral Fellow, Helbling's focus grew to encompass system-level design of the RoboBee. "I very much wanted to take all of the pieces people were working on—the mechanical design, the power source, the electronics and sensing capabilities, the communications—and figure out how to make an actual autonomous system," says Helbling.

As an assistant professor at Cornell, Helbling is planning to push her research into autonomous insect-scale robot platforms further. "My lab will be working toward having these autonomous, centimeter-scale platforms where some people will be thinking about the mechanical design, some will be thinking about how we power these platforms, some will be thinking about how we get these things to communicate with users or with each other, and some will be focused on sensors."

One of the most exciting aspects of the endeavor for Helbling is seeing how the platforms she creates will be used by other researchers. "There are the obvious possible applications like search-and-rescue and environmental monitoring," says Helbling, "but there are also researchers who will use the platform to pose and answer interesting questions I might not even have thought of."

Helbling is excited to be at Cornell. "When I visited campus it was clear there is such a great vibe here," says Helbling. "I already have some great relationships with other faculty, and the students here are just incredible. When I gave a talk they asked such insightful questions. I am excited to get my lab going and to start teaching."

FRANCESCA PARISE

Francesca Parise has joined the faculties of Cornell ECE and Systems Engineering as an assistant professor. Most recently, Parise held a postdoctoral research fellow position at MIT's Laboratory for Information and Decision Systems (LIDS) with Professor Asuman Ozdaglar.

Parise describes her research as focusing on "problems that arise in the analysis and control of multi-agent systems composed by a large number of users that make autonomous and selfish decisions while interacting with each other, with application to transportation, social, and economic networks." A main goal of her work is to be able to accurately model and predict the outcomes of these complex systems in the limit of large populations and under partial or inaccurate network information.

A second ambitious goal of her research is to have an effect on these systems. "Given a prediction about the outcome, how can we best intervene?," asks Parise. "Maybe there is a constraint of limited resources. If so, how could we optimally allocate these resources in the network to achieve some social goal?"

Parise has always aspired to be a teacher. "When I was growing up in Italy, I always wanted to be a teacher for the level of schooling I was at," she says. "By the time I got to the University of Padua it was already my goal to become a professor and researcher—there was no doubt in my mind that this would be my career."

Parise earned her B.S. in information engineering and her M.S. in control engineering from the University of Padua. She also earned a completion certificate from Padua's Galilean School of Higher Education, which is a special unit of the university open to just thirty students per year and designed to foster an intellectually stimulating environment where students from many disciplines can live and study together.

Parise then went to Switzerland to pursue her Ph.D. in control engineering at the Swiss Federal Institute of Technology (ETH) in Zurich. At ETH Parise worked with Professor John Lygeros in the Automatic Control Laboratory. "I liked working with John very much," says Parise. "He always allowed me to follow my research passions and gave me the opportunity to work on a broad range of topics." Over her time at ETH Parise's work evolved from looking at cultures of light-sensitive cells (trying to find the optimal pattern of light exposure to optimize their production of a certain compound), to looking at systems where the participants have agency and are able to make rational decisions.

"I AM TRYING TO INVESTIGATE NETWORK GAME THEORY WHEN THE NETWORK IS BIG, AND PARTIALLY UNKNOWN."

This interest in multiagent systems with selfish participants then led Parise to her postdoc with Professor Asuman Ozdaglar's group at MIT. "She (Ozdaglar) is a world expert on the interactions between engineering, economics and game theory," says Parise, "and a role model for the type of advisor that I aspire to be. Interacting with her and Professor Daron Acemoglu at MIT inspired me to explore the exciting field at the boundary of game theory and network science. During my Ph.D. I was looking at systems where you have a lot of people that influence each other in generic ways," says Parise. "In my postdoc I started to get interested in systems where the decisions made by some people have bigger effects than those made by others. I started to include network effects." Parise goes on to say that this is one of the reasons she decided to come to Cornell. "There are so many experts on networks here," she says, "and I want this topic to be central to my research as a faculty member."

With systems and networks getting larger and more interconnected, it is increasingly difficult for decision-makers to collect all the relevant data and to know how to use the data they are able to collect. "I want to see if we can still design optimal interventions even if we don't know the network exactly, but we have statistical information about it," says Parise. "I am trying to investigate network game theory when the network is big, and partially unknown." Parise is focused on the fundamental theory behind these questions now, but sees possible future applications in marketing as well as in public health, social and economic settings.

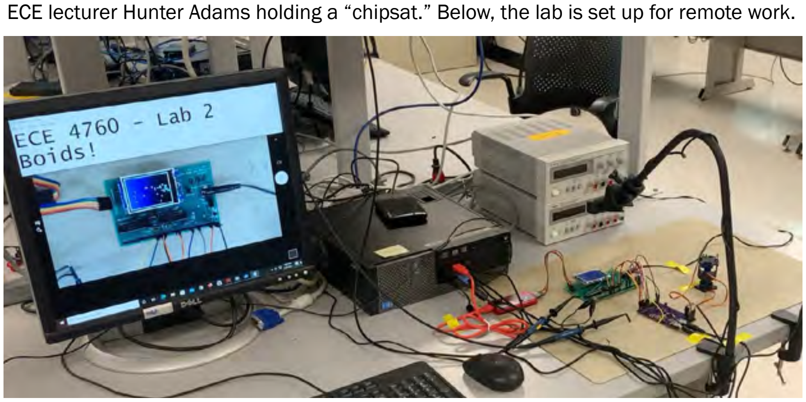
TEACHING SPOTLIGHT

BUILDING BIO-INSPIRED PROTOTYPES WITH PERSONALITY

Designing with Microcontrollers, ECE 4760, deals with microcontrollers as components in electronic design and embedded control. It's long been one of the more popular courses with students, due in no small part to the energy and enthusiasm the teachers bring to the material. Retiring Senior Lecturer Bruce Land taught the course for many years, and recently has handed the baton to one of the newest ECE faculty members, Hunter Adams.

We asked Adams to describe the course, what he hopes students will get out of it and why it's important in the ECE curriculum. In short, it's a classic example of how electrical and computer engineers approach a challenge with ingenuity and innovation.

ECE lecturer Hunter Adams holding a "chipsat." Below, the lab is set up for remote work.



I spent much of my Ph.D. designing and building very small spacecraft called "chipsats." These devices are essentially printed circuit boards outfitted with a suite of sensors, processors, and radios that make them useful in space. In graduate school, I found that my happiest days were those spent in the laboratory prototyping with electronics. I love this sort of work, so I feel very lucky to be instructing 4760.

The microcontrollers course is often the first opportunity students have to build something complicated and that comes entirely from their own imaginations. This is always exciting and often a bit jarring. Most of the technologies with which we interact in our daily lives "just work." The lights turn on when you flip the switch and your phone nearly always makes calls.

Through 4760, many students come to the uncomfortable realization that it is really hard to get things to work. Many come to another realization, however, that it is also really fun and outrageously rewarding.

The first eight weeks of the course consist of four guided lab exercises, each lasting two weeks. These are designed to add additional tools to the students' toolbelts, to introduce them to new concepts, and (where possible) to change the way that they view and understand the natural and constructed worlds. Then in the final four weeks of the course students are welcome to build anything they want using the knowledge they've gained through the lab exercises.

LAB ONE: BIRD CALL SYNTHESIS

The lab starts by studying birdsong spectrograms from the Cornell Lab of Ornithology, specifically the Northern Cardinal. We match the frequency sweeps in the spectrogram to mathematical functions, and the students implement an algorithm which generates those same frequency sweeps with the microcontroller. The result is a shockingly realistic simulation of a Northern Cardinal singing—realistic enough to fool both humans and birds!

Each lab is designed to be extensible. A student that is fascinated with the lab and wants to run with it should have interesting places to run to. In this lab, students may attempt more challenging birds or different animals. Students report that they notice and take interest in birds singing after this lab.

Boids generates realistic animations of flocks of birds.

LAB TWO: BOIDS

Lab two is a computer graphics and optimization exercise. Students implement an algorithm called Boids, an artificial life program that generates shockingly realistic animations of flocks of birds based on rules for interaction among a collection of animated particles. This lab is exciting because students create something that surprises them.

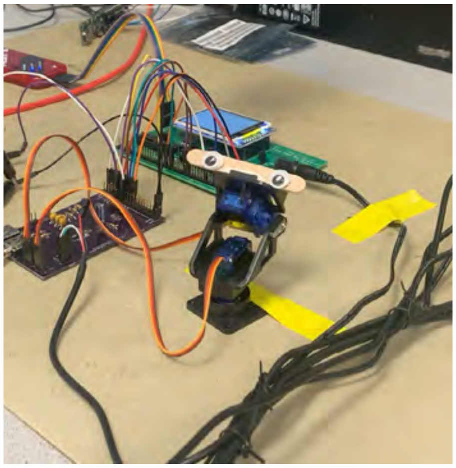
The algorithm has a few controllable parameters. As you change these parameters, the emergent flock behavior changes. The default values make the collection of particles look like a flock of birds, but change them a little bit and suddenly, for reasons that aren't entirely obvious, you have a school of fish. It transitions from bird-like motion to fish-like motion; and then you change the values again and it starts to look nonorganic, like robots, or the particles gather into crystalline-like structures. There's a competition element to this lab. The student with the biggest flock (i.e., the most optimized code) wins.

It's another exercise that gets students to see the world in a different way. When they see a group of starlings over Ithaca some evening, they can say, "I understand what's happening there!" Students report that they notice and pay attention to flocking behavior in the natural world after this lab.

LAB THREE: SPECTROGRAM

Students build a real time audio spectrogram generator in the third lab. They communicate sounds into the microcontroller, the microcontroller computes the frequency content of those sounds, and an attached screen displays that information as a spectrogram. Students talk and sing into the microcontroller to observe the frequency content of their voices. They play their favorite songs into the device, animal calls and sound effects. The results can be surprising.

For example, students are often surprised by the spectra of stringed instruments, which produce very ordered and evenly spaced harmonics going up the spectrogram. This is something students would have learned about years ago in physics, but it's very cool to see it happening in real time.


A robot that gets bored in Zoom meetings.

LAB FOUR: SERVO ROBOT

The fourth lab is a bit different from the previous three. In each previous lab, students build a scientific tool or a tool for understanding some natural phenomenon. In the final lab, students are asked to build something that makes them and other people smile. This year, it's a robot that gets bored in Zoom meetings.

Each student remotely accesses a variety of hardware in 4760. This hardware includes two servo motors that are oriented in a pan/tilt configuration and that carry a passive piece of hardware to indicate the robot's direction of attention (googly eyes). Students must control the two servos to point the eyes at the camera, have the robot look around when nobody is speaking, and point back at the camera when anyone yells at it. It's a simple behavior, but the effect is really endearing.

Students are challenged to give this little robot as much personality as they can manage, and they implement a variety of clever motor controls to make the robot appear bored, sad, anxious or excited.

LEARNING FROM ROBOTS

How robotics is driving new research into foundational aspects of ECE

by Eric Laine

What is a robot? For Cornell's School of Electrical and Computer Engineering, it's the intersection of a broad range of research and a useful vehicle to explore core aspects of engineering education. In the past several years, Cornell ECE has been expanding its robotics faculty and building a program that positions robotics as a central pillar of teaching and research within the department.

Robots are physical systems which can perceive, reason about, and act upon their environment. They use sensors to understand internal signals and external surroundings. Robots can be programmable and designed to make real-time computations and decisions about their tasks. A robot takes action to positively affect its environment. Perception, computational intelligence, and action represent foundational principles in ECE.

A robot is an intersectional device. From the design of its circuits and chips, to the actuators and algorithms that allow it to move and think, a robot represents research from many disparate fields working together in ever more novel ways to create something greater than electrical, mechanical, computer or systems engineering could produce on its own. All of those fields intersect in ECE.

Robotics research in Cornell ECE is taking inspiration from surprising sources and asking interesting questions. The core elements of a robot: sensing, planning and decision making, and control and action are all research areas within electrical and computer engineering. Robotics provides a unique platform for science education because so many disciplines converge to make a robot work.

Petersen and her students test the Martha robot in the Computer Systems Lab space in Rhodes Hall. Martha is an open-source platform designed for human robot interaction studies.

In short, robots could not exist without ECE, a field that excels at bridging novel hardware and computational architecture to create intelligent physical systems.

Biological Inspiration

Assistant Professor Kirstin Petersen is interested in bio-inspired robot collectives and studies of their natural counterparts, especially in relation to construction, exploration, and agriculture. She founded the Collective Embodied Intelligence Lab in Cornell ECE in 2016 to research the design and coordination of large robot collectives which are to achieve complex behaviors beyond the reach of single robot systems.

Collaboration with Associate Professor Al Molnar's lab has developed technology to leverage bees as bio-monitors, outfitted with backpack flight recorders to produce foraging probability maps. This lets farmers estimate which areas of a field have been pollinated.

"We're looking at alternative types of intelligence," Petersen said. "What kind of intelligence can we program into the body of the robot? What kind of intelligence comes from many robots working together?"

Petersen points out that social organisms demonstrate an implicit intelligence, incorporated into their morphology, into the physical interactions between organisms and into the way they modify their shared environments. They seem to use the environment itself as a shared database. Can social robots learn from this organic intelligence?

"There are a lot of things that many robots can do in collaboration that single robots can't, even if the single robots individually are much, much smarter," Petersen said. When many robots are working together embodied in the same environment, their physical interactions and their morphology mean something. "We're looking at how we can bring intelligence out in those kinds of systems," she said.

Once you get to big enough swarms, Petersen explained, it starts making sense to think about distributed intelligence instead of centralized controllers telling each robot what to do. "There are many examples in nature where we see that you can have really interesting and robust outcomes from systems like that," she said.

The Collective Embodied Intelligence Lab represents the core of robotics research in Cornell ECE. It embraces the multidisciplinary and intersectional nature of ECE to take inspiration from biology, systems engineering and artificial intelligence to research how swarms of devices can work better together, or how to distribute intelligence throughout the body of a robot to make it perform better.

"THIS NEW WAVE OF SOFT MATERIALS IS REALLY EXCITING BECAUSE WE CAN MAKE NEW KINDS OF ROBOTS THAT PEOPLE HAVE NEVER IMAGINED BEFORE."

"We work a lot with biologists to develop new instruments that help their research," Petersen said, "because that's where we get our inspiration from. Beyond that, we're also looking at how we can have robots and insects work together to do more interesting things."

In some cases, it doesn't make sense to create complex robots. For example, if you're trying to monitor an agricultural field, creating a robot to navigate that field can be tricky and require many different kinds of perception, which could be prohibitively expensive. But pollinators like bees already navigate fields very well. So, if pollinators could be outfitted with simple sensors, one could leverage their existing abilities and still get data without having to design a flight system.

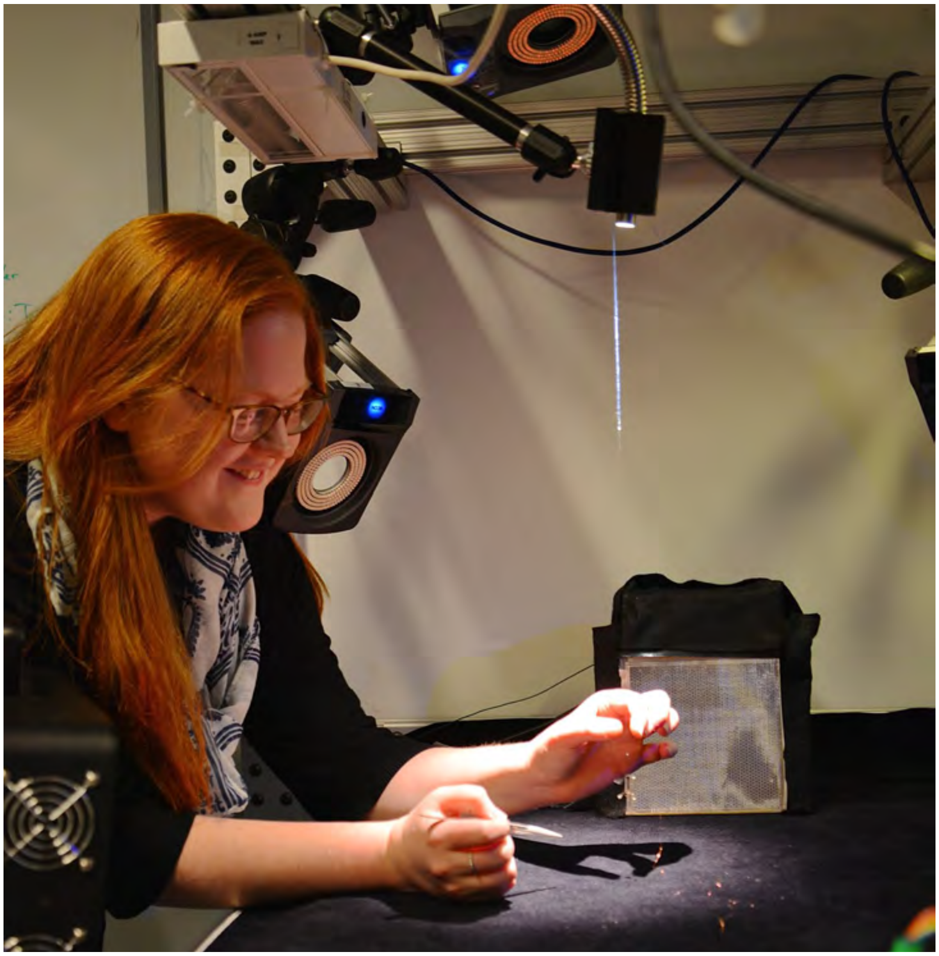
"Following the form-and-function idea from biology, we develop custom dedicated hardware for particular tasks," Petersen said. "This allows the individual robots to be much simpler, less expensive, and more robust. However, because we have flexibility in their distributed coordination mechanisms, they are still capable of adapting to different perturbations."

Biological inspiration has led Petersen's team not just to swarms of insect-like robots, but also to unconventional designs known as soft robots, which can integrate sensors throughout their forms instead of having discrete hard sensors on a rigid robot. Because of their simplicity and inherent robustness such robots are particularly well suited to operate in large collectives.

"The simple way of thinking of them is like a fancy balloon," Petersen explained. "You might have a polymer

The Martha robot has a human-scale inflatable interface with an internal camera, projector and speaker to facilitate intuitive and safe human interaction. With a low center of mass the robot can perform agile, stable motion and can deflate to fit in low clearance spaces. Graduate students Jonathan Jaramillo, Andrew Lin, Emma Sung and Isabel Jane Hunt Richter contributed to this project.

The Martha robot responds to touch using a camera-projector pair inside its inflated bladder.



Helbling worked on the RoboBee during her time with the Harvard Microrobotics Lab. Shown here hanging from a string, its tiny features are barely visible.

encasing which is pneumatically driven; air is used to change the morphology significantly upon inflation, whereas the elastic energy stored up in the polymer helps reverse that motion upon deflation."

Alexandra Nilles, a postdoctoral researcher in Petersen's group, is working with students on soft robot collectives that inflate and deflate. The project involves new materials that are more compliant when they interact with the environment, materials not typically found in robotic systems.

"Usually we've used metal, plastic, hard materials that are not flexible," Nilles said. "This new wave of soft materials is really exciting, because we can make new kinds of robots that people have never imagined before."

Envisioning a New Platform

The newest member of the ECE faculty, Assistant Professor Elizabeth Farrell Helbling looks at robots from a systems perspective. "I'm really focused on integrating all of the electronics and power systems on board to give a robot some level of autonomy," she said.

As a researcher Helbling asks, what can engineers do to improve on the sensing and locomotion methods we see in nature? Which tasks are better performed by flying or crawling? Would wheels work better than legs? "You need to think about the mechanisms," she said. "You need to think about the actuators, the control systems, the sensors, planning and estimation models, power sources, the list goes on." Understanding how biological systems integrate these elements is a useful method for exploring the capabilities of a robotic system.

Helbling's postdoctoral work focused on the systems-level design of the Harvard

RoboBee, an insect-scale flapping-wing robot, and HAMR, a bio-inspired crawling robot. "I work on insect scale robots with micro scale features," Helbling said. "It's a hard problem to solve because of the size, weight and power constraints that exist in micro scale platforms." The RoboBees Helbling worked on had a wingspan of about three centimeters and weighed about 80 milligrams each. It takes about 30 of them to weigh as much as a penny.

The Harvard RoboBee. Photo credit: Harvard Microrobotics Lab.

Helbling is now envisioning a robotics platform that can be used as the basis for creating new and various types of very small robots. She said that a lot of the growth that's happening in robotics has been made possible by the availability of stable, off the shelf robotics platforms that researchers can modify by adding actuators or sensors or other pre-packaged systems to suit their needs. But these off the shelf solutions are not really available for insect-scale robots.

"We have all the conventional scale manufacturing techniques, and we have all the nanoscale manufacturing techniques," Helbling said, "but for everything in this millimeter to centimeter range, the equipment is not there. If I can create a robust autonomous physical platform at this size scale, then hopefully it would open up robotic exploration to a lot more researchers."

This inchworm-inspired robot from the Collective Embodied Intelligence Lab is built using soft materials.

Part of Nilles' Ph.D. research involved how to automate the robot design process, including how to describe and formalize the trade-offs among the multitude of design decisions. "The goal is to eventually have some kind of automated assistant to help people design robots and to make the robots they design more robust," she said, "but it's a long way out."

Deep Learning

Professor Daniel Lee is part of the AI research group at Cornell Tech. His research in robotics deals with the way intelligent machines perceive, make decisions and execute their plans in an uncertain, dynamic world, both from a practical point of view and from a theoretical point of view. Artificial intelligence and machine learning have major impacts on how to program robots; is it possible to apply an algorithm and let the robot figure things out on its own?

"BEFORE DEEP LEARNING, EVEN SIMPLE TASKS WERE NOT STRAIGHT-FORWARD."

The problem is the huge variability in robot sensor data. Lee has found that this sensor data has an underlying geometrical structure and wants to design deep learning algorithms that can more efficiently deal with this structure to achieve faster learning or provide some sort of performance guarantees for robotic systems.

"From a geometrical point of view," Lee said, "you can think about your sensor input as a large high-dimensional vector. Every time something changes in the environment, this vector shifts its position in the vector space." We can measure the robustness of a machine-learning system by looking at how well it handles these shifts.

Before deep learning, even something seemingly as simple as detecting an object was not straightforward. "Machine learning and computer hardware developments really changed the landscape of what information robots can process," said Nilles. "Ten years ago, a robot with a camera would not be able to determine 'this is an apple' very reliably, but now computer vision systems are much more robust."

The next innovations will allow products or devices to better understand the world around them and that's critical for robots. "How does the robot understand the world, what are the actions it needs to take and how does it respond properly?" asks Lee. "This is one of the fundamental problems that my research addresses."

Lee brings industry experience and perspective to his role in Cornell ECE. He works part-time as an executive vice president overseeing global AI research for Samsung Research, the R&D arm of Samsung Electronics. His work for Samsung Research is helping to develop future products including mobile phones, TV's and smart appliances, while also informing his teaching, keeping his students aware of the current needs in high tech industries.

In his course at Cornell Tech, Intelligent Autonomous Systems, Lee and his students explore algorithms for robotic perception, planning and control with a focus on real-time adaptation and learning. "My approach in robotics is to think about how humans solve the problem," Lee said, "and then try to build a machine that can emulate what humans do.

Low-cost mobile manipulator made from off-the-shelf components that can handle (pickup/drop) compliant bags and navigate over unstructured terrain. Image from "Autonomous Adaptive Modification of Unstructured Environments," DOI: 10.15607/RSS.2018.XIV.070; Maira Saboia da Silva, Vivek Thangavelu, Walker Gosrich, Nils Napp.

Robotic Construction

Assistant Professor Nils Napp is also interested in taking inspiration from biological processes for robotics. His research looks at the way insects and animals manage to build structures in unstructured and fluctuating environments and applies these principles to robotic construction.

"What animals are able to do in building things is just mind boggling," Napp said. "I'm interested in the reasoning capabilities, because animals never took mechanics, but they can achieve construction behavior that would be hard for humans to match."

Napp works to understand how evolved biological systems work reliably with varied terrain and random disturbances in order to design control strategies with a similar robustness. The reason a robot fails a task is often because of something subtle or unanticipated, like a pebble in its path or a doorway that's slightly smaller than every other door. Humans and animals generally do not let slight variances in the environment derail them from their task.

Nilles describes two important algorithmic goals in robotics. "One is efficiency, being fast," she said, "and the other is robustness, so that it doesn't break immediately when one small thing about the environment changes. Balancing those two characteristics in the algorithms is really difficult."

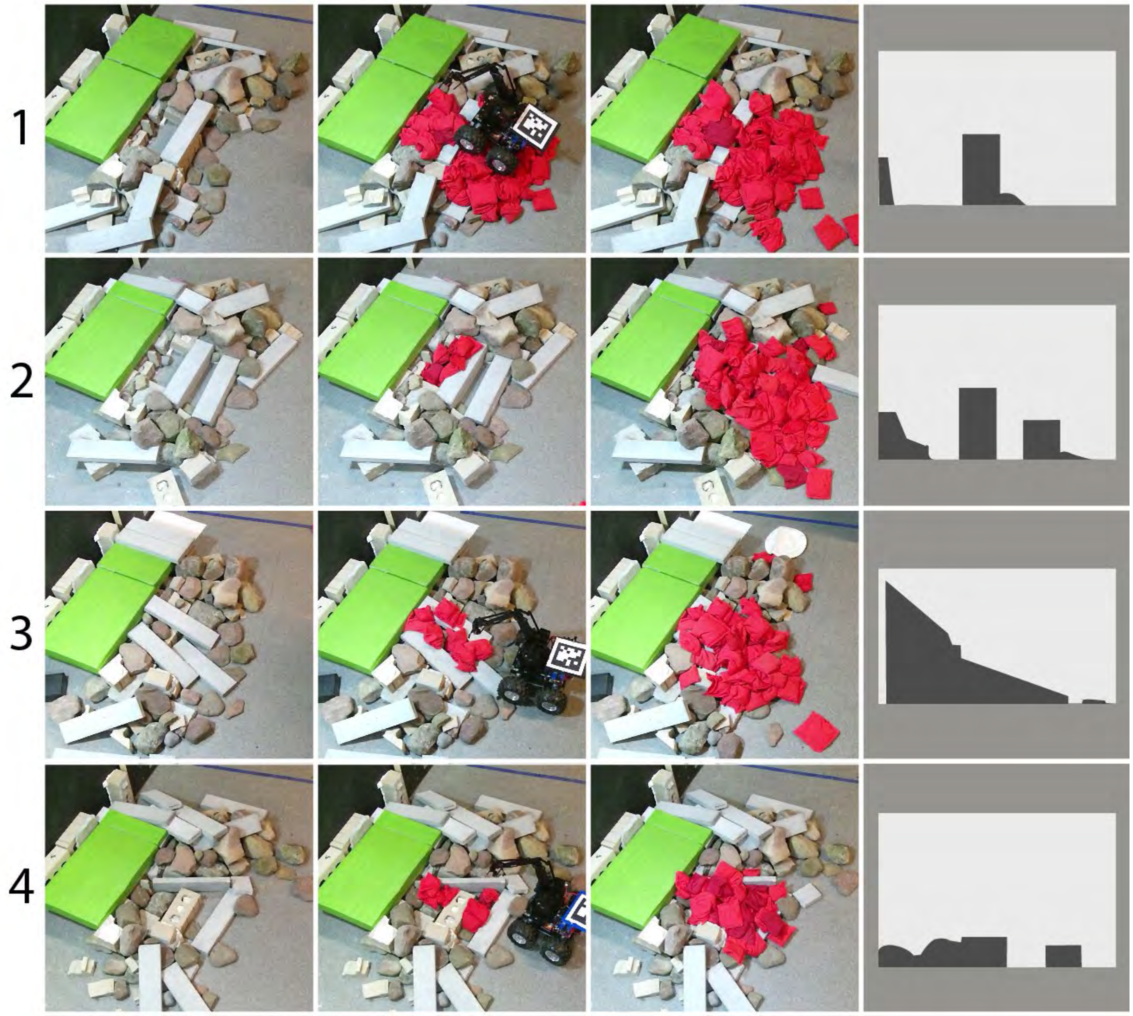
Construction is about changing the environment according to some predictable outcome. That requires the robot to understand the state of the environment before construction and after. Can researchers create representations or models of the external world in such a way that guarantees the robot can complete its task successfully?

"WHICH TASKS ARE BETTER PERFORMED BY FLYING OR CRAWLING? WOULD WHEELS WORK BETTER THAN LEGS?"

"I think what's going to make the biggest impact," Napp said, "is better reasoning and better guarantees, being able to deal with conflicting information. The main driver of progress in making robots more capable is algorithmic."

Creating the physical, mechanical and sensory parts of the robot is achievable with off the shelf components, but developing its ability to plan, perceive and adapt may be the greater challenge.

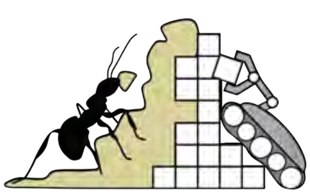
"I would eventually like to work on construction robots on a bigger platform



Experiments showcasing initial setup, intermediate and final structures. Last column of images depict the 2D crosssection of the initial setup (in black) along the center of the green platform of each experiment, as a visual aid to the reader; they do not convey the true nature of irregularities in 3D space. Image from "Autonomous Adaptive Modification of Unstructured Environments," DOI: 10.15607/RSS.2018.XIV.070; Maira Saboia da Silva, Vivek Thangavelu, Walker Gosrich, Nils Napp.

capable of building structures on a human scale," Napp said. "It's structured in interesting ways because some parts are very predictable. Building materials can be standardized; a prefabricated house is designed to fit together a certain way. Constructing things with robots is a really interesting application domain."

Robotics is transforming our lives and work practices and has even greater potential to provide enhanced levels of service, boost efficiency and promote workplace safety. Robotics is becoming the driving technology underpinning a whole new generation of autonomous devices and machines that, through their learning capabilities, interact seamlessly with the world around them and provide the missing link between the digital and physical worlds.

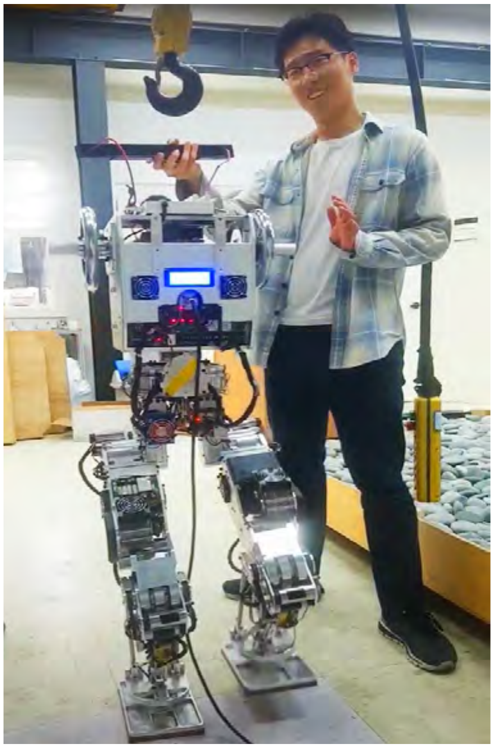


Visit the Collective Embodied Intelligence Lab online at **cei.ece.cornell.edu**

HELPING ROBOTS TO REASON ABOUT TOUCH

by Chris Dawson

Mark Lee ’15 M.Eng. ’16 is exploring reinforcement learning in robot manipulation



Lee with Hubo, a humanoid robot created at Korea Advanced Institute of Science and Technology.

Mark Lee ’15 M.Eng. ’16 grew up in both South Korea and the United States and he attended Thomas Jefferson High School for Science and Technology. One of his teachers there steered him toward a robotics team in tenth grade and once he discovered electronics and mechanical systems, he knew what he wanted to study. In some ways, Lee’s experience on that high school robotics team set the path for his next ten years. “I applied as an Early Decision applicant to Cornell,” says Lee, “and one of the main reasons was the Project Teams. I was looking to continue with those hands-on experiences where I learned so much and Cornell was a place where it was clear I could do that.”

As a first-year student, Lee joined the Cornell University Autonomous Underwater Vehicle team (CUAUV) and stayed with them all four years. “It became clear right away that things were on a whole new level compared to my high school robotics team,” says Lee. “With AUV, you’re not working from a kit. We had to go out and contact our own sponsors, buy our own materials, machine the mechanical frame, and build the electronic system ourselves. The logistics, designing, and testing were all on you.” Lee was on the electrical subteam of AUV, eventually becoming the team co-lead in his senior year.

Lee’s experiences with AUV informed his decision on what to major in at Cornell. “What helped me decide on the major I wanted to pursue wasn’t really the coursework I took, but rather the hands-on work such as designing circuit boards and programming microcontrollers.” For Lee that naturally meant choosing to major in Electrical and Computer Engineering (ECE).

Lee was a member of the CUAUV project team for four years.

After earning his Bachelor of Science degree, Lee continued for another year at Cornell and received his M.Eng. from ECE as well, working with Associate Professor Zhiru Zhang.

As a citizen of South Korea, Lee was obligated to then return to fulfill his military duty, which he did as a robotics researcher. From 2017 to 2020 he worked at the Korea Advanced Institute of Science and Technology (KAIST) Humanoid Research Center, the winning research team for the DARPA Robotics Challenge in 2015. “My experience at KAIST strongly resembled a lot of the experiences I had at Cornell,” says Lee. “We were creating a robot platform—the overall mechanical structures, the design, the electrical components, and the high-level software—but instead of an underwater robot, at KAIST it was a bipedal robot. Of course, a walking robot is necessarily a little more complex, but the overall concepts I learned at Cornell carried over nicely.”

The research problem Lee worked on was robot manipulation, or how robots can intelligently pick up objects. “Identifying an object and knowing where to grasp the object comes very naturally to humans through years of experience,” says Lee. "With computers, it's not so easy to distinguish objects from backgrounds, let alone determine where to make contact with the object that leads to a successful grasp. This problem becomes exponentially more difficult when there are multiple objects that are cluttered with one another. "

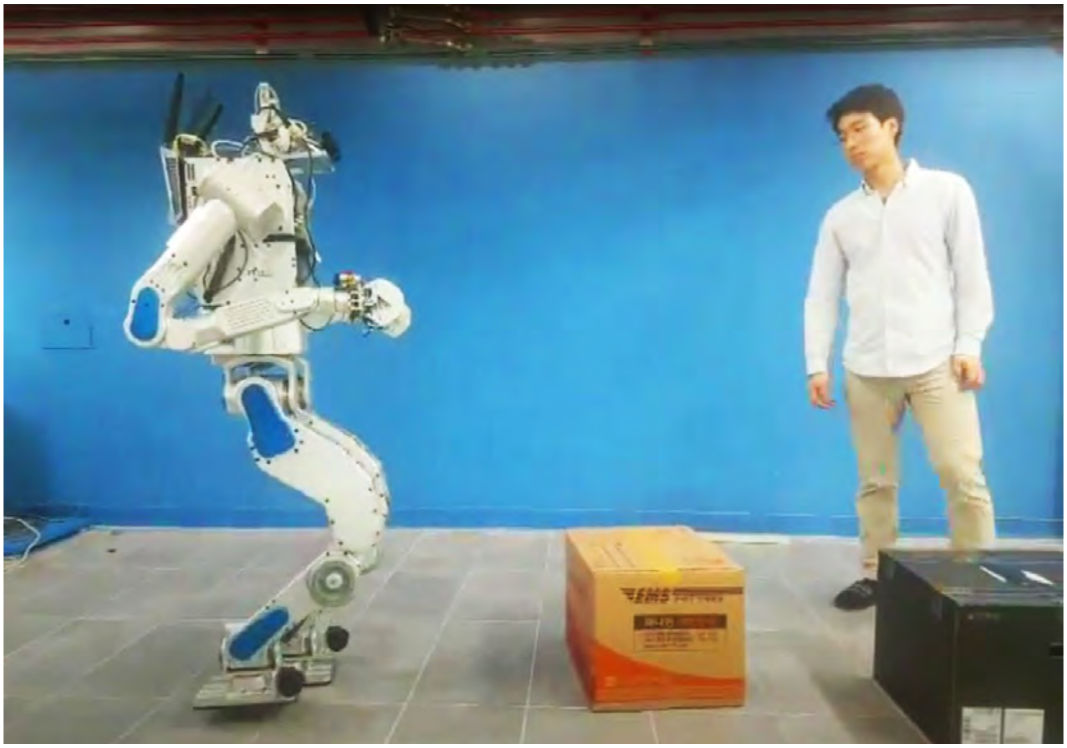
"ROBOTICS IS SUCH AN INTERDISCIPLINARY FIELD. IT REQUIRES A CERTAIN DEPTH OF KNOWLEDGE IN EACH OF THE COMPONENT FIELDS."

Lee's term at KAIST is now finished, but his interest in robot manipulation is just beginning. To research this problem more deeply, Lee is now set to begin his doctoral studies in robotics at Carnegie Mellon University in the fall of 2021. "Knowing that robotics is such an interdisciplinary field—and that it requires a certain depth of knowledge in each of the component fields—has made me want to learn more," says Lee.

At Carnegie Mellon, Lee hopes to focus on the value machine learning can add to robotics. "A lot of roboticists would agree that not a lot has changed for robots in general in a long time," says Lee. "And the limitations stem from the intelligence (or lack of intelligence) that robots have when reasoning about making physical contacts with the real world." Lee argues that if we want robots to be more useful, both industrially and socially, then we are going to have to start creating robots that are capable of more flexible approaches to their interactions with objects and people.

Lee wants to help push the field beyond traditional approaches and enable robots to supervise themselves and adapt their behaviors to the situations they find themselves in. The area he plans to work on at Carnegie Mellon is called model-based reinforcement learning and it would allow robots to act with more autonomy than they are currently capable of. Lee can foresee himself eventually working as a product developer for whatever innovations grow out of his doctoral work.

In his five years at Cornell ECE Lee had many valuable classes and experiences that influenced his path to a Ph.D. program at Carnegie Mellon. When he looks back at his Cornell years now, he specifically mentions faculty members Bruce Land and Zhiru Zhang as having been especially inspirational and supportive. "Bruce Land was the living embodiment of the "ECEs Can Do Everything" idea," says Lee. "His approach to understanding how things work taught me a lot. And Zhiru Zhang encouraged me to try to learn something new during my M.Eng. program and even helped put me on the path to wanting to do research and pursue my Ph.D."



Lee watches as Hubo walks to the box to pick it up. Robot manipulation is Lee's focus at CMU.

FROM CORNELL TO A LEADING ROBOTICS COMPANY

Q&A with Katie Bradford ’20, M.Eng. ’20

During her time in Cornell ECE, Katie Bradford ’20, M.Eng. ’20 was recognized as an emerging leader. She worked as a teaching assistant for several courses and her dedication and enthusiasm for her work were well-known on campus. Her studies focused on hardware, ranging from UAVs with the CUAir autonomous aerial system project team, to robotics projects in the Maker Club. Outside of class she could often be found in the Rapid Prototyping Lab helping other students try out new projects or setting up stages for artists with the Cornell Concert Commission.

Bradford recently relocated to Boston to join Vecna Robotics, a company dedicated to improving human/machine workflows, building robots for material handling applications in industrial spaces, such as the autonomous pallet jacks pictured here.

Responding to questions by email, Bradford highlighted the ways her experience in Cornell ECE prepared her for the next stage in her career, especially focusing on the maker-inspired, hands-on learning opportunities that engaged her the most.

Why did you choose Cornell Engineering for your B.S.?

I chose Cornell because of the potential I saw to do real, hands-on work. Between the project team program, research and maker spaces, there were plenty of opportunities to work on projects and learn by doing.

What drew you to ECE?

I was interested in ECE because it is so cross disciplinary. ECEs have the opportunity to build hardware and write software, and work on a wide range of systems including communications, power systems, digital design, analog design, firmware, and more. Because I did not yet know specifically what I wanted to do, this seemed like a perfect fit, and I ended up loving many parts of it!

What was your M.Eng. project and how did it relate to your previous studies?

My M.Eng. project was designing and running a PCB design seminar. I really enjoyed doing PCB design for my project team and during summer internships but found that there was no formal education for PCB design at Cornell in the ECE department. I worked with the Cornell Maker Club, for which I was an officer during my undergrad, and ran the seminar with 20 students. It was very rewarding to transfer some of the knowledge and skills I had gained over my four years at Cornell to other students. I hope the class continues now that I am gone!

Why is ECE an ideal major for someone interested in robotics?

ECE is so cross-disciplinary. With robotics, you need communications, power systems, digital design, analog design, firmware and more. You need to interface mechanical systems and the software running on those systems, and that's where ECE lives.

What have you been up to since graduating?

I recently moved to Boston to start working as an Electrical Engineer at Vecna Robotics, a warehouse robotics startup focusing on automated material handling. The skills I learned at Cornell definitely prepped me to start here, and I'm excited to keep applying and expanding my skills.

How did your ECE experience prepare you for what you are doing now?

Of course the basics of circuits classes and the like are crucial to be an electrical engineer in the workplace. But on top of that, my experience doing hands on work through my project team and the maker club prepared me to transfer those book skills to real hardware.

What advice would you give to students considering a similar path to yours?

Worry less about getting straight A's and more about getting your hands on some hardware! You have to build things to learn practical skills. Learn how to solder, play around with an Arduino or Raspberry Pi, pick an idea for a project and make it yourself! It can be intimidating at first, because you don't even know what you don't know, but start simple and learn from your mistakes.

HARNESSING CORNELL'S ENTREPRENEURIAL ENERGY

by Casey Verderosa

Growing up in Huntington, West Virginia, Austin Hickman had always envisioned "wheeling and dealing" as a businessperson. As he gravitated toward more concrete subjects in high school, such as math and science, practicality gained the upper hand.

"But it never really left me, the thought that entrepreneurship is exciting," he said.

Now a Ph.D. candidate in electrical and computer engineering, Hickman has been developing an aluminum nitride (AIN)-based power amplifier with the ability to produce millimeter-wave frequency signals that can travel farther than existing technology allows.

He mentioned his interest in business to his academic adviser, who suggested Cornell Engineering's Commercialization Fellowship program.

"My entrepreneurship experience prior to the fellowship was essentially zero," Hickman said. "That's really when it all hit the next level. Once you start, it's a rapid acceleration – like a rocket ship – and you just hold on."

The commercialization fellowship is one of many resources available to engineering students in the robust entrepreneurial ecosystem the university has cultivated in recent years. Hickman's company, along with two other startups affiliated with the College of Engineering, are taking advantage of every opportunity they can.

A trademark of the fellowship is enrollment in the National Science Foundation's I-Corps Teams Program, which trains researchers to identify the market for their product. Cornell is one of three universities that comprise the Upstate New York I-Corps Node. It's there that Hickman, like many other Cornell researchers, learned how to discover his customers.

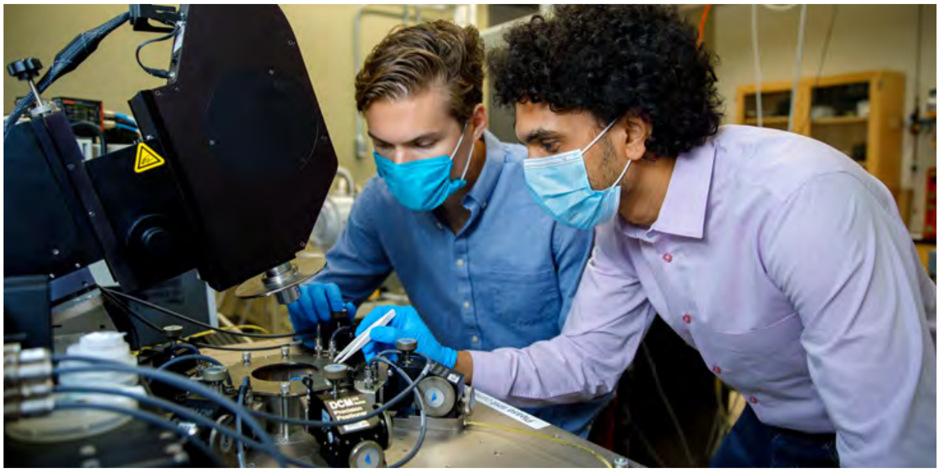
He enrolled in I-Corps in 2019 and learned through the experience that his technology could be used in defense radar systems and telecommunications – especially in the global race to develop sixth-generation wireless (6G) networks.

"It can be a little overwhelming because it's such a large space with so many competitors and established technologies that it's a lot to wrap your head around," Hickman said. "A year and a half ago I had no idea what the business environment surrounding 6G was like."

In early 2020 he co-founded a company, Soctera, based on technology from his doctoral research. This has been a busy year for his startup. The company was a recipient of the College of Engineering's annual Scale Up and Prototyping Award, which provides funding for academics whose technology may otherwise be passed up by institutional investors before their commercialization paths become clear.

The company secured membership with Launch NY, a nonprofit venture development organization serving upstate New York. It's also receiving mentorship from the Praxis Center for Venture Development, Cornell's on-campus incubator for startups in engineering, digital and physical sciences.

During their final year as Ph.D. students, Hickman and another Soctera's co-founder, Reet Chaudhuri, M.S. '16, will optimize their transistor technology and look for funding.



Soctera co-founders Reet Chaudhuri, M.S. '16, right, and Austin Hickman work on their aluminum nitride-based power amplifier, which produces millimeter-wave frequency signals that can travel farther than existing technology allows. Photo by Jason Koski/Cornell University

SEEING THE BIGGER PICTURE WITH MICRO-SCALE ROBOTICS

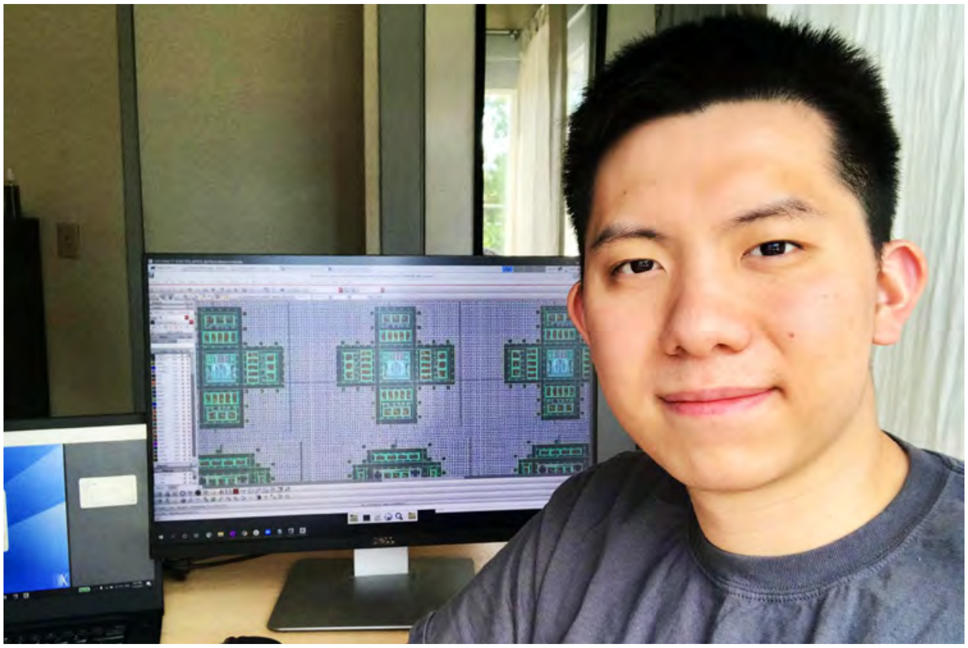
by Eric Laine

Over the past four years, Ken Ho '21 worked with Professors Alyssa Apsel and Christopher Batten as an undergraduate researcher in Cornell ECE. His research has been focused on the development of systems that leverage techniques in digital and analog integrated circuit design to explore novel applications such as ultralow power radio and micron-scale robotics.

That work has now earned him a fellowship from the National Science Foundation's Graduate Research Fellowship Program for his proposal, "Development of an Autonomous, μm-Scale Robotic System Using PCO Synchronization."

"My proposal was focused on tackling the issue of creating autonomous, micron-scale robotic systems," Ho said. "While autonomous macro-scale systems (e.g., self-driving cars) have become increasingly well understood, achieving similar behavior in the micro-scale under ultralow-power budgets (<1 microwatt) presents a unique set of challenges to be investigated."

Having worked previously on synchronization schemes for distributed radio systems, Ho proposed to apply these synchronization concepts from wireless system design in order to realize emergent behavior such as autonomous motion in microrobots. "The goal is to eventually be able to use these robots in a variety of multifunctional applications, including microsurgery and micro assembly," he said.



Ken Ho '21 with renderings of his micro-robots in the design software.

Funding from the GRFP will allow Ho to further his research in wireless systems as a graduate student. He will be joining the Berkeley Wireless Research Center (BWRC) this fall, where he hopes to broadly investigate current challenges in wireless communications and applications.

Ho credits support from Professors Apsel and Batten for helping him achieve this goal. "Since I first started doing ECE-focused research in my sophomore year, I have received invaluable technical advice and research perspective under their guidance," he said. "One of the most important things I learned from them is how to apply findings from within my area of expertise to potentially create new avenues of multidisciplinary research. Seeing the bigger picture is indeed important."

The NSF GRFP recognizes and supports outstanding graduate students who are pursuing research-based master's and doctoral degrees at accredited US institutions. The five-year fellowship includes three years of financial support including an annual stipend of $34,000 and a cost of education allowance of $12,000 to the institution.

ECE AWARDS

FACULTY AWARDS & HONORS

Jayadev Acharya, assistant professor, and **Qing Zhao**, professor, as members of the new USDA-NIFA AI Institute for Next Generation Food Systems, were awarded a share of $20 million from the National Science Foundation to help integrate a holistic view of the food system with AI and bioinformatics to understand biological data and processes, addressing issues of molecular breeding to optimize traits for yield, crop quality, and pest/disease resistance; agricultural production, food processing and distribution, and nutrition.

Khurram Afridi, associate professor, was selected to receive one of Cornell Engineering's annual Scale-Up and Prototyping Awards for his proposal, "Dynamic Capacitive Wireless Charging System for Electrified Vehicles."

Eilyan Bitar, associate professor and David Croll Sesquicentennial Faculty Fellow, published an op-ed in the Albany Times Union arguing that "the transition to an all-electric car future won't be possible without careful planning and coordination with the power grid and the companies that manage its operation."

Christina Delimitrou, assistant professor, is a recipient of Intel's 2020 Rising Star Faculty Award. Delimitrou has developed cluster management systems that introduced a new data-driven approach in cloud management which have been adopted by companies like Twitter and AT&T. Additionally, Delimitrou was named this year's TCCA Young Computer Architect by the IEEE Computer Society, recognizing her outstanding research contributions to the field of Computer Architecture.

Amal El-Ghazaly, assistant professor, was named an Engaged Faculty Fellow by Cornell's Office of Engaged Initiatives. She is developing a new course to assist new Ph.D. students in their transition to Cornell with the goal of strengthening the community and increasing retention for Ph.D. students from underrepresented minority groups.

Ziv Goldfeld, assistant professor, received an IBM 2020 University Award, which is intended to promote curriculum innovation to stimulate growth in disciplines and geographies that are strategic to IBM. Goldfeld received the award for the theoretical machine learning research he is doing jointly with collaborators from the IBM-MIT Watson AI Lab.

Zygmunt Haas, emeritus professor, and Zhong Zheng, ECE postdoc, received the Best Paper Award at the ICOIN 2021 conference. "Engineering a Network in the Sky," was among nearly 500 papers submitted. It describes a novel method of communication between unmanned aerial vehicles. Additionally, Haas was ranked 315 out of the top 1000 computer scientists in the United States, 496th in the world, by Guide2Research.

Debdeep Jena, the David E. Burr Professor of Engineering (ECE, MSE); **Huili Grace Xing**, the William L. Quackenbush Professor (ECE, MSE); and **Alyosha Molnar**, associate professor (ECE), received a 2020 Intel Outstanding Research Award for their project "Wide-Bandgap pFETs: Materials, Devices, and Circuits." This award is based on their seminal contributions to the p-channel FETs in wide bandgap semiconductors.

Edwin Kan, professor, published new research from his group in IEEE Access debuting a novel radio-frequency heartbeat sensor based on multi-point near-field observation via sensing antennas positioned outside clothing and over the heart.

Francesco Monticone, assistant professor, and Ph.D. student Federico Presutti published a new paper in Optica, "Focusing on bandwidth: achromatic metalens limits," which establishes, for the first time, fundamental limits on "metalenses," ultra-thin flat lenses able to function as ultracompact optical systems for focusing and imaging.

Kirstin Petersen, assistant professor, was named the Aref and Manon Lahham Faculty Fellow in the College of Engineering. The fellowship is intended to recognize early contributions to our understanding of collective intelligence in simple robot systems and the important role of building a community of excellence in robotics at Cornell.

Mert Sabuncu, associate professor, along with Ph.D. candidate Meenakshi Khosla and colleagues at Weill Cornell Medicine, published a paper in Science Advances, "Cortical response to naturalistic stimuli is largely predictable with deep neural networks," describing a new AI-based technology to gain new insights into how our brains respond to external stimuli.

Michael Spencer was awarded emeritus status. In 2016, Spencer moved on to serve a term as dean of the School of Engineering at Morgan State. His appointment as emeritus professor maintains a valuable connection between him, ECE and Cornell Engineering.

Zhiru Zhang, associate professor, won Best Paper at the 2021 International Symposium on Field-Programmable Gate Arrays for the paper "AutoBridge: Coupling Coarse-Grained Floorplanning and Pipelining for High-Frequency HLS Design on Multi-Die FPGAs." Additionally, Zhang received a $50,000 award from Facebook Research for his proposal titled "Algorithm-Systems Co-Optimization for Near-Data Graph Learning." The project aims to improve the efficiency of machine learning on graphs, which are being adopted in a new generation of recommender systems.

Photo by Patty Clark.

Visit the ECE website for the latest faculty and student news, awards and spotlights.

ece.cornell.edu/ece/news

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ECE AWARDS

Ph.D. Student Awards and Honors

Yingjie Bi (Tang Lab) is the winner of both the 2021 Society for Industrial and Applied Mathematics and the 2020 INFORMS Optimization Society Student Paper Prizes for "Duality gap estimation via a refined Shapley-Folkman lemma," co-authored by Bi's advisor, A. Kevin Tang.

Chenhui Deng (Zhang Group) is the first author of the paper "GraphZoom: A Multi-level Spectral Approach for Accurate and Scalable Graph Embedding," which is accepted to the International Conference on Learning Representations (ICLR'2020) as an Oral Presentation.

Jordan Dotzel (Zhang Group) was selected as one of the 2020 SRC TECHCON Student Presentation Award Winners. There were 160 research presentations, papers and posters from GRC, JUMP and nCORE, from which just 10 Student Presentation Award Winners were announced.

Ahmed Elshafiey (advised by Professor Hammer in the Lab of Plasma Studies) had his paper "Implosion Mediated Gas-Puff Hybrid X-pinch" selected as a featured article in the journal Physics of Plasmas.

Firehiwot Gurara (Afridi Group) was awarded a fellowship from the National Science Foundation's Graduate Research Fellowship Program.

Zeki Hayran (Monticone Lab) won third prize in the Metamaterials 2020 student paper competition for his paper titled "Temporally Modulated Non-Hermitian Optical Systems Based on Epsilon-Near-Zero." Additionally, Hayran and his advisor, Assistant Professor Francesco Monticone, published a new paper in ACS Photonics: "Capturing Broadband Light in a Compact Bound State in the Continuum."

Austin Hickman (Jena-Xing Lab), received the SSDM 2020 Young Researcher Award from the International Conference on Solid State Devices and Materials.

Weizhe Hua (Suh Group) received a 2021 Facebook Fellowship in Systems for Machine Learning.

Okan Koksal (Rana Group) received the 2021 Student Presentation Award at the Annual Meeting of the American Physical Society.

Kevin Lee (Jena-Xing Lab) received the best poster award at the 77th Device Research Conference, the longest running device research meeting in the world, for his poster titled "Efficient InGaN P-contact for deep-UV Light Emitting Diodes."

Lei Li (Jena-Xing Lab) was awarded a 2021 Graduate Fellowship from the IEEE Microwave Theory and Techniques Society.

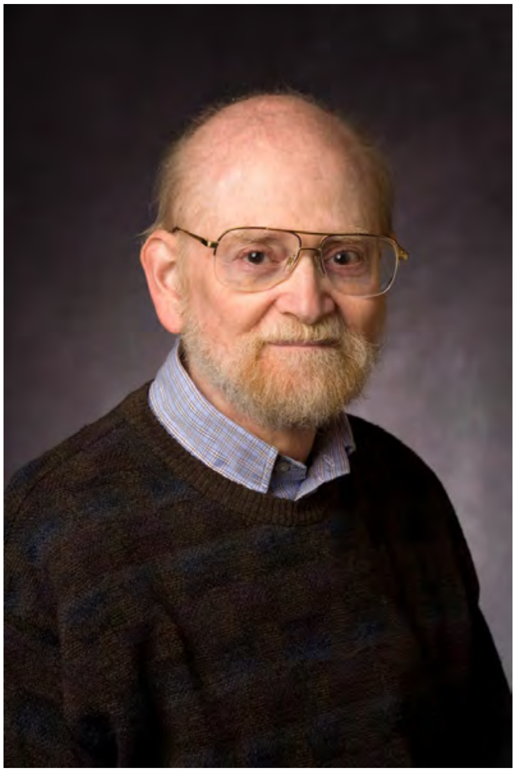
Wenshen Li (Jena-Xing Lab) won the best student paper award at the 2020 Electronic Materials Conference. Additionally, Li is the lead author of the paper published in Applied Physics Letters, titled "Near-ideal reverse leakage current and practical maximum electric field in Î²-Ga2O3 Schottky barrier diodes."

Kunal Shastri (Monticone Lab) won the 2021 ECE Outstanding Ph.D. Teaching Assistant Award for his work with Assistant Professor Francesco Monticone in ECE 3030 Electromagnetic Fields and Waves.

Thomas Tapen (Apsel Group) won this year's ECE Outstanding Thesis Research Award. His research is focused on multi-octave passive mixer-based duplexing transceivers.

Ecenur Üstün (Zhang Group) won Best Paper at the 2021 International Symposium on Field-Programmable Gate Arrays for her paper "AutoBridge: Coupling Coarse-Grained Floorplanning and Pipelining for High-Frequency HLS Design on Multi-Die FPGAs." The paper was co-authored by ECE professor Zhiru Zhang and others. Additionally, Ustun was selected to participate in the 2020 EECS Rising Stars Workshop, which is aimed at increasing the numbers of women interested in pursuing academic careers in computer science, computer engineering and electrical engineering.

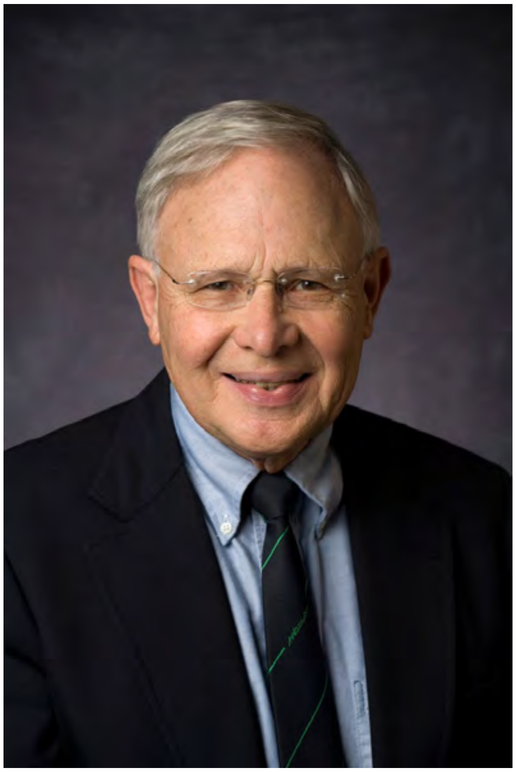
REMEMBERING TWO TITANS OF ECE



Terrence L. Fine

1939-2021

Terrence L. Fine, emeritus professor of electrical and computer engineering, died January 31, 2021 at age 81. Fine was known especially for his contributions to the defense and development of alternatives to the classical calculus for probabilistic modeling and decision-making. He was the recipient of the first patent awarded in the area of statistical delta modulation. Other contributions include Fine's theorem, the Fine numbers and the Fine-McMillan quantizer. He served as director of Cornell's multidisciplinary Center for Applied Mathematics from 1999 to 2004.



Thomas W. Parks

1939-2020

Thomas W. Parks, emeritus professor of electrical and computer engineering, died December 24, 2020 at the age of 81. Parks authored over 100 books and research papers in digital signal processing over the course of his career and received several notable awards for his work, including two awards for teaching excellence while at Cornell. He was a Life Fellow of the Institute of Electrical and Electronics Engineers (IEEE) and a recipient of the prestigious IEEE Jack S. Kilby Gold Medal for his work on interpolation and the 'Parks-McClellan algorithm.'

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