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# SYSTEMSOLUTIONS

THE INSTITUTE FOR SYSTEMS RESEARCH
A. JAMES CLARK SCHOOL *of* *ENGINEERING*

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# Microelectronics

## Semiconductor chips, security, bio-inspiration, sensors, devices, advanced materials, and an embedded systems graduate program

*ISR remembers our founding faculty member Roger Brockett—page 13*

# ISR's microelectronics expertise

The Department of Defense USDR&E office is evaluating proposals from regional university/industry collaboratives for its Microelectronics Commons project.

The project will advance U.S. interests in:

- Chips and hardware security
- Energy
- Materials
- Micro devices
- Neuromorphic
- Security
- Sensors

In our region, universities and critical industries are working together on the Mid-Atlantic Semiconductor Collaborative proposal. Last year, ISR and ISR Director Ankur Srivastava were tasked by Clark School Dean Samuel Graham, Jr. with organizing the University of Maryland's efforts within this collaborative. With its roster of highly skilled faculty experts, ISR itself is a key part of the microelectronics expertise needed for this immense undertaking.



## Chips and hardware security

ISR research is advancing semiconductor chip technology in domains including chip design, building chips with new capabilities (particularly for sensing) and addressing challenges in chip manufacturing. Specific research areas include biochips, hardware architecture and security, and advanced ICs.

Faculty include Pamela Abshire (ECE/ISR), Behtash Babadi (ECE/ISR), Cornelia Fermüller (UMIACS), Timothy Horiuchi (ECE), Nuno Martins (ECE/ISR), Adam Porter (CS/UMIACS), Gang Qu (ECE/ISR), William Regli (CS/ARLIS), Shihab Shamma (ECE/ISR), Ankur Srivastava (ECE/ISR), and Miao Yu (ME/ISR).

## Energy

ISR is helping to build a more sustainable, electric future for everything from planes to automobiles to implantable medical devices. Our researchers are improving existing types of batteries and exploring new possibilities for energy storage. They are uncovering ways to harvest energy from the environment and to manage the heat generated by electric devices. Specific areas include batteries, bioscaffolds, and energy storage devices; energy harvesting and thermal management; power electronics and microinverters; renewable and efficient energy.

Faculty include Gary Rubloff (MSE/ISR), Mark Fuge (ME), Reza Ghodssi (ECE/ISR, Alireza Khaligh (ECE/ISR), Sennur Ulukus (ECE/ISR), and Miao Yu (ME/ISR).

## Materials

ISR materials science research greatly benefits the development of more powerful and sophisticated microelectronics devices. ISR is particularly strong in battery materials science, thin films, and atomic layer deposition. Research includes chemical energy conversion, electrochemical energy, energy efficiency, power systems, renewables, energy systems safety, and reliability.

Faculty include Raymond Adomaitis (ChBE/ISR), Mark Fuge (ME), and Gary Rubloff (MSE/ISR).

## Micro devices

Micro devices bring together and transform microelectronics developments into useful packages. They make the benefits of microelectronics possible, in long-awaited breakthroughs like better biomedical devices, and in new micro devices never before imagined.

Faculty include Pamela Abshire (ECE/ISR), Mark Fuge (ME), Reza Ghodssi (ECE/ISR), Jeffrey Herrmann (ME/ISR), Timothy Horiuchi (ECE), Richard La (ECE/ISR), Nuno Martins (ECE/ISR), Eleonora Tubaldi (ME), Min Wu (ECE/UMIACS), and Miao Yu (ME/ISR).

## Neuromorphic

Understanding how the brain's neurons connect and process information can increase our understanding of this complex and powerful organ, and lead to vast improvements in computing and devices. Domains include health care, robotics, artificial intelligence, and defense applications. Research areas include cognitive sensors, neuronal learning, bio-inspired flight technologies, sound and speech processing, and mental health assessing tools based on speech patterns.

Faculty include Pamela Abshire (ECE/ISR), Behtash Babadi (ECE/ISR), Carol Espy-Wilson (ECE/ISR), Cornelia Fermüller (UMIACS), Timothy Horiuchi (ECE), Nuno Martins (ECE/ISR), Shihab Shamma (ECE/ISR), Jonathan Simon (ECE/ISR/Biology), and Miao Yu (ME/ISR).

## Security

ISR is at the forefront of both hardware security and cybersecurity research related to microelectronics. The combination of engineering expertise and well-established federal and industry partnerships in this area has enabled our faculty to win large hardware security contracts and cybersecurity grants. Primary research areas include design obfuscation, side-channel attacks, hardware trojans, embedded devices, wireless incentive compatible and physical layer security, non-black box cryptography and machine learning security and privacy issues.

Faculty include John Baras (ECE/ISR), Dana Dachman-Soled (ECE), Nikhil Chopra (ME), Jeffrey Herrmann (ME/ISR), Craig Lawrence (ISR/ARLIS), Michael Johns (ARLIS), Dinesh Manocha (ECE/CS/UMIACS), Michael Otte (AE), Derek Paley (AE/ISR), Nick Pandza (ARLIS), Adam Porter (CS/UMIACS), Gang Qu (ECE/ISR), William Regli (CS/ARLIS), Warren Savage (ARLIS), Ankur Srivastava (ECE/ISR), Sennur Ulukus (ECE/ISR), and Huan "Mumu" Xu (AE/ISR).

## Sensors

Sensors are an important part of many microelectronic devices. ISR researchers have decades of expertise developing sensors for many different purposes, from detecting pathogens and explosives in public spaces, to finding disease biomarkers inside the human body. They also are developing new kinds of sensors with enhanced capabilities based on neuromorphic and biological ideas. Research areas include general sensors, sensors used in medicine, and neuromorphic sensors.

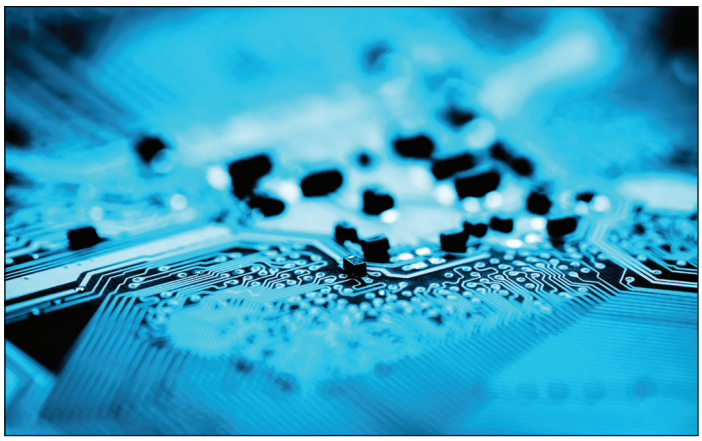
Faculty include Pamela Abshire (ECE/ISR), Reza Ghodssi (ECE/ISR), Timothy Horiuchi (ECE), Nuno Martins (ECE/ISR), Shihab Shamma (ECE/ISR), and Miao Yu (ME/ISR).

# Coming in Fall 2023—Embedded Systems Master of Engineering and Certificate

The program was developed by ISR Director Ankur Srivastava (ECE/ISR) and Professor Gang Qu (ECE/ISR).

Embedded systems are used in a wide range of applications, from consumer electronics like smart phones and smart appliances to automotive and aerospace systems. They can be found in everything from electronic toys and home automation systems to medical devices and industrial automation equipment. Embedded systems are designed to operate in real-time, with deterministic response times and minimal overhead. This means they are optimized for performance and reliability, rather than general-purpose computing tasks. They are essential to the design and development of many products. Embedded systems engineers may work on the hardware design, firmware development, or software programming.

ISR Director Ankur Srivastava (ECE/ISR) and Professor Gang Qu (ECE/ISR) have created a multidisciplinary graduate program that covers both the technical and management aspects of embedded systems design. The program begins in the Fall 2023 semester.



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The Master of Engineering in Embedded Systems (MEngES) is a professional degree that requires coursework only. The Graduate Certificate in Engineering, Embedded Systems (CGEN) is a 12-credit certificate designed for working professionals seeking to obtain additional credentials in embedded systems. Both programs are offered through Maryland Applied Graduate Engineering and can be completed online.

Core courses cover design and optimization of embedded software, embedded hardware, and networking and distributed systems. There also is a hands-on hacking lab. Students may choose to learn about emerging topics in embedded systems, including security and privacy, low power and energy-efficient design, project management, data science and machine learning, as well as specific embedded systems in smart grid, smart home, medical devices, and vehicular systems.

**Learn more** about this program, have your questions answered, and apply at *mage.umd.edu/embedded-systems.*

# Improving algorithms for thermal medical devices

During the COVID-19 pandemic, we became used to being scanned by thermal camera devices that remotely checked our temperature and respiratory rate. These infrared thermographs (IRTs) were widely installed in medical facilities, airports and offices, and are likely here to stay because the vital signs they measure are useful infectious disease biomarkers.

Hoping to make the devices work better, a team led by ISR-affiliated Professor Min Wu (ECE/UMIACS) is improving the software algorithms that automatically identify the best facial locations to extract these vital signs. "Detecting Essential Landmarks Directly in Thermal Images for Remote Body Temperature and Respiratory Rate Measurement With a Two-Phase System" has been published in *IEEE Access*.

The new system automatically and accurately estimates the inner canthus and nostril locations in thermal images. It can be applied in IRT algorithms to provide reliable temperature and respiratory rate estimates during infectious disease outbreaks.

**Learn more.** Read a more detailed version of this story on the ISR website: *go.umd.edu/822therm*.

# Better 'lifetime predictions' for NAND memory


REBECCA COPELAND

If you've used a smart phone, a flash drive or an external SSD drive for your computer, you've probably used NAND flash memory. NAND, shorthand for the boolean operator and logic gate "NOT AND," is a popular memory and storage solution for solid-state drives and smart phones; laptop and desktop computers; digital cameras and audio players; video games; and scientific, industrial and medical electronics.

NAND offers fast write and erase times, and delivers density at a low cost per bit, while providing greater endurance than its competitor, NOR flash memory. However, NAND storage is prone to wear, erasure, crosstalk and sensitivity issues that affect performance and reliability. There are only so many operable programming and erasing cycles NAND can run before it fails. But when will that happen to your device?

It's important to be able to predict how long a flash memory storage system will last before failing. Such estimates are known as "lifetime predictions," and machine learning models have been introduced to improve their reliability and accuracy. But resource requirements like overhead allocation and frequency of running the predictions also must be considered, because conducting excessive prediction actions can lead to unnecessary resource consumption on the device.

Research by Professor Gang Qu (ECE/ISR) and colleagues published in *IEEE Transactions on Computers* proposes techniques that can minimize redundant prediction operations by exploiting reliability variation.

"ADLPT: Improving 3D NAND Flash Memory Reliability by Adaptive Lifetime Prediction Techniques" was written by Qu; his former student Md Tanvir Arafin, (EE Ph.D. 2018), an ECE assistant professor at George Mason University; Zhaojun Lu, Qu's former postdoctoral researcher, who currently is an assistant professor at Huazhong University of Science and Technology; and additional authors in Huazhong and Wuhan, China.

To effectively reduce the overheads of lifetime prediction, the researchers developed a prediction judging method based on erase duration and raw bit error number.

To explore reliability variation, the authors investigated the error distribution of different 3D flash chips. They analyzed raw bit error rate (RBER) variation under two different kinds of stress: program-and-erase (P/E) cycling and data retention. They noted the features of RBER increasing after P/E cycling are similar among flash chips manufactured by the same vendor. They also found that RBER distribution becomes wider when erase duration increases and that the values of RBER measured only under P/E stress could not effectively reflect flash data retention capability.

Qu's team proposed a prediction judgment method called "adaptive lifetime prediction techniques" (ADLPT) that exploits reliability variation and reduces redundant prediction by 90 percent. ADLPT identifies necessary prediction by detecting the variation of erase duration and raw bit errors. Because each manufacturing vendor's products are slightly different from its competitors, the ADLPT model is trained product by product.

The model minimizes redundant prediction operations and is an improvement in both prediction frequency and required memory space for metrics. Using ADLPT can improve prediction performance of the static model from a 0.62 to 0.88 F1 score. This work will inspire further studies of NAND flash memory reliability and new techniques for building effective storage systems.

# A gachapon for private information retrieval

Gachapon is a capsule toy, widely popular in Japan and elsewhere, that is dispensed through a vending machine equipped with a roulette mechanism. This enhances the fun, since it makes receiving an item random and unpredictable for customers. Standing before a gachapon machine that shows a variety of possible toys, a customer has no idea which toy actually will be dispensed. Because gachapons are typically packaged in identical opaque 3-inch spheres, they are also called "blind boxes." The covers of blind boxes are identical in every way—nobody, including the manufacturer, knows what exactly is inside until the customer opens the packaging.

In digital form, the gachapon concept is being adapted as a random-type item for online games and 3D printing. Now Professor Sennur Ulukus (ECE/ISR) and her Ph.D. student Zhusheng Wang are considering the gachapon's usefulness for Random Symmetric Private Information Retrieval (RSPIR). Their paper, "Digital Blind Box: Random Symmetric Private Information Retrieval," introduces the idea.

In canonical Private Information Retrieval (PIR), a user downloads a message out of K messages from N non-colluding and replicated databases in such a way that no database can know which message the user has downloaded (user privacy). In Symmetric Private Information Retrieval (SPIR), not only do the databases not know which message the user has downloaded, the user itself cannot learn anything further than the particular message it has downloaded (database privacy).

In RSPIR, different from SPIR, the user is unable to query the databases. The user does not pick a specific message to download and instead is content with any one of the random messages received. In RSPIR, databases need to send symbols to the user in such a way that the user is guaranteed to download a message correctly (random reliability), the databases do not know which message the user has received (user privacy), and the user does not learn anything further than the one message it has received (database privacy).

## Abshire part of DARPA JUMP 2.0 'CogniSense' center

DARPA, the Semiconductor Research Corp. and a consortium of defense and semiconductor companies have launched the second Joint University Microelectronics Program (JUMP 2.0). Seven new centers are focused on keeping the U.S. at the forefront of microelectronics innovation.

Professor Pamela Abshire (ECE/ISR) is a co-PI in the JUMP 2.0 center "CogniSense." Short for Center on Cognitive Multispectral Sensors, CogniSense is focused on sensing capabilities and embedded intelligence that can enable fast and efficient action generation. Led by Saibal Mukhopadhyay of the Georgia Institute of Technology, CogniSense brings together 20 researchers from 13 universities.

The other six JUMP 2.0 centers are:

- COCOSYS, the Center for the Co-Design of Cognitive Systems, creating next-generation AI systems and architectures. (Georgia Tech)
- CUBIC, the Center for Ubiquitous Connectivity Communications and Connectivity, focused on efficient communication technologies for ICT systems. (Columbia University)
- ACE, Evolvable Computing for Next Generation Distributed Computer Systems, looking at distributed computing systems and architectures in an energy-efficient compute and accelerator fabric. (University of Illinois Urbana-Champaign)
- PRISM, the Center for Processing with Intelligent Storage and Memory, exploring emerging memory devices and storage arrays for intelligent memory systems. (University of California, San Diego)
- CHIMES, the Center for Heterogeneous Integration of Micro Electronic Systems, developing novel electric and photonic interconnect fabrics and advanced packaging. (Pennsylvania State University)
- SUPREME, the Superior Energy-Efficient Materials and Devices center, focused on novel materials, devices, and interconnect technologies to enable next-generation digital and analog applications. (Cornell University)

"We are at an inflection point in the evolution of computing systems and technologies," said Roman Caudillo, Intel-SRC assignee and JUMP 2.0 Director. "JUMP 2.0 is a key component in identifying and forging the best path forward by driving public-private investment for disruptive innovation in microelectronics systems at scale. I look forward to helping guide the semiconductor industry through the SRC JUMP 2.0 program in cooperation with DARPA in the years to come."

## Dachman-Soled part of new NSF quantum cybersecurity grant

Many familiar aspects of cryptography will look very different in a world where everyone, both honest parties and attackers, has access to quantum computers. ISR-affiliated Associate Professor Dana Dachman-Soled (ECE/UMIACS) is part of a $1M NSF award that is looking into new security possibilities. Jonathan Katz (CS/UMIACS) is the PI for "Cryptography in a Post-Quantum Future."

The researchers are exploring constructions that can be proven secure in a post-quantum future. They are focused on fundamentally changing the way that cryptography is taught, developed and practiced.

**Learn more** at *go.umd.edu/622DDSQ*.

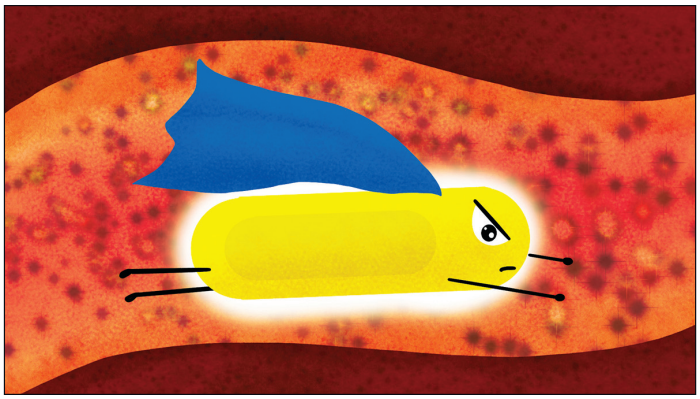


ILLUSTRATION BY VALERIE MORGAN, UMD MARKETING AND COMMUNICATION

THE UMD PUBLICATION *MARYLAND TODAY* ILLUSTRATED A STORY ON THE CAPSULE WITH THIS CLEVER "SUPER PILL" GRAPHIC.

## The evolving ingestible capsule

Some 3.1 million people in the United States suffer from chronic gastrointestinal (GI) autoimmune disorders like inflammatory bowel disease, Crohn's disease and ulcerative colitis. Medical science has made substantial advances in treating these diseases through "systemic" therapies like pills, injections and infusions. Sadly, the medicine can't be targeted to the inflammatory lesions that characterize these gut diseases, and it causes substantial side effects.

Scientists are working on alternatives, including an ingestible, minimally invasive capsule that can detect, monitor, and treat chronic problems inside the GI tract.

Practical problems remain to be solved before these capsules can be deployed. Professor Reza Ghodssi's (ECE/ISR) MEMS Sensors and Actuators Laboratory (MSAL) has been making steady progress in addressing the needed innovations.

### Anchoring the capsule for drug delivery

"Thermomechanical Soft Actuator for Targeted Delivery of Anchoring Drug Deposits to the GI Tract" was published in a December 2022 issue of *Advanced Materials Technologies*. It was written by MSE Ph.D. student Joshua Levy, BIOE Ph.D. student Michael Straker, alum Justin Stine (ECE Ph.D. 2023), UMD Research Associate Luke Beardslee, alum Vivian Borbash (ECE B.S. 2022), and Ghodssi. Ghodssi is the Ph.D. advisor for Levy, Straker and Stine; all are associated with the Robert E. Fischell Institute for Biomedical Devices.

The research demonstrates a compact mesoscale spring actuator to anchor the capsule, allowing it to deliver a drug deposit to locations in the GI tract mucosa. **Learn more** at *go.umd.edu/1222anchor*.

### FRRB coatings for capsule contents protection

Components inside ingestible capsules destined for the intestines must be protected from the acidic fluids and solids they encounter in the stomach. A new solution for this packaging challenge was published in the Nature journal Microsystems & Nanoengineering this spring.

MSAL has developed a hybrid, passive, freestanding, packaging technology called FRRB (freestanding region responsive bilayer) that can be used to cover, then expose, a capsule's mm-scale components.

"Freestanding Region Responsive Bilayer for Functional Packaging of Ingestible Devices" was written by Michael Straker, Joshua Levy, Justin Stine, Vivian Borbash, Luke Beardslee and Reza Ghodssi.

**Learn more** at *go.umd.edu/523frrb*.

# Funding for ISR faculty

## ArtIAMAS: third-year funding of up to $15.1M

The University of Maryland's five-year ArtIAMAS (AI and Autonomy for Multi-Agent Systems) cooperative agreement with the U.S. Army Research Lab (ARL) has received third-year funding of up to $15.1M. Professor Derek Paley (AE/ISR) is the lead researcher for the extensive project, which also includes faculty from the University of Maryland Baltimore County (UMBC). Co-PIs are Professor Jeffrey Herrmann (ME/ISR) and ISR-affiliated Professor Dinesh Manocha (CS/UMIACS/ECE).

The agreement builds on a more than 25-year research partnership between UMD and ARL in AI, autonomy, and modeling and simulation. The third-year funding is one of the largest single-year sponsored research awards in Clark School history. It brings ArtIAMAS funding to $26.5M to date. ArtIAMAS began in May 2021; funding eventually could reach $68 million.

Research focuses on safe, effective, and resilient capabilities and technologies that work intelligently and cooperatively with each other and humans, and spans engineering, robotics, computer science, operations research, modeling and simulation, and cybersecurity.

ISR faculty and their students are playing key roles in developing technologies to reduce human workload and risk in complex environments:

**Closer Human-Machine Teaming** explores how AI/ML sensor and computing systems can improve situational awareness, behavioral and physiological health assessment, battlefield uses, forensics, and metareasoning. Dinesh Manocha is the principal investigator. He is joined by ISR Director and Professor Ankur Srivastava (ECE/ISR); Assistant Professor Huan "Mumu" Xu (AE/ISR); ISR-affiliated Professor Nikhil Chopra (ME); Professor Ramani Duraiswami (CS/UMIACS); FPE Adjunct Lecturer Chris Campbell; Professor Ming Lin (CS/UMIACS); ISR Visiting Research Scientist Craig Lawrence; ISR-affiliated Professor Adam Porter (CS/UMIACS); Jeffrey Herrmann; and UMBC faculty.



**Collaborative Autonomy Research, Development, Test and Evaluation Infrastructure** addresses the lack of standard shared infrastructure, baseline scenarios, tools and common models for collaborative autonomous systems. Jeffrey Herrmann is the principal investigator. Co-PIs are Derek Paley; Craig Lawrence; Adam Porter; Dinesh Manocha; Ming Lin; Assistant Professor Michael Otte (AE); and MATRIX Lab Director of Operations and Outreach Matt Scassero.

**Harnessing the Data Revolution** addresses networking and sensing, a battlefield Internet of Things (IoT) testbed, adaptive cybersecurity for battlefield IoT, OpenML cross-domain learning, integrated mission planning for urban environments, and predictive maintenance for Army assets. Led by UMBC faculty, it also includes Research Engineer Michael Pack (CEE) and Professor Peter Sandborn (ME).

## Disrupting illicit kidney trafficking networks

Organ trafficking is an insidious form of human trafficking that preys upon the poor and vulnerable. Refugees in particular are approached to sell their organs in exchange for passage to other countries.

Kidneys are by far the most traded organ. The complex transnational kidney trade consists of young and healthy, but poor, sellers/"donors"; affluent but desperate buyers; transplant service providers like surgeons, hospitals, and labs; brokers who often provide similar services for other illicit trades; and transnational crime networks. Like playing "whack-a-mole," controlling trafficking in one country raises its prevalence elsewhere.

Professor Michael Fu (BMGT/ISR) is a co-PI on a $1M, four-year NSF grant focused on how these networks work and evolve. "Evolution of Global Illicit Kidney Trade Networks: Identification, Reconstruction, and Disruption" aims to produce a framework that models and predicts kidney trade network evolution and identifies its common patterns and mechanisms. Fu will be developing simulation optimization algorithms to handle the uncertain features and complex dynamic evolution of the networks.

**Learn more** at *go.umd.edu/1022kid.*

## Shared information theory and applications

Professor Prakash Narayan (ECE/ISR) is the PI for a three-year, $600K NSF grant, "Shared Information: Theory and Applications."

He will develop the shared information concept as a fundamental, quantifiable, and compact measure for capturing interdependence among multiple correlated signals. This will emulate and enhance Claude Shannon's idea of mutual information as a measure of correlation between two random signals.

Narayan will investigate the role of shared information for operational meanings in network information theory. He will establish theoretical and practical roles for shared information in network data compression, distributed function computation, reliable and secure information transmission, signal cluster detection, and a new category—statistical estimation and learning algorithms. Applications include smart homes, satellite image reconstruction, and messaging protocols in automated guided vehicles and drone swarms.

## 5G secure testbed

ISR Visiting Research Engineer Wayne Phoel is heading up a 5G secure testbed in the A.V. Williams Building. Funding, renewed in 2023, comes from the Cellular Telecommunications and Internet Association (CTIA), which represents the U.S. wireless communications industry. Launched in January 2022, the testbed is devoted to the security of commercial 5G networks. In Fall 2022, CTIA brought FCC commissioners to visit the testbed on two occasions: Nathan Simington in October and Geoffrey Starks in December.

PHOTO COURTESY CTIA

WAYNE PHOEL (L) AND FCC COMMISSIONER NATHAN SIMINGTON IN THE 5G SECURE TESTBED.

## A new way to study speaker pronunciation habits

Professor Carol Espy-Wilson (ECE/ISR) is the PI for a three-year, $500K NSF award, "Estimating Articulatory Constriction Place and Timing from Speech Acoustics." Co-PIs are Suzanne Boyce, University of Cincinnati; and Mark Tiede, Haskins Laboratories, Inc.

They will use recordings to study pronunciation habits that differ between individuals, and across languages and dialects, accounting for many aspects of accents, speech disorders and speaking styles.

The project will improve the researchers' speech inversion tool, enabling it to read acoustic recordings. Machine learning will recover details of articulation directly from the speech signal. This will help it identify dysarthria, a timing disruption associated with brain damage. It also may aid in tracking changes resulting from depression and schizophrenia.

## Austin-led project is one of 11 DoD Minerva Research Initiative awards for 2023

The Department of Defense's Minerva Research Initiative has awarded $18 million in grants to 11 university-based faculty teams for basic research in social and behavioral sciences relevant to national security.

ISR-affiliated Associate Professor Mark Austin (CEE) is the PI for one of these projects, "Semantic Foundations and Formal Methods for Evolutionary System-of-System Architectures." Austin, an expert in civil systems, semantic modeling, digital twins for urban networked systems, machine learning and systems engineering, is joined by Professor Jennifer Golbeck (Information Studies) as co-PI. Golbeck is an expert in social networks, social media, and privacy.

Many factors make it hard for military systems to integrate and deploy new technologies. There is a strong need for new approaches to understand, model, synthesize and optimize the operations of large-scale, distributed institutions and organizations ("system-of-systems" or SoS). This project will explore the benefits of semantic foundations and formal methods for synthesizing and formally analyzing evolutionary SoS decision models.

## ISR faculty part of seven UMD Grand Challenges projects

Seven projects led by ISR faculty have been awarded 2023 funding through the University of Maryland's Grand Challenges program. The program comprises 50 projects worth a total of $30 million. **Learn more** about the overall program at *go.umd.edu/522GC*.

### Microbiome sciences

Reza Ghodssi (ECE/ISR) is part of a team working on a global health and climate change project to develop technologies that can rapidly assess, characterize and manipulate microbial communities, as well as computational analytic frameworks for this data-intensive field.

### Values-centered artificial intelligence

Huan "Mumu" Xu (AE/ISR) and Pratap Tokekar (CS/UMIACS) are pursuing research to ensure AI is ethical, fair, trustworthy, transparent, supports human creativity, and facilitates privacy. They are working with the Army Research Laboratory and the National Institute of Standards and Technology.

### Inclusivity through technology

Carol Espy-Wilson (ECE/ISR) and colleagues are creating augmented spaces for communication that negotiate differences and bridge gaps in neurodiverse workplaces. Their video-calling platform for autistic people promotes mutual understanding by highlighting team sentiment, building rapport with strangers, connecting past and current topics in conversations, and unobtrusively identifying and resolving misunderstandings.

### Machine learning to measure and improve K-12 mathematics equity

Carol Espy-Wilson (ECE/ISR) and colleagues are combining machine learning, educational theory, and behavioral sciences to deliver an effective, affordable, and scalable mechanism that can measure and improve equity-focused teaching in K-12 math classrooms.

### Music education for all through AI

ISR-affiliated Cornelia Fermüller (UMIACS) and Irina Muresanu (ARHU/UMIACS) are building teaching technology that can reach underrepresented students. Their AI platform, VAIolin, will change how students learn how to play an instrument, help them master principles and skills, facilitate self-analysis, and enhance independent learning.

### Energy harvesting for UAVs

ISR-affiliated Cecilia Huertas Cerdeira (ME) is developing onboard energy harvesters that will enable UAVs to recharge their batteries while in use. Existing components will be used to harvest energy, minimizing added weight.

### Self-driving e-scooters

Professor Derek Paley (AE/ISR) is using robotics, engineering, and computer science to create self-driving e-scooters for urban settings.

## More funding

### Next generation energy storage

Professor Gary Rubloff (MSE/ISR) has secured $150K in funding from ST on Co for "Enabling Ion-Conducting Solid Electrolyte Films for Next Generation Energy Storage."

### AI/ML federated learning

ISR-affiliated Professor Dinesh Manocha (ECE/CS/UMIACS) and Visiting Assistant Research Scientist Amrit Bedi (ISR) are receiving $50K in funding from Amazon Research Awards (ARA) for their AI/ML project, "Ensuring Fairness via Federated Learning beyond Consensus." Federated learning is a decentralized way to unlock information that feeds new AI applications and trains existing AI models without individual users' data being seen or collected. The actual data never leave an individual mobile phone, laptop, or private server.

### Electro-thermally integrated traction inverter

Professor Alireza Khaligh (ECE/ISR) is the PI for "Electro-Thermally Integrated Traction Inverter," a three-year, $500K NSF award. The funding will enable him to design and develop a high power-density traction inverter for next-generation electric vehicles. Professor Bongtae Han (ME) is the co-PI.

Wide bandgap bare-die silicon carbide power semiconductor devices will be incorporated into an electro-thermally integrated design framework to achieve extreme power density. This will overcome limitations in power module designs and lead to advancements and generic methodologies.

# Neuroscience research shedding light on the brain

## Uncovering the mysteries of cortical neuronal networks

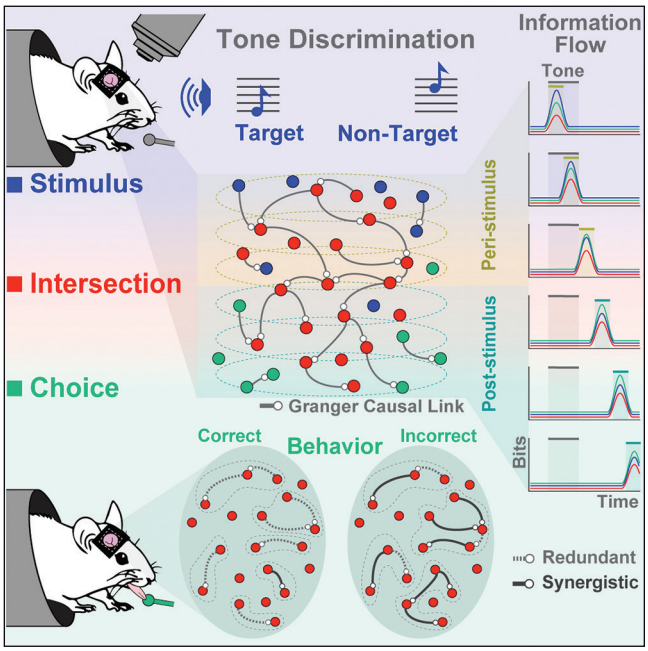
What's going on inside our brains when our senses gather information, we interpret what it means, then we act on our decisions? Recent UMD and Johns Hopkins University (JHU) work published in the journal *Cell Reports* provides some answers.

"Sequential transmission of task-relevant information in cortical neuronal networks" was written by a team led by Professor Patrick Kanold (formerly UMD, now JHU), Associate Professor Behtash Babadi (ECE/ISR), and Stefano Panzeri (Laboratory of Neural Computation, Istituto Italiano di Tecnologia in Italy).

As mammals navigate the environment, their brains help them behave appropriately by processing sensory information and its context. The researchers looked at how individual neurons and the cortical networks they form implement this information processing.

Two-photon imaging was used to record neuronal activity from the primary auditory cortex of mice during a pure-tone discrimination task where the mice not only need to recognize which tone is being presented but also what it means. The researchers found the mice used specialized neurons to integrate task-related information. The mice formed functional networks whose structures encode both sensory input and behavioral choice.

Additionally, the research team found that while some neurons carry only acoustic information and some carry information about the choice the animal has made, others specifically carry the intersection of the two—i.e., information about sensory input used to inform the animal's choice. Further examination of these "intersection neurons" showed that although individually they carry information transiently, they formed networks in which task-relevant information persisted and was sequentially transmitted between neurons throughout a task's duration.




GRAPHIC BY NIKOLAS FRANCIS

WHEN THE MICE PERFORMED AN AUDITORY DISCRIMINATION TASK, THE AUTHORS FOUND SOME NEURONS ONLY CARRIED ACOUSTIC INFORMATION WHILE OTHERS CARRIED INFORMATION ABOUT THE ANIMAL'S CHOICE. INTERESTINGLY, SOME NEURONS CARRIED "INTERSECTION" INFORMATION ABOUT BOTH.

THE RESEARCHERS FOUND THE INTERSECTION NEURONS FORMED NETWORKS IN WHICH TASK-RELEVANT INFORMATION PERSISTED AND WAS TRANSMITTED SEQUENTIALLY THROUGHOUT THE TASK DURATION.

FOR CORRECT DECISIONS, THE INFORMATION SHARED BETWEEN INTERSECTION NEURONS WAS MOSTLY REDUNDANT. BUT WHEN THE ANIMAL MADE A MISTAKE, THE SHARED INFORMATION WAS SYNERGISTIC—MEANING THE NEURONS CARRIED DISTINCT INFORMATION.

Furthermore, the information content of intersection neurons changed depending on a mouse's decision. When a mouse made a correct decision, the information shared between functionally connected intersection neurons was mostly redundant—neurons carried similar information. However, when the animal made a mistake, the shared information was synergistic, meaning that the neurons carried distinct information.

"Most existing work considers external stimuli encoding as a separate process from the readout of information in the brain that results in behavior," said Babadi. "Our results show there are indeed specialized groups of neurons in the auditory cortex that integrate the two processes by carrying both the information about the external stimuli and the animal's behavior sequentially through time. The way they carry information matters for correct vs. incorrect behavior."

"We can now target these 'intersection neurons' using holographic optogenetics," Babadi continued, "and test whether an animal's behavior can be altered by manipulating the neural network structure. We hope this work will help us develop better neural prostheses and brain-machine interface systems."

The research is funded by a 2019, $20M NIH BRAIN Initiative "U19" grant. U19s are among the largest awards given by NIH, and are dedicated to highly ambitious, multi-disciplinary, multi-university projects. This large project is providing a clearer picture of how the brain operates in real time, with sensory input, brain activity, and behavior interacting in complex, simultaneous, mutually informing ways. It is revealing how the external world shapes brain activity, how brain activity results in behavior, and how behavior in turn reshapes the brain.

**Learn more** at *go.umd.edu/522U19.*

### Robust, scalable computational methodology helps identify directed connectivity within the brain

An ISR cross-laboratory collaboration has produced a cutting-edge method for directional connectivity with magnetoencephalography (MEG). "NLGC"—for Network Localized Granger Causality—obtains directional cortical connectivity measures from MEG recordings.

A paper describing the inference method was published in the journal *Neuroimage*.

The research was led by Associate Professor Behtash Babadi (ECE/ISR); Professor Jonathan Simon (ECE/ISR/Biology); their current and former students; and Stefanie Kuchinsky, an affiliate of Hearing and Speech Sciences.

Identifying the directed connectivity that underlies networked activity between different cortical areas in the brain is critical for understanding the neural mechanisms behind sensory processing.

**Learn more** about NLGC's importance and how it works at *go.umd.edu/922NLGC.*

# n's functioning and health issues

## New funding to discover a digital biomarker for post-stroke cognitive problems

In recent years, pre-emptively removing blood clots in arteries and veins has improved outcomes for people who otherwise would have experienced major strokes. Today almost 80 percent of strokes are considered "small."

However, even a single small stroke can cause cognitive problems. While most people who have had small strokes gradually regain brain function, some do not show much improvement. They struggle with focus, attention, and multi-tasking, which makes returning to work difficult and negatively impacts their quality of life.

Doctors cannot yet predict who is at the highest risk of developing persistent vascular cognitive impairment or understand why some recover but others do not.

Discovering a biomarker that could predict who will exhibit long-term problems would help clinicians initiate early interventions to slow or even prevent decline.

Professor Jonathan Simon (ECE/ISR/Biology) is a co-PI on a five-year, $2.31M NIH National Institute on Aging grant to seek an accurate digital biomarker. Principal Investigator Elisabeth Marsh, Johns Hopkins Medical Institute; and John Mosher, UT Health Houston McGovern Medical School; are also part of the team.

The research is using a combination of magnetoencephalography and electroencephalography, cutting-edge analytic techniques, and machine learning. A deep-learning model will be employed to find shared signatures of vascular cognitive impairment, ultimately yielding a model that requires only affordable EEG data. The work should yield a powerful biomarker that can predict, soon after a stroke, which impaired patients might actually be exhibiting persistent—rather than transient—impairment.

Simon and Marsh are frequent collaborators who have worked on post-stroke research for several years. In a 2020 paper published in *Proceedings of the National Academy of Sciences of the United States of America*, they provided the first measurable physical evidence of "PSADES," diminished neural processing within the brain after a stroke.

**Learn more** at *go.umd.edu/223biomarker.*

## Hearing-focused BBI seed grant project seeks better understanding of autism

The relationship between hearing and autism is at the heart of a 2023 Brain and Behavior Institute (BBI) seed grant project led by Associate Professor Behtash Babadi (ECE/ISR) and former ISR Postdoctoral Researcher/current Assistant Professor Nikolas Francis (Biology/BBI). As a postdoc, Francis worked for Professor Shihab Shamma (ECE/ISR) and Patrick Kanold (JHU).

Autism Spectrum Disorder (ASD) affects 1 in 36 children, according to the U.S. Centers for Disease Control, and is characterized primarily as a communication disorder. It often entails issues with attention or listening—in particular a difficulty habituating to sounds and being distracted by background noise. This leads some people with ASD to rely on ear protection or headphones.

SHUTTERSTOCK

Francis became curious about how conditions within the brain's auditory system contribute to the condition.

"Neurons in the auditory cortex largely respond to sound," he said, "but our recent findings indicate that those same neurons also encode other kinds of information about perception, memory and decision-making. These factors drive the brain's total auditory response, and their dysfunction might contribute to autism spectrum disorder."

To test this idea, Babadi and Francis are investigating brain activity in an ASD mouse model. The mice in the study have an underdeveloped corpus callosum, the structure that mediates interactions between the brain's left and right halves. This causes the brain to struggle to send signals to distant areas. In humans, roughly 30% of those with an underdeveloped or absent corpus callosum fit the diagnostic criteria for ASD.

Francis is using BBI's Small Animal Magnetic Resonance Imaging core (SAMRI) to perform high-resolution structural scans on the mice and quantify their deficits in corpus callosum development. The team designed experiments to measure brain network activity while mice performed tasks that require listening or attending to sounds.

"For decades, we have looked at isolated neurons," said Babadi. "However, if you think about a disorder like autism, it could be that individual neurons in the brain are working fine, but they can't form networks together to collaboratively compute and perform a task."

The team expects functional MRI scans at the SAMRI will reveal a decrease in cross-area activation in the mouse brain, but a lack of communication between distant brain areas may be only part of the story.

One hypothesis about a source of autism's symptoms is that while the entire brain may be underconnected, local areas of the brain actually may be *overconnected*. Attending to a sound may be difficult because areas of the brain activated by sound are *too well* wired up. This could explain why some individuals with autism have trouble blocking out background noise.

Francis and Babadi expect to see increased activity within local networks using two-photon microscopy, a form of calcium imaging capable of seeing the individual activity of thousands of neurons in a single field of view.

The focus on ASD is a new research topic for both investigators, and the BBI seed grant is the impetus that promotes their collaboration.

"Cutting-edge neuroscience is increasingly moving toward the necessity for collaboration among specialists as opposed to hoping one individual has all the skills," Francis said.

*—ISR thanks BBI's Nate Underland for this story.*

# The falcon and the flock

PHOTO BY NICK DUNLOP; USED WITH PERMISSION.

Who among us is not moved by the balletic aerial displays of starling flocks? We recall this memorable description from naturalist Edmund Selous' famous book, *Bird Life Glimpses* (G. Allen Publishing, 1905):

"...and now, more and faster than the eye can take it in, band grows upon band, the air is heavy with the ceaseless sweep of pinions, till, glinting and gleaming, their weary wayfaring turned to swiftest arrows of triumphant flight—toil become ecstasy, prose an epic song—with rush and roar of wings, with a mighty commotion, all sweep, together, into one enormous cloud. And still they circle; now dense like a polished roof, now disseminated like the meshes of some vast all-heaven-sweeping net, now darkening, now flashing out a million rays of light, wheeling, rending, tearing, darting, crossing, and piercing one another—a madness in the sky."

In later work, Selous speculated on what enables such dynamic morphology in flocks. A considered reading of his book, *Thought Transference (or What?) in Birds* (Constable & Co., 1931), suggests that he may have been on to the idea of sensory mediation amongst the birds as key to flocking. A modern view treats flocking as the result of co-evolution of predator (peregrine falcon) and prey (common starling)—to quote naturalist Grainger Hunt (2013) from his essay (*A Darwinian Dance*), with photographs by award-winning videographer Nick Dunlop:

"What are we to make of the pulsating, other-worldly spectacle of a massive starling flock, moving amoeba-like across the open skies? A Peregrine Falcon or other winged predator is almost always involved, as the thousands of individual flock members fight to evade capture." He views the adaptive purpose of complex aerial displays of starling flocks to be mitigation of the risk of predation—"The wondrous cloud [of starlings] is thus secondary—an extraneous property, emerging from independent attempts by each individual, within the multitude of self-interested starlings, to escape the falcon." He further notes the self-interest of the falcon in avoiding injury from even a grazing collision with a starling in a flock—"so the peregrine attacks the flock gingerly, and in apparent moderation of its true ability to catch [an isolated] starling."

In this and other contexts, a phenomenon known as the confusion effect—the perceptual/cognitive challenge to a visual predator posed by the presence of numerous dynamic targets, contributes to reducing the risk to an individual prey. Understanding this effect remains elusive.

In "Flocks, Games, and Cognition: A Geometric Approach," published in *Systems and Control Letters*, Professor P. S. Krishnaprasad (ECE/ISR) and four of his former students—Udit Halder (ECE Ph.D. 2019), Vidya Raju (ECE Ph.D. 2019), Matteo Mischiati (ECE Ph.D. 2011), and Biswadip Dey (ECE Ph.D. 2015)—have proposed a notion of cognitive cost as a possible means to explore this phenomenon.

More precisely, they argue their notion of cognitive cost captures the high temporal variability of the modes of flock behavior and thereby assesses the impact of the confusion effect. The paper is based on analysis and modeling of data provided by the Collective Behavior in Biological Systems (COBBS) group led by Dr. Andrea Cavagna and Dr. Irene Giardina of the Institute for Complex Systems (ISC-CNR) in Rome, Italy.

Beginning with a collaboration between ISR and COBBS supported by the Air Force Office of Scientific Research, work in this area in ISR has received support from the Army Research Office, the National Science Foundation, and Northrop Grumman Corporation. The published work presents a new integrative treatment of avian flocking behavior by bringing together computational tools, optimal control theory, evolutionary game dynamics, and geometric decompositions to shed light on the question —Is there a quantitative mechanism, for ordering of flocking events that exhibit dynamic morphology, consistent with the idea that a purpose of flocking is to mitigate predation risk? Cognitive cost computed as an average Hamiltonian from an application of Pontryagin's Maximum Principle offers an answer.

There are possible applications of insights gained in this work to a new technology of robot falconry for deterrence of bird flocks near sensitive areas such as airport flight lines—by inducing dispersal through escape behavior; other applications may include collective deterrence by exploiting behavioral complexity to mitigate threats.

**Learn more** and view a video by Nick Dunlop at *go.umd.edu/323falcon*.

## Quick takes: robotics and autonomy

### The future of regulating autonomous systems

Autonomous systems are improvements of currently regulated complex systems, and their regulation will depend on preexisting frameworks, rather than on an optimal autonomy-focused approach. Assistant Professor Huan "Mumu" Xu (AE/ISR) and attorney Joseph Borson have developed a framework of regulatory approaches in "A Path Dependent Approach for Characterizing the Legal Governance of Autonomous Systems," recently published online by *IEEE Access*. **Learn more** at *go.umd.edu/123reg*.

### Robotic navigation without a map

Target-driven navigation in unstructured environments has long been a challenging problem in robotics—especially when robots have only a goal image and no map. Robots need to be able to learn an effective exploration strategy and avoid collisions. A hierarchical decomposition framework developed by a team including ISR-affiliated Professor Dinesh Manocha (ECE/CS) offers a promising strategy. The work is published in *IEEE Robotics and Automation Letters*. **Learn more** at *go.umd.edu/722nav*.

### Machine learning to improve strawberry harvests

Agricultural robots can monitor strawberries for better harvesting with less waste. Research led by ISR-affiliated Professor Nikhil Chopra (ME) uses a combination of robots, computer vision and machine learning to create a farm information system showing strawberries in different stages of ripeness. It processes videos and sequences of still images to create ripeness maps of the fields, using state-of-the-art, vision-based simultaneous localization and mapping techniques, commonly known as "SLAM." **Learn more** at *go.umd.edu/824straw*.

## Excess payoff evolutionary dynamics

A new paper in *IEEE Control Systems Letters* shows that for a considered protocol class, established conditions that ensure convergence under strategy-independent revision rates may be violated when the revision rates are strategy-dependent. The paper also shows that a minor, well-motivated modification of the considered protocol class satisfies these conditions for any strategy-dependent revision rates.

"Excess Payoff Evolutionary Dynamics with Strategy-Dependent Revision Rates: Convergence to Nash Equilibria for Potential Games" was written by Professor Nuno Martins (ECE/ISR) and his Ph.D. advisee Semih Kara.

Kara and Martins focus on a well-known class of protocols that prioritizes strategies with higher excess payoffs relative to a population-weighted average. In contrast to existing work for these protocols, they allow each agent's revision rate to depend explicitly on its current strategy. Motivated by applications and relevance to distributed optimization, the authors focus on potential games and investigate the population state's convergence to the game's Nash equilibria. **Learn more** at *go.umd.edu/1222nash*.

## A game theory epidemiology model

One of many things the COVID-19 pandemic wrought is an increase in funding for, and subsequently advances in, epidemiology models. For example, researchers have explored optimal prevention strategies using vaccines/immunization, recovery strategies featuring antidotes or curing rates, or a combination of both preventive and recovery measures.

In new work featured in the July 2023 issue of *Automatica*, Professor Nuno Martins (ECE/ISR), Professor Richard La (ECE/ISR), and their co-advised Ph.D. student Jair Certório take a different approach. Unlike studies that aim to suppress epidemic spread, their aim is to design policies for minimizing the endemic transmission rate subject to a constraint on the long-term average cost a planner bears. Game theory provides a natural framework and tools for studying such strategic interactions.

"Epidemic population games and evolutionary dynamics" proposes a system theoretic approach to select and stabilize the endemic equilibrium of a susceptible-infectious-recovered-susceptible epidemic model.

As the recent worldwide experience with COVID shows, human behavior and strategic interactions among individuals are major aspects of epidemic processes. These variables determine individual decisions over time in response to payoffs, and in turn shape the course of epidemic processes.

**Learn more** at *go.umd.edu/723sirs*.

# Two people in the truck for package delivery?

ISR alum Rui Zhang (BMGT Ph.D. 2016) and his Ph.D. advisor, Professor S. "Raghu" Raghavan (BMGT/ISR), have produced new work on the best way for logistics network companies to handle last-mile deliveries. Zhang is an assistant professor in the Leeds School of Business at the University of Colorado.

Last-mile delivery is a critical component of logistics networks, accounting for approximately 30–35% of costs. Logistics companies are under significant pressure to contain these costs while maintaining service and delivery commitments as delivery volumes have increased and truck route times have become longer. To address this issue, logistics companies including FedEx and UPS, will sometimes use an "aide," a second person in the truck, to assist with deliveries.

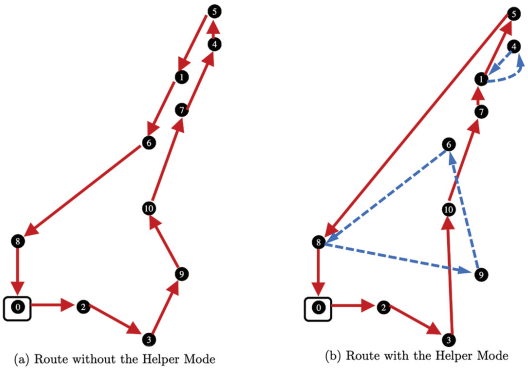



FIG. 1 FROM THE PAPER: AN ILLUSTRATION OF THE DRIVER-AIDE PROBLEM.

Aides can assist the driver in two ways. As a "jumper," the aide works with the driver in preparing and delivering packages, reducing the service time at a given stop. As a "helper," the aide independently works at a location delivering packages, while the driver leaves to deliver packages at other locations and then returns.

Given a set of delivery locations, travel times, service times, and savings from having an aide, the operations research "Driver-Aide Problem" determines both an optimal delivery route and the most effective way to use the aide to minimize total delivery time.

In their paper, "The Driver-Aide Problem: Coordinated Logistics for Last-Mile Delivery," Zhang and Raghavan model this problem as an integer program with an exponential number of variables and an exponential number of constraints, and propose a "branch-cut-and-price" approach for solving it. Computational experiments in their research are based on simulated instances built on real-world data provided by an industrial partner.

They conduct an economic analysis that considers the tradeoffs involved in employing a driver-aide system, and provide a high-level understanding of when it is most beneficial to use one. Roughly, delivery routes with greater than 50% of the time devoted to delivery (as opposed to driving) are the ones that provide the greatest benefit. Further, these routes are characterized by a high density of delivery locations.

Should the aide be used as a jumper or a helper? The researchers found there seems to be greater use of the helper mode when the average vehicle speed is somewhat higher, as it allows the driver to simultaneously perform one or more deliveries and return to the aide in about the same time it takes the aide to do his/her delivery.

The results characterize the conditions in which this novel operation mode can lead to significant savings in terms of both completion time and cost. Zhang and Raghavan show that the driver-aide model, employing both jumper and helper modes, is most effective when there are denser service regions and when the truck's speed is greater than or equal to 10 MPH.

**Learn more** at *go.umd.edu/323pkg*.

# ISR faculty news

## Academic society fellows, awards, positions

Professor Dana Nau (CS/ISR) has been named a Fellow of the American Association for the Advancement of Science. His citation reads, "for distinguished contributions to artificial intelligence, particularly for game-theoretic models and for the theory and practice of AI planning."

ISR Director Ankur Srivastava (ECE/ISR) has been elevated to Fellow by the Institute of Electrical and Electronics Engineers (IEEE) "for contributions to chip hardware security." He also was named associate editor for the security and privacy section of *IEEE Transactions on Computers,* the IEEE Computer Society's flagship journal.

Professor Alireza Khaligh (ECE/ISR) received the 2022 IEEE Power Electronic Society Vehicle and Transportation Systems Achievement Award. He was cited for contributions to the "advancement of power electronics for electrified transportation systems including electric vehicles and more electric aircraft." Khaligh also was named Editor-in-Chief of the IEEE journal, *Transactions on Transportation Electrification*. In addition, he was named an IEEE Featured Author for "research contributions to power conversion and transportation electrification."

ISR-affiliated Distinguished University Professor Emeritus Ben Shneiderman (CS/UMIACS) received the first Human-Computer Interaction (HCI) Medal for Societal Impact in 2022. The new award was given for Shneiderman's "innovative science, engineering, and design breakthroughs in theory and practice, as well as his tireless efforts to initiate and transfer HCI research outcomes to society."

Professor Michael Fu (BMGT/ISR) is one of two recipients of the Institute for Operations Research and the Management Sciences (INFORMS) 2022 George E. Kimball Medal. It is given in recognition of distinguished service.

Professor S. Raghu Raghavan (BMGT/ISR) was the runner-up for the 2022 INFORMS Computing Society Prize, which honors the best English language paper or group of related papers dealing with the operations research/computer science interface.

## NSF CAREER Award

ISR-affiliated Assistant Professor Eleonora Tubaldi (ME) won an NSF CAREER Award for "Reconfigurable Dynamic Metamaterials Interacting with Flowing Fluids." The five-year grant will support her research into flow-responsive multi-stable metamaterials with tunable dynamic properties, which can perform desirable tasks by harnessing fluid-structure interactions. The research could lead to more effective heart stents and robots that can shape-shift in response to their environments.

## New and promoted ISR faculty

Alumnus Alexander Estes (AMSC Ph.D. 2018) joined the ISR faculty as an assistant professor in Summer 2022 with a joint appointment in ISR and the Department of Decision, Operations, and Information Technology, Robert H. Smith School of Business. His research interests include integrating prediction tasks with optimization to improve the quality of decisions made in the face of uncertainty, while making efficient use of the available data, using optimization techniques to conduct data science tasks, and applying these areas in air transportation. As a student, Estes was advised by Professor Emeritus Michael Ball (BMGT/ISR). He is part of the NEXTOR III consortium.

Kaiqing Zhang joined the ISR faculty as an assistant professor with a joint appointment in Electrical and Computer Engineering in Fall 2022. Previously, he was a postdoctoral scholar affiliated with the LIDS Lab and the CSAIL robotics lab at the Massachusetts Institute of Technology. Zhang received his Ph.D. in ECE in 2021 from the University of Illinois at Urbana-Champaign, advised by Professor Tamer Başar. Zhang won the UIUC Coordinated Science Lab's award for his thesis on reinforcement learning. His research interests lie at the intersection of control theory, game theory, and machine/reinforcement learning, especially in multi-agent and safety-critical systems; with applications in intelligent and distributed cyber-physical systems.

ISR-affiliated Ryan Sochol (ME) was promoted to associate professor with tenure in July 2022.

## Invited lectures and conference service

ISR-affiliated Professor Steven Gabriel (ME) spoke on new gas perspectives for the EU at an international event convened to explore energy options for Europe after the Russian invasion of Ukraine. Gabriel's topic was "Can LNG stand for Liberty with Natural Gas?"

Professor Jonathan Simon (ECE/Biology/ISR) was an invited keynote speaker for the International Conference on Cognitive Hearing Science for Communication (CHSCOM), in Summer 2022. Simon spoke on "The progression of neural speech representations through auditory cortex and beyond, from acoustics to semantics."

In May 2023, Professor Reza Ghodssi (ECE/ISR) gave an invited talk at the NIMH Workshop on Brain Behavior Quantification and Synchronization. Ghodssi spoke about his MSAL Lab's work in "Serotonin Sensing Technologies to Promote Understanding of the Gut Brain Axis and the Physiological Role of Serotonin in Behavior."

ISR-affiliated Associate Professor Dana Dachman-Soled (ECE) was the program chair for the 2022 Conference on Information-Theoretic Cryptography at MIT.

## Books

Professor Jeffrey Herrmann (ME/ISR) has written a 2023 book that introduces key systems engineering concepts and design options for metareasoning to make robots smarter. *Metareasoning for Robots: Adapting in Dynamic and Uncertain Environments* is published by Springer. Herrmann's systems engineering perspective suggests metareasoning can improve an overall robot or autonomous system, not just one component or subsystem.

ISR-affiliated Professor Yiannis Aloimonos (CS/UMIACS) and Professor Giulio Sandini (Italian Institute of Technology/University of Genoa) have contributed a chapter on principles of computer vision to the 2022 MIT Press book, *Cognitive Robotics*. The chapter defines and provides a detailed explanation of cognitive vision. The book covers the challenges of building AI-powered intelligent robots inspired by natural cognitive systems.

A comprehensive new book on the performance metric called "age of information" features chapters by three ECE/ISR faculty and two of their recent alumni. *Age of Information: Foundations and Applications* is a 2023 book by Cambridge University Press. It provides detailed information on the metric, which ushers in new opportunities for rethinking communication system design.

"Age of Information in Source Coding" is written by ECE Department Chair and Professor Sennur Ulukus (ECE/ISR) and two of her former advisees, Baturalp Buyukates (ECE Ph.D. 2021), currently a postdoctoral researcher at the University of Southern California; and Melih Bastopcu (ECE Ph.D. 2021), currently a postdoctoral researcher at the University of Illinois, Urbana-Champaign.

"AoI-driven transmission scheduling in wireless networks" is written by Distinguished University Professor Emeritus Anthony Ephremides (ECE/ISR) and colleagues in Sweden.

"Networked control subject to random processing delay" is written by Distinguished University Professor John Baras (ECE/ISR) and colleagues in Sweden.

## University of Maryland positions and honors

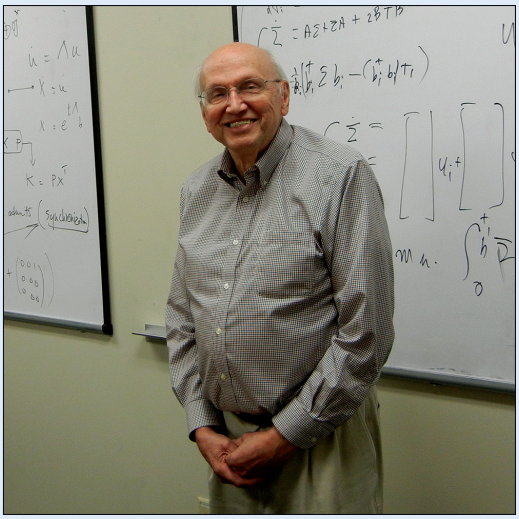
In Fall 2022, Clark School Dean Samuel Graham, Jr., named Professor Reza Ghodssi the inaugural executive director of research and innovation for the Clark School at the University System of Maryland campus in Southern Maryland. Ghodssi is initiating new state- and federally-funded research activities; creating partnerships with academic institutions, industry, and federal agencies; and developing outreach programs with the local community.

Professor Sennur Ulukus (ECE/ISR) became the chair of the Electrical and Computer Engineering Department in October 2022.

Professor Rance Cleaveland (CS/ISR) has been appointed as associate dean for research in the College of Computer, Mathematical and Natural Sciences. From 2018 to 2022, Cleaveland served as division director of NSF's Computing and Communication Foundations division within its Computer and Information Science and Engineering directorate.

## In memoriam

### Roger Brockett



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ROGER BROCKETT ON AN ISR VISIT IN 2015.

ISR founding and permanent faculty member Roger Ware Brockett, 84, passed away March 19, 2023.

Brockett earned his Ph.D. in electrical engineering from Case Western Reserve University. He began his academic career at MIT, then moved to Harvard and was a faculty member there from 1969–2011. Brockett founded the Harvard Robotics Laboratory in 1983 and was the An Wang Professor of Computer Science and Electrical Engineering.

During his career, Brockett advised 62 doctoral students. His advisees included two of ISR's founding faculty: Distinguished University Professor John Baras (ECE/ISR) and Professor P. S. Krishnaprasad (ECE/ISR).

Brockett played a key role in establishing ISR, enthusiastically embracing the effort to jointly establish the Systems Research Center (as ISR was first known) between the University of Maryland and Harvard. He worked tirelessly for its establishment and evolution, and contributed substantially to ISR's research and educational accomplishments.

Brocket wrote or co-wrote several hundred scholarly papers. His textbook, *Finite Dimensional Linear Systems*, is considered a classic. He was elected to the National Academy of Engineering, was an IEEE Fellow, and received the Donald P. Eckman Award, the Richard E. Bellman Control Heritage Award, the IEEE Control Systems Science and Engineering Award, the Rufus Oldenburger Medal, and the Giorgio Quazza Medal for lifetime achievement.

John Baras wrote: "From a certain perspective, ISR could be considered a natural outgrowth of his visionary and cross-disciplinary thinking, including the key and foundational concepts emanating from 'systems and control thinking and methodology.'"

"The freedom of thought that Roger exemplified was something he strongly encouraged in all his students," P. S. Krishnaprasad noted. "The value he placed on this and the cultivation of taste in research has served me well all these years. I remain most grateful to Roger for these and other lessons." **Learn more** about Roger Brockett on the ISR website: *go.umd.edu/322RB*.

### Christopher Davis

ISR sadly notes the passing of Christopher Davis (ECE), a former faculty member, on April 1, 2023. Davis was well known for his work in free space optical and directional RF communication systems, atmospheric turbulence, advanced surveillance systems, plasmonics, chemical and biological sensors, interferometry, optical systems, bioelectromagnetics, and RF dosimetry.

### Pravin Varaiya

A great friend of ISR, Pravin Varaiya, 82, Professor Emeritus in the Electrical Engineering and Computer Sciences Department at the University of California, Berkeley, died June 10, 2022.

Varaiya served on ISR's Strategic Advisory Committee, mentored generations of students and faculty, visited often and gave technical lectures on control-related transportation issues.

A student of Lotfi Zadeh, Varaiya earned his Electrical Engineering Ph.D. at Berkeley in 1966. He was a brilliant researcher who could effortlessly enter new areas and make important progress. He won the IEEE Control Systems Award, the Bellman Control Heritage Award, the AACC O. Hugo Schuck Award, and the IEEE Simon Ramo Medal.

Former ISR Director and ISR-affiliated Professor Eyad Abed (ECE) was advised by Varaiya as a Ph.D. student and remained a close friend for life. "Pravin was an outstanding advisor, supportive, kind, and never critical, always having an air of humility despite his obvious brilliance," Abed said. "I deeply appreciated his friendship, advice and mentoring."

# Alumni news

## Leonard wins 2023 Control Systems Award

Naomi Ehrich Leonard (EE Ph.D. 1994) is the recipient of the 2023 IEEE Control Systems Award "for contributions to applications and theory for control of nonlinear and multiagent systems." The award, established in 1980, is given for outstanding contributions to control systems engineering, science, or technology.

Leonard is the Edwin S. Wilsey Professor of Mechanical and Aerospace Engineering at Princeton. At Maryland, she was advised by Professor P. S. Krishnaprasad (ECE/ISR).

## Park wins O. Hugo Schuck Award

Shinkyu Park (ECE Ph.D. 2015) won the American Automatic Control Conference's 2022 O. Hugo Schuck Award, given to the best papers presented at the previous year's American Control Conference. "KL Divergence Regularized Learning Model for Multi-Agent Decision Making" was written by Park and Naomi Leonard while Park was her associate research scholar at Princeton.

The paper investigates a mathematical framework to study decision making in multi-agent systems. Applications range from autonomous vehicle route selection to regulating consumer electricity demands in smart grids.

At Maryland, Park was a student of Professor Nuno Martins (ECE/ISR), himself a winner of the Schuck award in 2006 for "Fundamental Limitations of Performance in the Presence of Finite Capacity Feedback," which he wrote with M. A. Dahleh.

## Vasconcelos joins Florida State University

Marcos Vasconcelos (ECE Ph.D. 2016) has joined the ECE Department at Florida State University as an assistant professor. Vasconcelos was a student of Professor Nuno Martins (ECE/ISR).

After graduation, Vasconcelos was a postdoctoral researcher at the University of Southern California and a research assistant professor at Virginia Tech. His research interests are in network systems, particularly cyber-physical systems; game theory; and distributed estimation, control and optimization.

## Al-Obaid, Adomaitis publish renewable energy work

In "Optimal design of a coupled photovoltaic-electrolysis-battery system for hydrogen generation," published in the Royal Society of Chemistry journal *Sustainable Energy & Fuels*, alumna Aisha Al-Obaid (ChBE Ph.D. 2019) and her former advisor Professor Raymond Adomaitis (ChBE/ISR) have developed a computational algorithm that models an integrated photovoltaic-electrolysis-battery system and can identify the optimal size a system should be.

Al-Obaid is an assistant professor in chemical engineering at Kuwait University. Hydrogen-based energy is a possibility for a world looking to replace fossil fuels with more environmentally friendly sources. Today, most hydrogen production relies on fossil fuels, but it is possible to produce hydrogen in greener ways. A photovoltaic-electrolysis-battery system that uses renewable sources such as wind and solar to power water electrolysis is one promising solution.

AISHA AL-OBAID

## Cryptography book has ISR roots

Two authors associated with Professor Prakash Narayan (ECE/ISR) have written a new book on information-theoretic cryptography. Shun Watanabe, a former visiting assistant professor who worked with Narayan, is an associate professor in computer and information sciences at the Tokyo University of Agriculture and Technology. Alum Himanshu Tyagi (ECE Ph.D. 2013) is an associate professor in electrical communication engineering at the Indian Institute of Technology Bangalore. Tyagi was advised by Narayan as a Ph.D. student.

*Information-Theoretic Cryptography* was published by Cambridge University Press in June 2023. The graduate-level book offers a mathematical foundation for modern cryptography, starting from Shannon's classic result on secret key cryptography.

## Tandon appointed to named chair

Less than a year after earning tenure, Ravi Tandon (ECE Ph.D. 2010) has been appointed the Litton Industries John M. Leonis Distinguished Associate Professor of Electrical and Computer Engineering at the University of Arizona. At Maryland, Tandon was advised by Professor Sennur Ulukus (ECE/ISR).

In 2017, Tandon won an NSF CAREER Award for "Communication-Efficient Distributed Computation: Information-Theoretic Foundations and Algorithms."

## Arafa wins NSF CAREER Award

Ahmed Arafa (ECE Ph.D. 2017) has received an NSF CAREER Award for "Towards Realizing Timely Information Transfer and Processing for Networked Communication Systems." Arafa, who was advised by Professor Sennur Ulukus (ECE/ISR), is an assistant professor in ECE at the University of North Carolina at Charlotte.

Inspired by the age-of-information (AoI) timeliness metric that assesses information freshness, Arafa's research will offer a path towards the timely exchange of data in federated learning, cloud computing, and remote sensing systems. Arafa's research has the potential to enable collaborative autonomous driving, precision health care, and other applications.

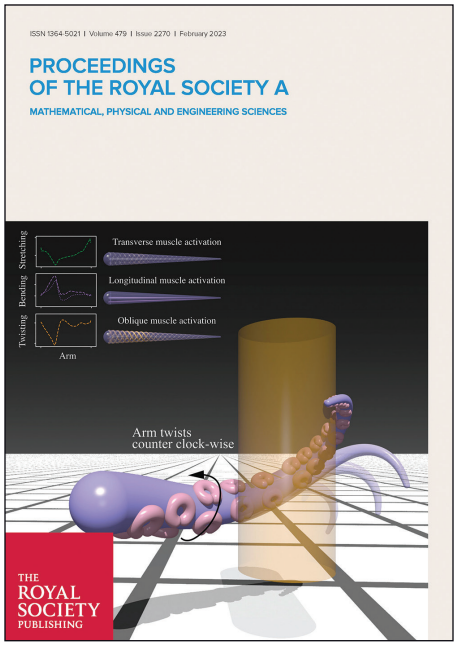
## Three IEEE SPS awards for Sidiropoulos

Nikolaos Sidiropoulos (EE Ph.D. 1992) has received three awards from the IEEE Signal Processing Society: the Claude Shannon-Harry Nyquist Technical Achievement Award, the Best Paper Award, and the Donald G. Fink Overview Paper Award. Sidiropoulos, a former student of John Baras, is the Louis T. Rader Professor at the University of Virginia.

## Halder publishes in *Proceedings of the Royal Society A*

Flexible octopus arms attract the attention of biologists and roboticists because of their exceptional ability to coordinate large numbers of degrees of freedom as they perform complex manipulation tasks. The arms are so versatile because of their intricate musculature, which contains three major types of muscles.

A new paper presents physiologically accurate mathematical models of the three muscle types.




"Energy-shaping control of a muscular octopus arm moving in three dimensions" was published as the cover article in *Proceedings of The Royal Society A* in February. It was written by Udit Halder (ECE Ph.D. 2019), a postdoctoral researcher at the University of Illinois, Urbana-Champaign, and his colleagues there.

At Maryland, Halder was advised by Professor P. S. Krishnaprasad (ECE/ISR).

## ISR alumni career profiles

Learn about ISR alums using their expertise in some unusual fields in these stories by Robert Herschbach.

Jacob Moschler (MSSE 2017). Managing air traffic will be very important in a future filled with small drones. Moschler is one of just a few people around the country with expertise in UAS traffic management. **Read the full story** at *go.umd.edu/623Jacob*.

Maria Coelho (Ph.D. Civil Systems 2022). Cities rely on interconnected systems to run transit, water, power, and waste. Coelho creates "digital twins," virtual simulations fed with real-time data from sensors, that can constantly monitor the city. **Learn more** at *go.umd.edu/623Maria*.

Sachraa Borjigin (Ph.D. Civil Systems 2022). Borjigin uses semantic modeling to monitor systems safety and promote dynamic decision-making at traffic intersections, airport taxiway operations, and disaster evacuation planning. **More info** at *go.umd.edu/623SB*.

# Student news

### Caitlyn Singam's wide-ranging interests

In 2022, *Aviation Week Network* named Bioengineering Ph.D. student Caitlyn Singam (MSSE 2021; Biology BS 2020) one of 20 graduate students worldwide who are likely to change the face of the aerospace and defense industries. Singam is advised by Distinguished University Professor Emeritus Anthony Ephremides (ECE/ISR).

Always thinking broadly, in summer 2023 Singam organized an INCOSE "mini-online-SySTEAM" workshop. She calls it "an opportunity for systems-minded folks from around the globe to convene, discuss, and exchange ideas relating to the intersection between STEM/STEAM education and systems thinking/systems engineering competencies," and says SySTEAM's goal is to "improve education for all students, everywhere."

### Three-minute thesis

Two ISR Ph.D. students were named UMD winners of the 2023 Three-Minute Thesis competition. The international contest challenges students to give a short video talk that explains their work in non-technical terms.

Behrad Soleimani, a student of Associate Professor Behtash Babadi (ECE/ISR), explained "Tracing Brain Connectivity over Time: Insights from Auditory Processing and Stroke Rehabilitation." Zachary Lazri, advised by ISR-affiliated Professor Min Wu (ECE/UMIACS), spoke on "Building A.I. on Accuracy and Ethics."

### Clark School Future Faculty Fellow

Ph.D. student Levi Burner has been named a 2023 Clark School Future Faculty Fellow. The program prepares engineering and computer science students for academic careers through training seminars, a teaching practicum, and a research mentoring practicum. Fellows learn what to expect in a tenure-track position, including research, teaching, and mentoring students. Burner is advised by Professor Reza Ghodssi (ECE/ISR).

### Clark Doctoral Fellow

Joshua Levy, a mechanical engineering Ph.D. student, has received a 2023 Clark Doctoral Fellows Mid-Career Award. He is advised by Professor Reza Ghodssi (ECE/ISR).

### AMAV team wins the NIST UAS First Responder Indoor Challenge

The University of Maryland Autonomous Micro Air Vehicle (AMAV) team bested 10 competitors in the NIST First Responder UAS Indoor Challenge. They brought home the grand prize and $150K.

What happens when disasters strike indoors, making building interiors dangerous for search and rescue personnel? This competition challenges teams to develop solutions for these situations. For 2023, drones were presented with a simulated earthquake disaster, navigating debris and rescuing victims.

THE GAMBIT DRONE

"It was an incredibly challenging environment to design for," said AE Ph.D. student Animesh Shastry, the team lead on this project. "Imagine a multi-story building with ceiling tiles and wires hanging down, furniture tipped over and mannequins under mattresses and just junk everywhere, with debris and dust in the air."

The team developed an incredibly agile and compact drone—dubbed Gambit—that used an advanced onboard sensing system enabling it to fly without the use of GPS.

"It's a technique called visual odometry," explained Professor Derek Paley (AE/ISR), the team's faculty advisor and director of the Maryland Robotic Center. "Onboard cameras allow Gambit to localize features and deduce its own motion relative to those features. It can hold its position with incredible stability and maneuver much more reliably even in the absence of GPS."

Gambit also features thermal, high definition, and night-vision cameras on a gimbal with 180° range so it can still 'see' in a dark environment. All of this technology had to be developed to be as cost-effective as possible per NIST competition guidelines.

"We created a small, highly capable drone that was best in class across a wide range of

*Continued on back cover...*

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# Student news

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considerations," explained Paley. "And we did it for $5,000 as compared to industry models costing over $50,000."

The team also wanted to ensure that first responders' needs were taken into consideration. Through participation in Maryland's I-Corps (an NSF-funded program offering entrepreneurial training), team members interviewed a variety of first responders.

"It really helped us better understand what kind of features they were looking for, and what features were lacking in existing drones," said AE undergrad Qingwen Wei, the team's design lead and pilot.

## Chahat Deep Singh's robot bee work featured in BBC video

Computer Science Ph.D. student Chahat Deep Singh is featured in a new video from the BBC. (Watch it at *youtu.be/ed3jg-xQfPw*) He is advised by ISR-affiliated Professor Yiannis Aloimonos (CS/UMIACS) and is part of the Perception and Robotics Group.

CHAHAT DEEP SINGH WITH A BEE DRONE

Chahat's work lies at the intersection of robotics, computer vision and computational imaging for resource-constrained robots. He draws inspiration from tiny insects and other biological beings to enable autonomy on robots using only onboard sensing and computing, at scales that previously were not thought possible. This March, Chahat gave a seminar at the Massachusetts Institute of Technology on his work in Minimal Perception. **Learn more** at *go.umd.edu/623Chahat*.

## 'Best paper' award for work on RIS-aided mmWave beamforming

ECE Ph.D. student Nariman Torkzaban is the first author on wireless communication research published in a special issue of the International Telecommunication Union *Journal on Future and Evolving Technologies*. It has been honored with a best paper award.

Beamforming that employs massive MIMO is primarily used to address high attenuation in the mmWave channel. Relaying also can be designed to generate constructive superposition and enhance signals at receiving nodes. Equipping MIMO communication systems with reconfigurable intelligent surfaces may extend the capacity of mmWave by covering the blind spots and providing diversity reception at receiving nodes.

Torkzaban; his advisor, Professor John Baras (ECE/ISR); and their co-authors address this challenge. Their "multi-beamforming" concept addresses beam design with multiple disjoint lobes that cover blind spots with sharp, high gain, effective beam patterns.