SPRING 2023

CONVERGENCE

The magazine of engineering and the sciences at UC Santa Barbara

FOCUS ON:

THE RISE OF AI

PROMISES AND CHALLENGES IN THE NEW ERA OF SMART MACHINES

TECH EDGE: THE NANOFAB

WHERE EXOTIC MATERIALS BECOME NEXT-GENERATION ELECTRONICS

CLARIFYING CLOGS

ALBAN SAURET INVESTIGATES THE PHYSICS OF WHY STUFF GETS STUCK

MAPPING BROADBAND

ELIZABETH BELDING DIGS INTO THE DETAILS OF SERVICE DATA

UC SANTA BARBARA

MESSAGE FROM THE DEANS

Tresa Pollock

Interim Dean, College of Engineering; Alcoa Distinguished Professor of Materials

Pierre Wiltzius

Susan & Bruce Worster Dean of Science, College of Letters & Science

Artificial intelligence (AI) is transforming our world, and the arrival of the large language model ChatGPT has accelerated this transformation. ChatGPT is a revolutionary AI entity powered by GPT-3, a model of 175 billion parameters drawn from the expanse of the internet, allowing it to exhibit human-like conversational abilities. Since its inception in late 2022, ChatGPT has left us in awe with its capabilities, ignited our hopes with its potential, and, admittedly, stirred a touch of trepidation with its unanticipated behaviors. While ChatGPT is demonstrating the huge potential of AI in natural language processing, AI in computer vision has already had a transformative impact across scientific disciplines ranging from healthcare and remote sensing to materials discovery and biology.

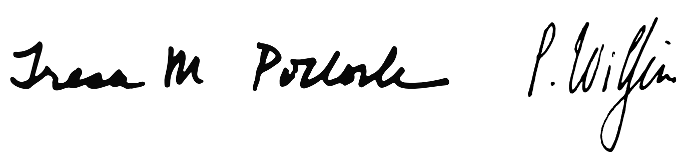
Standing on the threshold of a new era, where AI intertwines with every aspect of our existence, this feels like the perfect moment for *Convergence* to delve into this emerging realm. That's what we do in this issue's cover story. "FOCUS ON: AI" (P. 17) shines a light on the pioneering work of thirteen researchers from UCSB who are navigating the exhilarating, rapidly shifting landscape of machine intelligence. Their investigations promise not only to reveal many of the mysteries of AI, but also to shape its future in ways that will allow us to realize its nearly unlimited potential while ensuring that it works for all humanity.

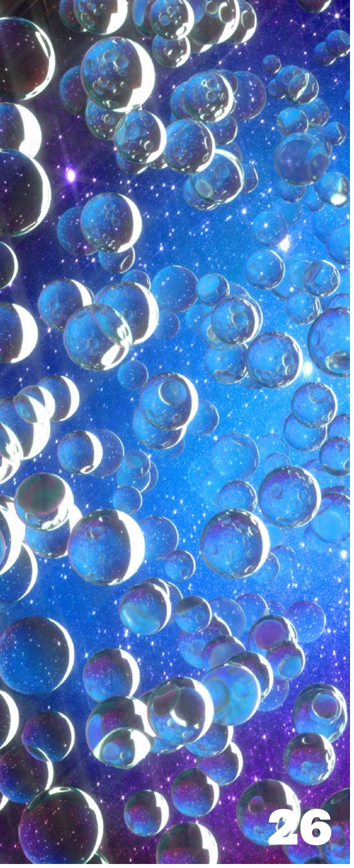
In this issue, we also introduce electrical and computer engineering professor **Umesh Mishra** (P.8), who this summer will assume the role of the next dean of the College of Engineering. In our regular "Tech Edge" section (P. 30), we visit the UCSB Nanofabrication Facility, aka "the cleanroom." In that highly collaborative, regionally important, incredibly fascinating state-of-the-art facility, industry users and UCSB researchers work side by side to create the nano- and micro-scale structures that power modern micro-electronics.

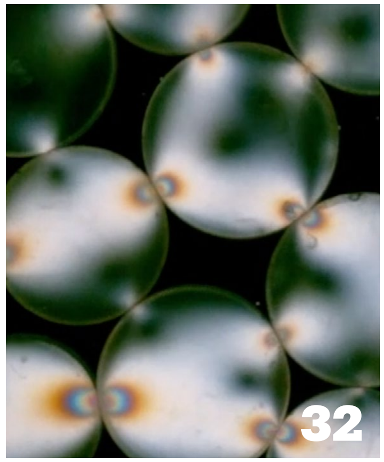
Elsewhere (P. 28), we hear about computer science professor **Elizabeth Belding**'s research in which crowdsourced "speed tests" are being used to map the quality of broadband and cellular coverage around the nation, a service landscape that often reflects societal inequalities. You'll also read about a team of interdisciplinary faculty who conducted automated experiments aboard the International Space Station to study the fundamental forces behind bubble dynamics (P. 26), and another project (P. 32) in which researchers look closely at the intriguing physics behind a ubiquitous, if seemingly pedestrian, fact of life: clogging.

This issue also includes an interview with **Professor Rachel Segalman** (P.13), the dynamic chair of the Chemical Engineering Department, and wraps up with a Q&A with our Champions of Engineering, the exceedingly generous donors **Tunç and Lale Doluca** (P.34). We hope you enjoy the issue as a prelude to a warm and relaxing summer.

Scan to read Convergence online







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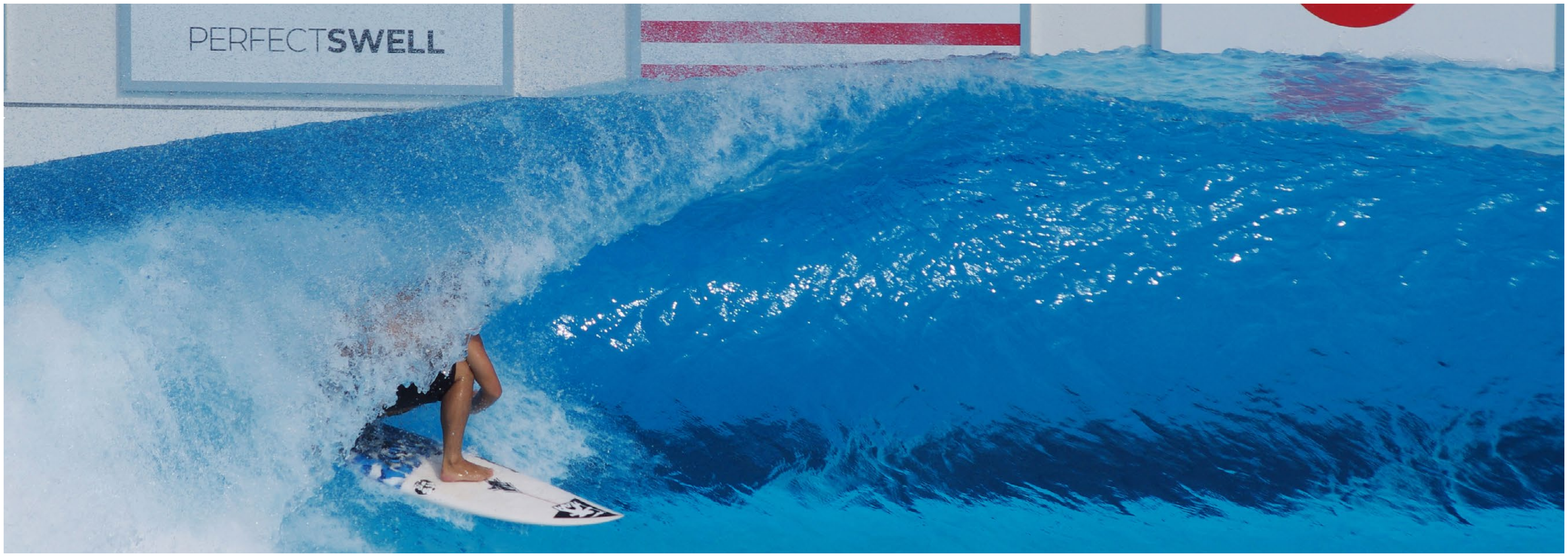
College of Engineering

NEWS BRIEFS



Masatoshi Ohno gets "barreled" thanks to a PerfectSwell wave machine at the Shizunami Surf Stadium, in Shizuoka, Japan.

MAKING WAVES

Ever since he was a teenager surfing along the Los Angeles County coast, **Bruce McFarland** (BS/MS '81) has been searching for the perfect wave. Now, more than forty years after graduating from UC Santa Barbara with degrees in mechanical engineering, he is making waves with his wife, **Marie** (BS, '80) and bringing them to surfers around the world.

The couple began developing the technology in 2000, after establishing careers in the aerospace industry — and having three children along the way. The operation was initiated when Bruce constructed a small-scale model to produce standing waves in his backyard shed. He then moved on to build a larger-scale model and a prototype.

Nearly twenty years later, their company, American Wave Machines (AWM), has emerged as a global leader in artificial waves. Their first patented technology, SurfStream, is now featured in fifteen facilities worldwide. Their second, known as PerfectSwell, is used in surf pools in Japan, New Jersey, Texas, and the largest, a six-acre pool in Brazil. Surfers from the U.S. and Japan trained for the Tokyo Olympics in one of their pools.

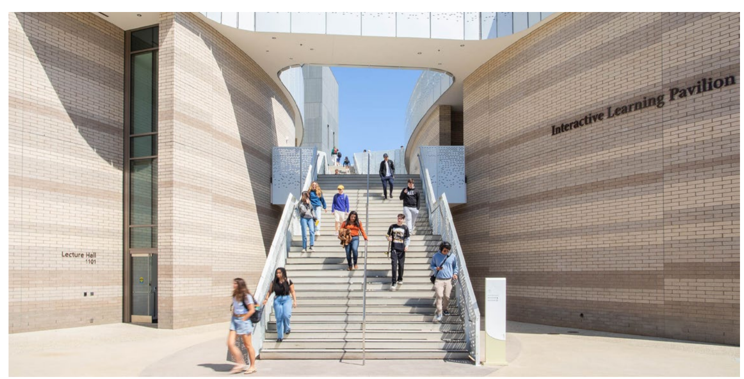
Bruce's waves are produced by an air-over-water system, in a process similar to how a piston acts in a car engine. "You have a chamber connected to a pool that is separated by a wall, with water on both sides," he says. "You create waves when the water travels under the wall to get into or out of the pool, which happens when you add pressure into the chamber."

The technology allows for customized waves: some peel like a point break, while others have multiple "barrel" sections.

Bruce credits his and Marie's UCSB education and their time working with computer-aided technology in the aerospace industry for their ability to ride an artificial wave of success, saying, "We owe a lot to UCSB, including finding one another."

NEW CLASSROOM BUILDING OPENS

The Interactive Learning Pavilion (ILP), the first UC Santa Barbara building dedicated to classroom space in more than fifty years, officially opened its doors on the first day of spring classes. Located next to the BioEngineering Building, the ILP is organized into three buildings, with a courtyard between them to allow for foot traffic. The four-story structure features five tiered lecture halls, twenty classrooms equipped with state-of-the-art technology, three project-based learning rooms designed to facilitate team learning, two group-study rooms, and multiple outdoor seating and study areas. The state-funded project increased the campus's classroom seating capacity by 2,000 seats, or 35 percent, and created an additional 1,800 bicycle parking spaces.



The new Interactive Learning Pavilion at UCSB.

BEATING "UNTREATABLE" BUGS

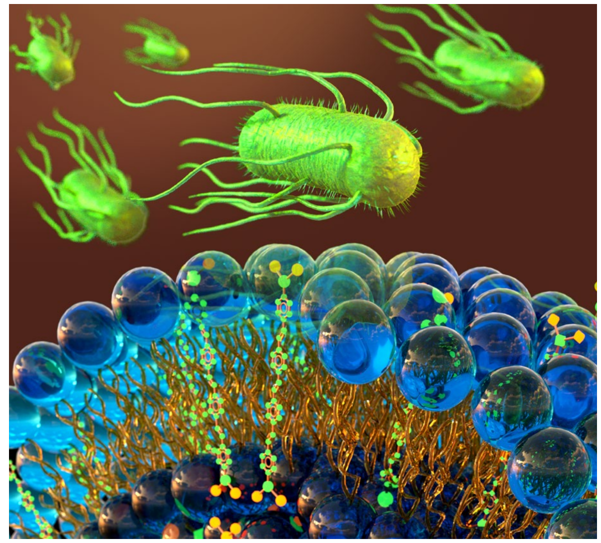
A study by a team of UC Santa Barbara scientists published in the February 15 issue of the journal *eBioMedicine* and titled "A Broad-spectrum Synthetic Antibiotic That Does Not Evoke Bacterial Resistance," describes a new drug that could be a game changer for the treatment of antibiotic-resistant "superbugs." The team developed a new class of antibiotics that cured mice infected with bacteria deemed nearly untreatable in humans.

The project was led by professors **Michael Mahan, David Low, Chuck Samuel** (all in the Molecular, Cellular and Developmental Biology Department) and their research team, with additional contributions from UCSB professor **Guillermo Bazan** (Chemistry) and Andrei Osterman, of the Sanford Burnham Prebys Medical Discovery Institute in San Diego.

The discovery was serendipitous. The U.S. Army had a pressing need to charge cell phones while in the field — essential for soldier survival. Bacteria are miniature power plants, so Bazan's group designed compounds to harness their energy as a "microbial battery."

Asked to consider whether the compounds could serve as antibiotics, the team thought that they would be highly toxic to human cells, said Mahan, the project lead. "Most were toxic, but one was not, and it could kill every bacterial pathogen we tested."

"The key finding was that bacterial resistance to the drug was virtually undetectable," said lead author **Douglas Heithoff,** senior scientist at the UCSB Institute for Collaborative Biotechnology. "Most drugs fail at this stage of development and never get to clinical practice."



Artist's depiction of the new synthetic antibiotic interacting with refractory bacteria. Illustration by Ryan Allen and Peter Allen, Second Bay Studios

#1

JUNIOR COE AND STEM FACULTY ARE OWNING

UC Santa Barbara ranks #1 among public universities in the percentage of eligible junior faculty who have received an Early CAREER Award, the National Science Foundation's most prestigious award for young faculty.

OVERCOMING RESISTANCE

For people who study fluid mechanics, like UC Santa Barbara mechanical engineering professor **Paolo Luzzatto-Fegiz**, drag, or the resistance between an object moving through fluid or, conversely, a stationary object that has fluid flowing around or through it, is a big deal. In trying to develop superhydrophobic surfaces (SHS) — seen as a potential solution to the problem of drag, which reduces the efficiency of things like cargo ships and increases the energy expenditure of, say, pumping liquids through pipes — Luzzatto-Fegiz and his collaborators developed a theory addressing what he calls a "messy problem," identifying ten parameters for an effective SHS. It turns out, according to research published January 12 in the *Proceedings of the National Academy of Sciences*, that one of them is by far the most important.

The same superhydrophobicity that makes plants like kale shed water, thanks to microscopic surface structures that create tiny pockets of air, could reduce drag on inanimate surfaces. But surface patterning turned out not to have the desired effect. The fly in the ointment of flow was surfactants, unavoidable compounds that reduce the tension between the water and the air in the bubbles, negating the performance of an SHS.

Microscopic structures that form pockets of air, making some plants naturally hydrophobic, are key to developing superhydrophobic surfaces.

The researchers found the most important parameter to be the length of the air bubbles. Simply put, the longer the tiny grating that generates the air pocket was, the less effect the surfactant molecules had. There appears to be a critical air-pocket length, which depends on the surfactant type and concentration. "If you make the grating about ten centimeters long, the surfactant can't quite do its thing of resisting the fluid motion," Luzzatto-Fegiz says. "And you could get this ideal drag reduction that people have been angling for, for twenty years."

SUMMIT OF SUCCESS

Six months of working in teams to conceptualize, design, test, and present capstone projects culminated this spring for dozens of students during summit.cs, the UC Santa Barbara Computer Science Department's annual capstone event. A two-course sequence gives seniors the opportunity to develop innovative solutions to real-world problems by working with classmates and industry partners.

Judges awarded first place to Tranquilitea, second place to Fat Stacks, and third place to Oversea. Working with industry partner Artera, Tranquilitea created an application to address an important aspect of the mental-health crisis, specifically around anxiety. The technology incorporates the use of wearable technology, medical data, and artificial intelligence to identify when a user is starting to feel anxious. When that happens, the biometrics prompt an AI chatbot to offer breathing exercises and other techniques to provide support and reduce stress.

Partnering with Allthenticate, Fat Stacks created a mobile authentication app that allows users to quickly log into pre-registered websites by authorizing the attempts on their phone, rather than manually entering their usernames and passwords on websites. Third-place winner, Oversea, created a platform to help naval personnel repair specialized equipment on ships. The team designed software that uses artificial- and virtual-reality technologies to provide remote maintenance.

They "summited" (from left): Professor Giovanni Vigna; Judges Jeremy Smith and Ben Mercier; Tranquilitea members John Rollinson, Samar Kahn, Heather Dinh, Victoria Reed, and Archana Neupane; Judges Randy Modos and Zoran Dimitrijevic.

REDEFINING THE PATH TO FACULTY

S. Shailja, a fifth-year PhD student in UCSB's Electrical and Computer Engineering (ECE) Department, recently earned a unique opportunity to participate in a federally funded program designed to diversify ECE faculties nationwide. She attended a two-day workshop, ImpRoving thE DivErsity of Faculty IN Electrical and Computer Engineering (iREDEFINE), during the ECE Department Heads Association Annual Conference in New Mexico. Supported by the National Science Foundation, the workshop brings department heads together with women and underrepresented minorities to provide a glimpse of the career of an ECE faculty, tips on how to prepare for a successful faculty interview, and networking opportunities.

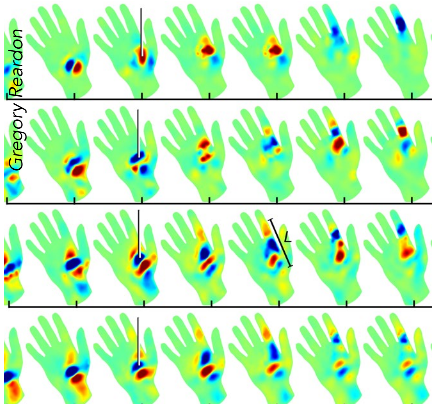
"The iREDEFINE workshop was a great source of motivation and confidence, [showing me] that my research was being recognized and appreciated," Shailja said of the experience. "I met fellow PhD candidates, and we formed a supportive community of like-minded individuals. It has inspired me to continue pursuing a career in academia."

S. Shailja

Advised by **B. S. Manjunath,** chair of UCSB's ECE Department, Shailja builds mathematical tools for modeling neuronal fibers in human brains as geometrical objects in three-dimensional space. Modeling connectivity of the human brain is critical to understanding and treating neurological disorders such as Alzheimer's disease and strokes.

During the workshop, Shailja received valuable advice from department heads during mock faculty interviews and was even invited to apply for open faculty positions at their institutions.

HONING HOLOGRAPHIC HAPTIC DISPLAYS



Measured skin oscillations in response to an ultrasound focal point scanned at different speeds.

Holographic haptic displays rely on what are called *phased arrays* of ultrasound emitters to focus ultrasound in the air, allowing users to touch, feel, and manipulate three-dimensional virtual objects in mid-air using their bare hands — without the need for a physical device or interface.

While such displays hold great promise for use in a range of application areas, the tactile sensations that they currently provide can feel like "a breeze or a puff of air," according to **Yon Visell**, associate professor in the UC Santa Barbara Mechanical Engineering Department. A new study from his lab explains why such holograms feel, as he says, "much more diffuse or indistinct than would be expected."

In a paper titled "Shear shock waves mediate haptic holography via focused ultrasound" and published in the March 1 issue of the journal *Science Advances,* Visell and PhD student researcher **Gregory Reardon** describe discovering the reason for such insubstantial sensations.

In haptic holography, Visell explains, focusing and scanning ultrasound waves in mid-air creates shock waves, which, in turn, cause vibrations on the skin. Vibrations resulting from this previously unknown shock-wave phenomenon can interfere with each other in a way that amplifies their strength at some locations, but can also create a trailing wake pattern that extends beyond the intended focal point, reducing the spatial precision and clarity of the tactile sensations. Current holographic haptic displays excite shock wave patterns that are so spread out on the skin that the sensations feel diffuse and indistinct.

"Our study reveals that new knowledge in acoustics is needed to spur innovations in the designs of holographic haptic displays," Visell said. "By understanding the underlying physics of ultrasound-generated shear shock waves in the skin, we hope to improve the design of such displays and make them more realistic and immersive for users. "

THE BREAKDOWN ON LIGNIN

Lignin, the structural biopolymer that gives stems, bark, and branches their signature woodiness, is one of the most abundant terrestrial polymers on Earth, surrounding valuable, energy-rich plant fibers and molecules that could be converted into biofuels and other commodity chemicals — if only we could get past that rigid plant cell wall.

For some years, UC Santa Barbara chemical engineering professor **Michelle O'Malley** has been working on how to accomplish that outside of the guts of large herbivores, where the process occurs automatically thanks to the actions of anaerobic microbes. Researchers in O'Malley's lab have now identified a group of anaerobic fungi, called Neocallimastigomycetes, that can do the job.

The results of the collaboration connecting O'Malley with colleagues at the U.S. Department of Energy Joint Genome Institute, the Lawrence Berkeley National Laboratory, the Joint BioEnergy Institute, and the Great Lakes Bioenergy Research Center, were published as the cover article of the April 1 issue of the journal *Nature Microbiology.*

In the project, lead author **Tom Lankiewicz**, who completed his PhD in Life Sciences at UCSB in December 2022, cultivated some fungi in the Neocallimastigomycetes group that O'Malley had used previously, growing them on poplar, sorghum, and switchgrass in an oxygen-free environment. Using advanced imaging techniques, the team was able to identify specific lignin-bond breakages caused by Neocallimastix californiae in the absence of oxygen — evidence of the anaerobic breakdown of lignin.

"This is a paradigm shift in terms of how people think about the fate of lignin in the absence of oxygen," O'Malley said. "You could extend this to understand what happens to lignin in a compost pile, in an anaerobic digester, or in very deep environments where no oxygen is available. It pushes our understanding of what happens to biomass in these environments and alters our perception of what's possible and the chemistry of what's happening there."

Goats and other large herbivores break down lignin naturally, thanks to anaerobic gut fungi.

30K

CAN YOU HEAR ME NOW?

In her first journal paper, written in 1999, UC Santa Barbara computer science professor **Elizabeth Belding,** then a PhD student in electrical and computer engineering, and co-author Charles Perkins of Sun Microsystems introduced a novel means of routing data packets in mobile networks. That work helped set the stage for networking in the then-nascent mobile ad hoc and mesh networks and has heavily influenced the development of the research field. The paper received the 2018 ACM SIGMOBILE Test-of-Time award and recently hit the 30,000-citation mark, an unusual achievement, as only 16 papers by UCSB professors have received more citations.

A NEW DEAN FOR THE COLLEGE OF ENGINEERING

Professor Umesh Mishra brings to the office a formidable combination of scholarship and innovation in both academia and industry

The UC Santa Barbara College of Engineering (COE) has a new dean. **Umesh Mishra**, professor of electrical and computer engineering and an expert in energy-efficient electronic devices built on a gallium nitride (GaN) platform, was named dean in March. He will begin serving in his new role on July 1 while assuming the Richard A. Auhll Professorship and Dean's Chair of Engineering.

"We are confident that our College of Engineering will continue to thrive and achieve new heights under Dr. Mishra's leadership," said UCSB chancellor **Henry T. Yang.**

"I am honored, humbled, and very excited to be granted the opportunity to lead one of the finest faculties, most exceptional student bodies, and most outstanding staffs in a college of engineering in the United States," Mishra said. His appointment came after a rigorous two-year nationwide search following the retirement of previous dean, **Rod Alferness,** in 2021. Since then, UCSB materials professor **Tresa Pollock** has provided outstanding leadership and guidance as interim dean.

Mishra joined the UCSB faculty in 1990, bringing with him years of research experience in both industry and academia. Here, he has specialized in gallium nitride, a high-performance wide-bandgap semiconductor material that continues to play a primary role in the development of ever-more-energy-efficient devices, such as LEDs, highly efficient microwave-power amplifiers for 5G connectivity and Department of Defense applications, and advanced electronics that convert power with minimal energy waste, such as solar inverters, server power supplies, and chargers and inverters for electric vehicles.

During his time at UCSB, Mishra has served as the chair of his department as well as associate dean of advancement for the College of Engineering. He has served as the director of numerous multidisciplinary university research-initiative centers, and he co-founded the university's Solid State Lighting and Energy Electronics Center. In an effort to bring GaN into wider use, in 1996 Mishra co-founded Nitres (now part of Wolfspeed), the world's first start-up to commercialize radio-frequency GaN transistors and GaN LEDs. In 2007, he co-founded Transphorm to commercialize GaN transistors for power conversion.

"During my tenure as dean, I would like to amplify UCSB's advantages — its location, reputation, diversity, and culture of collaboration — while leveraging its perceived disadvantages, which include its small size and limited local industrial ecosystem, to its advantage through interdisciplinary hyperconnectivity and engagement," Mishra said. "We have to punch above our weight class, and we can only do it together, collaborating not only within the College of Engineering, but also across the campus and the local community as a whole. We will be the best in the world in areas that we choose to focus on — areas that can also have maximum social impact."

> "We have to punch above our weight class...to be the best in the world in areas that we choose to focus on — areas that can also have maximum social impact."

A member of the National Academy of Engineering, Mishra is also a fellow of the Institute of Electrical and Electronics Engineers (IEEE) and the National Academy of Inventors. He has been recognized for both his research and his teaching, with honors including IEEE's David Sarnoff Award and Jun-ichi Nishizawa Medal; the International Symposium on Compound Semiconductors' Quantum Device Award and Heinrich Welker Award; as well as the Distinguished Education Award from the IEEE Microwave Theory and Technology Society, and the Faculty Research Lecturer recognition, the highest award given to a faculty member by the UC Santa Barbara Academic Senate. Recognized as a highly cited researcher by the Institute for Scientific Information, Mishra is also a dedicated mentor, having supervised 76 PhD students, mostly in the field of GaN materials and devices.

FACULTY AWARDS AND RECOGNITIONS

(June 2022 – May 2023)

Every year, UC Santa Barbara College of Engineering junior, mid-career, and senior faculty receive many of the most prestigious honors awarded by academic and professional societies in recognition of their leading-edge research and contributions to discovering new scientific knowledge. Here are snapshots of the faculty who have been commended by their peers within the past year, including those who were elected to the National Academy of Engineering or received Early CAREER awards from the National Science Foundation (NSF).

Jonathan Balkind

Assistant Professor, Computer Science

Early CAREER Award, (NSF); Trailblazer Fellowship, Open Source Hardware Association (OSHWA)

Jonathan Balkind's five-year, $630,000 Early CAREER award will allow him to develop a new application for cloud computing. He will use a technique called *microarchitectural checkpointing* to redesign computer processors for cloud-based serverless computing. Balkind also received a one-year fellowship from OSHWA to document his experience of making open-source hardware in academia to create a library of resources for others to follow.

Irene Beyerlein

Mehrabian Interdisciplinary Professor, Mechanical Engineering and Materials

Elected Fellow, The Minerals, Metals, and Materials Society (TMS)

Peers honored Irene Beyerlein for her outstanding contributions to the practice of metallurgy, materials science, and technology. The Mehrabian Interdisciplinary Professor was cited for "seminal contributions to multi-scale modeling of deformation of polycrystalline metals, severe plastic deformation, and interface-driven plasticity."

Elizabeth Belding

Professor, Computer Science

Best (Long) Paper Award, Association of Computing Machinery's Internet Measurement Conference

Elizabeth Belding, an associate dean and faculty equity advisor for the college, and her co-authors were honored for their paper, which established that using crowdsourced speed-test measurements was problematic and led to misleading conclusions about service provided. The paper included recommendations for speed-test vendors and the FCC to contextualize speed-test data and correctly interpret measured performance. (Read more on page 28.)

Kerem Çamsari

Assistant Professor, Electrical and Computer Engineering

Early CAREER Award, National Science Foundation (NSF)

Kerem Çamsari received a five-year, $546,000 NSF Early CAREER Award to pursue pioneering research in probabilistic computing. The work, which could provide an important step toward quantum computing, requires reimagining computers to use normally unwanted environmental "noise" to substantially improve the energy efficiency of machine-learning and artificial-intelligence algorithms.

Michael Beyeler

Assistant Professor, Computer Science

Director's New Innovator Award, National Institutes of Health (NIH)

Michael Beyeler received a five-year, $1.5 million NIH grant to push the boundaries of biomedical science and pursue high-impact research. He aims to bring to the mainstream an AI-powered bionic eye in an effort to increase the quality of life for patients who are blind or visually impaired.

Steven DenBaars

Mistubishi Distinguished Professor, Electrical and Computer Engineering, Materials

Elected Fellow, Optica

A member of the National Academy of Engineering and co-director of the UCSB Solid State Lighting and Energy Electronics Center, Steven DenBaars was honored by Optica for his "leadership and pioneering contributions to gallium nitride–based materials and devices for solid-state lighting and displays."

Arpit Gupta
Assistant Professor, Computer Science

Best (Long) Paper Award, Association of Computing Machinery's Internet Measurement Conference

In their paper, Arpit Gupta and his co-authors established that using crowdsourced speed-test measurements was problematic and led to misleading conclusions in terms of service provided. They included a set of recommendations that speed-test vendors and the FCC could use to contextualize speed-test data and correctly interpret measured performance. (Read more on page 28.)

Upanmanyu Madhow
Professor, Electrical and Computer Engineering

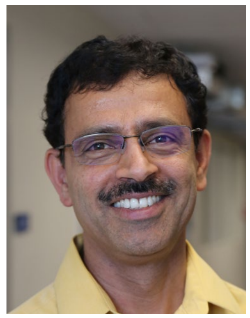
Elected Fellow, National Academy of Inventors (NAI)

Upanmanyu Madhow, who holds more than thirty patents, was elected an NAI Fellow as a result of his innovative contributions to wireless communication and sensing, reliable data transport, wireless networking, and localization. Among the most widely used of his inventions are those related to novel software-only methods for improving GPS accuracy in urban settings. His technology has been deployed by Uber, T-Mobile, Sprint, and more than 120 wireless carriers in sixty countries.

Jonathan Klamkin
Professor, Electrical and Computer Engineering

Elected Fellow, Optica

Jonathan Klamkin, who is director of UCSB's Nanofabrication Facility (see page 30), was elected an Optica Fellow for his "major contributions to integrated microwave photonics and photonics integrated circuits, particularly integrated optical-beam-forming networks."



B. S. Manjunath
Distinguished Professor and Chair, Electrical and Computer Engineering

Elected Fellow, National Academy of Inventors (NAI) and the American Institute for Medical and Biological Engineers (AIMBE)

B. S. Manjunath was named an NAI Fellow, considered the highest professional distinction awarded to academic inventors. A pioneer in the field of big-image data management, Manjunath holds 26 patents related to image-content representation, software licensing to commercial products, and integration of cybersecurity/forensics tools within government labs. AIMBE also named him a fellow "for outstanding contributions to the design, development, and deployment of a producible scientific-image analytics platform."

Carlos Levi
Mehrabian Distinguished Professor, Materials and Mechanical Engineering

Elected Member, National Academy of Engineering (NAE)

Carlos Levi was cited by NAE for "contributions to the understanding and development of high-temperature engineered surfaces and multilayers used in advanced gas turbine engines." His research interests include high-temperature engineered coatings and composites that improve fuel efficiency and reduce emissions in energy and transportation systems. Recently, Levi has helped guide the development of thermal and environmental-barrier coatings that are able to resist failures induced by deposits of molten silicates (CMAS) from volcanic ash, as well as from sandy and dusty environments. Such particles can accelerate degradation of aircraft-engine components.

Umesh Mishra
Donald W. Whittier Distinguished Professor, Electrical and Computer Engineering

Elected Foreign Fellow, Indian National Academy of Engineering

Umesh Mishra, who will become the eighth dean in the history of UCSB's College of Engineering on July 1, 2023, was elected as a Foreign Fellow to the Indian National Academy of Engineering, an honor bestowed on foreign nationals who have made outstanding contributions in engineering and technology and emerged as global leaders. An elected member of the U.S. National Academy of Engineering, Mishra previously received the Jun-ichi Nishizawa Medal, one of IEEE's most prestigious honors, in recognition of his contributions to the development of gallium-nitride-based electronics.

Chris Palmstrøm

Distinguished Professor, Materials and Electrical and Computer Engineering

Elected Fellow, American Association for the Advancement of Science (AAAS)

Chris Palmstrøm's peers named him an AAAS Fellow, which recognizes distinguished efforts to advance science or its applications. Researches in his lab use molecular beam epitaxy to "grow" novel materials atom by atom for making next-generation devices.

Tresa Pollock

Alcoa Distinguished Professor of Materials, Interim Dean of College of Engineering

2023 Acta Materialia Gold Medal, Acta Materialia, Inc.

Tresa Pollock received the 2023 Acta Materialia Gold Medal, a prestigious annual award given to just one person worldwide in recognition of outstanding leadership in the field. Pollock is the first woman to receive the medal in the fifty-year history of the award, which is considered the most highly regarded international accolade given to metallurgists.

Beth Pruitt

Professor and Chair, Biological Engineering

BRITE Fellow, National Science Foundation (NSF)

Beth Pruitt received one of five prestigious NSF Boosting Research Ideas for Transformative and Equitable Advances in Engineering (BRITE) Fellow awards in 2023. Pruitt plans to use the award to advance the understanding of the different ways that male and female heart-muscle cells handle stress. She hopes her work will reveal the extent to which observed differences, such as in disease progression and stress responses in the heart, are intrinsic to the cell.

Mark Rodwell

Distinguished Professor, Electrical and Computer Engineering

University Research Award, Semiconductor Industry Association (SIA)

Mark Rodwell, the Doluca Family Endowed Chair, was honored for "excellence in semiconductor technology research." His research group works to extend the operation of electronics to the highest feasible frequencies, focusing on semiconductor devices, semiconductor fabrication processes, integrated circuit (IC) design with very large-scale integration (VLSI), and interconnects.

Rachel Segalman

Professor and Chair, Chemical Engineering

Ernest Orlando Lawrence Award, Department of Energy (DOE); Andreas Acrivos Award for Professional Progress in Chemical Engineering, American Institute of Chemical Engineers (AIChE); Elected Fellow, AIChE and the Royal Society of Chemistry

Rachel Segalman received the Ernest Orlando Lawrence Award, the U.S. Department of Energy's highest scientific honor. Segalman was cited for "significant fundamental materials science and engineering contributions to self-assembly and structure-property relationships in functional polymer systems, with special applications to photovoltaic, thermoelectric, and membrane technologies." The second was the American Institute of Chemical Engineers' Andreas Acrivos Award for Professional Progress in Chemical Engineering. She was commended for "pioneering studies of functional soft materials, including semiconducting block polymers, polymeric ionic liquids, and hybrid thermoelectric materials." Segalman was also elected a fellow of the AIChE and the Royal Society of Chemistry, the latter being the oldest chemical society in the world.

Tim Sherwood

Professor, Computer Science

Elected Fellow, Association of Computing Machinery (ACM)

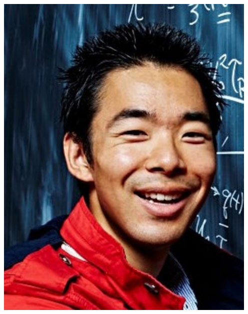
Tim Sherwood, who is currently serving as interim dean in the College of Creative Studies, was named an ACM Fellow for his "contributions to computer-system security and performance analysis." The prestigious honor is given to only the top one percent of ACM members.

Misha Sra

John and Eileen Gerngross Assistant Professor, Computer Science

Early CAREER Award, National Science Foundation (NSF)

Misha Sra's five-year, $606,290 NSF Early CAREER award will allow her to design an artificial intelligence (AI) and extended reality (XR) system for motor-skill learning and rehabilitation. (See page 21.) The project will advance a new human-AI interface paradigm in which the AI is represented as a 3D-humanoid agent in XR that can mimic the real-time verbal and non-verbal behaviors of a human trainer.



Sho Takatori

Assistant Professor, Chemical Engineering

Packard Fellowship, David and Lucile Packard Foundation

Sho Takatori was awarded a prestigious $875,000 Packard Fellowship for Science and Engineering to develop novel multifunctional surfaces through a deeper understanding of active matter, which is matter that converts chemical energy into mechanical work to drive emergent properties.

Mary Tripsas

Professor, Technology Management

Distinguished Scholar Award, Academy of Management (AOM)

Mary Tripsas was honored by the Academy of Management's Division of Technology and Innovation Management in recognition of her research on the transformation of industries by new technology. AOM said that her work illustrates "how the interplay of organizational capabilities, organizational identity, and managerial mental models shape strategic responses to technological shifts."

Chris Van de Walle

Professor, Materials

Vannevar Bush Faculty Fellowship, Department of Defense; Highly Cited Researcher, Clarivate Analytics

Chris Van de Walle received the five-year Vannever Bush Fellowship, which is worth more than $2.5 million in research funding and considered the Department of Defense's most prestigious single-investigator award. The fellowship supports his work to develop new computational approaches to improve the efficiency of electronic and optoelectronic devices based on wide-bandgap semiconductors. Van de Walle was also recognized among the top one percent of his field by citations, landing on Clarivate Analytics' Highly Cited Researchers List for the sixth straight year.

William Wang

Associate Professor, Computer Science

Undergraduate Research Faculty Mentoring Award, Computing Research Association (CRA); Karen Spärck Jones Award, British Computer Society

William Wang, the Duncan and Suzanne Mellichamp Chair in Artificial Intelligence Design, received the prestigious Karen Spärck Jones Award, named after the pioneer of information retrieval, who was also an outspoken advocate for women in computing. Wang also received the CRA's Undergraduate Research Mentoring Award for his dedication to exceptional mentorship, guidance on applying to graduate school, and matriculation of students to research-focused graduate programs in computing. During his time at UCSB, three of Wang's students have won Chancellor's Awards (CRAs) for Excellence in Undergraduate Research, and seven have received CRA Outstanding Undergraduate Researcher Awards.

Enoch Yeung

Assistant Professor, Mechanical Engineering

Enoch Yeung received a five-year, $644,000 NSF Early CAREER Award to develop new biotechnology to reveal how the dynamics of persistent twisting in DNA alters cellular activity and cell fate. The overarching goal is to understand the functional relationship between different spatial arrangements of genetic programs and the fluid landscape of DNA twisting.

Yangying Zhu

Assistant Professor, Mechanical Engineering

Early Career Faculty Award, National Aeronautics and Space Administration (NASA); Faculty Fellowship, Hellman Family Foundation

Yangying Zhu will receive up to $600,000 over three years to develop innovative technology to support exploration in the extreme conditions of space. (See page 26.) Zhu will examine the microscopic processes that occur within a lithium-ion battery during extreme temperature transitions, with timescales relevant to the lunar environment. Zhu received a Hellman Family Foundation Fellowship for a project titled "Blood-vessel-inspired cooling of batteries using internal convective flow."

Faculty Q&A
RACHEL SEGALMAN

The department chair shares her thoughts on community, collaboration, and diversifying the chemical engineering field

***Rachel Segalman,** professor and chair in the Chemical Engineering Department at UC Santa Barbara, is a global leader in materials and chemical engineering, having made major contributions to the design of conductive polymers, as well as bio-inspired polymer assembly. She applies that knowledge in developing functional polymers having applications in sustainability, water, and energy. Segalman has received many of the top awards and recognitions in the field. Most recently, she was named a Fellow of the National Academy of Engineering and received the Ernest O. Lawrence Award from the U.S. Department of Energy, and the Andreas Acrivos Award for Professional Progress in Chemical Engineering from the AIChE. We spoke with Professor Segalman in April.*

Convergence: *You have been department chair since 2015. How has it been serving in that role while pursuing a full research agenda?*

Rachel Segalman: I moved to UCSB in 2014 largely because I was so inspired by the community and the collaborative environment here. When the Chemical Engineering Department needed a new chair shortly after I arrived, it was an opportunity to help build on this tradition. I have been honored to continue to be a part of the department's evolution, which includes a universal commitment by our faculty to world-leading research, interdisciplinary inspiration, and sustaining a wonderful community where people support each other and truly enjoy each other's company.

Moving my research group from Berkeley to UCSB was a wonderfully entropic event for my research group, presenting us with many scientific opportunities that we had not previously considered. Even though my major draw in terms of moving to UCSB was the community of collaborators, it is still amazing to realize just how inspired by our neighbors and collaborators we have been in the past nine years. I am also so grateful for the generation of talented graduate students and postdocs I've had the privilege of working with during this time. I've always said that if I'm doing my job right, in their fourth year, graduate students should be working on things I never would have dreamed of, and I should be "panic-reading" to keep up. My chairship has perhaps increased the panic level, but it has been tremendous fun.

C: *Looking back on your time as chair, can you mention a few changes or advances that please you most?*

RS: It has certainly been an eventful eight years. I am most proud of the way the faculty of the ChemE Department has evolved over this time. We have had some amazing colleagues join our ranks — **Professors James Rawlings, Phil Christopher, Arnab Mukherjee, Siddarth Dey, Joe Chada, Sho Takatori, Tyler Mefford** — and there are a couple more I hope will join before I step down in the coming months.

I am further thrilled by a number of substantial changes that have occurred during my tenure as chair. We have built a strong relationship with the new

> "We need more role models for diverse faculty. Amid the chaos and difficulties of 2020, something special happened: the virtual platforms that rose combined with the community's heightened awareness of a need to change the way we had been approaching these issues."

Biological Engineering program, with many shared strategic goals and joint-appointed faculty. We now have two fully endowed undergraduate laboratories, the endowments ensuring continuous modernization of those facilities. Finally, the department is prepared for a new generation of leadership to sustain our vision into the future.

C: *What are your thoughts about the team efforts it took to complete those two lab endowments?*

RS: The endowment of the Rober G. Rinker Chemical Engineering Teaching Lab began as an alumni tribute to commemorate the 40th anniversary of the ChemE Department. For the department's 50th anniversary, a grassroots effort engaging alumnus **Darryl McCall** ('78), **Professor Emeritus Duncan Mellichamp, Professor Mike Doherty,** and many others completed the endowment. In this fully endowed lab, we can now give chemical engineers a modern, updated hands-on experience in their junior and senior years.

The Asbury Discovery Laboratory grew out of an idea presented by **Professor Joe Chada** about the value of a freshman hands-on experience, particularly for diverse and first-generation students. I then discussed this idea with another alum, **Doug Asbury,** who provided major funding and was so excited that the laboratory was endowed and built within two years.

C: *You have demonstrated dedication to addressing issues around diversity, equity, and inclusion. Can you share your take on where we are and where we might need to be*?

RS: Advances in science are accelerated when addressed by teams having diverse backgrounds and unique perspectives. While the national engineering community has made significant efforts in both educating and hiring such diverse teams, over the past twenty years, we have barely moved the needle in terms of representation of women and Black people, Indigenous people, and people of color (BIPOC). UCSB is a Hispanic Serving Institution, and 40 percent of our undergraduate body and 15 percent of our graduate student body are the first members of their families to attend college. As a result, we have a unique opportunity and responsibility to rethink, at every level, who gets to be an engineer. We have tried hard to do this in Chemical Engineering, particularly in rethinking how students discover chemical engineering.

As I mentioned earlier, I am thrilled with the Asbury Discovery Laboratory Experience that Professor Chada is designing for freshmen, to be offered both to our majors and to students across campus. Via this experiential course, in which freshman will perform chemical engineering processes and discover the connections among chemical engineering, biology, sustainability, and consumer products, we hope to open the doors to freshmen who may not have had the privilege of prior exposure. We are similarly excited to be expanding our reach at the graduate- and faculty-recruitment levels as well.

As a scientific community, we need more role models for diverse faculty, a better community of support, and, on a community level, better knowledge of who is in the pipeline. Amid all the chaos and difficulties of 2020, something special happened: the virtual platforms that rose in prominence combined with the community's heightened awareness of a need to change the way we had been approaching these issues. It was in this context that I helped found a national Zoom seminar highlighting future diverse leaders in chemical engineering. The idea was to create an opportunity for current graduate students and postdocs to present their work and be mentored by senior leaders in the field. The audience is made up of both faculty from around the country who may be in search committees, as well as other students who would like to see some diverse role models or simply attend some great talks about chemical engineering.

C: *Academic research is an endeavor of continuous change and evolution. What are you most excited about going into the next phase of your career?*

RS: This is a bit like choosing a favorite child. I am very excited about the work we are doing as part of the Center for Materials for Water and Energy Systems (MWET), which combines UCSB's expertise in polymer chemistry and physics with the University of Texas's leadership in water chemistry and membrane science. Together, we are gaining fundamental knowledge about the interactions between water and polymers, which will be used to design new membrane materials to efficiently purify water.

Recently, students working with myself and materials professors **Michael Chabinyc** and **Raphaële Clément** have developed new battery components, including electrolytes and binders. This work is particularly exciting, because we've both discovered new fundamental phenomena (for example, *superionicity* in polymer electrolytes) and then, how to use these insights to make robust, highly efficient batteries.

On a fundamental level, we're also having a lot of fun working with BioPACIFIC MIP [BioPolymers, Automated Cellular Infrastructure, Flow, and Integrated Chemistry Materials Innovation Platform], particularly to understand how the sequence of monomers in a polymer (like the sequence of amino acids in a protein) determines its structure and properties.

C: *You took part in writing the long-term vision document for the chemical engineering field. What do you see as the most pressing issue facing your field moving forward?*

RS: Chemical Engineering advances are critical to societal challenges, including the transition away from carbon energy sources and making food and water more efficiently. Specifically, we need new technologies to assist in decarbonizing the U.S. economy and mitigating climate change. While chemical engineers have always played a critical role in the energy value chain (both generation and use), the production and use of energy, food, water, and air are inextricably linked. Work at this nexus is something that I hope we can inspire the next generation of chemical engineers to tackle.

New Junior Faculty Bolster the COE

The UC Santa Barbara College of Engineering has hired the following seven new faculty members. Four have started during the 2022-'23 academic year, two will begin this summer, and one will start next fall.

Ananya Renuka Balakrishna
Materials (2022-'23)

Ananya Renuka Balakrisha received her PhD from the University of Oxford, where she wrote her dissertation on solid mechanics and materials engineering. Specifically, she says, "I developed a mathematical model to predict how microstructures form and evolve in ferroelectric materials and how such patterns govern macroscopic material properties, such as deformation, memory storage, and energy-harvesting capabilities."

She is building on that line of inquiry at UCSB. Her group's research is centered around the observation that microstructures can have dramatic effects on a material's physical properties. She notes, "We use the insights we gain to guide the discovery and design of materials having enhanced properties." To that end, her team is currently working on intercalation materials that are used as electrodes in lithium batteries, designing microstructures in multi-functional materials — such as ferromagnets, which have a magnetization dipole in their crystals and exhibit unique magneto-elastic properties important for energy-harvesting applications — and is newly branching out to understand microstructural evolution in light-interactive molecular crystals.

In describing why she was drawn to UCSB, Balakrishna says, "The collaborative environment both within the Materials Department and across campus was an instant attraction to me. The department is home to several important collaborative hubs, such as the MRL [Materials Research Lab] and CNSI [California NanoSystems Institute], which foster interdisciplinary research and are known for their cutting-edge facilities and education programs. As someone with a background in solid mechanics and computational materials, I am thrilled to be a part of such a vibrant research community, and I look forward to engaging with and learning from my colleagues in the years ahead."

Haewon Jeong
Electrical and Computer Engineering; Computer Science Affiliation (2022-'23)

Haewon Jeong says that her on-campus interview experience had a lot to do with her choosing to come to UC Santa Barbara. "The amazing colleagues I met during the interview process were definitely the biggest draw," one that was complemented, she says, by "the idyllic beauty of Santa Barbara. When I drove through Henley Gate for the first time, I couldn't believe how beautiful the campus was. It still captivates me, and every morning when I drive in, I feel grateful to work here."

Jeong earned her PhD at Carnegie Mellon University and wrote her dissertation on research she conducted at the intersection of information theory, high-performance computing, and machine learning (ML).

"I care about the reliability of large-scale machine learning algorithms," she says. "ChatGPT (see page 17) blew our minds and swept the world so quickly. Recent ML technologies that generate realistic and creative art with simple text commands seem to enable anyone to be an 'artist.' These fascinating ML tools are becoming part of our life so quickly, but their reliability has not yet been thoroughly tested. Is society ready for them? Oftentimes, the algorithms inherit societal stereotypes and discriminate against marginalized minority groups, or they inadvertently leak private information.

"At the same time, the inner workings of these large-scale ML models are so opaque that it is hard to tell where it went wrong," Jeong adds. "My research is aimed at tackling these problems and designing more reliable ML algorithms that can perform better in terms of fairness, privacy, and accountability. I use tools from information theory and statistics to provide theoretical understanding of algorithms and also provable guarantees of desired properties, such as fairness to all groups. I also closely collaborate with systems researchers to build hardware that is more reliable for running large-scale algorithms.

Sukhun Kang
Technology Management (summer '23)

Sukhun Kang will join the Technology Management Department as an assistant professor in fall, after completing his PhD this summer at the London Business School (LBS) in the United Kingdom. His area of expertise is strategy and entrepreneurship, with a focus on the biopharmaceutical and high-tech sectors.

Kang says that "many impressive aspects" of the College of Engineering attracted him to UCSB, but that he was especially drawn to "the genuine enthusiasm and passion that the faculty and staff in the TM Department displayed for their work. This level of excitement is not something I have seen at every university or department, and it was very appealing to me."

Further, he adds, "I was attracted to the emphasis on interdisciplinary research, which is highly valued at both the college and in the department. Technology management is not just about the technology itself, but also the companies and people behind it, and I am excited to explore how managing technology can have a broader impact on society."

Kang entered the PhD program at LBS intending to pursue research on entrepreneurship and venture capital. But when an immediate family member was diagnosed with cancer, he began looking through medical journal papers and following news of pharmaceutical companies to try to find what might be the best available treatment. During that process, he recalls, "I realized that strategic decision-making in the oncology industry was a complex and unconventional area to explore, given the various tensions involved." As a result, he adds, "My current research is focused on understanding how companies in this industry can better manage technology and innovation to improve access to novel drugs for patients."

Finally, he notes, "I have a deep interest in technology, innovation, and entrepreneurship, and how they can benefit society at large. I would love to connect with others who share these passions, and I look forward to joining the vibrant community at UCSB."

Ousmane Kodio
Mechanical Engineering (summer '23)

Ousmane Kodio, who will join the UC Santa Barbara faculty in July, received his PhD in mathematics from the University of Oxford and is currently an instructor of applied mathematics at the Massachusetts Institute of Technology. He says that he was attracted to UCSB by "the collaborative research environment" and that he is "very excited to be joining the vibrant community at UCSB and interacting with brilliant and supportive colleagues."

Kodio conducts research at the interface of applied mathematics, theoretical physics, and biology, with the aim of gaining insights into physical, biological, or societal problems through the lens of mathematical modeling. He uses mathematical modeling in conjunction with experimentation and computational tools to analyze the formation of patterns in complex systems, such as the growth and forms of living matter, and the emergence of collective behavior in active systems.

Ziad Matni
Computer Science (2022-'23)

"Every day when I drive into campus toward Henley Gate, with that big blue ocean to my left, I have to remind myself that this is not a fantasy, that I do work here!" says assistant teaching professor Ziad Matni.

Beyond Henley Gate, he says, "The UCSB College of Engineering is a world-class organization, and I am thrilled to be part of it, working among some of the most accomplished people in their fields. I also thoroughly enjoy teaching computer science courses to eager, intelligent undergraduate students. Finally, the collaborative environment here has already enabled me to work on research with colleagues not only in Computer Science, but also in other fields where computational approaches are valued."

Matni received his PhD in the area of information science from Rutgers University in 2018, after earning a Master of Science in Electrical Engineering from the University of Southern California. He says that a teaching assistantship there "cemented my love for teaching and research," but he chose to work in the tech industry for about thirteen years before, he says, "deciding it was time to go back to academia."

Teaching occupies at least half of Matni's work, with the other half divided among research, mentorship, and service. "I've had an affinity for teaching since my own undergraduate days," he says. "I especially value the opportunity it provides to positively impact the lives of young people, and I relish the role of teacher and mentor and enjoy honing my skills and developing my teaching philosophy and practice. Teaching gives me great personal satisfaction."

A key factor in Matni's choice to return to academia, he says, is the opportunity it provides "to meet a large variety of people on a daily basis. I am also always looking to understand not just the technical domain of computers, but also their impact on people's daily lives and, indeed, on society at large."

Just as *Convergence* was going to press, we learned that at least four more new faculty in the College of Engineering — in bioengineering, chemical engineering, and computer science — will be joining the seven assistant professors profiled here. Stay tuned, because we'll be introducting you to them in the next issue of the magazine.

Daniel Oropeza
Materials (summer '23)

Daniel Oropeza says that he was attracted to UCSB by the collaborative culture he found here, which became evident through his interactions with faculty and students during his visits to campus. "It was clear that the faculty cared for and knew one another not only professionally, but also on a personal level," he says, "and that they take pride and find enjoyment in working together, which is reflected, ultimately, in the enhanced impact of their research."

In his own research, Oropeza focuses on probing the fundamentals of materials processing for aerospace and extreme environments, including platforms such as hypersonics, spacecraft, and renewable and conventional energy generation.

"We are exploring the fundamentals of additive manufacturing for metals and ceramics by developing custom testbeds through material synthesis and characterization, and post-process optimization," he explains. "We aim to understand how material feedstocks and processing parameters influence a material's microstructure and properties, which drive performance." He is particularly excited to pursue research on novel refractory and magnetic alloys processed via additive manufacturing, fundamentals for inkjet-based manufacturing, and the implementation of emerging machine-learning tools to optimize and automate manufacturing processes."

Oropeza earned his PhD at the Massachusetts Institute of Technology, and then spent two years as a postdoctoral researcher at NASA's Jet Propulsion Laboratory. "I'm very much looking forward to mentoring and teaching students as they grow during their professional journey, setting up a new lab to enhance the research capabilities of the department, and learning from my colleagues as we pursue new research opportunities," he says.

Yao Qin
Electrical and Computer Engineering (2022-'23)

Yao Qin earned her PhD and master's degrees in computer science and engineering at UC San Diego, and her BS in electrical engineering from Dalian University of Technology in China. Prior to arriving at UCSB, she spent nearly three years in New York as a research scientist for Google. She currently focuses her research on the subject of robustness in machine learning (ML). "For example," she says, "a self-driving car system can be thrown off by a mischievous adversary or might not work in unexpected weather conditions. My key research agenda is to design machine-learning algorithms to improve the models' robustness when they encounter unexpected scenarios."

Like so many faculty members who come to UCSB, Qin says, "I really love the collaborative environment and the active research energy in the department. I am looking forward to working with excellent students and faculty to develop a deep understanding of machine-learning models that will allow us to improve their robustness."

That, she says, includes defending against not only adversaries that attack machine-learning models, but also out-of-distribution generalization, both of which require ML models to function well under unobserved scenarios. "I am also highly interested in applying ML models to help patients who have diabetes to control glucose levels by predicting the required amount of insulin," she notes.

Qin says that she finds particular enjoyment in "mentoring students and helping to shape how the new generation thinks about computer science. It is rewarding to witness the growth of students and to develop my own knowledge with them."

FOCUS ON:

THE RISE OF AI

Welcome to the promising — and challenging — era of smart machines

In March 2022, after the large language model (LLM) ChatGPT earned a nearly perfect score on a high school AP biology exam, it was asked, *What do you say to a father with a sick child?* The chat bot's response astonished Bill Gates, who was involved with ChatGPT and is keen on using artificial intelligence (AI) to address pressing global issues, such as climate change and childhood mortality.

The Microsoft founder-turned-philanthropist wrote in his blog, GatesNotes, "I knew I had just seen the most important advance in technology since the graphical user interface.... It will change the way people work, learn, travel, get health care, and communicate with each other. Entire industries will reorient around it...." He added, "It also raises hard questions about the workforce, the legal system, privacy, bias, and more."

Researchers in the UC Santa Barbara Computer Science Department, and their colleagues both in and beyond the College of Engineering are at the forefront of the AI revolution, pursuing research to develop, refine, examine, and question the rapidly evolving technology while ensuring that it serves all people and harms none. That is why, says computer science professor and AI natural language expert **William Wang,** "We established the Center for Responsible Machine Learning [which has more than sixty faculty affiliates from across campus] to tackle the ethical, legal, and social aspects of AI. It's essential for the AI community to come together and work toward responsible development and deployment."

Cyber defense is another huge area of AI application, and in May (see page 25), the COE received a major National Science Foundation grant to fund a new Institute for Agent-based Cyber Threat Intelligence and OperatioN (ACTION).

In this edition of "FOCUS ON:," we introduce just some of the AI research and researchers at UCSB, acknowledging at the outset that we cannot adequately cover the topic in eight pages and, so, will return regularly in the future to "catch up."

LANGUAGE, VISION, ACTION

Yujie Lu, a second-year PhD student in computer science associate professor **William Wang**'s research group, works on computer vision and natural language processing (NLP), specifically how to implement complex planning problems in autonomous artificial intelligence. Accomplishing that, she says, requires AI models to understand information and signals from three dimensions: language, vision, and action.

"That's how humans do things like making breakfast," says Lu, whose work mostly involves writing code for the application and then running experiments to see if it works. "You need to perceive the environment and have a plan for how to implement the information it gives you, and then you need to be able to take some action."

She has published a first-author paper about language and vision, and another about language and action. A third, expected to be out in late spring or early summer, examines how to use language and vision to initiate action.

The instantly famous large-language model ChatGPT, she says, "is part of the AI that's driving those models, but it doesn't monitor the process it tells you about. It doesn't know what you've done." She hopes to be able to empower ChatGPT to perceive the environment and assess whether a task is being done correctly.

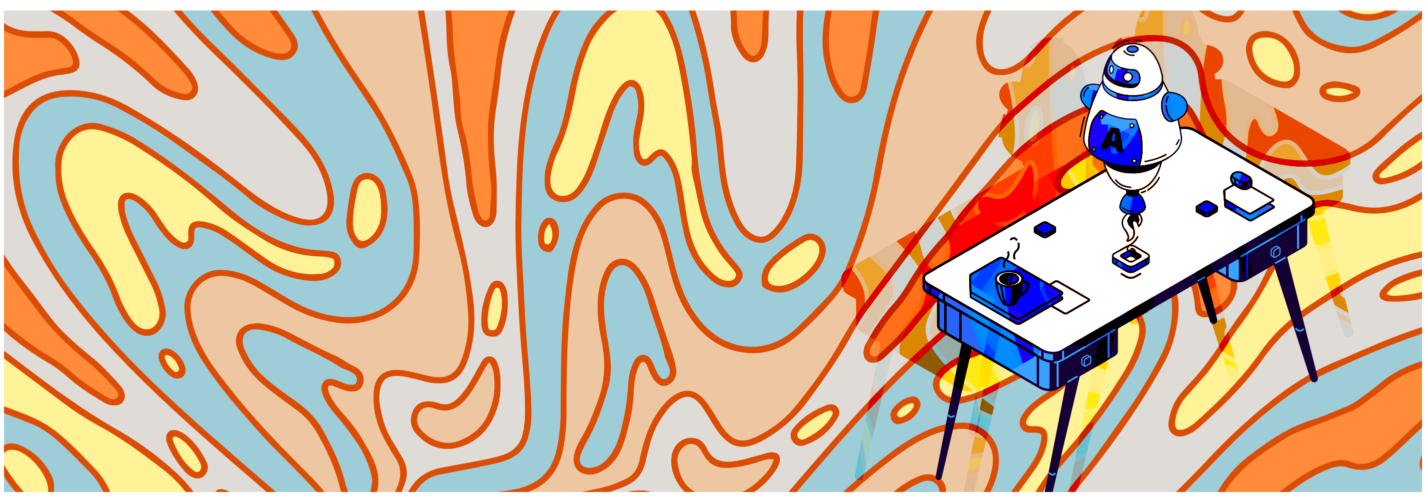
Lu's work and that of others in the field is changing how humans interact with robots. "In the past, when people were trying to train a robot to perform tasks, they had to provide a trajectory, such as a sequence of images reflecting what the robot would see in the environment, so that it could learn to navigate there," she explains. "The robot could then compare the original signals from the environment and the ground truth.

"But if I can use more-natural language, then humans can just give the robot a high-level command like, 'Go to the kitchen.' We can train the robot on those instructions, which are beyond low-level instructions, such as 'Go forward, turn left, turn right.' They have some hierarchy to them. The optimal goal would be for robots to connect a series of high-level natural-language instructions to a series of low-level actions. We want them to operate at a much higher level so that they can learn to reach the goal."

> **"THE OPTIMAL GOAL WOULD BE FOR THEM TO CONNECT A SERIES OF HIGH-LEVEL NATURAL-LANGUAGE INSTRUCTIONS TO A SERIES OF LOW-LEVEL ACTIONS... SO THAT THEY CAN LEARN TO REACH THE GOAL."**

Progress is occurring. "There is even a robot now that can communicate with people to perform tasks like making coffee or even more complex 'long-horizon' tasks, such as making breakfast," Lu says.

It will be a while, she suggests, perhaps thirty years, before robots exhibit such high-level functioning as being able to follow a simple command, maybe "Go back to the sink and start again," when they get "lost" and can't complete a task. But, she notes, "The technology is evolving very rapidly in a very promising direction."



Advanced robots and "hallucinating" chatbots add "interest" to the AI landscape.

AI AND PLANNING: BUT DO WE WANT *ALL* THAT DETAIL?

Paul Leonardi, professor and chair in the UCSB Technology Management Department, essentially studies AI through the lens of "how organizations will operate in the future." In one long-term project started in 2015, he examined how AI-empowered simulations might support decisions in two large metropolitan planning organizations in the U.S. that were trying to develop twenty-year regional plans related to such things as zoning ordinances and where to put transportation corridors.

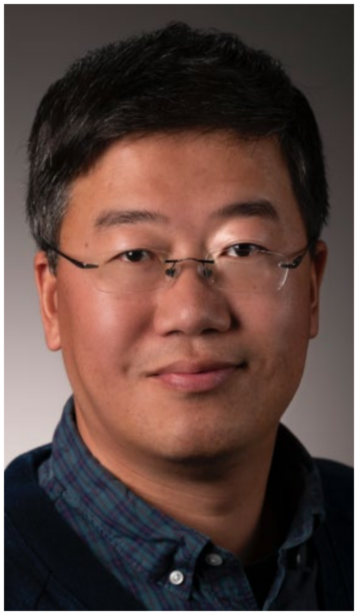
Planners always want more public participation in the process, but Leonardi explains, the models they've used for decades are, essentially, "numbers crunched in an Excel spreadsheet and a couple of bar graphs. They look at traffic congestion and commute time and run a regression analysis." No wonder average citizens at public-comment meetings feel disconnected from the data they don't understand and provide few valuable contributions.

Enter AI, which made it possible to build much more complex models. "We could take all of the data points we have today, run them through these complex algorithms, use AI to stitch the pieces together, make predictions about what's going to happen, render them in three dimensions, and even show a video of what the traffic will look like in an area if certain policies are implemented," Leonardi says. "It's a huge leap forward, but I was curious whether you would get more participation."

The findings were surprising. The two planning organizations made very different choices related to the models. One model was highly detailed; the other was much more sparse. "We thought the more-detailed one would produce much better citizen feedback and input, but it didn't," Leonardi reports. "Instead, when people looked at the model, they said things like, 'Wait, that's my house right there, and I don't want a five-story building around the block from me.' They started complaining about a lot of NIMBY kinds of things, and they didn't talk about the big-picture issues, like *do we want to have a traffic corridor?* Sort of paradoxically, the more detail and precision the model provided, the more the stakeholders focused on the wrong things and not the big picture.

"There's this balance," Leonardi says he learned from the study, "between what the right amount of information is to present and what the right amount of information is to withhold in order to provide the right level of abstraction and effectively stimulate engagement."

Just as we train AI models, we probably will need to train ourselves to work with them.



Xifeng Yan

AUTOMATIC PROGRAMMING: TOWARD DATA DEMOCRATIZATION

"We are on the eve of a big breakthrough in artificial intelligence, something very similar to the evolution of the internet, because it is foundational technology that can support many, many applications," says UCSB computer science professor **Xifeng Yan.**

Despite the limitations of current large language models (LLMs), Yan sees a huge value in them. "Yes, they hallucinate [i.e., embed plausible-sounding random falsehoods into generated content], and they do 'make up' facts, so they need us to verify what they do," he says. "But we are still in charge. AI helps us to finish a task much faster so that we can save our time for other meaningful things. It is much easier to check the bot's work than it is to come up with it yourself from scratch."

Automatic programming — a method that can enable an LLM to "auto-write a program so that we can use natural language to query the data" — is another focus in Yan's lab, and something he describes as "a very big development."

"To query and analyze data, you have to be trained to write code, but if you are, maybe, a biologist and don't know how to write code or don't have funding to have someone else do it for you, you can't leverage the huge amount of data you might have," he says. "But what if you could give natural-language commands to an LLM, and it would translate that into programs that would allow you to use your data to get the results you need?

"Sooner or later, you will see this kind of product in the MS Office suite," he continues. "It will democratize data by liberating people from having to learn programming before they can use their data. Everyone will have the freedom to query, manipulate, and analyze data."

Yan also sees tremendous *educational* value in chatbots. "When people think about Chat GPT and education, they might think fabout plagiarism and other negative things, but there is a lot of potential to use it to scale up teaching," he says. "I'm teaching a class with one hundred students. How do I give personalized feedback to every student? Chatbots can help. They can help teachers to plan better lectures and give customized guidance. They can help non-native speakers, such as international students, improve their writing skills. Some students at UCSB learned programming in high school, but others didn't have that chance. ChatGPT and similar models can help those students catch up.

"Imagine that you don't need to learn programming anymore," Yan concludes. "This is the future, and it's happening right now. We are transitioning away from having to write rigid code and to be able to use natural language to get our work done."

MAKING MEANING: AI AND UPDATING THE TURING TEST

Nelson Phillips

The Turing test was created in 1950 to test a machine's ability to exhibit the equivalent of intelligent behavior. While ChatGPT and other large systems have been able to defeat the original game-based test by "passing" as human in a conversation, "What Turing was getting the machine to do wasn't very sophisticated," says **Nelson Phillips,** a professor in the UCSB Technology Management Department. "It's sort of hiding out and managing not to be identified as a computer, but it's not showing human responsiveness."

Phillips and Mark Kennedy, a professor at London's Imperial College, started thinking about an update to the original Turing test, and created their own game-based version that requires players to categorize things and then convince others that their categorizations are reasonable. The point, Phillips says, is to test an AI model's "generative ability to participate in this thing that humans do when we create meaning by coming to a shared agreement about what something means."

They then wrote what Phillips describes as a "highly speculative" paper titled "The Participation Game" which appeared April 25 in *arXiv*, pitching their game as a better test of machine intelligence (than the original Turing test) and offering thoughts about the implications of some of AI's evolving abilities.

For instance, Phillips notes, "One thing humans do that computers can't is to create new symbols and new things, like the concept of a *selfie*," created when someone in Australia sent one to his friend group and first used the word. "They created a new concept," Phillips says, adding, "Humans are fabulous at this. We do it continuously, inventing new concepts like *influencer* or the *minivan* or the *tablet,* which establish a new category in our brain that has a certain set of characteristics."

If AI systems develop that ability, he says, "then they become really powerful but also really troubling. Imagine if you have a bunch of non-human influencers on the internet creating new ideas and populating our culture and our brains with new ways of thinking about the world. You very quickly go to either *Oh, my God, that would be amazing!* or 1984 and Big Brother and *who's controlling these things?*"

Today's chatbots essentially "take human-generated text and other data and mix and match pieces of them, so they are really just greatly amplifying the activity of some human who is actually thinking of the message," Phillips says. "This would just be giving these systems a goal and telling them to come up with and propagate new concepts. They could then convince people to think about the world in a certain way or not, a capacity that is much more powerful than just being able to participate in communication."

> **"IMAGINE A BUNCH OF NON-HUMAN INFLUENCERS. YOU VERY QUICKLY GO TO EITHER 'OH, MY GOD, THAT WOULD BE AMAZING!' OR 1984 AND BIG BROTHER AND 'WHO'S CONTROLLING THESE THINGS?'"**

COMBATTING LLM PIRACY

Yu-Xiang Wang, a UCSB computer science (CS) assistant professor and co-director of the Center for Responsible Machine Learning, conducts research on the statistical foundation of machine-learning (ML) algorithms while also addressing real-life concerns, such as security, privacy, and copyright protection in the time of large language models (LLMs) like ChatGPt. "We predict that the privacy concerns around AI, natural language processing (NLP), and ML are going to touch every single person on the planet in a few years," he says.

Related to this, people are using LLMs to generate code, which is both promising and troubling. (See "Automatic Programming, on page 19.) "The algorithms have sometimes generated verbatim code from proprietary software from the nineties," Wang says. "We consider such events the growing pains of LLMs, and we need to come up with technical solutions to such problems to make the transition as smooth and as painless as possible."

In addition to privacy and copyright concerns related to LLMs' training data, Wang also worries about the copyright of LLMs themselves. He notes that companies spend billions of dollars to train their models, and then, as OpenAI did, ship them as APIs. In a process referred to as a *model-stealing attack*, a rogue company can then use a well-developed method called *model distillation* to create a copy of the model from the API and then ship it at a fraction of the cost.

In 2022, Wang, his student **Xuandong Zhao,** and fellow CS assistant professor **Lei Li** (see page 22) co-wrote a paper predicting that practice. "Imagine if a rogue company created this model at a fraction of the cost, shipped it as its own, and hijacked all the traffic at a much lower price," he says. "That is not good for innovation."

To combat pirating, Wang's lab came up with "watermarking" tools that can be used to mark any output from an LLM. Then, if someone trains a new model on top of the original, every piece of information it generates will contain a "backdoor" from the original. "It shows up a little bit in the results," Wang says, "and once you get thousands of results, you can collect them and gather the statistical information to prove with high certainty that the model was derived from the original.

"Variants of these watermarking techniques can be used to distinguish AI-generated content, such as college admission essays, homework submissions, music, art, and computer codes from their human-created counterparts." Wang hopes that such research can help to ease the "growing pains" as LLMs change the world.

TASK-ORIENTED AI: IT TAKES TRUST

Suppose you need physical therapy (PT) but live far from a city and can see a therapist only once every few months. Between visits, how do you make progress? How do you know if you're doing your exercises correctly? How do you get encouragement and guidance?

In her Human-AI Integration Lab, **Misha Sra**, an assistant professor in the UCSB Computer Science Department who recently received a National Science Foundation Early CAREER Award, is developing multimodal AI models to help address such task-oriented needs. "We're looking at building new types of AI-enhanced tools that can augment human physical abilities," she says.

Creating such AI helpers is a huge challenge, and Sra started with a simpler analogous process: making a cup of coffee. "Cooking is a physical task that embodies many of the challenges that we will encounter in building a tool to augment physical abilities," she says. "It has specific procedures, end goals, mechanisms to track progress, variations in how each person follows the procedures, and potential for unknowns, all of which apply to other physical tasks we've thought about, such as physical therapy or fitness training."

In Sra's lab is a setup with everything needed to make coffee. A user puts on an augmented-reality (AR) headset, and the system provides step-by-step instructions, from measuring and grinding the beans to folding the filter, etc. A user who is unfamiliar with a step can choose to receive verbal instructions (if, say, their hands are dirty) or, in a noisy place, watch a first-person perspective video or view a 3D animation shown on top of the relevant object in physical space. A menu attached to the user's hand or one that is gaze-controlled shows them the various help options.

"So, the AI is helping you in real time, instructing you and correcting your errors. Everything is going great, right?" Sra says. "But then the AI makes a mistake, because maybe there's something in the scene that it hasn't seen before. Maybe it tells you that you measured the beans incorrectly, but you didn't. What happens then?

"In such a scenario it is essential for the user to be informed when AI makes an error," she continues. "This information needs to be presented clearly through the user interface in AR. Additionally, the user may wish to understand why the AI made the error, which means that its thought process must be explained to them. Subsequently, the user must decide how to proceed when an error occurs. All of these are design questions that we're currently exploring. The bigger question we want to answer, however, is how to build trust between the human and the AI, despite the AI making mistakes, and how to design a user interface where the human is in control and not the AI."

> "SO, THE AI IS HELPING YOU IN REAL TIME.... EVERYTHING IS GOING GREAT, RIGHT?...BUT THEN THE AI MAKES A MISTAKE.... WHAT HAPPENS THEN?"

The next step, user studies, will help Sra to evaluate the interface and define the path toward the full system design.

Far left: Second-year PhD student Arthur Caetano uses an augmented-reality headset to follow the AI's instructions and make coffee for Misha Sra:

TOWARD NATURAL-LANGUAGE TRANSLATION

One of UCSB Computer Science assistant professor **Lei Li**'s main interests is developing advanced AI for language translation and knowledge reasoning. The current crop of commercial translation tools, such as Google Translate, can interpret around one hundred languages, Lei says. "We want to develop translation technology for a thousand languages, to help people better communicate with each other around the world."

That's hard to do, he says, because of a lack of two main elements: web data to train the AI models on lesser-used languages and an algorithm that works well in "low-resource settings."

"When we collect data on the web, we need parallelism, so, if we have a sentence in English, we need the equivalent sentence in, say, Hindi," Li explains. "To teach the machine, we need to pair the languages, not just translate words. We want to develop translation technology that can work well even with limited data to generalize across a very large number of languages."

That process depends on leveraging similarities in linguistic structures, semantics, and even some words that are similar or the same in different languages. Further, Li says, "The same kind of human knowledge is shared in every language. We want to develop AI to automatically learn this universal representation so that it can be generalized across language, and not just for text, but also for speech, so that spoken language can be translated directly to another language."

Over the past two years, researchers in Li's lab have gone from starting with about 36 languages to having 450 in their newest work. During an interview, he pulled out his phone and used his app to translate spoken English into Chinese characters on his screen in real time.

Lei Li

He also wants to develop models that can reason in a natural way, in human language, rather than in traditional AI, which takes a more symbolic, formal, mathematical approach to reasoning. His goal is to have AI reason in natural language, the way humans do.

Li gives the example of Los Angeles as the largest city in California, a fact that might lead someone to assert that it is also the state capital. "If we ask the model whether that is correct, we want it to be able to reason with that statement in natural language, to look for evidence, which is also obtained in natural language," he says. "It might find text about California or L.A. on Wikipedia and then piece that together to determine that the statement is incorrect: L.A. is not the capital. That's called *factor verification,* and it's very important right now, including with ChatGPT [with its penchant for hallucinations, i.e., embedding plausible-sounding random falsehoods into generated content], because we need to verify that the generated content is faithful and actually correct."

An AI-enabled buoy monitors the channel for sounds of endangered whales and sends them to ships in nearly real time so that they can slow down.

AI IN THE OCEAN

Collisions with container ships are a top cause of deaths of endangered whales in the Santa Barbara Channel and around the world. UC Santa Barbara researchers have long been involved in seeking ways to eliminate those collisions, and now, **Douglas McCauley,** professor in the Ecology, Evolution, and Marine Biology Department and director of the Benioff Ocean Science Laboratory, is working with colleagues to put artificial intelligence on the side of saving whale lives.

"In the environmental science community, we're looking at existential crises coming down on the planet with climate and biodiversity," McCauley says, "and we're excited to bring the power of AI tools to do good into the domain of environmental problem solving."

Working under the Benioff lab's Whale Safe program, McCauley and colleagues at the Woods Hole Oceanographic Institution developed an AI-powered mapping and analysis tool that collects and displays near-real-time whale data. The technology involves what McCauley describes as a "relatively simple algorithm" that was created for Whale Safe and is integrated with an acoustic detector in the channel, which listens constantly for whales. The underwater microphone turns the acoustic profile of the sounds it hears into an image, like sheet music, and then, McCauley says, "The AI matches those sound images with known images of endangered-whale calls." The classification library used to train the AI was built using years of underwater sound recordings.

"The system notes the whales' presence in the area and identifies them in real time as an endangered blue whale, a humpback whale, or a fin whale," McCauley says. "That information goes to the ships, letting them know that endangered species are in the ocean roadways, so that they can slow down to avoid running over them."

TASKS, EMPATHY, AND ETHICS IN AI

"I think this is even bigger than the internet," says computer science professor **William Wang** in speaking about ChatGPT and other large language models (LLMs). "It offers a better way to access all the information we have on the internet. It's going to significantly change human society."

One focus of Wang's group is *multimodal AI* — AI that can understand and represent information in non-text-only representations, such as a table, a database with text, image data, and video data. Researchers in his lab are working to improve LLMs to be able to perceive and understand language in its many modes.

As director of the Center for Responsible Machine Learning (CRML) and the Duncan and Suzanne Mellichamp Chair in Artificial Intelligence Design," Wang is especially focused on the ethics of AI, which includes addressing people's fears and concerns about how it might evolve. One big issue in that realm is how to distinguish facts from misinformation.

"LLMs are trained on a gigantic amount of data, so when generating output, they still need humans to verify the truthfulness of the results," Wang explains. "For instance, if you ask an LLM to read a financial statement, it is likely to give you hallucinations [random instances of plausible-sounding, but false, information]. So, for instance, a company's earnings might be $1.2 billion, but the model tells you that rhey are $1.5 billion — a 25 percent error. Those numbers have to be precise and correct, but the models answer questions on numerical reasoning with only about 60 percent accuracy. We still need humans to verify the truthfulness of results from any large generative model." That lack of precision, Wang says, creates a gap between what LLMs can do now and what they might be capable of with significantly increased precision.

Wang is also working to address the fact that AI currently "lacks emotion or empathy." He gives the example of a "failure case" in which Microsoft's search tool Bing asked users to apologize, which, he says, "is really weird. The model doesn't understand pragmatics and social dynamics." For that reason, he says, "We started working on empathetic AI and conversational AI six years ago and wrote a paper about trying to generate an emotional response, a functionality that could be useful in, for example, customer call centers when you want to deploy GPT technologies and ensure that the responses the AI generates are appropriate to the context of a request."

So, while large language models bring many opportunities, Wang notes, "They also present challenges, and we have to figure out how to mitigate them by building more-robust models to reduce this kind of hallucination or misinformation. ChatGPT is a nice demo, but it can't be deployed in an actual product, because those have to be very precise. There is still a lot of fundamental research we have to do to improve these LLMs."

William Wang

SLEUTHING CHATGPT SURPRISES

Ask ChatGPT a question — how to make biscuits or change the oil in your car, or why the sky is blue — and in about twenty seconds a sensible, coherent response will appear on your screen. *Most* of the time, that is, because, as we now know, the model occasionally, infamously *hallucinates* by inserting plausible-sounding random falsehoods into generated content.

While each new version of the model is said to be less biased than its predecessors and also less likely to make up facts, it will still hallucinate, and the company that developed it, OpenAI (now part of Microsoft), continues to provide this warning to users: "Great care should be taken when using language-model outputs, particularly in high-stakes contexts."

"This model is very good at retrieving information and explaining it to people, but it also makes up things and does it in a very convincing way," says second-year PhD student **Xinyi Wang.** "And though it doesn't — and can't — do that intentionally, it can still mislead people, so mitigating that is important to avoid the many potential risks of putting LLMs [large language models] into real-world applications."

In Wang's research, she is "taking a scientific approach to understanding what the model can do and why it can do it." For instance, she notes, "Some of ChatGPT's ability doesn't align with the pre-training objective." She cites an example of something called *in-context learning,* which refers to the fact that models usually learn only during training, but as a model gets bigger, it sometimes seems to learn at what's called *interference time,* and then performs a task that was not part of its training.

Xinyi Wang

Wang describes one example in which a model was given four sentences in French and four corresponding English translations. When given a fifth sentence in French *without* the corresponding English translation, the model produced a translation on its own anyway, seeming to have learned from the previous examples.

"That's one weird example, because we did not explicitly train it to generalize to a new instance based on some examples," she says. "So we're studying why that happens."

She says that the most powerful thing about LLMs is this *emergence capability,* when something like an unexpected new skill emerges, which can happen when the model's data size grows. "One thing I want to know is, if we understand how this ability emerges, can we observe other such abilities and make better use of them?" she says. "Also, as we better understand the model, we hope to be able to mitigate any negative effects of such events."

BUT DOES IT KNOW ME?

Doctors sometimes don't know, or remember, much about us. While changing his primary-care physician, UC Santa Barbara's director of the Center for Information Technology and Society, social scientist **Joe Walther,** started thinking about whether he would be better "known" by a doctor who might have only his latest lab test results, or an AI system that "can memorize my medical history in no time and conjure up whatever information is relevant."

Out of that arose the question: what does it take to feel known — by another human and by an AI system? To find out, Walther collaborated with Penn State University professor S. Shyam Sundar and his students, who ran experiments in which human subjects did an online intake interview after being told they were interacting with a human doctor or an AI system. In the scripted dialog, the doctor entity would ask questions about exercise, diet, etc. In a follow-up a week later, two conditions were added: the doctor either remembered information from the previous interaction or didn't appear to remember it at all. When the human or AI doctor didn't recall data from the prior encounter, it would repeat previously asked questions, such as, "Are you getting any exercise?"

People in the study liked it when the human doctor remembered their history, but found it "creepy" when the AI did; they were worried about where the remembered information was going.

"So, then we asked ourselves what it means to know someone, beyond their medical information," Walther says. "We did the experiment again, but this time added that the doctor either remembers social information about the patient or doesn't. It might ask during the first visit, "How do you like to be addressed?" and use that form of address the next time, and say such things as "Last time, you mentioned you have a good relationship with your family. Is that still the case?"

In this instance, people liked both the AI and the human doctor better when they remembered and brought such information into the conversation. Under that condition, they also liked the AI's recall of their medical information. "So, if the AI remembered social stuff, they also liked that it remembered medical stuff," Walther says.

"We used to think that to be known by somebody was to be remembered by them in a distinctive way," Walther notes. "Now, we have to refine that. For AI to make you feel that it knows you, it has to remember personal and social aspects, not just the task-oriented data. It's still kind of surprising to me that, even though it's a machine that we recognize as being a machine, we like it better if it's 'personable' with us."

Joe Walther

USING AI TO MAP METHANE EMISSIONS

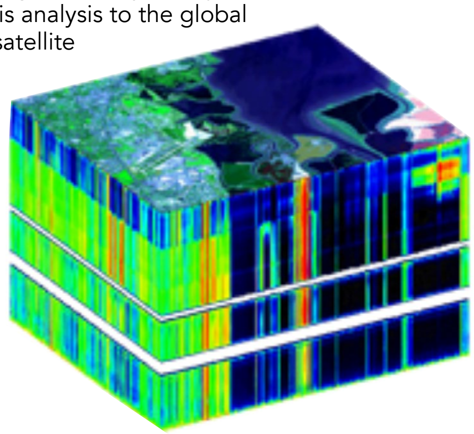
At the 2022 World Climate Summit, methane emissions were identified as being responsible for 30 percent of Earth's warming. "To put that into perspective," says **Satish Kumar,** a fifth-year PhD student in the Vision Research Lab (VRL), led by **B. S. Manjunath,** distinguished professor and chair of the Electrical and Computer Engineering Department at UC Santa Barbara, "The amount of damage to the environment that CO_2 will do in 100 years, methane can do in just 1.2 years." The problem has worsened in the U.S. since about 2010, when domestic oil and natural-gas production exploded.

Manjunath, a pioneer in the field of big-image-data management and director of the Center for Multimodal Big Data Science and Healthcare, was recently elected to the National Academy of Inventors (NAI). In the realm of multimodal big data, he developed the open-source BisQue (Bio-Image Semantic Inquiry User Environment) image informatics platform, the intent of which was, he says, "to enable reproducible computer vision [a main topic of AI research], bringing together data, annotations, and methods so that researchers could reproduce their results at anytime.

To help address the methane problem, Kumar developed a computer-vision/AI model, called the MethaneMapper (the data and AI models are distributed through the BisQue software platform), to detect emissions from two key sources: the gas and oil sector, which make up 36 percent of total methane emissions in the U.S., and agriculture and dairy farms, which account for 26 percent. He is the lead author on a scientific paper about the MethaneMapper that will be featured as a "Highlight Paper" at the 2023 Computer Vision and Pattern Recognition (CVPR) Conference, the premiere event in the computer-vision field, to be held this June in Vancouver, British Columbia.

Several methane-monitoring systems are currently in place, but existing methods for analyzing those images are not scalable, because they are prone to significant error and must be inspected by domain experts. MethaneMapper does everything automatically.

Kumar proposes what the paper describes as "a novel end-to-end spectral absorption wavelength aware transformer network…that introduces novel modules to help locate the most relevant methane plume regions." One module transforms what is called a *HyperSpectral data cube* into an aerial map displaying the location of a methane plume on the ground. Says Manjunath, "Our vision is to scale this analysis to the global level, using satellite images."



The stacked images of a HyperSpectral data cube reveal specific elements on Earth, such as methane plumes.

FASTER, MORE-EFFICIENT, MORE-AFFORDABLE AI

Given their remarkable abilities, perhaps its not surprising that the new AI-driven large language models (LLMs), like ChatGPT, are, well, power hungry. Training and running them is energy-intensive and expensive — the initial release of ChatGPT was trained on ten thousand Nvidia GPUs, at $1,500-$2,000 per unit, or $20 million — which is one reason why, for now, LLMs are the exclusive realm of large companies. UCSB Computer Science assistant professor **Yufei Ding** is working to make LLMs faster, more customizable by individual users, less expensive, and more energy-efficient as a way of reducing their carbon footprint.

Ding conducts research on three main fronts. The first is designing a hardware accelerator tailored for LLM computing, unlike the CPU in a laptop or desktop computer, which, she says, "is tailored for more 'general' computing. "It's a change in the architecture of the hardware itself."

The second area is software optimization, where she seeks to ensure that, "As hardware gets more and more complicated, an application can utilize it optimally, automatically," Ding says.

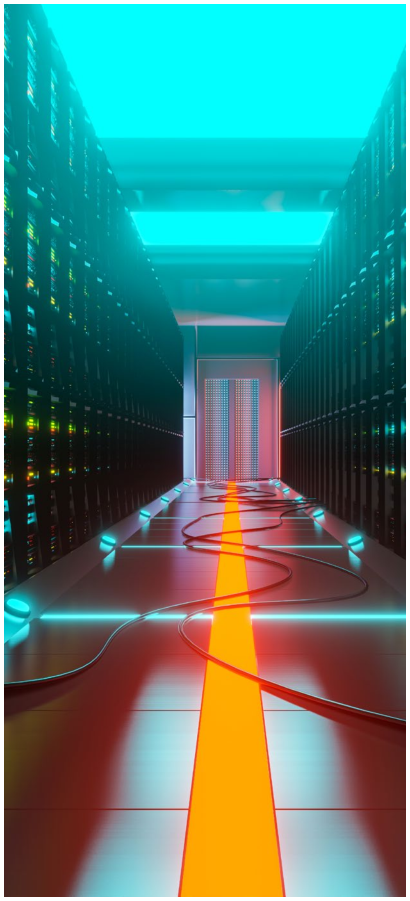
The third area is fine-tuning of the models. "At the algorithm level, instead of doing end-to-end training [complete training of the model] for everything, maybe we can have a general, powerful foundation model that we need to train once and that will just need some lightweight fine-tuning, such as tuning ChatGPT for medical care — to use it for other applications later," Ding explains.

"Or maybe I want to give personal information to ChatGPT so that it can help revise my paper, but I want to keep it private; I don't want the model to be trained on my data," she explains. "That's a fine-tuning process that could be done only on my own computer. Big companies have many thousands of GPUs running together, but I might have only one single laptop. How can I do that fine-tuning? It puts new challenges on the hardware and software designs."

The various areas of Ding's work address different scales of optimization that grow in scope and layer upon each other, from the smallest, a single device, to multiple devices within a node, up to inter-node coherence and communication. For end-to-end training, big companies are most concerned with parallelizing their thousands of servers to optimize efficiency and service. For a small company or an individual trying to fine-tune an LLM, privacy might be the main concern.

"Things like what kind of hardware you have, what you can afford, and what kind of task you want to do determine the optimization you need to have," she says. "We want to work across scales to ensure good performance in all kinds of scenarios."

Yufeig Ding wants to make everything about AI — including server centers like this one (right) — more energy efficient.



UCSB WILL LEAD A NSF COLLABORATION TO DEVELOP AI FOR NATIONAL INFRASTRUCTURE DEFENSE

ACTION Institute Logo

"Computer systems are increasingly central to national infrastructure in the financial, medical, manufacturing, defense, and other domains. That infrastructure is at risk from sophisticated cyber-adversaries backed by powerful nation-states whose capabilities rapidly evolve, demanding equally rapid responses."

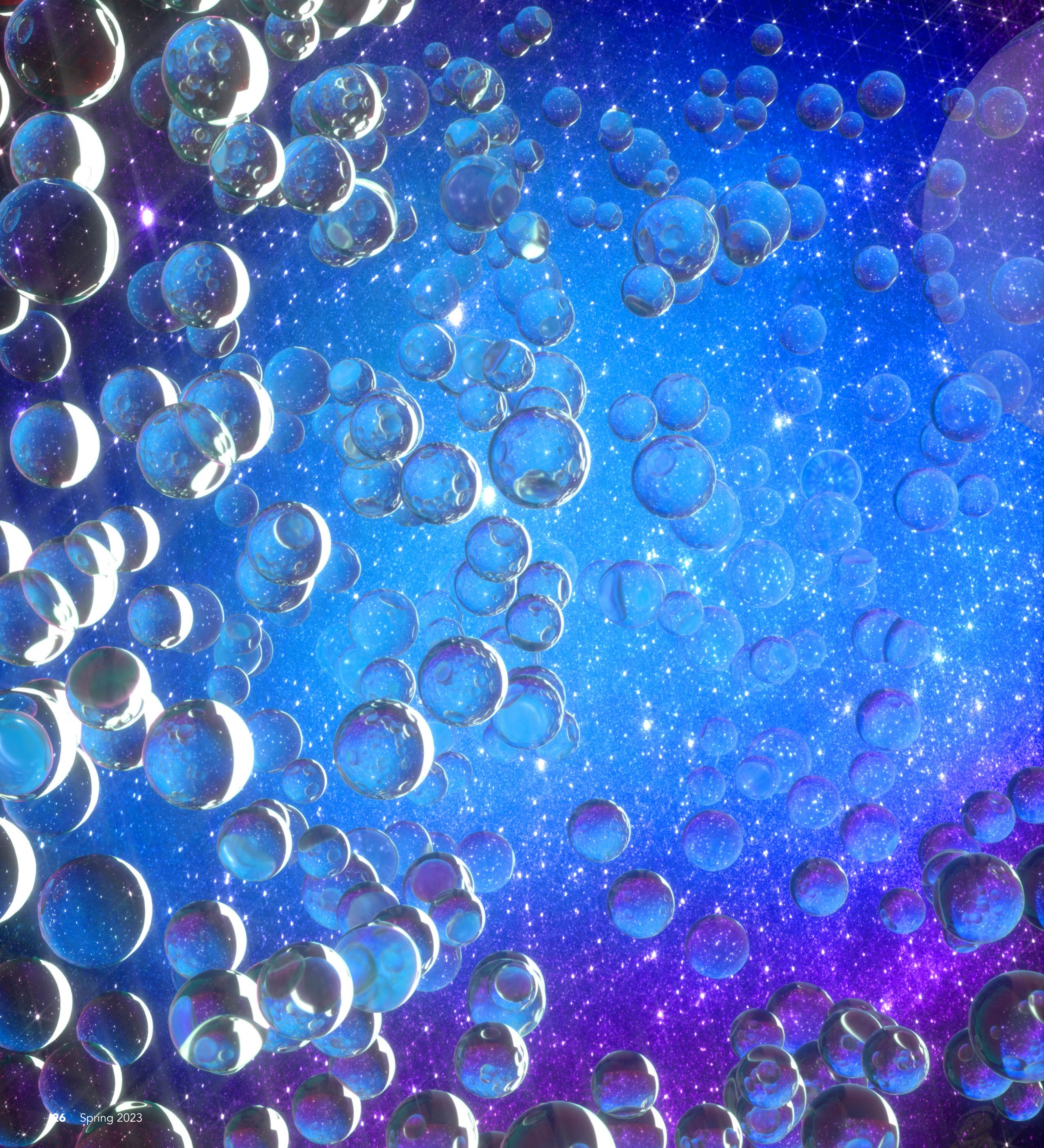
That passage is taken from the abstract for the ACTION Institute, which the National Science Foundation has just established to develop advances in "artificial intelligence and autonomous reasoning that will be tightly integrated with advanced security techniques to identify and correct vulnerabilities, detect threats and attribute them to adversaries, and mitigate and recover from attacks."

UC Santa Barbara is the lead institution on the $20 million, five-year NSF grant, and UCSB computer science professor and cyber-security expert **Giovanni Vigna** is the director. The project links UCSB and ten collaborating universities — UC Berkeley, the University of Washington, the University of Illinois Chicago, the University of Illinois Urbana-Champaign, the University of Chicago, Purdue University, Rutgers University, the Georgia Institute of Technology, Norfolk University, and the University of Virginia.

Together, researchers at those institutions "will develop novel approaches that leverage artificial intelligence — informed by and working with experts in security operations — to perform security tasks rapidly and at scale, anticipating the moves of an adversary and taking corrective actions to protect the security of computer networks as well as people's safety. The Institute will function as a nexus for the AI and cybersecurity communities, and its research efforts will be complemented by innovation in education from K-12 to post-doctoral students, the development of new tools for workforce development, and the creation of new opportunities for collaboration among the Institute's organizations and with external industry partners."

The institute will initiate a revolutionary approach to cybersecurity, in which AI-enabled intelligent security agents cooperate with humans across the cyber-defense life cycle to jointly improve the security posture of complex computer systems over time.

This was late-breaking news. Be sure to watch for more in-depth coverage of the institute in a future issue of Convergence.



A LIGHT ON MOVING BUBBLES ...IN SPACE

Automated experiments allow three UCSB professors to study bubble dynamics in multiphase liquids aboard the International Space Station

Multiphase flows contain one material in more than one phase, such as when bubbles (gas) occur in liquid. The dynamics of such bubbles play an important role in many applications, and the ability to control them would enable increased efficiency in such processes as liquid purification, water harvesting, and heating and cooling, both on Earth and in space.

Understanding the fundamentals of bubble dynamics is difficult on Earth, because gravity and other related phenomena, such as friction, pressure, buoyancy, and natural convection, affect their behavior, making it hard to isolate a single cause of a particular phenomenon. Things are more clear in space. That is why, last November, UC Santa Barbara professors **Yangying Zhu**, **Paolo Luzzatto-Fegiz** (both in Mechanical Engineering), and **Javier Read de Alaniz** (Chemistry) sent a cargo of experiments to the International Space Station (ISS).

"The question we wanted to answer," Zhu says, "was, can we manipulate fluid movement — for example, bubbles in liquid or liquid droplets on a surface — in space? And can we program a bubble to move in a certain direction and at a certain velocity? Doing these experiments in microgravity allowed us to have a better fundamental understanding of the physics involved."

Space-based applications include, for instance, boiling for thermal management, which is easy on Earth. "Buoyancy causes vapor bubbles to leave a hot surface, and the surface produces more bubbles for continuous heat transfer," Zhu explains. "In space, bubbles are stuck on the surface, dramatically hindering heat transfer."

> "Exploring the behavior of light-responsive molecules on the ISS provides a unique opportunity to investigate both stability and photo-reactivity in zero gravity."

Some researchers have used an electrostatic charge to try to manipulate bubbles in space, but the high voltage the system requires makes it prone to degradation. Others have used ultrasound, but that method is overly complex. "Our method is much easier," Zhu says. "We use light, which is programmable and can be reconfigured in real time, to manipulate droplets and bubbles."

The approach is based on two different light-sensitive molecules that Read de Alaniz developed in his lab. "Exploring the behavior of light-responsive molecules on the ISS provides a unique opportunity to investigate both stability and photo-reactivity in zero gravity, which will inspire new molecular designs," he says. The molecules were dissolved in a solvent, sealed in vials, and sent to space in eleven cuvettes, each containing a different combination of molecule and solvent designed to produce bubbles of different sizes. During the experiment, LED lights in a linear array adjacent to the vials were illuminated in sequence, lighting only one side of the bubble or droplet at a time. That caused the molecules to undergo a reversible, almost instantaneous conformational change, such that a long-chain molecule might become a ring but with its chemistry unchanged.

This series of cuvettes containing light-sensitive molecules dissolved in various solvents (giving the liquids their different colors) were sent to space. There, LED lights were shined on one side of each solution, causing a conformational change in the synthesized molecules and leading to a change in surface tension, which, in turn, led each bubble to move.

"The light-induced shape change of the molecule is really important, because it can modify the surface tension at the interface with the droplets or a bubble, producing higher tension on one side and lower tension on the other," Zhu says. "That causes the fluid to flow from the low-tension side to the high-tension side, inside and outside the bubble or droplet. It's like having two vortices, which can cause the droplet to move in a kind of swimming motion."

In another experiment, the bottom surface of a boiling chamber that Zhu built was heated to create a vapor bubble. (She designed and tested the various experimental components before sending them to the ISS.) The team anticipated that, when the bubble encountered the light beam, the same forces would be generated, causing it to "swim" away from the heated surface.

As is common for space experiments — where scientists cannot make adjustments after launch — Zhu describes the project as a "partial success," explaining that they were unable to observe what they expected to see in the boiling chamber. It is possible, she notes, that between the time when the experiments were sent and were run on the ISS, the surfactant in that part of the experiment may have degraded. Nevertheless, the overall experiments successfully showed that bubbles can be moved by light, and that the flow responds quickly even to relatively low light intensities. The experiments were captured on video, which Luzzatto-Fegiz, an expert on surfactant transport, is using now to develop a mathematical model. "We are getting to find out what the possibilities are with this approach," he says. "That's very exciting."

MAPPING BROADBAND SPEEDS AROUND THE NATION

Elizabeth Belding holds a smart phone while performing a speed test to check the quality of her broadband connection. Accessing and interpreting crowd-sourced speed-test data is a key element of the three related research projects discussed here.

IN A TRIO OF PROJECTS, ELIZABETH BELDING SEEKS GRANULAR UNDERSTANDING OF COVERAGE

Reliable high-speed internet access and dependable cellular service have become essentials of modern life. Increasingly, we need them to access education, health care, financial services, travel opportunities, entertainment, emergency services, government information, directions to our destinations, and so much more.

But not everyone has the level of service they need to tap into those resources, and inequalities abound. For instance, The Markup — a nonprofit news organization that investigates "how powerful institutions are using technology to change our society" — looked at data speeds offered around the United States. They found that, often, around the country, slower speeds are provided to non-White people living in low-income neighborhoods. In one low-income area of New Orleans, AT&T customers had download speeds of only 1 Mbps or less, a rate that does not meet Zoom's recommended minimum for group video calls, doesn't approach the Federal Communications Commission's (FCCs) definition of broadband, and is more than 150 times slower than the median home internet speed in the U.S., of 167 Mbps. Meanwhile, AT&T offers residents in the nearby mostly White upper-income New Orleans neighborhood of Lakeview speeds that are almost 400 times faster — for the same price.

UC Santa Barbara computer science (CS) professor **Elizabeth Belding** is currently collaborating with researchers at the Georgia Institute of Technology on two projects intended to identify the quality of cellular service around the nation as precisely as possible. One of those projects was funded by the National Science Foundation (NSF) in August 2022 and the other by the Rockefeller Foundation. Both are intended to empower local communities to take actions to get better cellular coverage where they live. In a third, related project, Belding and UCSB professors **Arpit Gupta** (CS) and **Mengyang Gu** (statistics and applied probability) aim to analyze the quality and cost of fixed-broadband access around the country and study the relationship of that data to socioeconomic demographic variables in those same regions.

A GRANULAR LOOK AT INTERNET SERVICE INEQUITIES

The goal of the NSF-funded ADDRESS project is to use crowdsourced internet measurement data to estimate the quality of fixed internet in different areas and at different levels of geospatial granularity, ideally, down to the census-block or even street-address level. "The big picture is that we're trying to understand where broadband is and isn't and what the quality of current deployments is," she says of the three-year, $600,000 mapping collaboration, adding that, historically, "FCC maps have tended to grossly overstate coverage, because they are based only on provider-reported information."

Problems with current coverage estimates abound. "For instance, FCC rules said that if one home in a census block was covered, a provider could count that whole block as being covered," Belding explains. "But often the coverage is not that extensive, especially in rural areas, and that representation of access doesn't describe the *quality* of the coverage provided, whether you can, for instance, conduct a Zoom meeting, or stream a movie on Netflix or some other service."

One way to get a better understanding of one's service quality is to run a speed test on a device. Several organizations make that possible, and they aggregate the crowdsourced data from all the tests that people run, which is useful to Belding and her collaborators. "If, for instance, ten thousand people near you have completed speed tests, you can start to understand what coverage looks like in your community," she says.

Data used to ascertain internet availability is full of biases, however. "What if people with higher incomes tend to do speed tests more often than people with lower incomes, or people in urban areas do them more than people in rural areas?" Belding posits. "Or, there might be other types of skews. A slower result in an apartment building might occur if wifi networks there are interfering with each other. If the demographics of who does speed tests vary, then you can't just use the data at face value."

Belding knows this terrain. She, Gupta, Gu, fifth-year PhD student **Udit Paul,** and third-year PhD student **Jiamo Liu** presented research on biases and skews in crowdsourced speed-test data sets in a paper titled "The Importance of Contextualization of Crowdsourced Active Speed Test Measurements," which won the Best (Long) Paper Award at the 2022 Association for Computing Machinery Internet Measurement Conference.

"This work is timely given the recent focus on crowdsourced speed-test measurements for policy-related decision-making," Gupta says. "One significant roadblock in contextualizing these measurements is to accurately infer a user's subscription tier. A speed-test result of 10 Mbps is not bad if the user subscribed to a 10 Mbps plan, but it is problematic if they subscribed to a 100 Mbps plan. The team developed a novel methodology to infer the subscription tier for crowdsourced measurements."

The researchers will also use statistics and modeling to get a better idea of internet service in areas for which less data is available. For instance, there might be areas of a city where the data shows certain trends and other areas that have no data because no one has run speed tests there. Rural areas may also lack data. "So, we have to extrapolate from the data we've collected to make predictions about areas for which data is missing," Belding says. "That's where the modeling comes in."

THE CELLULAR-COVERAGE LANDSCAPE

The NSF-funded project called MapQ has goals similar to those of ADDRESS, the key difference being that it's for mobile, so it incorporates signal-quality information. This project, too, is based on global data aggregated from people taking speed tests — but from their phones — and brings together statistical modeling, machine learning, and mobile networking. Cellular propagation has its own characteristics, because it is not tied to a wire coming into a wall. "Again, though, we are asking how we can use the points where we know the speed-test data was collected and we also know the signal quality when the test was conducted to predict what coverage looks like in areas where we don't have data," Belding says.

About 85 percent of people in the U.S. own a smartphone and use it to access diverse resources. Sometimes the applications work well, and other times they do not. When they don't, the problem is often with the mobile broadband cellular network in the place and at the time of use. Currently, no one knows completely and accurately where high-quality access exists, or where regions of limited or no access are present.

The FCC has coverage maps, but, Belding explains, "They don't mean much. They're far less granular than what we'd like, and they show what we call binary coverage: the coverage is there or not there. A big thrust of our work is that it's more than just yes or no, service or none. There's a whole gradient. For instance, there might be some service, and maybe you can text and do voice calls but you can't websurf or sustain a Zoom call. Or maybe there's good coverage on a clear day but not when it rains. We're trying to show the quality of coverage over both space *and* time."

The researchers want to aggregate all the speed-test data and create a map that can be pulled up, perhaps when one is driving or in a new location, to see how the cellular quality is there. "That's particularly important for rural areas and other areas that might be underserved, to be able to say, as a community, 'Look at our mobile cellular service. It's substandard.'"

ROCKEFELLER: RESPONSIVE TO THE FCC CHALLENGE PROCESS

In this 1.5-year, $500,000 project funded by the Rockefeller Foundation, Belding will work with Georgia Tech researchers to develop open-source software, called CellWatch. The package will comprise a mobile application for taking network measurements, a community planning dashboard and map, and a cellular-quality prediction tool. The intention is to enable everyday people to take connectivity measurements and merge their data with others in their community. That will allow communities to build maps of coverage and challenge cellular providers' claims of coverage, which are often misrepresented across FCC maps and, preventing communities from applying for available federal funding.

The goal is to eventually have informed machine-learning algorithms and statistical analysis that can predict the quality of service in areas that have not yet been measured. It is intended that participating in the FCC-defined challenge process to show that coverage is substandard — and qualify to receive funding to improve it — will empower communities to ensure improvements to the cellular coverage they receive.

"The project is motivated directly by our previous work with Native American tribes," Belding says. "The cell companies come to them and say, 'We want to be your main provider; won't you promote us?" The tribe says, 'Well, your coverage is spotty.' And the provider says, 'No, it's not.' So who's right? We need data to determine that, and we're trying to get it."

Speed-test team (from left): Udit Paul, Jiamo Liu, Arpit Gupta, Elizabeth Belding, and Mengyang Gu

In the acid bay, researchers and technicians clean wafers before or after various processes to eliminate particle contamination and material imperfections that can affect the final product.

The Nanofabrication Facility

The Nanofab, as it's known, is where researchers in "bunny" suits transform exotic materials into advanced electronics for academics and industry

Matthew Wong, a UC Santa Barbara assistant project scientist who earned his PhD with UC Santa Barbara professors **Shuji Nakamura** and **Steven DenBaars**, visited numerous cleanrooms recently while traveling the country to interview for faculty positions. Someone who worked at one of them and learned where Wong was from said to him, "The UCSB facility is like the Holy Grail of cleanrooms."

"In the global semiconductor community, UCSB is known in part for the Nanofab and the activities it supports," says electrical and computer engineering professor and Nanofab director, **Jonathan Klamkin**. "When prospective faculty interview and are asked why they are interested in UCSB, one of the more popular answers is 'the Nanofab.'"

The lab plays a key role locally and regionally in what the facility's technical and operations manager, **Brian Thibeault**, describes as a key "second part" of the semiconductor industry.

"There's the silicon industry, which supplies all the microelectronics and the computational stuff we have," he says, "but then there's a whole other semiconductor industry that produces many things — the devices that produce light, or RF [radio frequency] power out of your cell phone, or do the facial recognition on it. And it's all the other semiconductor materials developed at this university and others that make advancements in electronics, optics, and such possible. The bread and butter of our lab lies primarily in that 'beyond silicon' world."

Open 24/7 and often booked 16 to 18 hours a day for weeks on end, the lab sees some 6,000 to 7,000 billable hours of use per month. Industrial users — from small local startups to giants like Google, which has a team here doing development work on the chip for a quantum computer — account for about 55 percent of the total.

"We have a substantial industrial user base, and slightly over half of the more than 500 annual Nanofab users are employed by fifty-plus companies," Klamkin says. "Having industrial and academic users working in the same facility fosters a highly collaborative ecosystem that facilitates 'lab-to-fab' transitions. The Nanofab plays a critical economic role both locally and more broadly."

"It's a user-fee-based operation," Thibeault says, noting that the roughly 12,000-square-foot space, most of which is occupied by the cleanroom, has an annual budget of about $6 million and a staff of about 20. "Those billable hours keep the lab running and allow us to reinvest to keep improving it and keep it relevant and state of the art."

The Nanofab is also heavily used by UCSB researchers. Thibeault once did a study with the UCSB Office of Research and discovered that researchers on some 35 percent of all grants at UCSB used the facility in some way.

Nanofab leadership has also recently replied to solicitations for funds from the $50 billion-plus CHIPS and Science Act of 2022, aimed at strengthening the U.S. position in semiconductor R&D and manufacturing. As part of that effort, Klamkin notes, "We've had visits from our district Congressional representative and from the Deputy Secretary of the Department of Commerce."

Small, Complex, Precise

Describing Nanofab work in the simplest possible terms, Wong says, "You either remove material by etching or use a deposition to add relief. You add something or you take something off. That's basically what a cleanroom is."

It is, of course, the details within that easy description, reflected in dozens of related processes, the tiny scale at which they unfold, and the exacting precision with which they must be performed that makes this kind of "simple" adding and subtracting of materials Nanofab-dependent.

For his graduate research, Wong worked to eliminate an inefficiency in micro-LEDs, which he calls "the next generation of display technology." The lights are tiny, as their name suggests, and the semiconductor's light-emitting layer is susceptible to being damaged during fabrication, thereby reducing efficiency. "You define the lighting area, which has a diameter smaller than that of a human hair, by etching with plasma to remove materials," he explains. "Plasma etching works by placing a material sample between two plates and flowing gasses into the area. When a voltage difference is applied between the plates, the gas is ionized and hits the sample, performing the etching action." In his research, Wong employed different methods — and has developed recipes for them — to mitigate the effects of that damage and, thus, recover the efficiency of the micro-LED.

Nanofab work is all about scale, which is why everything needs to be so clean, and why users wear protective white "bunny" suits. "My work requires an environment largely free of particles to eliminate any chance of contamination, which can cause irregularities and variations on the wafer," Wong says. "At the micron scale, there is not much room for error."

Layout and Process

The cleanroom is arranged into seven rows, or bays, each about fifty feet long and equipped with tools and benches to support tasks related to specific processes. There are two lithography bays, each bathed in amber light, where the critical step of patterning on wafers occurs.

"Patterning is the heart of fabrication; it's how you implement your idea," Thibeault says. "We have people here who do this incredible high-end research for product development where they're patterning at the 10-nanometer scale or below. So, you might need electrons to come over here and photons to come out over here, and you need to have the shapes like so and arranged this way to work according to your mathematics. The more precision and quality you can bring to performing those steps, the more likely you are to implement your ideas."

Getting the pattern onto the wafer involves a series of steps that often start with cleaning to help with adhesion. This can be done using solvent or an oxygen-plasma process, or sometimes, a stop in the "acid bay" is more appropriate. "Brand-new wafers are pretty clean when they arrive from the vendor, but some processes require additional cleaning before the wafers are used," says **Paula Heu**, who has spent over a decade doing process development in the Nanofab for industry users. "Some materials have a native oxide that grows naturally, and certain electrical contacts require that the interface between them have no oxide. Specific acids are then used to strip off the native oxide before depositing metal."

Next door, the lithography bay includes "spin stations" for coating wafers with a photo-sensitive resist material. The lab has numerous ovens and hotplates for curing photoresist and for thermal processing of photolithography, as well as ion-beam and electron-beam lithography systems and stepper tools for exposing patterns at extremely high resolution.

During lithography, Heu explains, "a pattern is transferred onto a wafer by coating it with photoresist, exposing the photoresist to UV light through a mask, and then developing the photoresist. You then rinse it off and inspect it, with the pattern now transferred onto your wafer."

Next, the wafer is inspected using either an optical microscope or one of the lab's two scanning electron microscopes (SEMs), depending on the resolution needed, "basically to see if what you have intended to pattern looks good and is sharp," Heu says. "The first round is to see where you are in your process, and then you can fine-tune it so that it will allow you always to get a good result."

Once the pattern has been transferred to the wafer, the process moves to fabrication, which involves a series of steps. They may include wet or dry etching to remove material, using one of the deposition tools to add material, or plasma treatments, high-temperature baking, or annealing to achieve high-temperature bonding of metals. **Kaiyin Feng,** a sixth-year PhD student in the lab of **John Bowers** (Materials, Electrical and Computer Engineering) who focuses on high-performance lasers used in photonic integrated circuits (PICs), spends much of her time in the Nanofab working on process development and fabrication of prototypes of novel devices.

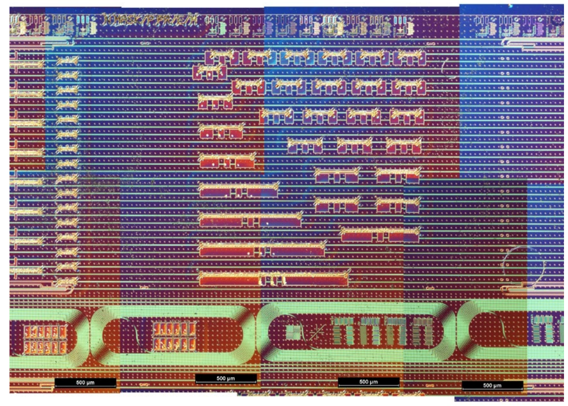
Using material grown by students or postdoctoral researchers in the Bowers group, she says, "We design single device components or sometimes a photonic circuit on-chip. That might be a novel laser or a tiny circuit, such as a laser connected to a waveguide that splits the light into two pathways for different downstream functionalities."

The work of building such nanoscale structures could not be done without the Nanofab.

"After the design is done, we also need to figure out how to make them," Feng says. "For example, we have to figure out which lithography recipe suits the patterning resolution, which chemistry gives the best etched sidewall, or what metal alloy gives the lowest contact resistance. There's a lot of chemistry and materials engineering happening, and sometimes, as process development, we need to do a few short iterations to figure out the recipe for one step. The Nanofab serves as a perfect environment for us to perform these experiments. After resolving all the challenges in each step of the fabrication process, we can actually make the device we designed!"

"Every imperfection may add to the 'loss' of the laser cavity and affect performance. Sometimes in our work, we're looking for the laser to have record-breaking performance, and for that you need everything to be perfect."

Evaluating results through observation and measurement — the entire metrology bay is filled with nothing but precision-measuring tools — is a time-consuming but critical part of both lithography and fabrication. "You might spend two hours using the SEM to check every detail of a step to make sure the fabrication went correctly," Feng says. "You're completing the process, because if something is a little dirty, it will affect all the following [fabrication] steps, so you have to clean it up. It might be some hardened polymer from the dry etch that sticks to the wafer, so you use different chemicals or different cleaning plasmas to remove it, and then you keep checking to see if it's clean. Every imperfection may add to the 'loss' of the laser cavity and affect performance. Sometimes in our work, we're looking for the laser to have record-breaking performance, and for that you need everything to be perfect."



Engineering the small (from top): a transmitter photonic circuit made by the Bowers group in the Nanofab; a technician works at a station in the amber-lit lithography bay, where light-sensitive materials are used to transfer patterns onto wafers to guide fabrication.

Talk to any Nanofab user, and especially long-term users, and they'll mention the incredibly helpful staff that makes the place work. "They do such a good job maintaining the tools, so that we don't have to fix them ourselves as students," Feng says. "We work 24/7 on a flexible schedule, and sometimes they are on call for emergencies late at night or during the weekend or on public holidays. That's really helpful when you're stuck in the middle of something and trying to figure out what's wrong with a tool."

The staff includes a team of process and equipment engineers who calibrate the various tools every week to ensure that they are within specifications. "That way," Heu says, "if your process results are unsatisfactory, maybe after lithography, you know that it's not an issue with the tool. The process people make sure that you get a repeatable result time after time."

In the Nanofab, it's always the (very) small things that matter most.

Clarifying the Dynamics of Clogs

From medical devices to bottles of glue to river canyons, clogs can bring any number of processes to a halt. Alban Sauret investigates how and why stuff gets stuck.

Scan the QR code to access the video

Clogs are a problem nearly everywhere — and anywhere — you care to look, and not just in the expected places, such as pipes, fuel filters, aerosol cans, or that tube of hardened glue in your desk drawer. In a paper titled "Clogging: The self-sabotage of suspensions," published in the February 2023 issue of the journal *Physics Today*, **Alban Sauret**, a UC Santa Barbara associate professor of mechanical engineering who specializes in developing quantitative models describing various flow-dynamics phenomena, and his colleagues write, "Clogging can occur whenever a suspension comprising discrete particles dispersed in a liquid flows through a confined geometry."

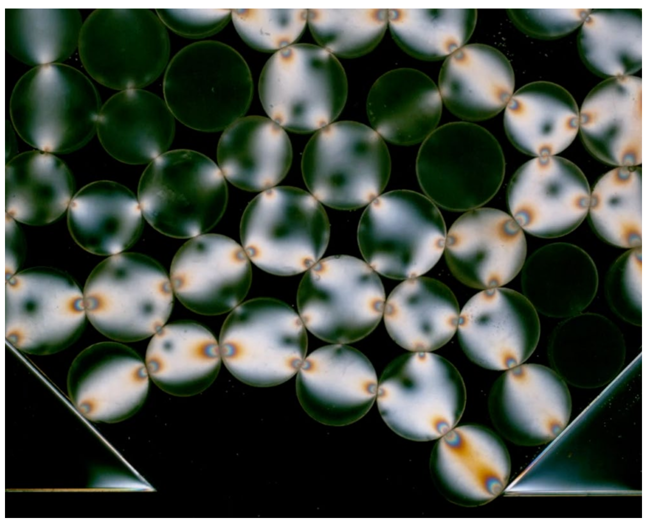
The clog can occur in confined flows of widely diverse dimensions that are carrying either too many particles or particles that are too large. "Channels and the constrictions in them can be microscopic," Sauret notes, "such as the pores of a filter or a bend in a microfluidic device, or macroscopic, such as pipes carrying water or a river carrying logs."

Remember the mega-container ship, the *Ever Given,* that became stuck in the Suez Canal for a week in 2021? Technically, that was a clog. Canyons can become clogged, and so can highways, exit doors in a crowded building, arteries in the body, and the nozzles of 3D printers and auto-injection devices that allow patients to self-administer medicine. Clogs can impede the flow of fresh water through natural aquifers, and can dramatically reduce the efficiency of drip irrigation systems for agriculture, which, when operating effectively, are fifty percent more efficient than sprinklers and furrow irrigation.

Clogs can be expensive. The *Ever Given* froze $10 billion worth of trade assets per day while it blocked the Suez Canal. Bloomberg did a study of a new U.S. Navy aircraft carrier, the toilets of which clogged easily. It cost $400,000 every time the system had to be cleaned.

But regardless of context or scale, for every clog, Sauret says, "The physics are the same."

Despite a long human history of developing clog-prevention methods, the underlying physics of clogging have only recently become an active research topic. Historically, most clog-prevention efforts have reflected trial-and-error approaches.



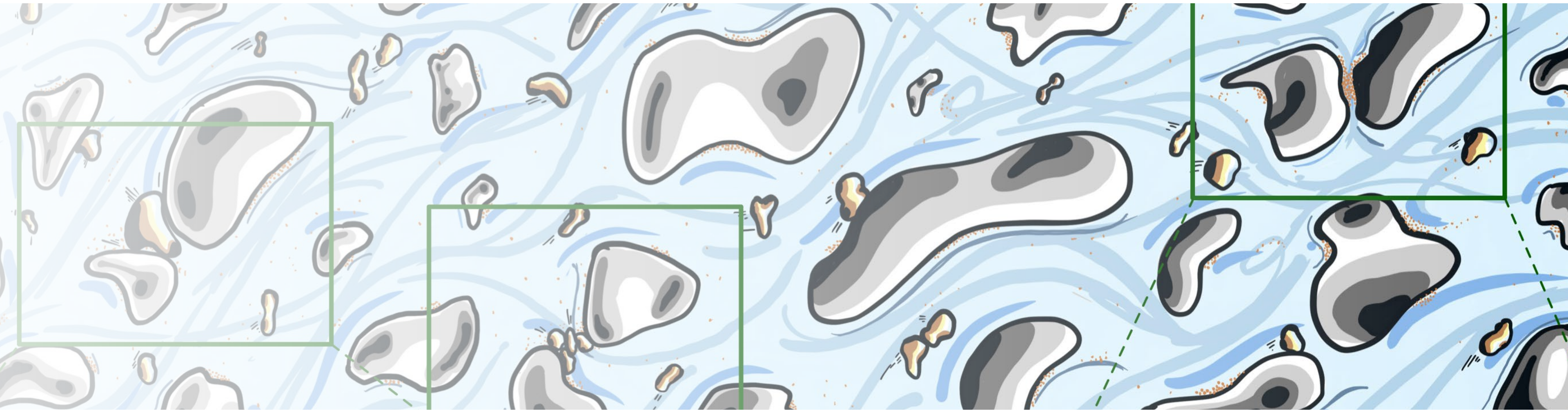
Polyurethane discs viewed through circular polarizers while flowing toward a constriction (as in a hopper) reveal patterns of light indicating the magnitude and direction of pressure. Eventually, a stable bridge clog forms at the opening.

Sauret would like to change that. In nearly any system, he says, "The particulate will flow for some time, but at some point, it's going to clog, so, the question becomes, can you predict when it will stop, and can you come up with guidelines to make a system work longer?" Sauret and researchers in his lab group addressed one common type of clogging — *bridging* — in a paper that was published in the August 2022 issue of *Soft Matter*.

Clogs occur in different forms. The most common are *sieving*, the above-mentioned *bridging*, and *aggregation*. Sieving occurs when a particle is too large to pass through a constriction. This happens with dust in a filter, when an individual dust particle is larger than the pores of the filter, producing a clog. Particles that are not of a uniform size and are free to reorient may enter a system at one orientation and then later reorient, causing a clog. This can happen to a log flowing down a river, which turns sideways and gets stuck between two rocks, as well as to a microfiber used to make the material in a 3D printer more solid. Sieving is also why rain gutters need to be cleaned periodically to prevent leaves and other debris from creating a clog.

In another type of clog — aggregation — particles stick on the wall of the channel and accumulate, eventually clogging it. "It's a long-term problem," Sauret says. "When you have a system that is operating for months, some particles stick to the wall and slowly accrete. That can happen in your body, too."

Bridging, the subject of the paper published in *Soft Matter,* occurs when too many particulates arrive at the opening in a channel and cause a kind of arch, or bridge, to form. The clog is held in place by a kind of keystone, just as an architectural arch is. Similarly, if a particle is removed from the bridge, the system will flow again. Conversely, just as gravity creates the force to make the bridge strong, the



Particles inside the three green-bordered squares in the illustration (above) depict the three main types of clogs (from left): sieving, in which a particle is too big to pass through an opening; bridging, when particles form a kind of arch, or bridge, at a constriction point; and aggregation, the phenomenon of particles accumulating on the walls of a channel.

flow in a channel also strengthens the bridge, which, lacking other changes to the system, has a zero probability of unclogging.

Another example of bridging is a crowd exiting by a single door or sheep trying to run through a narrow chute. Eventually, there are too many bodies pressing against each other, and forward progress stops. Sauret describes such situations as the clogging of "active" particles, i.e., those that can move on their own. Bridging can also clog a silo when dry particles flow in air; a video made by Sauret and his collaborators showing this effect was awarded the Gallery of Soft Matter award at the American Physical Society Meeting in March. (See opposite page.)

In the paper, the authors describe the specific conditions required for a bridge clog of particulate suspension to form. First, enough particles have to be present to form an arch spanning the entire constriction. Then, the arch needs to be stable, with a keystone and convexity in the right direction, that is, with the "high" end of the arch pointing upstream. Finally, the arch must appear.

By working through the probabilities of those steps occurring, Sauret says, "You are able to predict, on average, how many particles can escape as a function of the size of the constriction, the size of the particle, the volume fraction (that is, the number of particles per volume of liquid), and the probability of the arch becoming stable. You can then predict when a clog will occur for different sizes of constriction, with those having a high volume fraction (very concentrated) being likely to clog and those having low volume fraction still being likely to clog but not as fast. A solution is either to dilute the suspension sufficiently or widen the constriction, making it harder or even impossible to form a stable arch."

Sauret explains that in clogs that occur in manufacturing processes, no one knows what is happening inside. X-ray images have been used, but, he says, "It's very hard to know the physics behind what you see. In our experiments, we can actually see the process occur. It's obvious if the particle is too big to fit through the hole. The particle can be small enough in one dimension to flow through but long enough in another dimension to get clogged. You have to think about the alignment of the particles at the constriction. There are many variables."

Sauret would like to be able to predict when and where a clog in a system will occur. "In thinking about whether you can predict the bridging process, and you think of the constricted channel, what would seem to matter is the size of the constriction, the angle (i.e., the sharper the angle of transition from wide to narrow, the more rapidly the narrowing occurs), and the properties of the particles," he explains. "But what actually matters is the volume fraction. That is, if you dilute the liquid enough by controlling for the number of particles in the channel, you prevent, or at least delay, clogging."

While that is theoretically true, Sauret says that his research shows it not to be the case for particles that have a complex shape, such as long fibers used in additive manufacturing. Researchers in his lab ran experiments in which diluted suspensions of micro-scale fibers flowed through constructed channels of various widths to see if the fibers would negotiate the turn or become stuck. The result, according to the article: "Even systems of complex geometry without constrictions can be clogged by fibers."

Sauret's group is now experimenting with adding some kind of perturbation to help keep the particles in suspension before they reach the constriction or even developing ways to remove them from the surface. While it can be extremely difficult to prevent clogs altogether, designing systems so as to delay clogging would be a step in the right direction.

Alban Sauret

CHAMPIONS OF ENGINEERING

Tunç and Lale Doluca

A winter road trip led Tunç Doluca to attend UC Santa Barbara. More than 45 years later, he and Lale continue to have a big impact through giving.

Tunç and Lale Doluca

Tunç Doluca came to the United States from Turkey in 1976 to complete his undergraduate degree at Iowa State. He then attended UC Santa Barbara, graduating with an MS in electrical engineering in 1981, and then spent nearly forty years at Silicon Valley–based chip maker Maxim Integrated, where he retired as chief executive officer in 2021. He has served on the Semiconductor Industry Association board as a director and has been on the UCSB Board of Trustees since 2017. He and his wife, Lale, have provided more than $1 million in philanthropic giving to the College of Engineering, most notably to purchase equipment for the Electrical & Computing Engineering (ECE) Department's undergraduate teaching labs, to establish the Doluca Family Endowed Chair in the ECE Department — held by **Professor Mark Rodwell** — and to bolster the campaign to refurbish and modernize the Mechanical Engineering Department's machine shop. We spoke with him in February.

Convergence: *Were there any advances you saw during your long career that, when you first encountered them, you thought,* This is big?

TD: I thought the introduction of chips that could run a computer that you could have on your desk and, eventually, on your lap, was a really big deal. I was given an IBM PC in 1983, and when I started playing with a Lotus 123 spreadsheet, I thought, *Wow, this is just amazing that I can do this on my desk and don't have to pay big bucks to log onto a mainframe to do it.* The capability of the individual suddenly expanded dramatically.

The next big thing was networking. You had all these individually used PCs with no easy connection to each other or the outside world. As a newcomer at Maxim and the youngest design engineer, I wanted to drive change, so I went to the CEO and complained about our inability to simulate our designs before they were manufactured in silicon. I said that the company had no computing infrastructure at all, so guess what he did? He put me in charge of it. That's when I learned about all of that new networking technology that made it possible to connect computers so they could talk to each other.

When I hear what people are doing now, I'm amazed. If someone had told me about some of the current technology forty years ago, I'd have said, "That's science fiction." But here we are, with things like terahertz communication. Back then, I would never have thought that was possible.

C: *You hold eleven patents. What would you tell students about how to "unlock" their own innate creativity?*

TD: After forty years, what I've found with creativity and innovation is that you can't really say, "This is how it works." It's different for every person. Some need to go sit on the mountain top and think about things. Others do it by discussing alternatives with other people, and that triggers different thoughts and different ways of looking at a problem. Each student has to find what works best for them. In my own case, I've come up with solutions in my sleep [laughs]. I've woken up in the morning and thought, *Ah, that's the way to do that.* The important thing is to force yourself to be open and to listen to what other people are trying to tell you.

C: *Can you talk about engineering creativity within the constant pressures of meeting deadlines and turning a profit at a corporation?*

TD: For years at Maxim, I heard people say that tight project schedules didn't leave them time for creativity. But what I've noticed is that the most creative people make the time. I think, further, that the best innovations at Maxim were those that came out of crisis. It's, "Oh, my god, we have to solve this to save the company," or, "We have to find a new way for something to work to generate another revenue stream." There is always pressure, and you have to realize that that's the way things are.

C: *Did your father's being an engineer affect the path you chose?*

TD: My father was very good at engineering science, and he had an amazing ability to retain information; he learned English by memorizing the dictionary! I had a model train set in middle school, and we expanded it, and that got me interested in electrical stuff. I think it was probably the early seventies when Dad said to me, "Electronics is the future, and if you're going to be an engineer, you need to get into that field." He subscribed to *Time* magazine, and he once told me that he had read about a place called Silicon Valley and then said that I was going to end up living there someday.

> *"If you had the good fortune to benefit from the university, and you learned things there that propelled you in your career, at some point, you have to ask yourself, 'How am I going to pay back those who helped me out?'"*

C: *How did you, as a young man from Turkey, find your way to attending UC Santa Barbara?*

TD: I was attending the top technical university in Turkey in the mid seventies. But things went sideways in the country, and the universities became battlegrounds. My father moved us, and my brother and I went to Iowa State. During a Christmas break, the dorms closed, so he and I and a friend got in the car and drove west. The end of the road was Santa Barbara; that's where we turned around. Imagine three guys coming from a cold, 30-below-windchill state in December and arriving in Santa Barbara. I decided then that if Santa Barbara had a university, I'd like to get my master's there. My dad told me that there was a university there, because in 1953 he had actually lived in army barracks located where the UCSB campus is now. Then I found out that they had a really good semiconductor program. My first impulse was based on the place, but when I discovered that it was also strong in my field, it was a done deal.

C: *Can you talk about the difference in the challenges faced by individual engineers working on projects versus those encountered as a CEO running a company?*

TD: Working as an engineer, things are more deterministic. If you do this, you get that. You have more control. In the engineering management role, you have outside forces and competition that are hard to predict and that you don't control. In a senior leadership position, you have to deal not only with competition, but also with trends in the industry and changing human behavior. And you have to try to figure out where the economy will go.

The unpredictability makes things exciting though. You have to accept it and know that when unforeseen events happen, you're surrounded by a team that knows how to come together to deal with it. I have encountered so many situations for which there was no playbook. In 2008, Lehman Brothers collapsed and our orders were down fifty percent; what do we do? There's no playbook for that. You kind of need to take the view that we're flying as well as we can, but we need to be able to retrench and work together to find a solution when things don't go according to plan.

C: *You and Lale have given more than $1 million to the College of Engineering. What has motivated your philanthropy?*

TD: If you had the good fortune to benefit from the university, and you learned things there that propelled you in your career, at some point, you have to ask yourself, "How am I going to pay back those who helped me out?"

When I was CEO at Maxim, I noticed that we were having a harder time recruiting engineering graduates from schools in the U.S. Interest was decreasing, especially for analog, which people saw as the old way. They were more interested in digital and in software engineering. But all of this wonderful digital technology requires analog and mixed-signal technology to make it work. For instance, radio signals don't come as ones and zeroes; they come as analog signals that have to be translated into digital and then back from digital on the other end. I thought it would be helpful to have professors who could excite students about why analog is so important. And I thought that maybe if there was more funding, like what our endowment provides for Mark Rodwell, we could support more projects and more research in the analog and mixed-signal field and, hopefully, attract more people. The perpetuity of the endowed chair attracted us, because if you put in enough funds, it keeps giving and allows the professor to advance that area.

In terms of the lab gifts we provided for the labs, I have always loved learning by doing, so labs are very important to me. We decided to support ECE undergraduate labs for that reason, and the mechanical engineering machine shop for the same reason, even though that one was a little outside my field.

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The philanthropy of individuals like you helps to ensure that breakthroughs in science and engineering remain the order of the day across our beautiful UC Santa Barbara campus. Large gifts, small gifts, estate gifts — they all matter, because each advances academic excellence and leading-edge research that, together, help pave the way to a better tomorrow.

Please consider making a difference by making your gift today!

To learn more about opportunities for the College of Engineering and the Division of Math, Life and Physical Sciences, please contact
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