inquiry@

UC SANTA CRUZ
RESEARCH MAGAZINE

2019–20

Lighting up lightning

RADIO ART | DESIGNER VACCINES | AGENTS OF HOPE

UC SANTA CRUZ

The spirit of **inquiry**@UC Santa Cruz

Welcome to the 5th edition of *inquiry@UC Santa Cruz!* This annual research magazine, collaboratively produced by the Office of Research and University Relations, highlights pioneering work conducted across the university's broad suite of disciplines. Here, in stories created by alumni of our world-renowned Science Communication Master's Program (see INQUIRING**minds**), you'll find narratives covering a wide range of topics: how different perspectives based on contemporaneous texts and artifacts influence our modern perceptions of the ancient world; the discovery of unexpected and elusive high-energy particles emitted from the atmospheric electrical maelstroms that commonly, and spectacularly, produce lightning; the creation of sound-based art using radio waves and radio-based technology as the artist's palette; new molecular approaches to making more effective vaccines; and how to effectively—and responsibly—use Big Data to produce first-order insights of immediate societal relevance.

Credit: Kurtz Photographics.

You'll also find descriptions of some of the latest books authored by our faculty in the PEN**&**INQ section, and inventions discovered on our campus in **inquiries&**INNOVATIONS. From a picture-based overview of number theory to a patent-applied method for making plastics less toxic, UCSC investigators are making valuable contributions via a wide range of strategies.

We hope that you enjoy reading about the UCSC research on display in this 2019–20 edition of *inquiry@UC Santa Cruz*. You can also access these stories—enhanced with hyperlinks, additional artwork, and references for "**Further Inquiry**"—in the e-magazines of this and past issues online at *inquiry.ucsc.edu*. As evidenced in these pages, our research enterprise at UCSC continues to push the frontiers of knowledge forward in exciting and unexpected ways!

Scott A. Brandt
Vice Chancellor for Research
and Professor of Computer Science

inquiry@ UC SANTA CRUZ RESEARCH MAGAZINE
2019–20

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About the cover: Lightning lights up the Tucson, AZ, night sky in a single, seven-minute exposure captured from Babad Do'ag Vista Point during an August 2014 storm. Researchers studying the enigmatic physics of lightning are making surprising discoveries about this common and spectacular display of nature. Credit: Josh Wallace.

BRIEF **inquiries**

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inquiry@UC Santa Cruz
2019–20

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DIGITAL ART NEW MEDIA

The nature of eco-art

Created by professors emeriti of art Newton Harrison and his late wife Helen Mayer Harrison, the eco-art installation *The Future Garden for the Central Coast of California* at the UC Santa Cruz Arboretum and Botanic Garden serves dual purposes, as showcases for the impact of climate change and scientific experiments. Credit: C. Lagattuta.

Walk past the beds of succulents and aromatic flowers at the UC Santa Cruz Arboretum and Botanic Garden and there sit three geodesic domes. Inside each, native plants grow in climatic conditions forecast for the near future. One is drier than the California Coast today, another is wetter, and one contains plants watered intermittently. UCSC ecologists closely monitor the plants to study how native species will respond to drastic climate change. However, scientists did not initiate this project—it sprung from the imagination of ecological artists.

The Future Garden for the Central Coast of California is one of the dozens of art installations created by world-renowned ecological artists **Newton Harrison** and his late wife **Helen Mayer Harrison**, professors emeriti in the UCSC Arts Division. What constitutes "eco-art" eludes precise definition, but to Newton Harrison, it's art that inspires environmental stewardship and actively contributes to it. While the Harrisons designed *Future Garden* primarily to show people how unbridled climate change could diminish the natural biodiversity of California's coast, it also serves as an experiment with a valuable scientific purpose: knowing which native plants can endure will help maintain important ecosystems as global temperatures increase.

"It's the nature of artists to select subject matter they feel attuned to," said Harrison. "We're destabilizing all our natural systems, and it's affecting everyone. Artists should be taking this on as subject matter."

—Annie Roth

EARTH AND PLANETARY SCIENCES

Forecasting alien clouds

Xi Zhang always has his head in the clouds... of other planets. The assistant professor of planetary sciences has built a powerful computer model that can simulate how individual molecules in a planet's atmosphere coalesce and grow into billowing clouds.

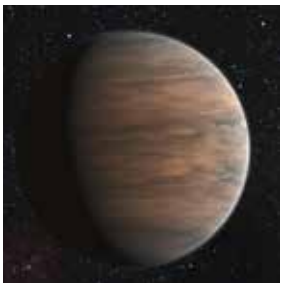
Far from fluff, planetary clouds can provide insights into how planets form and evolve, Zhang said. In addition, understanding clouds on exoplanets could also be crucial to detecting alien life, outed by tell-tale atmospheric chemical signs.

That has not happened yet. In the meantime, however, the model has proved

useful in helping to explain a puzzle involving "hot Jupiters." While some of these close-to-their-stars, Jupiter-sized planets show a strong chemical signature for the presence of sodium, others mysteriously show much weaker signals. For the latter, Zhang's research suggests that a thick haze is likely obscuring the view.

More recently, the model has helped explain why some brown dwarfs, despite their name, appear so red. These balls of gas aren't massive enough to ignite and become stars, but they do emit a reddish tinge. **Diana Powell**, one of Zhang's graduate students, has shown that the hue comes from smaller particles high in their atmospheres, where lower temperatures cause them to glow red. This possibility eluded earlier models, which couldn't predict the size distribution of the particles in these alien clouds.

—Marcus Woo



Assistant professor of planetary sciences Xi Zhang's computer model simulates the formation of clouds on planets like the hot Jupiter planet WASP-31b, depicted here in an artist's illustration. Credit: ESA/Hubble & NASA, Wikimedia Commons.

PSYCHOLOGY

Queer youth revolution

Unexpected results emerged from an extensive study examining the experiences of LGBT teens living in one historically supportive community (the San Francisco Bay Area), and another with historically more hostile attitudes toward sexual and gender diversity (the Central Valley).

THEATER ARTS

Monsters onstage

When Frankenstein's creature lurches onstage, or Dracula disappears into the wings, what do the audience's shudders convey? **Michael Chemers**, professor of dramatic literature and theater arts, sees the cultural processing of fear.

"I'm interested in freaks. I'm interested in monsters. I'm interested in deviants of all kinds," said Chemers. He is preoccupied, he said, with how humans define and demonize the "other."

The theater brings this question to life, literally, as actors embody society's greatest anxieties. In his 2017 book, *The Monster in Theatre History: This Thing of Darkness*, Chemers explores how theater acts as a testing ground for the monstrous. For example, in her 1818 novel *Frankenstein*, Mary Shelley's monster turned evil only after his creator abandoned him. But by 1931, the movie monster played by Boris Karloff was an abomination from the start. Bridging the two depictions is more than a century of theatrical reinvention.

Performance art has served as a tool of monsterization throughout human history, Chemers said, including, for example, medieval European plays that demonized Jews. Today, the same tropes pop up in political rhetoric, stoking fear of immigrants and Muslims.

"Fear is very important to humans. It keeps us alive," Chemers said. "But it also leads us into error—the more we know about fear and how it operates, the better we are prepared to move to a more just and harmonious society."

—Stephanie Pappas

As a testing ground for the monstrous, theater manifests the cultural processing of fear, said Michael Chemers, professor of dramatic literature and theater arts. This 1823 engraving by Nathaniel Whittock depicts T. P. Cooke as "The Demon" in the first-ever theatrical adaptation of *Frankenstein*, entitled *Presumption; or, the Fate of Frankenstein*, by Richard Brinsely Peake. Credit: Wikimedia Commons.

OCEAN SCIENCES

Deep sea surveying

Mining the ocean floor is inevitable, according to associate professor of ocean sciences **Phoebe Lam**. Unfortunately, that could cause changes in the ocean's dynamic metal chemistry with unanticipated consequences.

The concern centers on how miners will separate their quarry—black, potato-sized polymetallic nodules formed over thousands of years—from the surrounding sediment. The nodules contain valuable metals, including manganese, cobalt, nickel, and copper, highly prized for their use in modern electronics. Current schemes to mine the nodules involve scooping up the seabed, picking out the metal lumps on the boat, and finally pumping the dregs back below the surface. But dumping this mineral-rich sludge into the oxygenated upper ocean layer could have dire effects way beyond simply muddying the water.

Manganese oxides in the sludge, for example, bind trace metals. "Even at tiny concentrations of manganese oxides, we see a hugely disproportionate effect," Lam said. Some trace metals are essential for life; decreasing their bioavailability could make life harder for the photosynthesizing phytoplankton that provide half of Earth's oxygen.

In November, Lam and other researchers collected water samples from the Clarion-Clipperton Zone, a vast nodule hotbed. Part of the U.S. GEOTRACES GP15 cruise, a two-month expedition to survey ocean trace elements in waters from Alaska to Tahiti, the work will provide baseline measurements that predate mining. Their findings, said Lam, will help inform industry guidelines aimed at reducing the risk of harm to ocean geochemistry—and the vast web of life it supports.

—Alison F. Takemura

Deep-sea mining in the Pacific's Clarion-Clipperton Zone would harvest these black rocks, called polymetallic nodules, and disrupt attached life, such as the ethereal "anemone-like" *Relicanthus* sp. seen here with tentacles that are at least 2 meters long. UCSC ocean scientist Phoebe Lam aims to better understand how redistributing the sediment in the water column could disrupt ocean geochemistry, with potentially far-reaching consequences. Credit: Diva Amon and Craig Smith, University of Hawaii.

"I was surprised by how much new identity labels are being used," said **Phillip Hammack**, professor of social psychology and director of the Sexual and Gender Diversity Laboratory. "Among LGBT young people across these communities, 24 percent don't identify as male or female, but rather as gender non-binary. That's huge, and it's a relatively new concept. It's a quiet revolution."

There's a gender identity revolution among queer teens, said professor of social psychology Phillip Hammack. LGBT young people who do not fit neatly into traditional "male" or "female" gender categories are using new gender identity labels such as "gender non-binary" to describe themselves. Credit: pixabay.

A person identifying as gender non-binary may blend elements of traditional masculinity and femininity or may not fall within those two categories at all.

But this revolution isn't affecting all queer teens equally, said Hammack. Leaders within the unofficial movement were overwhelmingly teens who were assigned female at birth, but now identify as gender non-binary. And overall, there were twice as many openly transgender boys (assigned female at birth) as girls.

That doesn't jibe with the demographic makeup of the larger LGBT community, Hammack said. So, where are the boys? Teens who were assigned male at birth but who now have a different gender identity don't feel they can come out safely, Hammack said. "They're worried about stigma and bullying from other boys. If they can pass as gender-conforming, they'd rather stay in the closet."

—Sascha Zubryd

PHILOSOPHY

Seeking autism insights

There's always been a strong link between philosophy and psychology. Studying psychological disorders has helped philosophers understand atypical ways of interacting with the world, while philosophical theories have the potential to challenge preconceptions that often limit people with these disorders. But philosophers need to do a better job of understanding these disorders, said assistant professor of philosophy **Janette Dinishak**, whose research focuses on autism.

Dinishak sees the autism-philosophy link as a two-way street, where philosophy should draw on the personal experience of autism in order to translate it in a meaningful way for autism researchers and the public. Dinishak explores this experience by grounding it in reports from actual autists.

Most philosophical treatments of autism center on what is purportedly missing, an emphasis Dinishak's research suggests may be misguided. For example, one philosophical notion posits that people with autism are "aspect blind." Coined by the philosopher Ludwig Wittgenstein, the term describes the inability to see one thing as something else. As reported in *Philosophical Psychology*, Dinishak's close look at the statements of autists reveals that the concept of aspect-blindness may be far too limited to fully reflect their actual perception.

"We're only now just starting to create a language to describe the experience of autism," said Dinishak, who credits her mentor, Canadian philosopher Ian Hacking, with the broad ideas that shape her work.

—Stephanie Pappas

SUSTAINABILITY SCIENCE

Focus on the coast

Coastlines are changing fast, and management practices aren't keeping up, said **Anne Kapuscinski**, professor of environmental studies and director of the new Coastal Science and Policy Program. "There's real urgency now. The harmful impacts of climate change are already being felt in coastal areas worldwide."

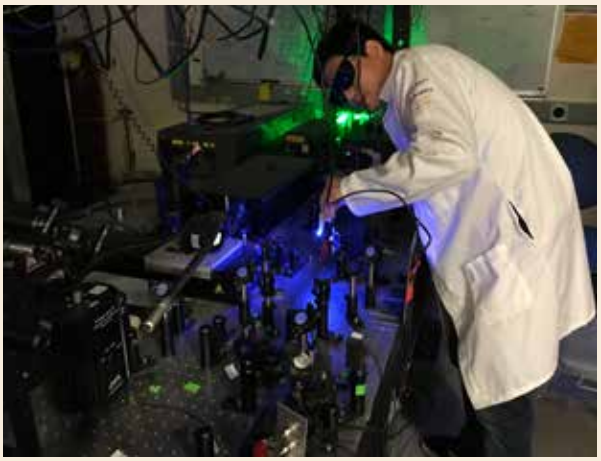
ELECTRICAL AND COMPUTER ENGINEERING

Laser-focused memory

As computer memory devices shrink and become more powerful, more sophisticated methods are needed to assess performance and improve designs. Lasers can help measure the magnetic properties on which most of these advanced devices rely, said **Holger Schmidt,** a professor of electrical and computer engineering with expertise in spintronics and ultrafast optics. "With lasers we can measure things that happen really fast in things that are really small."

For example, Schmidt is working with Samsung to study devices called STT-MRAM (spin-transfer torque magnetic random access memory). Already used in niche applications, STT-MRAM has no moving parts and at its heart contains two magnetic layers, approximately 10 nm wide and 1 nm thick (1 nm = one billionth of a meter), separated by a barrier. Within each layer, electrons act like tiny compass needles that are aligned to produce a measurable magnetization. But while the needles in the bottom layer are fixed, the top ones can rotate. Applied electric current turns the top needles, which otherwise resist rotating, and whether the top and bottom needles are aligned yields the 0's and 1's of computer memory.

To assess this dynamic—specifically, how much the top needles resist rotating (called magnetic damping)—Schmidt fires two laser pulses a few picoseconds apart at the magnetic material. The first spins the needles, and the second monitors their return to position, producing accurate measurements that are informing decisions about which materials to use in the next generation of memory devices.



In Professor Holger Schmidt's applied optics laboratory, postdoctoral fellow Weigang Yang adjusts the laser setup used to measure the magnetic damping in a prototype digital memory device. Credit: Mike Jaris, courtesy of Holger Schmidt.

—Marcus Woo

Based at UCSC's Coastal Science Campus on Monterey Bay, the two-year master's degree program aims to help students develop innovative strategies for coastal conservation and sustainable use management. The interdisciplinary curriculum emphasizes mentorship, collaboration, and leadership training. In addition to workshops and specialized coursework designed for the program, each student will complete a major project working closely with an outside partner such as a research institution, NGO, private company, or government agency. The interests of the inaugural class include Caribbean manatee protection, climate change insurance risk analysis, Chinese aquaculture management, and local grassroots watershed management.

"The program is exceeding my expectations," said student Mali'o Kodis. "One of the greatest achievements—and challenges—of this program is addressing the wide array of interests, backgrounds, and unique experiences within our cohort of 10 incredible young leaders."

"They help each other but they also push each other," said Kapuscinski, whose own research focuses on increasing the sustainability of aquaculture, the world's fastest growing food sector. "It's all aimed at informing policy and real action on the ground."

—Sascha Zubryd

COMPUTER SCIENCE

Protecting data privacy

What if your cell phone could assess your risk for developing diabetes? For that to be possible, a predictive model would first need to be trained on vast amounts of user data. And that poses a problem, said **Abhradeep Guha Thakurta**, assistant professor of computer science and engineering.

HISTORY

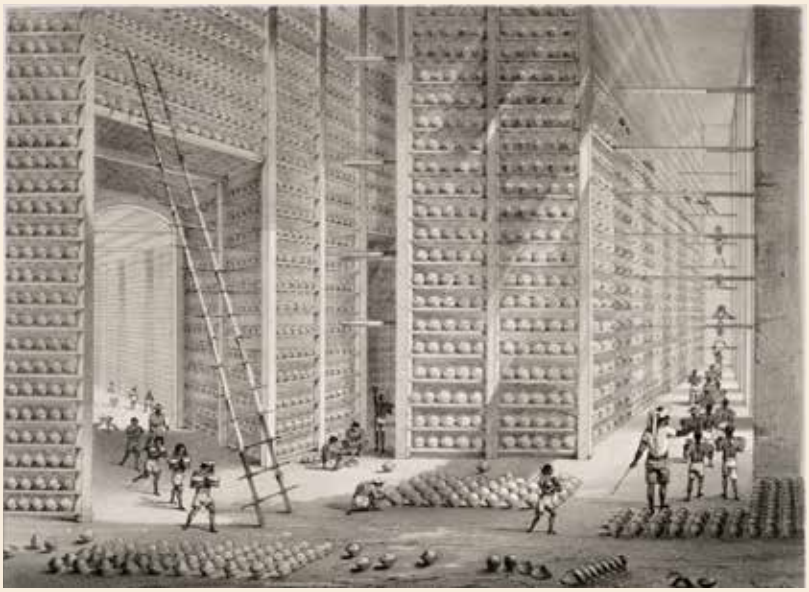
Opioid amnesia

It's big news that opioid addiction in the U.S. has reached epidemic proportions. More than 48,000 Americans died from opioid overdoses in 2017, leading the Department of Health and Human Services to declare the opioid crisis a public health emergency.

So where did this huge problem come from? One could argue it started in 1804 when German chemist Friedrich Sertürner isolated and extracted morphine from opium poppies. When morphine was first sold to the U.S., it was marketed as a treatment for pain and opium addiction. The irony became evident during the Civil War, when morphine addiction among the enlisted grew so widespread it became known as "soldier's disease." **Benjamin Breen**, assistant professor of history, sees our current crisis as "a continuation of an older story" that began long before Sertürner discovered morphine. In his forthcoming book, *The Age of Intoxication: Origins of the Global Drug Trade*, Breen examines the global drug trade and its role in shaping modern society.

His research underscores the point that history repeats itself. "As a society, we have amnesia when it comes to these drugs," he said. "We don't remember the experiences of our great-grandparents' generation. They had morphine and we have Oxycontin. The two drugs are slightly different but they're both opioids." And they cause the same problems.

—Annie Roth



Assistant Professor Benjamin Breen studies the history of drugs and how they have shaped modern society. Pharmaceuticals have been a big business for a long time. In the 18th century, opium addiction in China fueled a thriving, highly profitable trade that helped cement the dominance of the British East India Company in India as a colonial proxy for Great Britain. All the spheres in this c. 1850 lithograph are pure opium ("The Stacking Room, Opium Factory at Patna, India," W. S. Sherwell). Credit: Wellcome Collection, CC BY 4.0.

ELECTRICAL AND COMPUTER ENGINEERING

Prosthetics next step

When **Erik Jung** toured an exoskeleton company in high school, he witnessed how the device helped a paralyzed man, shedding tears of joy, walk for the first time in 20 years. That moment inspired Jung to study how robotics can help people.

Today, he's a graduate student in the lab of **Mircea Teodorescu**, associate professor of electrical and computer engineering. With graduate student **Victoria Ly**, they're designing prosthetic legs that mimic the anatomical motion of the real thing, using an approach called tensegrity. In place of bones, tendons, and ligaments, the prosthetic has a balanced system of rigid rods and elastic bands, all pulling and pushing on one another, distributing forces like a real leg. Electric motors act as muscles to add extra push as needed.

Associate professor of electrical and computer engineering Mircea Teodorescu (right) and graduate students Erik Jung (left) and Victoria Ly are using a design approach called tensegrity to build a low-cost prototype prosthetic that mimics the anatomical motion of a real leg. Credit: C. Lagattuta.

"It could lead to potentially cheaper prosthetics that feel more natural to users," said Jung. An unnatural gait, common in amputees using conventional prosthetics, can lead to pain and discomfort. Robotic exoskeletons work, but each device can cost tens of thousands of dollars.

Tensegrity, Teodorescu said, doesn't need as much electronics, which cuts the cost. The team's working prototypes, which are still far from what someone would use, only cost about $100. The researchers are still working out basic function and control, he said, but hope to begin human testing soon.

—Marcus Woo

"Access to this type of personal data is an insanely sensitive issue," said Thakurta. "How do we harness such data while still protecting privacy?"

Thakurta has developed machine learning algorithms, or computational rulesets, to help solve this problem. His approach is based on introducing randomness into the data. Imagine your data being sent from your phone to a company server. While your actual data might reveal a family history of heart disease, Thakurta's algorithms could replace this truth with its opposite—you don't. "The data are intentionally a little bad," he said.

Feeding models slightly bad data turns out to be good for them—they learn the general trends, without relying on any individual's "real" data. The method maximizes data utility, while also maintaining user privacy.

Several companies are working to adapt his approach to their technology, Thakurta said. Apple, for example, is already using it in all their devices to ensure keyboard stroke privacy.

—Alison F. Takemura

CRITICAL RACE AND ETHNIC STUDIES

Introspective U

Supporters of secondary education often fondly reminisce about the 1960s as the golden era of the university (free in-state tuition at UC!). But **Nick Mitchell**, assistant professor of feminist studies and critical race and ethnic studies, seeks to put this nostalgia into a broader perspective. Universities reluctantly made concessions to feminist and minority activists during this formative time, but less for the greater good and more as a public relations strategy to promote American Cold War ideals and to maintain control over student activism, Mitchell said.

Mitchell explores how such motivations impact the university within the U.S. capitalistic system in his forthcoming book from Duke University Press, *Disciplinary Matters: Black Studies, Women's Studies, and the Neoliberal University.* Universities can provide space to think outside of the market-driven box, Mitchell said, but they can also be exploitative, leaning hard on low-paid adjunct labor to teach students, for example. In the wake of the 2008 financial crisis that resulted in increasing budgetary constraints for universities, Mitchell and other activist scholars in the fledgling field of Critical University Studies aim to challenge nostalgia about the past, highlight inconsistencies between the university's public mission and actual practices, and propose policy changes to address them.

"It's incredibly difficult to be honest about universities from within, because so many times, our ideal of what a

university is conflicts with what is happening on the ground," Mitchell said. "I felt the need to try to rebalance the scales and tell a different story."

—*Stephanie Pappas*

ECOLOGY AND EVOLUTIONARY BIOLOGY

Fishy behavior

It might seem unlikely that fish have much to teach us when it comes to parenting. Most don't, and when they do, the father usually parents solo. However, as shown by the research of **Suzanne Alonzo**, professor of evolutionary biology, studying the reproductive habits of fish can offer insights into the evolution of our own.

Fish make useful models for this work for many reasons, Alonzo said. "When you think about reproductive systems, fish pretty much do it all." While some change sex throughout their lifetimes, others are male and female at the same time. And while some keep it simple, just releasing eggs and sperm into the water column, others engage in complex mating rituals involving social interaction and cooperation among several individuals.

The ocellated wrasses *(Symphodus ocellatus)* studied by Alonzo fall into the latter, more complicated camp. Three types of males—nesting, satellite, and sneaker—compete for the favors of females, but only nesting males parent the offspring. When these fish prepare to mate, unrelated nesting and satellite males—despite being competitors themselves—will team up to keep sneaker males away from potential mates. While hard to explain from an evolutionary perspective, this blend of cooperation and competition is observed across taxa from insects all the way up to mammals, Alonzo said, adding an intriguing twist to the science of seduction.

—*Annie Roth*

A male ocellated wrasse. Credit: Susan Marsh-Rollo, courtesy of Suzanne Alonzo.

ANTHROPOLOGY

Mushroom magic

Matsutake, one of the most valued mushrooms in the world, make a perfect subject for thinking about how humans impact other life on Earth—for worse and for better—according to professor of anthropology **Anna Tsing**. The mushroom takes center stage in her 2015 book, *The Mushroom at the End of the World: On the Possibility of Life in Capitalist Ruins.*

Now a global phenomenon, matsutake first found fame in ancient Japan. The mushrooms grew in *satoyama*, village forests where people cut trees for firewood, harvested fruits and mountain vegetables, and raked away litter to lay on their fields.

These forest management practices created a perfect environment for matsutake. Matsutake grow mainly on the roots of red pines in Japan, and the human activity encouraged the weedy red pines to flourish. Felling trees also favored deciduous oaks, which grew back from their intact roots. The oaks in turn discouraged red pine's competitors—all the better for matsutake. Satoyama are now less common in Japan, but, thankfully for its devotees, matsutake thrives elsewhere in the Northern Hemisphere.

Matsutake show us that many partners are required in the ecological dance that allows life to flourish, said Tsing. In fact, scientists have never been able to artificially cultivate matsutake. Rather, "you need a whole complex ecological community," she said—humans included.

Matsutake mushrooms are a highly prized delicacy, the rare product of an intricate network of ecological interactions and a subject of research for professor of anthropology Anna Tsing. Credit: Noboru Ishikawa, courtesy of Anna Tsing.

—*Alison F. Takemura*

inquiries&INNOVATIONS

By Marcus Woo

Safer plastics

Without a chemical called a plasticizer, PVC—the third most commonly used plastic—remains brittle. To make commercial-grade plastics, PVC is typically pulverized and then melted together with plasticizers. But over time, the plasticizer can leach out—a problem because many plasticizers are phthalates, chemicals the body can mistake for hormones. "It's a huge problem worldwide, both for humans and other species," said **Rebecca Braslau**, professor of chemistry and biochemistry.

Her solution is to chemically bind the plasticizer onto the polymer chain of PVC, which prevents it from leaching out. Braslau has shown success with two phthalates whose chemical structure resembles tadpoles and frogs. More tests are needed, she says, but the biggest challenge might be getting industry on board.

Braslau R. Dialkylcarboxylate-aromatic-functionalized polymers that do not release endocrine disrupting compounds. U.S. Patent Application 20180155464, filed November 27, 2017, published June 7, 2018.

Full genome decoding

To fully understand a genome, you have to know how the whole thing fits together. One major research goal is to find genome assembly techniques—ways to reconstruct sequenced DNA—that are more accurate, cheaper, and faster.

"We have developed a method that makes it better on all those fronts," said **Ed Green**, associate professor of biomolecular engineering.

With their technique, the researchers randomly slice up the genome and glue the pieces back together. Only segments that were originally close to each other are near enough to stick. Not only does this method identify neighboring sections, but it also reveals how far apart they are at all distance scales—something previous techniques couldn't do.

Green RE, Lareau LF. Methods for genome assembly and haplotype phasing. U.S. Patent 10,089,437, filed January 31, 2014, issued October 2, 2018 (also U.S. Patents 9,411,930 and 9,910,955).

Power-saving clocking

In every computer processing unit, a component sends electrical signals that dictate how fast the chip runs—its clock speed. "It's the heartbeat of the chip, the signal that synchronizes everything," said **Matt Guthaus**, professor of computer science and engineering.

Guthaus helped create a way for the chip to receive and interpret those signals using up to 90 percent less power. To achieve this, his approach detects the signals by measuring the flow of electricity through the wire (the current) instead of the amount of electricity (the voltage), as conventional chips do. Measuring the voltage requires draining the electricity—power that's lost forever. The invention has the potential to greatly improve the performance of central and graphic processing units.

Guthaus M, Islam R. Current-mode clock distribution. U.S. Patent 10,097,168 , filed September 11, 2017, issued October 9, 2018 (also U.S. Patent 9,787,293).

Current convertor

The direct current (DC) from any power source must be converted to the alternating current (AC) used by most devices. But when that power source fluctuates—such as with solar power—the varying DC must first be converted to a steady one.

To bypass that step—and the extra circuitry and costs—**Ricardo Sanfelice**, professor of electrical and computer engineering, helped to create an algorithm that performs the conversion directly and is implemented on top of existing hardware. "The beauty is that it doesn't change the architecture of standard conversion systems," Sanfelice said.

Sanfelice RG, Chai J. Robust single-phase DC/AC inverter for highly varying DC voltages. U.S. Patent 9,876,442, filed October 9 2015, issued January 23, 2018.

Much needed antibiotics

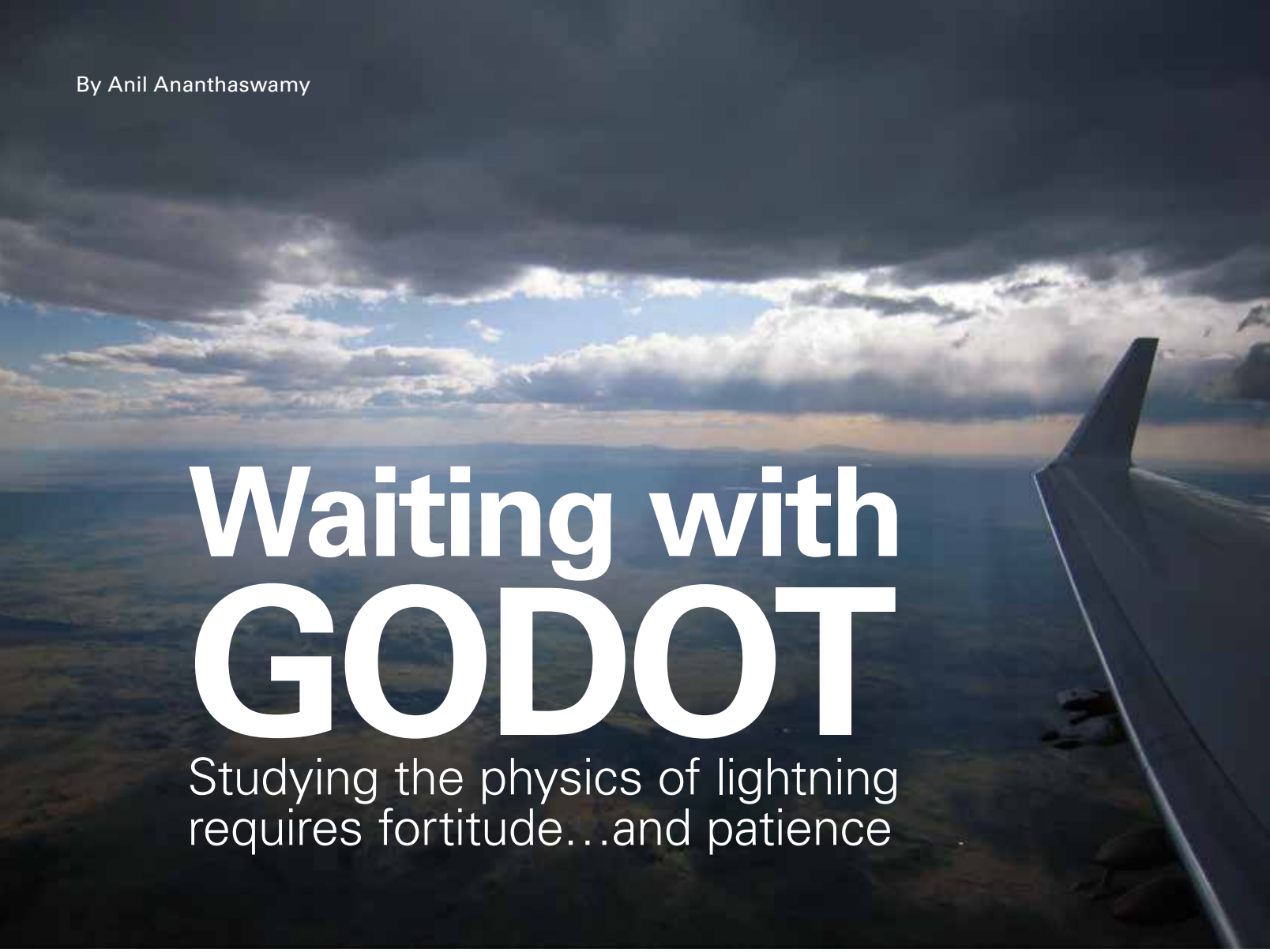
Many disease-causing gram-negative bacteria like salmonella, shigella, yersinia (plague), and chlamydia share a common mechanism—called a type III secretion system (TTSS)—that hijacks host cells by inserting needle-like structures into them and injecting proteins that drive infection. **Vicki Auerbuch Stone**, associate professor of microbiology and environmental toxicology, and colleagues discovered several compounds (piericidin and a derivative) that can block TTSS function by preventing the needles from forming.

The compounds are toxic, however, so in their current form they don't make useful drugs, Stone said. But studying how they work could lead to safer compounds, potential new antibiotics against which these important pathogens may be less likely to develop resistance.

"This is a first step to developing urgently needed new antibiotics that are effective against multi-drug resistant bacteria," Stone said.

Stone VA, Linington RG, Wong WR, Duncan MC. Piericidin bacterial inhibitors. U.S. Patent 10,080,745, filed November 24, 2014, issued September 25, 2018.

By Anil Ananthaswamy



Waiting with GODOT

Studying the physics of lightning requires fortitude…and patience

► "I thought I was going to die, I really did," said Joseph Dwyer, professor of physics and astronomy at the University of New Hampshire. It was August 21, 2009. Cruising at an altitude of about 45,000 feet, the Gulfstream V business jet, modified to enable scientists like Dwyer to study atmospheric physics, was flying around a thunderstorm. "I'm not sure exactly what happened, but we went through the middle of the thunderstorm," said Dwyer. The ensuing turbulence turned the flight into a violent roller coaster ride, disorienting him. "Your inner ear is all messed up. You can't tell if you are upside down or right side up," he said. While he was contemplating his imminent demise, an instrument designed to detect high-energy particles produced in thunderstorms lit up. Dwyer went from thinking "I'm going to die," to, "Oh, look at that, what's going on there?"

The instrument, called the Airborne Detector for Energetic Lightning Emissions (ADELE), had captured a gamma-ray glow—long-lasting high-energy emissions—from a thundercloud. On the same flight, ADELE also captured a much more powerful emission, called a terrestrial gamma-ray flash (TGF), an extremely elusive burst of energetic electromagnetic radiation that only infrequently accompanies lightning in thunderstorms. The TGF came from a thundercloud about 10 kilometers away. Until then, TGFs had only been seen from the ground and by satellites in space. The sighting was the first-ever made from an airplane.

ADELE was birthed in the laboratory of Dwyer's kindred lightning chaser **David Smith**, professor of physics at UC Santa Cruz and a member of the Santa Cruz Institute for Particle Physics, which is involved in cutting-edge experimental and theoretical particle

Above: The view from the large windows of a Gulfstream V business jet, modified to enable scientists to study atmospheric physics, as it flies toward thunderstorms in pursuit of elusive gamma-ray flashes triggered by lightning. Credit: David Smith.

physics and particle astrophysics. Dwyer, Smith, and other physicists have doggedly pursued these enigmatic high-energy outbursts from thunderstorms, seeking to gain a better understanding of how lightning develops and behaves. In addition to flying ADELE close to thunderstorms and even through a hurricane, their intrepid quest has also involved deploying instruments near mountaintops in Mexico and on the ground in Japan, all to study the inner physics of thunderstorms.

The research has revealed a smorgasbord of strange phenomena: TGFs that barely last a millisecond but are powerful enough to blind the electronics in satellites overhead; thunderstorms that glow in gamma-ray frequencies; anti-electrons (also known as positrons) generated by the same processes that produce gamma-ray flashes; and even a barrage of neutrons knocked out of air molecules by gamma rays. "It's a weird wonderland inside thunderstorms," said Dwyer. "There's a lot of strange stuff going on."

Eyes in the sky

The first clear indication of such high-energy strangeness came in 1994, when the Compton Gamma Ray Observatory (CGRO), a NASA satellite launched in 1991 to primarily study astrophysical gamma-ray bursts from space, produced an anomalous result. Composed of photons of the highest possible frequency, these gamma-ray bursts contain the highest possible electromagnetic energies. Unexpectedly, however, the CGRO had detected flashes of gamma rays coming from thunderstorms below, not from space above. Despite the satellite being in space, the intensity of these terrestrial flashes overwhelmed its detectors. Since gamma rays are mostly absorbed by the Earth's atmosphere, scientists argued that these gamma-ray flashes had to be originating at altitudes of more than 30 kilometers, above the dense regions of the atmosphere. For about a decade following this 1994 detection, TGFs were thought to be associated with "sprites," jellyfish-shaped lightning that occurs in the uppermost parts of the atmosphere during thunderstorms.

An early hint that TGFs were not connected to sprites and developed from much deeper down in the atmosphere came in 2004. Dwyer, then at the Florida Institute of Technology, was studying lightning triggered by firing meter-long rockets up into thunderstorms. Normally, lightning occurs when negative and positive charges build up in clouds. When these charge centers grow big enough, they can spark, creating intra- or inter-cloud lightning.

Positive charges can also accumulate on the ground during thunderstorms, and sometimes, a chunk of charge, called a leader, breaks free and moves toward the negative charge center in the clouds above. This creates a return path for lightning to strike the ground. Dwyer and his colleagues were using rockets to initiate this process. The rockets are tethered to spools of Kevlar-coated copper wire, which unspool as the rockets streak upward. The trailing copper wire creates a leader, providing the return path for lightning to come down and strike the rocket launcher. It was while observing such artificially created lightning that Dwyer's team detected a downward gamma-ray flash. The finding suggested that if thunderstorms could beam TGFs downward, they could also beam them up to be seen from space. Maybe sprites weren't the culprits.

Getting ready to fly ADELE (Airborne Detector for Energetic Lightning Emissions) on the NSF/NCAR Gulfstream V in 2009, Bryna Hazelton, then a UCSC graduate student, now a research scientist at the University of Washington, Seattle, and Forest Martinez-McKinney, principal electronics technician at the Santa Cruz Institute for Particle Physics (SCIPP), examine newly arrived parts for the terrestrial gamma-ray detector ADELE. Credit: David Smith.

Smith entered the picture about that time. As an assistant research physicist at UC Berkeley in the 1990s and early 2000s, he worked on a satellite called the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), which launched in 2002 to study solar flares. It turns out that the exquisite germanium detectors used in RHESSI could also capture TGFs, and Smith, soon to be hired to the UCSC faculty in 2003, and colleagues began to study them. RHESSI allowed the investigators to measure the energy spectrum of many TGFs, revealing that they originated deep within the Earth's atmosphere and not from sprites. "RHESSI was a real game changer," said Dwyer.

Runaway electrons

Meanwhile, the theoretical physics that might explain TGFs was also coming into focus. The earliest work dates back to 1925 and Charles Thomson Rees Wilson, who won the 1927 Nobel Prize for inventing the cloud chamber. Wilson showed that electrons encountering the electric fields that exist in storm clouds can "run away" to near relativistic speeds (i.e., near the speed of light) if they gain energy from the field faster than they lose energy through interactions with air molecules. When these runaway electrons hit the nuclei of atoms in the atmosphere, the collisions produce gamma rays. "The process is called 'bremsstrahlung'," said Smith. "It's German for 'braking radiation.'"

The runaway "seed" electrons that sprint to relativistic speeds inside thunderstorms arise either from the particle showers produced by cosmic rays striking the Earth's atmosphere, or nearer the ground from the decay of radioactive gases that constantly seep from the Earth's surface. But these seeds can't account for the great intensity of TGFs. "If I take every one of those electrons and accelerate it, and let it make gamma rays, it is still millions of times too weak to produce the TGFs we see," said Smith.

More of the essential physics had been worked out by Russian theorists, led by Aleksandr Gurevich at the Lebedev Physics Institute in Moscow. In 1992, Gurevich and colleagues showed that accounting for a process called Møller scattering—in which electrons scatter off other electrons—results in a snowballing effect, creating more and more relativistic electrons, a phenomenon called the relativistic runaway electron avalanche (RREA).

As physicists began combining the RHESSI data with the theories to explain TGFs, it became clear that something was still amiss. Even if electrons accelerated to relativistic speeds inside thunderstorms and in turn created an avalanche of relativistic electrons, it would still not be enough to account for the brightness of a TGF, said Smith.

Then, in 2003, Dwyer suggested a possible solution: an avalanche of relativistic electrons somehow triggers other avalanches (see sidebar). "If an avalanche can make new avalanches, you immediately have a mechanism to get as bright as you need to get," said Smith. But testing the theory required more experimentation. "I quickly decided that I didn't want to wait for satellite data," said Smith. "I wanted to go for a closer look."

Stormy beginnings

So, Smith and his students built ADELE at UCSC. At the heart of the instrument are devices called scintillators, which emit light when stuck by particles such as gamma rays or neutrons. This light is amplified and converted into an electric current by a photomultiplier tube, providing information about the incident particles. ADELE was designed to see both faint and bright events by including multiple scintillators of varying sizes. In 2009, the first ADELE began flying aboard the modified Gulfstream V operated by the National Science Foundation (NSF) and the National Center for Atmospheric Research (NCAR). Although the

Gregory Bowers, then UCSC graduate student, now postdoctoral researcher at the Los Alamos National Laboratory in New Mexico, stands in front of NOAA's N42 Hurricane Hunter 'Miss Piggy' that flew into Hurricane Patricia with the terrestrial gamma-ray detector ADELE on board. Credit: Gregory Bowers.

effort captured that first TGF occurring about 10 kilometers away in a thunderstorm (during the flight that had Dwyer fearing for his life), there was another danger besides motion sickness (and crashing) associated with flying into storms looking for TGFs: pilots and passengers could be exposed to potentially lethal doses of gamma rays.

This concern led Smith and his then graduate students, **Gregory Bowers** and **Nicole Kelley**, to build another iteration of ADELE, a more compact version that flew on NASA's unmanned Global Hawk. Unfortunately, the work came to naught. NASA didn't fly its drone anywhere near where you'd expect to see a TGF. "We didn't know this when we made all the effort to get on board," said Smith. "NASA was being very careful with a very valuable drone. They were unwilling to try to fly it into, or even over, a storm."

NASA's primary concern wasn't the lightning, but the convective turbulence in thunderstorms. They didn't want their Global Hawk flying into turbulence, said Bowers. Smith then turned to the only people who dare to tackle such risky conditions: the pilots who fly the Hurricane Hunters for the National Oceanic and Atmospheric Administration (NOAA).

It was a busy hurricane season in 2015 and ADELE spent a lot of time on a Hurricane Hunter (a Lockheed WP-3D Orion). The pilots even flew the

On October 23, 2015, ADELE flew on a NOAA Hurricane Hunter through Hurricane Patricia, at the time the strongest hurricane recorded by the National Hurricane Center, as it approached landfall on the southwest coast of Mexico. Credit: Jeff Schmaltz, LANCE/ EOSDIS Rapid Response.

plane through the most intense tropical cyclone ever recorded in the Western Hemisphere, Hurricane Patricia, which slammed into Mexico. "The plane

A blinding landslide of multiple avalanches

Even though terrestrial gamma-ray flashes (TGF) develop deep inside the Earth's atmosphere and then lose a lot of intensity moving out into space, they are still bright enough to saturate the detectors on satellites orbiting 400 miles above our planet. By the early 2000s, it was clear that an avalanche of electrons accelerated to near relativistic speeds by the powerful electric fields inside thunderclouds could create gamma rays (see main story). Yet, just one avalanche wasn't enough to account for the brightness of TGFs. In 2003, Joseph Dwyer, professor of physics and astronomy at the University of New Hampshire, suggested that an avalanche of electrons can initiate other avalanches—and this can explain the observed intensity of TGFs.

Dwyer has proposed several possible ways avalanches might trigger new avalanches. In one, an avalanche of accelerating electrons smashes into the nuclei of atoms in the air and creates gamma rays. Some of these gamma rays scatter in the atmosphere and end up in the region where the initial avalanche started. There, the gamma rays kick off more electrons from atoms in the air, starting a new avalanche.

Another possibility involves the production of pairs of particles and their anti-particles. Collisions of gamma rays with atomic nuclei can result in the formation of electron and positron (anti-electron) pairs. Being positively charged, the positrons get drawn to the region where the electron avalanche began, kicking out more electrons from atoms in the air, similarly starting a new avalanche.

According to David Smith, Dwyer's colleague and professor of physics at UC Santa Cruz, one of these processes or both could be active in thunderstorms. The theoretical calculations predict that TGFs will take up to 100 microseconds to reach full brightness, a result that is consistent with the observed data from actual TGFs.

Waiting with GODOT

took a straight cut all the way through the outer rain bands right through the eye wall, through the eye, back through the eye wall on the other side, and out," said Smith. "It's amazing they fly in those conditions. I would never ask someone to do that for my science, but since they were going to do it anyway, it was nice to be on board. We learned a lot."

In the eye wall, a column of tall, violent storms that line the eye of the hurricane, ADELE detected positrons beaming down at them, produced by terrestrial gamma rays interacting with atomic nuclei. It was another first. "We were actually underneath a TGF that was pointed upward," said Bowers.

Despite these successes, flying the instruments on planes poses challenges—not least because the instrument must be built both to handle intense vibrations and be fire-safe. Because of this, Smith and Bowers began to explore the possibility of placing their instruments near mountaintops.

From the ground up

Salvaging old ADELE equipment, Bowers built GODOT (for Gamma-ray Observations During Overhead Thunderstorms)—an instrument the team could simply install on the ground while thunderstorms raged above. The team first placed GODOT alongside the High-Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory, 4100 meters high on a plateau in the shadow of the Sierra Negra volcano near Puebla, Mexico. It waited there patiently, taking in the lightning season that lasts for three long months.

Despite all the lightning, no TGFs were detected by GODOT, further confirming their rarity. GODOT did, however, observe thunderclouds glowing in gamma-rays, a phenomenon the team attributes to some acceleration of electrons and some avalanches, but not enough to produce lightning or TGFs. The gamma-ray glows last much longer than TGFs, but are a million times dimmer, said Smith.

Above left: A top-open view of the GODOT (Gamma-ray Observations. During Overhead Thunderstorms) instrument, designed to study terrestrial gamma-ray flashes from the ground. The Lenovo notebook records data from five analog-to-digital converters on the left. The metal box in the bottom left corner is a GPS unit. Two small, shiny cylindrical detectors (each is a scintillator coupled to a photomultiplier tube) sit above two large detectors that are not visible. Above right: GODOT ready to be taken as checked-in baggage from San Francisco to Japan. Opposite page: The wind turbine and an adjacent lightning tower in Uchinada, Japan, where GODOT saw photoneutrons, which are neutrons knocked out of air molecules by the gamma rays generated during a terrestrial gamma-ray flash. Credit all photos: Gregory Bowers.

Another attractive location for GODOT was suggested by a collaborator in Japan: the town of Uchinada, on the western coast of the island of Honshu. The region gets hit by winter thunderstorms that are very low to the ground. A wind turbine at the mouth of a lagoon there had been repeatedly struck by lightning. The Japanese dismantled the wind turbine, erected a lightning protection tower, and reinstalled the turbine next to it. For researchers studying lightning, this was perfect. "This was a good place to look for lightning strikes from these winter thunderstorms," said Bowers. "We knew we had a big lightning rod that was getting struck."

Masashi Kamogawa, a fellow lightning researcher at Tokyo Gakugei University, agreed to host Bowers, so GODOT traveled to Japan. "I took it over as checked luggage," said Bowers, who now works as a postdoctoral researcher at the Los Alamos National Laboratory. "We deployed it, left it there for the winter, and we got really lucky."

On December 3, 2015, GODOT detected a unique and unusual signal. "Because of my experience in solar physics, I knew what it was," said Smith. "It's what happens when a neutron gets absorbed by hydrogen." GODOT had seen a theoretically predicted TGF signature. The *bremsstrahlung* gamma rays can knock out neutrons from air atoms. These neutrons scatter around until they are captured by hydrogen atoms in the scintillator, resulting in additional gamma rays with characteristic energies.

The neutron signal turns out to be a good proxy for a TGF, said Smith, especially because the TGF itself can be blindingly bright for terrestrial instruments. Smith's team compared the observed TGF event to another lightning strike that happened about four hours earlier, but without an associated TGF. Based on their findings, the team posited that TGFs may not vary in intensity from weak to strong, but rather are "all-or-nothing" events, only occurring when the electric fields in the thunderclouds reach a very high threshold. This might also explain why TGFs are elusive. Not all lightning strikes may have the requisite electric fields to create TGFs. Smith and others have estimated that only about one in a thousand lightning strikes result in a TGF.

Smith now has the funding to build a super-GODOT, an instrument with a wider range of detectors, both smaller and larger, than in the current GODOT. He hopes to deploy this instrument, tentatively called THOR, for Terrestrial High-Energy Observations of Radiation, on mountaintops, in aircraft, next to lightning towers—anywhere he can. "Every time you think of a new way to look, you discover something new," he said. "Every time you look in a new place, you discover something new."

One such interesting new place could be detectors flown into thunderstorms in balloons, a project Smith is working on with John Sample, an assistant professor of physics at Montana State University. By going where pilots cannot, the balloon-based detectors should see the weak TGFs if they exist and may permit a closer inspection of the intense ones that could provide further insight into Smith's "all-or-nothing" hypothesis. "When the balloons go up, we could be flattened or we'll see nothing," said Smith. "But maybe nature will surprise us, and that'll be very exciting too."

By Cameron Walker

Turn me on I'm a radio

Pioneering art along the electromagnetic spectrum

Just as the sun set on the eastern Icelandic town of Seyðisfjörður, the operator slipped on her headphones and began to broadcast the sounds of the night rising close to the Arctic Circle. If you had been in the right place, and tuned your radio to just the right frequency, you might have heard it: a rise and fall of static, followed by mournful, musical sounds. A foghorn, maybe, or the call of a creature from the depths of the sea? And, then, a calm, precise series of spoken "dits" and "dahs." A transmission from a sinking ship? A beacon from some faraway place? If you knew Morse code, you'd understand the message: "This is the evening of the year. Cheer us for the darksome hours."

Translating the haunting, ambiguous noises is harder. Are they whale songs? Train whistles? They elicit the vertiginous feeling of driving alone at night through an unfamiliar landscape. This ambiguity, and the questions it provokes, inspire radio and transmission artist and UC Santa Cruz film and digital media assistant professor **Anna Friz.** Throughout her career, Friz has sought ways to expand what we think of as radio, making pieces like this one, *Radiotelegraph*, which contains sounds including ones made by the radio waves themselves. Radio waves are electromagnetic waves that travel through the air and make their way to the antennas of radios, where they are transformed into the sound waves we hear. But along the way, the radio waves can interact with each other, the landscape, and anyone that encounters them, creating both new sounds and, for Friz, new ideas.

Friz's work includes these waves, and more. "Radio is often described as disembodied," Friz said. "But to me, radio also includes a tremendous amount of infrastructure." That infrastructure includes the

In UCSC assistant professor of film and digital media Anna Friz's installation piece *Respire*, hundreds of handheld radios hung from the ceiling interacting with each other and with the listeners who moved throughout the room. Credit: Tom Blanchard, with permission.

Friz simulcast her piece *Radiotelegraph* from the Icelandic town of Seyðisfjörður, shown here, where workers connected the first telegraph cable from Europe to Iceland in 1906. Credit: Anna Friz.

energy that's needed to send radio waves gliding through the air, the hardware that goes along with this, and the people who construct, tune, and play with the transmitting and receiving instruments. It also includes the surrounding world, in which sunspots create interference, and a clear night can bounce signals off the ionosphere and into unexpected, distant receivers. Radio can also connect deeply with place and history: in 1906, workers connected the first undersea telegraph cable from Europe to Iceland through the narrow fjord by the town of Seyðisfjörður, where Friz performed *Radiotelegraph*. "Making these things a little more apparent to people is really interesting," she said.

Friz has transformed the way artists use and think about both radio and other wireless technologies, said Jeff Kolar, a fellow sound artist and radio producer who commissioned *Radiotelegraph* for Radius, an experimental Chicago-based broadcast platform. Friz simulcast the piece from both her low-watt FM transmitter in Iceland and the Radius transmitter in Chicago, creating the impression for its temperate-zone audience of a dispatch from the far north. Friz's substantial body of work includes similar broadcasts heard on national public radio in countries such as Germany, Australia, and Austria, as well as radio-based installations that use sound to explore the dynamic interaction of radio with setting and listeners. "Anna is one of the first people to really push radio art off the traditional radio format and think about it as a way to present sound in art exhibitions," Kolar said.

Radio as medium

Friz's radio rapport began in college, while working at a Vancouver, B.C., community radio station, doing everything from sound engineering to hosting a weekly radio show. She had always been interested in performance art—at one point, she taught herself how to play the accordion so that she could join a clown band—but it took a few years at CiTR 101.9 FM before she realized that she could make radio her medium.

The sounds that interested her the most were the very ones that most radio broadcasts scrub from their airwaves: speaker distortion, a DJ's rattling inhale, other accidental squeaks and fumbles. To Friz, these sounds aren't mistakes. Instead, they remind us "that people are expressing emotions into microphones," and what you hear is a circuit of relationships crossing through people, their surroundings, and the technology they use. "The noise tells us something about those relationships," she said. "It offers the potential for something to happen."

To capture sounds for her compositions, Friz taps a wide variety of sources. She'll record the sound of radio interference. She might use walkie-talkies, or very low frequency (VLF) recorders, or transmitters and instruments that she's built herself. And then she might loop in interviews, scripted dialogue, or her own voice. Each piece is a little experiment, a world of its own. "I'm definitely creating a landscape out of all of these different sorts of electromagnetic signals," she said.

To Friz, radio is not only the sound waves that travel through the air, but the people, energy, and technology that make this possible. This is the first radio transmitter Friz built herself, in 1998. Credit: Anna Friz.

In her installation work, Friz seeks to create an immersive experience for listeners. Take *Respire*, for example, a piece she first presented in 2008 in Lisbon, Portugal, for the RadiaLx Festival, and later in Canada, Estonia, Chile, and the U.S. Picture hundreds of handheld transistor radios hanging from the ceiling on wires and swinging like mobiles as listeners enter and move about a darkened room. Attached blue bicycle lights transform the radios into constellations in the night sky. The interacting electromagnetic waves cause the receivers to emit strange, transient sounds—chirps, hums, and other textures that blend into a rich, evolving sonic experience. "People sensed that the array was responsive," Friz said. "You feel you are in an environment that is changing, that is unstable, that can tell you are there."

Friz voiced this seemingly living array with recorded sounds of breathing and interviews of witnesses to a shooting. In its largest presentation as a featured

The Chilean desert contains both human infrastructure and vast natural landscapes; Friz, assisted by Chilean-based artist Rodrigo Ríos Zunino, is working to capture the interactions between the two in a series of audio and visual recordings. Credit: Rodrigo Ríos Zunino, with permission.

piece in Nuit Blanche, a 12-hour overnight art event staged in 2009 by the city of Toronto, the installation involved 250 radios and a four-part composition flowing through four FM microradio transmitters.

Respire, which explored how people hear and feel distance and how empathy might be wirelessly communicated and felt, grew out of Friz's doctoral project in communication and cultural studies at Toronto's York University. The piece suggests that the noise, breathing, and voices don't distance listeners from what they're hearing, but instead make them more aware of the connections among themselves and the voices they hear, and the radios and the sounds they produce.

"Radio art speaks to the idea that you're a human body, and you're also an antenna attached to the ground," Kolar said. "We're always bathed in these waves, whether it's your WiFi or the radio waves of all the thousands of songs that are being played at that moment." The magic comes from being in the presence of the art itself, taking in the full sensory experience of interacting with the waves and the devices transmitting them.

Making the ethereal tangible

Radio art is part of a broader category called transmission art. Artists creating in this space intentionally incorporate electromagnetic waves into their work —from extremely low-frequency radio waves to high-energy gamma rays, said Galen Joseph-Hunter, author of *Transmission Arts: Artists and Airwaves* and executive director of Wave Farm, an Acra, New York-based nonprofit that focuses on experimental transmission art. The genre makes "the ethereal tangible," Joseph-Hunter said, allowing the audience to experience physical space through audio and visual representation.

Central to the ephemeral qualities Friz strives to bring to this felt experience is empathy. The theme plays a key role in *The Joy Channel*, a collaboration between Friz and composer and sound artist Emmanuel Madan. The work imagines a future world in which radios can broadcast pure emotion, and nomadic groups have developed a form of tele-empathy. The multiyear project, first commissioned by Radio Tesla, was originally performed live in Berlin in 2008, later broadcast in Austria, and in 2018 became available in a final version as a digital download from the Vancouver-based label IO.SOUND.

For the project, Friz and Madan developed a script as well as sonic elements to create a sense of optimism about the future of radio. Madan said that they were inspired by the work of science fiction authors whose envisioned futures blend harsh reality and hope. The heart of *The Joy Channel* is the connection between sound and human emotion: "Both can represent fields of resonance, commonality, and community," Madan said. *The Joy Channe*l, he said, "uses sound as a tangible representation of the kind of community and solidarity that we see as essential to a brighter future."

Community is a theme that runs through much of Friz's work. Many pieces require multiple collaborators and participants, from fellow sound artists to the radio platforms in more than 30 countries where her work has appeared, as well as the exhibitions and agencies that have provided homes and funding for her work. She continues to be involved in Skálar, a sound art and experimental music collective in eastern Iceland,

where *Radiotelegraph* was created. The Icelandic connection led to a recent appearance in the 2018 *New York Times Magazine* Voyages issue, which innovatively coupled images with audio from destinations around the world. Friz and her partner, **Konrad Korabiewski**, Skálar founder and UC Santa Cruz research associate, traveled around Iceland with a photographer to collect sound for their contribution.

Desert soundscapes

After working, traveling, and performing across Europe and the Americas, Friz has found a home in Santa Cruz, where she is collaborating with colleagues in film and digital media, as well as soaking in the influence of UC Santa Cruz's ecology and environmental research. These connections are key to her latest project, a series of works focused on the landscape of the northern Chilean deserts. Here, pyramid-sized piles of mining tailings can be seen from satellites, plastic bags flutter from miles of fences, and the infrastructure of roads, cables, and pipelines radiate from copper and lithium mines. Interspersed with all this is the high-altitude beauty of arid plains, distant peaks, and the plants and animals that struggle to survive there. Friz aims to capture this complex landscape with a combination of audio, photography, and videography in her project *We Build Ruins*.

Friz performs *Radiation Day*, a compilation of recordings from her work in northern Chilean deserts, at the Ars Electronica Festival in Linz, Austria, in 2017. Credit: Tom Mesic, with permission.

In these high deserts, Friz is recording sound with multiple microphone setups, including a contact microphone that records waves traveling through solid objects, an underwater microphone, and a VLF receiver that can detect activity in the ionosphere. She also takes photos and records each day's experience in a field diary. Assisting her is Chile-based artist Rodrigo Ríos Zunino, who takes photos, videos, and additional audio recordings. Together, they're exploring the expanse of the landscape and the long-lasting footprint of the mining activity that fuels the area's economy. Friz points out that the extracted materials are part of many of the recording instruments that she has used throughout her career, and the digital devices that many of us use every day.

Listen and you may hear truckers on the Pan-American Highway on their CB radios. You might hear the wisps of evaporation from salt ponds, the rumblings of a distant volcano, the crackling foil from a pile of contraband cigarette packages, the rustle of the plastic bags entwined in fences in the relentless desert wind. "The desert appears in my memory as a platform for things to disappear," said Ríos Zunino, "a place to smuggle, hide, and lose what we do not wish to see anymore." Friz premiered her first piece from the initial fieldwork, called *Radiation Day*, at the Ars Electronica Festival in Linz, Austria, in 2017, and performed it again in 2018 at a music festival in Quito, Ecuador.

In addition to capturing the distance and degradation with electromagnetic waves, Friz aspires to show the human connection. To this end, she is weaving an "earth suit" out of cassette tape and plastic bags, Andean wool, and alpaca yarn. She intends to use the suit as a sculptural element in future pieces, which will include installations, performances, and possibly publications. Combining visual and narrative elements, she hopes, will create many touchpoints through which listeners and viewers will find ways to connect. Friz knows that her work is often "noisy," but the purpose is to invite people in. As a composer, she said, "I need to give people space to pay attention in the way that I hope they will."

In many cases, Friz doesn't know who hears her work. It could be someone walking through one of her installations or sitting in the audience of a performance. But it could also be someone on a solitary journey, who, at the right time, in the right place, eases across their radio dial. They may hear strange musical noises or a screech that makes them question what they've heard, or soft breathing or a voice that brings some comfort. Or they could hear the last lines of the Morse code in *Radiotelegraph*, even though they can't translate them: "We remain together. We are here for the night. Confirm. Wait. End transmission. Closing station." Then, maybe feeling that the distance between them and everything else has shortened, they journey on into the coming night.

By Leslie Willoughby

Appraising clues from antiquity

Different lenses can reveal different truths

The lens of history allows us to assess the past, find meaning in the present, and plan the future. But history does not provide one tidy, unyielding viewpoint. Each scholar makes observations through a unique lens, to some degree defined by discipline, but often resulting in different narratives.

For her lens, **Karen Bassi**, UC Santa Cruz professor of literature and classics and director of the Classical Studies Program, studies the works of ancient authors who wrote about their relation to the past and future. But Bassi also has an abiding interest in sorting through how historical perspectives differ, depending on whether researchers read texts or interpret artifacts.

A major division splits Bassi's field of antiquities. Classicists identify either as philologists, like Bassi, and historians, who pore over ancient literature and history, or as archaeologists, who dig up artifacts. Although the texts and artifacts relate to one another, each approach employs different methodologies. Bassi posits that each approach conceptualizes their objects of study in different ways, often resulting in different interpretations.

Above: In the UC Santa Cruz classics program library, professor of literature and classics Karen Bassi writes the Greek word for "truth," alētheia, which means the absence of forgetting. Bassi studies how objects and texts help us to remember and give us access to the past. Credit: Leslie Willoughby.

"One of the things that makes Karen Bassi's work exciting is that she studies not only the past, but also the way we construct the past as an object of study," said Victoria Wohl, professor of classics at the University of Toronto. Like Bassi, she analyzes the literature and culture of ancient Greece. Wohl centers her attention on the social relations, political thought, and psychic life of democratic Athens.

We sat down with Bassi at UC Santa Cruz's Cowell College to talk about the differences between using texts and artifacts to identify truths about the past, and how these differences may affect what we choose to believe.

Truth seems like a modern, useful thing. The word that gets translated as "truth" in Greek is *alētheia*. The "a" in the word negates what comes after it, as in a-moral. Lethe is the river of forgetfulness that you cross when you die. You forget your former life. This concept is in Plato and other writers: truth is the absence of forgetting. I think this also says that truth is a temporal concept. Truth builds on things that came before it, things you've not forgotten, as this word implies. Objects and texts help us remember. They give us access to the past.

Left: Bassi studies death in ancient Greek tragic texts and how objects like this funerary monument (National Archaeological Museum, Athens) known as the "stele of farewell" from 350–325 B.C.E., convey the ephemerality of our lives and cultures. Credit: Yurie Hong, with permission. Below: Bassi observes that archaeologists and museum specialists share the metaphor "read the object." This reading, or interpretation, is limited by the distance between ourselves and the past. We may deduce what ancient objects, such as these Greek gold and cloisonné bracelets from fifth century B.C.E., meant to their owners, and texts may deepen our understanding, but the distance remains. Credit: The Metropolitan Museum of Art, the Cesnola Collection, Purchased by subscription, 1874–76. (CC0 1.0).

Questions may be the most powerful forms of speech. Especially the unanswerable ones: how do we determine the truth about the past? We have only traces of texts from antiquity. Statements we make about ancient Greece or Athens must be filtered through that lens of loss. My 2016 book, *Traces of the Past: Classics between History and Archaeology,* examines how ancient Greek authors wrote about objects in the world, the stories attached to those objects, and how those stories inform how we should think about the past. And that has ethical, political, and moral implications.

We're having a relationship to the physical world now, in my office. What objects are around? What do they say about me? This is a way of thinking about political and social structures. Objects occupy different positions historically and politically, and in terms of their value, everyday as opposed to the exceptional.

Archaeologists use these terms also, when they give meaning to the objects they dig up. And the same terms determine how those objects turn into exhibits in museums. I wanted to bring the three subfields of the classics into conversation with one another. The subfields are philology—those like me who work on literary texts, historians who work on historical texts and historical evidence, and archaeologists who work on material evidence.

How long ago are you talking about, and who are these authors? The fifth century B.C.E. Herodotus, for example, who is called the father of Western history, wrote about a kind of bowl. He uses a phrase when talking about such objects, "These are things that lasted up until my time." The objects have a history that comes with them and he has seen them. But his texts come down to us through manuscripts, and the manuscripts don't have pictures or illustrations.

I'm interested in factual statements about the past and how objects seem to make a true statement about an event. They seem to be evidence for that event, just as funerary monuments are evidence of people who lived in the past.

Appraising clues

In the Greek language, the past tense of the verb meaning "to see" means to know. In the Western tradition, sight is prominent as the vehicle for knowing the world. To describe his method of working, for example, Herodotus uses the word *autoptēs*, which means self-sight, or eyewitness.

If a picture's worth a thousand words, do objects outvalue text? It's a matter of interpretation. Archaeologists who work on ancient Greek artifacts use a metaphor. When they talk about the objects they study, they say they "read the object."

I'm reading text to see the object, and archaeologists see an object directly. But they want to be reading. In this case, reading means interpreting the object. And what is the aim of that interpretation? To get closer to the context in which the object was used.

Reading objects is also used as a metaphor in museum studies. But reading brings with it the notion that there's a distance between ourselves and the object. We can have a plausible argument about artifacts and what they might have meant to the people who owned them. And texts can tell us some things about that. But there's always going to be that distance.

How do these questions from the classics affect us here and now? The museum becomes another staging ground for thinking about these questions. When we look at objects in a museum, oftentimes they have historical significance. Somebody's ancestors touched, manipulated, buried, or venerated them. What gets embodied in these objects that tells us something about our humanity, about our families? Somehow, they bring history with them.

I think about things that my mother left for me, for example, old jewelry that I never wear. There are your family heirlooms on one hand, and then there's the museum end of that spectrum. What are we preserving when we put things in a museum, for what purpose?

This summer, I am codirecting a National Endowment for the Humanities Summer Institute, Museums: Humanities in the Public Sphere, in Washington, D.C. My codirector is **Gretchen Henderson**, a 2018 Tanner Fellow in environmental humanities at the University of Utah, a lecturer at Georgetown University, and a UCSC research associate. Participants will visit the National Museum of African American History and Culture, the National Museum of the American Indian, the United States Holocaust Memorial Museum, and the Freer-Sackler Museums of Asian Art.

One of our aims is to bring scholars together to think about how museums showcase and interrogate the humanities. For example, museum specialists will give workshops on digital humanities. There is software that allows you to look at an object on your computer screen and rotate it. But what is the difference between that and standing in front of the object itself? How do questions about what we mean by human life and human knowledge, and what we should be remembering, get filtered through these new digital platforms?

How does the meaning of objects inform your studies of death in Greek tragic texts? Objects are ephemeral, they come and go. Funerary monuments from ancient Greece may have inscriptions on them like, "She was the best wife." They name the person, and they'll have a sculptural image. You should see these! A child holds a pet bird. A mother reaches out to a baby being brought to her—did she die in childbirth? A husband gives his hand to his young wife. Why have the sculptor and family decided to make these images as though the dead are still living? The material world conveys to us the ephemerality of our lives and cultures.

Bassi is codirecting a gathering of scholars this summer in Washington, D.C., to consider how museums showcase and interrogate the humanities using objects like this drinking cup c. 500 B.C.E. Credit: Iris & B. Gerald Cantor Center for Visual Arts at Stanford University; Gift of Catherine Harwood Dewey, in memory of Dr. Hazel D. Hansen, with permission.

By Emma Hiolski

UC Santa Cruz goes to town

Grad Slam contest spotlights graduate research

Applause and appreciative laughter spilled through the doors of the Kuumbwa Jazz center and into the cool evening air of March in downtown Santa Cruz. By audience demand, **Caitlin Kroeger**, a Ph.D. student in ocean sciences, demonstrated an albatross mating dance after presenting a three-minute summary of her research on seabird resilience to climate change. Emcee **Lori Kletzer,** interim campus provost and executive vice chancellor, and host for the evening, gamely followed along, bobbing and shaking her head.

With that, the fifth annual UC Santa Cruz Grad Slam was off to a roaring start. An additional 12 Ph.D. students shared brief, public-oriented presentations of their graduate research in the UCSC section of the UC-only contest, similar in format to the Three Minute Thesis (3MT®) competition created at the University of Queensland in Australia. A panel of 10 judges, including Santa Cruz mayor Martine Watkins, Vice-mayor Justin Cummings, and several UCSC alumni, ranked the 13 presentations.

These presentations featured research in biology, computer science, outer space, and more. Computer science and engineering student **Minmei Wang** spoke about her work developing a collaborative authentication process to increase security and integrity for the "Internet of Things." **Natalia Koulinka**, a student in the History of Consciousness Department, shared her analyses of the collapse of the former Soviet Union. Physics student **Benjamin Lehmann** talked about his part in the search for our universe's elusive dark matter. And **Theadora Block**, an ecology and evolutionary biology student, presented evidence that golden-crowned sparrows with a more colorful cap have higher social dominance. Block also got the audience participating in a call-and-response whistling of the little brown bird's song.

Audience involvement wasn't limited to calling for bird demonstrations, however. Viewers voted for their favorite presentation, awarding this year's People's Choice award (and $750) to psychology student **Priscilla Sung.** Sung's research focuses on bilingual children, and whether children who "code-switch" between their languages more often are also better able to switch between different tasks. Runner-up for the top judged prize (and awarded $1,500), was **Rachel Harbeitner**, a student in ocean sciences. Harbeitner presented her finding that deep-sea, carbon-eating bacteria consume the remains of oceanic plankton at a rate 50 times faster than expected.

This year marked the first time UCSC's Grad Slam was held off-campus. The move was geared toward "taking research off the hill and into town," said Kletzer. Kuumbwa Jazz also offers a smaller, more intimate space than UCSC's Music Center Recital Hall, with the option of serving food and beverages, said Kletzer. "The students are enthusiastic about sharing their work, and this venue feels like a good match for that enthusiasm," she said. "We're going to stay here."

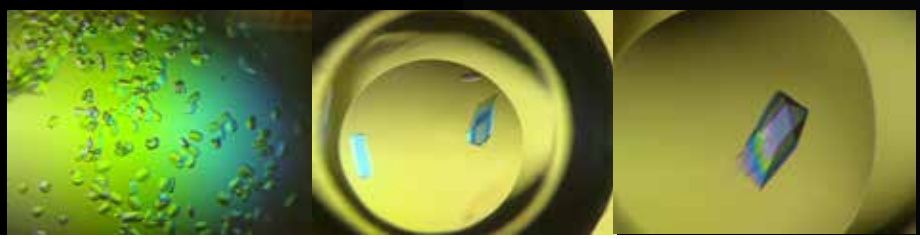
The top prize, along with $3,000, went to ecology and evolutionary biology student **Sarah Kienle**, who shared her doctoral research on sexual dimorphism in elephant seals. Not only are males and females of the species very different in size—males handily outweigh females—they also have very different foraging strategies. Elephant seals make good ambassadors for biology, said Kienle. "Showing people pictures and telling stories about what we do helps inspire people to become scientists and can help open a dialogue about the importance of science," she said. Due to Kienle's spring research trip to Antarctica to study leopard seals, runner-up Harbeitner represented UC Santa Cruz at the UC-wide Grad Slam competition on May 10 at the LinkedIn headquarters in San Francisco. To learn the final results and watch the presentations (spoiler alert: Harbeitner won third place!), point your browser to *gradslam.universityofcalifornia.edu.*

Interim Campus Provost and Executive Vice Chancellor, Lori Kletzer (left) and finalists at the fifth annual UCSC Grad Slam competition. Credit: Kurtz Photographics.

By Ben Shouse

Built from scratch

Improving vaccines with molecular insights



Above left: X-ray crystallography derived structure of a human antibody (light and dark blue) bound to the respiratory syncytial virus (RSV) G protein (yellow). RSV uses the G protein to attach itself to cells in the human respiratory tract and to modify the human immune response to virus infection. UCSC assistant professor of biomolecular engineering Rebecca DuBois and colleagues have discovered how protective human antibodies stick to the G protein and are engineering the protein for use in a vaccine.

Above right, inset photographs: Protein crystals of antibody bound to the (RSV) G protein are used in x-ray crystallography studies in the DuBois laboratory. The single crystal on the far right is about 0.3 millimeters across, just barely visible to the naked eye.

Credit, all images this feature courtesy of Rebecca DuBois.

Vaccines are one of history's most important medical advances, shielding large swaths of humanity from more than a dozen diseases. Worldwide, experts estimate that measles vaccinations alone have saved more than 17 million lives since the year 2000. In the United States, as a National Academies report put it in 2003, vaccines are a major reason that "death in childhood is no longer expected."

And yet, most vaccines are still made with the same basic approach Edward Jenner used for smallpox back in the 1790s: borrowing from nature. Later scientists and clinicians improved on Jenner, to be sure, but their work remained "empirical"—based on observation rather than a coherent theory.

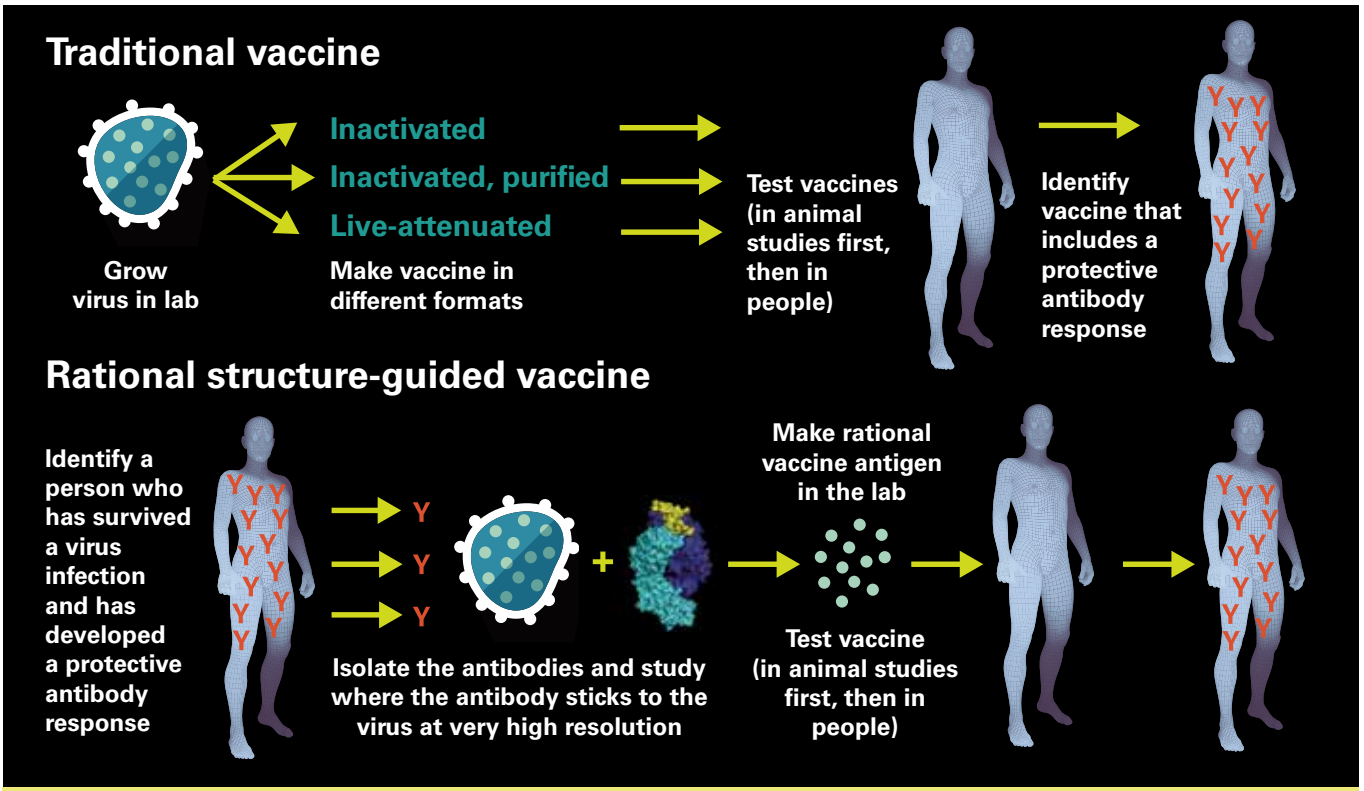
"They didn't have to understand what a virus was or what an immune system was," said Bruce Gellin, vaccine expert and president of global immunization at the Sabin Vaccine Institute, a research and advocacy nonprofit based in Washington, D.C.

Now, however, vaccinology is in the middle of a fundamental shift. "Insights from our investments in basic science have led to leaps in technology that allow you to do things in a totally different way," Gellin said.

One of the scientists making those leaps is **Rebecca DuBois**, assistant professor of biomolecular engineering at UC Santa Cruz. She is a rising talent in "rational" vaccine design, so called because it is based on an understanding of why vaccines work at the molecular level. Instead of borrowing from nature, her approach is to build vaccines from scratch. The aim? In addition to improving on existing vaccines, it's to develop first-time vaccines for viruses (and other disease agents) that have so far defied vaccination efforts. That includes viruses like HIV, but DuBois's work focuses on more common but less notorious bugs, like respiratory syncytial virus (RSV). "Traditional ways of making a vaccine have in some cases just epically failed," said DuBois. "So, we're taking a new approach."

Centuries old

The current approach is old indeed, and in some ways not terribly scientific. The earliest recorded version of vaccination—in 16th-century China—is called variolation. It involved grinding up smallpox scabs and either blowing them up a person's nose or injecting them under their skin. This proved fatal in about one in a hundred people, but that was



Rational vaccine design

The traditional way of developing vaccines is to alter a virus (or other infectious agent) so that it cannot cause disease but can still prompt the human immune system to arm itself against the real thing. This can be done by either killing the virus, or by "attenuating" it, meaning chemically or genetically altering it without killing it. The choice of method depends on the disease.

Structure-based approaches, like those used in the lab of UCSC virologist Rebecca DuBois, seek to build vaccines piece-by-piece instead of starting with the whole virus. To do this, scientists need to know more about the molecular structures on the surface of the virus, especially how they trigger infection, disease, and the immune response. This strategy has great potential to help improve on existing vaccines and engineer new ones that will work against diseases that have so far eluded the traditional development approach.

much better than the 30 percent rate of death from natural infections, according to the U.S. National Library of Medicine.

True vaccination was first attempted in 1796 by Jenner. At the time, it was widely believed that people who regularly milked cows were immune to smallpox because they had been exposed to cowpox. Jenner, a surgeon then working in Gloucestershire, England, took material from cowpox lesions and inoculated an 8-year-old boy. In a test that would give modern ethicists the vapors, he exposed that boy to fresh smallpox a few months later, thankfully with no ill effects. His initial paper about this episode was rejected, but after more rigorous work by Jenner and others, the practice became widespread in Europe by 1800. Jenner dubbed it "vaccination," from "vacca," the Latin word for cow.

About 90 years later, Louis Pasteur developed a more scalable way to protect people from viruses. Instead of finding a similar but less dangerous virus like cowpox, he used the actual disease agent he wanted to combat, rabies. He rendered it harmless by exposing it to dry air. Then, in another sketchy but successful trial, he used an untested formulation to inoculate two boys who had been bitten by rabid dogs. Fortunately, neither developed rabies, a routinely fatal disease.

The professionalism and safety of vaccine development have improved dramatically. But the underlying technology? Not so much. Most vaccines now in use were made by doing what Pasteur did: killing or weakening viruses and showing them to the immune system, like a wanted poster: "Look out for these guys!"

Molecular locksmithing

Vaccination works because the immune system can recognize invaders years or decades after being exposed to them. The human body has a cadre of "memory" cells patrolling the bloodstream. Their job is to recognize an invader, then rapidly produce proteins called antibodies to catch and neutralize it, usually with the help of a goon squad of killer immune cells. Antibodies stick only to one remembered feature on the surface of a specific invader, like a key fits a lock, and then wave a flag to bring in the killer cells.

Conventional vaccines expose the immune system to a whole virus, which can have several surface proteins. And each of those proteins can have several spots where antibodies can stick. This is like giving the immune system a bunch of locks and saying, "here, make keys for these in case you need them." Rational vaccine design tries to find a single lock that will produce the right key—an antibody that not only sticks but protects. "We're trying to help the immune system focus," DuBois said.

It has already started to work. A few vaccines made with a basic version of rational design are now in use, including Flublok® for influenza and Gardasil® for human papillomavirus (HPV). However, early efforts at rational design have also put a lot of focus on HIV, said **Phil Berman**, UC Santa Cruz professor emeritus of biomolecular engineering. Berman helped lead the effort to develop the first HIV vaccine to enter large-scale human trials. The vaccine was not protective enough to win approval, but the trials produced valuable information, and the Berman lab is now using structure-based vaccine design to develop an improved HIV vaccine. Still, it's a challenging disease for the relatively new approach. "HIV is the most difficult virus on the planet to work

Number of U.S. new infections, hospitalizations, and deaths for select diseases for which no vaccines exist, along with influenza, which requires annual vaccination

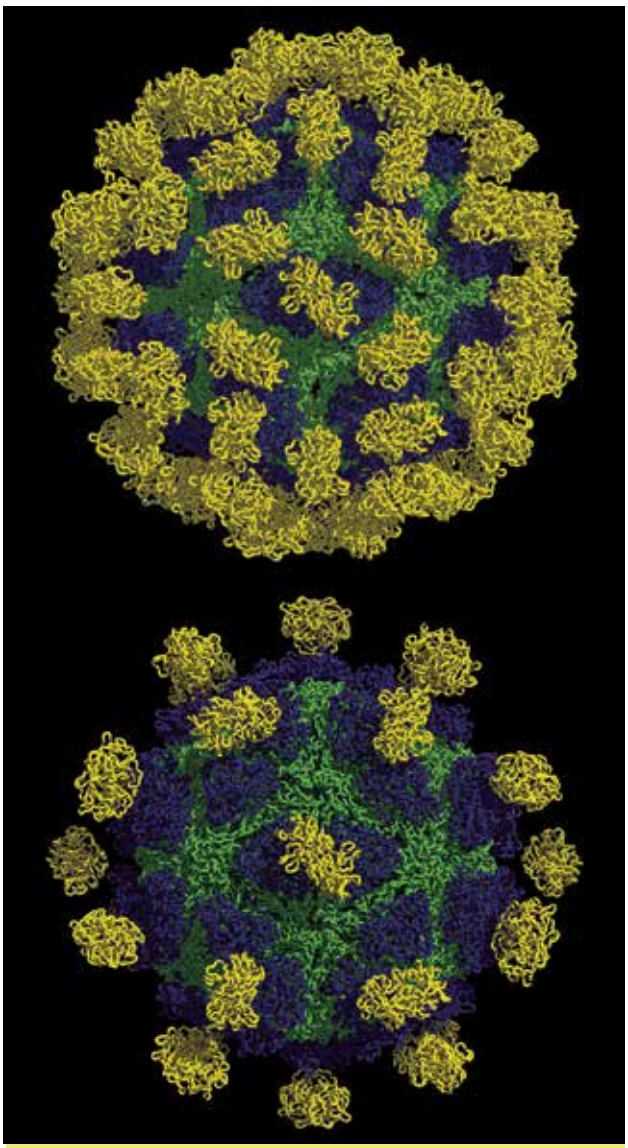
Disease		New Infections*	Hospitalizations	Deaths
RSV	0–5 yrs	2.1 million	57,527	No data†
	65+ yrs	Not estimated	177,000	14,000
Tuberculosis		9,105	11,000	528
HIV		50,000	36,970	5,400
Influenza		91	40,000	12,000

RSV, respiratory syncytial virus; HIV, human immunodeficiency virus.
Sources: CDC, NIH, HIV.gov, Agency for Healthcare Research and Quality
*For RSV and influenza, new infections based on outpatient visits. Actual new infections are almost certainly higher.
†No deaths from RSV were recorded in the 2014 study of 5,067 infected children in three cities, on which the other data in this row are based.

with, whereas there are a lot of other viruses that are very important for human health that this approach should benefit," Berman said. "Rebecca's really adding to our understanding of structure-based vaccine design and is filling in a lot of the gaps that have been left by jumping right to HIV."

DuBois's work focuses on viruses that mainly infect children, like RSV, and that have no approved vaccines. Her particular method of rational design is called "reverse vaccinology." Instead of trying to generate a healthy immune response with a vaccine, she aims to build a vaccine based on a healthy immune response. She said the approach asks, what does the immune system look like in people that either don't get infected or have mild disease?

In one prominent example of this approach, HIV researchers have studied the 25 percent of patients who generate "broadly neutralizing antibodies," antibodies that attack many strains of the notoriously fast-mutating virus. Although these antibodies do not fully protect the patients who generate them, studying them has led to vaccine candidates that might prompt stronger immune responses. A few are now in early clinical trials.



X-ray crystallography images of astrovirus from the DuBois lab. The virus forms an immature, poorly infectious form (top) and a mature, infectious form (bottom). The research group has discovered that astrovirus uses the yellow "spikes" to attach to human cells, and that antibodies can neutralize virus infectivity by sticking to the spikes, stopping the virus from attaching. The group is also trying to develop a vaccine by manipulating the spike with genetic engineering.

DuBois collects whiskers from her cat, Zuzu, that he sheds in her house. Her lab uses them to manipulate protein crystals.

Collaboration and cat whiskers

For her work with RSV, DuBois has partnered with drug developer Trellis Bioscience of Redwood City. The company discovered an antibody that binds the G protein on the surface of RSV. Most attempts to create an RSV vaccine have targeted the F protein, the other main component of the virus's coat. So far, they have all failed, including ResVax, a vaccine candidate that in March proved ineffective in protecting infants when given to their mothers during pregnancy. Colleagues said DuBois's choice to study the G protein is typical, showing how she can be tenacious but also creative.

"She has taken on incredible challenges and difficult problems, and she has nailed it," said Tuli Mukhopadhyay, a fellow virologist and associate professor of biology at Indiana University. "She has figured out things that other people have overlooked."

For example, DuBois was trying to catch antibodies in the act of binding to astrovirus, which, like RSV, is a common childhood infection. She tracked down a Spanish researcher at the Instituto de Salud Carlos

Built from scratch

III, Alicia Sánchez-Fauquier, who had created a mouse in the 1990s that produced antibodies to the virus. The mouse's cells had been lost in a freezer failure, but Sánchez-Fauquier had managed to save a small amount of antibody.

"She said, 'I'm about to retire, so this is perfect. I'll empty my freezer and give you everything I have'," DuBois said. In an unusual maneuver, DuBois used an x-ray image to deduce the sequence of building blocks, known as amino acids, that make up part of the antibody. She then programmed a bacterial cell to produce a miniature version of the antibody. It functioned like the real thing, allowing DuBois and her collaborators to make several discoveries about astrovirus. For example, they found that, in all cases, the antibodies stick to a much larger part of the virus's coat than anyone anticipated. This observation explains why previous attempts to develop a vaccine using smaller pieces of the coat did not work. It could, in addition, help design a more effective approach.

"I feel like nothing ever deters her. She's like, 'Okay, we have a roadblock. Let's think about this logically,'" Mukhopadhyay said. That attitude paid off again with RSV. DuBois heard about the new Trellis G protein antibody and decided to just ask for it. "Basically, I emailed Trellis and asked, 'Hey, can I study your antibody?' They were a little hesitant, but they said sure."

"It's been a very fruitful collaboration," said Larry Kauvar, Trellis founder and chief scientific officer. "She's interested in learning about not just how to do science, but how to do science that would be useful from a commercial point of view."

Once DuBois had the antibody, she wanted to study how it attacked RSV, trying to find the lock on the G protein where the antibody key fits. This requires inducing the proteins to form crystals, which can be shot with x-rays to produce clear images, a method called x-ray crystallography. It's an exacting technique. Researchers first must manufacture the protein using bacteria, separate it from other proteins through an elaborate electro-chemical filtering process, and then find the recipe for a solution that crystallizes it in just the right way. Sometimes it takes 500 different formulations to find one that works, DuBois said.

The final step may be the most maddening: pulling a single microscopic crystal out of the solution. DuBois's strategy for that involves cat whiskers, which, for some reason, work better than just about anything else. Something about them is just right for grabbing a protein crystal, she said, dragging it away from the rest, and then releasing it onto a plate of glass. The cat whiskers aren't purchased at a scientific supply company, which adds a bit more meaning to the phrase, "built from scratch." "My cat, Zuzu, a fluffy calico who is quite annoying and meows a lot, occasionally sheds whiskers," DuBois said. "I always save them and bring them to the lab."

A larger toolbox

The hard, meticulous work paid off in March 2018, when DuBois, graduate student **Stanislav Fedechkin**, Kauvar, and coauthors, published their work describing how the antibody attacks RSV in the prestigious journal *Science Immunology*. Trellis, for its part, plans to start clinical trials of its anti-G protein antibody treatment in the next year or so. If proven safe and effective, it would be given directly to infants who come to the emergency room with RSV. This is a potential improvement over the only current product for RSV, which is given preventively to high-risk premature babies. Success would also be a promising sign for a vaccine targeting the G protein.

But that vaccine is not yet in hand. It can't be made from the G protein alone, because that protein is known to weaken the body's immune response, which would make it unsafe in its current form. To get around this problem, DuBois and her colleagues must mutate the protein to eliminate the unwanted effects and save the good ones. There are lots of potential routes to achieve this. Perhaps a short, harmless fragment of the protein would be enough to key the immune system, or maybe a computer simulation will reveal a tweak that does the job.

By trying out options like these, DuBois and her colleagues are building a much larger toolbox for vaccine development. Gellin, of the Sabin Vaccine Institute, said the grand hope for rational vaccine design is to make people immune to the sneakiest and nastiest of viruses, as well as bacterial and other diseases that have so far eluded vaccine makers. "At the top of the list are HIV, tuberculosis, malaria, and a universal influenza vaccine," he said. "Those are the ones where these new techniques can be most helpful."

If the RSV efforts of DuBois and her collaborators pan out (see sidebar), the first step may be to vaccinate pregnant women to protect their babies. The duration of protection is likely to be short, Kauvar said, but even if it lasts only a few months, it would cover much of the period when the risk of severe illness is highest.

Rational design could also help reduce the impacts of other viruses for which there currently is no vaccine, like astrovirus. Americans mostly experience astrovirus as a mild nuisance, DuBois said. "It's different in developing countries. The infections last longer, there's no clean water, and children develop co-infections. Ultimately, it can send them to the hospital and affect their growth."

Indeed, many poorer countries have not received the full benefits of vaccination, and DuBois said she is driven partly by the desire to help children in such places. With that inspiration—and with luck, funding, and tenacity—a loftier goal may be in sight. If vaccines can reach more people and fight more diseases, perhaps everyone, not just the fortunate, will eventually be able to say that "death in childhood is no longer expected."

Thwarting RSV

Respiratory syncytial virus (RSV) infects virtually all children by the age of five, according to the Centers for Disease Control and Prevention. It generally causes only mild illness but causes severe disease in a minority of infants and can be dangerous or deadly in premature babies and the elderly (any immunity adults develop from childhood infection is ineffective against newer strains of the virus). The only treatment on the market is SYNAGIS® (palivizumab), an antibody targeting the RSV F protein. The treatment reduces the severity of disease but does not prevent it. Because it costs a few thousand dollars per injection, it is currently given only to premature babies and other high-risk infants, said UCSC assistant professor of biomolecular engineering Rebecca DuBois.

Pharmaceutical companies have investigated other treatments for RSV besides vaccines and antibodies, but none have worked so far. Most recently, Johnson & Johnson in March abandoned AL-8176, a small synthetic molecule resembling a building block of DNA. All told, the failure resulted in a write down of $1.5 billion in value.

DuBois and her collaborators at Trellis Bioscience, a drug developer in Redwood City, are attacking RSV—specifically its G protein—from two directions. DuBois is focused on a vaccine, probably to be given to pregnant women and the elderly, which would be cheaper than antibody therapy but might not work in all cases. And Trellis is working on an improved antibody treatment for infants who land in the emergency room with severe RSV disease.

Selected structure-based vaccines on the market and vaccine candidates in clinical trials

Disease	Vaccine/Vaccine Candidate	Status
RSV	F Subunit Protein Vaccine	Phase I trial underway
Rotavirus	Parental trivalent rotavirus vaccine	Phase II complete, results not yet public
HPV	Gardasil®	Marketed
HIV	eOD-GT8 60mer	Phase I trial underway
	Candidate based on "fusion peptide"	Phase I trial planned late 2019
Influenza	Flublok®	Marketed
	M-001 universal flu vaccine	Phase II clinical trial began in 2018

RSV, respiratory syncytial virus; HPV, human papillomavirus; HIV, human immunodeficiency virus
Sources: International AIDS Vaccine Initiative, NIH, ClinicalTrials.gov

By Erik Vance

The truth is out there

Extracting Big Data insights to believe in

Carlos Dobkin. Credit: C. Lagatutta.

Did you know that eating chocolate during a diet leads to more weight loss? Did you know that striking powerful poses is good for your mental health? Did you know that drinking a few glasses of wine every week is healthier than not drinking any? It's all true, I read it somewhere.

Today, statistics are everywhere—in the headlines, on viral TED videos, around the water cooler. And while fun to banter about with friends, all these pronouncements have fundamental flaws, some so egregious we should ignore them altogether. In fact, the biggest truth we can take from the statements above is that misinterpretation, often related to questionable statistical methods, occurs all too frequently with large datasets.

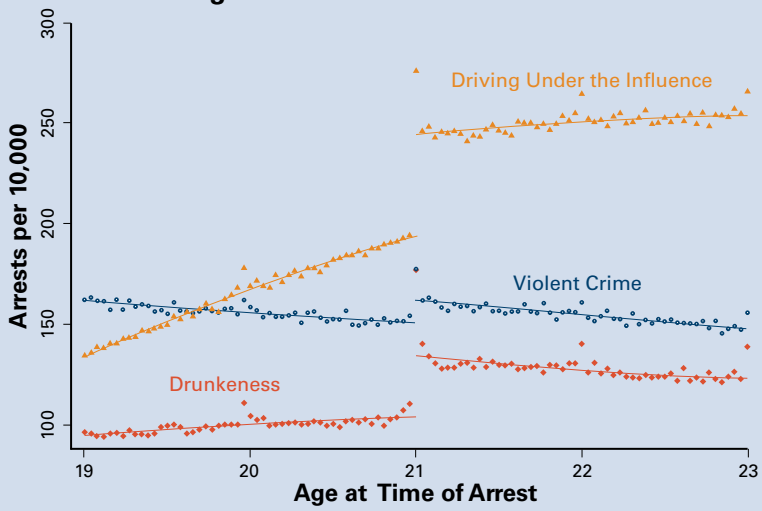
The problems with big data have boiled for decades in academia but recently have bubbled over into the popular press. Charges of "p-hacking" (most simply, selecting the data that gives you the correlation you want) and lack of reproducibility might lead some readers to think that you can't trust any of the statistics you see in print. **Carlos Dobkin** (shown at left), professor of economics at UC Santa Cruz, worries constantly about getting trapped by a finding that's too good to be true. "This is my great fear—that I'm screwing it up in some way and don't realize it. This is subtle stuff. You need to convince yourself that what you're doing is correct."

No mistakes

Dobkin has built a career as someone who does not make such mistakes, even with some of the thorniest of health issues, such as alcohol consumption or health insurance. He says a good analysis compares two groups that are identical to each other. Bad analyses find two groups and try to force them to be identical. For example, let's say you want to prove that blondes are happier than brunettes. And let's say you accessed a giant database that listed hair color and answers to survey questions on happiness. Sure enough, the lighter the hair, the happier the people were. All set, right? No, said Dobkin, you still haven't answered the most important question. "Do I think that the brown-haired and blonde-haired people are identical in every dimension other than their hair color?" he said. "If the answer's no, then you have to worry."

For instance, brunettes would be much more racially diverse. People who dye their hair brown might do it for the same reason as those who bleach it, or they may not. Statisticians use accepted but often complex ways to control for these differences. Ultimately, however, the two groups simply aren't the same and this limits the conclusions you can draw. To avoid this issue, Dobkin's research often depends on something called discontinuity analyses, which split groups by a discrete cut-off point, such as turning a specific age, and then compares observations on either side to measure any change.

Take alcohol consumption. Almost since the national drinking age was set at 21 in 1984, policy makers have tried to lower it. Is this a good idea? Dobkin saw an opportunity to help answer this question because 20-year-olds are essentially identical to their 21-year-old selves. So, starting in 2003, he began collecting databases for hospital visits, arrest reports, death certificates, and surveys of people six months before and after their 21st birthdays.



Combing through meticulously gathered mountains of data, Dobkin and collaborators found huge changes in alcohol-related behavior after Californians' 21st birthday. Credit: Carlos Dobkin.

This was no simple task. Dobkin had to find the data, convince state officials or private companies to let him see it, then make sure to collect it correctly. He made regular five-hour roundtrips to Sacramento to negotiate with officials and then to view the data. In the end, they put together a database of every arrest in California between 1979 and 2007—hundreds of thousands of arrests that occurred during that one crucial year of life.

"Carlos is the data whisperer," said Christopher Carpenter, professor of economics and director of

the Program in Public Policy Studies at Vanderbilt University and long-time Dobkin collaborator. "He can do mind-boggling things with those data—from 1979 to 2007, literally every single person who was arrested in the state of California."

Data whispering

With this unique dataset in hand, Dobkin and colleagues performed their discontinuity analysis. The results were dramatic. Arrests, hospitalizations, and deaths all spiked with the onset of the legal minimum drinking age. He found people were 25 percent more likely to get a DUI and 9 percent more likely to die. Most of this was related to cars—either being caught driving under the influence or having an accident. In fact, you can chart the driving skills of every age group as they get more comfortable behind the wheel and their rate of deaths related to driving decreases. When they hit 21, as a group, they essentially lose two years of improvement and their numbers worsen to match those of 19-year-olds.

In some sense, this becomes the strongest argument for keeping the age limit where it is. Underage people will always try to sneak a few drinks or slip into a club, but these are outliers. Whatever the drinking age might be, it will be tied to increased hospitalization and death; the law just buys a few extra years while young people develop not just driving skills but maturity and ability to recognize risk. Becoming a worse driver at 21 is likely preferable to doing so at 18.

But 21 isn't the only important age in our lifetime. We can drive at 16, join the military at 18, rent a car at 25. But how many of these ages offer opportunities to understand the effects of public policies on our lives? How about 65, the age at which Americans become eligible for Medicare? If you want to know how insurance affects health, age 65 is a good place to start. The problem is that you can't just compare people with insurance to those without because they are not identical. "People who have insurance differ from people who don't have insurance on many dimensions. For instance, they tend to have better jobs," said Dobkin. "They can afford insurance, with all that entails."

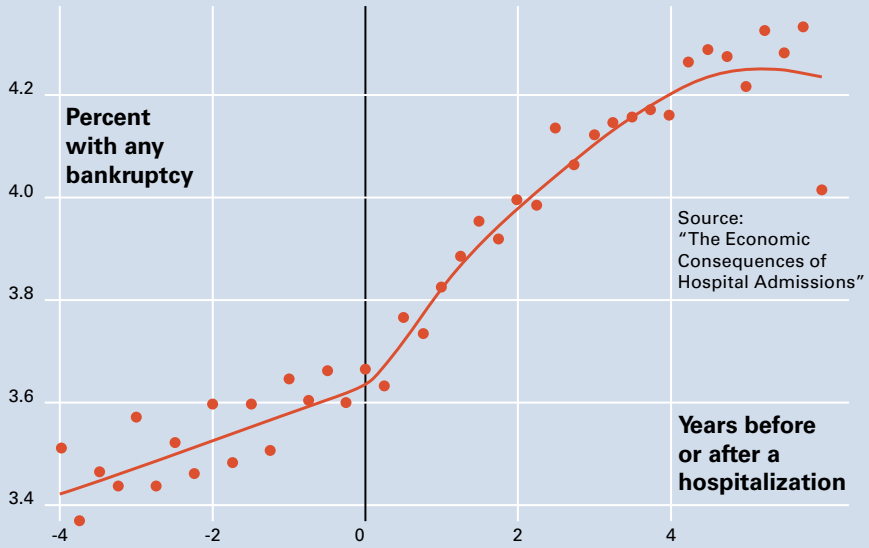
But people who don't have insurance at 64 can get Medicare at 65. In 2009, Dobkin started digging into this and other questions and quickly confronted a whole new level of red tape. He would need to convince the state to let him look at public hospitalization records and then compare them to privately controlled credit reports, using social security numbers. But, for privacy reasons, he couldn't see the social security numbers, so he had to get the two bureaucracies to coordinate in matching them. It took months of work, meetings, and endless hours in the car to Sacramento.

Health care unleashed

In the end, Dobkin built a dataset of 940,000 people around the age of 65 tracked at 10 different points in their lives. He found that having health insurance can radically change a person's life. Before the Affordable Care Act (ACA), 10 percent of people just under 65 were uninsured. As soon as they had Medicare, their doctor visits doubled as people went in for procedures that they had been putting off. Knee and hip surgeries, cataracts, cardiac

First Illness, then Financial Distress

For Californians between 25 and 64, the risk of bankruptcy rises after hospitalization.



Dobkin and collaborators charted dramatic increases in bankruptcies after hospitalizations. But unlike other experts, he traced them to the loss of work rather than the hospital bills themselves. Credit: Carlos Dobkin.

procedures, and colonoscopies all spiked. "The effects were almost too big to believe," he said. "There was an enormous amount of unmet need in this 10 percent of the population."

Today, with the ACA, the number of uninsured is less than half what it was but there is still a huge number of people suffering and just waiting for the 65-year clock to turn over. And it's not just the uninsured, many people with poor insurance are also waiting until their 65th birthdays to go to the doctor. Dobkin's work also found that—contrary to the popular belief that people without insurance use emergency rooms like a doctor's visit—the uninsured are actually less likely to seek treatment in an ER. Michael Anderson, associate professor of agricultural and resource economics at UC Berkeley and another Dobkin collaborator, summed it up simply: "People are very price sensitive in their consumption of health care."

Dobkin's Medicare-related research (see chart on page 32) suggests that increased use of health care services driven by pent-up demand would likely accompany any expansion in the popular program. Credit: flickr (CC BY 2.0).

Another outcome linked to having no health insurance is bankruptcy. Elizabeth Warren, Massachusetts senator and 2020 presidential candidate, wrote about this phenomenon when she was a professor at Harvard, noting that half of people declaring bankruptcy had medical debt. But while medical bills may wreck your personal finances, do they really drive bankruptcy?

Again, Dobkin saw an opportunity. But this time, rather than using a specific age as the threshold, he used hospitalization and looked at people's finances before and after. While Warren had looked at people who went bankrupt and worked backwards, Dobkin looked at people who were hospitalized and then evaluated how that affected their finances.

His findings were like Warren's in some respects—medical debt is certainly crippling—but also different in key ways. For one, his bankruptcy numbers were lower. When you tracked forward, medical bills factored in only 5–10 percent of bankruptcies. And Dobkin's work suggests that it's not only the medical bills that break people, it's also the time away from work. Not having health insurance does put you at higher risk, but it's not the only driver, he said. "The real issue is the unemployment that results."

This might seem like splitting hairs to most of us, but it's important to policy makers. If medical debt is the primary problem, then we should be looking for ways to help pay people's hospital bills. But if it's a matter of income loss, we might do better by seeking to broaden medical leave insurance.

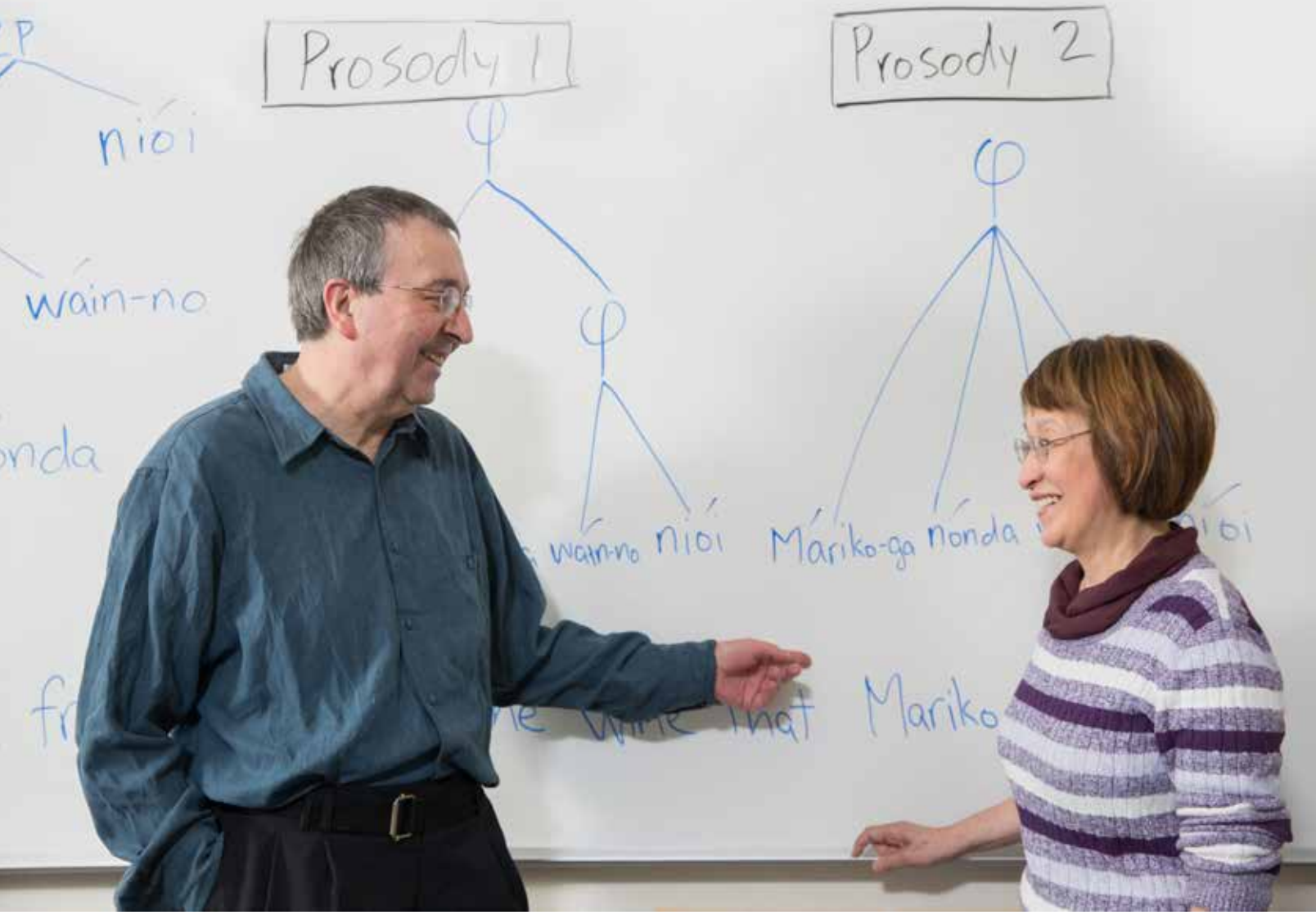
Fitting questions

Of course, Dobkin's careful attention to methods and process is somewhat limiting. One criticism of discontinuity analysis is that it only applies to a few big moments in a person's life. In other words, it forces you to look at questions that fit rather than ones that might address other important issues.

But in this era of unending dubious statistics, Dobkin said, it's too easy to see whatever you want to in big datasets. We know that mercury is bad for you because its toxic effects occur quickly. In contrast, fat, sugar, coffee, alcohol, and even tobacco take a long time to trigger disease. Likewise, the benefits of pomegranate juice or tea tree oil just don't pop up in straightforward analyses of even the largest datasets. "Most things don't have big, immediately discernible effects," Dobkin said. No matter how much we might want them to.

By Alla Katsnelson

What it means, how…it sounds

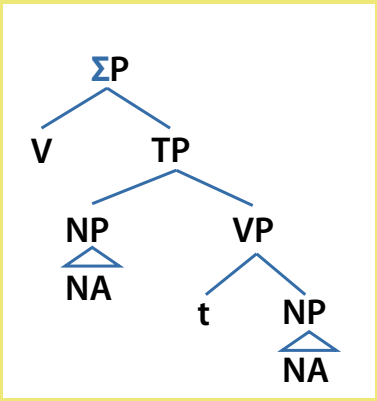


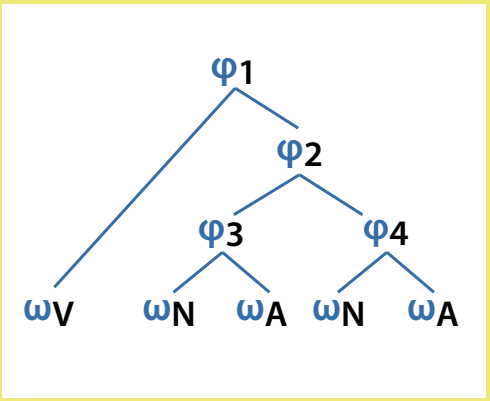
Armin Mester (left) and Junko Ito
Credit: C. Lagatutta.

Linking the linguistic puzzles of syntax and prosody

Language gets its sentence structure from syntax. The syntax of English, for example, dictates that the sentence "The dog ate the pie"—that is, a word order of subject-verb-object—is grammatically correct, while "The dog the pie ate"—subject-object-verb—is not. But on top of the grammatical rules of syntax, language is also defined by its sound and rhythmic structure. Linguists refer to this spoken cadence as "prosody," and it describes how we group syllables and words in speech. For example, in English we generally say, "The dog [pause] ate the pie," rather than, "The dog ate [pause] the pie."

Linguists have generally studied these two dimensions of language separately, but there is growing interest in how they intersect, said **Junko Ito**, UC Santa Cruz professor of linguistics. Syntax provides the basic structure, the traditional thinking goes, and prosody defines how it sounds in its spoken version. Yet while the word groupings in syntax differ from the emphasis groupings of prosody, they are clearly related, said **Armin Mester**, Ito's close collaborator and UC Santa Cruz professor emeritus of linguistics. "The question is, how do these two different structures link?"





The Irish sentence "díofaith leabharlannaí dathúil blathanna áille" means "the handsome librarian will sell beautiful flowers." Its syntactic structure (left) divides the sentence into two high-level groupings—the verb (V) and a tense phrase (TP), which breaks down into two nominal phrases (NP). Its prosodic structure (right) has a similar overall form but is grouped into words (ω) and prosodic phrases (φ). Credit: Emily Elfner.

Ito and Mester helped pioneer early work on this question in the 1990s, when they began studying how syntax and prosody interact in Japanese. Since then, the UCSC Linguistics Department's momentum in this field, called the "syntax-prosody interface," has snowballed, with the research including studies of German, Basque, Latin, several Mayan languages, and others. "We have a reputation for being one of the handful of places globally where people really understand this area of linguistic research," said **Ryan Bennett**, assistant professor of linguistics and another member of the UCSC group working in this area.

Bennett, along with UC Santa Cruz professor emeritus **Jim McCloskey** and Emily Elfner, assistant professor of linguistics at York University in Toronto, studies the sentence position of pronouns in Irish. In Irish, unlike in English, the basic word order is verb-subject-object, with any additional words tacked on at the end, Bennett said. "But when the object is a pronoun you can put it in all sorts of crazy places in the sentence."

Bennett and colleagues theorized that pronouns and other small words in Irish tend to drift rightward, to the end of a sentence, because their position toward the beginning "would be sort of counter-rhythmic, given the intonational structure of the language," Bennett said. That means that rather than syntax determining prosody, in this case prosody drives syntax—an idea that's counter-intuitive in the field, he said.

To truly understand the rules governing the syntax-prosody interface, Bennett and other UCSC linguists think that researchers will have to systematically explore how prosodic groupings form in as many languages as possible. The hope is that by mapping out the groupings that do and don't occur across different languages, they will identify principles by which such

What it means

groupings emerge in relation to a language's syntax. "Linguistic theory needs to have an explanation for what is possible, and what is not," Ito said.

That's a daunting task, however, because the possibilities are nearly limitless. For a sentence with two words, for example, you'd have eight structures—each word can be a prosodic phrase by itself, or not (four structures), and each of these four structures has a variant in which the whole sequence is a phonological phrase. But once you have five or more words, there are thousands of structures. "It really is exponential, and you cannot think of all these yourself," Mester said. To address this problem of scale, linguistics graduate student **Jenny Bellik** and postdoc and lecturer **Nick Kalivoda** built a computer program called "SPOT" (for Syntax-Prosody in Optimality Theory) that methodically assesses possible word groupings in different languages. "Initial work in this area didn't need computers, but as it has grown, the automation is essential," Mester said.

Credit: C. Lagatutta.

In December of last year, Ito and Mester received a two-year, $250,000 grant from the National Science Foundation to improve SPOT, making it more user-friendly, and to introduce it to a wider audience through symposia and conferences. Although now primarily used for academic research, the software could ultimately spawn commercial projects in natural language processing and speech recognition, Ito said.

It has already yielded important linguistic insights. For example, SPOT analyses performed by the UCSC team in collaboration with **Gorka Elordieta**, UC Santa Cruz visiting associate professor and associate professor at the University of the Basque Country, revealed similarities between Basque and Japanese that could not have been predicted otherwise. But another key benefit to SPOT, said Bennett, reflects the spirit of innovation and inclusivity within the UCSC Linguistics Department. "It provides an entry-point for everyone, from undergraduates to grad students to faculty," he said. "People can learn and contribute on all sorts of different levels."

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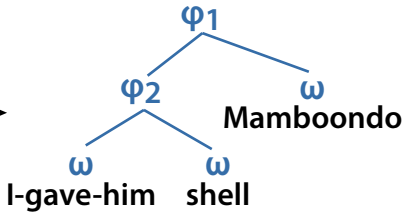
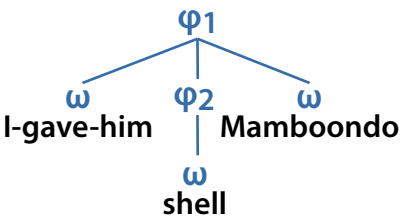
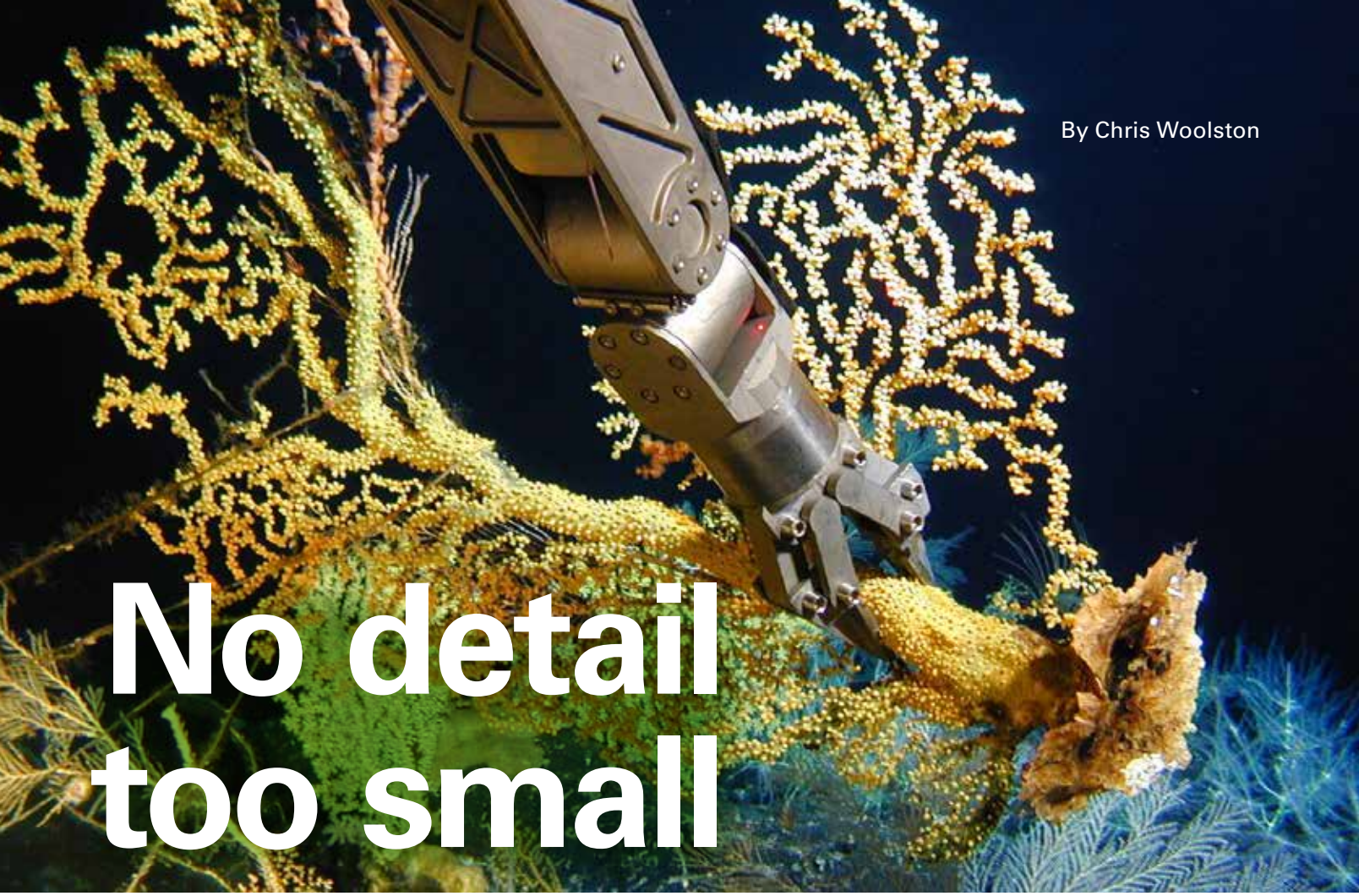
a. → 	1 $(\varphi_1\text{-}\varphi_2)$	1
b. 	W_2 $(\varphi_1\text{-}\varphi_2)$	e_1

Graduate student Jenny Bellik and postdoc Nick Kalivoda (above) built a computer program called SPOT (Syntax-Prosody in Optimality Theory), which generates the full set of possible prosodic structures for a given sentence. The screenshot at left shows two of the many possible prosodic structures for the Kimatuumbi, (a Bantú language of Tanzania) sentence "Naampéi kikóloombe Mambóondo," meaning "I gave Mamboondo the shell" (left column). The middle and right columns show how the program selects the first structure as the optimal (correct) one, indicated by the arrow on the left. Credit: Nick Kalivoda.



By Chris Woolston

No detail too small

Studying the oceanic carbon pump at the atomic level

Every year, humans spew tens of billions of metric tons of carbon dioxide into the atmosphere through industry and by burning fossil fuels. Carbon that lingers in the air can trap heat from the sun, potentially contributing to destructive global warming. It could be a lot worse. Fortunately, the Earth is blessed with a series of massive "pumps," natural processes that remove carbon from the atmosphere and lock it away for centuries or millennia. The biggest pumps are found in the oceans, which is why many scientists have devoted their careers to understanding the flow of carbon from the air to the sea.

The future climate largely depends on the continued power and efficiency of the ocean's carbon pump, so every gear and cog matters. Many scientists study the big-picture movement of ocean-based carbon, including the gigatons of carbon taken up by microscopic algae, also known as phytoplankton.

Matthew McCarthy, UC Santa Cruz professor of ocean sciences and codirector of the Stable Isotope Laboratory, is one of a growing number of researchers who study the pump in finer detail—in his case, down to the atomic level.

McCarthy and his team track naturally occurring isotopes of carbon, atomic-level variations that can help reveal changes in the Earth's carbon storage system, both past and present. His recent research suggests that a shift in ocean microbial communities driven by a warming world could potentially make the pump more efficient in some ocean regions that may be most affected by planetary warming. These changes could in part offset larger negative effects elsewhere, one piece of positive news in a sea of uncertainty. "I take a granular view, but the findings could have huge implications," McCarthy said.

Above: UC Santa Cruz professor of ocean sciences Matthew McCarthy and team use a robot arm to collect samples of coral—living archives of ancient carbon flow—in deep waters near Hawaii. Credit: Max Cremer, Hawai'i Undersea Research Laboratory.

Carbon lockup

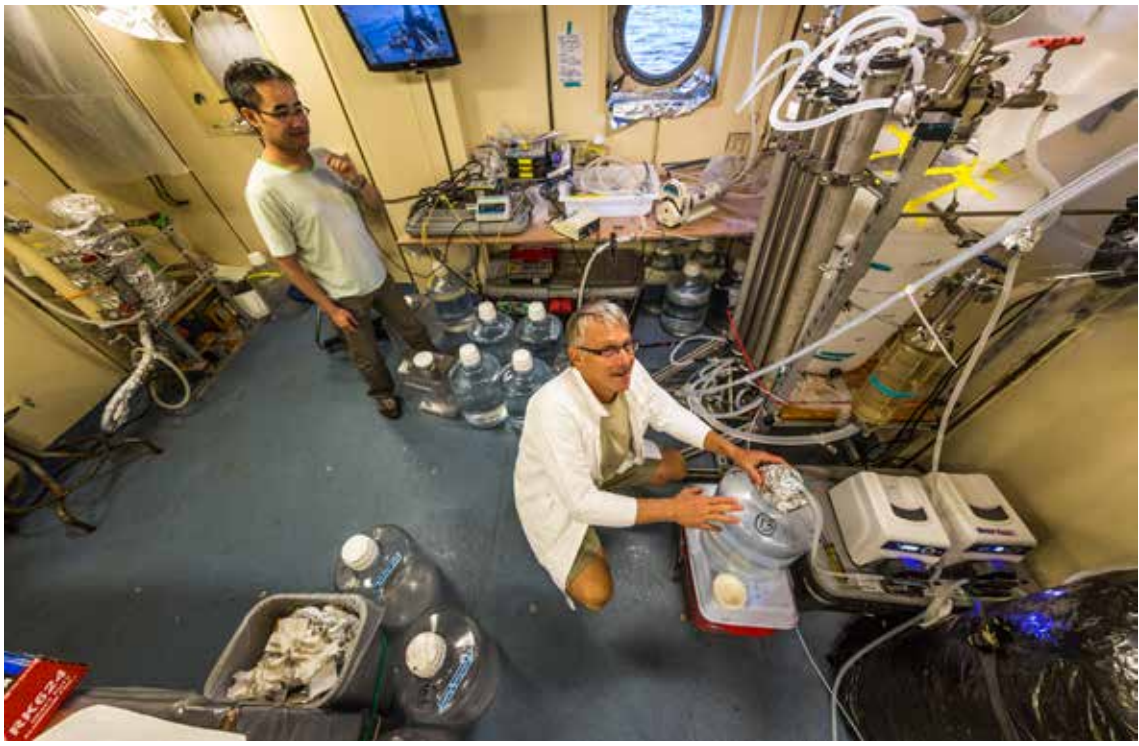
To understand the pump's inner workings, it helps to look at the whole machine. The great majority of the carbon in the ocean exists simply as dissolved carbon dioxide gas taken from the atmosphere. This removal process has picked up in recent years. "The massive amount of carbon that we're putting into the atmosphere is driving sustained carbon intakes," said **Andrea Fassbender**, UC Santa Cruz assistant adjunct professor of ocean sciences and marine geobiochemist at the Monterey Bay Aquarium Research Institute (MBARI) in Moss Landing.

The pump gains power when carbon enters the biological arena. Algae and photosynthetic bacteria take up the element to form particles of organic matter. Over time, some fraction of those particles sinks far enough below the surface to essentially seal the carbon away from the atmosphere for centuries. Remnants of algae and bacteria also break apart in the water, leaving behind residues of carbon-rich, dissolved organic matter that similarly can linger in the water for even longer, trapping carbon over millennia. Overall, sinking particles account for about 80 percent of the carbon pumped into long-term storage by marine organisms, and dissolved organic matter accounts for about 20 percent, Fassbender said.

Because the pump is primarily a biological process, it runs on the basic fuel for life: energy and nutrients. It's the nutrient flow that has sparked the attention of McCarthy and others. For more than a decade, he has been studying the life history of carbon and nitrogen in the ocean. These elements have naturally occurring isotopes, atoms with different numbers of neutrons but the same number of protons. Over the years, he and other scientists have shown that isotope ratios—like an atomic fingerprint—can help identify the sources, fates, and transformations of different forms of carbon. For example, the isotope ratios of individual amino acids from algae differ from those of amino acids from bacteria.

Those fingerprints can tell remarkable stories about the inner workings of the biological pump. Consider the subtropical waters off the coast of Hawaii, where McCarthy and his team gathered samples from long-lived corals some 200 meters below the surface. As reported in the journal *Science* in 2015, almost all of the carbon that reached the corals a thousand years ago came from one group of photosynthetic bacteria, known as cyanobacteria. However, as waters cooled during the so-called "Little Ice Age" between 1300 and 1850, very different green algae flourished, providing nearly half of the deep-sea carbon flux recorded by corals below.

In the ocean and elsewhere, the Industrial Revolution of the late 1800s marked the start of another major change towards warming. Around that time, the coral record shows that the biological pump shifted again away from green algae and



Right: McCarthy and postdoc Yasu Yamaguchi (standing) process seawater samples for carbon analysis on a research cruise in the Central North Pacific Ocean gyre near Hawaii. Credit: Bryan Berkowitz.

Opposite page: Research technician Jacki Long from the MBARI Marine Biogeochemistry Lab collects samples for a 2018 NASA EXPORTS (EXport Processes in the Ocean from Remote Sensing) project to track carbon flow in the northeast Pacific. Credit: Taylor Crockford.

instead became dominated by yet another type of cyanobacteria. Even though the water no longer teemed with the green algae of the past, the cyanobacteria kept the pump running. If corals 200 meters deep were eating it, that carbon clearly made it to the end of the pump, shifting our basic idea of how the pump can work, McCarthy said. "It had always been assumed that those bacterial cells don't really sink."

Hawaiian model

Hawaii could be a model for the Earth's future. Its surface waters are clear today largely because the warm, sunlit layers where algae might thrive don't readily mix with colder, denser, relatively nutrient-rich water below. As oceans everywhere warm, the assumption—and the worry—is that more parts of the ocean will become just as stratified, significantly slowing down algal growth and potentially putting a major damper on the pump. But the cyanobacteria around Hawaii suggest that pump can still work in a warming world. "Those waters aren't an ecological desert," McCarthy said.

McCarthy and others are also taking a closer look at the dissolved organic carbon that permeates the ocean. Dissolved carbon doesn't sink as particles of algae or bacteria do, but rather mixes slowly into the deep ocean, taking much longer to reach depths that can effectively seal the carbon from the atmosphere. Still, its sheer volume makes it a major player in the pump, said Craig Carlson, professor of microbial oceanography, ecology, evolution, and marine biology at UC Santa Barbara. Although only accounting for about 20 percent of the annual global export via the biological carbon pump, the inventory of dissolved organic matter carbon pool is huge, some 200 times larger than the organic particle pool, Carlson said. "Tracking organic matter in the dissolved phase could be very important for understanding carbon storage."

In recent years, McCarthy and colleagues have trained their isotope techniques on another, more recently recognized pump that can lock carbon away for hundreds or thousands of years: the microbial carbon pump. Through processes that still aren't entirely clear, bacteria can break down molecules of dissolved organic carbon into smaller chunks that can't be used by other microbes. Because it drifts around untouched, this inedible or "refractory" carbon doesn't cycle through the food chain and can linger in the ocean depths for millennia.

Through various measurements and methods, including carbon dating to estimate the age of the

refractory organic matter, McCarthy and others have found that the microbial carbon pump runs throughout the ocean, from the surface to the depths. In a 2016 paper in *Nature Geoscience*, McCarthy and his team estimated that bacteria in the deep ocean produce up to 140 million metric tons of dissolved, inedible carbon every year, an impressive feat. McCarthy suspects that the microbial pump works especially well in warm, stratified seas where microbes are both primary producers and consumers of organic matter. In theory, this pump could also therefore gain strength as ocean temperatures increase, potentially putting more carbon into long-term storage.

Carlson said it's still far too early to answer the biggest question: will these oceanic pumps become more or less efficient in our increasingly warming, carbon-rich world? The answer depends on the complex interactions of many variables, including the productivity of algae, the effects of acidification caused by dissolved carbon dioxide, and the never-ending work of microbes.

But the urgency of the question isn't in doubt. Stronger pumps could lock away more carbon and potentially slow climate change, but weaker ones could set off a feedback loop where the ocean takes in less and less carbon as humans continue to release more and more to the atmosphere. Whatever happens, McCarthy and others will be watching closely, down to the atoms. With so much at stake, no detail is too small.

By K. M. Watson

Agents of hope

Tackling the Golden State's crisis of poverty

Hermes Padilla still recalls hearing rats scamper above him in the ceiling of his $900-a-month room, once used for doing laundry in the rental house he shared with five others. "We had a slumlord," the UC Santa Cruz student said, and she wasn't fixing the rat problem, the leaks, the mold, or the lead paint. Eventually, Padilla left. Now couch surfing with friends, he's trying, like many others in Santa Cruz County, to find a safe and affordable place to live.

Padilla grew up in Los Angeles County, in a family that has always rented. Like many thousands, they dealt with rent increases and rental shortages, while others crowded into houses to make rent more affordable. Those who fell through the cracks and couldn't find a spot in the overburdened shelters ended up homeless. The City of Angels now has so many homeless people that Mayor Eric Garcetti recently declared it "the greatest moral and humanitarian crisis of our time."

But Los Angeles and Santa Cruz counties—with some of the highest poverty rates in the state—are not alone. In fact, most Californians don't make enough to afford the state's high cost of living. The entire state, while boasting one of the wealthiest economies in the world, also suffers from the highest poverty rate in the country, with dire consequences

With belongings in a cart, a homeless man sits on a curb in Santa Cruz. The growing number of people living on the streets due to the affordable housing crisis in California has been called "the greatest moral and humanitarian crisis of our time" by the mayor of Los Angeles. Unexpected rent hikes and housing shortages have exacerbated the homelessness issue, forcing people to live, among other places, in cars, on sidewalks, and in parks. Credit: ©Jessie Case, UCSC class of '16, a No Place Like Home project collaborator, who majored in art as well as the history of art and visual culture, with permission.

for many. How did this happen? Experts point to the state's housing and tax history, as well as to the rise of the information/technology economy.

What can be done? Answers for dealing with this seemingly intractable problem are being sought through one of UCSC's three recently designated academic priority areas, "Justice in a Changing World." Reflecting this major area of cross-disciplinary research at UCSC are three new studies led by UCSC faculty who examined different aspects of the wealth gap: income, affordable housing, and access to financial services. Based on their findings, they propose possible solutions to make life more equitable and dreams more achievable for those struggling in the economic shadows of huge financial success.

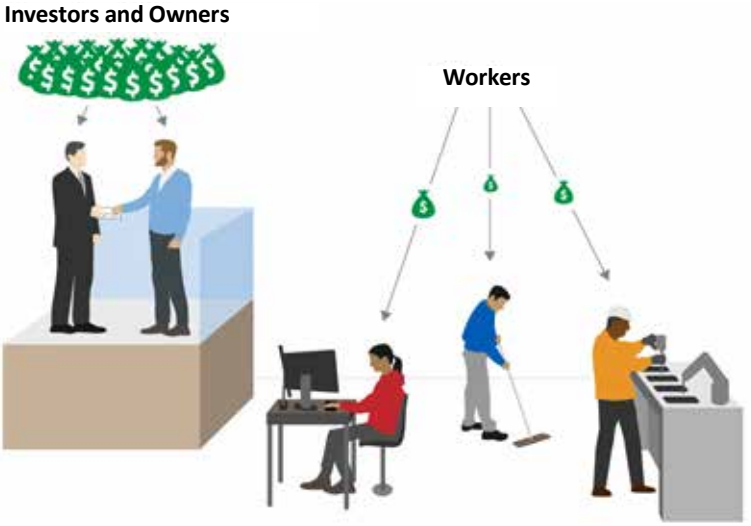
Shrinking incomes

Once a bucolic agricultural region called the Valley of Heart's Delight, Silicon Valley is now famous worldwide: first, for its computer and electronics industry; now also for the internet and rise of the digital economy. The technology hub stands as a model of success admired by many who want to emulate it.

Chris Benner, UC Santa Cruz professor of sociology and environmental studies and director of the Santa Cruz Institute for Social Transformation, sees it differently. As a graduate student 20 years ago, Benner published a research report on the impacts of Silicon Valley's emerging technology economy. At the time, he said, he wanted to contribute to the national debates about what was happening due to changes in the information economy. "People were worried about the disappearance of jobs," he said, and there were concerns about how to regulate the emerging tech industry and protect workers. When Benner began to see similar concerns surfacing again—such as those highlighted in the last presidential campaign—he approached several colleagues and community partners to follow up on his earlier findings.

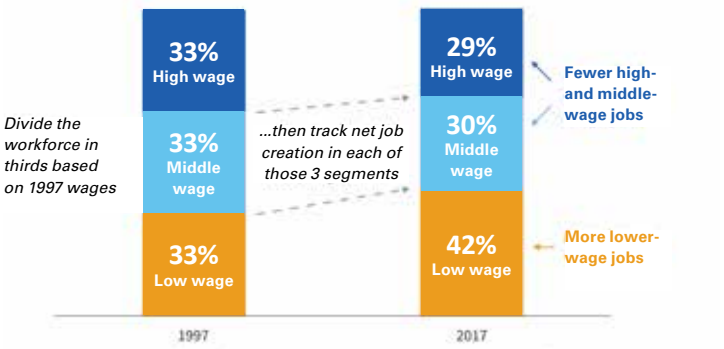
Funded by the UC Berkeley Labor Center, Everett Program, and Working Partnerships USA, Benner and collaborators sifted through and analyzed reams of economic data in search of answers. The resulting report is aptly titled *Still Walking the Lifelong Tightrope: Technology, Insecurity and the Future of Work.*

One of the biggest surprises, said Benner, was the level of wage stagnation among workers in the information/tech economy. Even though their per capita output had increased substantially, most workers weren't seeing the rewards of their efforts.



Investors, top executives, and shareholders in the tech economy are typically the biggest winners when it comes to the wealth generated by their companies. A UCSC-led research team found that employees and subcontracted workers that support company operations usually see little of the profits. This is because tech has adopted a different business model than industries in the past. Instead of linking worker pay to production, tech companies give venture capitalists and top executives the lion's share of the profits.

Shift towards low-wage jobs:



Source: *Author's analysis of Center for Economic and Policy Research, 2017. CPS ORG Uniform extracts, version 2.3.*

Note: *Figures are 3-year datasets ending in the year indicated. To track wage shifts, the 1997 wage cutoffs for each bucket were inflation adjusted to 2017 dollars, and then the share of jobs below each cutoff was calculated.*

Silicon Valley's employment trend has shifted substantially toward low-wage jobs since 1997, according to UCSC-led research. At the same time, the share of middle- and high-wage jobs in the technology economy has declined. While the concentration of high-wage tech and finance jobs in the region is still large, the researchers found that most of the jobs added by employers in the last 20 years have been low-wage. Credit, both figures: Jeff Barrera. Courtesy of *Innovating Inequality?*, Working Partnerships USA.

Instead, wages in the region—when adjusted for inflation—were less than what was paid 21 years ago. In fact, nearly nine out of 10 jobs in Silicon Valley paid lower wages. On top of that, the concentration of jobs had shifted from high- and middle-wage to low-wage.

"We expected to see inequality," said Benner. But they did not expect to see how widespread it had become. The huge profits generated by

Agents of hope

industry giants such as Facebook, Apple, and Amazon, he said, are going mostly to the owners, executives, and stockholders, not to workers' wages and operations. The business models of these companies focus on global expansion and turning small technology-related changes into big money-makers. This means, he said, there's little or no associated expansion of local middle-class employment and minimal change in spending or investment in the local community.

Most who make the enormous revenues possible, including the communities that provide the infrastructure to support business operations, are short-changed, said Benner's coauthor Louise Auerhahn, director of economic and workforce policy for Working Partnerships USA, which produced the related brief *Innovating Inequality?* "The creation of rules and incentives that promote winner-take-all markets and the pursuit of windfall profits," she said, "are leading firms to choose business models that exclude the vast majority of people who contribute to the tech industry's success."

To help remedy this, the group's report includes several recommendations, especially for changes at the local level. For instance, tech companies could commit to sharing a greater portion of their revenue and profits with workers and, through taxes, to help maintain and develop the communities that support them. In another step toward improving wage equity, businesses could guarantee at least the minimum wage and insist on high standards in working conditions for subcontractors. Finally, businesses also could partner with surrounding communities to reduce the negative impacts of tech-industry growth on, among other things, housing, increased traffic, cost of living, schools, and transportation.

Some suggested changes are already underway. The city of San Jose is negotiating with Google on

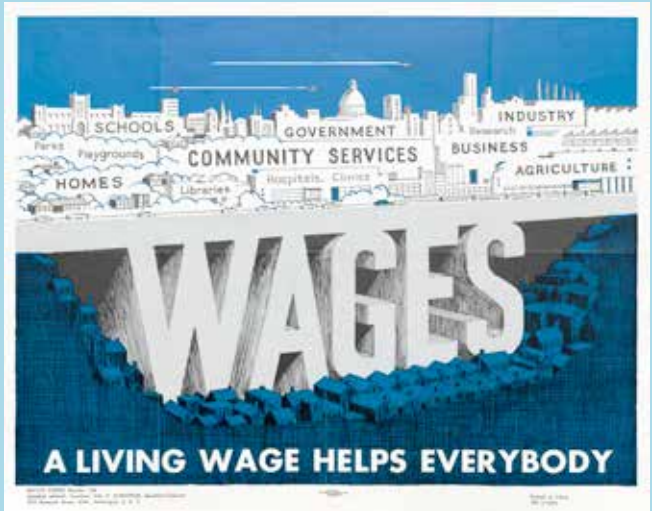
Falling behind

Oklahoma high-school science teacher Craig Troxell told CNN last year that his job as an educator didn't pay enough to make ends meet. To meet the bills, he also drove a school bus, sold roofing, and mowed lawns. It got to be too much. Together with thousands of fed-up and worn-out colleagues and supporters around the country, Troxell walked out in protest. "We're at the end of the rope," he said.

Teachers aren't the only ones. Across the country people complain about depleted wallets and bank accounts. In January 2019, Bankrate announced in its Financial Security Index survey that 58 percent of Americans reported that their savings couldn't cover a financial emergency costing $1,000.

All this despite an economy that is booming. Close observers of U.S. households' financial turmoil aren't surprised. Wages have stagnated for decades, and the 35-day partial shutdown of the federal government in 2018–19 highlighted just how precarious finances are for many U.S. families. Now is the time, some argue, that the country should consider implementing living wages. "A living wage," claim volunteers with North Carolina's Orange County Living Wage coalition, "can pull working families out of poverty."

The minimum wage was initiated in the U.S. in 1938 in part to support a basic standard of living. But like real wages, the minimum has also stagnated. While the MIT Living Wage Calculator pegs the 2018 living wage for a U.S. family of four at $16.14 per hour, the federal government mandates a minimum wage of just $7.25 per hour, a figure that 29 states have decided to raise and continue doing so. California's current $12-per-hour minimum wage is set to increase in phases to $15 per hour by 2022.



A poster from the AFL-CIO alliance of labor unions in the 1950s–1960s declares the value of living wages. Currently, under the Fair Labor Standards Act, the federal minimum wage is $7.25 per hour. While many states have their own minimum wage laws with higher pay, none still meet the goal of a living wage, which requires enough pay to cover basic necessities for a decent life. Credit: AFL-CIO Bound Pamphlets Collection, RG34-002, George Meany Labor Archives, Special Collections, University of Maryland Libraries, College Park, Md.

ways to mitigate the impacts of a proposed complex with up to 20,000 new employees. And the call-to-action for the relatively new coalition campaign Silicon Valley Rising is "We're inspiring the tech industry to build an inclusive middle class." According to campaign director Maria Noel Fernandez, "It's incredibly important that these workers organize, especially in an area where the cost of living and risk of being priced out of your community are so high."

Usually uninhabited spaces such as converted garages, closets, pool sheds, and even laundry rooms are places where tenants live due to the affordable housing crisis in Santa Cruz County. UCSC alumnus Sam Ciaramitaro, now a local bartender and musician in a band, has sometimes made his home in garages, including this one. Even though he now lives in an apartment, he said he still doesn't consider his garage days over, since his lease is ending soon and it's not clear what he can afford next. Credit: ©Jessie Case.

Unaffordable housing

Fallout from the wealth gap in the San Francisco Bay Area and its impact on the shortage and soaring cost of housing reverberates throughout the region. In Santa Cruz County, long-time public works employee John Holguin had to move farther south to put a good roof over his family. Rentals simply were too high in Santa Cruz, he recently told the *Santa Cruz Sentinel*.

With the dismal lack of affordable housing construction, people are at the mercy of the rental market. And it has not been kind. "Rent eats first" was the refrain heard over and over again from the 1,900 Santa Cruz County renters recently surveyed for the UC Santa Cruz No Place Like Home (NPLH) research project (see sidebar on page 47). Residents said that they would put paying rent ahead of buying food or taking care of health-care needs, said associate professor of sociology **Steve McKay**, who co-led the project with sociology professor **Miriam Greenberg**. The work "brought home how essential housing is to general well-being."

The research began at the request of the nonprofit community partners Community Bridges, Community Action Board, and California Rural Legal Assistance (CRLA), as well as the Service Employees International Union, Local 521. Together, the group designed a three-year investigation into how the affordable housing crisis affected the community, particularly the most vulnerable and undercounted—low- and moderate-income renters.

The study showed that more than 40 percent of renters spent over half their income on housing. Nearly 30 percent lived in overcrowded conditions. Half of the renters who moved in the last five years did so involuntarily, forced out due mostly to rent increases. Renters also told stories of living under slumlord conditions. Over and over, residents in crisis explained their troubles and seemed thankful to have someone listen.

"In the debate about affordable housing development, the voices of those most affected are rarely heard," said Gretchen Regenhardt, a CRLA regional directing attorney. To have UCSC step in was important, she said, "Agencies like mine that deal with the legal issues affecting low-income people operate on a shoestring and don't often have the capacity for such a wide reach."

Although the final report remains in progress, many of the findings were released and posted on the NPLH website (*noplacelikehome.ucsc.edu*) to help inform the Santa Cruz community as residents debated both a proposed renter-protection measure and an affordable housing bond on the November ballot. Project members also helped

Agents of hope

UCSC researchers with the No Place Like Home project shared their findings in numerous regional public forums on the affordable housing crisis, including this one on campus hosted by the Division of Social Sciences. "Our job is to inform local debate," said sociology associate professor Steve McKay, who was among six scholars on a panel presenting different views on possible solutions. Credit: Aashia Bajwa, courtesy of the UCSC Division of Social Sciences.

organize and present information at several forums on the affordable housing crisis, with some events drawing hundreds of participants.

Greenberg and McKay also wrote an op-ed in the local newspaper that included recommended solutions. The research, they said, made it clear that steps need to be taken to protect tenants "through rent control, just-cause eviction, and legal aid; preservation of existing affordable housing, through dedicated funds and land-use; and, over the long-term, production of new affordable housing, through reinvestment in social housing, expansion of workforce and student housing, and creation of nonmarket alternatives like limited-equity co-ops and community land trusts."

It remains unclear, however, when change might come to Santa Cruz. The November ballot's rent-control measure, which would have restricted evictions, limited rent increases, and created a rent board, was opposed by 62 percent of voters. The affordable housing bond similarly failed; while it was supported by 55 percent of voters, a two-thirds majority was needed for passage.

Un- and Underbanked

Raisa Sanchez grew up in the rural town of Watsonville south of Santa Cruz surrounded by a family with agricultural roots. A child of immigrants, she knows firsthand the difficulties of navigating new cultures, with their different languages, skills, and traditions. She now draws on this life experience in her work helping low-income Watsonville residents as a senior program manager with the affordable housing enterprise MidPen Housing Corp. One of the most important systems to access and navigate, said Sanchez, is banking services. Otherwise, it's tough to get out of poverty.

"The financial system in the United States and internationally depends on credit and your ability to build it," said Maria Cadenas, executive director of the nonprofit financial services organization Santa Cruz Community Ventures (SCCV). To build wealth, "it's important to understand credit and leverage it." This typically means having savings and loan accounts within the traditional banking system. But low-income workers in particular don't have them or use them infrequently, so they become the "unbanked or underbanked."

To investigate the challenges of this group, SCCV and the UC Santa Cruz Blum Center on Poverty, Social Enterprise, and Participatory Governance partnered together. "Nationally, we know that families who are unbanked and/or underbanked are especially likely to turn to alternative lenders to meet basic financial needs and that the exorbitant rates charged by these services deepens hardship. We wanted to learn more about this problem locally and what could be done to foster greater economic inclusion," said psychology professor **Heather Bullock**, Blum Center director and coprincipal investigator with postdoctoral researcher and lecturer **Erin Toolis**.

Latinas who managed households appeared to be among those facing the greatest barriers, so the team decided to focus on them. More than 100 women in the region shared their experiences with the researchers. The resulting report, *Mamás con Más* (Mothers with More), identifies obstacles as well as possible solutions. What stood out, the authors noted, was that most of the mothers have a strong understanding of money management but encounter significant barriers to using mainstream banking services. Barriers included feeling unwelcome in banks as well as dealing with language gaps, requested documentation, and a lack of transparency regarding fees. Many found the institutional processes and documents confusing and off-putting. And then there were those whose budgets and income were so limited that they couldn't afford, or see the sense in, monthly account charges or other fees.

Ofelia, for instance, is a single mother of two who makes money working in the fields and in child care. She went without a banking account for four

Student-powered research

When community partners approached UCSC faculty about investigating the housing affordability crisis in Santa Cruz County, the challenge appeared daunting. To collect residents' stories about their experiences would require a lot of feet on the ground and bilingual skills, said sociology associate professor Steve McKay.

In an approach admittedly "pretty unusual," the faculty turned to students in their classes to make No Place Like Home (NPLH) possible. Since the project launched in 2015, about 250 students—mostly undergraduates—trained in data collection, participated in project discussions, created digital media, surveyed renters, analyzed data, conducted historical research, and helped plan and attended community meetings and presentations. They completed 150-question surveys with 1,900 residents.

Many of the students admitted to housing challenges themselves. It's these personal experiences that helped them better connect with people to get stories that added richness to the data, said McKay. He and UCSC colleagues Miriam Greenberg, professor of sociology, and **Rebecca London**, assistant professor of sociology, have since submitted a paper for publication about their model for engaging students in community-initiated research.

Fourth-year transfer student **Jeff Hao**, for instance, emigrated from China with his family and recalled growing up with the stress of rent hikes in the San Francisco Bay Area. Now, he and a roommate live in a converted garage in a house shared by eight people. "Working on NPLH helped me understand the reality my parents had always faced," said the undergraduate major in sociology and education. Couch surfer **Hermes Padilla**, who hopes to graduate this year with a double major in community studies along with Latin American and Latino studies, was among the many students who used their bilingual skills to talk with residents who didn't speak English. This proved especially valuable in the nearby agricultural community of Watsonville, with its large Latinx community. Residents Padilla surveyed often were proud and encouraging of him, he said, and they would thank him for doing the work and being a student.

These community connections weren't a fluke. More than half the students who took the university field survey course were first-generation college students, eligible for Educational Opportunity Programs (EOP), and from the Latinx community. Working for the project, many told the researchers, helped give them a better sense of place in Santa Cruz. NPLH, said one UCSC student in a post-study reflection, "helped me feel more connected to Santa Cruz. I only get to see the wealthy areas and it can be discouraging as a person of color. Interacting with more working-class people of color helped me feel like I wasn't alone."

His involvement, said Hao, "was one of the most formative experiences of my college career. I really appreciated how they included us in all aspects of the project and valued our input." In addition to learning important skills, the students made it possible for the university to meet both its research and public-service missions. Without students such as Hao and Padilla, the project wouldn't have been the same, said McKay. "They lit it up."

During the No Place Like Home project, 250 UCSC students talked with 1,900 renters in Santa Cruz County about the affordable housing crisis, considered a primary driver of the county's high poverty rate. Here, as student researchers prepare to collect survey data, they gather around sociology associate professor Steve McKay, in one of many team meetings held throughout the three-year project. Credit: ©Jessie Case.

years, she said, because she didn't have enough money to support a minimum account balance. After participating in one of the study's listening circles and having a lot of her questions answered, she found herself motivated to try again. She discovered a local bank that treats her well, with bilingual staff who recognize and greet her.

If the mothers in the project didn't use banks but needed financial help, they turned to alternative services. These include payday loans, check-cashing services, money transfers, rent-to-own services, and car-title loans—services often considered predatory because they can charge steep fees and high interest rates.

Alternative lenders, such as check-cashing services, are often concentrated in communities with low-income residents and people of color. While street signs offer easy services, they don't advertise the high rates and fees being charged. Using these lenders can push families further into debt and poverty and should be limited or banned, according to the authors of the *Mamás con Más* report. Credit: Karen Apricot, Wikimedia Commons.

What the researchers found was that Watsonville had more than twice as many alternative lenders as the city of Santa Cruz. Using these lenders can push families further into debt, so their availability should be limited or banned, the report recommended. In addition, there should be improved access to mainstream financial services. Unfortunately, said Cadenas, government social-service asset limit policies often discourage their use. "Various programs and policies designed to assist the poor actually discourage them from building credit and financial assets." To address this potential barrier, the report recommended eliminating asset limits that can discourage families from using mainstream financial services. Providing useful and specific information such as this is helpful, said Robert Singleton, executive director of the Santa Cruz County Business Council. It can guide the development of business practices and policies that improve the region's economy and "collective quality of life."

For Victoria, an agricultural worker and mother of three, supports such as the ones identified by the study have gone far. She is benefiting from bank classes held by the Santa Cruz Community Credit Union as well as by MidPen. "Both helped me out a lot," she said, adding that the credit union makes her feel safe and comfortable. The process of getting a car loan was difficult, but has made her more organized and careful, she said. "It's a good thing to prepare for the future."

By Jane Palmer

Responsible data science

Embracing a more holistic approach to digital technology

The accelerating use of digital technology over the last decade has raised thorny questions about ownership, privacy, accuracy, and bias. To address these issues, some concerned scientists have begun to call for "responsible data science"—a new approach that requires thinking critically about the increasing interactions between people and digital technology.

"The potential benefits to society of improved data-driven discovery and decision making are clear," said **Lise Getoor**, UC Santa Cruz professor of computer science, director of the D3 Data Science Research Center, and a leader of this nascent call-to-action. "But we also need to take into account unintended societal effects of technological systems and seek a deeper understanding of the ethical implications."

From social media to biological systems to the Internet of Things, there is a pressing need for principled computational methods that intentionally consider the full range of interactions in richly interconnected systems, Getoor said. Among other projects, her research group is working to develop such methods; one example is an open-source software toolkit they've created called Probabilistic Soft Logic (PSL).

By using statistical science and logic to process and interpret highly interconnected systems so that contextual information is not lost, the highly scalable PSL enables users to take a more holistic approach to modeling and interpreting the connections between data in a particular context. Getoor's team has successfully used the toolkit to understand cyberbullying, analyze online debates and online learning, study the effect of severe environmental events on human trafficking, and integrate multiple sources to probe how drugs might interact in the human body. "We model the interactions and dependencies," Getoor said. "In this way we are looking at richer and more nuanced models than people often do within machine learning."

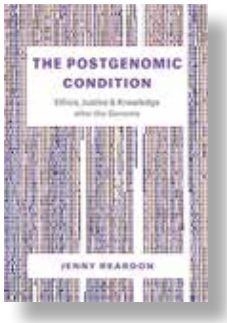
Responsible data science is especially warranted for projects intended to promote social good, Getoor said. Such work might include, for example, applications in education, the environment, health, homelessness, and when data are used to inform criminal justice issues. "Complex societal problems require more holistic approaches that account for all of the stake holders, their values, and the interactions between them," she said.

In addition to new tools like PSL, embracing responsible data science will also require collaborative efforts between scientists across disciplines, Getoor said. "Computational scientists need to work with domain experts who can provide additional context about interpretations," she said. "And then both need to work with ethicists to ask, what are the benefits? What are the potential harms?"

"Lise Getoor is leading the way in trying to bridge the gaps between these communities," said Bill Howe, associate professor in the Information School at the University of Washington and head of Urbanalytics, an interdisciplinary group that applies responsible data science to advance urban projects. "She's a data science expert who is able to put her work in the context of the social sciences."

Such interdisciplinary collaborations will mean raising awareness among computer scientists about the potential impacts of the algorithms they develop. But, equally importantly, Getoor said, everyone should receive basic literacy training in computational and data-science methods, to help them critically interpret the output of the data-driven and algorithmic systems that will only become more commonplace in the future. "People need to understand the ways in which data-driven systems are useful but also how they can go wrong," said Getoor.

By Emma Hiolski

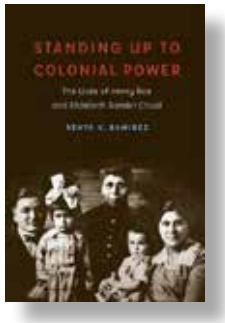


Genomic (R)Evolution

Ever since the human genome was fully sequenced in 2003, genomics has permeated our lives and culture. Advances in sequencing technology make the information locked within our genes ever easier to access. But to what end?

This is one of the questions **Jenny Reardon**, UC Santa Cruz professor of sociology, grapples with in her book **The Postgenomic Condition: Ethics, Justice and Knowledge after the Genome**. Reardon applies historical and sociological analyses to genomic science to convey the challenges of creating meaning—biological, medical, and social—from a series of DNA base pairs.

Deciding what genetic information is valuable, and who gets to make those decisions, is an inherently social and political process, she said, that cannot be untangled from the science. Reardon hopes her book empowers readers to engage in that process. "I want people to know that they can take part in contemporary debates about genomics and biotechnology," she said.



Native American Rights

Renya Ramirez, UC Santa Cruz professor of anthropology, inherited the drive to document her grandparents' lives and activism from her mother. Ramirez's grandparents, Henry Cloud, a Ho-Chunk, and Elizabeth Bender Cloud, an Ojibwe, were intellectuals and fierce advocates for Native American rights during the first half of the 20th century.

Starting with boxes of documents collected by her mother, Ramirez blended her roles as both a scholar and a descendant of the Clouds. Other, non-Native scholars had already written about them, she said, but had omitted important tribal and family perspectives.

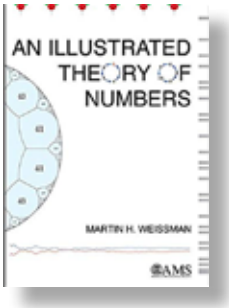
The result of Ramirez's efforts is a family-tribal history, **Standing Up to Colonial Power: The Lives of Henry Roe and Elizabeth Bender Cloud**. Ultimately, Ramirez hopes that readers will find inspiration in the story of her grandparents' perseverance. "Even through very dark periods of our history, we can organize together and fight back," she said. "We have to keep hope alive."

Roots of Racism

During the late 19th century, antisemitism was widespread in Europe but especially virulent in France, said **Dorian Bell**, UC Santa Cruz associate professor of literature. Rather than simply forming within France's borders, he argues, this ugliness flared in response to—and supported—French colonial expansion.

For example, granting French citizenship to 35,000 indigenous Algerian Jews in 1870 through the Crémieux Decree helped stoke wide acceptance of international Jewish conspiracy theories. In **Globalizing Race: Antisemitism and Empire in French and European Culture**, Bell reflects on how different forms of racism interact across space and time, and how French history in particular foretells modern antisemitism and Europe's increasing anti-immigrant xenophobia.

"You can't understand the rise of antisemitism in France and Europe in a way that's divorced from the rise of imperialism and colonialism," he said. "And you can't understand antisemitism in France today if you don't understand that history. That history casts a long shadow."



Visualizing Number Theory

Illustrations can provide a fresh take on the ancient field of number theory, a branch of mathematics devoted to studying the properties of whole numbers. "Complex proofs and formulas become easier to understand with the right picture," said UC Santa Cruz mathematics professor **Martin Weissman**.

However, such illustrations can be difficult to create and incorporate into books. To create a "visual grammar" for number theory, Weissman learned how to code and craft graphics. Nearly 500 images appear in his book, **An Illustrated Theory of Numbers**.

In this textbook, Weissman provides an accessible introduction to number theory, complete with historical notes, recent developments, proofs, examples, and exercises.

"I hope it gives people an appreciation for what number theory problems are, why they're interesting, and how to solve them," he said. "It's a beautiful field, but outside the mathematical community, people rarely encounter it."

Japanese American Internment

During World War II, members of **Karen Tei Yamashita**'s family—including parents, aunts, and uncles—were sent from Oakland, California, to internment camps in the Utah desert. Yamashita, UC Santa Cruz professor of literature, said she was sheltered from the worst of those experiences in her youth.

A more complete picture of her family's wartime incarceration came to light when members of the earlier generation passed away and relatives discovered collections of letters, photographs, and documents. The family began to digitize these items, creating an online archive. Portions of this material appear in Yamashita's book, **Letters to Memory,** a blend of family history and memoir.

"I was particularly interested in the family's relationship to people who had helped them during the war," she said, like Quakers and the Fellowship of Reconciliation. "I wanted to talk about how this wartime event relates to the larger picture of civil rights."

Anil Ananthaswamy ('00)
David Egerter, Editor ('88)
Emma Hiolski ('17)
Alla Katsnelson ('07)

Jane Palmer ('10)
Stephanie Pappas ('09)
Annie Roth ('18)
Ben Shouse ('01)

Alison F. Takemura ('16)
Erik Vance ('06)
Cameron Walker ('02)
K. M. Watson ('84)

Leslie Willoughby ('15)
Marcus Woo ('07)
Chris Woolston ('95)
Sascha Zubryd ('11)

**Names are listed left to right.*

With the unique expertise of scientists-turned-journalists, the 16 graduates of the UC Santa Cruz Science Communication Master's Program shown above created the stories that populate these pages. Their reporting well documents the breadth and depth of the research enterprise at UCSC and how its impact reaches around the world.

This sizable impact also applies to the "SciCom" Program (*scicom.ucsc.edu*). Directed by veteran science journalist **Erika Check Hayden**, the program is recognized as one of the world's best training grounds for former scientists who wish to use their expertise to foster the public understanding of science, health, technology, and the environment. Perhaps the best measure of the program's impact is the substantial body of work its 300-plus graduates author nationally and internationally in newspapers, radio, television, online media, peer-reviewed journals, magazines, and university public relations.

More immediate evidence of SciCom success from just the last year includes:

- The certificate-to-Master's-of-Science (M.S.) program upgrade.
- Substantial two-year grant awards from the Chan Zuckerberg Initiative for promoting diversity in science communication and from the Heising-Simons Foundation for training and teaching.
- National Association of Science Writers (NASW) Diversity Fellowships to Jennifer Leman ('18), Helen Santoro ('19), and Rodrigo Pérez Ortega ('19).
- George Foster Peabody Awards to Vicky Stein ('18) and Nsikan Akpan ('14).
- American Association for Cancer Research (AACR) June L. Biedler Prize for Cancer Journalism to Esther Landhuis ('04).
- American Astronomical Society (AAS) Jonathan Eberhart Planetary Sciences Journalism Award to Alexandra Witze ('93).
- Massachusetts Institute of Technology Knight Science Journalism Fellowship to Anil Ananthaswamy ('00), author of "Waiting with GODOT" cover story in this issue.
- Council for Advancement and Support of Education (CASE) District VII Award of Excellence (Bronze), for *inquiry@UC Santa Cruz*, 2018–19 (last year's issue).

We hope you enjoy reading this year's *inquiry@UC Santa Cruz*.

Learn more: **news.ucsc.edu**

AT UC SANTA CRUZ ASTRONOMY, **"DIVERSITY"** IS SYNONYMOUS WITH **"EXCELLENCE."**

Diversity of opinion enhances the success of scientific teams; likewise, diversity of experience that broadly reflects all members of society drives healthy, thriving, vibrant science. UC Santa Cruz Astronomy has established a new kind of endowed faculty chair—one created deliberately to advance the cause of diversity, equity, and inclusive excellence in astronomy.

CELEBRATING THE VERA RUBIN PRESIDENTIAL CHAIR FOR DIVERSITY IN ASTRONOMY

The world-renowned astronomer Vera Rubin (1928–2016) was a pioneering champion for inclusivity in science and a beloved mentor for younger women and dozens of astronomers from varied backgrounds. Pictured above: Vera Rubin at the Vassar College Observatory. Credit: Courtesy Vassar College.

Join with the lead donors and UC Santa Cruz Astronomy to honor the legacy of Vera Rubin. Make a gift today at: **ucsc.edu/rubinchair**

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