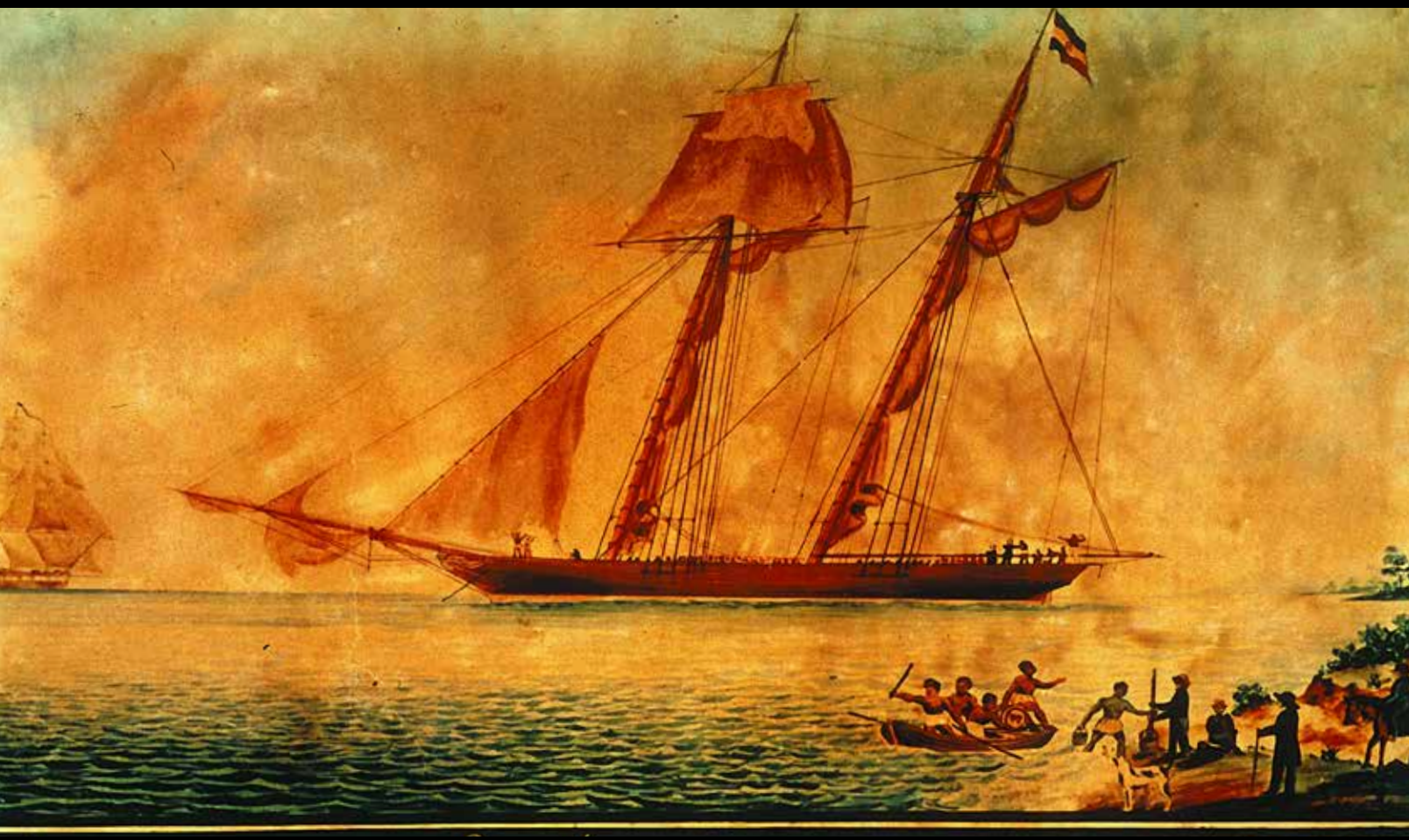
inquiry@ UC SANTA CRUZ RESEARCH MAGAZINE

2018–19



Beyond the middle passage

GEOENGINEERING | DEADLY BIOFILMS | LOST LANDSCAPES

UC SANTA CRUZ

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

Credit: Steve Kurtz

The Offices of Research and University Relations are proud to present the 4th edition of *inquiry@UC Santa Cruz!* This issue of our campus research magazine—written and edited by graduates of UCSC's internationally renowned Science Communication Program—continues to highlight the superb research being conducted across all disciplines on the campus. This year's reporting covers work in the humanities aimed at generating a deeper understanding of the African slave experience in the Americas, art exploring lost urban landscapes, engineering providing innovations in microscopy* and telescopy, physical and biological sciences probing of bacterial biofilms and stressors on marine mammals, and social sciences tackling complex issues in geoengineering and environmental politics.

This issue also incorporates several new features. We have a new department, inquiries&INNOVATIONS, which highlights our campus's intellectual property and industry partnerships. And readers will now find a robust e-magazine at *inquiry.ucsc.edu*, with hyperlinks and references for those who want to conduct "further inquiry" into the topics presented.

Welcome to the 2018–19 issue of *inquiry.* We hope that you enjoy its samplings of the breadth, depth, and creativity of the UCSC research enterprise!

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

*Shortly before publication we received the sad news that Joel Kubby, professor of electrical engineering, had passed away. We are glad to be able to honor him in these pages for a life well lived advancing inquiry across many scientific fields, including, most recently, microscopy (see page 37).

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About the cover: The schooner *Amistad* is one of thousands of slave ships included in the new *Intra-American Slave Trade Database*. Its African captives revolted in 1839 while the *Amistad* was transporting them from one end of Cuba to the other, as chronicled in the 1997 Steven Spielberg blockbuster movie.
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BRIEF **inquiries**

ECONOMICS

Preparing for recession

Distinguished professor of economics Carl Walsh speaks on monetary policy at Norges Bank, the central bank of Norway. Credit: Courtesy of Carl Walsh.

During the 2008 financial crisis, the Federal Reserve reinvigorated the economy by slashing its benchmark interest rate to zero. Today, as the economy continues to rebound, interest rates are climbing.

But due to shifts in the global economy—in particular, the emergence of China—economists expect slower growth and interest rates to remain low overall. If there's another financial crisis, inflation will again plummet, taking interest rates down with it.

With rates already low, the Fed won't be able to cut them further to spur spending. "When interest rates hit an effective lower bound, monetary policy is constrained in its ability to help stabilize the economy," said **Carl Walsh**, distinguished professor of economics.

Other safeguards may be needed. Walsh and other economists are evaluating whether central banks should move away from current policies that work to maintain a certain inflation rate. They could instead aim to keep general prices at a certain level or promise to keep future interest rates low. Such forward guidance policies are discussed in a new chapter in the recently published fourth edition of Walsh's textbook, *Monetary Theory and Policy*.

If and when another recession hits, investors would expect these price-level targeting policies to bump prices—and inflation—back up, Walsh said. The anticipation of higher inflation coupled with rock-bottom interest rates would incentivize people to borrow and spend, thus stabilizing the economy.

—Marcus Woo

SOCIOLOGY

Big data for kids

"Imagine you're a school principal with a struggling student and you have no information about what's going on," said **Rebecca London**, assistant professor of sociology and research liaison to the Silicon Valley Regional Data Trust (SVRDT).

Substantial information about health, living situation, and other social factors—which contribute in major ways to school performance—resides in public agency databases, said **Rodney Ogawa**, research professor of education and a SVRDT director. However, because each agency's data are isolated, they're unavailable to outside educators and health and human service workers trying to help children. The SVRDT aims to change that, Ogawa said, while safeguarding students' privacy.

Working with San Mateo, Santa Clara, and Santa Cruz county child welfare services, Offices of Education, juvenile probation, and behavioral health staff, the SVRDT has nearly completed a prototype Internet "portal" that will allow authorized individuals—including teachers, social workers, policymakers, and UC Santa Cruz researchers—to access certain student information. Made possible by recent California legislation, the "big data" sharing collaboration so far includes information about some 265,000 students.

"We expected some hesitation, but everyone said 'yes, we need this,'" Ogawa said, "This is ultimately for the kids and families of Silicon Valley, particularly those at risk for poor outcomes. That's what's driving us."

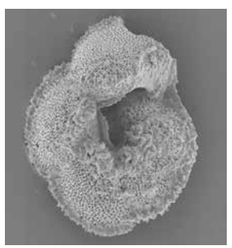
—Sascha Zubryd

EARTH AND PLANETARY SCIENCES

Sedimentary climate clues

To what extent has human activity contributed to today's powerful storms and heat waves? To help answer this key climate change question, **James Zachos,** professor and chair of Earth and planetary sciences, looks to the past.

Fifty-six million years ago, during the Paleocene-Eocene Thermal Maximum (PETM), the Earth heated up 6° C and stayed warm for 150 thousand years. In a recently published study, senior author Zachos and collaborators analyzed ancient plankton shells from this period to reveal increasing ocean salinity and temperature. By producing greater evaporation near the equator, these changes would likely have led to more intense storms at higher latitudes and poleward shifts in dry and wet regions.



Professor of Earth and planetary sciences James Zachos analyzes the chemistry of ancient plankton shells like this one (~200 microns in diameter) to infer what the climate was like when the plankton were alive. Credit: James Zachos.

Although the heating during the PETM didn't occur nearly as fast as today's human-caused climate change, such case studies can be used to inform theories about how global warming will impact future hydrology. In California, for example, Zachos's work supports models that predict more severe droughts and storms.

"We're basically doing forensics," said Zachos, who has been studying ancient ocean sediments for 30 years. "CO_2 levels are going to go up, and climate specialists want to accurately predict how that will impact things like precipitation, so communities can plan."

—Ula Chrobak

LINGUISTICS

Lost languages

The task of saving indigenous languages has acquired increased

MOLECULAR, CELL AND DEVELOPMENTAL BIOLOGY

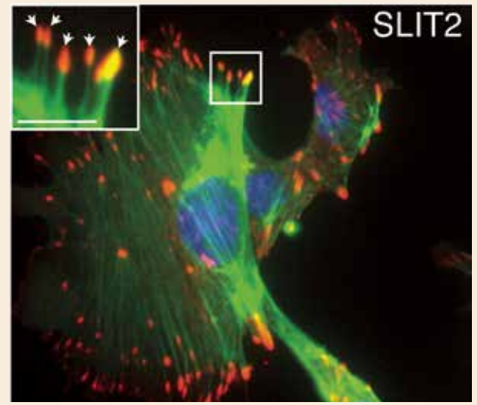
Stiffing cancer

Within the body's tissues, a framework of molecules called the extracellular matrix (ECM) holds cells together. As tumors develop in many types of cancer, this framework stiffens.

"A lump felt during a monthly breast exam does not necessarily reflect the number of cancer cells," said **Lindsay Hinck**, professor of molecular, cell and developmental biology. "It reflects both the cancer cells and the stiffened extracellular matrix."

ECM stiffening appears to block cancer progression by maintaining a balanced state, or homeostasis, of intracellular tension. Conversely, loss of this homeostasis can contribute to cancer progression by promoting tissue disorganization and metastasis.

Hinck's research focuses on understanding this complex biology. Senior author Hinck and collaborators now report that normal breast epithelial cells sense and respond to increased ECM stiffness by reducing levels of the microRNA *miR-203*, a short, noncoding RNA fragment that normally suppresses the Robo1 gene. This raises levels of the protein ROBO1, which, in turn, alters the cell's cytoskeleton and boosts production of adhesion molecules, changes that help cells retain their shape and position within the stiffened ECM. The investigators also found that breast cancer patients with low-*miR-203*/high-ROBO1–expressing tumors had improved survival, identifying this pathway as a potential therapeutic target.



Activation of ROBO1 by its signaling partner SLIT2 induces breast epithelial cells to produce cell-matrix adhesion molecules (red, arrows), helping the cells to maintain their position within the extracellular matrix. The cytoskeleton and DNA are labeled green and blue, respectively. Credit: Reprinted from Le, et al., *Journal of Cell Biology* 2016:212(6):707-19. © 2016, with permission from The Rockefeller University Press.

—Chris Palmer

urgency as more and more are threatened by emigration, rapid cultural changes, and the failure to teach native tongues to children.

Associate professor of linguistics **Maziar Toosarvandani** stands on the forefront of this effort. To preserve their rapidly disappearing language, Toosarvandani partnered with Northern Paiute speaking elders near Mono Lake—of whom only a handful remain. He's now taken on the Santiago Laxopa variety of Zapotec, an endangered native language from Oaxaca, Mexico. Of the 100,000 Oaxacan immigrants who live in communities across California, including Santa Cruz, nearly all speak Spanish. Fortunately, some also speak Zapotec.

In their research, Toosarvandani and his team collect stories, oral narratives, and historical texts from which they infer the structure of the language. Then, by speaking Zapotec with native speakers, they test their hypotheses about its structure and collate their findings in an open access database integrated with a dictionary.

Toosarvandani and his colleague, associate professor of linguistics **Pranav Anand**, have also partnered with the organization Senderos to establish *Nido de Lenguas*, a nonprofit that sponsors monthly language classes and summer camps where native speakers teach their ancestral language to other Oaxacan immigrants. This work is vital, Toosarvandani said. "When we lose a language, we lose an aspect of what it means to be human. If we're interested in saving the world's diversity, we should be interested in saving these languages."

—Sukee Bennett

ASTRONOMY AND ASTROPHYSICS

Flash in the sky

Assistant professor of astronomy **Ryan Foley** was enjoying an afternoon off in Copenhagen when a student texted him. LIGO, the Laser-Interferometer Gravitational Wave Observatory—which had previously detected ripples in the fabric of space-time for the first time, garnering fanfare and a Nobel Prize—had found another gravitational-wave signal.

This time, the signal likely came from merging neutron stars—exotic, city-sized objects with the mass of one or two suns. And unlike previous detections, this cosmic crash was expected to light up.

Astronomers around the world raced to find that flash of light. Just 17 minutes into their search using the Swope Telescope at the Carnegie Institution's Las Campanas Observatory in Chile, Foley and his team found it: a bright dot in a galaxy 130 million light-years away. Their and others' observations were quickly published in multiple papers in *Science*, *Nature*, and *Astrophysical Journal Letters*.

It was the first time anyone measured the light from an event that also produced gravitational waves. The observations revealed that these mergers could have produced most of the elements heavier than iron in the universe. This kind of measurement also provides a new way to probe the expansion rate of the cosmos—crucial for understanding deep questions like the nature of dark energy, Foley said. "It's really just the beginning of a new scientific field."

—Marcus Woo

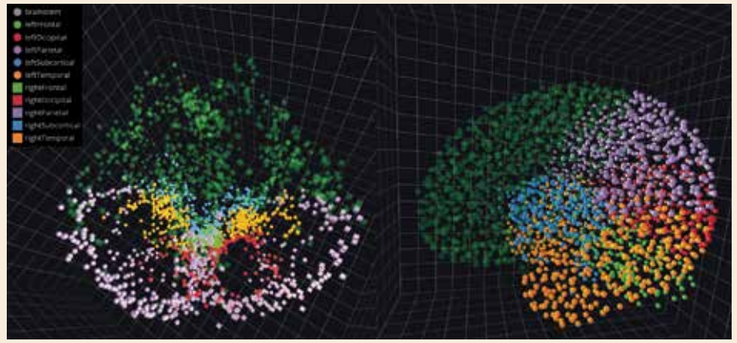
COMPUTATIONAL MEDIA

Connecting the dots

Widely used by clinicians for decades, noninvasive neuroimaging techniques such as CT, MRI, and PET have also enabled neuroscientists to explore structural and functional networks, or "connectomes," in the brain. Critical to this research are tools for effectively visualizing and interpreting the great mass of data generated by these imaging modalities.

A common task in studying neurological disorders such as Alzheimer's disease involves comparing the connectomes of healthy and diseased groups to identify brain changes due to illness. However, no application existed that allowed robust comparisons in real-time of two or more connectome datasets.

To address this need, UC Santa Cruz researchers, working with collaborators at the University of Illinois, Chicago, built the first system for 3D visualization of multiple connectome datasets via a synchronized side-by-side layout. Brain researchers and clinicians can access the system, NeuroCave, via a standard desktop environment or, for a more immersive experience, portable VR headsets.



NeuroCave representation of human subject functional MRI data broken into 2514 regions. The map on the right shows the anatomical clustering of the regions, while the map on the left arranges them according to specific functional characteristics. Credit: Keiriz, et al., *Network Neuroscience*. ©2018 Massachusetts Institute of Technology, Creative Commons 4.0.

"The ultimate goal is for a psychiatrist or neurologist to do precision medicine by using NeuroCave to compare a patient's connectome with the average connectome for any number of diseases," said **Angus Forbes**, assistant professor of computational media and senior author on the paper describing the tool.

—Chris Palmer

LITERATURE

A traveling memory space

How did history's first ghetto affect Western culture and Jewish identity? That's what **Murray Baumgarten**, distinguished professor emeritus of English and comparative literature, seeks to understand.

Created to impose surveillance and control while also allowing a measure of autonomy, the Venice Ghetto is a walled-off section of the city in which Jews were forced to live from 1516 until 1870.

"The Venice Ghetto shaped how many Jews and Jewish communities think of themselves in relation to their outside social situation," said Baumgarten, whose research has focused on how its impacts are described in both fiction and nonfiction writing, such as *Coryat's Crudities*, a travelogue published in 1611.

From 1516 to 1870, Jews were forced to live in the Venice Ghetto (view of present-day outer wall). Credit: Getty Images.

Baumgarten brings this insight to his current study of the writing of Primo Levi, an Italian chemist and Holocaust survivor. Describing Levi's book *The Periodic Table* (1975) in a recent essay, Baumgarten writes, "...Primo Levi, writer, is inseparable from Primo Levi, Holocaust witness, and the discourses of science and art are subtly intertwined and reciprocally illuminating."

"You have to look in many places, because this space has traveled, and it is also a memory space," said Baumgarten. "It's also a space of trauma that has changed many things."

—Ula Chrobak

ECOLOGY AND EVOLUTIONARY BIOLOGY

Resilience under redwoods

There's more to redwood forests than iconic trees. On the drought-prone Central Coast, the forest understory includes a typically tropical resident—ferns.

Jarmila Pittermann, associate professor of ecology and evolutionary biology, and Emily Burns of Save the Redwoods League, noticed that during persistent drought, ferns' fronds dry out and often become infested with tiny insects called thrips. To unveil drought's physiological effects and how the ferns recover during rainy spells, Pittermann's team studied the region's two most abundant species of fern, *Polystichum munitum* and *Dryopteris arguta*, comparing ferns growing in the forests surrounding UCSC to potted, greenhouse specimens that they periodically dried out and rehydrated.

As reported in *New Phytologist*, the ferns were surprisingly resilient, but didn't produce many fronds

Polystichum munitum, commonly called sword fern, is one of the most robust species of fern on California's Central Coast. Its leaves, called fronds, are much thicker and more resilient than those of tropical ferns. Credit: Jarmila Pittermann.

when it was particularly dry. Doing so would cause them to "consume their supply of water and carbohydrates too fast," Pittermann said. The ferns can also rehydrate quickly, taking up water—including from fog—directly from their fronds, as previously shown by Burns.

"People think of ferns as inferior to angiosperms and conifers, and that's untrue," Pittermann said. "Ferns are holding themselves up. They have had to be resistant to make it through 350 million years of our changing planet."

—Sukee Bennett

PSYCHOLOGY

Race in schools

Students who feel they belong perform better. And when students feel stereotyped in school, their academic performance suffers. Years of sociological research bear this out. But there are other, subtler elements that can contribute to a school's racial climate and impact student outcomes.

"The biggest surprise was how understudied some of these factors are," especially the negative outcomes when racial differences are simply ignored, said **Christy Byrd**, assistant professor of psychology.

Byrd studies how students perceive their school environment in relation to their racial and cultural identities. Her survey of adolescent students led to a new framework that combines a wide variety of factors impacting students' sense of belonging.

"It's about how they all fit together," said Byrd, who hopes her framework will inform future research. The most influential factors included the quality of interactions between racial groups, whether students felt they were treated fairly, and if there were opportunities to learn about other cultures, prejudice, and racial inequality.

Her work also shows that students with a strong sense of belonging in their school's racial climate felt more motivated compared to students who believed their racial identities were represented negatively or not at all. And crucially, strong intrinsic motivation correlated closely with academic engagement and success.

—Sascha Zubryd

CHEMISTRY AND BIOCHEMISTRY

Beneficial binding

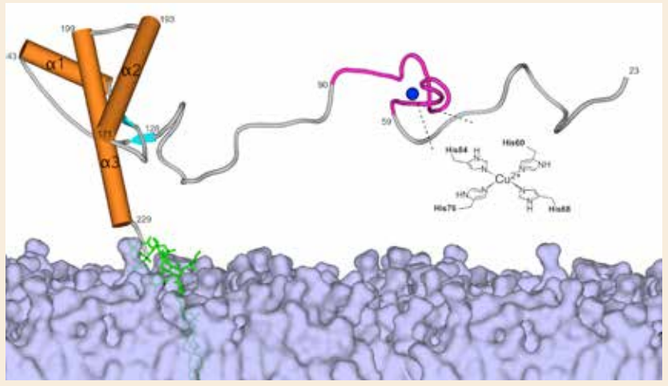
Prion diseases, including mad cow and, in humans, Creutzfeldt-Jakob, are fatal neurodegenerative diseases. They arise, usually late in life, from massive aggregations of endogenous prion proteins.

Compared to the hallmark aggregating proteins of Alzheimer's and Parkinson's, "the prion protein is quite complex," said **Glenn Millhauser,** distinguished professor of chemistry. "Its multiple domains with all sorts of chemical modifications point toward an important function in the central nervous system."

The bulky end of the prion protein binds to the surface of neurons where it modulates the flow of chemical messengers. Research has also shown that the extended, flexible end, in an unfolded configuration, drives prion toxicity and neuronal death.

Millhauser has been studying the prion protein structure for two decades. Of particular interest to him is how the protein binds copper ions. Scientists believe the protein binds copper to regulate the metal ion, which is essential for cellular function but extremely toxic if left unbound. Based on nuclear magnetic resonance spectroscopy, Millhauser and collaborators have now reported that copper, in turn, also regulates the prion protein by forcing its extended end to fold inward, thereby keeping its disease-related activity in check.

—Chris Palmer



When the prion protein (orange, gray and pink) binds copper (blue sphere), it neutralizes the toxicity of the unbound metal ion. This binding also prevents the flexible, extended end of the protein (gray and pink) from unfurling and triggering the toxicity associated with prion-induced neuronal death and its fatal consequences. Credit: Reprinted from Evans, et al., *Structure* 2016:24:1057-67, © 2016, with permission from Elsevier.

MUSIC

Gender equality via music

Women stand at the forefront of music in Uzbekistan, a stature rooted in the hujum, a Soviet-era women's emancipation movement. Women went free of culturally sanctioned, modest attire, and, through music, found "a natural space at the table in the state music conservatory and other institutions," said **Tanya Merchant**, associate professor of music.

Merchant's 2015 book, *Women Musicians of Uzbekistan: From Courtyard to Conservatory*, draws on her almost 20 years of studying Uzbek music. Her research focuses on the female artists who have contributed to modern Uzbek music, many of whom play the Uzbek dutor (also spelled dutar). A two-stringed lute, the dutor is the only non-percussive instrument traditionally played by women. Because of this, after the fall of the Soviet Union, women continued their prominence with the instrument, rising to positions of power rare in any patriarchal society.

Unfortunately, the current political climate and travel bans make it difficult for Merchant to bring dutor teachers from Uzbekistan to help "immerse" her students in Uzbek musical practices. "Ethnomusicology isn't about sitting down, listening to sounds, and making assertions," Merchant said. "It's best to be embedded in the culture."

—Sukee Bennett

Associate professor of music Tanya Merchant (left) plays the dutor, a two-stringed lute from Central Asia, with her primary Uzbek musical mentor, Malika Ziyaeva. Ziyaeva visited UC Santa Cruz in 2014 to teach and also perform with the Eurasian Ensemble. Credit: Courtesy of Tanya Merchant.

ELECTRICAL ENGINEERING

New coats for telescopes

Silver makes better telescope mirrors. It reflects more visible and infrared light than aluminum, the metal most telescope mirrors are made from. But while aluminum forms a natural protective layer when exposed to air, silver doesn't—that's why it tarnishes.

To combat this degradation, telescope makers coat the silver with a protective layer using physical vapor deposition, spraying, for instance, aluminum oxide vapor onto the silver. Even so, the mirrors still corrode after a couple years.

The problem is that this coating method leaves pinhole-like gaps. "All kinds of stuff—oxygen, water, sulfur—those elements go through the pinholes to reach the silver," said **Nobby Kobayashi**, professor of electrical engineering.

With collaborators UC Observatories astronomers **Andrew Phillips** and **Michael Bolte**, UCSC postdoc **David Fryauf**, and Structured Materials Industries (SMI), Kobayashi designed a new instrument that employs atomic layer deposition (ALD) to coat the silver. Widely used in making semiconductor chips, ALD creates a dense, even film by coating surfaces one atomic layer at a time.

Because ALD systems are designed for small, thin silicon wafers, the researchers had to build a much larger one to accommodate telescope mirrors. While the prototype is still being tested, proof-of-principle experiments have shown promising results, Kobayashi said.

—Marcus Woo

COMPUTER SCIENCE

Bringing storage up to speed

Storage systems—the software that connects an electronic device's applications to its disk or solid-state drives—have lagged behind other improvements in computer systems. New applications normally add layers of software to get what they want from storage systems, leading to bloated software and inefficiency.

"Storage systems are complicated and they slow things down," said **Carlos Maltzahn**, professor of computer science and director of the Center for Research in Open Source Software (CROSS).

To address this problem, the CROSS team created a uniquely programmable storage system based on Ceph, a widely used, open source storage system also created at UC Santa Cruz. Called Malacology (after the science of molluscs: cephalopod molluscs,

like octopi, are agile and have many arms moving in parallel), the new storage system lets programmers tap into existing storage system software and adapt it for new purposes, while retaining code that took years to optimize. The group published their work at the EuroSys 2017 conference.

"Open source software community efforts are allowing innovation to flow much more freely and appear much more quickly on the market than proprietary solutions," said Maltzahn. He thinks Malacology will help enable innovation and entrepreneurship, ultimately leading to improved computers, smartphones, and other digital technology.

—Ula Chrobak

Computer scientists at the UCSC Center for Research in Open Source Software (CROSS) created the new storage system Malacology, which allows programmers to efficiently adapt existing software to suit their needs. (l to r: graduate students Ivo Jimenez, Jianshen Liu, and Yiming Zhang). Credit: Carolyn Lagattuta.

ENVIRONMENTAL STUDIES

A dwindling wellspring

During Peru's long dry season, seasonal glacier melt releases sorely needed water from frozen storage. The warming climate initially increased the flow, boosting agriculture and hydroelectric power. But Andean glaciers have continued to shrink, and so has the water supply.

"It's much farther along than we thought," said **Jeffrey Bury**, professor of environmental studies and faculty director of the Center for Integrated Spatial Research. Bury's research focuses on how glacier loss and social factors impact access to water in Peru, from its high mountains to its coastal cities.

Bury and collaborators now report that the Cuchillacocha glacier is shrinking 37% faster than previously predicted. Streams and wells have dried up, forcing people to travel, build new infrastructure, or relocate to find water.

The Cuchillacocha—shown here during the dry season—and other glaciers in the Andes are receding, significantly reducing access to water in Peru, from its high mountains all the way to its coastal cities. Credit: Bryan G. Mark, courtesy of Jeffrey Bury.

In addition, heavy metals from bedrock exposed by the receding glacier and the area's long history of mining have contaminated mountain streams.

"The scale of these changes is astounding," Bury said. Demand is growing, with cultivation of profitable, water-intensive crops for export on the rise, and expanding cities consuming more clean water and power. "There will be a point when supply won't meet demand," he said. "It's just a matter of time."

—Sascha Zubryd

inquiries&INNOVATIONS

By Marcus Woo

Diagnosis on a chip

To diagnose diseases like Ebola, clinicians seek viral or bacterial DNA or RNA in patient samples. Traditionally, tests used for this employ PCR (polymerase chain reaction), a method that induces those molecules to replicate, making them easier to detect.

By eliminating the PCR step, UC Santa Cruz professor of electrical engineering **Holger Schmidt** and collaborator Brigham Young University professor Aaron Hawkins invented a potentially simpler, quicker, and cheaper way to diagnose diseases.

The lab-on-a-chip device channels a liquid like blood or saliva containing fluorescently labeled, infectious DNA across an optical waveguide, a tiny tunnel that steers light. When light hits tagged DNA, the dye glows, revealing the presence of the pathogen.

"This could hopefully be a new way to do medical testing," Schmidt said, providing a practical point-of-care tool to use in clinics and the field.

Schmidt H, Hawkins AR. Method for amplification-free nucleic acid detection on optofluidic chips. U.S. Patent 9,551,667, filed November 18, 2011, issued January 24, 2017.

Time and place

The Large Hadron Collider (LHC) in Switzerland slams trillions of protons together, each collision producing hundreds of particles spraying in all directions. Particle detectors must then track their trajectories.

But a typical silicon detector can only accurately measure a particle's position—not how long it's been traveling. So UCSC professor of physics **Abraham Seiden** and research physicist and adjunct professor **Hartmut Sadrozinski** helped design a new silicon detector that does both. Researchers will use the improved detectors to start building a new instrument for the LHC as early as 2021, Seiden said.

The technology could also be used to improve medical imaging systems that doctors use to target and destroy cancerous tumors with proton beams.

Sadrozinski H, Seiden A, Cartiglia N. Segmented AC-coupled readout from continuous collection electrodes in semiconductor sensors. U.S. Patent 9,613,993, filed June 30, 2016, issued March 9, 2017.

Dimmable LEDs

In 2013, as part of a senior design engineering class, UCSC students built an LED (light-emitting diode) light bulb that would cost only $5 to make—substantially less than what they sold for at the time.

The experience taught them real-world skills, said **Julian Dahan**, student lead on the project. "It put us ahead of the curve in job interviews."

They also discovered a new circuitry design that allowed the brightness of the LED to be controlled with a switch, knob, or even via Wi-Fi. In contrast to most adjustable LEDs now on the market, this adjustability is built right into the LED itself.

"That was the novelty that no one had ever done before," said **David Munday**, the lecturer who teaches the class. "Just plug it in and go."

Munday D, Baker R, Dahan J, Peterson R, Sloan C. Switchable luminance LED light bulb. U.S. Patent 9,730,282, filed August 5, 2015, issued August 8, 2017.

In a living cell

Its tip is so small you can't see it with an optical microscope. Like a tiny needle, the nanopipette pierces a living cell and extracts contents from its organelle structures—all without harming the cell. The device can also inject biologically relevant chemicals, to test single-cell effects of potential drugs, for example.

No other technology can examine a cell in this way without killing it, said UCSC professor of biomolecular engineering **Nader Pourmand**. The nanopipette provides a powerful tool to study how a living cell changes and behaves.

His lab uses the nanopipette to study how a variety of dynamic processes within single cells contribute to degenerative brain diseases and drug resistance in cancer, Pourmand said.

Karhanek M, Webb CD, Umehara S, Pourmand N. Functionalized nanopipette biosensor. U.S. Patent 9,766,204, filed January 22, 2015, issued September 19, 2017.

Superior sequencing

Technology developed at UCSC underlies the MinION, a handheld gene sequencer manufactured by Oxford Nanopore Technologies (Oxford, U.K.). The MinION reads sequences via nucleotide-specific changes in ion current as DNA strands pass through a nanopore, a tiny hole in a polymer membrane. The nanopore approach has led to smaller, faster, and cheaper devices, expanding access to sequencing and invigorating genome research.

UCSC professor of biomolecular engineering **Mark Akeson** and collaborators have now devised a novel method that applies voltage to move a DNA strand back and forth through a nanopore at a controlled rate.

The invention could be useful for new sequencing technologies, Akeson said. "It's a terrific way to couple electronics to biology directly at the single-molecule level."

Olasagasti FA, Lieberman KR, Benner S, Akeson MA. Compositions, devices, systems, and methods for using a nanopore. U.S. Patent 9,481,908, filed February 27, 2014, issued November 1, 2016.

By Robert Pollie

Beyond the Middle Passage

Intra-American trafficking magnified slavery's impact

Slaves cutting sugar cane on the island of Antigua. The sugar industry's relentless demand for labor turned the Caribbean into a hub of intra-American slave trading. Credit: ©John Carter Brown Library, Brown University, Providence, RI.

▶ Between the early 1500s and the mid-1860s, millions of Africans were captured, sold into slavery, and transported to the New World to live out their days in bondage. The African diaspora is believed to have been the largest forced migration in human history, though "mass abduction" might be more apt. Nothing conveys the scale of it better than the *Trans-Atlantic Slave Trade Database* (TSTD). Hosted at *slavevoyages.org*, the TSTD provides details of almost 36,000 slave-trading shipments that took place over three centuries. It's the most complete record we have of transoceanic slave routes and an essential tool for researchers. One prominent historian likened its impact on the study of slavery to that of the Hubble Space Telescope on astronomy.

But like the Hubble—before it was repaired by the crew of the space shuttle *Endeavour*—the TSTD suffers from a kind of myopia. True to its name, it only includes voyages that made the transatlantic crossing from Africa, the infamous "Middle Passage." But slave shipping didn't stop there. It continued full throttle on this side of the Atlantic, with thousands of vessels and voyages ferrying enslaved people to and from points *within* the Americas.

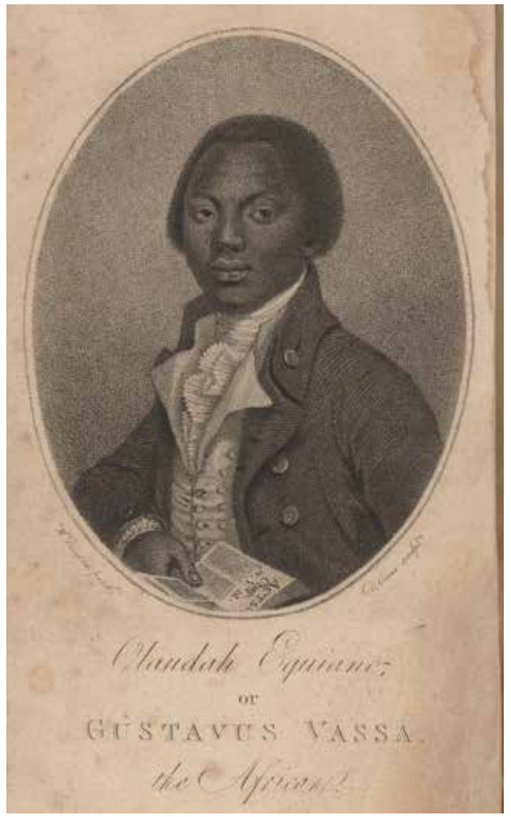
The TSTD isn't alone in overlooking that second stage of slave shipping. "For a long time, most research on the American slave trade focused on the shipments coming into major slaveholding colonies, and those were almost all arriving directly from Africa," said UC Santa Cruz associate professor of history **Greg O'Malley**. "It missed a big piece of the overall picture."

The missing piece—the bustling *intra-American* slave trade—played a critical role in spreading slavery across the Western Hemisphere and embedding it deep in the economic and social foundations of the New World. To grasp the full scope of that commerce is to gain a broader understanding of the way slavery shaped life in the Americas, with repercussions that are still playing out today.

O'Malley has spent much of his career as a historian advancing that broader understanding. The work began in graduate school, when he built his own database of thousands of slave shipments in British Colonial America (the 13 North American colonies and British Caribbean islands) as part of his Ph.D. thesis. He expanded on that research in his 2014 book, *Final Passages: The Intercolonial Slave Trade of British America, 1619–1807*, a wide-ranging look at intra-American slave trading and its economic, political, and cultural consequences.

Now he's taking another step, pooling his data with that of fellow historians to compile an even larger database, to be added to the *slavevoyages.org* site later in 2018. With information on more than 11,000 voyages, the new *Intra-American Slave Trade Database* will fill a crucial gap in the historical record and provide an essential complement to the TSTD.

"The *Intra-American Slave Trade Database* will give us a far richer picture of the slave experience," said David Eltis, professor emeritus of history at Emory University and one of the creators of the TSTD. "I think it will inform a wide range of historical scholarship."



Enslaved as a sailor on intercolonial vessels, Olaudah Equiano witnessed the brutality of the intra-American slave trade firsthand. His best-selling 1789 memoir was one of the slave narratives associate professor of history Greg O'Malley drew on when writing his own book. Credit: ©John Carter Brown Library, Brown University, Providence, RI.

An unexpected detour

O'Malley had a very different project in mind when, as a Ph.D. candidate in history at Johns Hopkins University specializing in British Colonial America, he began scouting for a dissertation topic in 2003. "I was thinking about the complex mix of people in the colonies," he said, "with a particular interest in the cultures that enslaved Africans were bringing to America."

To understand those cultural currents, he had to get a handle on the demographics—who the enslaved people were, where they came from, and in what numbers. And the numbers weren't adding up.

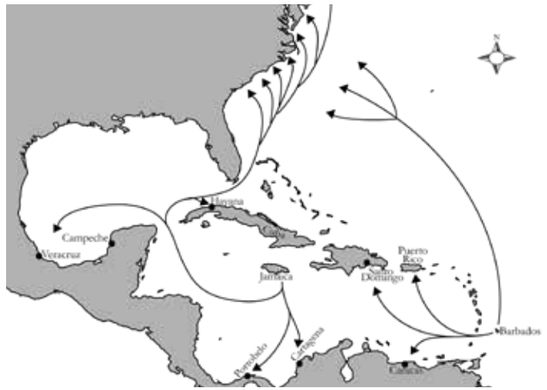
"I'd be reading a book, for example, that said there were 90,000 people of African descent in North

Carolina on the eve of the American Revolution," O'Malley said. "And yet the book cited only one slave ship carrying at most a few hundred people that had come to the colony from Africa. So where did those other 89,000-plus people come from?"

It was a glaring discrepancy, one that O'Malley ran into again and again as he surveyed the literature. "There was a lot of scholarship on the transatlantic portion of the slave trade, describing where people landed in the Americas from Africa," he said, "but that data didn't line up with where we knew enslaved people actually lived in the New World."

He did have a hunch. There had to be an extensive shipping system that was moving people from a small number of arrival points—like Charleston, South Carolina, the Chesapeake Bay in Virginia, and Kingston, Jamaica—to the many places they lived and labored throughout the Americas.

To confirm that hypothesis, O'Malley went to the only detailed records that still survive—British Naval Office shipping lists, where colonial officials dutifully logged the contents of arriving and departing ships at ports throughout British America. The innocuous-looking ledgers contained a grim accounting.



The colonies of Barbados and Jamaica were the major centers of the British American trade, where slaves from Africa were reshipped to many locations in North, South, and Central America. Credit: Greg O'Malley.

Finding the Amistad

Tens of thousands of visitors explore the *Trans-Atlantic Slave Trade Database* (TSTD) at *slavevoyages.org* each year. Many of them search for one ship in particular: the schooner *Amistad*, depicted on the cover and famed for a slave revolt in 1839 and a Steven Spielberg blockbuster more than 150 years later.

But those queries come up empty. The TSTD lists only transoceanic voyages, whereas the *Amistad* was engaged in more local business. When its African captives rebelled, they were being transported from one end of Cuba to the other. That's one of many gaps the *Intra-American Slave Trade Database* will fill. When it's published on the *slavevoyages.org* site this year, the new database will provide searchable records of thousands of slave-carrying ships that sailed American waters—including the *Amistad*.

Alongside entries for goods like sugar, rum, salt pork, and naval supplies, many had a column for "Negroes."

O'Malley spent a year systematically cross-checking thousands of such records (most were available on microfilm at Johns Hopkins's Eisenhower Library), tallying the shipments and creating his own growing database, which he modeled on the TSTD. "I had the notion even then that the editors of the TSTD might someday incorporate my data," he said.

By the time he was done, he'd documented intra-American slave trading on a previously unknown scale—over 7,000 voyages from the 17th through 19th centuries. "The magnitude of it surprised even me," he said.

Behind the numbers

It was depressing work at times, and not only because of the sheer monotony of combing through shipping lists day in and day out. "There was a terrible tension between the boredom on the one hand and the realization that all those numbers flashing past on microfilm were human beings," O'Malley said. "I really wanted to present a human story of what the captives suffered in this horrific business, but these documents are the opposite of humanizing."

Eventually, by analyzing the numbers along with other sources such as merchant correspondence and slave narratives, he was able to flesh out a fuller story. In his Ph.D. dissertation and later book, he showed how, for many enslaved Africans, the transatlantic passage was just a segment of a longer journey. He estimates that more than 400,000 of the Africans brought to British American ports between the mid-17th and early 19th centuries were promptly packed aboard other ships and dispatched to distant parts of the Americas.

"Although some of the enslaved were purchased by plantation owners and put to work near where they made landfall, many were bought by merchant speculators who then transported them for resale elsewhere in the colonial world," O'Malley said. In other words, the major ports served as hubs in a vast distribution network.

The busiest hubs in the British Americas were in the Caribbean, principally Kingston, Jamaica, and Bridgetown, Barbados. From there, large numbers of slaves were shipped to North American colonies or shuttled between various British Caribbean territories. Even more were exported to other colonial empires, going mostly to the French Antilles and Spanish settlements in South and Central America. "If you look at the transatlantic data alone, you see a few key hot spots," said O'Malley. "But with this broader data set you get a more powerful sense of the real pervasiveness of slave trading."

Longer journeys, greater hardships

For people who'd already endured the deprivations of the oceanic crossing, the further passages only added to the ordeal. The port records O'Malley examined showed many intra-American slave-trading ships arriving at their destinations with fewer captives than they set out with, owing to deaths en route. Comparing the numbers, he was able to calculate an average mortality rate of 5% for enslaved people on intra-American voyages. That's lower than the estimated 20% who perished during the Middle Passage. "But given that the intra-American voyages were much shorter, it tells us that people were actually dying at faster rate," he said.

Those who survived found themselves increasingly isolated with each step of the journey, as friends, family members, and people with common ethnic backgrounds who'd managed to stick together or form bonds during the trip from Africa were split up and sent their separate ways according to the needs of merchants.

As for the merchants themselves, many were middlemen who purchased enslaved people at their initial port of arrival, then resold them wherever they could fetch a higher price; in effect, buying wholesale and selling retail. "Most of the previous work assessing the economics of slave trading considered only the transatlantic trade. They looked at the price paid on the coast of Africa, the transportation costs, and the price received in America," O'Malley said. "But this complicates that picture, adding a whole other round of buying, selling, and profits."

By sea and by land

The first iteration of the *Intra-American Slave Trade Database* consists almost exclusively of maritime voyages. In part that's because most colonial settlements were on coasts and waterways, and ships were the most efficient means of transport. Many ships' cargoes were also carefully logged, helping historians construct a detailed picture of seaborne trafficking.

Overland transport of slaves tended to involve spottier record keeping, making such movements harder to track. One major exception was in Brazil, where large convoys of captives were marched to mines deep in the country's interior and official records were preserved. That's enabled Daniel Domingues, assistant professor of African history at Rice University, to collect data on thousands of overland journeys, which will be added to the *Intra-American Slave Trade Database* by 2019, pushing the total number of records to more than 15,000. Efforts by other researchers are also underway to document overland slave trafficking in North America, further expanding the database.

A hidden logic

While the transatlantic trade was run largely by slave specialists, the players in this second layer of trafficking were often ordinary merchants happy to sell whatever the market wanted, be it raw materials, products, or people. Slaves were treated like livestock and frequently combined with other cargoes such as rum, timber, and cloth. The mix sought to maximize the returns on each leg of a ship's travels.

This financial logic became clear when O'Malley studied the letters that merchants wrote each other as they negotiated deals and planned their shipments, and it helped explain trade patterns that at first glance seemed nonsensical.

He discovered, for example, that many of the slaves in North Carolina were being brought from Kingston, Jamaica. That helped to solve the original puzzle that started him investigating slave routes in the first place, but it begged another question. Why would anyone ship slaves all the way from Jamaica when there were plenty available in the neighboring

Auction of estates, pictures, and slaves in a hotel rotunda in New Orleans. Slaves were bought and sold like any other merchandise, reflecting what O'Malley calls "human commodification." Credit: Wikipedia Commons.

colonies of Virginia and South Carolina? "It only makes sense if you look closely at the commerce," O'Malley said. "Traders in North Carolina were exporting food and materials to the sugar plantations in the Caribbean, and they needed something to take back in return. North Carolina could only handle so much sugar and rum, but there was always a market for slaves."

It was the imperatives of the marketplace, O'Malley argues, that spread slavery far beyond the plantation zones to many corners of the Americas, including areas we don't typically associate with slavery today, like New York, Massachusetts, and Pennsylvania.

Slave trading greased the wheels of commerce, and helped entrepreneurs get a toehold in new markets. While demand for other goods ebbed and flowed with supply, the need for workers was nearly unquenchable. The Americas offered up a seemingly endless bounty of land and natural resources. All that was needed to reap the spoils was cheap labor. Slaves became a widely accepted medium of exchange, a bargaining chip that merchants could trade for almost anything else.

"I found examples of merchants writing to each other, saying, 'If you want to get into this business or that business, get some slaves, because there are always planters in need of labor who will deal with a slave trader,'" O'Malley said. "So if you wanted to get into the rice export business in South Carolina, the advice was, 'Pick up some slaves in the Caribbean. There will almost always be a plantation owner who will sell his rice to you for slaves.'"

British manufacturers went a step further, using the cover of slave trading to break into lucrative Spanish American markets in the late 17th and early 18th centuries. At the time, Spain barred foreign imports to its American colonies, but made an exception for slave traders because of the pressing need for labor. The British exploited this loophole, gaining entry to Spanish American ports by bringing slaves for sale while simultaneously smuggling in mass-produced goods such as textiles. Selling those products was the real endgame. It gave a timely lift to British factories at the dawn of the industrial revolution and helped fuel a boom in manufacturing. (Many of the same manufacturers depended on raw materials supplied by slave labor in the Americas, especially cotton.)

Slavery at the center

The overview that emerges is of a slave trade thoroughly entwined with, and instrumental to, the economic growth of the colonized Western World. O'Malley's research makes the case for what the writer Ta-Nehisi Coates calls "the centrality of slavery in American history." In this view, slavery wasn't an ugly footnote in the story of American prosperity and economic opportunity—it was a driving force.

And it wasn't just slave traders and slaveholders who benefited. It was everyone who shared in the wealth of the New World. The slave business went far beyond plantations, and touched all sorts of people. There were the sailors and dockworkers who transported slaves, the brokers and auctioneers who sold them, the bankers who handled the transactions, the farmers who sold provisions to arriving slave ships, and the ordinary consumers buying goods whose availability depended on slave trafficking.

This ubiquitous commerce had a normalizing effect, O'Malley believes. Many European Americans came to accept slavery as a necessary part of doing business and getting ahead, while turning a blind eye to the human toll. That indifference is painfully clear in the merchant letters. Amid pleasantries and small talk, the businessmen casually mention shipments of slaves, with no sign of empathy or recognition that these were actual people.

Illuminating past and present

The British American trafficking O'Malley studied was just a slice of the overall intra-American slave trade. Other colonial powers—Portugal, Holland, Spain, France—were doing their own trading, and a number of historians have been collecting data on those networks. For example, Alex Borucki, UC Irvine associate professor of history, has amassed details of roughly 1,000 slave voyages in the Portuguese colony of Brazil and in Spanish South America (areas that became Venezuela, Uruguay, and Argentina).

Funded by a National Endowment for the Humanities grant administered by the UCSC Humanities Institute, Borucki and O'Malley have been combining their data with that of other researchers tracing slave routes in the Dutch and Spanish Caribbean to create the new *Intra-American Slave Trade Database*. When the database goes live at *slavevoyages.com* later this year, scholars, students, and the general public will be able to search its 11,000-plus voyages using criteria such as the name of the ship, the date of the voyage, the itinerary, and even the outcome (for example, if slaves were successfully delivered or rebelled). "It's really an astonishing expansion of the raw data we have," said Linford Fisher, associate professor of history at Brown University. "It's giving us a much deeper understanding of the mechanics of the slave trade in the Americas."

Slave trafficking dates back to antiquity, but the mechanics that Fisher refers to reflected modern economic developments. As the intra-American slave trade grew, an entire ecosystem of merchant speculators took shape and inserted itself between slave suppliers and slaveholders. This middle layer of resellers valued slaves not as laborers, but as commodities, fungible assets used to exploit price differentials in markets (buy low, sell high). That cold-blooded calculus is manifest in the port records O'Malley examined. Their rows and columns offer no information on who the slaves were—not even their ages, genders, or origins—just quantities: the number of units shipped.

The reduction of persons to financial abstractions pushed the dehumanization of enslaved people to new depths. Plantation owners and overseers at least had to live beside and interact directly with slaves over extended periods. But for many of the merchants and others in the trafficking business—aside from the relatively small number of sailors and handlers who did the actual dirty work—the enslaved were mere line items on balance sheets.

This industrial-scale "human commodification," O'Malley contends, was part of a "systematic devaluation of black lives that's still with us." He believes a reckoning is long overdue, and that historical research has a vital role to play. "My hope is that the work that I and other historians are doing helps American society finally come to grips with the legacy of enslavement and how it shaped the inequalities we see today," he said. "If the information in this database can move us toward a more honest appraisal of our past—and our present—that would be the ultimate accomplishment."

By Amy West

Save the data!

Scholar activism seeks social and environmental justice

▶ Following the 2016 presidential election, what started as a flurry of emails between academic colleagues launched a new watchdog for science and the environment: an online activist network called the Environmental Data and Governance Initiative (EDGI, pronounced "edgy"). Troubled by the incoming administration's anti–climate change stance, the group of scholar activists, including UC Santa Cruz sociologist **Lindsey Dillon**, coordinated teams of volunteers to pre-emptively copy government websites. Anticipating the potential loss of years of environmental research, this systematic rescue of federal data occurred at 49 events in 2017 and helped build a comprehensive archive of federal websites and data. It also sparked hundreds of media mentions of the work, including a bit on *The Daily Show*.

Dillon, who had just begun her first year as a UCSC assistant professor, took on the role of co-chairing EDGI's 11-member steering committee. Following the inauguration—in between the Women's March and airport protests—she helped coordinate a data archiving event in the San Francisco Bay Area with 170 volunteers. She also became deeply involved in EDGI collaborative research that has generated three comprehensive reports to date. For the first, the group interviewed more than 60 former and current OSHA and EPA employees, some of whom had worked at these agencies since the 1970s. The resulting *The EPA Under Siege* compares the threat in the current situation to that in the Reagan years. The second report, *Pursuing a Toxic Agenda*, reveals how the new administration's environmental policy changes disproportionately affect vulnerable communities that are already marginalized. The topic dovetails with Dillon's own primary research into the environmental politics of San Francisco's Bayview–Hunters Point neighborhood.

Above: UCSC assistant professor of sociology Lindsey Dillon addresses the room of volunteers during a daylong DataRescue event held at the Berkeley Institute for Data Science at UC Berkeley. The event focused on archiving pages from the websites of the DOE National Laboratories and NASA Earth Science. Credit, all photographs: ©Jamie Lyons, with permission.

Copy that

Unlike history preserved through physical media like newspapers and books, virtual history is intrinsically ephemeral, potentially vanishing with the tap of a delete key. To preserve this rich digital history, the Internet Archive, headquartered in San Francisco, has archived billions of web pages since 1996. Their digital library collection occupies more than 30 petabytes (1 PB=1 million GB) of server space, with multiple copies saved in other cities around the globe. Their web crawler tool, the Wayback Machine, captures snapshots of websites, allowing anyone to view a website's history.

Although federal websites often change when a new president takes office, this time the very real threat of rapidly losing access to valuable environmental data inspired activists to first gather in Toronto, then throughout the U.S. Coders at these "archive-a-thons" first designated important URLs (web addresses) for the Internet Archive to capture, such as the EPA climate change pages, to guide web crawlers beyond the first few links of a web page. Anyone can nominate web pages for archiving, but EDGI developed a web tool to make that easier, as well as a toolkit for anyone wanting to host a DataRescue event. They also worked to archive uncrawlable pages containing complicated or dynamic data, like maps of greenhouse gases or marine protected areas. In total, the organized data rallies nominated more than 100,000 new web pages or datasets—a major contribution to a pre-existing project that had aimed to archive all federal websites by the time President Obama left office.

Out in the open

Federal records law prohibits unannounced destruction of government information. Once removed from public access or taken offline, this information must remain stored and available through public requests via the Freedom of Information Act. But you have to know what information you are looking for to know if it vanished, said Dillon, and the process to track down that information can be convoluted.

Take, for instance, one case involving major website facelifts to the EPA's climate action plans for cities. Although the EPA relocated the original pages to an accessible online archive, the archive is incomplete, ending in broken links. Changes like this are not necessarily deliberate. In some cases, agencies have rewritten climate science pages to escape defunding, so EDGI did not want to alarm people unnecessarily. "There was so much going on, it's easy to think website changes were a conspiracy. We didn't want to play into that," Dillon said.

EDGI continuously monitors tens of thousands of web pages, but thus far has only identified "socially meaningful" changes, leaving deeper contextual analysis and probing to journalists. Their third report, *Changing the Digital Climate*, details how words like "climate change" and "greenhouse gases" have been replaced with less clear language. Links to raw data have also been removed, essentially limiting access, but the group found no evidence that any of this valuable resource has been deleted. "I'd love to attribute that to the work we are doing, the spotlight we put on," said Dillon.

A newly constructed condominium looks out over the Hunters Point Naval Shipyard, where workers decontaminated ships from nuclear weapons testing and disposed of radioactive waste on site. This industrial area of southeastern San Francisco, the focus of Dillon's primary research, has also housed a power plant, sewage treatment plant, and waste transfer station, and is now vulnerable to storm surge and sea-level rise.

It's important to recognize that some website manipulations can have greater negative impacts than others. There's a difference between simply changing words and removing access altogether, Dillon said, like when the EPA eliminated links to web pages listing educational climate change resources for students. Limiting access to such public information is a form of social injustice, Dillon believes, because not everyone has the time, awareness the information ever existed, or the know-how to find it once it's gone. "Changes

in accessibility are important," concurred Nicholas Shapiro, Dillon's co-chair on the EDGI steering committee and research fellow at the Science History Institute in Philadelphia, "They really affect public knowledge and discourse."

Urban assault

Dillon knows her way around government records. Such information provides the foundation for her primary research on the history, social, and economic dynamics of San Francisco's Bayview–Hunters Point. Historically, this industrial neighborhood had the highest concentrations of pollutants in the city, coupled with abnormally high rates of diseases, like asthma and heart failure, compared to the rest of California. In addition, radioactive and other hazardous waste contaminating the soil and water qualified the World War II Hunters Point Naval Shipyard as an EPA superfund site. The area has been a hotbed of environmental justice activism; residents have long voiced their concerns about living in San Francisco's most polluted area. "There's a connection between race and urban inequality in the U.S.," said Dillon. "The place where you live really does influence your health."

Hunters Point drew African Americans with its shipyard jobs during World War II. But racist real estate practices and urban planning also limited where new migrants could live, relegating them to less desirable—and frequently polluted—parts of the city. Dillon's research explores the ways humans experience racism through the lens of environmental pollution. "It's not discrete from class, or gender, or environment, or pollution," said Dillon. "Racism is entangled in all of those."

Developers have now begun to breathe new life into Hunters Point, but not without protest and controversy over the cleanup. With Bay Area real estate at a premium, the area has started to gentrify, increasing housing costs and further disenfranchising long-time residents. Dillon advocates that such "urban greening" projects should incorporate policies for equitable housing and environmental planning. Her book-in-progress uses Hunters Point as a model to examine the political ecologies of toxic cleanup and urban redevelopment.

Scholar activism comes with the territory, said Julie Sze, UC Davis professor of American studies. "Not everyone does it, but there are people who work on race and social movements for whom there is no separation between their research and their activism," she said. "Many of the leading activist scholars are in the UC system, and Lindsey is part of that tradition."

In July 2017, a protest against pollution and gentrification took place in front of the housing office for the San Francisco Shipyard, an upscale housing development being built on the former site of the Hunters Point Naval Shipyard.

By Marcus Woo

A three-minute challenge

Competition showcases graduate student research

Credit: Judy Glass

▶ As a graduate student, you spend years on your thesis or dissertation, mastering every detail of your experiments, calculations, interpretations, and analysis. Now try distilling all that expertise into a talk just three minutes long. And do it in an engaging and entertaining way with no jargon, so any intelligent person can understand it.

This year, more than two dozen UC Santa Cruz graduate students took on that challenge, competing against one another as part of the fourth annual UCSC Grad Slam. "Experiencing the diversity of the work our grad students are doing in all kinds of areas and in all disciplines—that's very exciting," said Vice Provost and Dean of Graduate Studies **Tyrus Miller**, who emceed the final round of competition, held at the Music Center Recital Hall in late February.

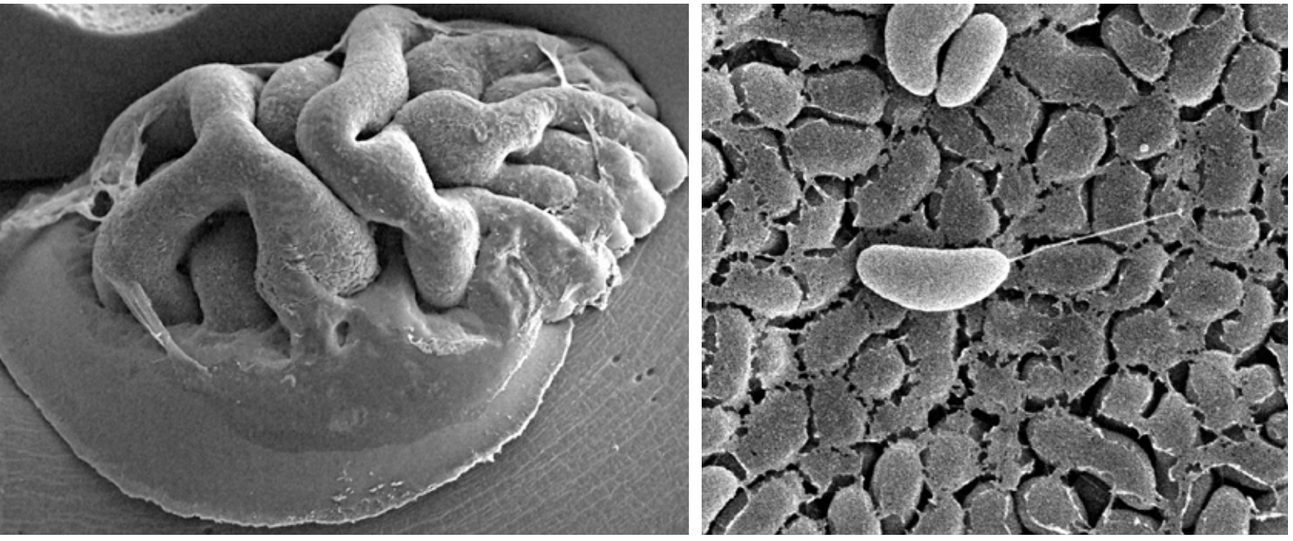
A systemwide, UC-only, annual contest with its own rules, Grad Slam is similar to the popular Three Minute Thesis (3MT®) competition that originated at the University of Queensland in Australia. Each UC campus holds its own competition to choose one champion to compete in the final systemwide event (runner-ups are also invited to attend). For the first round of the UCSC competition, students submitted videos of their three-minute talks—some honed with the help of a series of workshops on presentation skills. Twelve finalists—chosen by a group of UCSC administrator and staff screening judges—presented live onstage in front of an audience and a final judging panel that included Santa Cruz mayor David Terrazas, city council members, and other community leaders.

For the first time, all five academic divisions were represented in the competition. Finalists included **Tony Assi**, an M.F.A. student in digital arts and new media, who uses eye-tracking technology to understand perception of visual art, such as Leonardo da Vinci's *The Last Supper*. **Eilin Francis**, a Ph.D. student in economics, has found that scheduled payment plans can help people in the developing world—who often don't have bank accounts—save money. **Sharmistha Guha**, a Ph.D. student in statistics and applied mathematics, uses statistics to analyze brain networks, hoping to unlock the secrets of creativity. And **Tiffany Thang**, an M.S. student in computational media, is developing virtual-reality games to help people with developmental disabilities learn to recognize emotions.

Taking home the runner-up prize (and $1,500) was **Nickolas Knightly**, a Ph.D. student in philosophy. He's tackling one of the deepest questions around: how we know what we know. Events like the Grad Slam underscore the importance of being able to clearly communicate your research, he said. "If people can't understand what we are working on, they cannot possibly open up to what it might mean and how it might help us all to grow."

In the end, Ph.D. student **Kimberley Kanani Bitterwolf** emerged victorious as both the UCSC Grad Slam champion and the people's choice (audience vote) winner, receiving $3,000 and $750 for each prize, respectively. Glory by association goes to her fellow finalist and husband, **Stephan Bitterwolf**, a Ph.D. student whose research aims to identify molecular signatures of environmental stress on coral reefs. Her own research analyzes the geochemistry of river systems to calibrate measurements of ancient climate. "I didn't think that paleoclimate was something that people would get excited about," she said. "I'm really surprised and happy." In May, Bitterwolf represented UCSC at the UC-systemwide Grad Slam at the offices of LinkedIn in San Francisco, where she competed against the champions from the other UC campuses. To learn the final results and watch the presentations, point your browser to *gradslam.universityofcalifornia.edu*.

By Sarah C. P. Williams



Scanning electron micrographs of an entire *V. cholerae* biofilm colony (left) and a small section of a biofilm (right). The colony contains cells producing ample matrix (wrinkled part) and cells producing less matrix (smooth part). Credit, all images: Fitnat Yildiz.

Canvassing bacterial communities

Targeting biofilms to bust cholera

From above, the cholera colony looks like a piece of brain or a work of modern art. Deep grooves wind between wrinkly mountains of *Vibrio cholerae* bacteria. It's tempting to reach out and touch this living landscape, but one swipe could kill. This is the same bacteria that sickens millions of people around the world each year, killing many of them, and it's especially dangerous in its current form: a biofilm.

Bacteria are single-celled organisms; by definition they exist and function as lone entities. But to protect themselves from environmental stressors and optimize resources, groups of bacteria often interact, building communities held together with a kind of molecular glue. By virtue of their teamwork, their sheer number, and their structural properties, bacteria in these biofilms are more of an environmental nuisance and health hazard than populations of solo bacteria. That's why researchers like **Fitnat Yildiz**, UC Santa Cruz professor of microbiology and environmental toxicology, are seeking to better understand biofilms. The goal? To develop new strategies to prevent biofilm formation and potentially discover new drugs urgently needed to combat the often antibiotic-resistant diseases caused by these bacterial communities.

"Scientists used to believe that most bacteria were free-living," said Yildiz. "Now we know that the majority of bacteria live on surfaces in biofilms, and yet we understand very little of biofilm biology. There's a lot to be discovered."

Bacterial biofilms of one sort or another are everywhere: coating your teeth before you brush them and making your dirty dinner dishes slimy when they've sat in the sink overnight. They can grow so large they clog sewage pipes and cover the bottoms of ships. And they cause infections when they grow on the lining of a person's lungs, gut, or urinary tract, or on contact lenses, pacemakers, artificial heart valves, or replacement joints. Yet the vast majority of all research on bacteria—including antibiotic development—is performed using bacterial cultures containing bacteria in their single, or planktonic, form.

By focusing on *V. cholerae* in biofilms, Yildiz's lab has already revealed many of the major components of biofilms, including the molecules that make up the matrix—or glue—between the bacteria. The researchers have now turned their focus to how these components interact and how microbes know when to form a biofilm. "If you know what's in the matrix and how all these steps are regulated, you can use it to your advantage," said Yildiz.

Gripping and grabbing

In nature, cholera bacteria live in rivers and estuaries, alternating between a solo, free-floating "planktonic" state and biofilms depending on all sorts of poorly understood environmental factors including salinity, temperature, and nutrient availability. In general, though, it seems that harsher conditions promote biofilm formation, with the gatherings acting as a kind of safety net for bacterial survival.

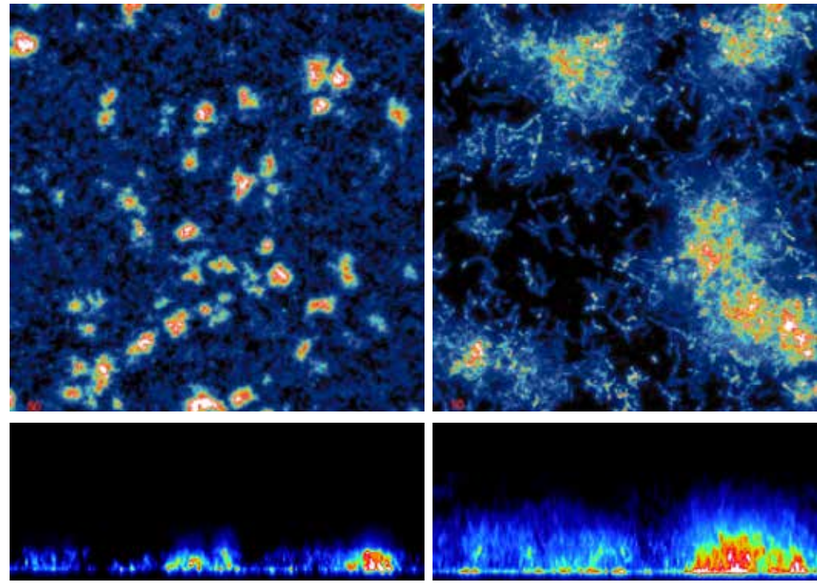
Like all biofilms, *V. cholerae* biofilms form on surfaces. They often coat the exoskeletons of tiny plankton, which explains why large plankton blooms often go hand-in-hand with cholera outbreaks.

The first step in making a biofilm is when individual bacteria attach to a surface—whether on the shell of a plankton, the lining of your gut, or the interior of a sewage pipe. For *V. cholerae* and many other pathogens, clutching onto a surface involves pili—hair-like appendages that extend from the bacteria. Some types of bacteria also use pili to move, extending and retracting them like grappling hooks. *V. cholerae*, though, mostly rely on their single long flagellum—like the tail of a sperm—to swim in a fashion characteristic of the genus. When they first reach a surface, weak interactions between pili and the surface may cause them to move in small tight circles.

Without pili, bacteria like *V. cholerae* can't attach to a surface and can't form biofilms. So understanding how cells produce and control pili is critical to understanding biofilms. But there are more questions than answers about these miniscule limbs.

"Right now, we don't know a lot about how the bacteria regulate the production of pili," said **Kyle Floyd**, a postdoctoral fellow in the Yildiz lab. "We also don't know exactly how they sense a surface."

What is known is that a signaling molecule found only in bacteria, called cyclic dimeric guanosine monophosphate or c-di-GMP, is required for the



Confocal microscopy shows growing (left) and mature (right) *V. cholerae* biofilms. Bottom panels show side views. The intensity (black to red and white) correlates with bacterial density.

cells to latch onto surfaces. In 2015, the Yildiz group discovered that c-di-GMP binds directly to a molecular motor that helps assemble MshA, the main protein component of pili. C-di-GMP, as reported in *PLOS Pathogens*, promotes the assembly of MshA, leading to new pili. The higher the levels of c-di-GMP, the more MshA is made and the more pili that can form.

To uncover more about this interaction, as well as what other molecules help *V. cholerae* sense surfaces and produce pili, Floyd is now labeling pili proteins with fluorescent tags, so he can see and study them in real-time. "Hopefully we'll be able to watch them extend and retract," he said. "And once we can do that, we can start manipulating other molecules and observe the effect on pili." Learning how to stop bacteria from producing pili, he added, could lead to ways to completely block their ability to form biofilms.

The matrix revealed

A biofilm isn't just composed of bacteria that gather on a surface, pili tightly gripping each other. To form a biofilm, the bacteria must produce the sticky molecular matrix that holds them together. Biofilm matrices are mostly composed of large sugar molecules called exopolysaccharides, but also include proteins, fats, and even bits of DNA.

In *V. cholerae* biofilms, Yildiz and her colleagues had previously shown that the major components are *Vibrio* exopolysaccharide (VPS)—about half the mass of the matrix—and the proteins RbmA, RbmC, and Bap1. In a recent collaboration with **Carrie Partch**, associate professor of chemistry and biochemistry, the researchers created mutant versions of RbmA that let them probe exactly how the protein contributes to biofilm formation. As recently reported in *eLife*, RbmA binds directly to VPS, helping to organize the exopolysaccharide structure.

"This was really exciting work," said Yildiz. "It is the first direct interaction we've shown between matrix components."

But that wasn't all the RbmA mutants revealed. The team also showed that the protein has multiple possible forms—an open conformation and a more closed conformation, as well as a processed, shorter version. When the researchers mutated RbmA, locking it in the closed formation, the normally mountainous *V. cholerae* biofilm instead appeared smooth and shiny, suggesting a role in biofilm conformation. In the initial stages of biofilm formation, Yildiz hypothesizes, full-length, RbmA is required to switch between closed and open conformations to bind VPS and coax the sugar molecules into the right architecture for a strong biofilm. Later, when the biofilm is more structured, this relationship isn't needed, and VPS takes on its shorter form. In this short form, the protein may have other functions, potentially including recruiting bacteria that aren't yet producing VPS to join the community.

Another biofilm question the lab is focusing on is how VPS is produced in the first place. To address this, postdoctoral fellow **Carmen Schwechheimer** has homed in on two proteins with seemingly opposing functions—VpsO and VpsU. While the work is still ongoing, Yildiz's group has shown that VpsO is a tyrosine kinase, an enzyme which adds a phosphate chemical group to tyrosine—a nucleic acid building block of proteins. VpsU, on the other hand, is a tyrosine phosphatase, which does the exact opposite—removing phosphates from tyrosine. In addition, VpsO itself switches between a phosphorylated and nonphosphorylated form. And when it does this, it appears to interact with VPS.

"It seems like you need that cycle of phosphorylation for the matrix to form," said Schwechheimer. "If you delete VpsO, the bacteria don't make exopolysaccharides and don't form biofilms, so it's clearly critical."

Schwechheimer is working with professor of chemistry and biochemistry **Seth Rubin** and his lab members to create tyrosine-mutated VpsO variants. These should enable the researchers to determine which tyrosines in the VpsO protein are phosphorylated, and how the changes contribute to VPS production. The kinase, Schwechheimer said, is particularly attractive to study because it's different from any of the native tyrosine kinases found in mammals, including humans. That means that drugs blocking VpsO—and biofilm production—would likely not impact the many tyrosine kinases that are endogenously expressed in the human body. "It definitely has potential as an antibiotic target," she said.

Sending signals

Underlying all these molecular mechanisms is the central question of how bacteria first sense changes in their environment that trigger them to start building biofilms. "In bacteria, everything is about sensing and responding," said Yildiz. "Cholera has to respond to all sorts of changes in its environment, from changing salinity in the water to a whole new set of factors when it's ingested by humans."

A killer with history

Anywhere from a few hours to a few days after being exposed to cholera, the vomiting and uncontrollable, watery diarrhea starts. As your body loses water, your muscles cramp, and your eyes and mouth feel as dry as cotton. When people die of this disease—sometimes within mere hours after symptoms appear—it's because of dehydration. When they survive, it's because they stayed hydrated through this seemingly endless diarrhea and vomiting.

In the 16th century, people living in the Ganges River delta—near the border of modern-day India and Bangladesh—called cholera "moryxy" and one historian wrote of how it killed so many that communities struggled to bury all their dead.

A cholera treatment facility operated by Partners in Health in Mirebalais, Haiti, in 2011. Credit: © Kendra Helmer/USAID, Wikimedia Commons.

In 1817, contaminated rice from the Ganges delta began cholera's spread around the globe. Within six years it had killed hundreds of thousands of people in Thailand, Indonesia, the Philippines, China, Japan, the Persian Gulf, Turkey, and Syria.

In 1829, another cholera pandemic emerged, again following trade and military routes from India—this time heading to Russia, where it killed hundreds of thousands, then spreading throughout Europe, thanks to Russian soldiers, and finally reaching North America by the 1840s, where it claimed the life of former U.S. president James Polk, as well as hundreds of thousands of others.

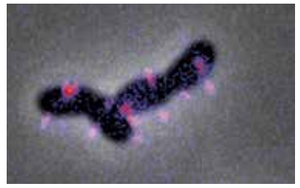
Throughout the 19th century, cholera epidemics and pandemics continued around the globe, spreading with the global movements of immigrants and travelers. During a large 1854 outbreak in London, physician John Snow discovered that a contaminated pump was responsible for spreading the disease—a finding credited with making Snow the father of modern epidemiology and eventually leading to hygienic changes in the water and waste systems of major cities.

In recent years, the vast majority of cholera cases have occurred in Africa, with occasional small outbreaks in Iraq and India. In 2010, after a massive earthquake weakened Haiti's already poor public health and sanitation infrastructure, cholera began to spread throughout the country. Hurricanes and slow rebuilding efforts led to a ripe ground for further spread over the coming years, and, as of 2017, over 800,000 Haitians were sickened, and nearly ten thousand died of the infection.

In Yemen, a cholera epidemic that began in 2016—tied to the ongoing war and collapsing infrastructure—has sickened more than a million people and killed thousands. Based on the suspected number of cases, it's considered the worst cholera epidemic in history and is not currently under control.

Canvassing bacterial communities

Researchers know that c-di-GMP is one of the important intermediaries in this sensory cycle, helping to communicate messages within bacterial cells. Its role isn't just limited to producing pili, as Floyd is studying, but also appears to include biofilm and matrix formation more broadly. Studies by Yildiz and her colleagues over the past two decades have shown that high levels of c-di-GMP mean production of higher levels of a variety of proteins needed to produce biofilms. Currently, postdoctoral fellow **Jin Hwan Park** is leading a project to study how c-di-GMP inhibits *V. cholerae* motility and controls biofilm matrix production.



Overlay of fluorescence and phase contrast images shows pili (pink) on the surface of several *V. cholerae* cells.

"C-di-GMP is a key, bacterial-specific signal for biofilm formation and maturation. Because it is not found in the host, it could make an outstanding drug target," said George O'Toole, professor of microbiology and immunology at the Dartmouth Geisel School of Medicine and another biofilm expert. Work by the Yildiz lab on c-di-GMP has inspired studies in his own lab, he added.

But exactly how c-di-GMP receives an initial signal to trigger biofilm formation remains unclear. Yildiz and former graduate student **Andrew Cheng** (now a senior scientist at Whole Biome, Inc., in San Francisco) wondered whether a two-component system might play a role. Common in bacteria, these systems are made up of two proteins—one that senses conditions outside the organism, and a "response regulator" that reacts, carrying out changes inside the cell. "Two-component systems are capable of sensing environmental conditions and telling bacteria how to adjust their physiology, so it certainly makes sense that these could be involved in biofilm formation," said current graduate student **Jennifer Teschler**.

Teschler, Cheng, and Yildiz deleted all 52 known response regulators in *V. cholerae*, one at a time, and studied the effect of each deletion on the bacteria's ability to form a biofilm. Seven of the response regulators, they found, impacted biofilm formation, with the biofilms developing abnormally in their absence. One, called *vxrB*, had never been characterized before so the researchers looked at it in more detail. Levels of *vxrB,* they discovered, impacted levels of c-di-GMP. Their findings, published in the *Journal of Bacteriology*, suggest that a two-component system involving *vxrB* could be one way that *V. cholerae* senses environmental changes, triggering, in turn, the increase in c-di-GMP that promotes biofilm formation.

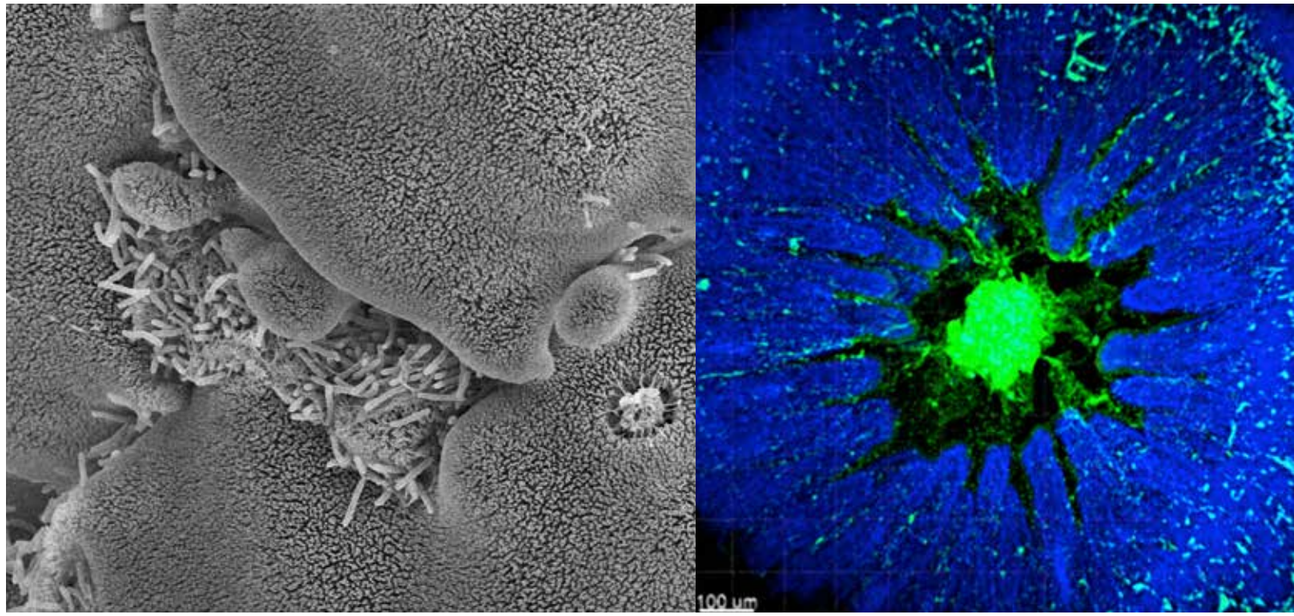
Biofilm busters

In the U.S. alone, it's estimated that every year nearly 2 million hospital-acquired infections involve bacteria in their biofilm state, costing health-care systems more than $10 billion. These infections are often resistant to antibiotics—in some cases, it's hard for the drugs to penetrate the dense biofilms; in others, antibiotics simply don't work against the altered molecular state of the biofilm-associated bacteria. When a replacement knee or hip becomes coated with a biofilm infection, a complication affecting as many as 2% of patients, the standard treatment recourse is repeat surgery to replace the prosthesis. In general, antibiotic resistance remains a critical and persistent public health concern, for which new drug strategies are urgently needed.

As with other bacterial pathogens, it's clear that *V. cholerae* in biofilms are more infectious than bacteria in their planktonic form. A study in Bangladesh showed that using even a crude filter—such as one made from sari cloth—to filter drinking water can reduce the incidence of cholera by nearly half. That's in part because such a filter removes the microscopic plankton that are coated with the most dangerous, biofilm-associated bacteria, Yildiz said.

When biofilm-associated *V. cholerae* are ingested, though, what happens to them in the human gut remains unclear. In a collaboration with **Roger Linington**, a former UCSC associate professor of chemistry and biochemistry now at Simon Fraser University, Yildiz discovered that bile acids, which break down fats in the gut, can disperse biofilms. But studies of cholera patients have found evidence of intact biofilms in their stool samples. This suggests that bacterial biofilms may be broken up during early digestion, but form again during later stages of infection. In the human disease setting, "There's this interesting dispersal and reformation cycle going on," said Yildiz. "And there are certain situations in which bacteria really need to form biofilms to be better protected, and other times it's perhaps not as advantageous." Studies focused on this important area, the molecular biology underlying *V. cholerae* biofilms *in vivo*, are being led by postdoctoral fellow **Ana Gallego**.

With Linington, who specializes in screening natural products for their therapeutic potential, Yildiz has helped identify other molecules that break up *V. cholerae* biofilms. She hopes this combination of natural chemical screening for existing anti-biofilm molecules plus working out biofilm biology to rationally design drugs will eventually lead to new antibiotics to treat biofilm-associated infections. Such drugs could stop pili from extending, keep exopolysaccharides from assembling to form a matrix, or block signaling by c-di-GMP, among other mechanisms.



Scanning electron (left) and fluorescence (right) micrographs of *in vivo* intestinal *V. cholerae* biofilms. In the image on the right, epithelial cells—those that line the gut—are blue and the bacteria are green.

And while Yildiz's research focuses on *V. cholerae*, other researchers are focusing on the biofilms of other bacteria. At Dartmouth, for instance, O'Toole mainly studies *Pseudomonas aeruginosa*, which forms biofilms in the lungs of cystic fibrosis patients. He said, however, that *V. cholerae* is a good choice for this work. "*V. cholerae* is a terrific model. The factors that drive maturation of the biofilm for *V. cholerae* are conserved across a number of other microbes."

As always, there's a lot more research to be done. Not many biofilms in the natural world are composed of a single species of bacteria, Yildiz said. An additional important question for biofilm researchers moving forward is how different species of bacteria interact. Just as biofilm research has uncovered a more complicated biology than that associated with isolated bacteria, investigating how biofilms relate to the larger picture of microbiomes will likely add even more complexity. "Nothing lives in isolation, and—as with so much of biology—the challenge is going to be seeing what happens when we start increasing the complexity of biofilms," said Yildiz. "Will everything we've found so far still hold true?"

By Adam Mann

A window to the early universe

Witnessing the birth of galaxies

Astronomers are using the Atacama Large Millimeter Array (ALMA)—a radio telescope with 66 massive antennas ("dishes") in the Chilean desert—to observe celestial phenomena that occurred near the dawn of time. Credit: ESO/C. Malin, public use.

▶ The present day is relatively dull, cosmologically speaking. Most of the action happened in the first few billion years after the Big Bang, when enormous swirls of gas and dust collapsed down to produce the earliest stars and galaxies, filling the universe with their light. Half of today's stars arose during this peak era of formation.

Teasing out the details of this active early epoch has proven difficult. It's only recently that astronomers have switched on facilities like the Atacama Large Millimeter Array (ALMA), one of the world's most powerful radio telescopes, allowing them to draw back the curtain to very nearly the dawn of time.

"With these new tools we will be able to really map out the distribution of star formation in individual galaxies 12 billion years ago," said **J. Xavier Prochaska**, UC Santa Cruz professor of astronomy and astrophysics and ALMA researcher.

Astronomers have used sophisticated computer models to develop ideas about this period. Simulations of the effects of dark matter and dark energy, plus the matter content of planets and stars, show virtual galaxies coalescing out of an unstructured fog. The results suggest that uneven distributions of massive dark matter drew gas and dust into galactic knots, where the material cooled and fragmented into stars. Astronomers have long awaited physical data to corroborate or challenge these views, and ALMA—which became fully operational in 2013—has begun to deliver.

Observatories like ALMA work in radio bands, searching for light coming from the glowing gas and dust present in the first galaxies. Only slightly warmed by young massive stars, this material is much fainter and further away than recently formed objects. ALMA, located in the Chilean high desert, can capture these light signatures with its large array of 66 massive antennas ("dishes").

A quasar was originally used to indirectly find this distant galaxy (*) in the early universe. When researchers used ALMA to directly image the object, it was 100,000 light-years off from where they thought it would be. Credit: Neeleman & Prochaska (UCSC), courtesy of Xavier Prochaska.

"It's sort of a new window, and when you open a new window you see different physical phenomena," said Christopher Carilli, who also studies the earliest galaxies at the National Radio Astronomy Observatory, a major radio telescope facility in the U.S. that hosts the North American ALMA Science Center. Whereas most astronomical observations have been of stars, "the focus is now shifting to the source of those stars, and completing the picture of the conversion of gas to stars as a function of cosmic time."

Some limited physical clues were already available. Strange cosmic beats called quasars formed during an even earlier period, sending out powerful light beams that intersected the later gas and dust, imparting characteristic signatures onto it. Astronomers have used these indirect observations to locate and study a few early galaxies.

As reported by Prochaska and colleagues in a 2017 paper in *Science*, the more direct ALMA observations have produced surprises. For instance, quasar light had pegged one of the team's galactic targets to a specific location. But ALMA placed the object about 100,000 light-years away, suggesting that the quasar light had passed through a much-larger-than-expected halo of gas and dust. The galaxy also glowed much brighter than predicted, indicating prodigious star formation of roughly 100 suns per year, 100 times greater than the modern rate.

And this is just one galaxy. These first observations mainly show that ALMA, built in part for this purpose, is capable of performing as planned. Prochaska and collaborators intend to follow this promising early work with close looks at the births of many more galaxies. "It's inspired us to start a large survey of these phenomena," he said. "That's really how you learn and rigorously test these models of galaxy formation."

By Katharine Miller

Detecting human diversity

Variation graphs facilitate genomic discovery

▶ After the first human genome was successfully sequenced in 2003, researchers established it as *the* reference genome. It became the singular, highest-quality, most well-understood, standardized genome against which all other human genomes would be mapped and compared for the foreseeable future.

It turns out this commitment to a single reference genome has a big downside. Called reference bias or mapping bias, it can cause potentially important observations to be misinterpreted or rejected when they don't fit the expected pattern. "With the existing reference genome," said **Benedict Paten**, UC Santa Cruz assistant professor of biomolecular engineering, "it's easier to find variants that are in the reference genome than ones that aren't."

The problem is particularly acute for structural variations in the genome—long stretches of DNA that differ from the reference in various ways, including changes known as insertions, deletions, inversions, and translocations. When these interesting and potentially important variants exist in a new sample that is being mapped against the reference, they might not be seen at all. As a consequence, the new sample is deemed more similar to the reference than it actually is. The failure to find important variants can have consequential downstream implications for patients if a missed variant is the cause of a genetic disorder or plays a key role in a patient's cancer. And as the pace of sequencing-based genomic research continues to increase, so too have the potential impacts of reference bias.

Above: UCSC assistant professor of biomolecular engineering Benedict Paten (left) with the genome graphs team: (left to right) graduate students Charles Markello and Yohei Rosen, and senior software engineer Adam Novak. The genome graph visualization on the computer screen was created by Wolfgang Beyer. Credit: Tina Bernard.

To address this critical and growing concern, Paten and colleagues at UCSC and the Sanger Institute set out to build a set of technologies for replacing the existing reference genome with a more comprehensive foundational structure. "The natural thing is to have a graph that includes all the known gene variants," Paten said. And though the idea of replacing the linear reference genome with a graph might sound simple, he said, "we've had to solve some pretty tricky computer science problems to make this work."

Having a great solution doesn't mean it will be used, especially given the deep entrenchment of the single reference genome in the field. Nevertheless, even members of the Genome Reference Consortium who've spent their careers maintaining and improving upon the linear reference agree that genome variation graphs make sense. "The representation of variation in the human population is a type of data that fits very neatly into and is well-represented by a graph model," said Valerie Schneider, program head for sequence displays and tools at the NIH's National Center for Biotechnology Information (NCBI) and team lead for the NCBI's involvement in the Genome Reference Consortium. "Benedict is at the leading edge of where this is going."

Tina Graves-Lindsay, leader of the reference genomes group at Washington University's McDonnell Genome Institute in St. Louis, agreed, "When we get to the point where they're ready to be used, genome graphs are the future representation."

Genomic fake news

Understanding the source of reference bias requires at least a passing understanding of how sequencing technology works. The most common approach to genome sequencing today relies on repeated sequencing of short stretches of DNA—typically 100–600 base pairs (the A, C, T, and G nucleotides that make up DNA). Researchers generally try to get 10x to 30x coverage of every portion of a genome using these short "reads." They must then piece these together to create a contiguous model of a person's genome, a task accomplished by mapping the short reads against the latest generation of the very first genome ever sequenced—the human reference genome, now in its 20th iteration (*GRCh38*). During this genome assembly task, the reads are scored relative to how well they match the reference. "The more similar a read is to the reference genome, the higher probability that the mapping will be deemed correct," Paten said. As a result, reads that diverge from the reference may map incorrectly or fail to map altogether.

For example, if a researcher tries to map 100–600 base-pair short reads from an individual who has a 10,000 base-pair insertion that isn't represented in the reference, this structural variant gets a poor matching score. Essentially, there is no place to map those reads against the reference, and the insertion is ignored.

It's also true that no single reference can truly represent the genetic diversity present in a worldwide population full of varied and interesting ethnic groups. Curiously, the human reference genome used today does not even represent the set of genes from a specific human being. This mosaic model of a single set of unpaired chromosomes gets 70% of its 3-billion base-pair DNA sequence from a single male of mixed African and European ancestry, and the remaining 30% from an assortment of more than 50 individuals. "The idea at the time was that a linear reference derived from many individuals would be a good way to capture diversity," said NCBI's Schneider.

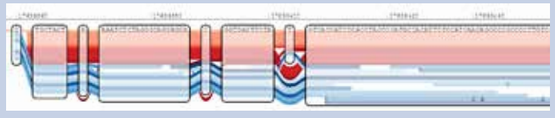
We now know that humans are more genetically diverse than expected. Today, geneticists estimate that the average person's genome differs from the reference by about 3.6 million base-pair changes, called "SNPs" (pronounced "snips") or single-nucleotide polymorphisms. In addition, each human genome contains about 2500 structural variations that aren't included in the reference—variations that affect about 8.9 million bases per person. The human genome variation graphs developed by Paten and collaborators capture and display all this diversity in one visualization.

Graphing genomes

To imagine a genome variation graph, picture the 3-billion base-pair linear reference genome itself as a single path through a graph with an incredibly long horizontal axis. Next, imagine many other paths converging with the reference for stretches where their sequences are identical, but diverging at other points before converging again. One divergence might be a bubble that represents a single nucleotide change; another might be an inserted sequence or even an inverted stretch of DNA that can be conceptualized as a loop-de-loop that leaves the path and rejoins it. There can also be bubbles within bubbles or loops that have additional divergences internally. Any observed variant can be accounted for in the graph representation. "The graph captures information about what we'd expect a human to look like in a computationally practical

Genomic graph visualizations

A.



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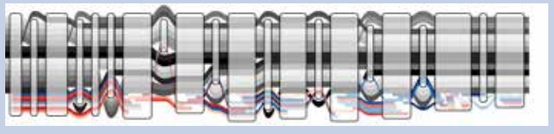

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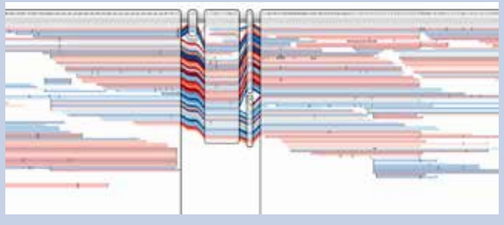


D.

In these visualizations of Paten's human genome variation graph (created with ivg, the visualization portion of the vg toolkit), the continuous lines toward the top of the graphs represent haplotypes (known genomic sequences from one of a given person's two chromosomes) in a 2500-person population cohort. The shaded rectangles represent nodes (shared DNA sequences) with the node's nucleotide sequence (A, C, T, or G) shown at top. The colored ribbons between the nodes are paths/edges (not sequences). When a haplotype's path bypasses a node, this signifies a deletion of the sequence at that node. The segmented lines below the haplotypes (in A, B, and C) are sequence reads aligned to the haplotypes. Like the haplotype paths, these sometimes bypass a node, signifying a deletion of the sequence at that node. **A.** In this zoomed-in visualization of the human genome variation graph for a short sequence from human chromosome 22, the red lines represent seven haplotypes and their widths encode their prevalence in the population. **B.** In this zoomed-out visualization of a different piece of chromosome 22, the nodes are actually longer than the longest ones in A but are compressed horizontally (leaving insufficient room to label them with their nucleotide sequences). Here, 13 haplotypes are shown in gray with unvarying widths. Forward sequence reads are shown in shades of red, while backward reads (from the opposite strand of the DNA) are shown in blue. **C.** Here we see a sample with higher read coverage. Haplotypes are grey, forward reads are red, backward reads are blue, and the letters on top are the sequences of the graph's nodes. Letters, asterisks, and grey rectangles shown on the reads are, respectively, substitutions, insertions, and deletions. When viewed on a computer, one can hover the cursor over an asterisk to see the inserted sequence. **D.** The visualization tool can also provide an intuitive graphical view of inversions, as shown by the green and red loops in this simulated example.

Credit: Courtesy of Benedict Paten and Wolfgang Beyer, software developer for the Computational Genomics Laboratory at UCSC.

manner," Paten said, "so that when we get a new sample we can infer things that are correct."

Ultimately, the linear reference genome will be just one path through a graph that contains many possible paths. Any other haplotype (the set of alleles—gene variants—a person inherits from each parent) could be represented as a path as well. While that might sound like a simple concept, it presented a challenge for Paten's team: how to encode a population's haplotypes through a graph in a way that would be small, compact, and searchable on a computer? "We found a really beautiful solution to that," Paten said, which involves weighting different paths according to their prevalence in the population. "If I trace a path through a graph that might correspond to a haplotype, it's actually very useful, from a genetics point of view, to be able to ask, 'What's the probability of that path given what we know about the population?'" Paten said.

The team also had to establish a novel coordinate system for the human genome variation graph. "When you live in the topsy-turvy world of graphs, it isn't initially that clear how you represent alleles and sites," Paten said. The coordinate system for the linear reference genome is straightforward. Each chromosome begins at a point A and ends at a point B with defined locations all along the way. To define the unambiguous position of an allele in a genome graph (as well as what its alternatives are) and do it in a way that works for all forms of variation, "took some really hard thinking," Paten said. But it is a problem his team has now solved by developing a mathematical model that represents an allele's coordinates relative to its neighbors.

"The graph is a way to organize a population's genomic information together so that we can answer questions in an efficient manner," Paten said. Given a new sample, it should be easier to find the variants it shares with the population because they are already contained in the graph. And finding new variants should also be easier because the graph allows researchers to make better inferences about what's possible or probable.

Paten's human genome variation map currently contains data from a 2500-person cohort. To these he plans to add additional variant information from 150,000 individuals. But the 2500-person graph can already do almost as good a job as the linear reference genome at finding small genome variants (e.g., SNPs) in a new sample, and a far better job of finding structural variations, particularly if these involve long stretches of DNA, Paten said.

Transition tools

As previously mentioned, in the field of genomics where large data sets that rely on the linear reference already exist, changing the foundational structure for genome mapping won't happen overnight. Even uptake of formal updates to the linear reference is slow. *GRCh38*, the current iteration of the standardized reference genome, was released more than four years ago, yet many projects are still using *GRCh37*, Paten said. "It takes that long to accomplish all the things you have to do to switch from one to another—it's an enormous headache."

Paten predicts the shift to the genome graph will be even slower and may also proceed in an uneven way. During the transition, it's likely that researchers will use the graph and then project their findings back onto the reference genome, he said. "This should provide a compatibility layer for a good while." Indeed, he said, the graph may never fully replace the reference genome, "but that's just fine because it's just a set of paths in our graph."

The shift to genome graphs also faces major technical hurdles. All of the tools for genome mapping and variant analysis are built around alignments to one linear reference. "When you introduce these new models, such as graphs, you need a robust tool suite that can take advantage of the additional information," Schneider said.

To that end, Paten's team has created a software toolkit called "vg" (short for variation graph). Publicly available on GitHub, vg is already the most popular software of its kind, Paten said. "Several hundred people have started trying to use it. That's not big, but it's promising." Paten also plans to release probability-weighted paths for the current map's 2500 human genomes in the next year.

Eventually, Paten hopes there will be consensus around the human genome variation graph just as there is now consensus around the linear reference genome. The graph model offers an intuitive way for computers to infer the next genome, he said. "It's a much better basis for making inferences in human genomics." And that could ultimately power much more precise precision medicine.

By Cameron Walker

Viewing lost landscapes

Home movies capture history through a personal lens

▶ During the late 1930s, Ivan Besse, a theater manager in Britton, South Dakota, filmed home movies of his town and its inhabitants and showed them as shorts before the features he screened at the local Strand Theater. In these films, men husk corn, snowstorms blow in, kids pour out of the schoolhouse at the end of the day—each scene recording a moment of daily life during the waning years of the Great Depression.

When UC Santa Cruz professor of film and digital media **Rick Prelinger** found these films 50 years later, he was enchanted, and brought them back to Britton to show them again on the Strand's movie screen. During most films, the audience sits silently while the movie plays. But this time, when Prelinger turned on the projector, people started talking. They pointed at the screen, calling out the names of people, of places, of relatives and friends—some long gone, others, like Besse, sitting in the theater with them. "I'd never seen people talk back to the screen like that," said Prelinger.

Prelinger, a film archivist, had been amassing a collection of "forgotten" 20th-century films, from advertising to educational and industrial films, to government-sponsored shorts. Home movies like the ones he showed in South Dakota turned him into a filmmaker. In the *Lost Landscapes* series, his compiled and edited films provide portraits of a city and its people through this most personal of lenses. So far, he's presented films about San Francisco,

Left: UC Santa Cruz professor of film and digital media Rick Prelinger sorts through his extensive collection of ephemeral film and home movies, part of the Prelinger Archives. Credit: Megan Prelinger. Top: Still image from Prelinger's 2013 film *No More Road Trips?*, an automobile-based adventure across the country as told through home movies. Credit: The Prelinger Archives.

Viewing lost landscapes

Still images from Prelinger's 2017 film *Lost Landscapes of New York* capture the prewar atmosphere at a 1936 May Day parade (right) and, in postwar 1948, an informal gathering on an East Harlem street corner. Credit: The Prelinger Archives.

Detroit, Oakland, Los Angeles, and, in 2017, New York City. He has also created several thematic films, including *No More Road Trips?*, an automobile-based adventure across the country, told through home movies. For researchers, home movies can broaden their understanding of issues such as gender dynamics and reveal history not caught on mainstream film. The films also offer a path to the future, Prelinger said, one in which people can collectively experience these images of the past and use them to help shape what they want their communities to become.

Personal to public

Home movies are typically considered second-class citizens of the film world. "Home movies have been treated by professionals and cinema experts—scholars, critics, and serious filmmakers—as something that hobbyists and amateurs did that was of, at best, documentary value," said Prelinger's UCSC colleague **Jonathan Kahana**, professor of film and digital media. People began using handheld movie cameras in the 1920s, and their use expanded in the following decades. These cameras allowed people to record their personal lives—from family birthdays to summer vacations—and to preserve and share these memories on a small scale. Capturing time, places, and people through a small lens, the resulting movies were "treated as unskilled, unpolished, unreliable, and, to anyone but their subjects, nearly unwatchable," Kahana said.

But as Prelinger observed in the South Dakota theater, these movies are transformed when they emerge from the family room, and so are the people watching them. "Something very interesting happens when movies made for showing on a small scale get blown up to the size of a theater screen. Details jump out. Audiences become much more contemplative," he said. Viewers pick out buildings lost to modernization, recognize changing styles in clothing and social interactions, and become cultural ethnographers and geographers in their own right. "Home movies," said Prelinger, "turn ordinary viewers into sophisticated visual analysts."

While usually intended to document personal moments, home movies also preserve the landscape that surrounds them. Scenes of children riding bicycles down the street can include backdrops of buildings now lost to new developments; footage of rural areas may document the arrival of telephone lines, roads, tracts of homes in place of fields. In Prelinger's films of San Francisco, footage from a glider club in the 1920s reveals a Sunset District covered with dunes, not houses. "These films create a visual history of the 20th century, captured by people who didn't have public agendas, who weren't working to an official brief," said Heather Norris Nicholson, visiting researcher at the University of Huddersfield, United Kingdom.

Hidden history

Home movies, and the films that Prelinger has made from them, reveal lost cultural as well as physical landscapes. Once 8 mm cameras and film were introduced in 1933, home movies became more affordable and accessible to a wider segment of America, enabling families of color and those in working-class and rural communities to start shooting their own films.

In editing footage for his San Francisco films—he has been showing a new one each year since 2006 to sold-out crowds—Prelinger uncovered movies from a 1950s Latino family that showed them celebrating birthdays, confirmations, and family holidays. "The family is so charismatic. Their body language is a joy to observe," he said. Their home movies counter the notion that working-class San Francisco at the time was all white and Catholic; other segments show street scenes with diverse pedestrians, the homeless population in the 1950s before the South of Market area was developed, African Americans in the crowd at the 1956 Republican Party Convention. "There's a sense of justice in filling gaps in the record," said Prelinger, who joined the UC Santa Cruz faculty in 2013.

This information can help shift preconceived perceptions about the past. Nicholson, coauthor of the forthcoming book *British Women Amateur Filmmakers: National Memories and Global Identities,* said one of the things she loves about amateur film is its ability to "open up alternative ways of seeing place and people and experiences of the past." While most people think of the 1950s as a single decade where everyone had the same traditional experience, these small, filmed moments show the heterogeneity of the past. For example, films made by the head teacher of a northern English nursery school during this period document many men dropping off and picking up their children. This could counter the notion that men were not as involved with child care during that time. But it could also reflect male unemployment in the area, or parents needing to balance shiftwork at the local mill. "There is always so much that remains unknown and unknowable with amateur film, whether visual details or a filmmaker's intentions, or what was just out of view," she said. "This is why it challenges our ways of thinking about the past."

Forgotten films

Prelinger's initial entry into film collection was through what he calls "ephemeral film." From government films showing what to do in the event of a nuclear bomb, to business films training workers on a new project, to educational material for high school students, these films were made for a purpose—and were usually discarded once their useful life seemed over. In 1982, Prelinger began collecting these films, some straight from the dumpster, others from production companies that were closing their doors or transferring their film collections to videotape. At some point, he realized this footage provided visual evidence of a hidden American history. The films show everyday life, the environment, and visual records of culture, including dress and hairstyles. But they also contain subtle, pervasive fingerprints of the past, revealing, for example, how the government aimed to create and encourage patriotism and how society defined and reinforced gender roles.

"These are some of the richest artifacts telling stories about the time period in which they were made," said Howard Besser, professor of cinema studies and associate director of the Moving Image Archiving and Preservation Program at New York University. "In fact, if you're trying to understand gender dynamics in the '50s and '60s, one of the best places to look is the instructional films kids were being shown in school." Ephemeral films, including advertising and other promotional material, provide "amazing insights into the mindsets and ideologies of a particular time," Besser said.

Prelinger's interest in these films grew into the expansive Prelinger Archives, a San Francisco–based collection of more than 60,000 films. By the end of the 1990s, he realized that, rather than just sitting in a New York warehouse, these films would be best preserved as part of a public resource. In 2002, the Library of Congress acquired most of the films as the Prelinger Collection. A number of the films can also be accessed online as a companion piece to Prelinger's 2006 book, *The Field Guide to Sponsored Films*.

Making both these ephemeral films and home movie footage available for a wider audience is an essential part of Prelinger's work. Currently, the Prelinger Archives has approximately 7,000 films digitized and available online for people to view, download, and create their own projects. Prelinger estimates that hundreds of thousands of projects have been created from the archives since 2001.

Such open, reusable film archives are unusual, with many closed to all but select researchers pursuing scholarly projects. While this is changing, very few archives allow visitors to watch short segments of film online and to download and use them in their own work. "The old archive is a place things go to die. They're like mortuaries—you can go in and look at the dead bodies," Besser said. Instead, he said, film archives should be "lively places" that facilitate interactions with a wide community.

Community building

That lively place is in evidence at *Lost Landscapes* screenings, annually in San Francisco and at frequent special showings and film festivals around the

Still image from one of Prelinger's *Lost Landscapes in San Francisco* films shows women from a Latino family dancing on San Francisco's Ocean Beach, circa 1951. Credit: The Prelinger Archives.

Viewing lost landscapes

country. "In a way, the actual screening of the edited works is an extension of the idea of opening up the archives," Besser said. "People are contributing cataloging to the work as they're watching. What used to take place in a darkened back room is now happening in the public space of a theater."

Tom Rankin, a professor in the Art, Art History & Visual Studies Department at Duke University in North Carolina, concurs. Recalling a screening he attended of *Lost Landscapes of Detroit*, he said the conversation started less than two minutes into the film, and continued throughout. "As someone who never lived in Detroit, I merely listened, feeling like I was at a combination of a family gathering and a graduate seminar in cultural geography," he said.

Prelinger is trying to further expand this community participation by giving the films he's made back to the public. In some cases, he has transferred *Lost Landscape* films to local residents, allowing them to use the films to build and create community ties in whatever form they envision. In Oakland, filmmaker, writer, and artist alex cruse has screened *Lost Landscapes of Oakland* both with Prelinger, and, more recently, on her own. This year she plans to incorporate additional footage into the film. She uses the film to work with local historians and people who've lived in the Bay Area for generations. Each time she shows the film to someone, she said, she learns more.

Elsewhere, scholars have been using this emerging appreciation of forgotten films to shape their own work. In Montreal, Concordia University professor of film studies Catherine Russell tasked her undergraduates with finding footage of their city for a class project inspired by *Lost Landscapes*, and one of her graduate students included a chapter discussing Prelinger's films in her dissertation. Russell's own new book, *Archiveology*, explores how archives can go beyond film preservation to become rich resources for artists and the public to learn about and create new understandings of history and memory. This process is made possible with collections like the Prelinger Archives, she said, although "their actual uses and the knowledge we can gain are still very much untapped."

Along with future *Lost Landscapes* films, Prelinger plans to create a more ambitious film of 20th-century America, to help this century's viewers connect with their recent past. Prelinger hopes his films will inspire more of these connections. Seeing *Lost Landscapes* with a community of others—like the South Dakota audience in the Strand Theater absorbing Ivan Besse's view of their world 50 years earlier—can give viewers a better understanding of where they are and a deeper commitment to further that understanding. "I invite viewers of my films to look into the future and extrapolate to how environments to come will evolve from those that exist today," Prelinger said.

From 8 mm to 5G to ?

We've come a long way since 1893 when the first film production studio in the world, Thomas Edison's "Black Maria" in West Orange, New Jersey, began shooting magic shows and vaudeville performances, lit via a retractable roof. Today, most of us have high-definition video cameras in our pockets, smartphones that give us the ability to chronicle every last second of our lives.

The rapid evolution of technology has led to substantial changes in the way we relate to video. We make movies whenever we want with the virtual push of a button, capturing realities that used to be subject to "he said, she said" and trumpeting our accomplishments and adventures to the entire world in real-time. Kids growing up today live with technology that wasn't even imagined in *Star Trek*. No one bothers to think of how amazing it is to so easily record baby's first steps or school plays, to capture lip-synching in the car or suspected police brutality. Software automatically stabilizes images and enhances them to illuminate and define details. Artificial intelligence now powers wearable cameras that capture "interesting" moments throughout the day, all without a person ever having to touch record.

On top of it all, we can almost instantaneously watch a virtually limitless smorgasbord of video. By 2021, video is projected to account for more than 80% of all consumer Internet traffic; every second, a million minutes of video will cross the network. This video tsunami begs the question: What will future archivists, the Rick Prelingers of 50 years from now, be looking at, preserving, and researching?

– David Egerter

By Sarah McQuate

Guided by the light

Stars bring biology into focus

UC Santa Cruz professors Joel Kubby (far right) and William Sullivan (far left) work with (at the time) graduate students Oscar Azucena and Justin Crest and postdoctoral fellow Shaila Kotadia on a fluorescence microscope equipped with the "guide star" adaptive optics system. Credit: Courtesy of Joel Kubby.

When we look at the stars, we often marvel at the vast universe surrounding us. **Joel Kubby**, UC Santa Cruz professor of electrical engineering, saw a tool that could help scientists understand cell biology.

Neuroscientists use microscopes to study cells in living tissues. However, simple light microscopes—like those found in high school classrooms—don't provide enough contrast to see cellular details. This task requires fluorescence microscopes, instruments that capture light from molecular probes that glow when they're added to cells. But even with these beacons, overlying tissues can obscure the cells deep within, for example, the brain of a fruit fly.

In the early 2000s, engineers started using adaptive optics, a technique developed for astronomy, to improve fluorescence microscopy. The swirling gases in our atmosphere blur the light coming from celestial objects, just like biological tissues blur fluorescence coming from cells. Kubby noticed these efforts employed a different method than the one used in astronomy. "I thought it'd be interesting to take a look at why," he said.

The astronomy method first measures how the light from galaxies and planets gets distorted. It does this by focusing on a "guide star," either a nearby star or a spot generated by a yellow laser pointed into the sky. Then the adaptive optics system bounces the reference starlight off small mirrors that rapidly deform to erase its distortions. When the guide star comes into crisp focus, it brings a clearer image of its celestial neighbors with it.

In cells, however, there are no stars. Adaptive optics systems for microscopy estimated the biological light distortion, allowing viewers to adjust the light until the image became clear, like finding the best sound with a radio dial. Knowing how well the guide-star method worked for astronomy, Kubby decided to adapt it for microscopy.

"Joel is one of the early pioneers," said Na Ji, UC Berkeley associate professor of physics and neuroscience. "He is the first person to use the measurement that was developed for astronomy in microscopy."

In his system, Kubby uses fluorescent regions in tissues as guide stars. He first illuminates a tiny point in a fluorescently labeled sample so that it glows, and then corrects it into a perfect circle with adaptive optics to clarify the image of the target tissue. Faster than the radio-dial system, Kubby's system is now being used by many researchers, including Ji, particularly with live samples that are rapidly changing. It may also open new areas of research by unveiling previously hidden cellular physiology. At UCSC, Kubby and team are planning to explore what happens when neurons in the brain misfire, like during epilepsy or Parkinson's disease.

Although his system is still limited to use by engineers who are microscopy experts, Kubby hopes it will become ubiquitous as more biologists see how it can improve their imaging studies. He sees a future where adaptive optics is a standard feature on fluorescence microscopes. "You just press your 'AO button' and there it is," he said.

By Barbra A. Rodriguez

Crossed currents

Conflicting stress responses may beach marine mammals

A narwhal pod near Scoresby Sound in Greenland. As part of their physiological research, UC Santa Cruz professor Terrie Williams and her team visually monitor the movements of these whales that reside among icebergs. Credit, all photographs: Mads Peter Heide-Jørgensen, courtesy of Terrie Williams.

For millennia, ocean mammals have beached themselves along coastlines, and people have wondered why. But while theories abound, the cause of mass strandings in particular has remained elusive. New clues are now emerging thanks to submersible technology that allows near real-time observations of marine mammal physiology and behavior.

Because they share the same basic anatomy of all mammals, whales and dolphins (cetaceans) hold on to a single breath of air while diving so deep that their lungs may temporarily collapse. This reliance on the "plumbing" of land dwellers could play a heretofore unrecognized role in stranding, said **Terrie Williams**, UC Santa Cruz professor of ecology and evolutionary biology.

Using sophisticated monitoring technology to study deep dives, Williams and her team have found suggestive evidence that being startled—by human-produced sounds like marine sonar, for example—during a demanding dive that already taxes their physiological limits could overstress deep-ocean whales and dolphins. The resulting disjointed stress response could indirectly damage their brains—and clear-thinking skills—leaving them prone to stranding.

Rescuers often describe disorientation in stranded cetaceans that fits with brain damage, said Williams, who has studied the physiology of large mammals for three decades. All kinds of things, from sunspots to geomagnetic anomalies, have been proposed to explain this confused behavior, she said. "Maybe it's simpler—something happened before they got to the beach that disrupted their normal brain function."

All mammals react similarly to cold water exposure of their faces. To conserve oxygen and warm blood for vital organs like the brain, the involuntary part of the nervous system slows the heart rate and constricts blood vessels in the extremities. In some humans, this "dive response" also produces irregular heartbeats.

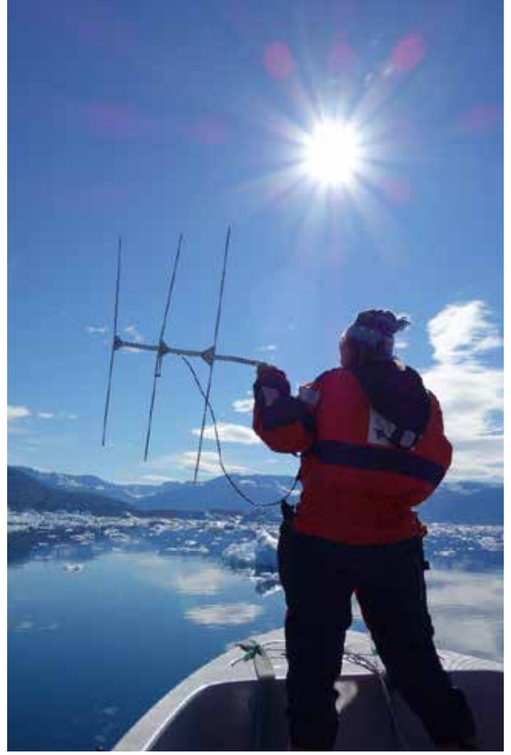
Given their underwater skills, marine mammals were expected to keep a steady heart rate during deep dives. To test this assumption, Williams developed the first monitor for wild cetaceans that records detailed information about their heart rates. Initial studies with the device, which also tracks fin speed and depth, were performed with bottlenose dolphins at UCSC's Long Marine Laboratory and Weddell seals in the Antarctic.

The results, reported in 2015 in *Nature Communications*, disproved the prevailing dogma. During normal hunting dives, the hearts of these deep-ocean dwellers rapidly switched between slowing down and speeding up. The greater the depth, the greater the heartbeat irregularities. In effect, the involuntary dive response that slowed down the heart appeared to oppose the exercise-related messages the brain sent to accelerate it while chasing prey. And blood flow stalled by the erratic heart rate would be expected to decrease the oxygen and nutrients reaching vital organs. "The more we looked at the heart and exercise responses of these animals, the more we wondered how they were getting enough oxygen to the brain," Williams said.

Testing her monitors on narwhals in Greenland provided additional key insights—reported in *Science* in December—about how the stress of human interaction impacts this physiology. Working with Inuit that hunt narwhals in Scoresby Sound, Williams, former postdoctoral researcher **Susanna Blackwell,** and lead collaborator Mads Peter Heide-Jørgensen have now tagged and studied nine of these elusive tusked whales.

The longer the net-entangled narwhals were handled, the further their heart rates dropped once released. Moreover, the animals' heart rates during their initial dive plunged to as low as three or four beats a minute and stayed there much longer than normal. "I realized we had recorded a type of stress response," Williams said.

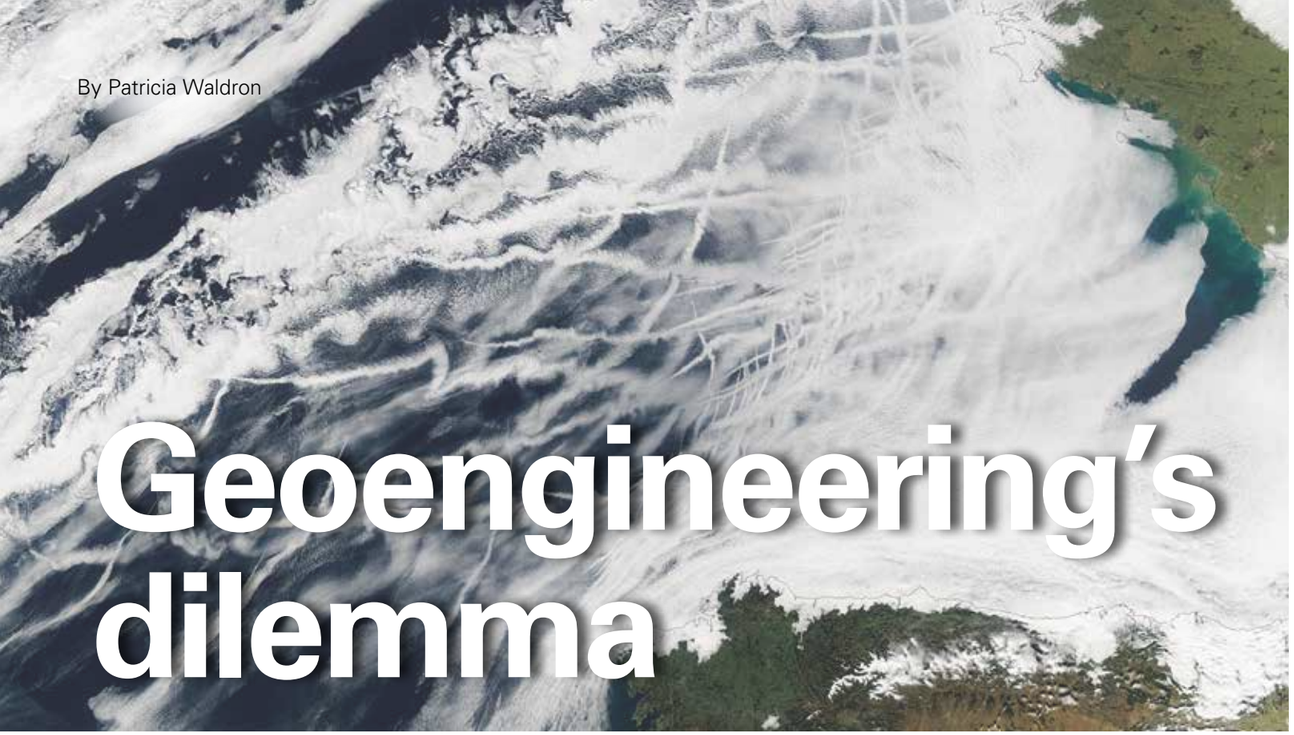
Williams touches a narwhal to which she has attached monitoring equipment. The heart-rate monitor is along the curved line at upper right on the animal's back, while fin-speed and dive-depth monitors sit below the yellow float that enables the team to retrieve the device when it releases from the animal.



While retrieving a monitoring device, Williams holds a receiver at the bow of an Inuit fishing skiff, searching among icebergs for the signal from the device's radio satellite tag.

Stress-triggered, whole-body freezes in which heart rates dropped by half had been reported in marine mammals. But not the extreme cardiac freeze (heart rates more than 90% below normal) observed in the released narwhals, which could last ten minutes. Importantly, during this period of likely reduced blood flow, the fleeing narwhals also often doubled their normal swimming speed. That is, the heart freeze and flight response occurred simultaneously, requiring the animals to pump their muscles into overdrive on an emptying "tank." Fear exacerbating these opposing freeze and flight responses appeared to create a "trifecta" effect with the hypothetical potential to instigate brain damage, Williams said.

Ultimately, Williams's research aims to make a difference in the survival of the animals she studies. "Every day we're getting reports of species either becoming endangered or becoming extinct," Williams said. "We've got to try to get ahead of that extinction curve and figure out the information that's necessary to prevent these rapid declines."



By Patricia Waldron

Geoengineering's dilemma

What comes first, research or governance?

▶ Geoengineering may be the most controversial technology that doesn't yet exist. Also called climate engineering, it's a group of proposed strategies with the potential to counteract climate change by altering climate on a global scale. Critics assert that geoengineering could cause tremendous environmental harm and distract from established efforts to reduce greenhouse gas emissions. However, as nations have struggled to reduce their emissions, geoengineering may be the only way to meet the internationally agreed upon target of keeping the global temperature rise well below 2° C.

Perhaps because geoengineering does not yet exist on any significant scale, there are no national laws or international treaties restricting or enabling its use. Any country could attempt a geoengineering scheme with Earth-changing effects within its own borders or the global commons, and there is no oversight to guide the necessary research into how—and, more importantly, *if*—nations should use this technology. This lack of governance and research creates a chicken-or-egg conundrum. Scientists need better governance to support responsible geoengineering research, but efforts to develop an international governance system are stalled by resistance to the poorly defined technology.

To break this stalemate, **Sikina Jinnah**, UC Santa Cruz associate professor of politics, thinks that governance and research need to ensue simultaneously. "We shouldn't hold off on initiating governance mechanisms until we know if these technologies are viable or not," she said. "Governance and research need to inform each other—neither should evolve in a vacuum." Jinnah and colleagues are proposing an initial path forward using a polycentric approach that taps into existing international institutions at multiple levels. Her research suggests that public discussion and decisions on geoengineering can be guided in the near-term using governance systems that already exist, not necessarily the ones that ultimately may be needed if large-scale geoengineering becomes a reality.

Jinnah has spent almost two decades researching how international institutions respond to environmental problems. In 2014, she became interested in the emerging field of geoengineering governance as an assistant professor of international relations at American University in Washington, D.C. She quickly established her standing in the field and was invited by her American University colleague Simon Nicholson, assistant professor and director of the Global Environmental Politics Program, to join the academic working group for his research and public policy initiative, the Forum for Climate Engineering Assessment. The working group attempts to bridge academic and policy conversations on geoengineering governance and will publish their first comprehensive policy recommendations later this year.

Geoengineering attracted Jinnah for both its enormous potential and incredible risks. "It's the most alive space I've ever worked in," she said. "It's not just a banal academic topic. People who are engaged in this have strong and deep feelings about what they're doing and what it means for present and future generations." In 2017 she received an Andrew Carnegie Fellowship to further her work on geoengineering governance.

Climate control

Geoengineering is not a new idea, but it is receiving increased attention as the debate over what to do about climate change intensifies. Its roots lie in cloud-seeding operations from the 1950s designed to bring more rain to farmlands and military attempts to flood the Ho Chi Minh Trail in Vietnam in the 1960s. Nobel Prize–winning atmospheric chemist Paul Crutzen brought the idea to the forefront in 2006 when he proposed a form of geoengineering as an antidote to global warming. In 2009, The Royal Society amplified that message by releasing a report on geoengineering aimed at policymakers.

Geoengineering technologies roughly fall into two camps: solar radiation management (SRM) and carbon dioxide removal (CDR). SRM approaches would attempt to reflect more sunlight back into space, in effect dimming the sun. One strategy, called stratospheric aerosol injection, would mimic the effects of a volcanic eruption by using an airplane or balloon to spray particles into the stratosphere to block sunlight. A second strategy, called marine cloud brightening, would seed the formation of brighter, more reflective clouds. The effect would be the same as the long strings of clouds called "ship tracks" that form from boat exhaust, but on a far larger scale.

Above: When ships traverse the ocean, their exhaust causes water vapor to condense into thin bright clouds called ship tracks. These clouds reflect solar radiation away from Earth, leading some scientists to propose that creating more marine clouds would cool the global temperature. Credit: NASA (public domain).

A geoengineering glossary

Bioenergy with carbon capture and storage (BECCS) A proposed technology to achieve negative carbon emissions by generating energy using biomass and storing the resulting carbon dioxide underground in geological formations.

Carbon dioxide removal (CDR) A diverse group of technologies designed to remove carbon dioxide gas from the atmosphere.

Intergovernmental Panel on Climate Change (IPCC) A scientific advisory council formed under the U.N. that makes assessments and publishes reports on climate change research.

Paris Agreement A climate agreement under the U.N. Framework Convention on Climate Change where each country sets its own goals for greenhouse gas emissions mitigation and adaptation by 2020. The agreement was adopted in Paris on December 12, 2015, and went into effect November 4, 2016.

Solar radiation management (SRM) A type of geoengineering that reflects sunlight back into space to reduce global temperatures, potentially by injecting aerosols into the atmosphere or making clouds more reflective.

U.N. Educational, Scientific and Cultural Organization (UNESCO) A U.N. agency that encourages international cooperation to promote quality education, scientific advances, and the preservation of cultural heritage.

U.N. Environment A U.N. program that advises developing countries on sound environmental practices and policy.

U.N. Framework Convention on Climate Change (UNFCCC) An international environmental treaty adopted on May 9, 1992. The treaty was created with the goal of stabilizing atmospheric greenhouse gas concentrations at a level that prevents dangerous anthropogenic changes to the climate.

World Meteorological Organization (WMO) A U.N. specialized agency that provides leadership and expertise regarding weather, climate, and hydrology issues.

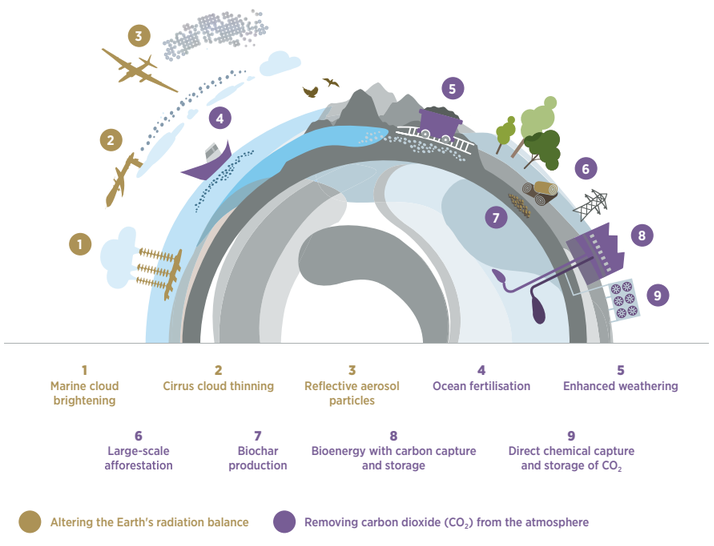
Geoengineering's dilemma

Thus far, scientists have limited SRM research primarily to theoretical modeling. While most models predict that SRM could rapidly and cheaply lower global temperatures, some of those same models predict that the technology would cause significant changes to global rainfall patterns that could affect agriculture. SRM could buy humanity more time to reduce emissions, thus avoiding the worst effects of climate change, but it does nothing to address greenhouse gas emissions or ocean acidification. Also, if SRM begins without concurrent aggressive reductions to atmospheric carbon dioxide, any interruption could cause global temperatures to jump up to what they would have been without the intervention, which could have brutal impacts.

In the second camp of geoengineering, CDR comprises a range of technologies that remove and sequester carbon dioxide from the atmosphere. CDR includes large-scale tree planting and biochar—the burial of charred organic waste for long-term carbon storage—as well as the more extreme idea of fertilizing the ocean with iron so that phytoplankton blooms soak up atmospheric carbon dioxide (see sidebar). Companies are also developing machines that suck carbon dioxide directly from the air and a system called bioenergy with carbon capture and storage (BECCS), where power plants would burn biomass to generate energy and then pump the resulting carbon dioxide underground. These options are generally more appealing to the public because they feel more contained than SRM. However, these strategies would have to be greatly scaled up and widely adopted to have a global impact, an effort likely to carry a hefty price tag.

Though most of these technologies remain closer to science fiction than applied science, CDR has recently assumed a more prominent position in the climate change governance discussion. In the U.N.'s Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report from 2014, a majority of presented scenarios depend on BECCS to reach negative carbon emissions by mid-century and to keep the global temperature increase below 2° C. The 2015 Paris Agreement, which provides a framework for individual countries to set their own goals to reduce carbon emissions, does not mention geoengineering but also has called for a net negative carbon economy after 2050, a goal that some argue may be impossible to reach without CDR technologies. "Suddenly something that wasn't really part of the international climate change conversation is very much a part of the mix because these models, which the world depends on for its policy decisions, have started to incorporate them," said Nicholson. In addition, if its withdrawal from the Paris Agreement means that the U.S. fails to deliver on its greenhouse gas reduction commitments, this could increase demand for geoengineering solutions.

CLIMATE ENGINEERING MEASURES UNDER DISCUSSION



Researchers have proposed multiple geoengineering strategies to counteract rising temperatures, which vary greatly in popularity, feasibility, and environmental risk. Credit: © IASS, Fact Sheet 1, 2017, reprinted with permission.

No rules

Despite emerging awareness of geoengineering's potentially pivotal role, how and if it should be applied are questions that remain largely unaddressed. "There are no existing laws or institutions at the international level to regulate or control or do anything about geoengineering," said Edward Parson, professor of environmental law at UC Los Angeles. He noted that parties to the Convention on Biological Diversity have requested that participating countries not employ geoengineering until research has adequately considered its environmental, economic, and social impacts, but the decision is nonbinding. And the IPCC is simply a scientific assessment body and the U.N. Framework Convention on Climate Change (UNFCCC), the international environmental treaty, whose 2015 annual meeting produced the Paris Agreement, does not address geoengineering. If it did, it would not have the administrative capacity to regulate it, said Parson. "What it would take to effectively govern geoengineering at the international level is very much an open question."

One emerging international governance mechanism is a code of conduct put forth by Anna-Maria Hubert, assistant professor of law at the University of Calgary. The code provides guidance for responsible geoengineering research with the objectives of minimizing environmental harm, enhancing legitimacy, and creating a better understanding of the technologies' efficacy and risks. Hubert's code is an important contribution, but further governance mechanisms are also needed, Jinnah said.

In addition to the absence of governance, there is the problem of "moral hazard," the concern that pursuing these technologies could divert institutional resources needed to reduce emissions. "Even thinking about geoengineering, let alone deploying it, could have adverse effects on mitigation efforts, because it creates this idea of a technological fix that maybe provides a get-out-of-jail free card for fossil fuel companies," said Rob Bellamy, a University of Oxford research fellow with a particular interest in how public participation affects issues related to climate change, including geoengineering governance.

Several major environmental nongovernmental organizations (NGOs) have taken a precautionary stance against geoengineering, due to the moral hazard and environmental concerns, said Jinnah. This view has kept NGOs from having a meaningful voice in the geoengineering discussion. Through the Forum for Climate Engineering Assessment, Jinnah, Nicholson, and others are trying to change that. "We're working to help NGOs and policymakers understand the existing information so we can have a real and meaningful conversation," said Nicholson.

A geoengineering fish story

Greater international governance of geoengineering may help rein in rogue experiments, such as the ocean fertilization scheme attempted by the Haida Salmon Restoration Corporation in 2012. The group dumped about 120 tons of iron dust into the Pacific Ocean off the coast of British Columbia in the hope that adding this nutrient to iron-deficient waters would trigger a phytoplankton bloom that would revive the local salmon population. To undertake the project, American entrepreneur Russ George partnered with the Haida tribe, a First Nations society on Canada's Queen Charlotte Islands that historically has depended on salmon for its livelihood. The tribe invested $2.5 million dollars in the corporation, which in turn, had planned to sell carbon offset credits on the international market for the carbon dioxide that the phytoplankton consumed. The dumping ignored the 1972 London Convention and London Protocol on preventing marine pollution and the Convention on Biological Diversity's voluntary moratorium on ocean fertilization. The corporation released the data from the experiment and claims that a subsequent phytoplankton bloom created bigger salmon hauls the following year. Independent scientists, however, say it is unclear what impact the fertilization had on the salmon population, and whether the bloom resulted in any long-term carbon storage.

Outlook cloudy

Two impending SRM field experiments highlight the need for greater governance. Neither experiment will have any impact on the climate, but some fear that outdoor experiments could initiate a slippery slope toward reliance on such technological fixes to address climate change, said Jinnah.

SCoPEx, which stands for Stratospheric Controlled Perturbation Experiment, involves sending a balloon more than 12 miles into the atmosphere to spray two pounds of ice or limestone dust. In a later stage, a small amount of sulfur-containing aerosols may be released. Harvard University researchers Frank Keutsch, professor of chemistry and chemical biology, and David Keith, professor of

applied physics, lead the Harvard-funded project, which aims to show how the aerosols move and interact with gases in the atmosphere. The results will inform future models of the potential risks and effectiveness of large-scale spraying.

"In the grander scheme of things, this is a relatively benign project in terms of environmental impact," said Jinnah. "That said, a lot of people are up in arms about it because some think of it as opening the door to more invasive types of field experimentation."

Equally benign is the Marine Cloud Brightening Project, proposed by Thomas Ackerman, professor of atmospheric sciences at the University of Washington in Seattle. Ackerman's group wants to spray saltwater droplets to seed cloud formation over a small area of Monterey Bay, just down the road from UCSC at Moss Landing. The experiment would show the size and quantity of aerosols needed to form brighter clouds, but has not yet received funding.

Experts estimate that viable SRM technologies could be ready in about 20 years at a cost of $1 billion to $10 billion U.S. dollars annually to deploy at a scale that could impact global warming. This relatively low price tag means that a single country or even a billionaire with a balloon could initiate SRM with worldwide consequences. "SRM would have trans-boundary impacts," said Jinnah. "It has to involve cooperation between different countries because it's not going to be contained within the boundaries of a single country."

In an ideal world, representatives from each country would gather to negotiate a treaty regarding SRM and other geoengineering approaches. However, it's unrealistic to think that this will happen in the near-term, said Jinnah. "There's no political appetite for it right now."

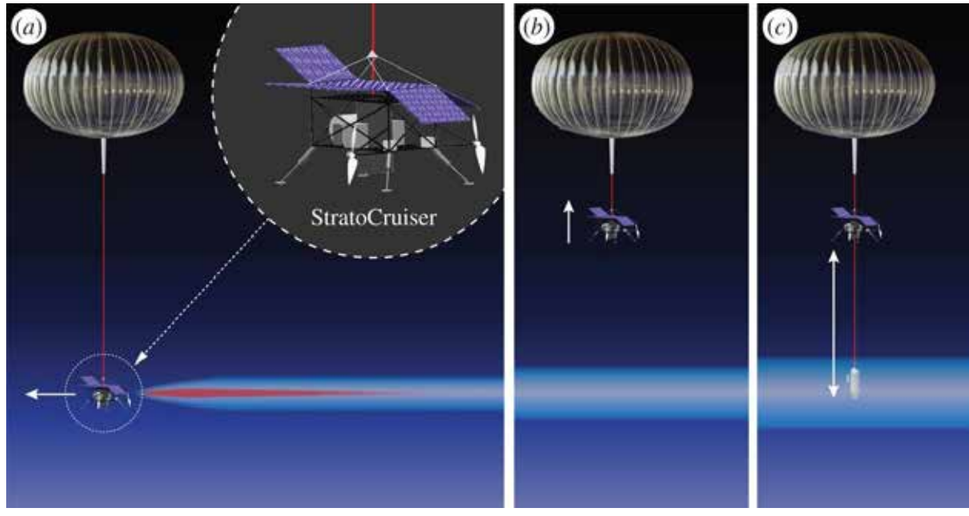
A last resort

In lieu of a new, international, top-down agreement, Jinnah, Nicholson, and colleague Alexander Gillespie, professor of international law at the University of Waikato in New Zealand, propose three concrete policy recommendations as part of a polycentric approach to governing SRM, in which multiple existing institutions can take on different roles to govern geoengineering technologies.

Stratospheric aerosol injection has a good chance of lowering global temperatures because it mimics a volcanic eruption. The 1991 eruption of Mt. Pinatubo launched about 15 million tons of sulfur dioxide into the stratosphere, which dropped the global temperatures by half a degree Celsius for 18 months. Credit: Richard P. Hoblitt, USGS (public domain).

An artist's conception of a ship designed by Stephen Salter, emeritus professor of engineering design at the University of Edinburgh, to spray saltwater into the air for marine cloud brightening. Credit: © John MacNeill, with permission.

A key part of this approach is to increase the transparency of SRM research. "I advocate strongly for some sort of transparency mechanism so that people who are interested in being engaged in these discussions have a pathway through which to understand what's happening," said Jinnah. Both Keith and Ackerman maintain highly informative websites on their proposed SRM experiments, but an international clearinghouse might better inform policy decisions, create funding opportunities, and help researchers coordinate their activities.



In the SCoPEx experiment, Harvard researchers propose to launch a balloon into the stratosphere. They plan to release environmentally insignificant amounts of aerosols to understand how these particles behave in the atmosphere and to inform future solar geoengineering research. Credit: © Dykema, et al., *Philosophical Transactions of the Royal Society A* 2014;372:20140059. Creative Commons 4.0.

Jinnah and her colleagues suggest that the World Meteorological Organization (WMO) could develop such a clearinghouse, as it not only has a mandate as an agency of the U.N., but already facilitates worldwide weather monitoring and the sharing of information, expertise, and resources for weather, climate, and hydrology research. Alternatively, the U.N. Educational, Scientific and Cultural Organization (UNESCO) could fill this niche. UNESCO helps researchers coordinate their efforts and advises countries on science policy, especially with regard to emerging technologies. Its Global Ethics Observatory, a database of researchers, institutions, codes of conduct, and resources related to scientific ethics, could be expanded to include SRM research.

The second recommendation from Jinnah and her colleagues would establish a global forum that unites policymakers, NGOs, and other stakeholders. This forum, which could be organized through U.N. Environment, would help advise governments and guide public engagement on SRM. The role of U.N. Environment is to coordinate environmental activities and sustainability efforts through the U.N. system. The program also has experience in advancing public engagement, which could help legitimize research, leading to greater funding and more comprehensive studies. Such engagement efforts have been conducted by researchers in the United Kingdom, Germany, and the U.S., but it will be important to engage stakeholders worldwide.

Finally, Jinnah and colleagues recommend that SRM assessment be included in the next "global stocktake" under the Paris Agreement, due out in 2023. Scheduled every five years (beginning with an initial exercise in 2018), the global stocktake reviews global progress toward climate change goals. As an existing vehicle, it could lend transparency to country-level activities regarding geoengineering research.

While these recommendations do not constitute a comprehensive governance plan for geoengineering, they represent a good start to cracking the chicken-or-egg dilemma. With at least a rudimentary governance framework in place, important research can be encouraged to help inform decisions about geoengineering's possible role in managing climate change. Mid-century, when the IPCC estimates that humans must soak up as much carbon dioxide as they emit to stay below a 2° C increase, is just three decades away.

"The possibility of this being a last ditch resort for solving climate change if we find ourselves in a terrible situation is a big part of why I'm engaged," said Jinnah. "There's so much at stake."

By Emma Hiolski

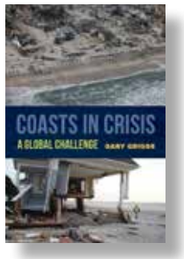
Emotional Gaming

Although video games have now beguiled players for 40 years, we don't have nuanced cultural conversations about them, said **Katherine Isbister**, UC Santa Cruz professor of computational media. According to Isbister, the language to support rich discussions—like those we have about books or movies—hardly exists.

In **How Games Move Us: Emotion by Design**, Isbister aims to give readers a clear understanding of how design choices influence the way players feel—and a way to talk about what's happening and why.

Eschewing violent games, she instead analyzes video games designed to build empathy. Such games can provide a space for people to experience real emotional responses to both the choices they make and the subsequent consequences. The "emotional texture" of these games can closely match that of life, said Isbister.

"It's worthwhile to develop literacy about games," she said, "because they really are the medium of the 21st century."

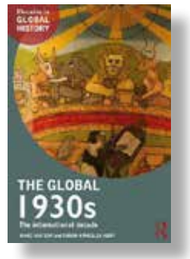


Hitting the Beach

Gary Griggs, UC Santa Cruz distinguished professor of Earth sciences, has spent a lifetime observing coasts. That's where it all comes together, he said. "Over the years, I've worked on water pollution and dabbled in desalination, sand, dams, offshore oil, and nuclear power."

In his ninth book, **Coasts in Crisis: A Global Challenge**, Griggs explores growing human impacts on coastal environments. Written to accompany his undergraduate course of the same name, the book also discusses the increasing dangers coastal hazards pose to swelling populations worldwide. Griggs makes sure to include a positive note—like the great strides made in wind and solar energy technology—at the end of every chapter. "We always have to have hope," he said.

Griggs is also co-author, with Kim Steinhardt, of **The Edge: The Pressured Past and Precarious Future of California's Coast**, in which they share tales of—and their personal connections to—California's coastal history.

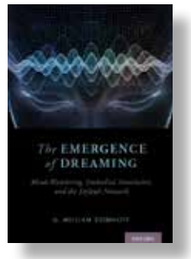


Between World Wars

During the 1930s, globalization was on the decline: countries cut ties with one another, the Great Depression was devastating the United States, and fascism was on the rise around the world. At least that's the perspective that history books typically offer, said **Marc Matera**, UC Santa Cruz associate professor of history.

Matera and coauthor Susan Kingsley Kent shed a different light on the decade in **The Global 1930s: The International Decade**. They synthesize interdisciplinary readings from global scholars to share voices typically excluded from history books—those of women, minorities, and colonized peoples.

Through this new lens, they illustrate pervasive global connections between these marginalized groups during the 1930s. They also demonstrate that these connections formed a foundation for later global movements promoting decolonization and civil rights. "If we look at things from a different angle," said Matera, "we can see that the global connections were as important as ever."



Dream Theory

"Our minds are restless," said **G. William Domhoff**, UC Santa Cruz distinguished professor emeritus of sociology and psychology. During waking hours, this is obvious: Our thoughts flit between current tasks to future errands or past problems. As it turns out, our minds do something similar when we sleep.

In **The Emergence of Dreaming: Mind-Wandering, Embodied Simulation, and the Default Network**, Domhoff explores nearly 15 years of new research on dreams and dreaming. He concludes that dreaming is an intensified version of mind-wandering.

Dreaming and mind-wandering activate specific, closely overlapping regions of the brain. When we dream, brain regions linked to imagination are activated and our sleeping minds "escape from time," Domhoff said. And, while some suggest that dreaming is an evolutionary adaptation, he argues that imagination is the true adaptation. "We just happen to dream as a byproduct of that," he said.

Plant Sexuality

Long after sexual reproduction in animals became scientific canon, plant reproduction remained a mystery. It wasn't until the end of the 17th century that the idea of pollination and plant sex arose.

This discovery was "hotly debated" until the middle of the 19th century, said **Lincoln Taiz**, UC Santa Cruz professor emeritus of molecular, cell, and developmental biology. The primary objection, he said, stemmed from the strong association between plants and the female gender. Flowers and plants, like women, were supposed to be chaste and pure.

Taiz and his spouse, **Lee Taiz**—a former UCSC research biologist—spent 20 years traveling and unraveling this story. The result is **Flora Unveiled: The Discovery and Denial of Sex in Plants**.

"It is a fascinating topic," said Lee Taiz, "and it says so much about cultural development and the way that culture either enhances or stands in the way of scientific fact."

**Names are listed left to right.*

With the expertise of scientists-turned-journalists, the 16 graduates of the UC Santa Cruz Science Communication Program shown above created these stories about research that span the university's five divisions: Arts, Humanities, Physical & Biological Sciences, Social Sciences, and Engineering. As their reporting well documents, while the academicians at UCSC may keep offices, laboratories, and studios on the redwood tree–studded campus, the breadth and depth of their work—and its impact—reaches around the world.

This sizable impact also applies to the "SciCom" graduate certificate program (*scicom.ucsc.edu*). Begun in 1981, the program has 300-plus graduates who work regionally, nationally, and internationally. They communicate on science and related issues in newspapers, radio, television, online media, peer-reviewed journals, magazines, and university public relations. Required to have scientific training and experience, SciCom students spend a year on campus honing their storytelling skills in journalism training and internships now overseen by the program's third director, **Erika Check Hayden**.

At a time when the credibility of science and the news media remains under scrutiny, the SciCom program and its mission to "strive to use accurate and engaging science journalism to improve society," is more important than ever, said Check Hayden, an international investigative reporter and social media expert. "Through our students, alumni, and instructors, we have a huge role to play in promoting well-informed dialogue on science."

Despite concerns about the current media climate, with the sensationalism and click-ability of "fake news" threatening to overshadow real news, Check Hayden is optimistic about the sway of UCSC's science-savvy SciCom media specialists: "Doing our jobs as communicators means telling stories that resonate with readers, listeners, and viewers in ways that make true news far more compelling."

We hope you find compelling reading in this edition of *inquiry@UC Santa Cruz.*

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

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