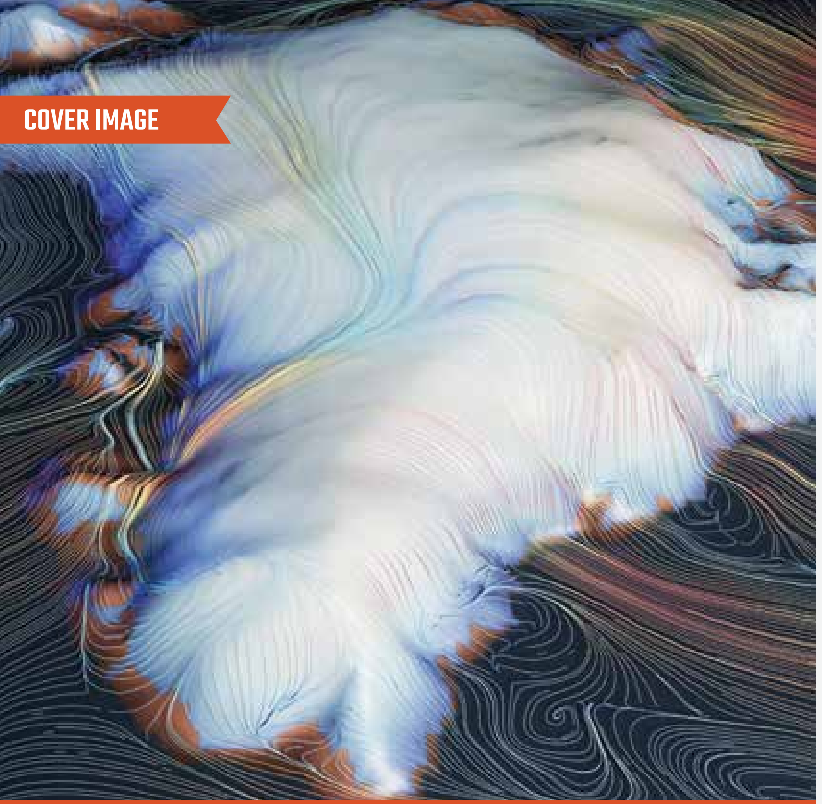
COALITION FOR ACADEMIC SCIENTIFIC COMPUTATION

CASC

2022

INSIGHTS & INNOVATION

Computational Science at the Forefront of a Changing World



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ABOUT THE COVER

The future of ice in Earth's polar regions is inextricably linked with the future of life along Earth's coastlines. As ice sheets melt, sea levels are rising, putting many coastal cities at risk. While predictive models of sea level rise are crucial to help communities prepare and plan for possible inundation, the ability to predict future sea level rise is currently hindered by significant uncertainty in scientists' ability to model and predict ice sheet dynamics.

To better understand the factors affecting polar ice sheets and global climate, researchers created the System for Integrated Modeling of the Atmosphere (SIMA), a platform for simulating atmospheric dynamics on the scale of minutes to centuries. Adam Herrington and Matt Rehme of the National Center for Atmospheric Research (NCAR) recently used the computational power of the NCAR-Wyoming Supercomputing Center to perform a simulation using the SIMA running in the Community Earth System Model. This image shows a 3D visualization of what happens when storms pass over the Greenland Ice Sheet. By offering a realistic picture of regional atmospheric dynamics at meaningful resolution, the simulation provides a valuable resource for scientists to study how much snow and ice is accumulating on the ice sheet—and how much is being lost.

ABOUT CASC

Founded in 1989, the Coalition for Academic Scientific Computation (CASC) is an educational nonprofit 501(c)(3) organization with 90+ member institutions. CASC envisions a robust, sustainable ecosystem supporting academic research computing and data services, enabled by a vibrant, diverse community of professionals.

CASC MISSION

- To advocate for the importance of and need for public and private investment in research computing and data services to support academic research.
- To serve as a trusted advisor to federal agencies on the direction of relevant funding programs.
- To actively engage in discussions of policies related to research computing and data services.
- To foster advancement of a robust and diverse community of current and emerging leaders in this field.
- To provide a forum for the community to share strategic ideas and best practices.

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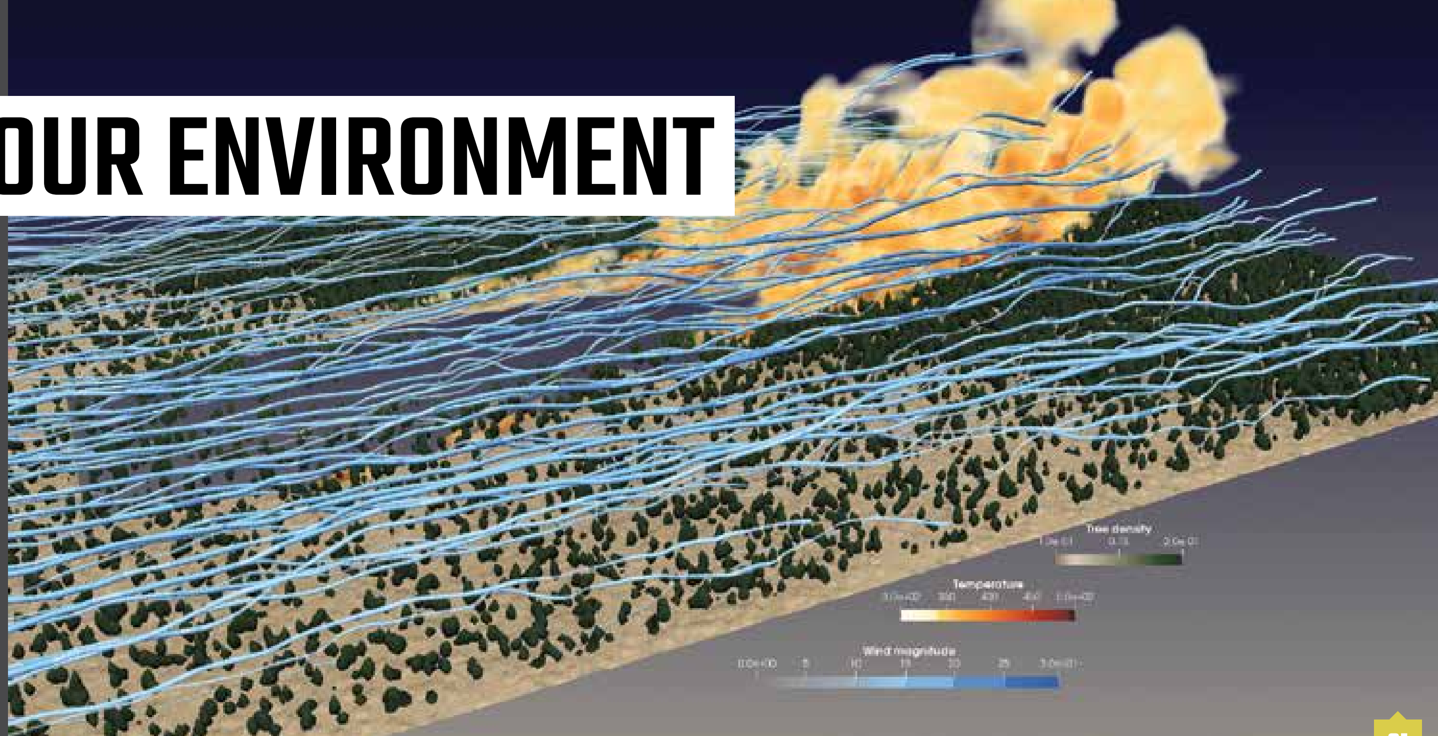
OUR ENVIRONMENT



FIGURING OUT FIRES

Firefighters grapple with many unknowns when strategizing about how best to control a wildfire. Rod Linn of Los Alamos National Laboratory (LANL) and his partners worked for years to develop FIRETEC, a simulation to help firefighters understand fire conditions and likely outcomes. This image, a visualization by Francesca Samsel, Texas Advanced Computing Center (TACC), and John Patchett, LANL, shows how the simulation accounts for wind magnitude, air temperature, and tree density—variables that are interdependent and must be individually distinguishable throughout each timestep. The extremely complex models behind FIRETEC bring together statistical, empirical, and physical information from numerous sources, and present equally complex visualization challenges.

SEEING SOOT

As researchers continue to study how to control them, wildfires pose a significant threat to people and property, and the risks extend far beyond the area that is burned. Soot from wildfires can carry dangerous contaminants and cause health problems for people even hundreds of miles away. It can also damage plants, clog equipment such as car engines and heating and air conditioning systems, and contribute to air pollution more broadly.

Researchers Randy McDermott of the National Institute of Standards and Technology and Rod Linn of LANL are using computer simulations to better understand wildfire behavior and the dynamics of soot. This image shows airborne soot from a simulated structure fire that McDermott created with Greg Foss and Dave Semeraro of TACC at the University of Texas at Austin, computed on TACC's Stampede2.

HELPING THE PAST TAKE FLIGHT

Many dinosaurs sported feathers that were both functional and beautiful, playing a role in flight and body temperature regulation, while producing distinctive color patterns. Because the fossil record provides only a few intact feathers, paleornithologists rely on computer simulations to study dino feathers and compare them to those of modern birds. Due to their complex microstructures, feathers are notoriously difficult to simulate and visualize, especially when they interact with light to create iridescence and other qualities.

To provide better simulations, Clemson University visualization experts Jessica Baron and Eric Patterson are developing physically-based models of feather structure and appearance. The top image shows custom lighting and imaging equipment used for measuring light scattering from modern-day feathers at multiple angles, producing photos like the one on the left. The bottom shows a scanning-electron microscope image of the complex arrangement of feather structures; overlays in the bottom center and right show work-in-progress modeling of feather structures for computer-graphics rendering.

A NEW POINT OF VIEW

Ever wonder what it would be like to swim through the ocean as a sea turtle? The TurtleCam Project offers a unique peek at life in the sea. By mounting small cameras on the shells of sea turtles, the project has brought incredible insights into what sea turtles eat, how they interact with their environment, and their key habitats. Manually analyzing the 200+ hours of footage is very time-intensive, so TurtleCam leader Nathan Robinson of the Cape Eleuthera Institute in the Bahamas partnered with data scientist Aiman Soliman and ecologist Brian Allan at the University of Illinois at Urbana-Champaign National Center for Supercomputing Applications to automate the video analysis. The team's novel machine learning tools automatically identify specific behaviors, such as breathing or feeding, to dramatically speed analysis.

The work not only offers the opportunity to vicariously experience life as a sea turtle—the biological insights it generates can help guide efforts to protect endangered sea turtles and conserve marine habitats around the world.

IMAGE COPYRIGHT:

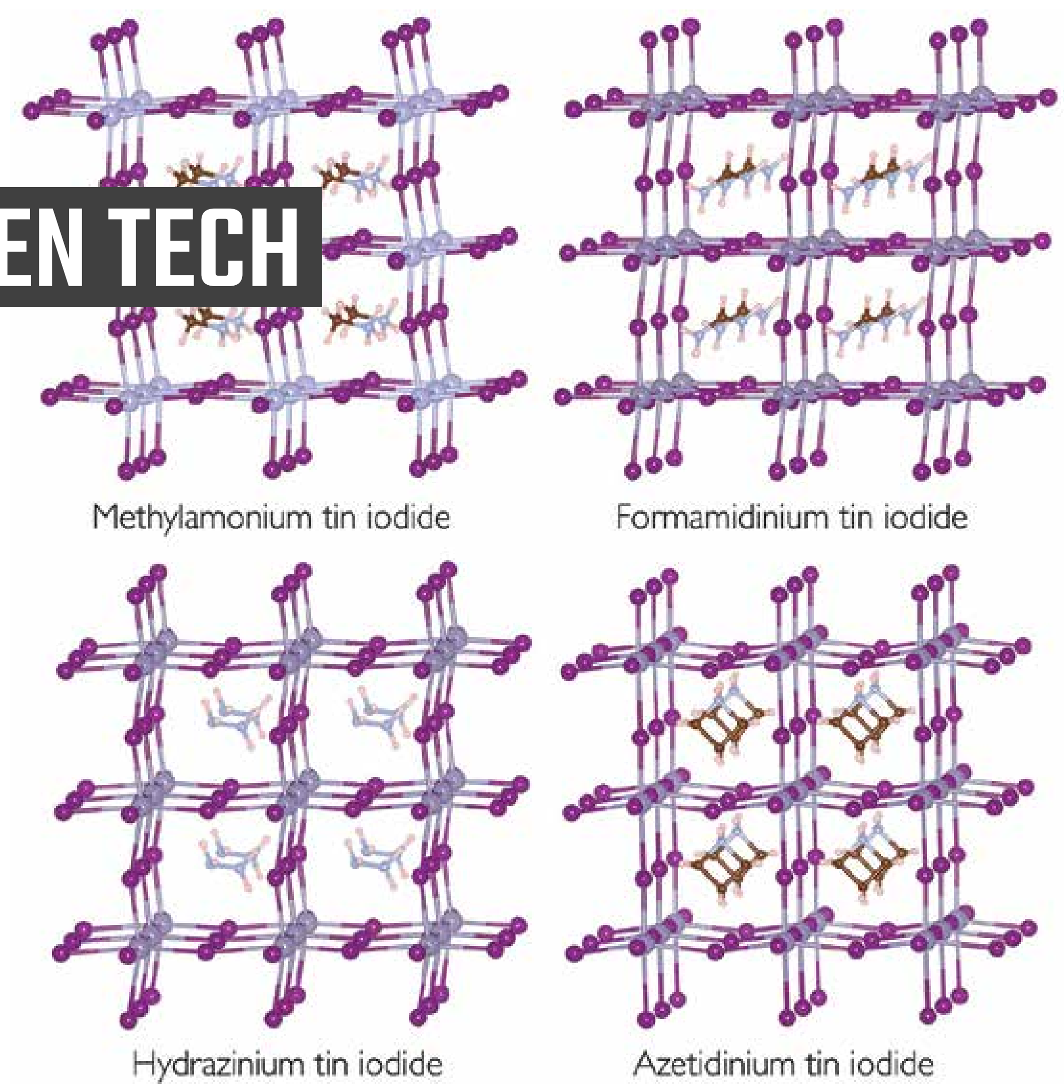
01 *Francesca Samsel, TACC; Rod Linn and John Patchett, LANL*

02 *Greg Foss, University of Texas at Austin*

03 *Eric Patterson and Jessica Baron, Clemson University*

04 *Nathan J. Robinson, Cape Eleuthera Institute*

GREEN TECH



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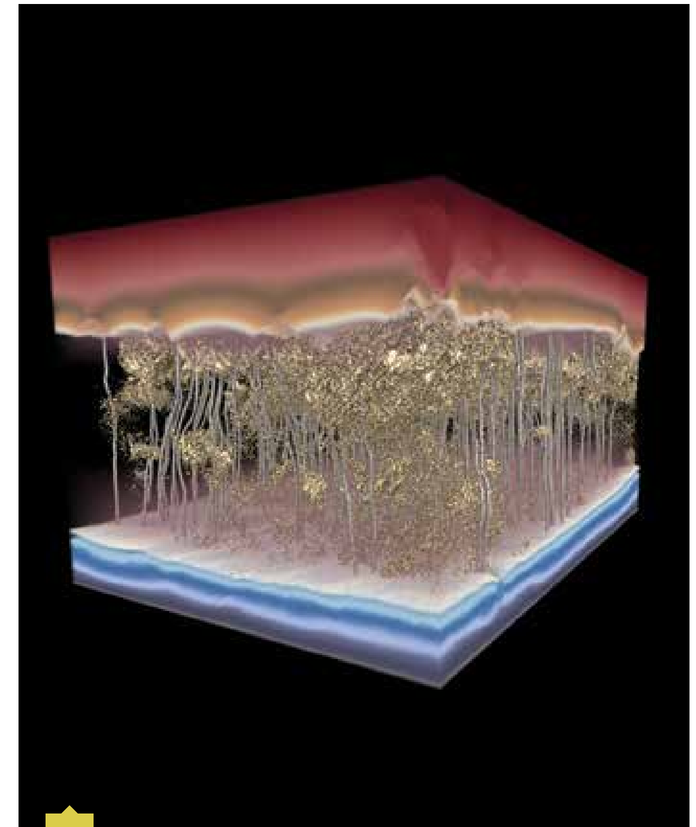
DESIGNING NEXT-GENERATION SOLAR CELLS

Solar power will be a vital part of our future energy mix. While the costs of solar cells have come down, new materials could make solar technologies even more efficient and cost-effective. The quest for better solar solutions has focused attention on perovskite—a naturally occurring mineral—and synthetic compounds that are modeled on its structure. Perovskites could represent a lower-cost, highly efficient alternative to the silicon used in today's solar panels.

Despite their promise, some perovskites are unstable in certain environmental conditions and have been found to contain lead, raising health concerns. Huan Tran of Georgia Institute of Technology and colleagues at the Hanoi University of Science and Technology in Vietnam are designing lead-free perovskites that could form the basis for low-cost and environmentally friendly next-generation solar cells. The image shows the structures of four perovskite candidates the team has designed with simulations computed on the Comet supercomputer at San Diego Supercomputer Center and Stampede2 at TACC.



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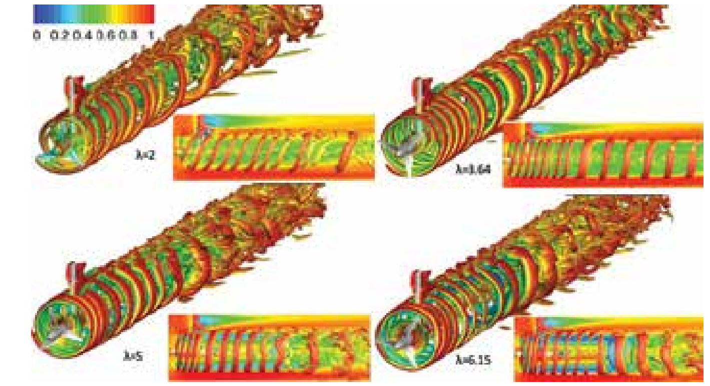
DELIVERING ON DESALINATION

Could the world's oceans help solve urgent water shortages? Yes, but only if we can get the salt out. Desalination technologies could provide a way forward for water-scarce regions, but current technologies can be energy-intensive and cost-prohibitive.

Iowa State University researchers Baskar Ganapathysubramanian and Biswajit Khara are helping to design new desalination technologies inspired by the biological membranes found in nature. This visualization, created with computation on TACC's Stampede2 and Frontera supercomputers, shows how the team's membrane selectively filters out salt while remaining highly permeable to water. The membrane's 3D nanostructure (shown in gold) illuminates the path water takes as it flows from top to bottom (grey lines).



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HARNESSING THE POWER OF WIND AND WATER

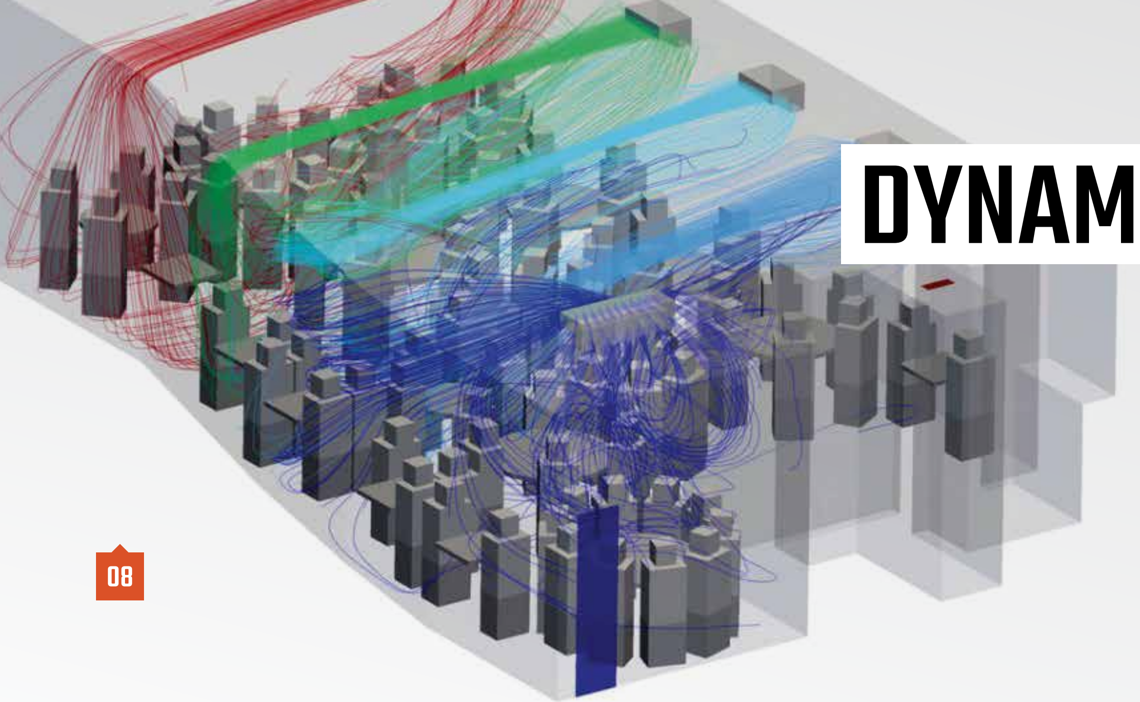
The U.S. energy portfolio shows a steady rise in renewable energy sources from wind farms and hydrokinetic technologies, which generate electricity by harnessing the movement of wind or water, respectively. The efficiency of these technologies depends on the spacing between the rotors, which in turn depends on how quickly the flow momentum recovers in the wake. Mississippi State University researchers Oumnia El Fajri and Shanti Bhushan used Mississippi State's High-Performance Computing Collaboratory to identify possible solutions to this problem. As illustrated in this image, computer modeling represents a powerful tool to discover how slight changes to blade tip design and speed ratio can enhance wake recovery and help optimize the design of renewable energy technologies.

IMAGE COPYRIGHT:

05 *Huan Tran, Georgia Institute of Technology*

06 *Baskar Ganapathysubramanian, Iowa State University and Greg Foss, University of Texas at Austin*

07 *Oumnia El Fajri and Shanti Bhushan, Mississippi State University*



DYNAMIC DESIGN

THE ARCHITECTURE OF AIR

The COVID-19 pandemic has brought a great deal of attention to an important yet invisible aspect of architecture: how air flows through a space. Whether air moves along swiftly or stagnates in a particular spot can make the difference between a COVID-safe environment and a hotbed for transmission. Some measures, such as installing plexiglass partitions, can actually make things worse if air flow is not properly studied.

To help inform a responsible return to schools and offices, Cornell University researchers Zoe De Simone, Patrick Kastner, and Timur Dogan created a new indoor module for Cornell's Eddy3D software. The tool packs complex computational fluid dynamics insights into a user-friendly tool for architects to determine how factors like ventilation, partitions, and furniture placement affect air flow. Seeing how eddies form and identifying areas where stagnant air can allow pathogens to concentrate can help users design the safest possible indoor spaces—and help all of us breathe a little easier.

MODELING VEHICLES AND VORTICES

When designing vehicles for performance and efficiency, companies like D2H Advanced Technologies need to know precisely how air moves around the vehicle. Traditionally, designers have reached these insights from wind tunnel tests, in which designers place a car in a wind tunnel and then observe how smoke flows around and behind it. However, these physical tests are expensive and time-consuming, creating a bottleneck to innovation.

Looking for a better way, D2H partnered with the Ohio Supercomputer Center, using its Pitzer Cluster to run sophisticated simulations. The models use computational fluid dynamics techniques to determine the angles, pressure, and speed of air flow as it interacts with a vehicle. Shown here is a visualization from the model that shows how smoke would stream around the car in a wind tunnel test. Seeing airflow at sub-millimeter scale lets designers tweak car designs with exquisite precision, optimizing designs for incredible performance while reducing the need for physical tests.

IMAGE COPYRIGHT:

08 *Zoe De Simone, Cornell University*

09 *D2H Advanced Technologies, Inc.*

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HEALTH FRONTIERS

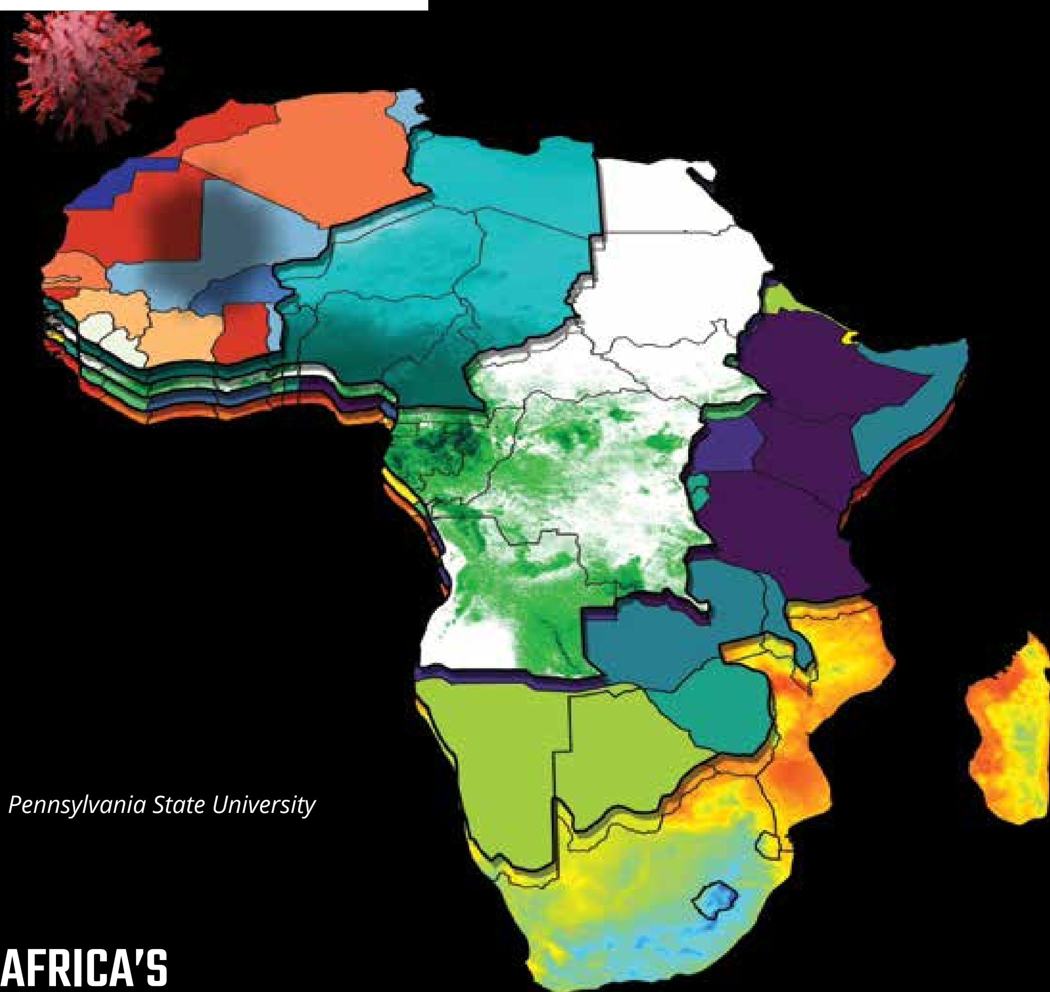

IMAGE COPYRIGHT:

10 *Andrew Geronimo, Pennsylvania State University*

INFORMING AFRICA'S COVID-19 RESPONSE

Numerous factors influence the spread of infectious disease, from socioeconomic characteristics to testing and containment capacity to weather and climate. Since these factors vary greatly from place to place, it is important to base public health decisions on data that is relevant to each locale. To inform the response to COVID-19 in Africa, Pennsylvania State University researcher Steven Schiff developed a predictive model of COVID-19 spread that accounts for socioeconomic development, testing capacity, containment policies, and environmental factors. By pooling the collective expertise of physicians, meteorologists, biologists, statisticians, and health informatics researchers, the team's computational tool distills a bewildering amount of data into usable one-week forecasts of COVID-19 cases per country.

This visualization, developed by Andrew Geronimo, shows how the tool can be used to navigate layers of information to anticipate COVID-19 impacts and needs. The layers, from top to bottom, reflect COVID-19 case counts, specific humidity, rainfall, population, and temperature.

UNCOVERING LASTING CHANGES AFTER CHILDBIRTH

Giving birth is one of the most dramatic events the human body experiences. While a woman's body is remarkably resilient to the changes experienced during pregnancy and childbirth, the incredible amount of strain can cause lasting internal damage, particularly to the soft tissues in the pelvis. The effects of this damage can manifest years or even decades later, with serious impacts on a woman's quality of life.

To better understand these issues, Steven D. Abramowitch's lab at the University of Pittsburgh developed a detailed computer model of the female pelvic bone and pelvic floor muscles, using resources of the University of Pittsburgh Center for Research Computing. The project, carried out by Megan R. Routzong and Liam C. Martin, defines anatomy obtained from MRI scans using thousands of points to model pelvic shape variation in pregnant women. These images show one example of anatomical variability defined by the statistical shape model. The right panel shows an "average" pelvis calculated from MRI scans of 25 pregnant women; points where lines intersect are the points on which the shape model is based. The left panel shows population variation from that average shape; blue and black areas have the least variation and green and white regions have the most variation compared to the average.

IMAGE COPYRIGHT:

11 *Steven Abramowitch, University of Pittsburgh*

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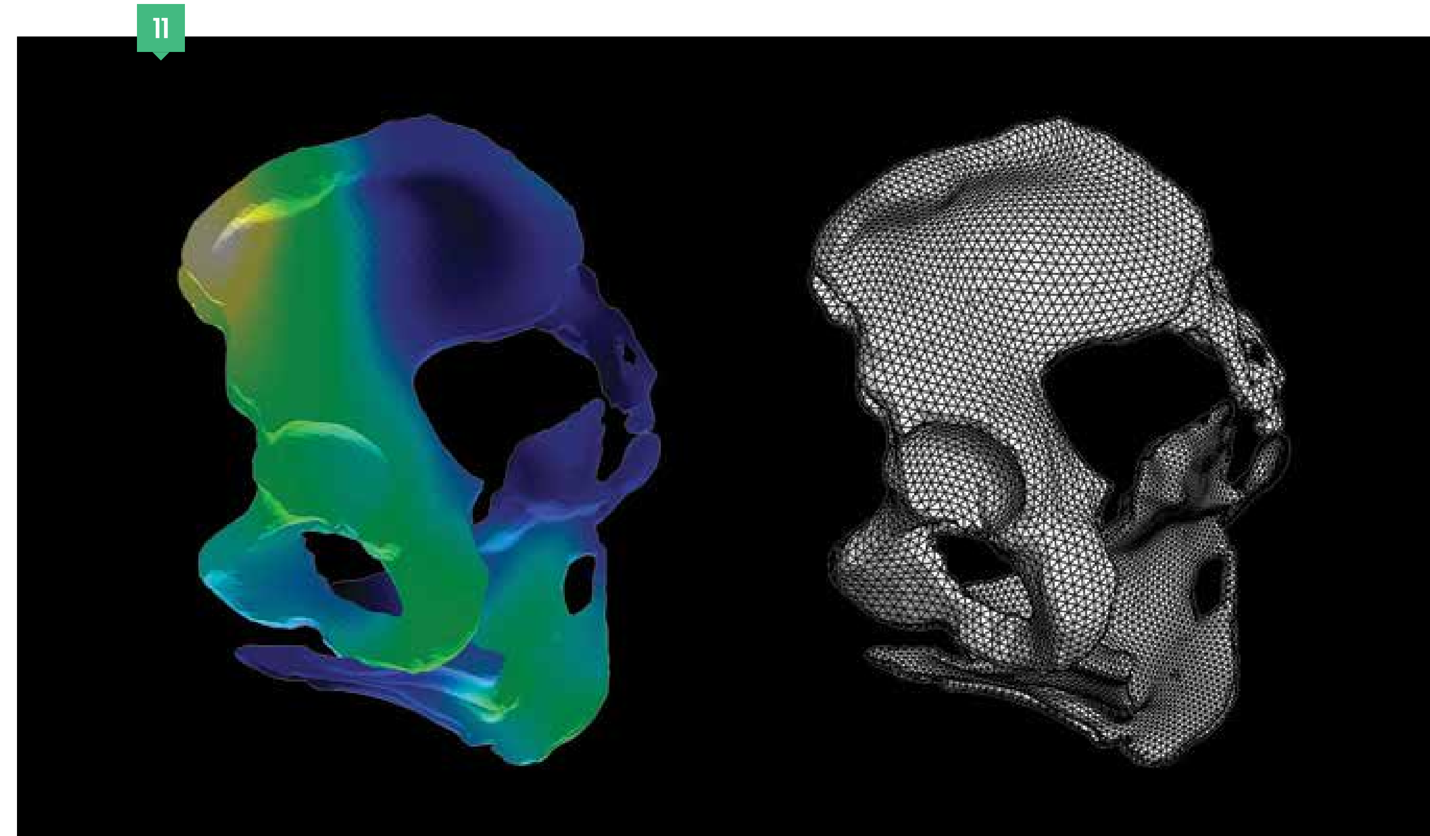
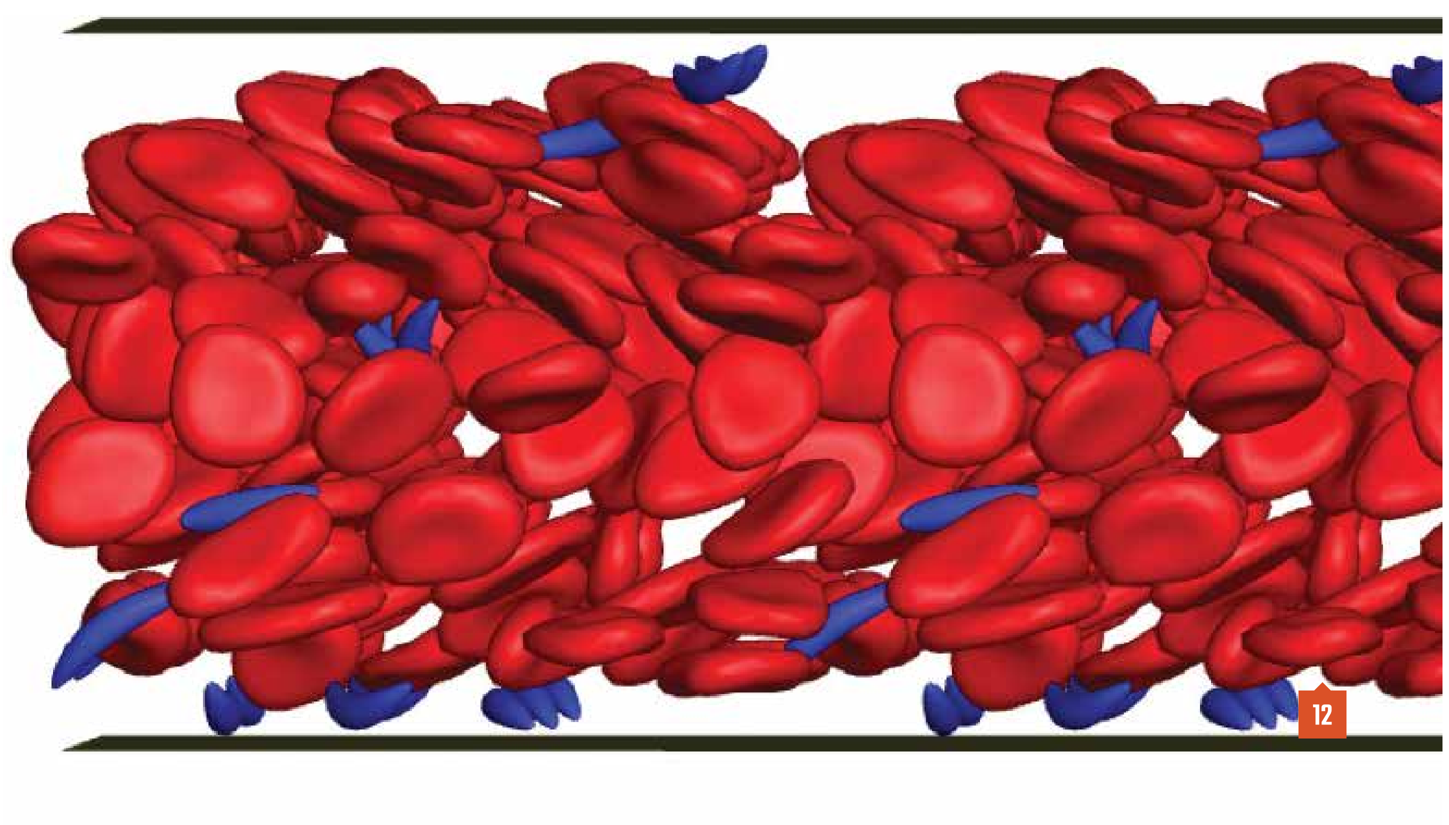




▲ SIMULATING THE FORCES BEHIND SICKLE CELL PAIN

Sickle cell disease is a blood disorder affecting an estimated 100,000 Americans. It is caused by a genetic mutation that makes a person's red blood cells become abnormally stiff and curved; these "sickle" cells create traffic jams in the blood vessels, damaging the vessels and causing episodes of intense pain.

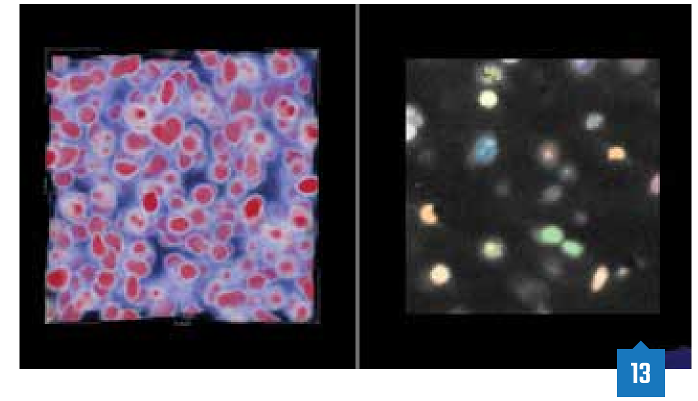
Researcher Michael Graham of the University of Wisconsin–Madison used the Comet supercomputer at San Diego Supercomputer Center to simulate how sickle cells influence the fluid dynamics within blood vessels. This image shows healthy red blood cells (red) and sickle cells (blue) as they flow through a channel that models laboratory studies of blood flow.

The sickle cells cause collisions and generate large forces near vessel walls, leading to painful inflammation and tissue damage. Scientists are using the simulation to better understand the mechanisms behind sickle cell disease in hopes of developing new treatments for this debilitating and under-studied condition.

IMAGE COPYRIGHT:

12 *Michael D. Graham and Xiao Zhang, University of Wisconsin–Madison*

13 *David Borland, University of North Carolina at Chapel Hill*



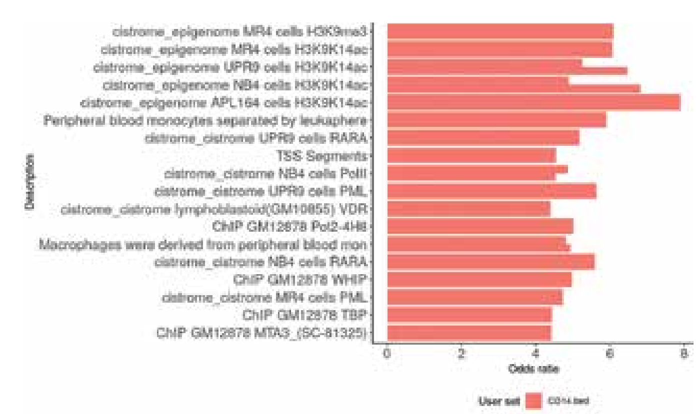
▲ TRACING THE EFFECT OF DNA MUTATIONS ON MILLIONS OF BRAIN CELLS

New imaging methods allow scientists to study the brain at an unprecedented level of detail, imaging all ~100 million cells in a mouse brain. Tracing how genetic mutations influence broader changes in brain structure could lead to important breakthroughs in understanding and treating neuropsychiatric disorders. However, since there are so many cells, it is impossible to count all of them manually.

To solve this problem, Jason Stein, Guorong Wu, and David Borland of the University of North Carolina at Chapel Hill are developing methods that automate the process of analyzing microscopy images of the brain. These machine learning algorithms "read" 3D brain images and identify mutated nuclei, annotating the images with information scientists can use to study how the mutations affect brain health. Shown here is a screenshot from Segmentor, a visual interface through which researchers can refine annotations to serve as high-quality training data for the machine learning algorithms. Using the tool significantly reduces the time scientists must spend manually annotating brain images without impacting accuracy.

▼ DECODING WHAT DNA DOES

Scientists have long known that DNA encodes the proteins that make our cells tick, but it was only more recently that researchers began to really untangle how certain segments of DNA control which genes are expressed, and when. These segments of "regulatory DNA" are now the focus of a great deal of research, but bringing information about genes together with insights on the DNA that regulates their expression has created a tangle of its own. How can researchers best navigate the vast amount of information being generated about the genome? Nathan Sheffield of the University of Virginia (UVA) Center for Public Health Genomics partnered with UVA's Research Computing Group to create LOLAweb, an online tool that automatically searches thousands of data points to help researchers gather all the known information, or annotations, about particular areas of DNA. Scientists specify what DNA region they are interested in, and LOLAweb compiles interactive plots and annotated data that reveal, as shown in this image, the likelihood that the region of interest is connected in some way with existing knowledge about particular biological pathways and functions.



CONNECTING WITH THE COSMOS

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▸ PLOTTING A 'KISS' WITH AN ASTEROID

On October 22, 2020 the Spacecraft OSIRIS-REx swooped down to the surface of the asteroid Bennu, collected a sample of dust and small pebbles, and took off. The event, lasting mere seconds, marked the culmination of years of meticulous planning. One unexpected challenge was Bennu's rough terrain, which made it critical to select a contact point that would allow OSIRIS-REx to sample the asteroid and return to Earth unscathed.

To pick the perfect spot, University of Arizona Lunar and Planetary Laboratory Research Professor Mike Nolan developed a model to analyze the asteroid's complex terrain and select a sampling site. Running the model on the University of Arizona's Ocelote system, Nolan and colleagues were able to pinpoint the optimal place for touchdown, a site named Nightingale. The mission was a success, and OSIRIS-REx is on track to deliver its precious cargo to Earth in 2023. Scientists plan to analyze the samples for insights into the origins of planets, how life began, and how asteroids could impact Earth.

IMAGE COPYRIGHT:

14 *NASA/Goddard/University of Arizona*

15 *Robin Canup, Southwest Research Institute and Advanced Visualization Lab, National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign*

16 *Predictive Science Inc., San Diego, California*

▾ THE MOMENT THAT FORMED THE MOON

Scientists have long sought to uncover the origins of Earth's moon. Researcher Robin Canup of Southwest Research Institute has devoted much of her career to this question, modeling how a collision between Earth and another object—specifically, a hypothesized planet named Theia—could have kicked off enough debris to form the moon. This visualization, created in partnership with Donna Cox, Robert Patterson, Stuart Levy, Jeff Carpenter, A.J. Christensen, and Kalina Borkiewicz of the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign, shows a simulated collision between Earth and Theia, bringing this pivotal moment to life in stunning detail.

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▴ SIMULATING—AND SEEING—A SOLAR ECLIPSE

Seeing a solar eclipse is a captivating experience for anyone. For scientists, the phenomenon also offers an opportunity to better understand the inner workings of the sun. In the lead-up to a recent solar eclipse, visible only in regions of the South Pacific, Chile, and Argentina, Cooper Downs and a team of scientists at Predictive Science Inc. used the Expanse supercomputer at San Diego Supercomputer Center to generate a simulation of how the eclipse would appear. After the event, scientists compared the computer-generated image with footage of the actual eclipse to improve the model for future study. This image shows the simulated 3D magnetic field of the sun's outer atmosphere, or corona, at extremely high resolution. Scientists study the solar corona for insights into its heating, dynamics, and the solar wind it produces, which can disrupt vital technological infrastructure—including power grids—here on Earth.

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STUDYING SOCIAL CHANGE

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MAPPING MOVEMENTS FOR CHANGE

Millions of Americans took to the streets in recent years to express outrage and inspire change. Many of these protests and demonstrations drew attention to issues of police brutality and systemic racism; others focused on contentious issues surrounding COVID-19, immigration, and the 2020 election.

The constant flow of information on news sites and social media can make it hard to keep track of the people and issues involved in these protests in the context of where and when they occur. To provide a nationwide perspective of recent demonstrations in context, Princeton University researchers Nealin Parker, Shannon Hiller, and Autumn Lewien teamed up with visualization experts Eliot Feibush, William Guthe, and Carolina Roe-Raymond to produce this visual snapshot of over 27,000 demonstrations between January 1, 2020 and April 1, 2021. The source data was collected by The Armed Conflict Location & Event Data Project.

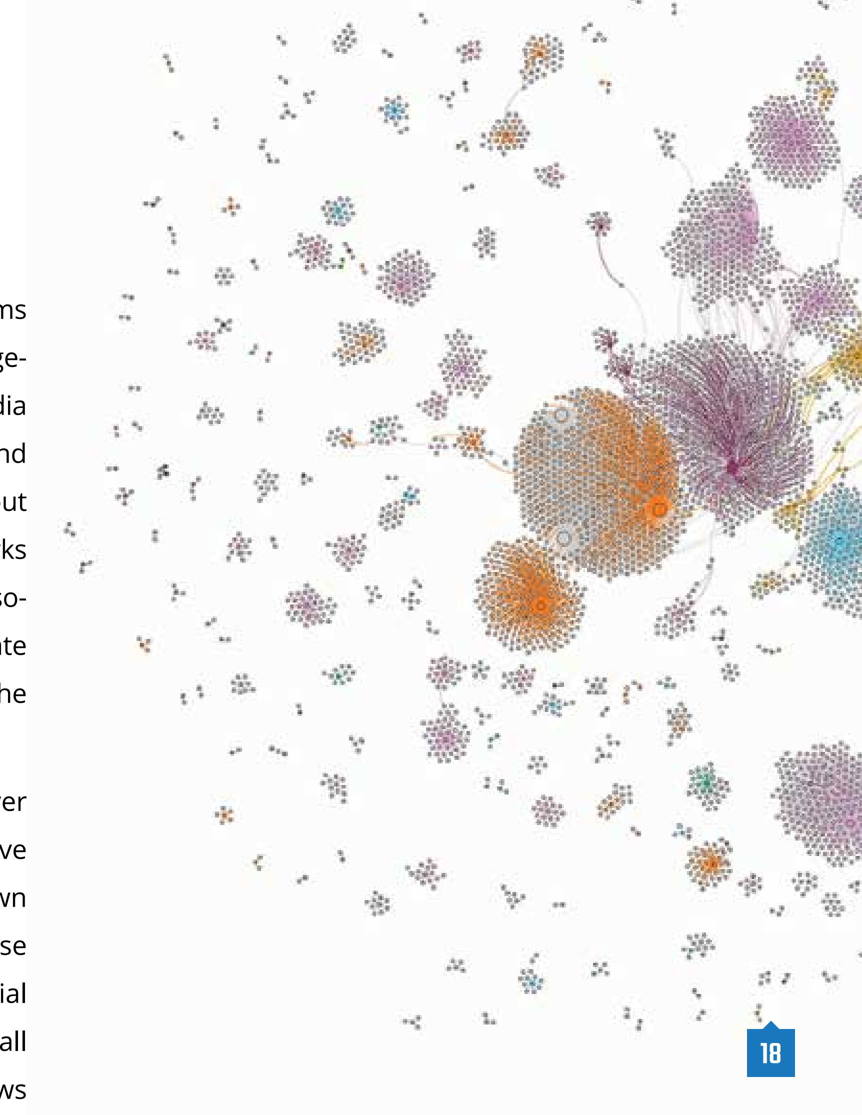
The researchers developed a new visualization technique, the geo-stackgraph, to represent multiple aspects of protest events in locations around the United States. The height of each stalk reflects the number of events at a location; the orange segment indicates Black Lives Matter demonstrations; white segments indicate events focused on other topics; and red segments show the number of counter-protests. Shading of the base map indicates population density, and the timeline shows the number of demonstrations per day, with a notable increase following the killing of George Floyd on May 26, 2020. Visualizations like this help social scientists—and the public—understand demonstrations and their impacts.

PROBING PROTEST NETWORKS ONLINE

Twitter and other social media platforms are an invaluable tool for coordinating large-scale protests. Organizers use social media to spread messages, galvanize action, and communicate with protest participants about event logistics and safety. But these networks can also be infiltrated and leveraged by so-called "information operations," which generate coordinated social media activity to advance the agenda of a particular group or nation.

Major Brown, Shawn Walker, and Gil Speyer of Arizona State University, using the Agave supercomputer, traced the activities of known information operations (IO) accounts (those that were later suspended by Twitter) in social media networks surrounding the Occupy Wall Street movement. The image at left shows the prevalent role IO account activity played in Occupy Wall Street conversations on social media; grey nodes are non-IO accounts; colors indicate IO accounts linked with various countries; and the lines between nodes represent mentions between accounts. This network view reveals clusters of suspended accounts that mention each other and also interact with other clusters.

The graphs at right show the total volume of Occupy Wall Street tweets, IO tweets, and IO mentions, with vertical lines indicating days when key metrics for IO accounts were significantly different than those of regular accounts. Further analysis could help researchers uncover what role these accounts had in the protest, especially on those significant days.



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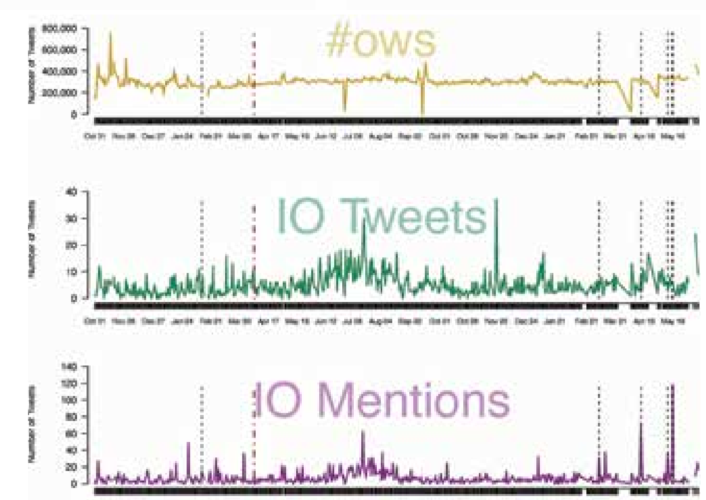

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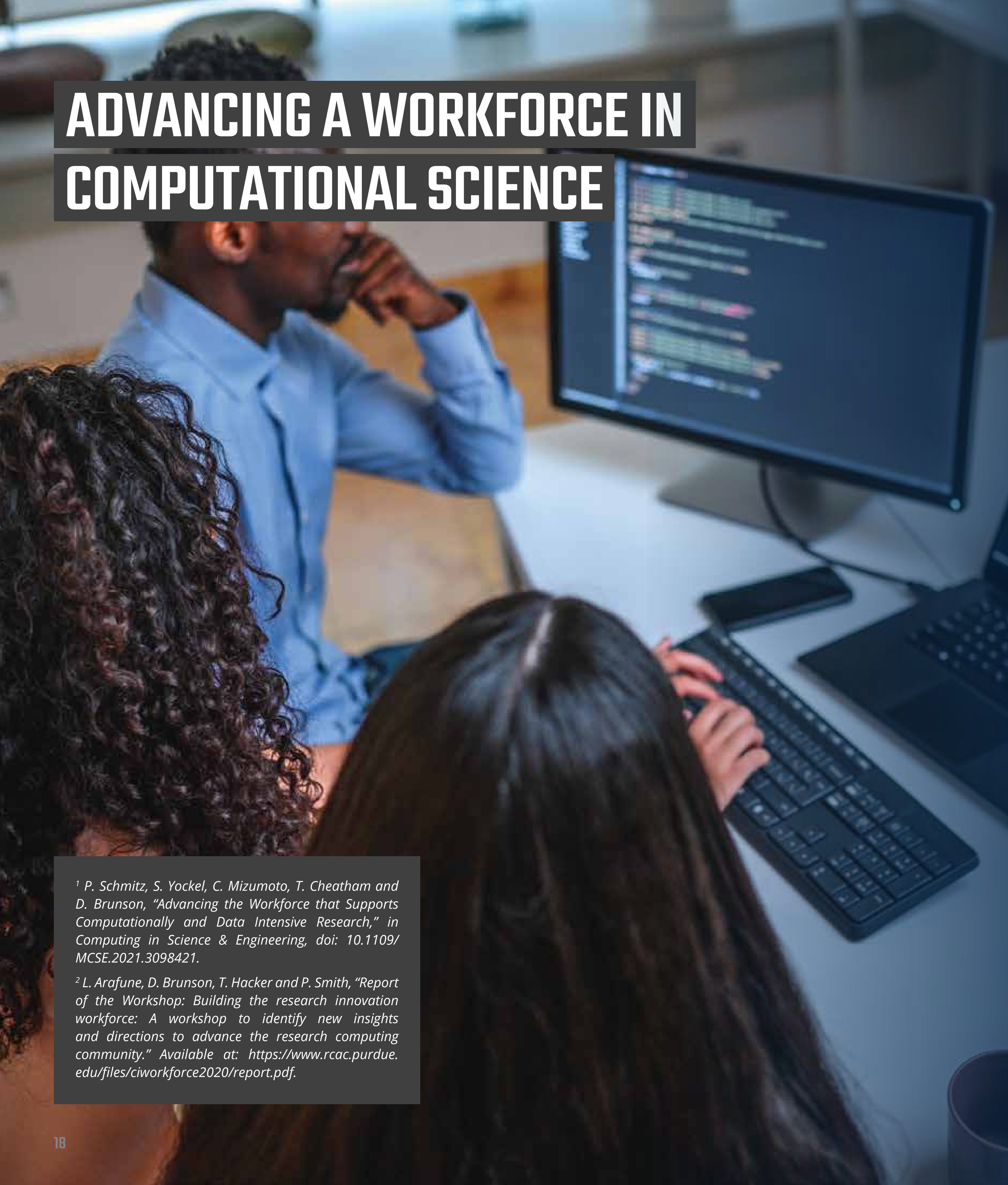
IMAGE COPYRIGHT:

17 *Princeton University*

18 *Major Brown, Shawn Walker, and Gil Speyer, Arizona State University*



ADVANCING A WORKFORCE IN COMPUTATIONAL SCIENCE

Science has always been about data. But the past several decades have marked a dramatic shift in the way we "do science"—and data is at the heart of that shift. As data has become more complex, more voluminous, and more real-time, computation has grown ever more critical to scientific progress. In many disciplines, from astrophysics to genomics to the social sciences, to be a scientist today is to rely on the power of computation, both to extract meaning from data and to model phenomena in order to better understand them. Computation is also critical to the application of scientific insights to inform decision-making and drive innovation.

This way of doing science requires specialized expertise, tools, and infrastructure. Running large data-generating assets such as telescopes and sensor networks, combining and analyzing disparate data sets, and building models and machine learning algorithms all require advanced knowledge and skills, as does managing the ethical, privacy, security, and legal compliance dimensions of these activities. To meet these needs—and many more—the computational science workforce has emerged as an increasingly integral part of the broader scientific and engineering workforce. CASC members, who rely heavily on these experts to run their centers and interact with domain scientists, have been instrumental in exploring the future needs of the community.

A recent IEEE article[1] discusses challenges and progress toward recognizing research computing and data (RCD) as a distinct profession. The authors outline ways to support this growing field through a professional association with a dedicated journal and an active presence at events and conferences. Coordination among disparate existing communities will be vital to communicating the essential role of RCD professionals in supporting research, charting educational and career paths to ensure a robust recruitment pipeline for the field, and curating resources to build and maintain RCD expertise. The article also outlines key steps to support professional development for individuals in the field, stressing the need to ensure broad access to RCD resources, educational opportunities, and career pathways.

Along similar lines, a recent workshop funded by the National Science Foundation (NSF)[2] examined opportunities to advance the research computing community. Participants identified high-priority needs related to recognizing cyberinfrastructure and RCD as a viable career path and communicating about the cyberinfrastructure ecosystem. In particular, participants emphasized the importance of educating institutional leadership about the role of these professionals in the research enterprise, creating an inclusive workforce pipeline, and establishing sustainable pathways for growth and professional development for the field. Toward these goals, participants identified specific steps the RCD community, higher education and other research organizations, and the NSF can take to reduce barriers, bridge existing gaps, and foster a robust computational science workforce to support science and engineering for the nation.

[1] P. Schmitz, S. Yockel, C. Mizumoto, T. Cheatham and D. Brunson, "Advancing the Workforce that Supports Computationally and Data Intensive Research," in Computing in Science & Engineering, doi: 10.1109/MCSE.2021.3098421.

[2] L. Arafune, D. Brunson, T. Hacker and P. Smith, "Report of the Workshop: Building the research innovation workforce: A workshop to identify new insights and directions to advance the research computing community." Available at: https://www.rcac.purdue.edu/files/ciworkforce2020/report.pdf.

STEM EDUCATION

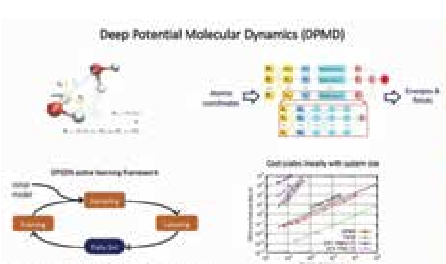
Participants of Princeton Institute for Computational Science & Engineering (PICSciE) Graduate Certificate in Computational Science and Engineering Colloquium on April 30, 2021. The group was the first cohort to earn the new credential.

FORMAL RECOGNITION FOR SCIENTIFIC COMPUTING

The application of computational methods as a tool for discovery has played an increasingly central role across many areas of science and engineering in recent years. Now, the field of scientific computation is gaining more formal recognition, both in academic career pathways and the educational pipeline for such careers.

At Princeton University, the Princeton Institute for Computational Science and Engineering recently formalized its scientific computing educational offerings with an official credential for Graduate Certificates in Computational Science and Engineering. While the program has included foundational skills in scientific computing since 2013, students are now able to earn formal recognition for this skill set beginning in 2021.

At the same time, Princeton is also growing its professional staff of Research Software Engineers, who support research projects across a wide spectrum of disciplines, including genomics, hydrology, applied mathematics, high-energy physics, and many others. While such experts have long been integral to academic research, the formalization of the Research Software Engineer job position and team is part of a growing trend at U.S. universities to recognize and cultivate expertise in scientific computing.



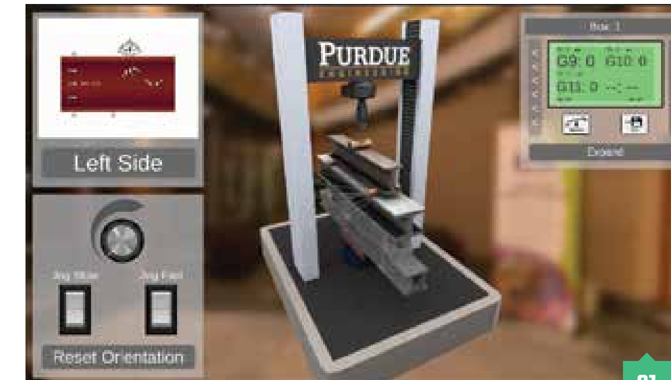
Shuwen Yue, who recently completed Princeton's Computer Science and Engineering certificate program with PICSciE. Yue uses machine-learning algorithms to model the molecular dynamics of water and aqueous solutions.

Geomentor Jim Hanson assists a student in a Minnesota classroom.

CULTIVATING GEOSPATIAL SKILLS

Geospatial information underlies many fields, and cultivating spatial thinking can help students prepare for careers in the knowledge-based economy of the 21st century. The University of Minnesota's U-Spatial program supports spatial capabilities both on campus and beyond with a robust array of outreach projects for students across Minnesota.

U-Spatial partners with the Minnesota Alliance of Geographic Educators, Esri, K-12 educators, and GIS professionals to connect students and educators with classroom activities, webinars, workshops, and mentorship opportunities. For example, U-Spatial created a suite of Minnesota-based "Geoinquiries" modules that help middle school students build spatial skills as part of their social studies classwork, and the Minnesota on the Map Contest recognizes student work using ArcGIS online software, further building awareness and excitement around this important field.



VIRTUAL LABS SUPPORT TOP-NOTCH ONLINE EDUCATION

While many educators scrambled to transition to online teaching amid a pandemic, engineering faculty at Purdue University had the perfect tool already in hand. In response to a growing demand for online classes even before COVID-19, the university had begun creating a set of virtual labs that let students interact with simulations and remotely-controlled physical lab equipment from their own computers. The virtual labs, spanning topics from aeronautics to civil engineering to chemistry, were poised for scale-up when the pandemic shuttered in-person labs.

While the tools are still being formally evaluated, students and professors are enthusiastic, noting that virtual labs can provide students more hands-on time with a piece of equipment and allow for more extensive and longer-term experimentation. Even as in-person classes and labs resume, professors anticipate that the virtual labs will remain a valuable part of the educational experience.

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