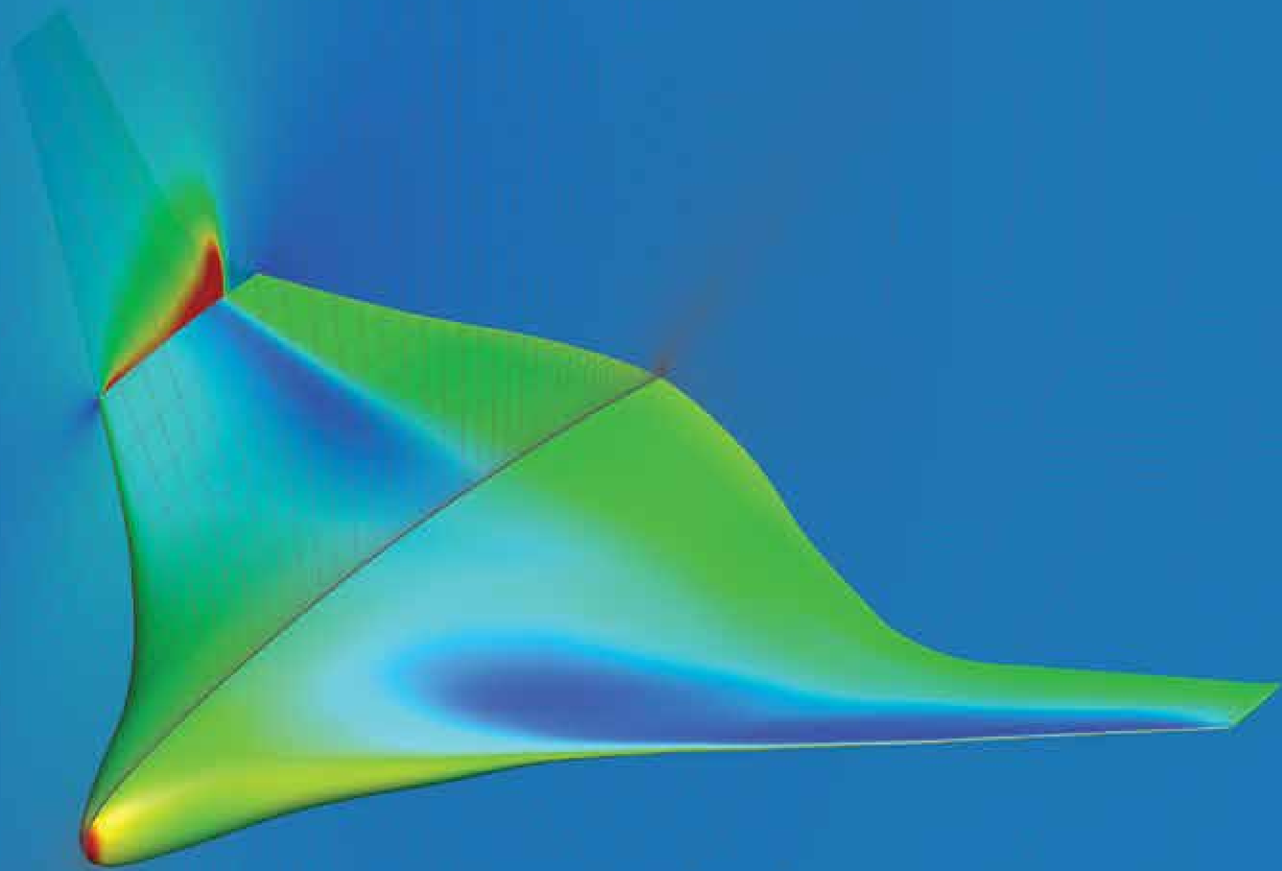
TRANSFORMING RESEARCH

TRANSFORMING OUR WORLD

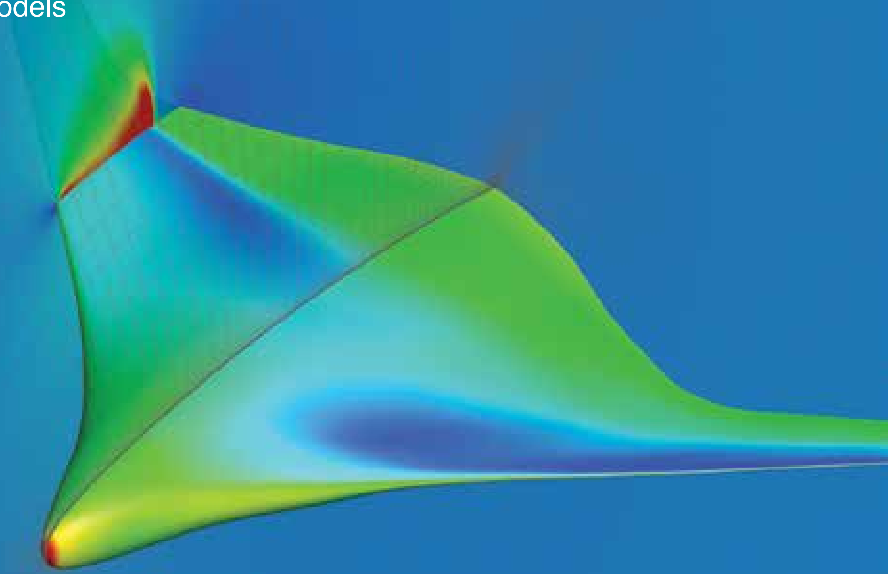


Coalition for
Academic Scientific
Computation

2016

ABOUT THE COVER

With roughly 90,000 commercial passenger planes taking to the skies each day, even miniscule improvements in plane design can make a major difference in the safety, economics and environmental impact of flight. This image, created by a team led by Joaquim Martins at the University of Michigan (pictured below), shows how researchers are using innovative numerical simulations to design the next generation of aircraft. Martins' Multidisciplinary Design Optimization Lab deploys complex algorithms to optimize hundreds of design parameters at once, allowing them to envision and virtually test radically new wing and body designs. Computational models developed in academic labs are a crucial component in the innovation pipeline that fuels the aerospace industry, leading to advances in defense, shipping, commercial air travel and more.



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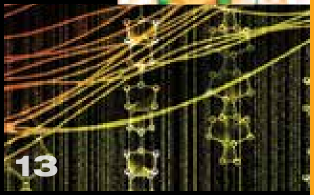

About CASC

The Coalition for Academic Scientific Computation is an educational nonprofit 501(c)(3) organization with 85 member institutions representing many of the nation's most forward-thinking universities and computing centers. CASC is dedicated to advocating the use of the most advanced computing technology to accelerate scientific discovery for national competitiveness, global security, and economic success, as well as develop a diverse and well-prepared 21st century workforce.

In addition, CASC has formed a collaboration with the United Kingdom High Performance Computing Special Interest Group (HPC-SIG), with the collective goals of advancing the use of scientific computing across all disciplines, and supporting economic and workforce development in high-performance computing-related fields.

"...the predominant driver of GDP growth over the past half-century has been scientific and technological advancement. It is likely, given the current pace of progress in science and technology fields, that this will be equally true in the decades ahead, if not more so."

—Restoring The Foundation: The Vital Role of Research in Preserving the American Dream, AAAS, 2014

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A simulation of the dynamic behavior of plasma, the universe's most abundant form of matter, in Earth's atmosphere. Image courtesy of researcher Wendell Horton and colleagues at the University of Texas at Austin and Texas Advanced Computing Center.

CYBER INFRASTRUCTURE
A National Imperative

While high performance computing (HPC) capability has long been a priority for numerous federal agencies, the 2015 National Strategic Computing Initiative (NSCI) represents a more unified and strategic path for U.S. federal agencies to build their resources and expertise. The collaboration will be led by the Department of Energy (DOE), Department of Defense (DOD) and National Science Foundation (NSF), with foundational research and development by the Intelligence Advanced Research Projects Activity (IARPA) and the National Institute of Standards and Technology (NIST). The initiative will be deployed across the National Aeronautics and Space Administration (NASA), Federal Bureau of Investigation (FBI), National Institutes of Health (NIH), Department of Homeland Security (DHS) and National Oceanic and Atmospheric Administration (NOAA).

The NSCI recognizes the crucial role of HPC in America's economy, security and scientific research, and outlines a concrete plan for beefing up the country's HPC capabilities to maintain its position as a global science and technology leader. The initiative has received an overwhelmingly enthusiastic response from tech industry leaders, academic researchers and the government agencies charged with leading its implementation.

But the initiative isn't merely a "moon shot" to create the world's most impressive supercomputer. It's about cultivating a national ecosystem of HPC resources to support a wide range of applications in industry, research and national security.

The United States is already home to more supercomputers than any other country, with more than six times the number held by China and substantially more than all of Europe combined, according to tracking by the TOP500 organization. But there is room for improvement in the way these resources are used by researchers and engineers. By making existing and future HPC resources easier to access, the NSCI aims to increase their reach and utility, both in the academic world and for industry.

Titan, currently the nation's fastest supercomputer. Image courtesy of Oak Ridge National Laboratory and NVIDIA Corporation.

> **"Maximizing the benefits of HPC in the coming decades will require an effective national response to increasing demands for computing power, emerging technological challenges and opportunities, and growing economic dependency on and competition with other nations."**
>
> –National Strategic Computing Initiative, July 29, 2015

TAPPING BIG DATA: *FROM THE INNER BRAIN TO OUTER SPACE*

The ability to collect and compute data sets that are vastly larger and more complex than ever before has fueled a cyber gold rush to mine big data for big gains in medicine, Earth and space science, robotics, security and more. As a result, recent years have seen a surge of national investment in cyberinfrastructure and high-performance computing applications.

Many far-reaching efforts are underway at the national level; numerous other important endeavors are being deployed by states, universities, research institutes and companies. At the crux of many of these initiatives is a focus on facilitating collaborations that leverage the strengths of government, academia and private industry. CASC member institutions are involved in the following programs, providing a wide range of computing, visualization and data mining resources, software development, expertise and training.

Big Data Initiative

Although our ability to collect data has ballooned, the technologies for storing and managing big data have lagged behind, creating bottlenecks that limit the ability to effectively use and share big data. By supporting research and training geared toward developing new techniques and technologies that can handle large, complex data sets, the National Big Data Research and Development Initiative, jointly administered by NSF and NIH, aims to increase our capacity to use the data to its fullest potential.

The first awards granted under this program form a National Network of Big Data Regional Innovation Hubs (BD Hubs). Forty of the grant recipients are supported by CASC member centers.

Brain Initiative

The Brain Research through Advancing Innovative Neurotechnologies initiative is a sweeping research effort focused on creating a dynamic understanding of how the human brain functions. With participation from NSF, NIH, DARPA, FDA and IARPA, the initiative supports and advances research aimed at deciphering the workings of a healthy brain, as well as the processes behind debilitating problems such as

> **"Research is the lifeblood of a high-tech economy and plays a critical role in the economic and personal well-being of most citizens."**
>
> *–Restoring The Foundation: The Vital Role of Research in Preserving the American Dream,* AAAS, 2014

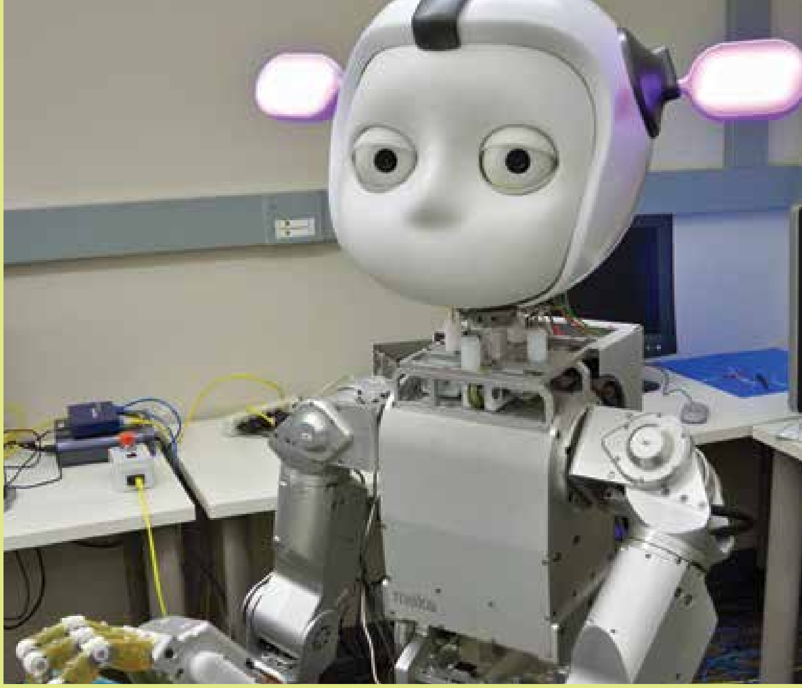
Alzheimer's, Parkinson's, depression and traumatic brain injury. Twenty CASC institutions have received grants under this program, in areas as diverse as human imaging, brain cell research, understanding neural circuits and large-scale data recording and optimization.

National Robotics Initiative

Robots are already widely used for manufacturing and other industrial applications, and engineers are hard at work developing even more sophisticated robots suited to serving people in more direct ways, such as by providing personal care and home maintenance services. This initiative, jointly administered by NSF and NIH, supports the development of robotic technologies that cooperatively work with people to enhance individual human capabilities, performance and safety. Researchers at CASC member institutions have received more than $29 million to further robotics research in areas including skeletal and muscular function, manual dexterity, and robots assisting children who suffer from chronic diseases.

Big Data for Public Health and Biomedical Breakthroughs

Research institutes and public health agencies across the federal government are tapping big data to improve Americans' health and well-being. Big data is now an integral part of the systems we rely on to detect disease outbreaks, manage health records and track the health of our population. Advanced techniques for analyzing the human genome, internal biological processes and medical images have yielded important discoveries for disease treatment and prevention. A few of these projects are highlighted under Biomedical Breakthroughs (p. 10).



Credit: Georgia Institute of Technology

Plumbing the Ocean's Depths and Outer Space

Physics, earth and the space sciences were among the first fields to begin exploiting the power of big data. Today, initiatives led by NASA, NOAA, USGS, NSF and other agencies are developing cutting-edge data management and modeling techniques to advance the responsible use of Earth's resources, improve weather and climate predictions and explore our universe, among numerous other applications. Read more about these projects in Understanding Our Universe (p. 16).

Defense and Intelligence Initiatives

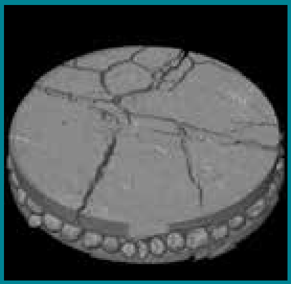
Agencies across the Department of Defense and the Department of Homeland Security are working in a number of areas to refine methods for mining images and surveillance footage to identify threats, develop advanced machine learning technologies, and improve cybersecurity protections to defend the nation's sensitive data and infrastructure. High-performance computing and forward-reaching engineering innovations are crucial to our ability to stay ahead of emerging threats. CASC member institutions support industrial innovation in defense areas, including creating stronger bulletproof materials, designing more aerodynamic ship hulls, and addressing cybersecurity threats.

POWERING OUR ENERGY FUTURE

Modeling More Efficient Natural Gas Extraction

Hydraulic fracturing, or fracking, has expanded dramatically in recent years as a way to release natural gas and oil trapped within underground rock formations, allowing access to previously untapped reserves across the United States. The process involves pumping large quantities of fluids into the rock at high pressures, along with proppants such as sand, ceramic pellets or other particles that hold the cracks open after the high pressures are released.

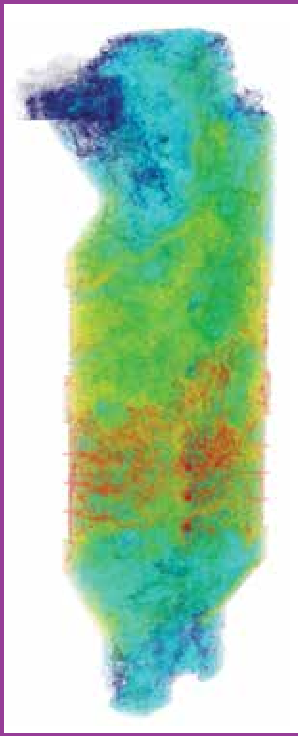
High-resolution imaging and simulations by a team at Louisiana State University offer a window into how proppants pack into fractures and the corresponding impact on fluid flow under various stress conditions. Insights from this work are helping to improve the efficiency of oil and gas production. The left image shows two shale slabs with a single layer of proppants in the middle; the right image is a cross-section that shows the individual proppants. The research is led by Clinton Willson and Karsten Thompson at LSU; imaging was performed at Argonne National Laboratory and visualization and simulations are done utilizing LSU high-performance computing resources.

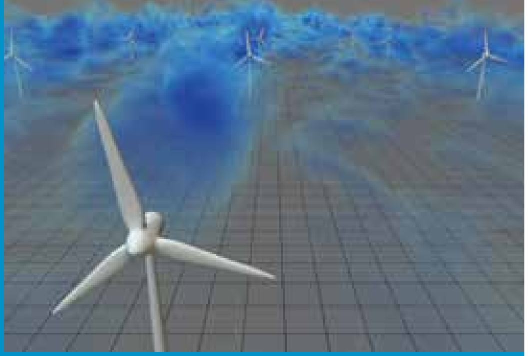


Coal Technologies for Lower Costs and Reduced Emissions

Nearly 40 percent of U.S. electricity generation comes from coal. While coal-fired power plants have become markedly cleaner and more efficient in recent decades, there remains room for improvement. A multidisciplinary team led by University of Utah researcher Phillip Smith develops custom simulations to rapidly evaluate and deploy new technologies for coal power generation at lower cost and with reduced emissions.

This image shows the concentration and distribution of particles in a conceptual oxy-coal burner boiler after a simulated 2.4 million core hours of use. Such simulations allow researchers to assess the benefits of new approaches and pinpoint potential problems virtually before building and testing equipment at scale. The project is a collaboration involving the University of Utah, the University of California, Berkeley, and Brigham Young University. The group has established a collaborative agreement with Alstom Power, which generates almost 25 percent of the world's power production capacity; the simulation will inform the design of a new oxy-coal boiler capable of producing 450 Megawatts of electrical output.





The Answer is Blowing in the (Simulated) Wind

Wind farms often include numerous turbines for economies of scale in power generation and transport. But giant wind farms carry a downside: upwind turbines disrupt the flow of air, creating a turbulent wake that makes downwind turbines less efficient. This effect, observed in field experiments, is modeled in a numerical simulation performed by Richard Stevens and Charles Meneveau at Johns Hopkins University, with visualization support from David Bock at the National Center for Supercomputing Applications at the University of Illinois. The model allows researchers to virtually manipulate the placement of turbines to help optimize the design of real-world wind farms for maximum power output.

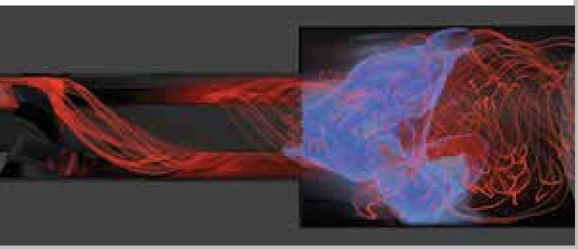
Visualizing Energy-Efficient Buildings

Commercial buildings are responsible for a significant portion of the energy use and greenhouse gas emissions in the United States. Cutting energy use in buildings such as offices, warehouses and retail stores is good for the environment and good for the bottom line—but achieving significant reductions is no easy feat.

Researchers at the Interdisciplinary Center for Applied Mathematics at Virginia Tech have developed an immersive virtual-reality simulation to gain new insights into how air moves within large buildings. Rather than focusing on individual building components such as lighting or HVAC units, the simulation allows researchers to explore airflow patterns throughout a building as a whole. The simulation is helping to inform the design of more energy-efficient buildings and guide the placement of sensors to provide accurate, real-time feedback for more precise control over heating and air conditioning systems.

Harnessing the Power of Hydrogen

Hydrogen—present in enormous quantities in water, methane and organic matter—holds tremendous potential as a plentiful, zero-emission energy source. NASA has used hydrogen for spaceflight since the 1950s, and today, hydrogen fuel cell vehicles are rapidly becoming more common in the United States. But for hydrogen fuel to reach its full potential, new technologies are needed to efficiently extract and safely use this powerful element to meet our growing energy needs.

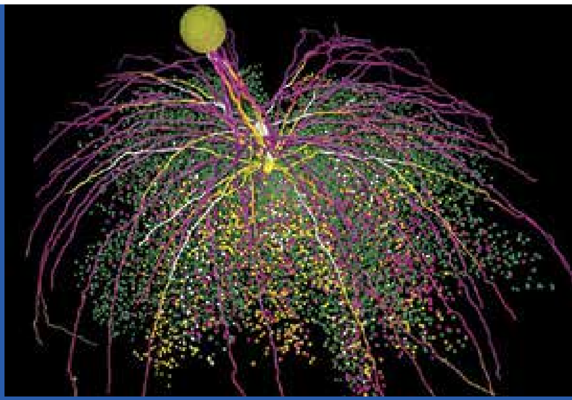


TOP: Nanoparticles are commonly used to split hydrogen from oxygen, allowing the extraction of hydrogen gas from water. But manufacturing nanoparticles in sufficient quantities can be an expensive proposition. This image models a jet of hot zinc vapor as it is released into a cool argon environment. As the zinc cools, it turns into nanoparticles. The model, developed by Sean Garrick of the University of Minnesota, helps engineers optimize nanoparticle production to make hydrogen extraction more energy-efficient and cost-effective. The same model can be used to optimize the use of nanoparticles for a wide range of other applications in mechanical and chemical engineering and beyond.

BOTTOM: Hydrogen's biggest strength is also its greatest weakness: it is extremely volatile. As a result, it is both a powerful energy source and somewhat difficult to control. To ensure the safety and reliability of hydrogen-based fuels, researchers are taking a close look at how these fuels burn—and where things can go wrong. This simulation shows the early stages of a "boundary layer flashback," a dangerous situation in which the flame doubles back against the flow. The red lines trace the flow of a hydrogen-methane-air mixture into the chamber; the blue area is the advancing flame. The simulation was developed by University of Michigan researcher Venkat Raman to improve scientists' ability to predict—and prevent—flashbacks when using hydrogen-based fuels. Computational resources were provided by the Texas Advanced Computing Center.

BOOSTING BIOMEDICAL BREAKTHROUGHS

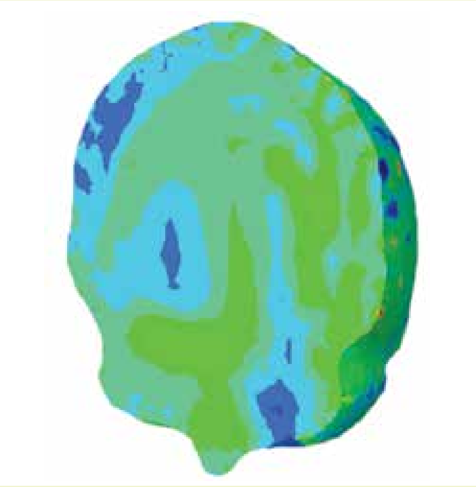
A Gateway to the Brain



As researchers decipher the intricate wiring of the human brain, neuroscience has become increasingly dependent on high-performance computing. Mapping the brain's billions of cells and understanding the interactions among them can push the limits of even the most robust supercomputers. To remove this research roadblock, the University of California at San Diego and Yale University launched the Neuroscience Gateway portal, a National Science Foundation-funded project that provides free, remote access to supercomputing power for neuroscientists. The portal also provides a platform for scientists to collaborate and implement new simulation pipelines needed by the computational neuroscience community.

This figure shows a small portion of a large scale, 3-D model of the olfactory bulb, the part of the brain that handles the initial information processing behind the sense of smell. The model was created by Gordon Shepherd and colleagues at Yale University, who run simulations of it on high-performance computing resources to study how brain cells and circuits respond to odors. Other research teams are using similar modeling approaches and Neuroscience Gateway resources to investigate the neural basis for brain functions such as vision, control of movement, and learning and memory.

Protecting the Brain from a Blast or Crash



Traumatic brain injury, such as that caused by an explosion or a collision, can cause serious disability or death. In a project led by Rajkumar Prabhu at Mississippi State University, researchers are challenging 50 years of science on how shockwaves travel through the brain to cause injury. The findings could be used to improve the design of military helmets or athletic gear to better protect the brain.

It has traditionally been thought that a shock wave induced by a blast or blunt force strikes the scalp, travels through the skull until it hits the opposite side and then ricochets back through the brain. But the virtual model developed by Prabhu and his team reveals a more complicated story. The team's simulation, which reflects the physical properties of brain tissue in 3-D and at the microscale, suggests most of the damage is caused by brain cells being torn apart by small tension waves that are generated when compressive waves travel through the skull and then reflect back into the brain. The team is applying their model to aid in the design of protective headgear, and plans to develop similar models for traumatic injury to the lungs, hips and limbs.

Healing the Heart

Heart disease is the #1 cause of death in the United States. Although remarkable medical innovations have helped to manage symptoms and prolong life for people with the disease, even tiny variations from person to person can make a world of difference. As a result, what helps one patient may harm another. New high-tech tools give doctors patient-specific insights to inform a more personalized approach to cardiac care.

TOP: This image is from the world's largest full-body scale 3-D blood flow simulation. The simulation, developed by Alberto Figueroa of the University of Michigan, provides a window into the arteries and veins of a specific patient under various simulated conditions (during rest or exercise, for example), helping doctors pinpoint problems and choose among treatment options such as drugs, surgery and medical devices. The advanced computational techniques behind the model can also be used to conduct research on the root causes of cardiovascular conditions or to develop and virtually test ideas for new medical devices. Computation for the simulation was performed at ARCHER and the Hartree Center, two high-performance computing facilities in the United Kingdom.

BOTTOM: Whenever someone survives a heart attack, doctors act quickly to assess the location and extent of the damage to the heart tissue. This information is crucial to guiding a treatment strategy that will help the patient recover and avoid future heart attacks. Yet current methods used to assess heart tissue damage have significant downsides. When viewing the heart with ultrasound, doctors get an incomplete picture because parts of the heart can be obscured by bone and other tissues. Using radioactive isotope dyes gives a more complete view of the heart, but is more invasive and raises waste disposal concerns. This image shows an innovative approach that uses data from DT-MRI, a non-invasive imaging technique, to create a 3-D rendering of the heart's muscle fibers. By comparing a rendering of a healthy heart to that of a patient who has suffered a heart attack, doctors could potentially use the modeling system to comprehensively assess tissue damage and guide treatment decisions. The project is led by Jun Liao and Song Zhang and the research, visualization and computation were performed at Mississippi State University.

Seeing Past the Surface

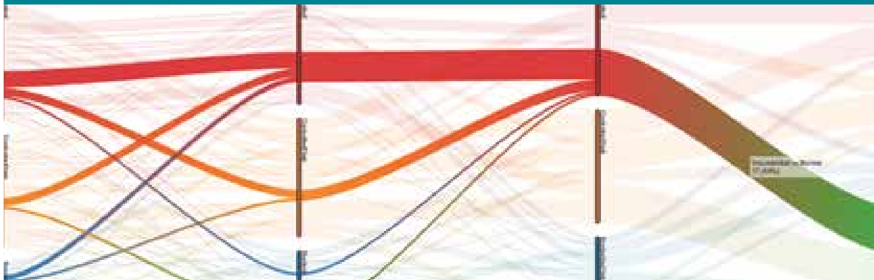
About 1 in 200 people have irregularities in the small blood vessels in the brain, a condition called cerebral cavernous malformations. Although about a quarter of people with these malformations never experience symptoms, the condition can lead to headaches, seizures, hearing or vision loss, and even paralysis or death. In a study led by Issam Awad and Huan Tan at the University of Chicago, researchers and computer scientists are using advanced imaging techniques to peer inside patients' brains, with the goal of enabling more informed diagnoses and treatment decisions.

These images show lesions on the brain of a mouse with cerebral cavernous malformations as detected using a 3-D microCT scan. The image at left shows only surface lesions. The image at right, rendered using a "maximum intensity projection," reveals lesions throughout the brain's interior. Similar techniques may be applied in human patients with the condition to allow doctors to more accurately assess the number, locations and sizes of brain lesions when determining a course of treatment.

Understanding What's Normal—and What's Not—in Diabetes

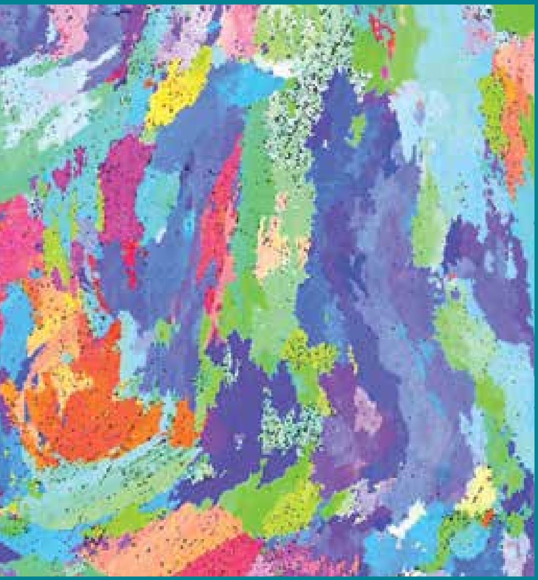
Diabetes diagnoses are on the rise in the United States. According to the Centers for Disease Control and Prevention, more than 29 million Americans are currently living with the disease—more than 1 in 11 people. Patients must closely monitor and control the condition to prevent debilitating complications such as damage to the eyes, kidneys, nerves and cardiovascular system.

One of the key tests used to monitor diabetes is HbA1c, a marker of average blood sugar levels over the past six weeks. While the goal of diabetes treatment is to maintain normal HbA1c levels, it is unclear whether the "normal" threshold actually changes over time, and some studies suggest patients could suffer ill effects from treatment regimens that may be more intense than needed. To help refine diabetes treatment, a team of researchers from Duke University's Center for Health Informatics including W. Ed Hammond, Eugenia McPeek Hinz and Vivian West analyzed 10 years of HbA1c levels in a sample of patients. The analysis, developed with visualization support led by David Borland from the Renaissance Computing Institute of the University of North Carolina at Chapel Hill, helps explain how HbA1c levels vary over time in different patient groups with various diabetes management regimens.



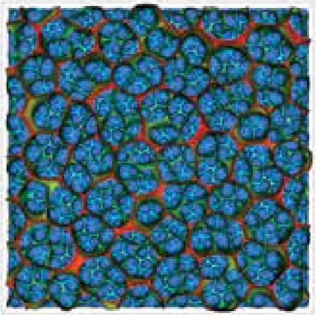
ADVANCING INDUSTRIAL INNOVATION

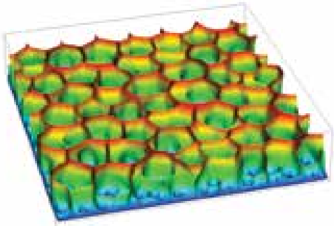
Perfecting 3-D Printing for a Manufacturing Renaissance



Most of us are all too familiar with the frustration of waiting for a new car part to arrive or having a flight canceled due to mechanical problems. What if your car shop or airline could simply create the part locally or on-site, completing the repair in hours instead of days or weeks? That's just one example of the potential and promise of additive manufacturing, also known as 3-D printing.

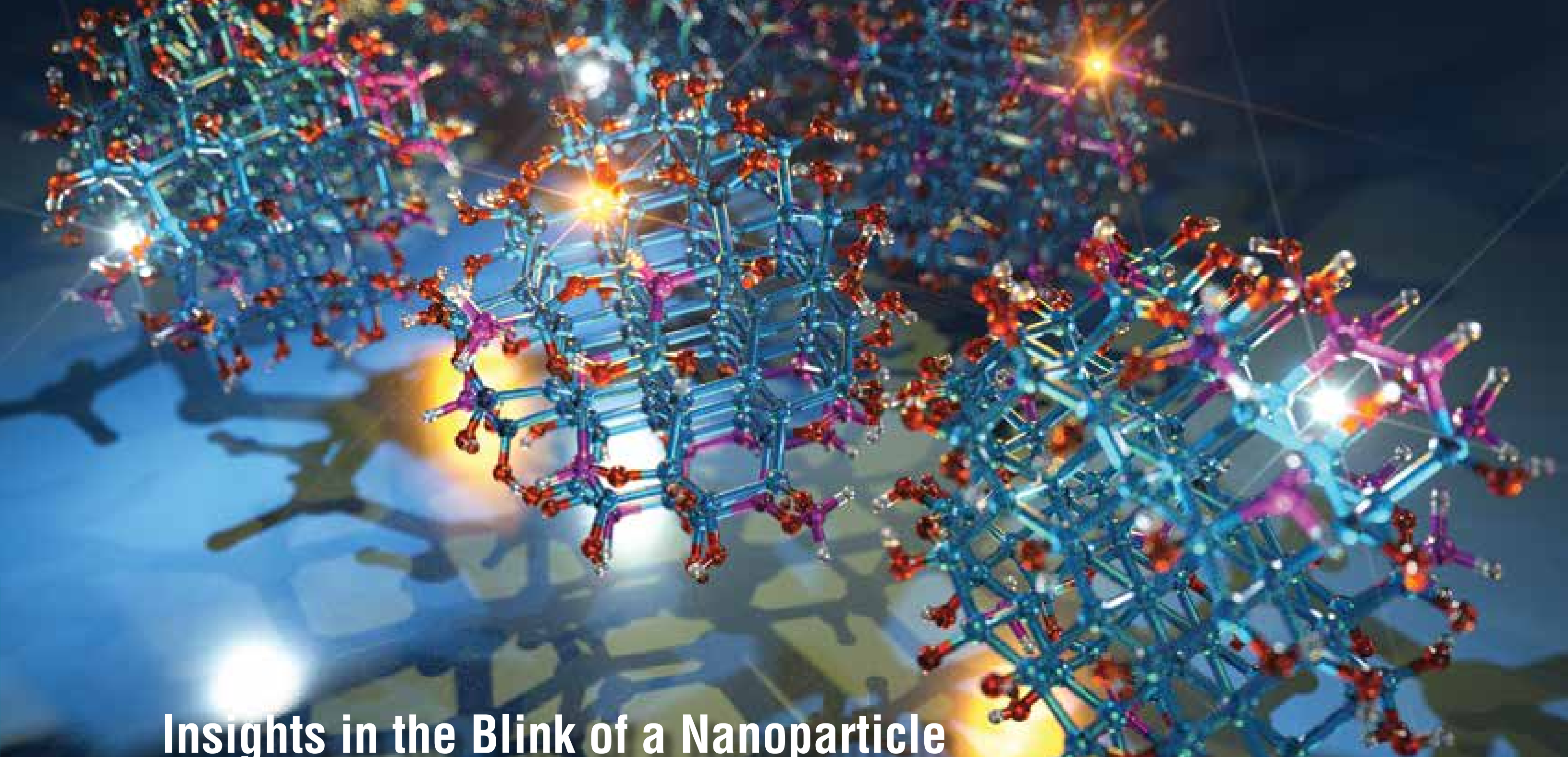
Some industry experts believe 3-D printing could reduce our reliance on mass-production manufacturing facilities—many of which are located overseas—and fuel a U.S. manufacturing renaissance by making it cost-effective to create an infinite variety of products on demand. But more work is needed to ensure 3-D printed products are as strong and reliable as mass-manufactured ones. Mississippi State University engineers Nima Shamsaei and Scott Thompson are working to optimize 3-D printing techniques geared toward metal parts for the automotive, aerospace and biomedical industries. This visualization, created as part of the team's research, shows how heat and other factors affect the microstructural features that ultimately determine the structural integrity of a 3-D printed metal product.





Cracking the Code on Materials that Crack

When fractures develop in the materials that make up our buildings, bridges and vehicles, the results can be catastrophic. Cracks were at the heart of several recent building and bridge collapses, as well as the disintegration of the Columbia space shuttle in 2003. Although scientists have developed sophisticated techniques to predict how an existing crack will grow and spread, less is known about how to predict cracks before they occur. Blaise Bourdin and colleagues at Louisiana State University are developing mathematical models to understand and predict cracking in brittle materials. This simulation, supported by matching results in real materials, shows the complex fracture patterns that form during the drying process or when brittle materials are exposed to sudden, extreme temperature changes.



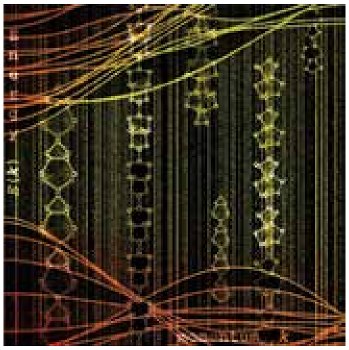
Insights in the Blink of a Nanoparticle

Since their discovery in the 1980s, nanoparticles known as quantum dots have captivated imaginations with their unique ability to be tuned to emit or absorb different colors of light. These properties offer tantalizing prospects for all kinds of new technologies, from paint-on lighting materials and solar cells to biological imaging tools or communications technologies. But such applications have remained stubbornly out of reach thanks to one persistent problem: Quantum dots intermittently and unpredictably blink on and off, making them too unreliable for many applications.

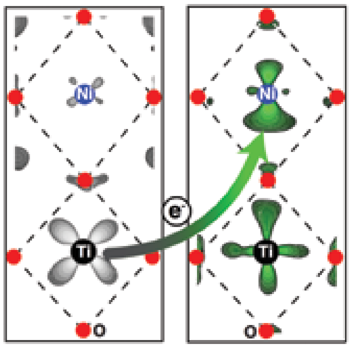
Nicholas Brawand, Márton Vörös and Giulia Galli at the University of Chicago developed simulations of quantum dots to help researchers decipher the dots' mysterious blinking behavior—and perhaps someday learn to control it. Through intensive computations requiring more than 100,000 processor hours at the Department of Energy's National Energy Research Scientific Computing Center, the team built a virtual model of quantum dots that shows, based on fundamental scientific principles, the complex dynamics at work behind the blinking dots.

New Materials for Better Electronics

Semiconductor technology is at the heart of most major electronics innovations. Silicon Valley, for example, earned its nickname from the silicon semiconductors on which so many tech companies rely. Although many materials can serve as semiconductors, each has its downsides. Scientists and engineers are making significant strides in developing new materials to support tomorrow's electronic innovations.



TOP: A research team led by Boris Yakobson at Rice University is exploring the potential use of black phosphorous for developing longer-lasting semiconductors. While atom-scale defects cause the electronic properties of most 2-D materials to degrade over time, the defects in black phosphorous do not appear to affect its electronic properties, making it a promising material for semiconductors and other nanotechnology applications. This visualization represents key structural and electronic signatures of 2-D black phosphorous, also known as phosphorene.



BOTTOM: Researchers led by Yale researcher Sohrab Ismail-Beigi have discovered a novel way to engineer metal oxide materials by manipulating the electrons that form the bonds between atoms. Using modern theoretical methods and calculation-intensive modeling, the team is working to develop new design principles to control the distribution of electrons in layered materials for electronics and energy applications. In this figure, showing a layered metal oxide of titanium and nickel, the movement of electrons from the titanium layer to the nickel layer impacts the behavior of electrons on the nickel. The modeling outcomes have been verified in experiments by collaborators at Yale. The project is a partnership of Yale University and Southern Connecticut State University.

PREPARING FOR EXTREME EVENTS

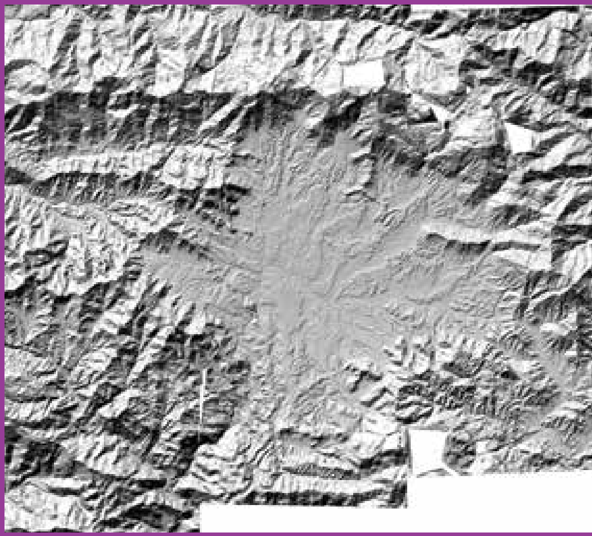
From Brilliant Burst to Blackout: An Up-Close Look at Solar Storms

The sun's superheated atmosphere is quite unstable, causing it to give rise to violent storms (also called solar flares or space weather) that release billions of tons of highly energetic charged particles into space. If a powerful enough solar storm were directed at the Earth, the wave of energetic particles could wreak havoc on technological systems, causing catastrophic collapse of power grids, damaging satellites and crippling communications infrastructure worldwide.

To better understand the effects of solar storms on the Earth and improve our ability to forecast space weather, Homa Karimabadi and colleagues at the University of California, San Diego teamed up with the Advanced Visualization Lab at the University of Illinois at Urbana-Champaign to create a dynamic visual representation of how solar storms interact with the Earth. The beauty of the resulting images belies the incredibly intensive numerical simulations behind them, as well as the potential danger if such a storm were to hit Earth. The data-driven visualization is a centerpiece of a 24-minute high-resolution science documentary now showing in more than a dozen planetariums and science centers.

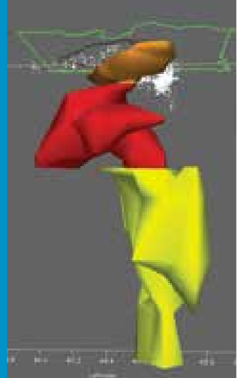
Real-Time Data for Real-World Emergency Response

Information is everything during a disaster. But when a magnitude 7.8 earthquake rocked Nepal in April 2015, responders had precious little information about the on-the-ground conditions where thousands of people perished and thousands more faced continuing danger. Given the threat of aftershocks, mudslides, floods and building collapses, emergency responders faced tough decisions as they prioritized rescue efforts.



A research team led by Ian Howat at The Ohio State University, along with colleagues from the University of Minnesota, contributed to the response and recovery effort by donating high-resolution satellite images of affected areas. These images, compiled at the Ohio Supercomputer Center, helped responders map the remaining infrastructure and assess the stability of mountainsides. Although the software used to produce the images was not designed for emergency response—it was originally developed to map changes in glaciers and other ice-based landscapes—the results proved invaluable to the Nepal recovery effort.

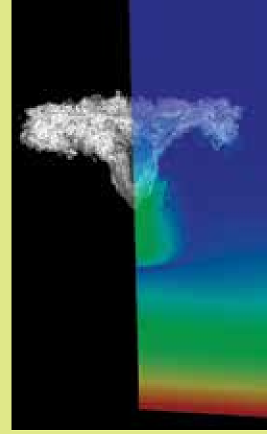
A Beast within the Earth



As impressive as they are, the spewing geysers and bubbling mud pits of Yellowstone National Park are merely the surface symptoms of an even more remarkable geologic feature: one of the world's largest active volcanoes. Research by a University of Utah team led by Fan-Chi Lin with postdoctoral researcher Hsin-Hua Huang provides a surprising new view of this beast lurking beneath Earth's surface. The team used advanced imaging techniques to discover, hidden under the Yellowstone volcano's main magma chamber (shown here in orange), a deeper chamber nearly five times larger (red). The deepest part (yellow) is the mantle plume that feeds hot material into the deeper magma chamber. Together these chambers have enough magma to fill the Grand Canyon nearly 14 times.

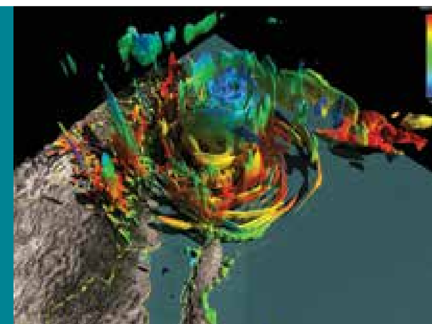
Although it is impossible to control volcanic eruptions, having accurate maps of their structure and potential reach can help us prepare and plan for the worst case scenario. The research team developed their computation-intensive 3-D models using data from University of Utah seismograph stations and National Science Foundation-funded Earthscope seismographs around the country.

Research that Takes Cloud-Gazing to a Whole New Level



Much of our atmospheric and meteorological research focuses on powerful weather events—hurricanes, tornadoes, snowstorms and the like. But we also have a lot to learn about the most frequent sightings in the sky—clouds. Researchers led by Max Duarte at Lawrence Berkeley National Laboratory developed a new kind of mathematical model to decipher how individual clouds form and move. This method is similar to those developed to study low-speed flames in combustion research and convection in stars. This image of a cloud uses a color scale to show where water vapor has condensed into cloud water.

Peering into the Heart of the Storm



When Hurricane Odile made landfall on the Baja California Peninsula in September 2014 as a category 3 storm, it inflicted widespread damage, flooding and power outages in Mexico and the Southwestern United States. This image of the storm is from a visualization developed by Mrinal Biswas, Matt Rehme and Tim Scheitlin of the National Center for Atmospheric Research. Using the Hurricane Weather Research Forecast, an advanced hurricane prediction system developed by the National Oceanic and Atmospheric Administration, the simulation combines data from a dropsonde (an atmospheric profiling device), conventional observations, and satellite data into a 3-D grid with 3-kilometer horizontal resolution and 61 vertical levels. The system, now deployed for real-time storm tracking, fills gaps in previous weather simulations to provide a more accurate assessment of intensity, structure and expected rainfall for severe storms.

Manmade Twisters

This image of a powerful EF5 tornado is virtually indistinguishable from a photograph—yet it is nothing of the sort. In fact, it is a simulation developed by Leigh Orf, David Bock and colleagues in a collaboration between the University of Wisconsin at Madison and the University of Illinois at Urbana-Champaign. The model was created as part of an effort to better understand why some storms produce devastating tornadoes while others do not.

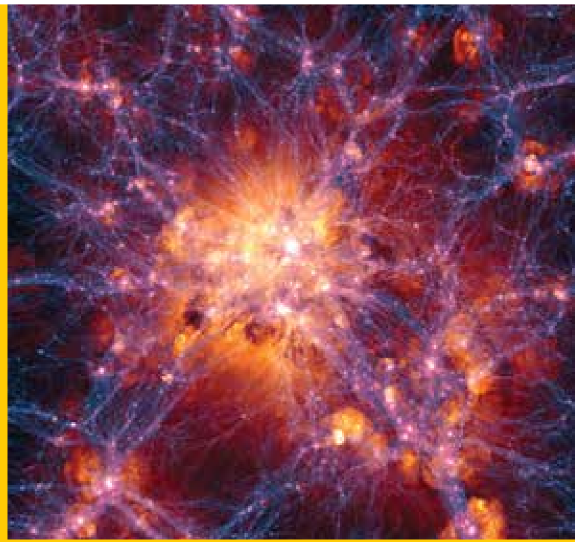
The simulation's photorealistic visual cues such as lighting and deep shadows help the researchers confirm that their numerical models are reflecting the dynamics at play inside real-world storms. Such techniques can be applied to a variety of simulations, allowing researchers to compare their visualizations to field data and pinpoint any potential deficiencies in their models.

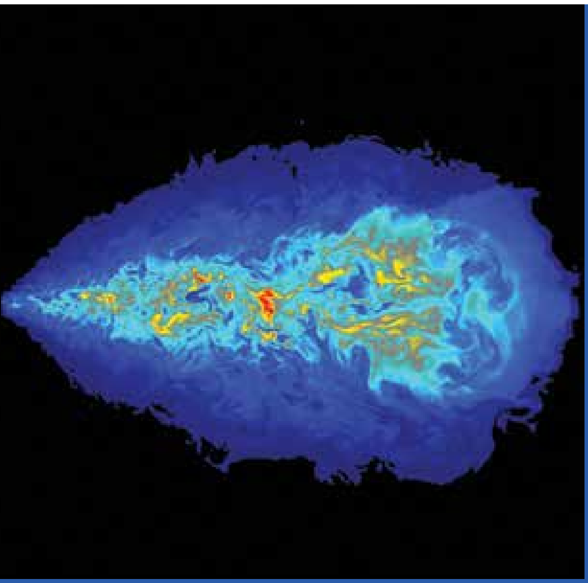
UNDERSTANDING OUR UNIVERSE

A Bold New Universe

A team from Harvard, the Massachusetts Institute of Technology (MIT) and other institutions has developed the most detailed model of the universe's formation ever attempted. The 3-D simulation spans more than 13 billion years and shows how galaxies, black holes and other cosmic phenomena developed. Simulating the universe simultaneously at large and small scales, the model represents a cube-shaped piece of the universe 350 million light-years long on each side that, by the end of the simulation, contains more than 40,000 galaxies. Comparing the simulation to real observations of the universe allows researchers to test new theories and continue to refine the model.

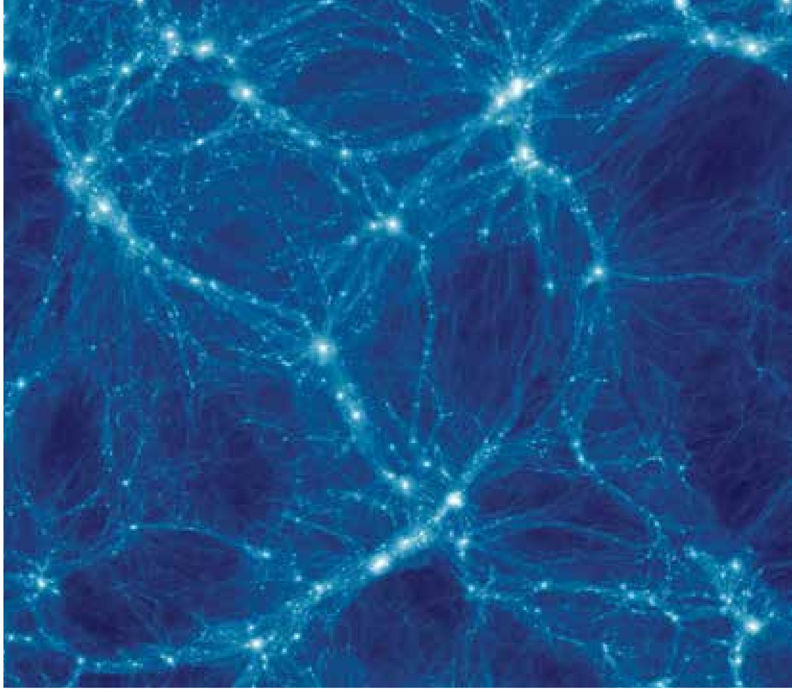
Five years in the making, the Illustris model is so complex that it would take a regular desktop computer 2,000 years just to run the simulation once. Computations were run on supercomputers in France and Germany, as well as those at Harvard, the Texas Advanced Computing Center and the National Institute for Computational Sciences. Dylan Nelson of the Harvard-Smithsonian Center for Astrophysics and Mark Vogelsberger of MIT led the development of the visualization.





A Mystery that Outshines the Brightest Stars

Some galaxies have an extremely energetic central region known as an Active Galactic Nucleus. These regions are among the brightest objects in the universe, often outshining all of the stars in their home galaxy combined. In some cases, the power source at the center of these extraordinary nuclei is actually a black hole; as gases are drawn toward the black hole, they spiral around it, generating gravitational energy that is converted into heat and electromagnetic waves. A simulation created by John Hawley at the University of Virginia with collaborators from Johns Hopkins University reveals this process at an unprecedented level of detail. By allowing researchers to better understand the complex dynamics surrounding black holes, the simulation sheds new light on some of the universe's brightest—and most mysterious—features.



Last Words from a Dying Star

In the universe's recent past, the collapse of a massive star often created a black hole in its place. But this was not always so. In the early universe, some enormous stars vanished completely after a final spectacular explosion. These explosions were crucial to the development of the universe as it exists today because they produced the first heavy elements—from carbon to silicon—paving the way for subsequent generations of stars, solar systems and galaxies.

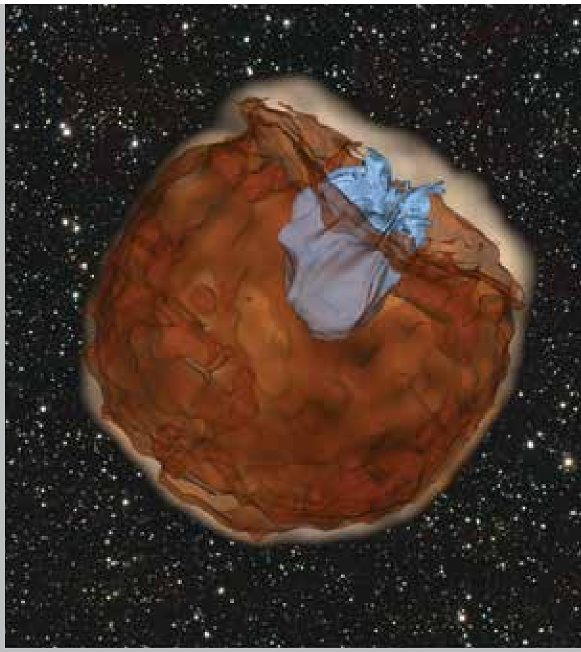
This simulation from University of California, Santa Cruz researcher Ken Chen recreates the death of one such ancient star, which would have led to an explosion with a radius larger than Earth's orbit around the sun. The model was supported by collaborators and computation from the U.S. Department of Energy's National Energy Research Scientific Computing Center and the Minnesota Supercomputing Institute.

Shedding Light on Dark Matter

Some 80 percent of the universe is made up of "dark matter"—particles that humans have yet to see or even detect. Although scientists have not found a way to observe dark matter directly, they can use supercomputers to simulate its behavior, bringing us one step closer to seeing the unseeable. Phil Mansfield and Benedikt Diemer of the University of Chicago created this visualization of a simulated "cosmic web" believed to form when dark matter collapses into a network of filaments and nodes.

A Flash of Insight

Unlike many cosmic phenomena, stellar explosions known as supernovae are observable for only a few weeks or months, making it hard for researchers to catch them in time for proper study. This simulation, developed by Daniel Kasen and colleagues at Lawrence Berkeley National Laboratory and the University of California, Berkeley, gave researchers a virtual roadmap that led them to new discoveries from a rare real-life Type Ia supernova. Calculated at the Department of Energy's National Energy Research Scientific Computing Center, the simulation shows the supernova explosion (in red) as it crashes into and absorbs a nearby star (blue). The model indicated such an event would cause a brief flash of ultraviolet light. That prediction proved to be exactly right when an image-analysis algorithm picked up intriguing signals from a galaxy 300 million light-years away on May 3, 2014. The signal turned out to be the first direct evidence that some of these supernovae form in binary systems with nearby companion stars. Together, the simulation and the observation provide important new evidence about how these supernovas form.



EDUCATING THE NEXT GENERATION

From High School to High Tech

Today's high school students are tomorrow's science and technology innovators. Summer programs around the country serve a crucial role in creating our future workforce by igniting interest in science, technology, engineering and mathematics (STEM) disciplines.

TOP: If two weeks sounds like a short amount of time to learn two programming languages, build a custom computer, network 32 computers into a cluster, and design and build a robot, then you haven't met the 50 high school students who participated in CODE@TACC, a STEM experience created by the Texas Advanced Computing Center at The University of Texas at Austin. The program, designed to de-mystify technology and expose students to STEM careers, gave students hands-on experience working with computer hardware, code, supercomputers and visualizations. Interspersed throughout the program were chances for students to interact with professionals and college students in STEM fields to help participants chart a path for their own STEM futures.

BOTTOM: Students gain first-hand experience working with faculty mentors at the San Diego Supercomputer Center at the University of California, San Diego through the Research Experience for High School Students (REHS) summer program. Over eight weeks, 60 students contributed to research in computer science, biomedicine, neuroscience, visualization and more. The program, intended to serve as a stepping stone for students considering the pursuit of computational science as a major or minor in college, has grown rapidly over its six-year history and attracted about 200 applications this past year. (Photo by Ben Tolo/SDSC)

Learning Environments Built to Inspire

Universities are taking advantage of advances in visual display technology to create immersive data visualization rooms that allow students and faculty to literally surround themselves with information.

TOP: In the Social Computing Rooms at University of North Carolina campuses, students and faculty get an immersive 360-degree view of any visual content, allowing users to interact with and explore data in groups in ways that aren't possible with a typical computer screen. The custom-designed rooms, developed by UNC-Chapel Hill's Renaissance Computing Institute, use 12 projectors to display 9.5 million pixels on four walls. The rooms' many uses have included image analysis for cancer research, deciphering erased text hidden in an ancient manuscript, art exhibits, and class presentations for courses in computer science, English, medical geography, law and more.

BOTTOM: 3-D virtual reality rooms known as CAVEs provide unique environments in which to test engineering innovations, plan construction projects and conduct research in numerous scientific fields. At the Brown University Center for Computation and Visualization's CAVE, literary arts professor John Cayley merges this new technology with one of humanity's oldest technologies—the written word—to unleash creativity and explore new modes of literary expression. In his "Cave Writing" class and associated work, users read, listen to, and interact with literature artifacts while immersed in the 3-D environment. In this image, Ben Knorlein interacts with the virtual poetic text, "Cubes" by former fine arts student Ian Hatcher.

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Tempe, Arizona

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Boston, Massachusetts

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Providence, Rhode Island

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Pittsburgh, Pennsylvania

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Cleveland, Ohio

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Clemson, South Carolina

Columbia University, Shared Research Computing Facility
New York, New York

Cornell University, Center for Advanced Computing
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Florida State University, Research Computing Center Information Technology Services
Tallahassee, Florida

Georgia Institute of Technology
Atlanta, Georgia

Harvard University
Cambridge, Massachusetts

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East Lansing, Michigan

Michigan Technological University
Houghton, Michigan

Mississippi State University, High Performance Computing Collaboratory (HPC2)
Mississippi State, Mississippi

Montana State University, Information Technology Center
Bozeman, Montana

National Center for Atmospheric Research (NCAR)
Boulder, Colorado

New York University
New York, New York

North Dakota State University, Center for Computationally Assisted Science & Technology
Fargo, North Dakota

Northwestern University
Evanston, Illinois

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Oak Ridge, Tennessee

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West Lafayette, Indiana

Rensselaer Polytechnic Institute
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Rutgers University, Discovery Informatics Institute (RDI2)
Piscataway, New Jersey

Stanford University
Stanford, California

Stony Brook University, Research Technologies
Stony Brook, New York

Texas A&M University, Institute for Scientific Computation
College Station, Texas

Texas Tech University, High Performance Computing Center
Lubbock, Texas

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The Ohio State University, Ohio Supercomputer Center (OSC)
Columbus, Ohio

The Pennsylvania State University
University Park, Pennsylvania

The University of Texas at Austin, Texas Advanced Computing Center
Austin, Texas

University at Buffalo, State University of New York Center for Computational Research
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University of California, Los Angeles, Institute for Digital Research and Education
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University of Illinois at Urbana-Champaign, National Center for Supercomputing Applications (NCSA)
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Ann Arbor, Michigan

University of Minnesota, Minnesota Supercomputing Institute for Advanced Computational Research
Minneapolis, Minnesota

University of Nebraska, Holland Computing Center
Omaha, Nebraska

University of Nevada, Las Vegas, National Supercomputing Center for Energy and the Environment (NSCEE)
Las Vegas, Nevada

University of New Hampshire
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University of North Carolina at Chapel Hill, Renaissance Computing Institute (RENCI)
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University of North Carolina at Chapel Hill
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CASC

COALITION FOR ACADEMIC SCIENTIFIC COMPUTATION
P.O. Box 898
Gambrills, Maryland 21054
(202) 930-CASC (2272)
www.casc.org
Lisa Arafune, Director
lisa.arafune@casc.org