glimpse

research *and* creative discovery

Clemson University

fall 2013

Carbon's magic carpet

a mighty coil

Exotic new materials are taking shape in the lab of Apparao Rao that have the potential to help power new devices into the marketplace. Learn how some of the world's tiniest structures have huge implications for energy, medicine, manufacturing, and the environment. The cover image shows a resonating nanocoil made in the Rao lab. Page 11.

glimpse

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After more than three centuries, specimens of Carolina larkspur, *(Delphinium carolinianum* Walter) still tell a story about their environment. In 1773, William Bartram, an American naturalist, began a four-year exploration of eight southern colonies, collecting flora as he traveled. Today, a team of researchers from Clemson and Furman University unveiled Bartram's collection, along with those of several other naturalists, online. For more, see page 5.

Images from Bartram and Mark Catesby in this issue were photographed by Amy Hackney Blackwell, Patrick McMillan, and Christopher Blackwell in November of 2011 at the Sloane Herbarium of the Natural History Museum, London, in collaboration with Mark Spencer, curator.

in this issue

Learning to see

When we decided to name this magazine *Glimpse*, we knew it would offer a peek at some things that are usually hidden from view. None of us can see, in the usual way, a film of carbon, only one atom thick, that could power the next generation of cars and devices and tools. Or the violence of stars exploding millions of years ago. Or the long-forgotten African slaves whose knowledge of indigo dye helped Eliza Lucas Pinckney build an industry around it.

So research helps us *see*. It supplies the specialized instruments and methods we use to penetrate the dark. And it teaches our scientists and students a very special kind of vision, an ability to recognize something of potential value, even when it is not what we expected to find.

Very often, that is what happens in the laboratory of Apparao Rao (page 11). His team looks for one thing and discovers another—an unintended shape that proves useful as a tiny sensor, for instance, or a “defect” that improves the flow of ions in batteries. No one can plan for such breakthroughs. They happen by accident. But if we blend the right talents and tools, the breakthroughs will come. And those breakthroughs will sometimes mature into companies, products, and jobs (page 22).

In a time when our economy is struggling to regain its momentum, we are tempted to promise too much from research. It would be nice if our faculty cranked out inventions on cue and according to plan. But that is not how research works. Christian de Duve, the 1974 Nobel Prize winner who helped unlock the mysteries of the cell, freely acknowledged that his own discoveries were largely accidental. We venture into the unknown, he said, and prepare ourselves to learn. The great appeal of science, he said, is the unknown.

At sixteen years old, when she first began to experiment with indigo on patches of high ground between rice fields, Eliza Lucas faced a vast unknown. Left by her father to manage his plantations in a wild and exotic new land, she had no way of knowing that her experiments would, in her lifetime, help create a powerful commercial enterprise that would build wealth on both sides of the Atlantic. But she was curious about botany, and the wizardry of making dye, and she had the good sense to learn from the people around her, even though they did not look like her.

Today more than ever we need that kind of brave curiosity, that willingness to venture out into a vast unknown. Somewhere out there in the dark is a breakthrough, a missing piece of knowledge that could help us to build something of value, solve a costly problem, protect our health or our environment, or treat a disease. We will not always know exactly what we are trying to find. But we will know it when we see it.

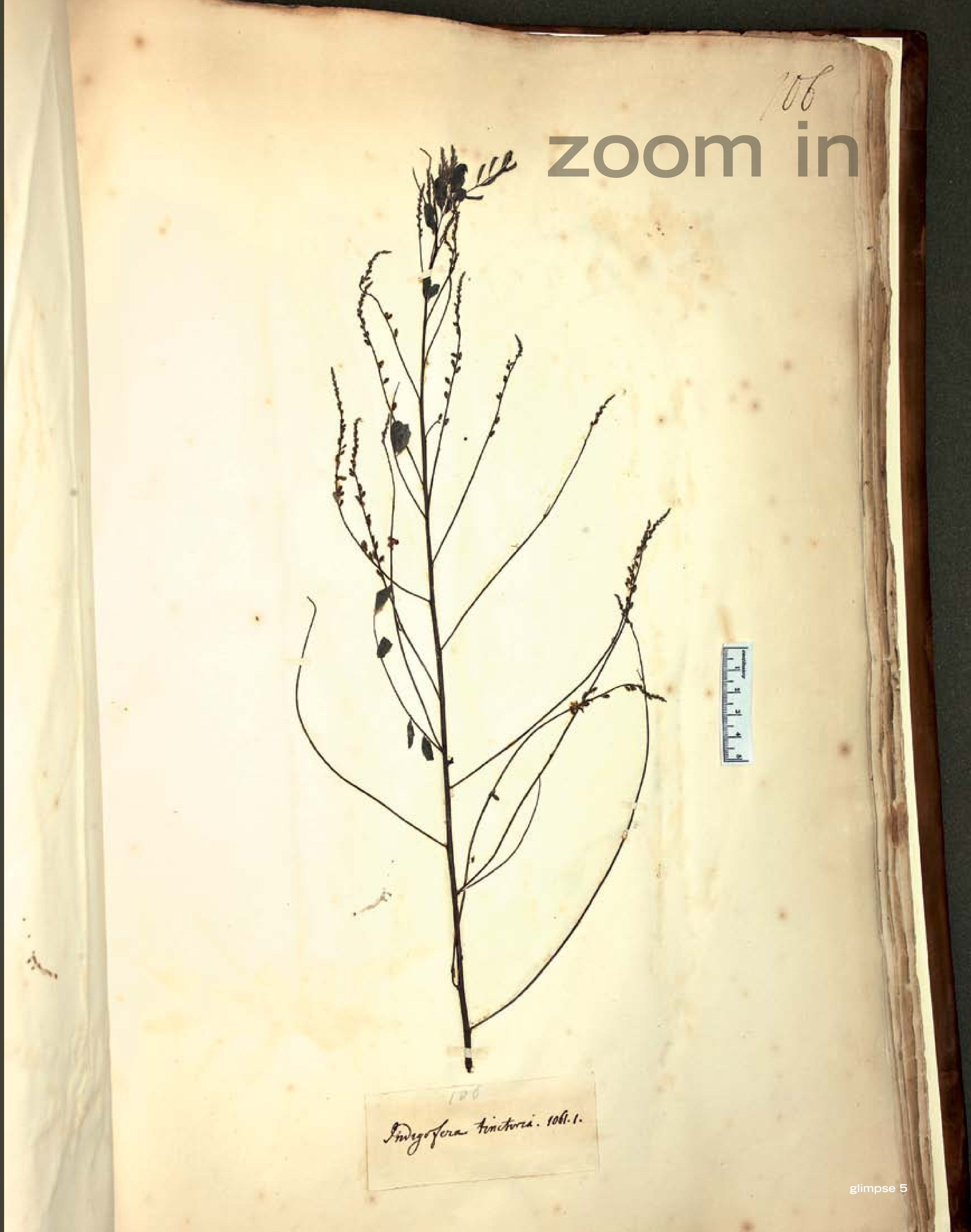
R. Larry Dooley

R. Larry Dooley
Interim Vice President for Research

Life as an open book.

Mark Catesby’s collection, carefully rendered as digital images by the Botanica Caroliniana project, includes this page of African indigo, the plant that rivaled rice as a cash crop and transformed colonial South Carolina. For more about indigo, see page 34.

zoom in



Enduring flora

These sample images were excerpted from whole-page photos of Bartram's collection, *H.S.* Georgia, and from Mark Catesby's *H.S.* volumes 212 and 232.

Treasures of ecology

For the first time, the ecological history of the Carolinas and Georgia is virtually an open book. Botanica Caroliniana, a project led by a team from Clemson and Furman University, has created an online database of high-resolution images showing plant specimens collected centuries ago by several legendary naturalists, including Mark Catesby, John and William Bartram, and John Lawson.

Before now, the only way to study the specimens was to travel to London, where they reside in the Sloane Herbarium of the Natural History Museum.

The team began its work last year with an analysis of the complete collections of Mark Catesby, the first naturalist to study in depth the habitat of the low country and Piedmont areas of the Carolinas. He arrived from England in 1722 and spent the next four years exploring and collecting the botanical wonders of a region largely untouched by European settlers.

"These specimens provide insight into the nature of the flora of the Carolinas and Georgia prior to extensive modification by European immigrants," says Amy Hackney Blackwell, a research associate at the South Carolina Botanical Garden.

A century before Audubon

Catesby's specimens became the basis for his illustrated two-volume book, *Natural History of Carolina, Florida and The Bahama Islands*, completed in 1743. His paintings and etchings of birds and plants captured the biological diversity of North America one hundred years before the publication of John James Audubon's *The Birds of North America*.

"While much has been learned from Catesby's beautiful and meticulous illustrations, primary sources are the holy grail of research," Blackwell says. "Through Botanica Caroliniana researchers can now view in detail the original specimens without traveling to London and use this primary source material to do taxonomic work these naturalists did not have the resources to do themselves at the time."

Researcher Amy Hackney Blackwell and Sloane Herbarium curator Mark Spencer prepare plant images for digitization.

Blackwell is a member of a team of researchers that includes Clemson plant scientist and South Carolina Botanical Garden director Patrick McMillan, host of the Emmy award-winning nature program *Expeditions with Patrick McMillan*, and Furman University classics professor Christopher Blackwell. The Botanica Caroliniana team deploys technology and techniques used by Furman's classics department for digitizing ancient manuscripts.

Botanica Caroliniana has already inspired new insights. Catesby's specimens, for example, show that he visited a range of diverse habitats, and his notations establish his interest in the medicinal and economic value of plants to Native Americans as well as Europeans. The specimens also include some surprises.

"Catesby collected specimens of a type of catalpa that we previously thought was only native well south of the Carolinas," Blackwell says. "Catesby's collections also contain some plants obviously introduced by Europeans, such as catnip and indigo, which shows just how quickly species can move and establish themselves in new environments."

Ecology, past and present

In June, the Botanica Caroliniana team visited London to digitize specimens collected by Joseph Lord. The specimens, collected in 1704, are the oldest the team has digitized. Lord helped found the town of Dorchester, South Carolina, and collected plant specimens along the Ashley River. Blackwell and McMillan are identifying the Lord specimens and plan to publish their findings soon.

"Lord wrote very detailed notes on the plants he collected, and they've been very helpful as we identify specimens that are over three hundred years old," Blackwell says. "He collected some plants that are now endangered, such as American chaffseed. He and Catesby both collected a native orchid, which is now virtually extirpated from South Carolina."

McMillan is in the beginning stages of producing an episode of *Expeditions* focusing on what Catesby's work reveals about the historic ecology of South Carolina and how human interaction with the landscape has changed ecosystems over the centuries.

"Catesby can help us to understand the ecological processes and dynamics that existed, such as the importance of fire, especially human-generated fire in the landscape. Human choices and actions have always been a vital factor in determining the character of the world around us. To understand today's ecology, we must consider the past," McMillan says.

—Jonathan R. Veit

Patrick McMillan is a Clemson plant scientist, director of the South Carolina Botanical Garden, and host of the television program, Expeditions with Patrick McMillan. *Christopher W. Blackwell is the Louis G. Forgione University Professor of Classics at Furman University. Amy Hackney Blackwell is a research associate at the South Carolina Botanical Garden. Browse Botanica Caroliniana at folio.furman.edu/projects/botanicacaroliniana/index.html.*

Jonathan Veit is a public information coordinator in the School of Agricultural, Forest, and Environmental Sciences.

Self-healing plastic

Scratched-up army tanks and chipped nails may one day get closure from the sun.

Learning from Mother Nature, Marek Urban has been creating plastics that are able to heal their own damage. Urban, who designs polymers and measures how they respond to chemical changes, has found ways to equip them with a built-in ability to react to a stimulus from the environment. In the process, he can fashion plastics that complete automatic functions, such as self-healing, in a controllable and predictable way.

"Mother Nature is so clever," Urban says. "It's inspirational from a materials point of view." A prime inspiration is the human body, which, according to Urban, repairs approximately eighty percent of the damage it sustains. If you cut yourself, a series of reactions occur, without your having to give any conscious thought to them. Blood flows, a clot forms, and the skin heals itself. Urban has decided to mimic this process using simpler materials.

The chemistry of healing

Taking inspiration from processes in living organisms, Urban has created a plastic that can mend itself when exposed to sunlight. Polyurethanes, which are polymers linked by urethane, typically make scratch-resistant materials due to their hardness and elasticity. He has modified the chemical structure to create an even more resilient substance. For the new mixture, Urban introduced chitosan, which is derived from chitin found in the exoskeletons of crabs and shrimp, to a compound called oxetane, and incorporated the new unit into the polyurethane. He scratched the plastic and then exposed it to ultraviolet light from the sun. This energy combines free radicals, highly reactive molecules, by forming cross-links between them. As a result, the material spontaneously repairs the defect.

Another chemical approach uses copper-containing polymers that undergo charge transfers when subjected to sunlight. The energy from the light causes a change in electron placement from bonding to antibonding orbitals, thus transforming the shape of the molecule and completely restoring the plastic to its original condition.

A third form of self-healing materials actually changes colors when scratched, imitating the process of bleeding. When the substance is damaged, a chemical ring opens to form a new structure composed of hydrogen bonds. Energy from the sun is then used to break these bonds, and the polymer reverts to its original shape. The making, and subsequent breaking, of bonds temporarily creates different chemical structures, changing the color of the plastic. This was the first process that combined both mechanical and color-changing responses in the material, Urban says.

From vehicles to cosmetics

The real-world use of these self-healing plastics is diverse and widespread. "The beauty of this research is that you can always dream of more things to try," Urban says. With a grant from the U.S. Army, the team is exploring the possibility of coating vehicles, namely army tanks, with this new material. When the transportation units are scratched or struck by rocks, they will naturally heal themselves in the sun. This could save the army money, time, and resources by eliminating a need to manually repair minor abrasions on their tanks.

The biomedical field has shown an interest in stimulus-responsive plastics for the creation of implants. The new process would both extend the life of the materials and help sustain their functions.

On a different scale, a cosmetics company plans to incorporate the new materials in a nail polish that repairs chips and blemishes when the wearer steps out in the sun. While Urban never expected this type of application for his research, he is interested in collaborating with the polish manufacturers to create a long-lasting nail wear.

Urban even hints that maybe one day we'll be able to develop a synthetic skin-like plastic that can repair itself the same way that human skin heals, which could help with skin damaged by injury or aging. "The sky is the limit," he says. "You can dream up and make new things through a variety of resources that are available." Each new idea fascinates Urban, because each requires a different chemical design.

Starting from scratch

In Urban's lab, everything is made from scratch. Rather than ordering ingredients that have already been processed, the team gets down to the most basic level, using atoms and molecules as building blocks. From here, they can build larger polymers that serve functions in specific environments. Designing plastics this way, from what Urban calls a genomic point of view, gives the researchers the flexibility to generate exactly what they intend.

But starting from scratch also requires a broad, working knowledge of the natural sciences, chemistry, and engineering. Unusual combinations of specialties have evolved in Urban's lab to handle, for example, the chemistry behind creating polymers or the engineering of functional materials. "The key ingredient in understanding nature's complexities and behavior is coupling between different physical and chemical processes," Urban says. The interdisciplinary nature of research at Clemson is important, Urban says, as it creates opportunities for collaboration among departments.

"History teaches us that crossing disciplines leads to new discoveries," he says. "One discipline can often be used to solve the other's problems." Rather than sending his findings off to distant locations for further testing, Urban can interact with numerous researchers on campus. As a result, his team will collaborate with others in the College of Engineering and Science and help develop the plastics they design.

On average, ten or more graduate students work in Urban's lab, and he takes care in choosing his team. "It needs to be fun and creative for them," he says. "It needs to fit." With the right members, he says, no day is ever boring in the lab. "As much as you try to design experiments and think through how to do something, anything can happen and the environment changes. There is always excitement."

He tries to teach values, along with the science. To protect the environment, his lab uses water as solvents and other sustainable practices, avoiding chemicals that cause irreversible damage.

As Urban sees it, a good way to protect Mother Nature is to emulate the way she works. "The mission of this discipline is to communicate to the public how to use plastics in a proper and respectful way," he says. "Through this, we can save people's lives."

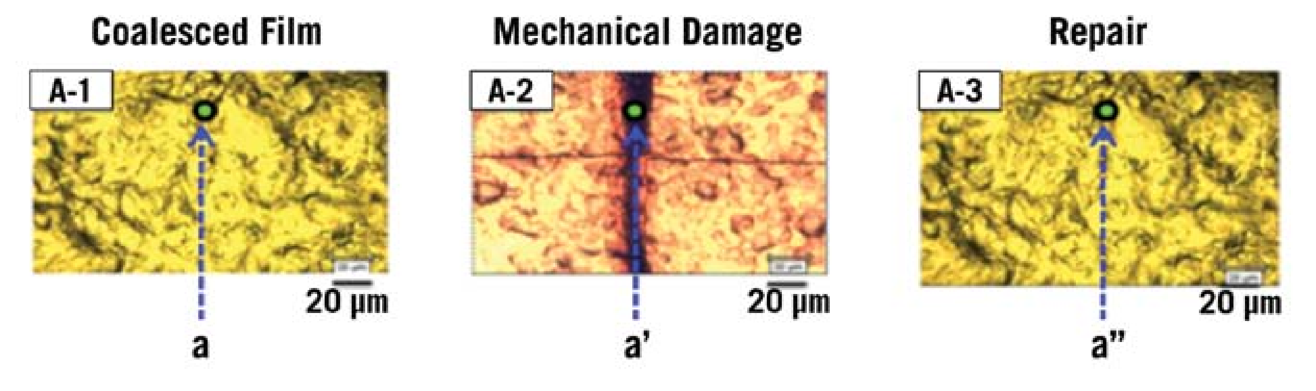
–Rachel Wasylyk

Marek W. Urban is the J.E. Sirrine Foundation Endowed Chair and a professor in the Department of Materials Science and Engineering, College of Engineering and Science. The Urban Research Group (www.clemson.edu/ces/urbanresearch/) is currently funded by federal grants (the U.S. Army and the National Institutes of Health) and various private sector institutions. Rachel Wasylyk, a 2012 graduate and former editor of Decipher, *a student-led research magazine at Clemson, is now a marketing coordinator and freelance writer based in Charlotte, North Carolina.*

zoom in

Almost anything under the sun

Marek Urban's team has found ways to mend damaged plastics with sunlight. In the lab, a polymer film (A-1) sustains a scratch (A-2) and then repairs itself (A-3). Applications for the technology are almost endless, Urban says, from defense to medicine to cosmetics.



Craig Mahaffey

David Kwartowitz (right) and students wired a test dummy to record the force of impacts like those that cause concussions. **Below**: a crossbar mounted on rails hammers the test dummy's helmet.

Craig Mahaffey

Heads up

Taking on concussions in sports

Concussions in big-time sports have been making the news, but the athletes most at risk are probably not on TV. They are children.

"Some parents are in denial about the severity of their child's injury because they want them to become the next stand-out athlete," says Jimmy Sanderson, assistant professor in the Department of Communication Studies. "And in many cases coaches are not equipped with training to identify concussions. At times, the desire to win can trump concern for the child's well-being, and therefore allow youth athletes to continue playing despite potential injuries."

Playing with pain

Sanderson, who is conducting research on the media's portrayal of concussions and fans' perceptions about player safety, notes that communication is key to athlete safety. But communication barriers are rampant at every level of sports. If coaches and parents shame injured players into playing with pain, long-term damage can result, he says.

Sanderson serves as the director of the sports communication major, planned for launch in the spring, in which students will examine such a variety of issues including concussion awareness and prevention, parent behavior in youth sports, and social media's influence on sports. Students will also work directly with faculty members in bioengineering who are conducting concussion-related research.

David Kwartowitz, John DesJardins, and Delphine Dean, assistant professors in the Department of Bioengineering, are mentoring an undergraduate Creative Inquiry research team that will investigate the scientific implications of concussions. The students designed a dummy simulation that is equipped with brain sensors that provides concussion data.

"We designed this dummy for the education of elementary, middle, and high school students on the severity of concussions, as well as the benefits of wearing protective equipment," Kwartowitz says. "We control impact and collect concussion data while the dummy is donning an NCAA approved football or baseball helmet."

Whacking helmets

The students built a tracking system to strike the head of the dummy with numerous objects, including weights, footballs, baseballs, and helmets. Using the tracking system, the researchers can manipulate the impact of these objects on the head of the dummy and the sensors provide instant concussion results.

"We've begun a competition for the students to design their own padding inside the shell of a football helmet to avoid probable concussions at high impact," Kwartowitz says. "Ultimately, the data collected will offer insight as how to better protect an athlete from concussion."

The researchers plan to make their findings available to athletes, coaches, and parents. The dummy simulation will eventually be on display in Greenville, South Carolina at the Roper Mountain Science Center's newly renovated health research facility, which has 120,000 students visiting annually.

–Brian Mullen and Lindsey Johnston

Brian Mullen is director of research communications. Lindsey Johnston is a senior majoring in communication studies and English at Clemson.

carbon's magic carpet

In the material world, an ethereal skin of pure carbon can deliver a jolt.

by Neil Caudle

If you set fire to this page,

a flake of ash might rise and float away. That little smidgen of carbon, as black as the wing of a crow, is so fragile it crumples to dust when it lands in the palm of your hand. But carbon is also the stuff of a diamond, which is eternal (or so we say, when we propose), and hard enough to sever steel.

Between these extremes, meet Apparao (Raja) Rao.

Rao is a physicist, which most of us are not. But he is, like all of us, a walking contradiction, a carbon-based life form akin to both diamond and ash. Rao is adept with contradiction. In his lab, he can make the flimsy strong, the rigid pliant, the bulky small, and the ephemeral built to last. Almost every time Rao mows his lawn, drives his car, adjusts his thermostat, boots his computer, or reads the news, he imagines a new incarnation for carbon.

In the lab, Mehmet Karakaya, a graduate student from Turkey, lifts a blue-gloved hand to show me a swatch of black carbon so thin and ethereal that he might have just plucked it from the air. He scrunches it, wraps it over his thumb. The stuff is pure carbon, but it flexes and dimples and drapes like a skin.

I tug it with tweezers; it puckers but does not break. This is not diamond; this is not ash. This is something surreal from a realm in between.

But I am on the job today and therefore bound to ask, *so what?* What good is this thin little carpet of carbon? Can it carry us away?

In a manner of speaking, it can. Nanomaterials, Rao believes, have a nearly magical potential to support new industries, maybe even levitate an economy or two.

This is more than wishful thinking. Last year, the National Science Foundation (NSF) awarded Rao and his collaborators $1.2 million to find ways to scale up production on some of their nanomaterials, to make them practical for manufacturing. The goal: energy-storage devices that could pump up the power of batteries and capacitors in hybrid and electric vehicles, power tools, and various other products. And today's industries, especially those working with renewable energy, could use a good jolt.

High energy, low power

The problem with current technology, Rao explains, is that while our batteries store lots of energy, the power we extract from them is relatively low, because the batteries cannot deliver their energy fast enough. Capacitors, which regulate flow, can release energy quickly but cannot store very much of it at once. So there's a mismatch, a gap. And the gap has been holding back progress, especially in the use of renewable energy from sun and wind.

"When you are making power tools and hybrid vehicles, you need high power and high energy at the same time," Rao says. "So that's the goal of this project, to fill that gap."

The gap-filling technology Rao and his colleague Mark Roberts, a chemical engineer, have in mind is a new kind of nanomaterial, one they have already made in the lab in small batches: a very thin layer of carbon, much like the film I tweezed, coated with a special kind of polymer, to hold and deliver a charge. With the NSF grant, they intend to crank it out in rolls.

"There has been a lot of talk on the amazing properties of nanostructured materials," Rao says, "but if you go ask somebody for the nanomaterial, they'll ask you how many milligrams you want. With milligrams you can't do anything, right? So the NSF and other funding agencies realize this, and that's why they're funding grants that focus on scalability."

But will the system Rao has in mind really work? He smiles, sits back in his chair. "Yes," he says. "I think it will."

A spin around the lab

Rao has several reasons for optimism, but we'll come back to that later. For now, let's take a spin around his lab. It is not very large, as Big Physics goes these days—three faculty members and six students—but the range of projects under way is daunting. The lab and its collaborators are pursuing dozens of potential applications in medicine, electronics, optics, sensing, energy, environmental protection, and more.

The list, to consider it now, seems outrageously ambitious. But Rao, a slender, soft-spoken man, doesn't show the ambition; he passes most credit to colleagues and students. What I heard, when he described their work, was not brag but delight.

I want to know the source of that delight, so Rao begins to explain it. This requires some patience on his part, because physics does not readily peddle its marvels to tourists like me. For a physicist, the delight is in the details, in the unfolding story of the science. But for print, I need a punch line, a takeaway, a gist. So here, for the record, it is: Rao's lab and its collaborators are creating new technologies that could advance high-tech industries, generate jobs, and help provide cleaner, cheaper energy. That's the bottom line.

> This is not diamond; this is not ash. This is something surreal from a realm in between.

But I still want to know what makes the magic carpet fly.

The soccer ball that could

Rao begins the story with a toy-like model, a skeletal sphere. He sets it on his desk between us to help me consider its faceted structure, which, as he points out, is geometrically the same as a soccer ball: twelve pentagons and twenty hexagons. The toy is plastic, but the structure

Facing page: Growing graphene directly on metal foil, by chemical vapor deposition (CVD), may help researchers solve the problem of delamination, which shortens battery life in hybrid cars and other products. Image from the Rao lab

In carbon nanotubes, hints of a new industrial revolution, built in miniature, from the atoms up.

it represents is made of sixty carbon atoms, hence its scientific name, C_{60}. The structure is also known as a spherical fullerene, or, more commonly, a buckyball, after the famous geometry of Buckminster Fuller's geodesic dome.

An actual buckyball is small, about one nanometer in diameter, which is one *billionth* of a meter. This is a very strange neighborhood indeed, governed by the quirky laws of quantum mechanics, where a particle is a wave is a particle, where gold reveals its true color (pink), and where buckyballs breathe like pufferfish.

Scientists like Rao make fullerenes in the lab, but they also occur naturally, even in outer space. And they are incredibly tough. "The bonds in the carbon are what we call covalent bonds," Rao says. "They are very, very strong."

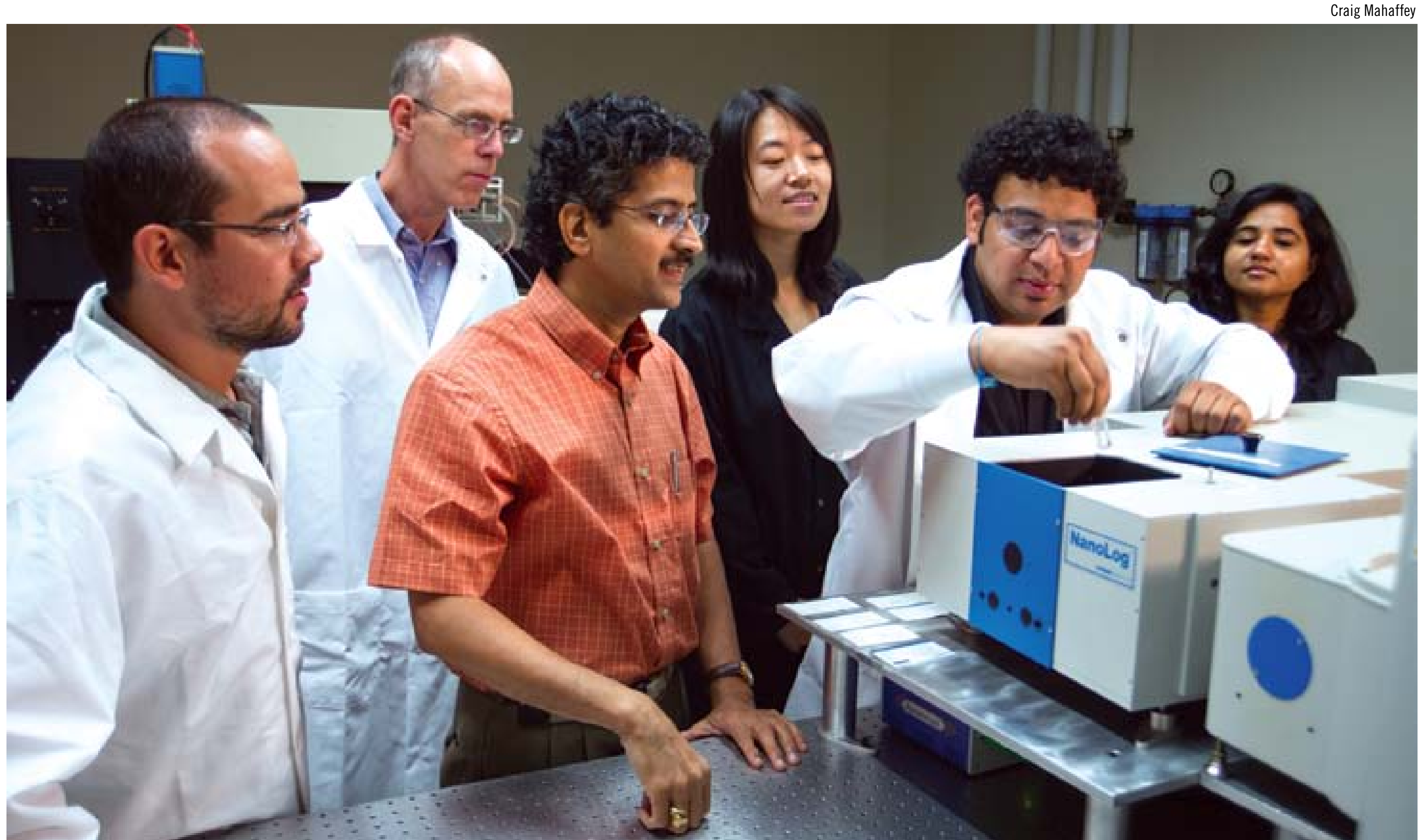
For Rao, the buckyball was generation one. He worked on it through his early career, at the University of Kentucky, and wrote a book on the subject with his mentor, the late Peter Eklund. Today, buckyballs are famous, proving useful as ball bearings for tiny machines, for example, or as cages for safely transporting heavy elements that fluoresce in the body, to pinpoint disease.

But the buckyball was just the seed. The tree was still to come.

Generation two: the nanotube

Rao took the mesh-like structure of the fullerene and wrapped it into carbon nanotubes. He was not the only person doing this kind of thing. By the year 2000, when Rao arrived at Clemson, carbon nanotubes were among the hottest new topics in science, and labs around the world began cranking them out. Nanotubes, the stiffest and strongest materials ever discovered, soon found their way into carbon-fiber baseball bats, golf clubs, and auto parts.

Craig Mahaffey



Apparao Rao (in orange) and members of his lab watch as Ramakrishna Podila (Rama) loads a cuvette with graphene quantum dots into a photoluminescence spectrometer. Others include (from left to right): Mehmet Karakaya, Herbert Behlow, Jingyi Zhu, and Deepika Saini. Rama and Rao's work on the origin of photoluminescence in graphene quantum dots is featured on the cover of the October issue of *Advanced Functional Materials*. The quantum dots "glow" under ultraviolet light and have great potential for biomedical imaging.

But salting the world with nanotubes posed some risks, especially when the tubes escaped in the flows of industrial waste. In the environment, nanotubes quickly acquired scummy coatings of organic matter and began to masquerade as food for microbes. Making their way up the food chain, nanotubes concentrated in the tissues of fish and other animals, where they proved to be toxic to cells.

Rao, working with Pu-Chun Ke in biophysics and Hong Luo in genetics and biochemistry, has shown how this works, in both animals and plants. Rice plants, Rao says, take the nanotubes up in their roots, stems, and leaves, and then pass them along in their seed, afflicting the next generation. Rao is a member of a consortium operated by the National Institute of Environmental Health Sciences (NIEHS) studying the fate and health effects of nanomaterials. He collaborates with Jared Brown's group at East Carolina University, who tests them in mice and then sends tissue samples back to Rao, whose team uses spectroscopy to detect the particles. "Mostly they seem to end up in the liver and the spleen," Rao says, "and they cause inflammation. We're studying how this works."

Pollution and health risks aside, using nanotubes only as fibers to reinforce other materials—much as fiberglass and asbestos were used in the past—was a rather crude application of an elegant material. Carbon nanotubes had more on the ball than brute strength. Their extraordinary properties—electrical, optical, and thermal—hinted of a new industrial revolution, built in miniature, from the atoms up.

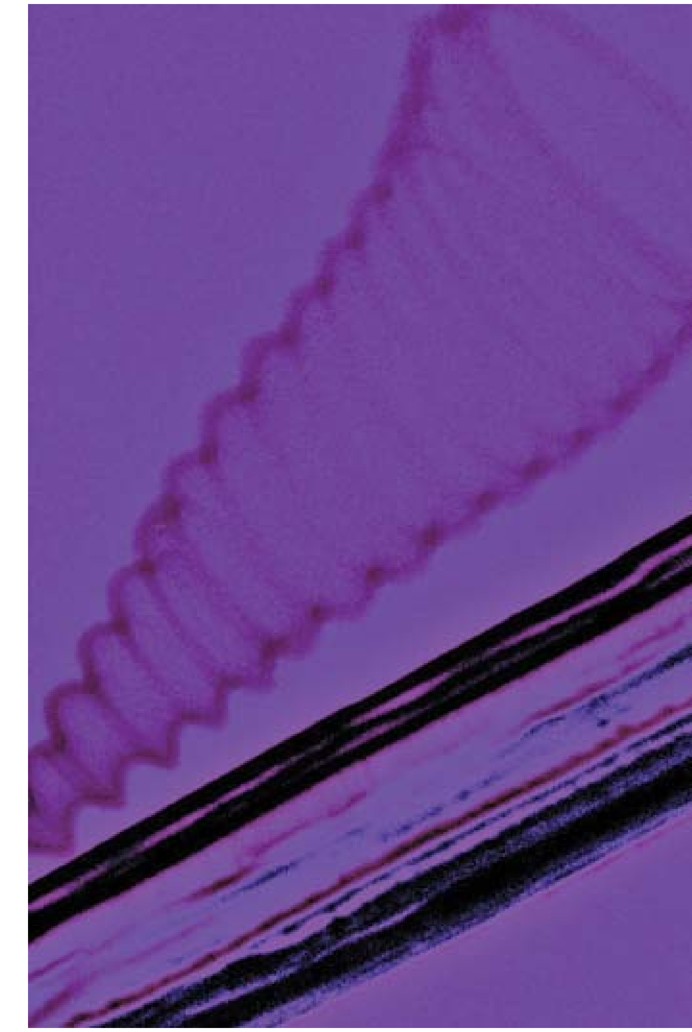
Into a new continent

The problem was how to take advantage of those properties. Nanotubes, and fullerenes in general, were so tiny that the usual methods and tools could seem clumsy at best. Scientists were groping their way across a new frontier, into a new continent mostly uncharted and untamed. At Clemson, Rao and his team had an advantage. They were experts in something called Raman spectroscopy, whose namesake was Sir C. V. Raman, an Indian scientist who, in 1928, first uncovered its principles by exposing organic liquid vapors to sunlight through a set of special filters. Modern Raman spectroscopy was a tool that could, in the right hands, help illuminate the realm of nano in all of its exotic detail.

But using this tool was not as simple as flipping a switch and turning a dial. There was a whole lot of science involved. The instrument scatters a powerful light, usually from a laser, that excites certain properties of molecules, shifting the energy of photons. Because the shifts reveal a material's special modes of vibration, a scientist skilled in Raman spectroscopy can detect not only the type of material but many of its features and properties. With this powerful tool of perception, Rao's lab began to blaze some trails across the wild frontier.

To pick up that part of the story, Rao hands me off to his right-hand man, Ramakrishna Podila, known around the lab as Rama. Rama, who earned his Ph.D. under Rao, returned to the lab as a faculty member. His projects range all over the map, but they share a common technology: Raman spectroscopy, which enabled Rama, Rao, and company to sort, select, modify, manipulate, and replicate the nanomaterials they were making or using in the lab. It also helped them reveal, to the world of science, the shape of things to come.

Rao Lab



A nanocoil developed in the Rao lab could become a versatile component in protective coatings, biosensors, and other technologies.

The long-awaited Y

In the menagerie of nanoscience, some shapes are more equal than others. One of the shapes long desired was a Y. If you had a Y, you had a junction, a potential transistor, and the makings of a circuit. It was no secret that carbon nanotubes were excellent electrical conductors and acted like rifle barrels, guiding electrons with ballistic speed. In electronics, the shorter the distance electrons must travel, the faster the device. And so, from the early days of nanoscience, people had effused about the potential for carbon to upstage silicon as a platform for supersmall microprocessors and other devices. Many a presentation to funding agencies, donors, and investors began with something like this: "Imagine a computer chip so tiny that you could park it in in a living cell..."

But none of those dreams would come true without a Y. And making a Y out of nanotubes mechanically would have been sort of like piecing them together from rolls of chicken wire: Snip off the ends of three rolls at precisely the correct angles and then weld the severed hexagons together, without wrecking the pattern, into one seamless tube with two branches. And do this on the nanoscale, working almost blind.

Helically coiled nanowires: This scanning electron microscopy image reveals a coveted helical shape synthesized in the Rao lab. The bright spot at the tip of each bundle indicates the catalyst particle. Image: Rao lab.

The Rao lab didn't weld their Y together from pieces; they grew it, like a branching tree, using titanium as a catalyst to make branches erupt from the trunk. The results were, quite literally, electric. "Working with Prabhakar Bandaru at the University of California, San Diego, we were able to make a nanoswitch and logic gates," Rama says. He pauses, letting that bell finish ringing. Even a tourist like me hears the implications: In electronic devices, logic gates and switches are two of those vital organs we cannot do without.

In 2005, Rao's research group and their collaborators at UCSD published their findings in *Nature Materials*, announcing a dramatic breakthrough in electrical switching. Their Y transistor could serve, they wrote, as the basis for a new kind of logic device.

The capacious coil

As useful as the Y proved to be, the Rao lab did not hang a hammock on its prongs and take a rest. The team gave their nanotubes a twist. Literally. Once again, the Rao lab grew a structure it wanted, from scratch. As Rama explains it, certain metals—among them aluminum, indium, and tin—will not "wet" carbon, meaning they will not adhere. In fact, carbon has such a phobia for these metals that a nanotube will twist and turn to avoid them, growing like a vine around a tree.

That's how the team made a coil. Some applications were obvious. Rama picks up his cell phone. "Think about the protective coating on a phone like this. The rubber coatings we have now can only take so much impact. We solve this by using nanocoils to protect devices from very high forces, by acting like coil springs in a mattress. And you don't need a coating this thick. You only need maybe few-hundred-microns coating, about the thickness of a human hair, and it can still absorb the force."

The Rao lab led the work on the coil, which was awarded a patent in 2010. As soon as the news of their breakthrough went public, big-time research labs came calling. Rama describes a "huge demand" from researchers at Stanford, Cal Tech, and elsewhere, all wanting samples to test in their labs. A lab at Stanford, for instance, began testing it for use in flexible electronics.

But the value of coils goes beyond the mechanical. By growing a nanotube into a coil, researchers multiplied its surface area. Think of a spiral-shaped pasta, with plenty of surface for red sauce. Nanotube coils work much the same way. They collect and retain much more charge than a simpler shape could hold.

"In a straight nanotube, you can only store energy on the surface," Rama says. "But in a nanocoil, you can store so much more because the surface area in the coil is so much greater.

So a capacitor made of nanocoils would have a much greater storage capacity than a linear one. And the coil shape could also increase the payload of polymer coatings designed to do all kinds of jobs, from drug delivery to pathogen sensing.

The accidental antenna

Rama says the lab made the Y and the coil by design: in each case, they knew what they wanted and planned ways to grow it. But sometimes, they take advantage of a happy accident. That was the case with a nanoscale tetrapod Rama made of zinc oxide.

"I was not trying to make a tetrapod," he says, laughing. "I was just trying to make nanowires. And it so happened that the reaction I tried gave me nanotetrapods, because of zinc oxide's polar nature. And then we said, 'Hey, it looks like an antenna, so why don't we use it for sensing?'"

> A coil can increase the payload of coatings for all kinds of jobs, from drug delivery to pathogen sensing.

Sensing on the nanoscale is a big idea in science, and most especially in medicine. Doctors want to see where the trouble is, in minute detail. But many of the nanomaterials tested for imaging have had a serious limitation: They needed too much light to make them glow.

"If you increase the intensity of light, it can burn the surrounding tissues," Rama says, "so you just want to increase the energy locally, around the area you are sensing." With a thin coating of gold or silver, the tetrapod's "whiskers," as they are called in the lab, could harbor a swarm of electrons, and thereby amplify the signal for sensing.

But a tetrapod isn't the only shape that makes sense for sensing. The lab is also working with nanotube cantilevers, tiny diving boards anchored at one end. Each diver bounces the board a slightly different way, and Rao's lab has found that cantilevered nanotubes resonate at various frequencies, depending on their length and diameter. The team can detect analytes—chemicals of interest in analysis—by treating the nanotube diving boards with specific chemical groups that increase sensitivity and selectivity. The sensors can detect, for example, hazardous chemicals in the tiniest amounts (parts per million).

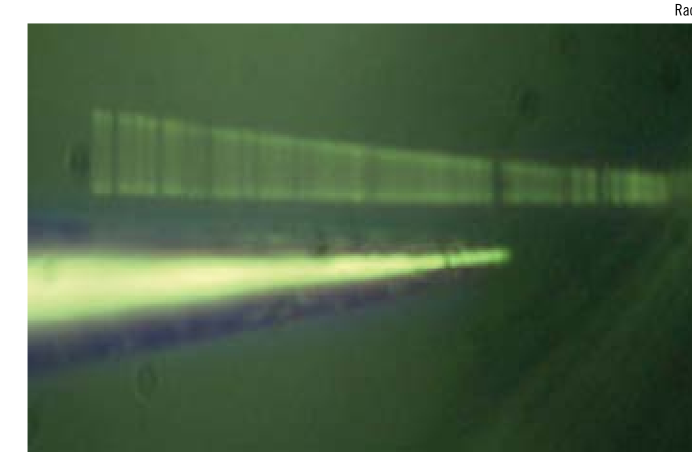
But medicine isn't the only endeavor in need of good sensing. The health of the environment is also at stake, and the lab pursues several technologies for detecting or cleaning up contaminants. With Tim DeVol in environmental engineering and earth sciences, the Rao lab is working on a nanoscale device for detecting radioactivity. Current technology relies on helium, which has become very scarce and expensive. The Rao lab has also created a carbon-based "bucky" sponge that separates oil from water, with a much higher capacity for soaking up an oil spill than other available products. The new sponges have a structure that resembles a parking deck, with closely knit nanotubes forming the deck and the microfibers supporting them as pillars. Bucky sponges, which have an extreme distaste for water, selectively take up oil. The sponges can be burned with no structural damage or loss of elasticity, Rao says, and can be reused over tens and hundreds of cycles.

Generation three: peeling the pencil

The lead in your pencil isn't lead. It is most likely the mineral graphite, another form of carbon. If you had a sharpener so precise it could peel off a shaving one atom thick, you would have graphene. Graphene is a honeycomb lattice of carbon atoms with many of the same mechanical and electrical properties as the nanotube. It is just infinitesimally thin.

For Rao, graphene is the third generation, another magic carpet on which to fly a host of applications. With Rama and Frank Alexis in bioengineering (see "Don't Be Afraid," Spring 2013 *Glimpse*), Rao's lab has used graphene as a protective wrapper for stents, the tube-like structures inserted into arteries or

Rao Lab



Mounting nanostructures as cantilevers, researchers build tiny sensors that detect with precision the telltale resonance of each substance.

Rao Lab

The Rao lab coated zinc oxide nanotetrapods with gold and created a biomolecular sensor.

other bodily passageways to repair damage or improve flow.

"The biggest problem with stents has been thrombosis, because proteins in the body interact with the stent material to create blood clots," Rao says. "Eventually the patient has to go back to replace the stent, and the average time is about five to six years, depending on the patient. So what we have shown in the lab is that if we put one layer of graphene on this stent material we can increase the longevity of the stent and prevent the thrombosis." The graphene, Rao says, protects the stent without adding bulk, and, like carbon nanotubes, does not break down or dissolve in the body.

Rao's partners at East Carolina University plan to test the stent system in laboratory animals, a first step toward use in humans.

Meanwhile, the team is exploring the basic science of graphene. Last year, Rama and Rao helped resolve a scientific debate about defects in graphene, an advance that could provide insights into other questions such as: How can you fold, twist, or scroll the sheets to create and control the band gap? What happens when you fold the graphene, layer by layer? Do its electrical properties change? At what point does layered graphene begin to behave more like graphite? The answers could point to new materials and new applications.

Whiskers on the tetrapods could harbor a swarm of electrons, to amplify a signal for sensing.

"We have grand plans," Rao says.

One of those plans is to take advantage of the new materials' optical properties. Currently, the Rao lab is designing and developing thin-film optical diodes, based on graphene and buckyballs. These new optical diodes potentially could replace silicon-based technologies and result in much faster, all-optical computers.

The upside of being defective

With so many balls in the air, how will Rao's team ever manage the task of building its supercapacitors and scaling them up for production? Won't all the tantalizing tangents lead them astray?

No, Rama says. By working with multiple materials, across several scientific disciplines, the team improves the odds for creative breakthroughs, he says, because a broad frame of reference allows scientists to connect the dots and think by analogy (see "Breakthrough," Spring 2013 *Glimpse*). "We can see those analogies because it's the same physical laws that govern everything," Rama says.

Just last year, a basic-science breakthrough in Rao's lab added unexpected value to the NSF project on scalable manufacturing. The breakthrough? A defect.

"People generally assume that defects are not good," Rama says, "but it turns out that at the nanoscale you only have a few atoms, so if you rip one atom off in a nanotube, it makes a very big deal. We discovered that, by introducing defects, we could tune the properties. And we're seeing that defective nanotubes can be better for capacitors and batteries."

For one thing, a defect adds surface area, and therefore increases the capacity for electrical charge. But that's not all. For batteries, Rama says, the goal is continuous power. But when you charge, say, a lithium-ion battery, some of the ions get clogged up inside the electrode, reducing the available energy. To solve this problem, Rama envisions something like a sprinkler head for ions. "The lithium ion should come out freely when the battery is discharging," Rama says. "So it's good to punch out some holes in the graphite electrode that are just about the size of lithium ions—just the right amount of holes so that the lithium ions can come out really nicely."

Fighting carbon with carbon

At first glance, it might seem paradoxical to suppose that carbon could help decrease pollution. After all, it's the excess of carbon, in the form of carbon dioxide, released into the atmosphere that gets most of the blame for global warming. But carbon, in the right configuration, has an almost peerless ability to conduct electricity. So, with it, we wouldn't necessarily have to burn a carbon-based fuel such as oil, gas, or coal to put carbon to work in our energy supply. And even though the Rao lab works with a range of materials, carbon is clearly the star of the show.

"We've stuck with energy because we're working with carbon, and anything related to energy you see carbon is always there," Rao says. "Already, a lot of people are working on energy sources such as solar and wind. So we said okay, if everyone is working on how to *make* energy, let's work on how to *store* energy. So that's the niche we found. We want to take this to the point that, regardless of how the energy is generated, you will use this storage device."

How is that going, so far?

"We have convinced the NSF that we have the ability to grow carbon nanotubes the way we want them, aligned in an array," Rao says, "and that we can modify them in the right way for energy storage applications."

Does this mean that we could use smaller batteries, extract more power from the batteries we have, and increase the use of renewable energy?

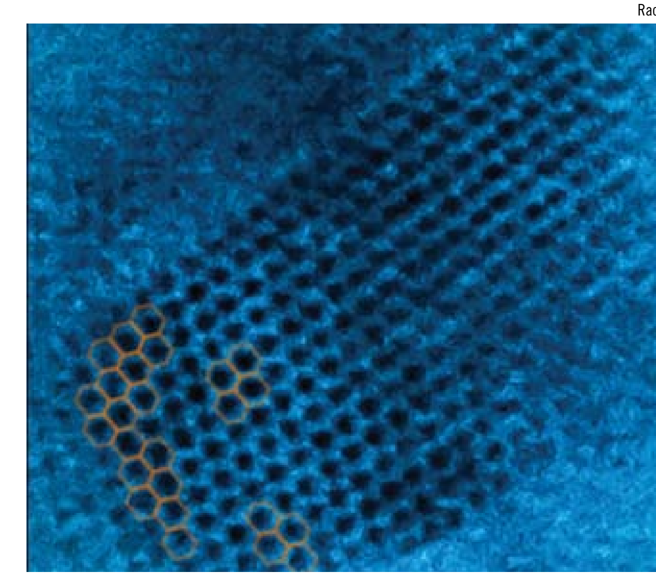
"That is the hope," Rao says.

To get there, his team will build what they call a supercapacitor, which would store and release more energy than ordinary capacitors can handle—and last longer, too. Today's supercapacitors typically are made with a layer of aluminum foil coated with a layer of activated carbon. But the bond between the two layers breaks down, over time.

"One of the main problems with current technology is that after the charge-discharge cycle there is delamination of the layered carbon and the aluminum," Rao explains. "And once it is delaminated the device is useless."

Rao and his collaborator in chemical engineering, Mark Roberts, have two plans for solving that problem. Plan A involves using aluminum foil, much like the foils in production today, but instead of applying a layer of activated carbon, the team will grow carbon nanotubes directly on the surface, essentially welding them to the foil. That could solve the delamination problem, Rao says.

Rao Lab



Even a dot gets a shot: Working with a company called Nanoparticle Biochem, Inc., based in Missouri, the Rao lab helps make and evaluate quantum dots of graphene, doped with chemicals, that can move through the body and attach themselves only to cancer cells.

But Plan B has promise, too. "Since the carbon material itself is conducting, we want to get rid of the aluminum completely and make it an all-carbon supercapacitor," Rao says. "That way there is no need to use aluminum, and that gives more room for boosting energy storage. For Plan B, the team would buy nanotubes in bulk and form them into a paper, known as buckypaper, that would have its own electrical conductance and could also accept various polymer coatings.

“We can satisfy both ends of the market,” Rao says. “We already have some industrial partners.”

Charge for cheap

For the polymers, Roberts takes the lead. “The system we’ve been using enables us to look at a variety of materials, tailored across a broad spectrum of cost versus performance,” Roberts says. “So the versatility is extremely high and rare from the standpoint of an energy system.”

The cost of storing energy, Roberts says, has been one factor limiting the widespread use of renewable energy from solar collectors or wind turbines. “Wind and solar require you to store a charge,” Roberts says. But storage is expensive. “If every renewable-energy system had to have a lithium battery pack, it would never be cost effective. So the Department of Energy is really interested in materials that can store energy for cheap.”

Roberts is testing various polymers for the supercapacitor, some of them inexpensive and easy to find.

“We’re looking at materials that have previously been dismissed as not useful for batteries because they can’t conduct electrons,” he says. “But if the carbon nanotube is providing the pathway for the electrons, then the polymer can supply the charge capacity. One of the polymers we’re testing is lignin, which is a waste product from papermaking.”

Lignin, he says, has chemical properties—redox groups—that allow it to hold a charge. When Roberts tested a coating of lignin on the layer of carbon nanotubes, the combination significantly boosted charge capacity. “So now we can have storage on the polymer and also on the interface,” he says. “We think that this lignin-carbon combination eventually could compete with lead-acid batteries. And we also have some ideas for things that could rival lithium.”

Rao says that when Roberts learned about the plan to use carbon nanotubes for a supercapacitor, Roberts quickly proposed adding a layer of polymer to increase the storage capacity.

“I knew that there would be a benefit in combining these materials,” Roberts says. “The buckypaper is an excellent conductive material, and it’s easy to process and bind things to in the lab.”

Once he began working with the combined materials, some of the test results surprised him. Roberts, who likes to push the limits, jacked up the power, exposing the polymer-coated carbon to very high voltage. “When we went to a higher voltage limit, we saw the energy storage property change,” he says. “The material was not only absorbing ions as predicted, it leveraged the presence of catalyst nanoparticles like iron that actually increased the electrical storage capacity.”

The team is building, in Clemson’s Advanced Materials Research Laboratory, what Rao calls a mini-pilot plant. The equipment feeds a spool of aluminum foil through a hot oven where the nanotubes will grow, and then into another unit for controlling defects, and then into a vat of the polymer, and then onto a take-up spool. This sort of roll-to-roll process, as Rao calls it, is common in manufacturing.

But it’s not as simple as I’m making it sound. Problems that look small in the lab can turn out to be huge on the industrial scale. The heat required to grow the nanotubes introduces various physical and chemical complications, and the mesh-like structure of the nanotube layer has to be constructed with precision—just porous enough for electrons and ions to move through it.

But Rao expects to solve these problems on schedule. “We have already made good progress,” he says.

Powerful potential

An electrically conducting coiled carbon nanotube buckypaper synthesized by Mehmet Karakaya can fold, twist, and stretch without breaking. The material has potential applications in mechanical, electronic, and energy-storage technologies. Rao and Roberts are funded by the National Science Foundation to explore how engineered defects in carbon nanotube buckypaper can result in a new class of supercapacitors that have sufficient power and energy to propel automobiles.

Craig Mahaffey

Craig Mahaffey

Mark Roberts: “We’re looking at materials that have previously been dismissed as not useful for batteries.”

Both ends of the market

With either Plan A or Plan B, the team plans to produce a range of energy-storage capacities, for various budgets and applications.

“We can satisfy both ends of the market,” Rao says. “We can make a really cheap energy-storing device or we can do a very high-end device, depending on what materials we put in there, so it allows us to cater to specific applications.”

Low-cost devices might include those in toys, health-care test kits, various disposable electronics, and low-cost batteries and capacitors. High-end applications could include electric or hybrid vehicles, power tools, and high-tech equipment of various kinds. With such a broad range of potential products and markets, the supercapacitor technology could, if it succeeded, lift whole industries on a carpet of carbon.

“We already have some industrial partners who are interested,” Rao says. KEMET Corporation, a capacitor maker based in Greenville, South Carolina, and SAI Global Technologies, Inc., a nanomaterials company based in Texas, are both working with the research team on the NSF project.

It’s this kind of possibility for real-world relevance that excites Rao most, he says. A problem solver by nature, he likes to think beyond the lab. “Research is all fun and exciting,” he says, “but at the end of the day, it should be useful to humanity. This is the reason I get up early in the morning and come to work.”

Apparao M. Rao is the R. A. Bowen Professor of Physics in the College of Engineering and Science. He was elected to the rank of fellow by the American Physical Society (2008) and the American Academy for the Advancement of Science (2012) for his contributions to the science of carbon. Members of his laboratory include: Malcolm J. Skove, Alumni Distinguished Emeritus Professor of Physics; Ramakrishna Podila, research assistant professor; Ph.D. students Deepika Saini, Mehmet Karakaya, Jingyi Zhu, Anthony Childress, Sai Sunil Mallineni, and Chris Cortis; Herbert Behlow, a research associate; and Poonam Choudhary, an M.S. student.

Mark E. Roberts is an assistant professor of chemical and biomolecular engineering in the College of Engineering and Science. Pu-Chun Ke is an associate professor in the Department of Physics and Astronomy, College of Engineering and Science. Hong Luo is a professor in the Department of Genetics and Biochemistry, College of Agriculture, Forestry, and Life Sciences. Timothy A. DeVol is the Toshiba Professor of Nuclear Engineering in the Department of Environmental Engineering and Earth Sciences, College of Engineering and Science.

Rao, Roberts, and Podila lead Clemson’s work on the National Science Foundation (NSF) scalable manufacturing grant. They collaborate on the project with Prabhakar Bandaru, a professor of mechanical engineering at the University of California, San Diego.

Many of the projects mentioned here are patented or patent-pending technologies available for licensing and are managed by the Clemson University Research Foundation (CURF). CURF is a nonprofit corporation that facilitates the transfer of Clemson University’s intellectual property to the private sector for commercial development and societal benefit. For further information on these or other Clemson technologies, please visit www.clemson.edu/curf or email contactcurf@clemson.edu.

Launching the venture

How do inventions grab traction in the marketplace? Consider a few case studies.

Craig Mahaffey

An employee works in a lab of Tetramer Technologies, a spin-off company that grew out of research conducted at Clemson.

Can a start-up compete with DuPont?

by Brian Mullen

Twelve years ago, four Clemson faculty members got together and decided to create some new materials. They didn't set out to start a business, hire a work force, or establish a brand. They were doing their jobs: teaching and research.

"We were just junior faculty from four different departments on campus talking to one another," says John Ballato, professor and director of the Center for Optical Materials Science and Engineering Technologies (COMSET) at Clemson. "We were trying to get promoted and tenured without any upfront thoughts about creating a company."

The four began their work with research grants from the National Science Foundation and the Department of Defense. They made small amounts of material—an advanced polymer whose initials are PFCB—so that they could take measurements, publish their findings, and present them at major conferences.

As word spread about PFCB, which showed strong potential for use in next-generation technologies such as telecommunications and fuel cells, requests for the material rolled in from researchers and businesses asking to test it.

"Fortunately, for us at least, the devices that generally use our material only require a small amount," Ballato says. "We did not have to go into developing a commodity-scale material. We could get away with something that was just very high value."

The foursome used a $20,000 check from a company interested in purchasing a significant amount of material to buy equipment and supplies. At that point, they not only had a material, they had a product with an actual market. In 2001, they decided to form a company, Tetramer Technologies, LLC, and later licensed intellectual property from the Clemson University Research Foundation (CURF). Initially, the company's revenues came from small sales and small business innovation research grants from the federal government.

"We had a material platform that we knew worked for this one application," Ballato says. "That is why there was an initial attraction, and people were pulling it out of us, but we knew that we could do more with the material than what we originally used it for."

Thinking big

So they began working with the material that had been developed for one application and found multiple uses by modifying the same polymer technology. Tetramer's research and the versatility of its products enabled the company to forge partnerships with large industrial companies such as General Motors and Cargill to work on fuel cell technology and create renewable biomaterials.

"We sent some competing materials to GM and asked them to test it and let us know if the material worked as well or better compared to other materials that are produced by DuPont and other large global manufacturers," says Earl Wagener, Tetramer's CEO. "The material worked out well, and GM was intrigued as to how material from a small start-up company in rural South Carolina was competing with DuPont."

Tetramer can compete with DuPont because the Clemson facilities and equipment are just as good, if not better, than what DuPont possesses, especially in creating and characterizing such advanced polymers, Wagener says, since material science is a key focus of Clemson University. "If you look at product development as a five-stage process with stage five being commercialization, you don't know the commercial and technical value of the product until you are in stage two or three. Your product is not worth anything until your customer tests the product and finds the same results."

And GM found additional value-added results compared to DuPont's polymers, testing the material in fuel cells, devices that convert chemical energy into electricity.

Much as they did for GM, Tetramer researchers have continued to develop new uses for its material, working with companies to offer a product that can meet their needs.

"We took advantage of the fact that our polymer platform was good for more things than just optics," Ballato says. "We developed materials for automotive, energy, and other applications and were able to move into those markets too."

According to the founders, bringing Wagener on board to run the company was a key to success. Wagener, a Clemson alumnus who had spent twenty-five-plus years developing new products at Dow Chemical and ten years as the vice president of research and development at Stepan, a specialty chemical products maker, understands the business.

"We are good at being faculty members," Ballato says. "We aren't good at running a company. So we gave the reins over to somebody who knows how to run a business."

Homegrown know-how

Wagener and the researchers carefully evaluated each of their products, deciding which to keep and which to discard. As it happens, none of today's products employ that original PFCB chemistry. New materials were developed along the way to meet the market's performance and price-point demands. Using a combination of Clemson and Tetramer resources, Tetramer has created products ranging from high-temperature lasers and biorenewable lubricants to low-fat chocolate.

"We have wound up with basically five platforms that are really interesting," Wagener says. "When you are a small company, it is tough because you get fewer at bats. So you want to avoid going for the home runs at first and stay with the smaller stuff."

After twelve years, Tetramer has grown to about thirty employees, many of them "homegrown," Ballato says. "The vast majority of our employees, past and present, passed through Clemson as students or postdocs." One of these employees, Jeffrey Dimaio, who earned his Ph.D. with Ballato in 2004, joined Tetramer, and became an owner in 2012.

What makes a successful start-up venture based on university research? Ballato says that faculty members have to set aside some personal preoccupations about their research and surround themselves with people who understand the business side.

"I think the successful ones realize that start-up companies are a combination of market and science driven," Ballato says. "And so they need to understand commercial needs and that these needs change with time."

John Ballato is a professor of materials science and engineering and a professor of electrical and computer engineering in the College of Engineering and Science. He is also the director of the Center for Optical Materials Science and Engineering Technologies (COMSET), which is a South Carolina Research Center of Economic Excellence. Steve Foulger, another cofounder of Tetramer, is a professor of materials science and engineering. Brian Mullen is the director of research communications.

Bits &bites

Overeat, and your wrist could rat you out.
by Anna Simon

The Bite Counter, a device to measure how much people eat, was conceived over lunch.

Eric Muth, a psychologist, and Adam Hoover, an electrical engineer, were building tracking systems for soldiers doing urban police work in war zones. The tracking systems, funded by the U.S. Department of Defense, record soldiers' body movements as they conduct building-to-building searches for the enemy or use guerilla tactics in urban terrain.

A lunch-break conversation drifted to potential ways the technology could benefit civilians. "We thought about the obesity problem," Muth says. "They have pedometers to track steps. What if we had something to track bites?"

Hoover cites statistics: One in three U.S. adults and one in six U.S. children are obese. "That's scary," Hoover says. "Especially children."

In South Carolina, 66.9 percent of adults are overweight and 31 percent of adults are obese, according to the Centers for Disease Control (CDC). The CDC reports that 15 percent of South Carolina children and adolescents are overweight, and 16.7 percent of high-school-age adolescents are obese. The problem starts young. Nearly 13 percent of South Carolina children between age two and five are obese, according to the CDC.

Wear it like a watch

So Muth and Hoover decided to build a device that tracks wrist movements to measure bites of food. They wanted it to be simple to operate and nonintrusive so that people would wear and use it. Worn on the wrist like a watch, the device they created tracks wrist movement and records data in the form of an eating diary that can be viewed when the Bite Counter is plugged into a computer.

In 2008, Muth and Hoover disclosed the technology to the Clemson University Research Foundation (CURF), which applied for a patent in 2009 on behalf of Clemson University.

Embarking on the project at a time when the economy was tanking and university research dollars were drying up, Muth and Hoover launched their own company, Bite Technologies, and licensed the technology from CURF in 2010. With CURF's help, they approached South Carolina Launch for seed funding to build the device. South Carolina Launch, a private nonprofit organization that helps start-up companies move new technologies from university research labs to the marketplace, provided $50,000 in matching funds.

Bite Technologies and Clemson University also received a National Institutes of Health small business technology transfer grant of $148,556 from the National Institute of Diabetes and Digestive and Kidney Diseases to assess the Bite Counter as a tool for food-intake monitoring.

Patrick Wright

Adam Hoover (left) and Eric Muth, wearing their work.

Clemson was issued a patent on the Bite Counter in November 2012, three years after the application was submitted.

The researchers ran studies to assess the accuracy of the device. In one study, nearly three hundred people were videotaped as they ate, wearing the device. Their food was weighed and recorded, and graduate students, along with an undergraduate Creative Inquiry team, reviewed the videos and helped collect and analyze the data. The researchers looked at gender, height, weight, age, ethnicity, food eaten, utensils used, and which hand was used to eat. They amassed a database of more than 22,000 bites.

"It does indeed count bites accurately," Muth says. Now the team is translating bites to calories through research designed to learn what they call "the language of eating." This will enable users to personalize and fine-tune data the Bite Counter collects based on gender, size, and other factors. For example, the researchers found that, on average, males consume seventeen calories per bite and females consume eleven calories per bite, and taller people consume more calories per bite than shorter people.

They also are further refining the analysis of wrist movements to indicate the type of food eaten. They hope their ongoing research will enable the Bite Counter to tell the difference between a fast-food cheeseburger and a fresh vegetable salad by the frequency of bites; between drinking and eating through the range of wrist movement; and even between drinking from a glass or through a straw and whether the user is cutting food or eating food. Those data could go a long way toward keeping the wearer honest about portion size and calories, Muth says.

In fact, the Bite Counter is more honest than we are about our eating habits, according to one of the team's recent studies. After eating, study participants were asked how many calories they'd eaten. Some participants were given menus listing what was on their plate. Most participants underestimated calories. Those without a menu far underestimated the calorie count compared to those with a menu, the study found. The general inability of participants to accurately estimate calorie intake, especially those without a menu to use as a guide, told the researchers that current work to more closely correlate bites and calorie count does enhance the benefits the Bite Counter can offer.

"Our research shows it does count better than people on their own," Muth says. "People will wear it. It relates to calories and people can use it to lose weight without doing anything else."

A new study planned for this fall will examine whether the device can get people to stop eating when they want to stop eating. Another study will develop a weight-loss protocol. People will start with a certain bite count based on size and gender. They'll be taught how to use the device and instructed to keep an eating calendar and weigh themselves on a weekly basis. Researchers will look at their weight and reset the bite count to find their individual bite number that gives them an optimal number of bites to lose weight at a healthy pace and then maintain a healthy weight after the desired weight loss is achieved.

Too useful to sit on

Currently Bite Technologies is working with a sublicensing company to find a corporate partner to license the technology and take the Bite Counter down the home stretch from the lab to the marketplace. The inventors hope a big-name, national brand company with experience in marketing other monitoring devices will add the Bite Counter to its product line.

They've attended conferences of professional organizations including the Obesity Society, a scientific society that studies obesity, and the American College of Sports Medicine, to let people know the device is available, but the item is pricey. The current Bite Counter sells for $800, with bulk discounts available. Muth and Hoover agree that the price tag is way too high for the consumer market. Most of their sales so far are to researchers and professional health and fitness trainers. They envision a target price of $100 for the consumer version.

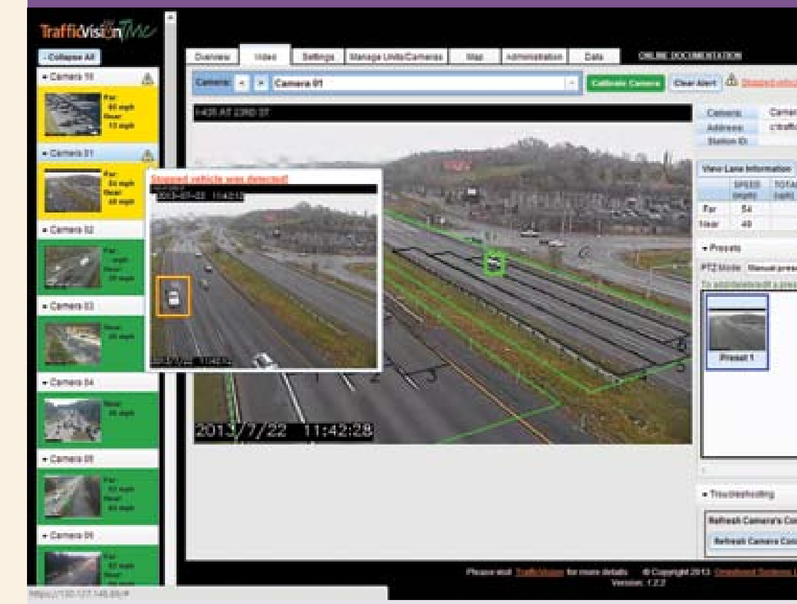
They're passionate about the Bite Counter because they believe it can and will help people live healthier lives.

"I think this technology is too useful to sit on," Hoover says. "It's rare as an academic to find something that has the potential to help people in your lifetime."

Eric Muth is a professor of psychology in the College of Business and Behavioral Science. Adam Hoover is an associate professor of electrical and computer engineering in the College of Engineering and Science. Anna Simon is a freelance writer based near Pendleton, South Carolina, and writes for Your Day, *a radio program produced at Clemson University for South Carolina ETV Radio.*

For information on licensing Clemson University intellectual property, go to www.clemson.edu/curf or contact CURF at contactcurf@clemson.edu.

Launching the venture



Tracking traffic

TrafficVision, a division of the Clemson-based start-up company Omnibond, develops software to automatically process video from roadway cameras. Clemson researchers Stan Birchfield, Wayne Sarasua, and Neeraj Kanhere created the initial technology when they discovered that thousands of manually operated cameras along major roadways in the United States were underused. Meanwhile, state and federal transportation officials and local municipalities needed better real-time information about traffic volume, vehicle type, speed, and density.

The team's patented technology, licensed through the Clemson University Research Foundation (CURF), builds a background model that adapts to changing light and weather conditions and tracks vehicles over time by comparing their appearance in successive frames. After a presentation at a transportation conference in 2007, the team received invitations to install the technology in Maryland and New York, including the Long Island Expressway. Since then, as transportation officials have become more convinced about the benefits of using TrafficVision, the technology has been installed in numerous U.S. locations.

For more information about TrafficVision, go to www.trafficvision.com.

Technologies and jobs

Over the past two decades, more than seventeen spin-off companies have licensed Clemson University technologies, and many of these companies have been established near Clemson. Clemson start-up companies have created more than a hundred jobs in the advanced material, biomedical device, and information technology sectors. Many of these jobs require at least a bachelor's degree and offer salaries well above the per capita income of South Carolina.

The Clemson University Research Foundation (CURF), through its Office of Technology Transfer, guides the development of start-up ventures and commercializes the university's intellectual property. Over the past twenty years, Clemson has licensed more than forty-five technologies to start-up companies, generating more than $400,000 in license revenue.

Here are several examples of start-ups that have licensed Clemson technologies:

Company	Location
Bite Technologies, LLC	South Carolina
BioSurfaces, Inc.	Massachusetts
KIYATEC, Inc.	South Carolina
Earth Renewable Technologies, Inc.	South Carolina
Advanced Photonic Crystals, LLC	South Carolina
SensorTech, LLC	South Carolina
Medusim Solutions, LLC	South Carolina
Luminescent MD, LLC	Maryland
Tetramer Technologies, LLC	South Carolina
Omnibond, LLC	South Carolina
Selah Technologies, Inc. *(Acquired by Lab21 Inc. in 2009)*	South Carolina
Vatrix Medical, Inc.	Minnesota
Tiger Bioanalytics Ltd. Co.	South Carolina
NUBAD, LLC	South Carolina
Specialty and Custom Fibers, LLC	South Carolina
Sila Nanotechnologies, Inc.	Georgia
Lamprogen, Inc.	Washington

Craig Mahaffey

the secret book

A hijacked work of art grows rampant and weed-like into new art.

by Peter Kent

Craig Mahaffey

The first time I met David Tillinghast, at Starbucks, we chatted about woodcraft and archery. An artist and a scribbler, we sat sipping coffee, swapping stories. At the time, I did not know that Tillinghast had created the Secret Book. And he didn't know it either.

There is a secret book at Clemson. Maybe not so secret. Hundreds of students know about it. They have all had a hand in making the book into what it has become, transforming it from its creator's artistic vision into crowd-sourced journal for graduating seniors. It has become a tradition, a rite of passage, to write a passage or leave a memento in the Secret Book.

From the book:

"You spend 4 years trying to get out of this place and the rest of your life trying to get back. There really is something in these hills." Courtney Nations, 10/21/10, Class of 2010

Cooper Library keeps the book on restricted circulation. Students have used it so many times that the book has gone through four rebindings. Often it ranks among the most checked-out library books in the monthly circulation reports, especially at the semester's end. English instructors use the book as an example in English 103, first-year composition. One made Tillinghast's work part of a scavenger hunt exercise for her class.

The book comes with a curse and it includes a clue used in solving a puzzle that led to a cash gift for a newlywed couple. It's a mystery how the tradition started—no one lays claim to it—and problematic in its perpetuation. Is it a willful act of destruction or the realization that public art ultimately belongs to the public?

From the book:

"Rules. You may tell anyone of the existence of the book, but no one the location or call number. You may give 5 (five) people hints on where to find this call number on campus. Keep it secret. Keep it safe." Unsigned

"You don't know about the Secret Book?" Denise Woodward-Detrich asks, as though I should have known about it, the way we all should have known about the five mass extinctions in the history of Earth. No, the book isn't the reason for my visiting her in Lee Hall, where she oversees the Lee Gallery. I have come to find out about the miniature silo. To the people who can see the silo from their windows in Barre Hall, it looks like an abandoned agricultural totem, and they are mostly clueless to its purpose or provenance. Woodward-Detrich laughs. "The silo and the book are connected. You need to meet the artist David Tillinghast. He's a sculptor, got his master's here and lives here; his father is an author, retired from the English Department."

A talk of two vessels

"Do you remember me?" Tillinghast asks.

I nod, lying. We sit at Starbucks, again, and talk. He is lean and long-limbed, with lanky brown hair framing a face serious but open to laughter. His eyes would lose him his shirt at almost any poker table, and, as we talk about the Secret Book, his face goes through page after page of emotions—bewilderment, outrage, resignation, delight.

The students coined the name Secret Book. Tillinghast knows the volume as one half of P211. t45, the title of his campus public art project installed in 2001. The other half is a brick-and-brown-metal, twenty-one-foot-tall silo. Together, the pieces are Tillinghast's view of the relationship between agriculture and written language. Embossed in a deep brown-red on the original book front cover, P211 .t45 is a Library of Congress call number, ascribing it an address in the history-of-writing collection.

"The silo and book are linked," Tillinghast says. "Growing crops led to settlements and a way to record harvests and distribution. But the connectedness is more than recordkeeping. Agriculture is a way of organizing nature in fields and rows. Writing is a way of organizing ideas, experiences and events. Nature, from cells to cities, is organized."

There also is meaning in the "two vessels," Tillinghast adds. Both the book and silo are containers filled with meaning. The silo looks empty, but embedded in the floor is a bronze disc with "Cooper and P211 .t45" set in raised letters and numbers. When viewers position themselves to read the legend, it aligns them for the next step in putting together the pieces.

Before the new Academic Success Center arose and broke the line of sight, the silo's slit portals aligned to point precisely to the reference section bookshelf on which the book was placed. But that was before it became so popular that the librarians moved it to a shelf behind the circulation desk and restricted borrowers, faculty included, to a two-hour checkout.

Chaos and order

The black linen-covered book is a field guide to Tillinghast's imagery of the age-old struggle between chaos and order. He collected weeds in wintertime, particularly thistles, from roadsides and unkempt patches, and arranged them to create spare assemblages, prickly with brittle stems, sharp leaves, and dried seedpods, pressed like botanical samples set as silhouettes.

"Weeds are nature's wild antagonists to crops," he says. "They create tension and relentlessly grow, symbols of nature's independence in spite our efforts to control it. The tension between the wild and the domesticated is part of human nature."

Stark black-and-white images evolved as Tillinghast ran the unbound pages repeatedly through a copier, accreting layer on layer of ink, adding depth and weight to the images. He has kept the proofs and a failed version of the book, which he refuses to let me see. "It tried to please an audience. I did not want that."

Tillinghast rubbed two of the pages with red dirt from the region. There are also drawings of the silo's rooftop ribs and flashing, an homage to Renaissance architect Brunelleschi's dome, one of Tillinghast's favorite artists. Finally, there is one page with two words: "field" and "join." Tillinghast says the book of symbols is a symbol itself of "a field of pages joining together to make a book—a whole, a oneness, no separation between nature and our making."

The original book is intriguing—what you can see of it. The Secret Book has nearly obliterated P211 .t45. Personal notes, famous quotes, snippets of songs and poems, wisecracks, witticisms, truths, lies, boasts, smut, smack, doggerel, drawings and photos, football ticket stubs, pennies, buttons, Post Its, playing and business cards, and hundreds of names and dates, a gushing orange hemorrhage of young hearts and minds. The impact is sacred and profane, something less than a canticle to Clemson but something more than the scrawl on a beer joint's restroom wall.

From the book:

"I spent 2 hours looking at this book so now I will probably fail my exam tomorrow." Unsigned, 7/27/2011

Students see nothing wrong with what they're doing. "He should be honored that we have chosen the book to be a tradition," writes one student in an email. The sentiment is repeated in other emails. I have asked the librarians to invite students to email me; a handful do. Their views are fairly consistent: They do not know who the artist is. They do not know the book is art. Most say they like art and many say they do not know there are artworks on campus. They have found out about the book mostly from Facebook or from other students.

"You have no clue how valuable this is to us," one senior says at the library. Seniors are the ones who are supposed to sign the book, according to tradition. Woe unto undergraduates who make their mark too early. "If you are an undergraduate and sign it, you will not graduate," says Katherine Mercer, a library student aide, who graduated last semester.

From the book:

"I found this and now I'm haunted..." Talia Kahoe, 8/26/12, Class of 2016!

Mercer has signed the book and has been given a special distinction. Students who work in the library can select a book to have a bookplate attached commemorating their service. Mercer picked the Secret Book. She knows that her bookplate is as vulnerable as the book. "It will get written over, but I'm okay with that, because that's what happens in the book."

Tillinghast expected a notation or two. In the back of the book, he included a few blank pages for the seekers to sign and date their discovery of the art installation. "Maybe a few dozen, at most," he says. In the 2005, he stopped in to see if anyone had signed the book. There were lots of signatures, including ones by family members. "The pages were filling up. I knew something was going to happen, but I didn't do anything about it." He did not return until 2013. The second visit staggered him. "The pages had become palimpsest in reverse. The monks in the Middle Ages scrubbed the pages of ancient texts to write their holy words. What the students are doing is writing over the pages, eclipsing my images. It's the same thing—one wiping out another."

From the book:

"Twelve days to graduation...here it goes...." Katherine Helen Dantzler, April 28, 2013, Class of 2013

It was like a cancer claiming his book, and Tillinghast was whipsawed by emotions. "I was angry at first. Then I wanted to do something like take the book back. I thought maybe I could fix it, or wipe out what they had done, or figure out how to market it, maybe sell prints or T-shirts and make some money. Now, well, I am thinking about what's next."

Some people want Tillinghast to do a second volume. "This one is falling apart," says Fredda Owens, circulation librarian. "We have added blank pages, but the book isn't in great shape, and we can have it rebound only so many times." The original covers are now in a slipcase pocket as part of a new binding.

Public takeover

Art professor David Detrich (Woodward-Detrich's spouse) was Tillinghast's adviser, and Tillinghast was Detrich's first graduate student. Detrich leads Atelier InSite, a program whose goal is to sharpen the university's vision of what it wants from public art.

"Artists who create public artworks deal with additional pressures," Detrich says. "Public response to the work can be dramatic." He mentions, for example, Richard Serra, a sculptor whose *Tilted Arc* in 1981 blocked easy access New York City's Federal Plaza and was so despised that local officials had it removed in 1989.

If art is about evoking response, Tillinghast's art has succeeded. But it has been a Prufrockian experience for him. He tells me he has not decided about making a second volume of P211 .t45. "No, it's become something else," he says. "Maybe without the signatures and other items the book would remain a dark cave. It's interesting that while my original book is self-destructing, the new signatures create the new book. The very thing that destroys the book gives it life. The overlapping signatures are like torches illuminating the cave walls."

While working on this story, I was in the city and stopped by the New York Public Library to ask a question. "No, we don't have a secret book I know about," answered the librarian. "But we do have a disappearing book."

Before I was allowed to see it, the librarians in the rare book room explained the rules, which include no permanent markers—only pencils—and no bags or satchels, just paper or a computer. On a long, dark wood table, under a pool of lamp light, librarians set out *Agrippa* in its stone-textured, slate-gray plastic case. *Agrippa* (a book of the dead) was created in 1992 by writer William Gibson, artist Dennis Ashbaugh, and publisher Kevin Begos Jr. A cryptic cult classic and scholar's fetish, it is a poem about childhood memories by Gibson on a computer minidisc set to erase after one reading, inset in Ashbaugh's book made of light-sensitive paper and ink meant to fade away. Eighty-five copies were made; the library's copy is thought to be in the best condition, much to the author's displeasure.

"Gibson was in here a few weeks ago and asked to see it," said a librarian. "He was disappointed that we had kept it so well."

Tillinghast chuckles as I tell the *Agrippa* story. "A disappearing book," he says. "What a concept."

Later in an email, Tillinghast, who feels a bond with T.S. Eliot's "The Love Song of J. Alfred Prufrock," sends me a quote from the poem: "In a minute there is time/For decisions and revisions which a minute will reverse."

Peter Kent is a news editor and writer in Clemson's Public Service Activities.

Craig Mahaffey

David Tillinghast revisits the miniature silo he created on campus. Like its companion piece, the Secret Book, it is vessel of meaning.

Charting the **stormy seas** of social media

by Lauren J. Bryant

If you think tweets come from feathered things, posts are for fences, and pinterest is merely a typo, this story may not be for you. But if you're among the one billion users of Facebook or YouTube, or the hundreds of millions who use Twitter, Pinterest, LinkedIn, Instagram, and Tumblr, then meet Jason Thatcher and the faculty and students at Clemson's Social Media Listening Center.

In fact, they may have heard from you already.

Since February 2012, when the SMLC opened under the auspices of the Clemson CyberInstitute, Thatcher (*@jasonbthatcher*) and dozens of students and faculty members have been "listening" to social media—meaning, they are monitoring information drawn from hundreds of millions of updates, posts, and tweets to track what people are saying about a particular person, place, or thing.

They accomplish this listening using systems from Radian6 (a division of Salesforce Marketing Cloud *@marketingcloud*) and PeekAnalytics (*@peekanalytics*), six high-powered computers provided by Dell (*@Dell*), and six forty-seven-inch monitors arrayed around the often-busy room that constitutes the center.

There's a lot to hear. As an article on social media analysis in *The Guardian* put it, in its June 10 edition, "online social networks bleed information." Every status update and Facebook "like," every hashtagged tweet and repinned pin, offers potentially valuable data if you know how to look or listen. Conversations via the "social web" generate a dataset like no other—constantly updated, broadly diverse, largely unfiltered, and, in terms of quantity, utterly overwhelming.

"Here's the problem," says Thatcher, an associate professor in the Department of Management at Clemson and a faculty lead at the SMLC. "You have seven hundred million data sources, five thousand tweets a second. How do you find something useable in that? How do you identify, extract, and analyze relevant data?"

That's where the Social Media Listening Center comes in. Using straightforward keyword searches and sophisticated algorithms, students and faculty at the SMLC monitor words and phrases used in social media conversations, analyzing the sentiment and intentions they may reveal.

"We sort the signal from the noise," Thatcher says. "Defining keyword sets and refining searches isn't rocket science, but what you do with the data is. What we're good at is figuring out what to do with it."

Keeping the trust

There's no denying that social media listening is surveillance, but Thatcher is quick to point out that the work of the Social Media Listening Center is anything but covert.

"We're upfront and transparent about collecting data," he says. "We collect data only where people do not have their privacy settings turned on. We're not reaching into anyone's pocket."

In fact, Thatcher firmly believes that academics should collect and mine data from the social web (as does Clemson's Chief Information Officer Jim Bottum, who had the original idea of partnering with Dell and Salesforce Radian6 to create the SMLC).

"When I make my pitch about why academics should be doing this work," says Thatcher, "I tell people that universities are keepers of the public trust. We can ask questions that others can't. If we don't do this work, then the intelligence and business communities will know what's going on, and we won't."

Good analysis depends on context, says Thatcher, who stresses this point with students working on projects at the SMLC. "You really have to be a content expert and have some mastery of an event or issue to run a good data analysis," he says. "You have to apply your understanding of the issue to the data along with the technology."

Katy Perry and Halo 4

Last fall, with funding from a National Science Foundation Early Concept Grant for Exploratory Research, Thatcher and an SMLC team took a look at the 2012 congressional and national elections, specifically the impact of social media on polarization.

"We were really interested in learning about what made folks 'pick a team,'" Thatcher explained in an interview on the Sales-Force Marketing Cloud blog after the presidential election.

Working together, Thatcher and Clemson students built search queries to listen to online discussion of several key issues such as medical marijuana, celebrity chatter, Katy Perry, Halo 4, and memes (remember Big Bird and Binders Full of Women?).

Monitoring conversations related to these issues, the team discovered that medical marijuana talk focused on policy issues, not partying, and that Katy Perry engaged young people to support Obama but her tweeting peaked too soon. "Her numbers spiked before Election Day with her offer [to retweet photos of outfits people wore to vote] but didn't jump back up on the day of the election itself," Thatcher reported in his blog interview.

As far as celebrity chatter (Clint Eastwood, Kanye West, etc.), the team found that celebrities encouraged more positive feelings toward Obama and negative ones toward Romney, but overall played a modest role. Memes, too, were low-profile influencers on Election Day.

The search for conversation about Halo 4 (a popular video game series that launched its latest installment on November 6, 2012) was used to track whether people were talking about other aspects of their lives in relation to the election. The team found that Halo 4 fans may have been disgruntled by the timing of the game's release but managed to attend to both the election and alien enemy attacks.

Illustrations by Neil Caudle, adapted from Winslow Homer

Craig Mahaffey

Jason Thatcher: Making sense of social media "is hard to do well."

The most significant results from the NSF study are still to come, though. First, Thatcher and his team have collected a very large dataset reflecting how social media influences the opinions of U.S. citizens about elections, a dataset that can now be used by other researchers. Second, the SMLC team is wrapping up work on a prototype of a digital tool that will take all the snippets of social media data and create an online "dashboard" that displays the data in one place.

"What we're hoping to have when we're done with the project is a visualization tool—a piece of software—that researchers will be able to import social media data into for analysis," Thatcher says. "You'll be able to manipulate the data, map conversations to see if they are positive or negative. It will be applicable to a number of different areas where researchers are interested in studying conversations on the social web."

"We're the pioneers."

One of those researchers is Vernon Burton (*@VernonBurton1*), professor of history and computer science and director of the Clemson CyberInstitute. Author of the award-winning *The Age of Lincoln* and a former president of the Southern Historical Association, Burton is using the SMLC to help him "measure what people think about the South," he says.

Craig Mahaffey

Vernon Burton measures what people think about the South.

Tracking posts, tweets, and hashtags, Burton and his colleague Simon Appleford (*@sjappleford*), associate director for humanities, arts, and social sciences at the Clemson CyberInstitute, are looking for mentions of the word "south" and what terms are associated with the mentions. Burton notes that this is considerably more complicated than typing a few words into your Google search bar.

"It's a very complex process, a lot more complicated than people are aware of or would think," he says. (Jason Thatcher concurs on this point: "Analyzing social media is a long, involved process," he says. "It's not necessarily hard to do, but it's hard to do well.") For example, Burton and Appleford had to construct their social media searches to exclude "souths" such as South America, South Africa, South Chicago, South Pole, and South Park.

Their social media analysis is ongoing, but certain conclusions were quickly evident. For one thing, Burton says, "Southern history is negative. It's significantly less important to users of social media than Southern food." Southern food and culture trend positive, while mentions of religion and gender in connection with the South are negative.

Burton also tracked racist terms and comments on social media but found that geographic differences complicate things. In social media data coming from Philadelphia, New York City, and Louisiana, for example, Burton notes that the "n-word" has been appropriated as an affirmation of identity. Likewise, when tweets from Texas showed up containing the racist term "mammy," it turned out that it was "an African-American woman in Texas tweeting 'mammy' all over the place," he says.

Nevertheless, Burton, an American history scholar for more than thirty years, is enthusiastic about the future of social media analysis in social science research. "You can learn a lot from it," he says, "especially when you parse it out by region and put it into historical context. You can look to see if the image of the South is changing. Is there a South and a North anymore?

"We've never had the opportunity to gather this kind of data," he continues. "It was unimaginable even ten years ago. Social media is a different kind of data. It's unguarded, more out of the heart than the head. We're the pioneers in figuring out what you can and can't learn from it."

The wisdom of the crowd

Clemson students are definitely among the university's social media analysis pioneers. Kyle LePrevost *(@KyleLePrevost)*, who graduated in May 2013 with a degree in management information systems, was part of a Creative Inquiry group who took advantage of the SMLC shortly after it opened. In early 2012, he and four other students (Scott Cole, James Kaplanges, Brett Smentek, and Paul Smith) decided to explore whether social media analysis could help them predict movements in the foreign currency exchange market (*@FOREXcom*).

First, the students listened to social media conversations on Twitter about a specific pair of currencies, EUR/USD (the Euro and the U.S. dollar). Then they created an algorithm—an

Social media data are "unguarded, **more out of the heart than the head."**

—Vernon Burton

Craig Mahaffey

Right: Kyle LePrevost and fellow students beat the market with a demo brokerage account guided by social media research.

automated computer script—that scanned thousands of tweets looking for spikes in social media data related to buying or selling. The script made trades based on what people were saying, that is, on how strongly they were tweeting about a currency pair. LePrevost calls this the "wisdom of the crowd" (after the book by *New Yorker* staff writer James Surowiecki).

"The basic idea," says LePrevost, "is that we can scrape actual trade data from Twitter and use it to make real-time decisions about when to buy or sell currencies."

The students opened a "demo" brokerage account, using pretend money, to conduct practice trades and test their algorithm. It was a wildly successful experiment. Out of 58 trades made using the algorithm in spring 2012, only 13 moved in the opposite direction—a 77 percent prediction rate. The students began with $5,000 in their "dummy" account and ended up with $44,000 in theoretical funds just seven weeks later, a 780 percent increase. As Jason Thatcher put it on the SMLC blog, the students "beat the snot out of the market."

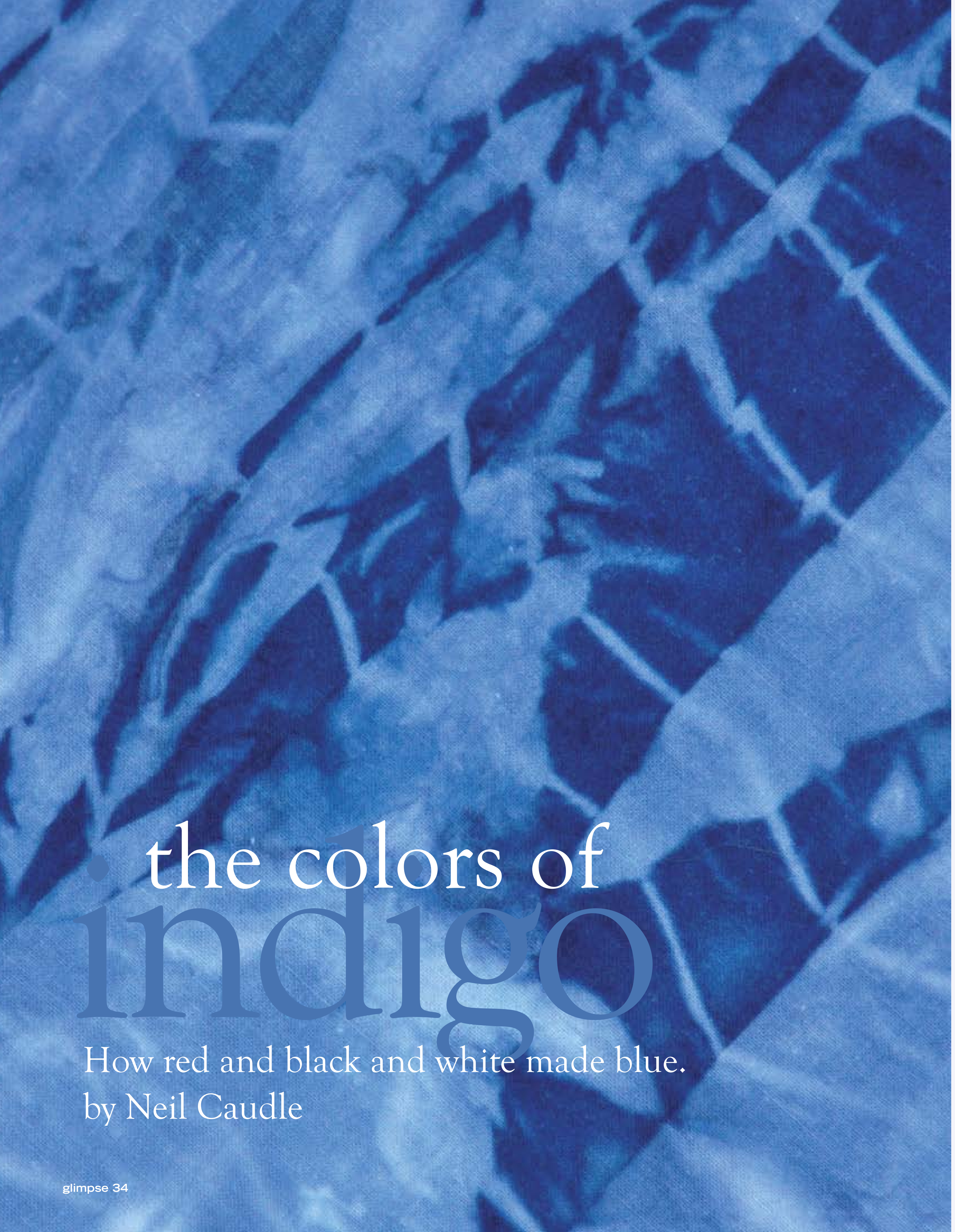
Over the last year or so, the group—now going by the name #TeamForex—has "backtested" their algorithm using historical market data. The algorithm did not sustain its 780 percent increase level; it dropped to 600 percent. "It still beats out most hedge funds by a wide margin," LePrevost says. "We have seen about a six hundred percent return per year over two years, which is very exciting." It's no doubt exciting too for the investment firms now interested in helping #TeamForex expand their project.

Studies of U.S. elections, Southern history, and foreign currency exchange are just the beginning of the research projects to be carried at the Social Media Listening Center, according to Jason Thatcher. "Our goal is to create a platform for research projects across the campus and with other universities," he says. "The questions we can pursue are limitless."

Jason Thatcher is the faculty leader of the Social Media Listening Center and an associate professor in the Department of Management, College of Business and Behavioral Science. Orville Vernon Burton is the director of the Clemson CyberInstitute and a professor of history in the College of Architecture, Arts, and Humanities. Jim Bottum is the chief information officer and vice provost for computing and information technology; he is also a research professor of electrical and computer engineering in the College of Engineering and Science.

In January, Clemson's Board of Trustees approved a new Social Technologies and Analytics Research Institute (STARI), which will include the Social Media Listening Center, along with several other Clemson units and industry partners. STARI will conduct research into the role of social media in organizational performance.

Lauren J. Bryant is a science journalist in Bloomington, Indiana.



the colors of indigo

How red and black and white made blue.

by Neil Caudle

The story we've heard is quite pretty: Eliza Lucas, an adventuresome young woman of sixteen, arrives in the low country from Antigua, takes charge of her father's plantations as he careers abroad, and nurtures the seeds of a mighty industry that transforms the landscape of South Carolina and bathes all of Britain and its colonies in blue.

The plant itself is pretty: a shrub with frond-like branches, seedpods curved like tiny smiles, and delicate, coral-pink flowers.

But indigo did not surrender blue without a fight. Slaves had to plant it, weed it, and coax it through cold spells in spring. When the summer swelter thrummed with insects, slaves would pick pests from the indigo leaves. When the shrub grew tall and bushy and heavy with with sap, the slaves would hack it down and lug it on their backs, heave it into giant vats, pound it to pulp, cover it with water, and weigh it down with stones to make it rot.

Putrefaction was not pretty. Neighbors complained of the stench. The odor of rot was so great it could nauseate slaves as they beat at the mixture with large, wooden paddles, feeding air to the sludge.

And the dye itself, dried and packed and sold in cakes or sock-like canvass bags, was useless until it was ground to a powder and doused with urine. Stirred into water, it slouched into a splotchy, pea-green soup with a yellow-green fluorescent sheen.

But when the dye master dipped into this soup a swath of fabric, and raised it to the air, the sopping cloth began to blush a living blue. Oxygen was the final ingredient, the kiss that brought color to life.

Andrea Feeser has lifted the history of indigo into the air, where the oxygen can reach it. Her new book, *Red, White, and Black Make Blue: Indigo in the Fabric of Colonial South Carolina Life*, tells a new kind of indigo story, in multiple hues.

The art *and* the facts

This is not Feeser's first case of the blues. At the University of Hawaii, she coauthored a book about Waikiki, where, in local memory and art, blue bubbles up from the grays of concrete jungles and flows like water from the past. When she left Hawaii and came to Clemson, in 2002, having never before lived in the South, Feeser found a different landscape, a different culture, and a new sort of blue. Here, where agriculture had long shaped the land and its history, she came across a charming story. It was about a young woman, a mere teenager, who had started the second largest staple for South Carolina in colonial times.

"That's the popular story," Feeser says, "that Eliza Lucas Pinckney was responsible for the indigo boom. She is, in fact, the first woman inducted into the South Carolina Business Hall of Fame, and that was in nineteen eighty-nine—late recognition, but recognition nonetheless. So I began to investigate that history."

Feeser is not, strictly speaking, a historian, but she excavates the historical record to understand the meaning of place. Her experience as an art historian and artist helps her interpret the art as well as the facts of artifacts, and what they meant to the people who made them and used them. In the introduction of her book, she describes confronting a particular artifact that would haunt her as she wrote:

> *While visiting the Museum of London, I was captivated by a garment that prominently featured blue: a gorgeous eighteenth-century silk brocade dress alive with a rhythmic dance of flowering vines. My eyes were drawn in particular to delicate blue blooms scattered amidst the profusion of leaves and petals, and for a moment, I felt transported to a field of azure blossoms.*

Beside her, a schoolgirl broke the spell, muttering, with her nose to the glass of the display case, "A ghost must be wearing that dress." Feeser understood what she meant. There was no mannequin, no model. The dress held an absence, a ghost.

Aubree Ross

Andrea Feeser: filling an absence in the story of indigo.
Facing page: Karen Hall used indigo dye to create a willow pattern.

Eliza Lucas Pinckney's indigo-patterned wrap, photographed by Anderson Wrangle.

An heirloom alive with light

The enchanting, shawl-like wrap caught the team in its spell, stitched them together into the fabric of the indigo story. As soon as Tim Drake unfurled the wrap and draped it on Andrea Feeser's shoulders, she knew that the piece was a treasure. Eliza Lucas Pinckney, the woman most responsible for South Carolina's indigo industry, had wrapped herself in a silken shawl whose needlework rendered the indigo plant—not in blue, but in sublimely subtle white on white. It was the stylized form of the living plant itself, and not its dye, that she chose to wear.

Feeser knew that the wrap, for its value as both history and art, should be preserved as an image, documented for her book and for anyone who could not see it firsthand. She also knew just the photographer for that kind of assignment: her colleague in the Department of Art, Anderson Wrangle.

Very soon, Wrangle was learning not only the garment but the history and science behind it. Karen Hall explained the botany, the chemistry, and the methods for making an indigo dye. He met Kendra Johnson and photographed the skirt she had made.

"It was terrific," Wrangle says. "They drew me into their project, made me a part of the team."

Photographing the wrap proved difficult, at first. It was six feet long and very sheer. "I had never photographed anything like it before," he says. "It was so old and fine, it had a presence. I wanted to create something more than a document. I wanted people to see it and feel it the way I did."

He tried shooting the wrap from several angles, but none of them satisfied him. He constructed a scaffold in his studio, covered it with protective fabric, and draped the wrap to hang vertically. "I had to experiment with the lighting, moving it around," he says. "Finally, I got the light to shine through the fabric like light through glass. All of a sudden, it came alive."

I imagined a disembodied presence that wanted to be felt, reaching out to the land of the living from the realm of the dead and trying desperately to say something to those of us on this side of the grave.

Later, in the midst of her indigo project, Feeser and two colleagues, Karen Hall and Kendra Johnson, were presenting a lecture one evening when a man came forward from the audience and draped a wrap across Feeser's shoulders. The man was Tim Drake, manager of the historic Woodburn Plantation and a descendent of Eliza Lucas Pinckney. Eliza, Fesser says, had designed the garment herself, sometime around 1752. For that moment, Feeser occupied the absence, feeling the drape of old fabric alive with a tracery of indigo plants.

"It is a beautiful, openwork silk wrap," Feeser says, "and she decorated it with indigo plants. It was a moment of disbelief that we had access to this spectacular garment. It was extraordinary."

Beyond the spotlight

We have no idea what Eliza Lucas looked like. We have no paintings or drawings from life, no detailed descriptions. But when the drama of indigo opens, the spotlight shines on her. And deservedly so, Feeser says. Eliza Lucas was a remarkable woman. When her father left her in charge of his holdings and returned to Antigua, she learned not only to thrive in her strange new land but to manage it and build an industry within it, all the while probing the low country's natural history as a botanist would, recording its marvels, conducting experiments, and corresponding with scientists about what she observed. Widowed at age thirty-six from Charles Pinckney, a prominent public official, Eliza Lucas Pinckney continued to manage vast holdings, and, despite her long and lucrative ties with England, became an ardent patriot of the revolution and the new American republic. When she died, in 1793, President George Washington was one of her pallbearers.

This was indeed a lovely story, but Feeser chose to look beyond the spotlight, to learn about Eliza Lucas's supporting cast. Who was the figure behind her, mostly obscured by the dark? His name was Quash, a mullato slave. The record tells us, Feeser says, only a little about him. He may have been a driver, a kind of foreman who managed the slaves and took day-to-day charge of the indigo enterprise, from planting seed to packing finished cakes of dye. He was, by all accounts, an accomplished carpenter. He built the sturdy wooden vats that held the indigo. After Eliza married Charles Pinckney, Quash continued to serve them, on the plantation but also in town. He helped build for them in Charles Towne a grand house worthy of their standing among the elite of their time.

Every successful indigo plantation probably had a Quash or two, and planters took pains to keep such experts on the job, coercing or rewarding them, trying to prevent their defections to rival plantations in Florida, where the Spanish were promising freedom to workers who could help them gain ground against their enemy, Britain. Quash was one of those who stayed. Perhaps for his loyalty as well as his contributions, Quash won his freedom and was christened William Johnson. Eventually, he would buy two of his children out of slavery, oversee his own plantation, and manage his own slaves.

Eliza and Charles Pinckney were leaders among the low-country elite, but they were not the only white planters promoting Carolina indigo. Henry Laurens, a prominent merchant, slave trader, and planter of the time, promoted and defended the crop. Alexander Garden advanced the botanical knowledge about it. And James Crockatt lobbied the British government for laws that would subsidize indigo imports from the colony. We know about these men, and their way of life, because they

Duke University Library

Slaves making dye from indigo. Original image was on a map of St. Stephen Parish in Craven County, South Carolina, by Henry Mouzon, 1773.

composed the record. We have their letters and notebooks, their accounts of transactions, their pamphlets and public arguments. On occasion, such men saw fit to mention, in writing, a slave as essential as Quash. But legions of other slaves, bought and sold and mastered, are mostly absent from the record.

Reading the absence

So Feeser ventured farther into the darkness, piecing together obscure details unearthed from the archives, detecting the presence of slaves who supplied not only the toil but the knowledge of growing and using a difficult crop. To understand their contributions, Feeser examined every scrap of evidence she could find—a dye vat that survives from the period, for instance, and drawings depicting indigo production. The drawings probably had their own sort of bias, she says, having been rendered by whites, but they suggest the heavy toil and technical demands of indigo production. You couldn't just toss the plants into a vat and wait for them to rot. The reeking soup had to be moved

Wikimedia Commons

The Old Plantation, a watercolor painting attributed to John Rose of Beaufort County, South Carolina, in the the late eighteenth century, shows several garments that would have been dyed with indigo blue.

from vat to vat, aerated, and dosed with just the right amount of caustic lye or lime. Any misstep in the process could spoil the dye. "It's rather extraordinary to imagine the physical labor and also the expertise that went into this process," Feeser says.

With her colleagues—Karen Hall, an ethnobotanist, and Kendra Johnson, a costume designer with an expertise in slave clothing—Feeser launched her own experiment with indigo. The plan was to sow and raise a crop of indigo at Woodburn Plantation, just a few miles from the Clemson campus, and then to turn the crop into dye, as Lucas Pinckney and her slaves had done. There is no evidence that planters ever grew indigo commercially as far west as Clemson, Feeser says, but the team decided to give it a try. Tim Drake gave his okay, and the group went to work. Matt Rink, a sculptor and Clemson alumnus, built a small-scale set of wooden vats, which are now on display at the plantation. Johnson researched the dress of slaves during the period and created a skirt like those the women would have worn. And Karen Hall mastered the process of making and using indigo dye. (See "Affection for indigo," page 44.)

But the crop itself failed to thrive, and Hall cites several reasons. "Number one, faculty members don't have a lot of time to be there to help it along," she says. "Number two, that land is pretty used up. It was cottoned to death, and it was red clay we were planting in. So it probably needed a lot more help than I gave it."

Feeser and her colleagues lacked plants to process into dye, but they did glean some insight into Eliza Lucas's early struggles with the crop. In a letter to her father, on June 4, 1741, Lucas described how a frost killed most of her seedlings, the first time she planted the indigo seeds he had sent her from Antigua:

> *I wrote you in [a] former letter we had a fine Crop of Indigo Seed upon the ground, and since informed you the frost took it before it was dry. I picked out the best of it and had it planted but there is not more than a hundred bushes of is come up which proves the more unluckey as you have sent a man to make it. I make no doubt Indigo will prove a very valuable Commodity in time if we could have the seed from the west Indias [in] time enough to plant the latter end of March, that the seed might be dry enough to gather before our frost. I am sorry we lost this season.*

A few plants survived to make seed, and over the next several years Eliza Lucas and her slaves established productive crops, shared seeds with her neighbors, and proved that indigo could thrive in the low country.

The other race of slaves

Some, perhaps most, of the slaves on the Lucas plantations were African. But Feeser found evidence that others were not. Especially in the early years of the indigo boom, Native Americans also worked on plantations as slaves, she says. Feeser found records referring to mustees—a term for people who were part black and part Indian—in the Lucas Pinckney household. "In fact," Feeser says, "one of their slaves was named Indian Peter, and for all I know he may have been all Native American."

On the topic of enslaved Native Americans, and their contribution to the indigo industry, the stories have been rather quiet, Feeser says. "Indian slavery, frankly, is not discussed as much as it should be in South Carolina's history. I suppose that may be because the numbers pale, alongside those of African slaves. And part of what happened is that those Indian slaves who were enslaved earlier in the colony's history often intermarried with African slaves."

As she tracked the scant evidence through a thicket of colonial records, Feeser realized not only that native slaves probably helped produce the indigo but that free Native Americans were trading for indigo garments and cloth. Dyed fabrics and garments came back to the colony in shipments of provisions and trade goods. For natives and Africans alike, clothing dyed with indigo had special significance. "There were things they could communicate about their own power and agency through what they wore," Feeser says, "and that blue was a part of that."

Native Americans favored cloth and ready-made garments from Britain, trading deerskins that found their way into gloves and breeches back in England. "When you look at trade records from the period, you can see that quite a lot of what the Native Americans got was dyed blue," Feeser says.

Craig Mahaffey

Kendra Johnson in the costume-design studio: "I try to imagine it from what I know—especially the labor involved."

Making it real

Kendra Johnson, a costume designer and associate professor in performing arts, researched, designed, and sewed this woolen skirt, dyed with indigo, to illustrate a type of garment worn by eighteenth-century slaves and poor whites. Johnson, whose academic research investigates African-American clothing during the antebellum period, says that clothing signified status, even among different groups of slaves.

"On huge plantations like Drayton Hall or Middleton, slaves had their own class system, and it was very strict," she says. "If you were a weaver, for example, you didn't get together with someone who worked in the field. And those differences in class were reflected in their clothing. But on the smaller plantations in the upstate, slaves usually did several jobs, so you wouldn't see as many differences in the clothing."

This year, Johnson and her students will be researching the clothes worn at historic Fort Hill, now a part of Clemson's campus. To recreate the clothing of slaves, the team will research the work people did and build garments true to the times, simulating wear and tear.

"It's called distressing," Johnson says. "Let's say I'm doing a skirt for a particular slave. I would need to know what her job was, and what kind of movements she would have done, and then I would dye the skirt and distress it, make it dirty where it would have been dirty, at the hem, for instance. Or it may have been faded and worn at the knees, if she had done a lot of squatting or kneeling."

Johnson gets plenty of practice imagining life at Fort Hill.

"When I walk by Fort Hill, I wonder what life was like back then," she says. "I try to imagine it from what I know—especially the labor involved, but also the weather and everything else, even the smells. That's how you make it seem real."

Johnson designed and made the skirt, and dyed the fabric with help from Karen Hall. The photo, by Anderson Wrangle, became the cover art for Andrea Feeser's book.

As the family told it

A descendent of Eliza Lucas Pinckney attends to her legacy.

The Civil War's fiery rampage through South Carolina destroyed many of the documents, paintings, and other artifacts that could have borne witness to the colonial past. Lacking those records, families preserved their histories as best they could, in stories they tended as carefully as they tended the last of their heirlooms.

One of those heirlooms is an indigo-patterned wrap designed by Eliza Lucas Pinckney and woven on her plantation. Today, that wrap belongs to Tim Drake, a direct descendent of Eliza Lucas Pinckney through her son, General Charles Cotesworth Pinckney, a statesman and delegate to the Constitutional Convention. Drake inherited the wrap, along with a handheld fan and several other items, from his grandmother, Azalee Mitchell Drake. Tim Drake says that the trunk's contents had been carefully labeled many years before, probably in the late 1800s or early 1900s, on scraps of yellowed paper pinned to the heirlooms.

"She called them 'vestiges of aristocracy,'" Drake says.

For the past twenty years, Drake has worked as a volunteer director with the Pendleton Historic Foundation, which manages Charles Cotesworth Pinckney's summer house, Woodburn, one of the few remaining treasures from a family fortune built largely on indigo. "I like history," Drake says, "and I think it's important to preserve a record of the past."

In his other job, Drake manages state programs for Clemson's Department of Pesticide Regulation. With the welfare of people and crops on his mind, he depends upon data and documented facts. So he understands the historians' preference for solid documentation. But for the early history of indigo in South Carolina, Drake relies upon a different kind of source: stories from his extended family.

"What I learned from them is anecdotal," he says, "so if you ask me to prove it with some kind of record, I can't."

The ring of truth

But to Drake, the family stories ring true. For one thing, they don't always track with conventional wisdom or the biases of their time; nor do they sugarcoat the past. "Some of the slave-holding Pinckneys," he says firmly, "were not kind to their slaves."

While much of what Drake absorbed from family stories confirms historians' accounts of the indigo era and Eliza Lucas Pinckney's starring role, the stories also fill some gaps. Historians speculate, for instance, that the knowledge of indigo cultivation and dye making came from Africa, with slaves. Drake's family stories do not equivocate on this point. Eliza Lucas, they say, got the idea for growing indigo by watching slaves grow it and make dye for their own use. She gradually built, on a commercial scale, an enterprise she learned from them.

Because official documents typically cited husbands, not wives, as the responsible parties in matters of property and business, some accounts describe Charles Pinckney, Eliza's husband, as a prominent planter and credit him with much of the couple's success with rice and indigo. But Drake's family told a different story, he says. "Charles was a lawyer and spent most of his time in town. Eliza was the one who knew about agriculture. The plantations were hers, and she was the one who ran them. And she was the person most responsible for building the Pinckney family fortune."

Tim Drake at Woodburn: "She was a woman of the future."

Photos by Patrick Wright

Drake spreads the shawl-like wrap that belonged to Eliza Lucas Pinckney. He inherited the treasure from his grandmother.

Even though there is no tangible evidence that planters grew indigo as far west as Pendleton or Clemson, Drake heard about experiments with indigo at Woodburn Plantation from two of his distant relatives and local historians, David Watson and "Punch" Hunter of Pendleton. The lack of a written record, Drake points out, does not mean that indigo never grew in western South Carolina. If experiments with indigo failed, or if people were growing it only for local use, there might not have been any record at all. "I think they were growing it here," he says. "Indigo was a part of their way of life."

As stories of that way of life came down through the generations, there was no figure more inspirational than Eliza Lucas, the daring young entrepreneur who would build a mighty industry in commerce with Britain and then reject British rule to give her allegiance to a revolutionary army marching off to war in uniforms of indigo blue.

"She was a woman of the future," Drake says. "She had a lot of agricultural knowledge, which was highly unusual for that time. And she was one of the people who became nation builders. I admire her."

Tim Drake is state programs manager in the Department of Pesticide Regulation, part of Public Service Activities at Clemson. He is also secretary of the board of directors of the Pendleton Historic Foundation, which manages two historic houses, Ashtabula and Woodburn.

Blue Stroud, a type of cloth made in the Stroud area of Gloucestershire, was one of the natives' favored materials for match coats, a kind of mantle or a wrap worn around the shoulders, and in a belted garment similar to a loincloth.

"I don't mean to suggest that they were taking on purely European modes of dress," Feeser says. "They were enhancing and making their own textiles and garments, which is true of what slaves were doing too, as much as possible."

The power of pigment

Today, we take pigment for granted. Modern chemistry and commerce supply, at low cost, any color we desire. But in the colonial period, pigment came dear. It was difficult to find and extract, and difficult to use. The most cherished red, cochineal, required that people collect by hand teeny-tiny bugs from cactus plants. Like gemstones or precious metals, well-colored fabrics asserted one's standing in the social order. Sports fans, decked out in the colors of their teams, have something in common with eighteenth-century consumers. The passion for color was serious business, Feeser says, and blue was the most popular color of all.

As indigo planters shipped more cakes and canvas bags of dye from the colony, and British manufacturers stepped up production of textiles, the once-scarce blue, an emblem of nobility in the imported silks and fine woolens of the upper crust, began to spill downward through the classes, Feeser says, into the common cloth of working-class families and then into the coarser goods of servants, too. Indignant "blue bloods" from the gentry complained that ordinary folk were dressing above their station, threatening the social order.

In the colony, the social status signified by clothing was a matter of law. The 1740 Slave Code specified how much a master could spend to clothe a slave and what types of fabric a slave could wear.

But by midcentury, blue was out of the bag, and, on both sides of the Atlantic, indigo wove its way into the culture. The records of John Dart, a merchant and the commissary general for South Carolina, show that his office distributed indigo seed to settlers headed for the frontier and supplied British-made fabric and clothing to people in every walk of life, including poor and wealthy whites, sovereign Native Americans, and slaves. Many of those goods, Feeser says, had been dyed in England with indigo produced in South Carolina. The colony's indigo traveled a circuit, making fortunes at both ends of the loop.

A smear campaign

Not every British merchant was happy with the boom. Carolina indigo faced a smear campaign by opponents with a vested interest in dyes imported from French and Spanish colonies in the Caribbean and Central America. These more southerly climes, the critics argued, offered the optimum growing conditions and hard-won expertise that South Carolina lacked. Carolina indigo, they claimed, would always be inferior.

The public relations war over indigo reminds Feeser of a similar clash over wine two centuries later: During the 1960s and '70s, the European wine establishment and its U.S. importers used an almost identical campaign to discredit their new competition from upstart American vintners.

Feeser acknowledges that not all Carolina indigo came from

Karen Hall

Fabric test strips show how repeated dunking in indigo dye intensifies the color.

scrupulous planters with high standards, but some of it did, and she suspects that the good stuff was probably equivalent to the best from Britain's rivals. British manufacturers may even have padded their profits by substituting Carolina dye for the more expensive French or Spanish versions, assuming that no one would know the difference.

"I'm convinced that South Carolina indigo was in every type of textile that was made at the time," Feeser says. "It's actually really hard to figure out whether something was dyed with Spanish, French, or what they called Carolina indigo."

Whatever the merits of the smear campaign, colonial Britain generally bought the notion that Carolina indigo was second-rate, a poor man's substitute for the real thing. "So the bulk of it wound up in cloth that made its way to the lower echelons of society," Feeser says.

Beyond the reach of rice

As indigo transformed the clothing of British common folk, Native Americans, and African slaves, it also began to transform the landscape of colonial South Carolina. From the beginning of the colony, rice had been king, the staple that built fortunes in Charles Towne and other British settlements. But rice needed low, soggy ground and rarely thrived outside the coastal zone. The first experiments with indigo, by planters including Eliza Lucas, took root in low-country rice plantations, on patches of high ground unsuitable for rice. Indigo, the planters hoped, would help them exploit off-season labor as well as unused land.

From the planter's point of view, this makes good practical sense: Keep the workforce busy when it's not working rice. But Karen Hall, Feeser's collaborator who studies people's relationship with plants, has a different take. "The slaves were already having to grow their own food," she says, "so adding indigo was probably adding insult to injury for them."

For planters and merchants, though, indigo was a money-maker. The crop soon outstripped its low-country knolls and rises, and planters moved inland, clearing and sowing new fields. From the late 1740s until the Revolutionary War, the colony surged westward on an indigo tide.

"That meant the land itself was transformed in order to accommodate plantations and farmsteads," Feeser says. "But it also meant that the Native Americans increasingly were pushed out of areas that had been their homeland, and more slave labor was brought into the colonies. So indigo was part, and I would say a big part, of the ultimate transformation of South Carolina from a place known for what was possible in the low country to a place known for what was possible in the midlands and upstate areas too."

A Cherokee visit to London

This 1762 engraving from a British periodical depicts the visit of three young Cherokee men from South Carolina. The clothing of high-status Native Americans was rich in texture and color, and often featured indigo blue. Dye produced in the colony by African and native slaves traveled to England, where it was used to color textiles. Exporters shipped cloth and finished garments back to colonies, where Native Americans acquired them in trade for deerskins and other goods.

Peter Newark American Pictures

The great dispossession

Feeser documents a long series of trades, concessions, alliances, skirmishes, and wars in which the colonists outmaneuvered or overpowered the natives, forcing them out of their hunting grounds and farms. At first, commerce and cunning were the primary instruments of land acquisition. British officials, keen to avoid a bloody conflict with the natives, frowned on the outright theft of native land. So colonists acquired Native American tracts in trade for manufactured goods, especially textiles, or by agreeing to protect a tribe from its enemies.

But as the number of colonists increased and appetites for indigo profits grew voracious, whites began taking land by force, carving out farmsteads and large plantations, working the land with African slaves. As dispossessed natives left their homelands, heading toward some reservation or distant frontier, many of them probably wore garments dyed indigo blue. And the slaves and white farmers who replaced them? They wore indigo, too.

The indigo boom continued to expand across the state until the Revolutionary War, which brought a halt to indigo exports to England. During and after the war, India came to dominate the world's indigo production, and South Carolina's indigo era was over. By that time, Feeser says, indigo had already left an indelible mark on the land and its people.

Today, slavery is long gone. The indigo industry is long gone. But their absence remains almost palpable, like that ghostlike absence in the dress Feeser saw in the Museum of London.

"Indigo became our state color a few years ago," she says. "I wanted people to know about all of the colors that contributed to that blue, metaphorically speaking. When we look at blue in South Carolina today, I am hoping we can see the red and the black alongside the white. These are the colors that made the blue."

Andrea Feeser is an associate professor of art and architectural history in the College of Architecture, Art, and Humanities. At the time of this writing, Karen Hall was the director of the South Carolina Master Naturalist Program and the state coordinator of the South Carolina Master Gardener Program, and a faculty member in the Department of Forestry and Natural Resources, College of Agriculture, Forestry, and Life Sciences. Kendra Johnson is an associate professor of theater, specializing in costume design and costume technology, Department of Performing Arts, College of Architecture, Art, and Humanities.

Andrea Feeser, Karen Hall, and Kendra Johnson received grants from the South Carolina Humanities Council and from Clemson University to investigate indigo history and culture.

Feeser's book, Red, White, and Black Make Blue: Indigo in the Fabric of Colonial South Carolina Life, *is scheduled for release in November from the University of Georgia Press.*

"Indigo became our state color a few years ago," Feeser says. "I wanted people to know about all of the colors that contributed to that blue."

Affection for indigo

Karen Hall may have overdone the blue.

"My mother tried to put me in blue all the time, so of course I hated blue as a child, but I love it now. I can't get enough of it. I take a look at my wardrobe and say, 'Okay, what else besides blue do you *have?*'"

Some of that wardrobe she colored herself, with indigo dye. She has grown the plant in her backyard garden and extracted the dye, using a method that is hundreds, if not thousands, of years old. But Hall, who has a Ph.D. in plant physiology, has been learning both the art and the science of indigo dye.

Indigo plants—there are more than twenty species used for making dye, Hall says—do not have a stream of blue pigment running like blood through their veins. So squeezing an indigo plant will not yield a single drop of blue. But in their leaves, indigo plants conceal a molecule called indican that bonds, as the plant breaks down through fermentation, with another molecule released from the same plant. The bond yields a substance called leuco indigo, or white indigo. Leuco is not yet blue, but it's a step in the right direction.

Hall can see the stuff, which is a pale, patchy, eerie green in the fermentation water, after she's rotted the plants for a day or two. She draws the mixture off into another pot and adjusts the pH upward to enable what chemists call reduction, a change in the molecule's number of electrons. Without this reduction and its flip side, oxidation, leuco indigo will not yield a dye. So Hall adds lime and beats the fermenting liquid sludge with a paddle to feed it air. As she paddles, indigo settles to the bottom of the pot as a muddy sediment. She leaves the settled indigo, draws off the liquid, and beats at the mixture again.

"You can tell by the color of the water that you've got leuco in it," she says. "So as long as you're getting that color, you keep repeating the steps. The last time I made indigo dye, I did that six times, at least, beating for fifteen minutes at a time, until I got tired and gave up."

Colonial planters and their slaves weren't making a few cakes of dye from a small patch of indigo plants; they were harvesting whole fields of the stuff and processing batch after batch, day after day, in giant vats, in the hottest months of summer. "So you can imagine with a vat that's as big as this room is, it was probably an all-day process to add oxygen and get that indigo to fall out of solution," Hall says.

Predictably unpredictable blues

After Hall dries the indigo sediment into a hard, chalky cake, she grinds it to powder and adds water and a chemical called thiox—not urine, which was the solvent of choice in colonial times—to make the dye. In her dye vats at home, she colors various fabrics and garments, experimenting with patterns and tints. Some plants yield blues with a blush of red; others trend toward purple. The darkest shades require dunking and airing the cloth multiple times. And with indigo, as with other natural dyes, the results are unpredictable. The plant's genetic variations, climate and soil, and many other variables influence the ultimate color.

"I can use the same formula every time I make a vat, but its properties vary," Hall says, laughing. "But the chemists who have synthesized it to dye our blue jeans today, they've got it worked out."

Producing and using natural indigo is messy, smelly, and tiring, Hall says; it is also addictive. She blames her mother for getting her hooked. "My mom is a dyer and weaver, and for many years she did some natural dyes and also a lot of chemical dyes. I was teaching a class called Ethnobotany for Teachers, through a program where I used to work, so I asked my mom to please come to teach my students about indigo. So that's how I learned, from watching her teach the teachers."

Hall the dyer's daughter had learned the how-to, but Hall the scientist wanted to know a lot more. "I was trying to figure out chemically what was really going on in front of our eyes," she says.

Even though indigo is one of the world's oldest and most popular dyes, there was not much information available about its chemistry, Hall says. She had to dig through lab reports, texts, and journal articles to figure out the chemical sequence behind the dye. In the process, she gained an appreciation for just how technically challenging producing indigo would have been in the colonial period. The necessary expertise was considerable, Hall says, and may well have come from Africa, along with the slaves.

"To me, this is an excellent demonstration that an enslaved person does not mean a dumb person," Hall says. "From an intellectual perspective, this is a complicated dye. It takes expert knowledge in order to understand how to grow it, how to make it, and how to use it. And that's a story that should be celebrated, despite the fact that the history is tied to something so awful."

At the time of this writing, Karen Hall was the director of the South Carolina Master Naturalist Program and state coordinator of the South Carolina Master Gardener Program, and a faculty member in the Department of Forestry and Natural Resources, College of Agriculture, Forestry, and Life Sciences. Currently, she is an applied ecologist with the Botanical Research Institute of Texas. For more about Hall's experiments with indigo and dyeing, see her website, www.chaoticgardening.com.

About the dye

(from Karen Hall's course material for teachers)

Indigo must be chemically reduced before it can be used in dyeing. As ground indigo is added to an alkaline vat with a reducing compound (thiourea dioxide, hydrosulfite, diothionite, or others), it quickly transforms into leuco indigo—or white indigo—a soluble salt. In a dye vat, the liquid is amber green or yellowish green. After the cloth is immersed in the dye bath and then raised into the air, the indigo white salt compound exchanges its bond with the salt for a bond with the fiber as it oxidizes into the familiar blue indigo. In this form, the dye is relatively permanent but lightly bound with the fiber in the cloth. Indigo doesn't penetrate cellulose fibers very deeply. It mostly attaches to the frayed edges of microfibrils, cellulose strands wound into a cable-like structure. Blue jeans fade not only because they have lost some indigo but because friction has exposed the inner, whiter parts of the cellulose microfibril. Animal, plant, and some synthetic fibers can be dyed with indigo, but the cloth must first go through a chemical scouring to fray the fiber slightly so that indigo can penetrate; the chemical scouring also removes any of the chemical treatments used on modern fabrics.

The caustic chemicals used to reduce indigo dye are hazardous, and in factories during the eighteenth and nineteenth centuries, accidents injured or killed many workers.

Photos and background cloth by Karen Hall

Indigo dye the old way

By learning the science and the history, Karen Hall recreated the dye-making process of colonial times and taught it to her students.

In Hall's backyard, a batch of indigo begins to rot.

Matt Rink built a small-scale set of wooden vats at Woodburn.

Wikimedia Commons

Above left: indigo grains begin to form in the liquid. **Above right:** Karen Hall, Andrea Feeser, and Kendra Johnson planted this indigo at Woodburn, but the crop failed to thrive. **Left:** indigo dye cakes. **Right:** Karen Hall wearing two of the garments she dyed, part of a wardrobe dominated by blue.

El Purgatorio

In the desolate terrain of coastal Peru, archeologists unearth clues to a culture of artisans and urban prosperity.

by Jemma Everyhope-Roser photos by Melissa Vogel

Left below: Student researcher Fatima Vidal maps Sector C at the El Purgatorio site in Peru.
Left above: Fragment of a blackware face-neck jar.
Above: Platform 2 and its associated plaza in Compound A1, with niched wall, stairway, and pilasters.

El Purgatorio.

It's a name that sounds too poetic to be true. But it's the name of the largest city in a civilization that lasted for over six centuries, a civilization whose very name has been lost to time. Melissa Vogel, an archaeologist at Clemson University, is set on digging up the truth.

"Our understanding of this civilization, our investigation, is really in its infancy," she says. So little is known about the people who lived in this city that almost any discovery she makes is a contribution to her field. She explains, "It was already a known site, but the only work done on it previously was by a grad student in the fifties. It hasn't really been investigated at all, which I found shocking, and after seven seasons of patient mapping and excavations, we've learned so much more."

Today, archaeologists call the people who lived in El Purgatorio the Casma, named after the Casma valley where the civilization flourished. The Casma came into prominence around 700 AD, when their powerful neighbors, the Moche, collapsed in part because of a series of environmental catastrophes brought on by El Niño events.

"If I can speculate a little," Vogel says, "it looks like that, while the area was dominated by the Moche, the Casma valley was very sparsely populated. Probably, there were people living there at that point who'd managed to keep the Moche out, people who had a fierce, local culture and they just took advantage when the Moche fell apart to reassert their independence and take control over their lives. That's what I see happening."

A city of elites

According to Vogel's radiocarbon dating, the entire city was inhabited contemporaneously, which means it's exactly as big as it looks. It's hard to estimate the population estimate without knowing more about family structure, but one of Vogel's grad students worked up a conservative estimate, at 40,000. That number would make El Purgatorio the largest city in the Casma region but not necessarily the capital, Vogel says.

"The way I've looked at it so far is that it was probably a confederacy of elite leaders from various valleys that all held some kind of allegiance and shared culture. Perhaps they would have unified against external threats, but El Purgatorio's elite weren't the kings and queens of the Casma." Unlike other cultures, such as the Chimú, the Casma don't appear to have been centrally organized with all roads leading like spokes into a single hub. Vogel says that's why she currently calls the Casma a "polity" rather than a state or empire.

Source: Melissa Vogel

The El Purgatoroio site is in the Casma district, known as a polity. The Middle Horizon was a period of Peruvian history, 600 AD to 1000 AD.

When carefully sifting through the rough sands at the archeological site, Vogel discovered that El Purgatorio seemed primarily a city of artisans, religious personnel, and administrators. Beautifully preserved adobe friezes are still adorned with yellow, orange, red, blue, black, and white paint. A ceramic workshop hints at pottery mass production. Rows of grinding stones for maize imply central food processing, and ceramic vessels, used to store maize beer, show the presence of brewing. Spindle-whorls and other weaving implements indicate that textiles were produced here.

"A lot of what was lost and what we'd love to know about involves cloth," she says. "In the pre-Columbian Andes, textiles were like currency,."

Quipus were a series of knotted strings, with different knot types, spacing between knots, and different colors of yarn. The Casma may have used quipus as the Chimú and the Inca did, as a kind of accounting device, but none have been found.

Vogel discovered a very few pieces with ornamental yarn, but as she says, "When folks abandon a city, they don't leave their blankets or clothes behind."

The cloth that was left behind seems to have been mostly cotton, which Vogel found surprising, because she had expected stronger evidence for llamas. She had thought, going into the research, that there would be more evidence of trade with the highlands, and alpaca or llama wool would have provided a very material link. "So far it doesn't appear to be as much of a trading center with the highlands as I expected," she says, "although they did seem to be taking advantage of opening trade routes." So far, she has some evidence of trade ranging up and down the coast of Peru and into Ecuador.

Intact burials, unbroken artifacts

Usually, when textiles are found at a site, it's in a burial, but the Casma buried their dead in plain shrouds. Vogel found thirty-three intact burials and twenty more that were incomplete, as looters had dug through them and scattered the bones.

Even without gloriously embroidered shrouds, the burial sites still have a lot to offer—it's not only the bones that whisper old stories, but the ceramic vessels buried with them, unshattered. Vogel says the imagery on some vessels hints at complimentary male and female agricultural deities and goes on to describe a maize goddess with delicate feline features. Other jars, called "face neck jars" because they have faces on—you guessed it—the jar's neck, seem to depict individuals or occupations. But, Vogel says, they're probably not portraits of the deceased. Some jars drew on natural imagery: felines, octopuses, fish, lizards, turtles, and butterflies.

"What we're working on right now is trying to source our ceramics," Vogel says, "testing the compositions of the clays to see if they were imported from elsewhere."

Other goods, such as the copper beads and tools found on the site, cannot be sourced at all, because unlike silver, copper displays a surprising amount of variation even within a single mine. But overall, the city looks to have been a place of urban prosperity.

Above: Melissa Vogel cleans a burial in Compound A3. After careful excavation, the project osteologist, Susan Mowery, will analyze the bones, gently pack them, and place them in the Sechin Museum, the location designated by Peru's National Institute of Culture.

Below: A stone-lined pit tomb in Sector C, Cemetery 2B.

Ian Curcio

Melissa Vogel: "I want you to know that these people existed."

Treasures intact

Well-preserved artifacts unearthed at El Purgatorio include Casma-style jars, a flute made of bone, copper beads and pendant with string still attached, and a large fragment of basketry.

Since the burials show a relatively healthy population, Vogel believes that poorer people may have lived closer to their workplaces, either on the coast on the farms. As there is virtually no rainfall, farmers would have had to rely on the intricate system of canals for irrigation. Seashells discarded in kitchen middens indicate that seafood would have been packed up seven miles from the nearest coastal fishing villages.

The differences in architecture, the lack of malnutrition found in bones on site, and the manner in which farmers and fishermen seemed to have supported skilled artisans producing specialized goods, seems to point toward a stratified class system. Vogel explains that this would not be unprecedented: "Coastal peoples, such as the Chimú, have a mythology as to the origin of the elite and commoner classes, that they were actually born of different stars, that there were celestial origins for class divisions, and that's pretty immutable."

The Casma's complex culture all but ended when the Chimú, a centrally organized and imperialistic culture, conquered them around 1350 AD. Vogel believes that the Chimú allowed for a "negotiated surrender," as she found evidence during her graduate work at a more northerly site that the Casma were permitted to ritually "close" their places of worship before leaving; they also did this at El Purgatorio. She assumes that the urban people probably, in her words, "high-tailed it to the hills," while the farmers and fishermen continued life relatively uninterrupted. She says, "Usually with farmers and fisherfolk, the only thing that changes for them is who they're paying taxes to."

The Chimú set up their own regional center along what is now the Pan-American Highway and was at that time a main trade route, and by the 1400s, El Purgatorio had been all but abandoned. Shortly after that, relatively speaking, the Chimú were conquered by the Inca and the Inca by the Spanish, and the rest is, as they say, history.

Rejecting human sacrifice

Vogel is trying to figure out, exactly, what role the little-known Casma played in history's greater scheme. One of the reasons El Purgatorio has not been thoroughly investigated is that archaeologists have thought of the period when the Casma gain prominence as a period of change and instability in pre-Columbian history. So far there have been no royal tombs, glowing with treasures and gold, no intricately shriveled mummies, no exceptionally artful pottery, no extreme centralization. Vogel hopes that, since the tombs of the elite do not seem to be obvious, she'll manage to get there before the looters do. She wonders aloud, "Where *did* they bury their rulers?"

But dreams of royal treasures and tombs aside, Vogel suggests that the Casma left behind a far more subtle and far-reaching legacy: "There's a clear change in public architecture." This could indicate an apparent rejection of human sacrifice.

To put this in context, we have to return to their warlike predecessors. The Moche had a culture of conquest and ritualized warfare; their warrior-heroes would capture the warriors of other nations and sacrifice them upon truncated pyramid altars in a ritual that was both gory and public. The religion surrounding selective human sacrifice would have inspired fear and obedience, and it would have also been entertainment for the masses. Vogel

A pedestal bowl in black, white, and red.

likens this to Roman gladiatorial spectacles in the coliseum.

In contrast, the Casma's religious mounds were significantly smaller and within enclosed compounds. Right now, there's no evidence that the Casma practiced human sacrifice in these compounds, although there may be some evidence for dedicatory burials. Individuals may have been buried in the foundations before certain public buildings were constructed, but it is unknown whether this was done to bless the building or whether it was done by families wanting their dead closer. As a people, the Casma seem to have focused on ritual feasting and intoxication, with large segments of the urban population making huge quantities of the fermented corn beer, chicha.

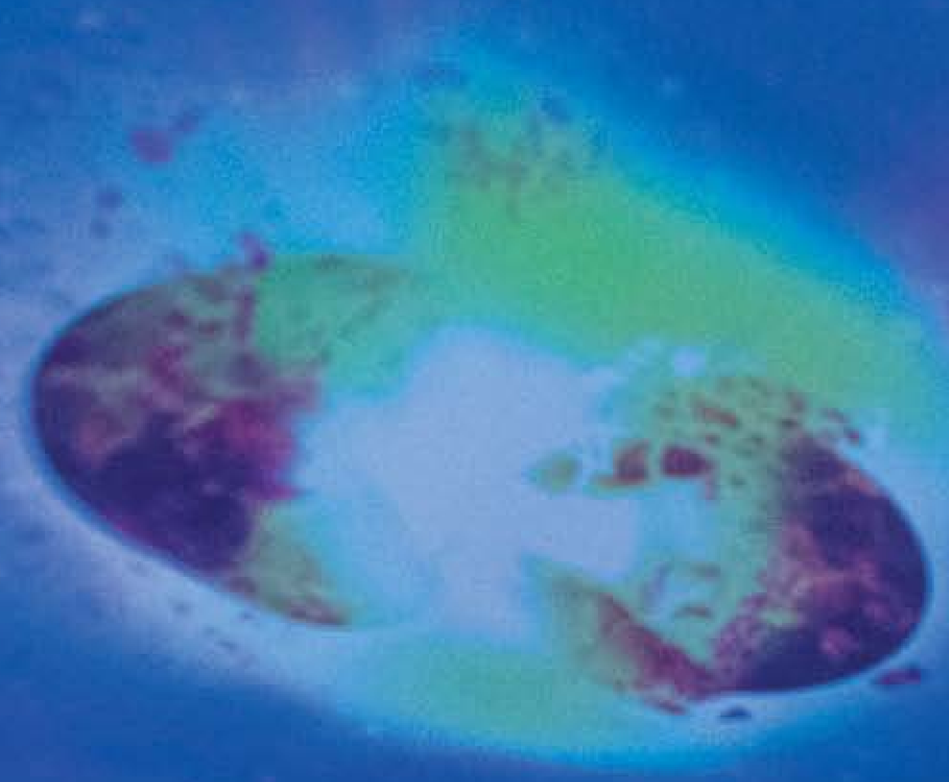
The Casma built high walls around their religious compounds. The walls, preserved in the arid coast desert of Peru, were clearly not used for defense but would have kept people from easily seeing or hearing what was going on inside. The restricted access to rituals, and the control of access to religion by the elite, is the Casma's legacy. The Chimú, who eventually went to conquer the Casma around 1350 AD, built even grander versions of these compounds.

"The phrase I'm dancing around using to describe this," Vogel says cautiously, "but has been proposed in the past, is 'the secularization of state.'"

The Moche were more theocratic and the Chimú more bureaucratic. Learning about the Casma may help Vogel understand that transition and the Casma's place in history.

Vogel says that, most of all, she wants people to understand that they were a major culture at this time. Its true name may be forgotten, but we can still learn about who these people were and how they lived. Or, as Vogel says simply, "I want you to know that these people existed."

Melissa Vogel is an associate professor in the Department of Sociology and Anthropology in the College of Business and Behavioral Science. Her work is funded by the National Science Foundation, the Brennan Foundation, and Clemson University. Jemma Everyhope-Roser is the assistant editor at Glimpse.



the biggest, baddest BOOM

by Jemma Everyhope-Roser

Dieter Hartmann has always been keen on explosions.

Now he can study the most thrilling of them all.

Background: a graphic representation of what happens when two neutron stars spiral into each other and collide. The result is a brief but intensely explosive gamma-ray burst.

Photo by Craig Mahaffey.
Background graphic by NASA /Dana Berry.

"It's raining like crazy outside. It's a perfect time for telling stories." Dieter Hartmann scheduled our phone interview for Independence Day. His son has come up from Greenville for a barbecue, and I get the feeling that Hartmann's family is waiting for him in the other room to finish our call.

But Hartmann can't resist the chance to tell his favorite story.

"When you look back, a long, long time ago, at what galaxies were like, versus what they're like today, with their metals and their gasses, *that* is the question of cosmological evolution, and that is what I'm interested in," he explains. "But I've always liked explosions, my entire life."

If you Google "Dieter Hartmann, astrophysicist" one of the top five hits will be titled "An Expert in Explosives," and in it, Dieter Hartmann describes his passion for explosions, starting as a boy in Germany watching the Apollo rockets boom upwards and vault into space. After playing soccer professionally and spending a year in the military, he completed a master's degree in physics and won the Fulbright that would bring him to the University of California at Santa Cruz. It was there he'd discover his love for the best and the brightest explosions of all.

When I ask him about the biographical information on the site, Hartmann laughs and explains, "NASA—it's actually done via the University of Chicago—wanted to have a few scientists reach out and say high-energy physicists are people too and this was why they became scientists. It was rather fun sharing it."

I can tell from the tone in his voice that Hartmann wants to get back to telling the story that's most important to him—not his personal history, but that of the universe itself.

Gamma-ray bursts: the brightest and fastest

At Santa Cruz, where Hartmann was working on his Ph.D., he was intensely interested in supernovas. As explosions go, it was hard to beat them for size, but Hartmann was looking for even bigger, badder booms. He'd already switched his focus to a relatively unexplored and newly discovered phenomenon, gamma-ray bursts.

At that time, no one really knew what they were.

Because of Hartmann's interest in nuclear astrophysics and gamma-ray astronomy, Clemson University's Don Clayton, who was leading and defining the university's astrophysics program, invited Hartmann to join the faculty. It was only after Hartmann came to Clemson when a final breakthrough occurred in satellite technologies and the gamma-ray bursts could be pinpointed precisely enough to be studied.

"We'd thought we were looking at energetic events that were relatively nearby," he says. "But there was a real paradigm shift in this field. We went from thinking we had galactic events to cosmological events. Now, that was a different story altogether."

When astrophysicists thought gamma-ray bursts were happening in our galaxy, they were impressive enough. But when they learned that the gamma-ray bursts were actually happening much farther away, across the vast distances of the universe, it meant that the power involved was huge. If you saw a flashlight shining from nearby hilltop, its power would be impressive. But if a flashlight beam could reach you from the moon, that would be shocking.

"If you converted our entire sun into energy, using Einstein's e equals m times c squared, and annihilated the sun totally," Hartmann says, "that would the amount of energy we were talking about."

Gamma-ray bursts are explosions involving the brightest lights and the fastest speeds in the universe, and they're related to supernovas and the collapse and formation of black holes. Although they happen about a hundred times per day, we're only able to detect one per day, because they're not spherical explosions but more like sharp jets (more like a flashlight than a lamp) that have to shine in our general direction for us to see them.

"I have always studied the extreme aspects of the universe," he says. "When you look out at stars, they're pretty extreme, but they're not the hottest things, they're not the biggest things, they're not the fastest things. Gamma-ray bursts are extreme, right at the very limit."

With this new information brought to light, theoretical physicists had to revise their models and the way we conceived of the universe. It's one of the reasons Dieter Hartmann looks forward to going to work every day: He can test theories by watching explosions in the sky.

Craig Mahaffey

Finding a black hole in Andromeda

Amanpreet Kaur, now a doctoral student of Dieter Hartmann, was the lead author of a paper that announced the discovery of a stellar mass black hole in Andromeda, a spiral galaxy about 2.6 million light-years from Earth. Kaur and Hartmann joined an international team of astronomers, including scientists at Germany's Max Planck Institute for Extraterrestrial Physics, to publish their findings in February 2012.

When a satellite observatory detected an unusual X-ray transient light source in Andromeda, "The brightness suggested that these X-rays belonged to the class of ultraluminous X-ray sources, or ULXs," Kaur says. "But ULXs are rare. There are none at all in the Milky Way where Earth is located, and this is the first to be confirmed in Andromeda. Proving it required detailed observations."

The paper announcing the black hole was originally part of Kaur's master's thesis.

But these explosions can do more than tell us about how the universe works—they can tell us about its history. Unlike historians and archeologists, who must piece together the past with what remains in the present, Hartmann can see the past directly: "When light travels from a distant object, I'm seeing the light from long ago. I'm really seeing it how it was many billions of years ago."

A gamma-ray burst can also tell an astrophysicist about the chemical contents of the universe—Hartmann refers to this as "abundances" and "metallicity." As the light from the burst travels through space, it passes through gas whose material absorbs a little of the gamma ray. When it passes through an object containing iron, the iron will absorb the some of this light at a particular frequency; when it passes through an object containing nitrogen, it will absorb at a different frequency altogether. By reading the gaps in the gamma rays that arrive here, Hartmann can determine the chemical compositions of the intervening objects.

Hartmann likened this to taking X-rays but told me that this wasn't exactly right, as X-rays are visual representations with different opacities representing the difference between flesh and bone. Hartmann prefers to call absorption lines "fingerprints."

"By looking at the absorption of the matter between us and the burst," Hartmann says, "we can determine metallicity, abundances, and chemistry, and we can determine look-back time." He goes on to explain that the longer the light has to travel, the redder its frequency becomes, so astrophysicists measure distances in how "redshifted" the light is or how long ago the emission took place. He adds, "In cosmological terms, we're talking gigayears."

Explosions that led to life

In order to understand why metallicity is so important in terms of the universe, you need to know a little about the biggest explosion of all time—the Big Bang. After the Big Bang, the universe had only hydrogen and helium. The other elements, the vast bulk of what we see in the periodic table, was formed later in stars. The building blocks of human life—oxygen, nitrogen, and carbon—were built from the bodies of stars after the initial boom.

"I really like to study how the explosive violence of stars is responsible for creation of new elements," Hartmann says, "which then get incorporated in the next generation of stars, which then leads to a cycle of chemical enrichment."

This slow and sure enrichment process happened gently and can be traced by using gamma-ray bursts.

"So, when I see a burst that has happened in the history of the universe, by looking at these absorption lines, I can determine what the metallicity was, say, five gigayears after the Big Bang, coming from a particular direction with intervening sources," Hartmann says. "So, slowly, we're assembling what the metals are doing as a function of time in the universe as the universe evolved."

But the universe isn't simply handing these snapshots over to Hartmann and his fellow astrophysicists. Unlike some of the other subjects astronomers and cosmologists study, gamma-ray bursts aren't steady sources of light. You can't just write up a proposal saying, 'I need to use this telescope for ten hours and in that time I will determine *x*.' No, gamma-ray bursts are called "bursts" because they're short and fast.

Sometimes you only have seconds to pinpoint the source—and that can only be done from space, because gamma-ray bursts are absorbed by the Earth's atmosphere. Satellites, robotically detecting and locating the source of a gamma-ray burst, beam the information down to telescopes on Earth.

Worldwide, astronomers interrupt their own work and direct their telescopes toward the gamma-ray burst. Obviously, they can't record the gamma-ray burst itself (remember, it can't penetrate our planet's atmosphere). So they're looking for the "afterglow," which is made of lower frequency emissions, including visible optical emissions. The land-based telescopes spend twenty minutes taking spectrums of that. After taking a spectrum, the astronomer uploads it before getting back to work.

"It truly is a global effort," Hartmann says. "It means we're *all* participating in collaborations, in an international network of observers. The community applies resources in a sequence that depends on how fast you need to respond, and a gamma-ray burst is astronomy that takes place on a minutes-to-hours timescale. It really moves you to the fast lane."

Hartmann directs me to NASA's ADS, an online service through which the community of astronomers and now physicists share their articles and data.

Right now, Hartmann has been working with NASA on a thirty-year plan, a visionary roadmap as to where NASA should be going in the future. He says it's "a political process," in a somewhat weary tone that implies he'd rather look at the afterglows from vast cosmic explosions. He serves as the chair on the Swift satellite's user community—the Swift satellite is the only one dedicated purely to studying gamma-ray bursts—and overall he's involved in the data analysis of three out of a dozen satellites that detect gamma-ray bursts.

NASA's satellites and their robotic detection systems are a key factor in this research, because the reaction time must be so brief. As Hartmann puts it, "You can wake up the next day, and you've missed the boat. With a gamma-ray burst, you have only a few minutes, maybe hours if you're lucky, to do your work. So this is transient astronomy, rapid response, quick."

It's strange, to me at least, that such immediacy is necessary when it comes to telling a story that's been so long in the making. Hartmann's story, when he tells it, starts with a bang, and then continues in a series of explosions that produce more stars, which in turn produce galaxies, which collide to form larger galaxies, and the universe itself is structured by clusters of dark matter, whose nature, Hartmann says, "we don't really understand."

"The process of assembling galaxies and gas evolution in galaxies is one of those cosmic evolution stories." It's the longest and most important story of all time that Hartmann's trying to piece to together, explosion by explosion. It's far from being understood—and luckily, for us—it's far from done.

At the end of our conversation, when Hartmann is called away to celebrate Independence Day with his family, I hope for his and his family's sake that the rain was transient. And here is what I picture: Dieter Hartmann, the man who so enjoys cosmic explosions and the stories they tell, looking up at the night sky to watch the fireworks.

Dieter H. Hartmann is a professor in the Department of Physics and Astronomy. Funding for his research is provided by grants from NASA and the American Astronomical Society. Jemma Everyhope-Roser is the assistant editor of Glimpse.

Photo by David Iliff, license CC-BY-SA 3.0

a gnawing problem

by Peter Kent

Birth control for squirrels? First, a good laugh—and now back to science.

Wildlife biologist Greg Yarrow was working in his yard when he realized he had forgotten something. It was Saturday, April 5, 2008, his daughter's second birthday, but there was something else, something important like a doctor's appointment. There *was* an appointment, and he was the doctor, a professor, about to miss his interview on National Public Radio.

Disheveled and grungy, Yarrow dashed to the Brooks Center theater on campus. "I got there and the place was full," he says. "President Barker and his wife were there, so were the provost and lots of other people I knew. I was sick at what I saw."

Thinking it was going to be a recorded interview, Yarrow had not imagined he was to be on a live radio show. Michael Feldman's *Whad'Ya Know?* is heard on hundreds of stations by more than a million listeners.

Backstage, the producer asked Yarrow if he knew who Feldman was. "I said I never had heard of him," Yarrow says. The producer explained that Feldman did ad-lib interviews, having fun with his guests.

"I heard my name," Yarrow says, "the guy gave me a little push, and I was on stage, and Michael was setting me up. I was the scientist giving birth control to squirrels. I was screwed."

Retelling has polished the story. Yarrow repeated it last March to a group of wildlife biologists attending a conference at Clemson.

"Michael, it's a very delicate process," Yarrow confided like a surgeon instructing an intern. "You need soft hands and a gentle touch. We trap the squirrels, take the males, and turn them belly up. Then we very carefully put on tiny condoms."

The story always gets a laugh. Yarrow pauses, smiling, waiting to deliver the kicker. "Then I said, 'Michael, that's not what we really do. Let me tell you the real story about our research,'" Yarrow says. Then he begins to explain the eight-year project to find out if birth control can manage the university's squirrel population.

Loveable and useless

Clemson has a gnawing problem. Squirrels chew the bark on tree limbs, weakening the tree, killing the limbs. Falling branches create a hazard to people and property, and could cause as much as $1.3 million in maintenance and replacement costs, say campus landscapers. About a hundred trees are damaged and another hundred are vulnerable.

It's hard to imagine squirrels as formidable adversaries. For most of us, squirrels fall in the "lovable and useless" category, which is the second-best position for an animal to be in, according to animal-human relationship scientist James Serpell. The top spot is "lovable and useful," which includes guide dogs, monkey caregivers, and winning horses. The worst place is "loathed and useless," where rats and mosquitoes thrive. Different cultures assign different statuses. Dogs don't get a whole lot of love in Saudi Arabia.

Status can change, and damage by Clemson's squirrels has some people calling them "rats with bushy tails" and "day-shift rats."

Animal damage has become a big problem. The wildlife biologists who Yarrow was telling the "tiny condom" story to were some of the researchers attending the 15th Wildlife Damage Management Conference, spotlighting a multi-billion-dollar conflict: humans vs. wildlife. Nationally, wildlife causes well over $28 billion in damages and loss—loss that includes lives. More than 200 people die each year in deer-vehicle collisions alone.

Shifts in human residential patterns, along with wildlife protection and restoration programs, have brought more people and wildlife closer together than ever before.

Peter Kent

Andrew Watson, an undergraduate student in wildlife ecology, releases one of the research subjects.

The Squirrel Whisperer

On campus one warm June day, a squirrel meets a friend, a woman who wears a poker-chip sized silver heart pendant side-kicked by a charm of a small silver squirrel. Her friends tease her with the moniker "Squirrel Whisperer."

She slows the rump-sprung, blue Ford F150, hoping the squirrel will hop into the bushes, but she has to brake and wait for it. "Get out of the road, I don't want you to die!" Kristina Dunn yells from the driver's seat at the squirrel standing stock still on Jersey Lane just off Cherry Road.

Dunn cares about the squirrels not only as part of her personal philosophy—she's a vegan and an outspoken animal conservationist—but also because they are her research subjects.

A Ph.D. student advised by Yarrow in the Department of Wildlife Biology and Fisheries, Dunn is in her third year of a four-year study of oral contraceptives as a way to manage Clemson's squirrel population.

In 2005, the university landscaping service asked for Yarrow's help when the number of dead branches in some varieties of trees alarmed groundskeepers. "We were having to prune limbs that we would not normally remove because they could fall on sidewalks and parking lots," says Paul Minerva, Clemson arborist.

The culprits were caught gnawing, squirrels chewing on oaks, hickories, and other thin-bark trees. "I wasn't going to have the squirrels dictate how we care for the trees," Minerva says.

Peter Kent

Andrew Watson identifies a squirrel, wrapped for safety in a woven pouch of cloth, by reading its implanted microchip.

Nixing the air guns

Yarrow proposed deploying Clemson's crack-shot air rifle team. The cull would come when campus was empty of students and faculty. University leaders nixed the idea. A place full of scientists surely could find alternatives.

Besides, a squirrel hunt would create a furor on a campus where feral cats are treated as sacred cows and landscaping services sends out emails to explain why a tree will be cut down.

As for nonlethal alternatives, repellents would not control births. Trapping was no-go, too. In an unconfined space, traps catch squirrels, but other squirrels simply move in. "It's called the vacuum effect," says Yarrow. Birth control was worth a try. If nothing else, it would provide research projects for wildlife biology graduate students.

Doctoral student Murali Pai started in 2005 to research GonaCon. The drug decreases mating and pregnancy in a wide range of animals, from white-tailed deer to horses and even prairie dogs. It works via the immune system, triggering antibodies that interfere with sex-hormone production. One or two doses can last for years. But GonaCon is far from ideal.

Pai found out how hard it is to give a shot to a squirming, biting, clawing, pound-plus animal redlining its flight-or-fight response. Pai managed to vaccinate only 317 squirrels. What's more, the expense was startling. "It cost about sixteen dollars and fifty cents per squirrel," says Yarrow, Pai's adviser.

Pai graduated and moved on. The squirrels remained, breeding, gnawing. Yarrow had recruited a new doctoral student for the squirrel study.

Kristina Dunn began in 2011 by setting up a survey plot for a statistical count of the squirrels. She reckons that there are nine squirrels per acre—about 7,200 squirrels at Clemson. Wildlife biologists figure that five squirrels per acre is optimal in the Southeast.

Other researchers have concluded that squirrel boars do the chewing. Why they chew is not settled.

"It could be that males do it to establish territory, or wear down their teeth, or it could be because the bark contains nutrients, or it's a stress behavior," Dunn says.

Tricking the body

Motive is not Dunn's line of investigation, though "I'd like to know," she adds. Her research focuses on the oral contraceptive DiazaCon and the timing to put it out.

DiazaCon mimics cholesterol. It tricks the body into sensing it has sufficient cholesterol, consequently reducing production. Cholesterol plays a pivotal role in reproduction, stimulating production of sex hormones. The drug, though, did not begin as an animal contraceptive.

Pharmaceutical maker S.E. Searle developed DiazaCon as a human cholesterol reducer. Side effects, however, made it unpopular with men, causing some to grow breasts and lose interest in sex. Searle discontinued the drug. Scientists at the U.S. Department of Agriculture's National Wildlife Research Center in Fort Collins, Colorado, bought the inventory, using it for research.

DiazaCon is mixed with other ingredients so the squirrels eat it. Dunn and professional lab technician Wayne Chao follow a recipe that includes hulled sunflower seeds, corn oil, DiazaCon, and Rhodamine B, which is a purply pink dye that stains squirrel teeth, fur, and whiskers. "I've tasted it and it's not bad," says Dunn, quickly adding that her sample was DiazaCon free.

The contraceptive, which lasts several months in the liver, is put out in April and November, leading up to mating seasons. The bait mixture goes into aluminum L-shaped feeding bins mounted in trees in the five test sites. Dunn waits to see if the squirrels take the bait.

The full treatment

June is one of four data-collection months. For five to ten days, Dunn and student assistants catch a hundred squirrels to identify them by ear tag or microchip, much like the one used for pets, and exam them in a lab. "New ones get the full treatment," Dunn says. "They're tagged and logged in." Within two hours of capture, the trapping process is reversed. The squirrels are set free.

Kristina Dunn and Andrew Watson pack a pickup with squirrel traps. In June, their team captured and examined a hundred squirrels. Photo by Peter Kent.

Dunn alone, or with helpers, will do this as often as four times a day during daily trapping periods. At sunset traps are closed and upended.

The sturdy wooden box traps are roughly twenty-four inches long and eight inches square. One end has an opening and the other is covered in hardware cloth. Inside, the trigger is a simple tray baited with sunflower seeds. A squirrel steps on the bait plate, tripping the door release. Dunn prefers thick plywood traps that make the enclosure a dark lair. "It's less stressful for the squirrels than the exposed, all-wire traps."

Traps are set on five test sites on campus and the control site at the South Carolina Botanical Garden. Some sites are more productive than others. "The ones near Lehotsky, Fort Hill, and the library reflection pond always are good," Dunn says.

The area around Lever and Martin dorms is the worst site. Construction and leaf-blower noise keep the squirrels away. But a big reason for empty traps is not around now. "Students shoo the squirrels away from the traps," says Dunn. "I wish they wouldn't. Let them know we release the squirrels."

Of the more than one thousand squirrels Dunn has handled, seven have died, either from trap stress or because she put them down due to their poor condition. There have been no deaths in the other species Dunn captures. Red-tailed hawks are caught to see if DiazaCon affects squirrel predators. So far, the data do not show a problem.

Trap check

This June day, Dunn does a trap check. Riding shotgun is Andrew Watson, a junior in the Wildlife and Fisheries Department. He and Brittany Sumner, also a wildlife biology junior, help out and are working on a Creative Inquiry project using Dunn's data to plot the squirrel population and range. Ten squirrels take the bait. Watson and Dunn lug the traps to the truck.

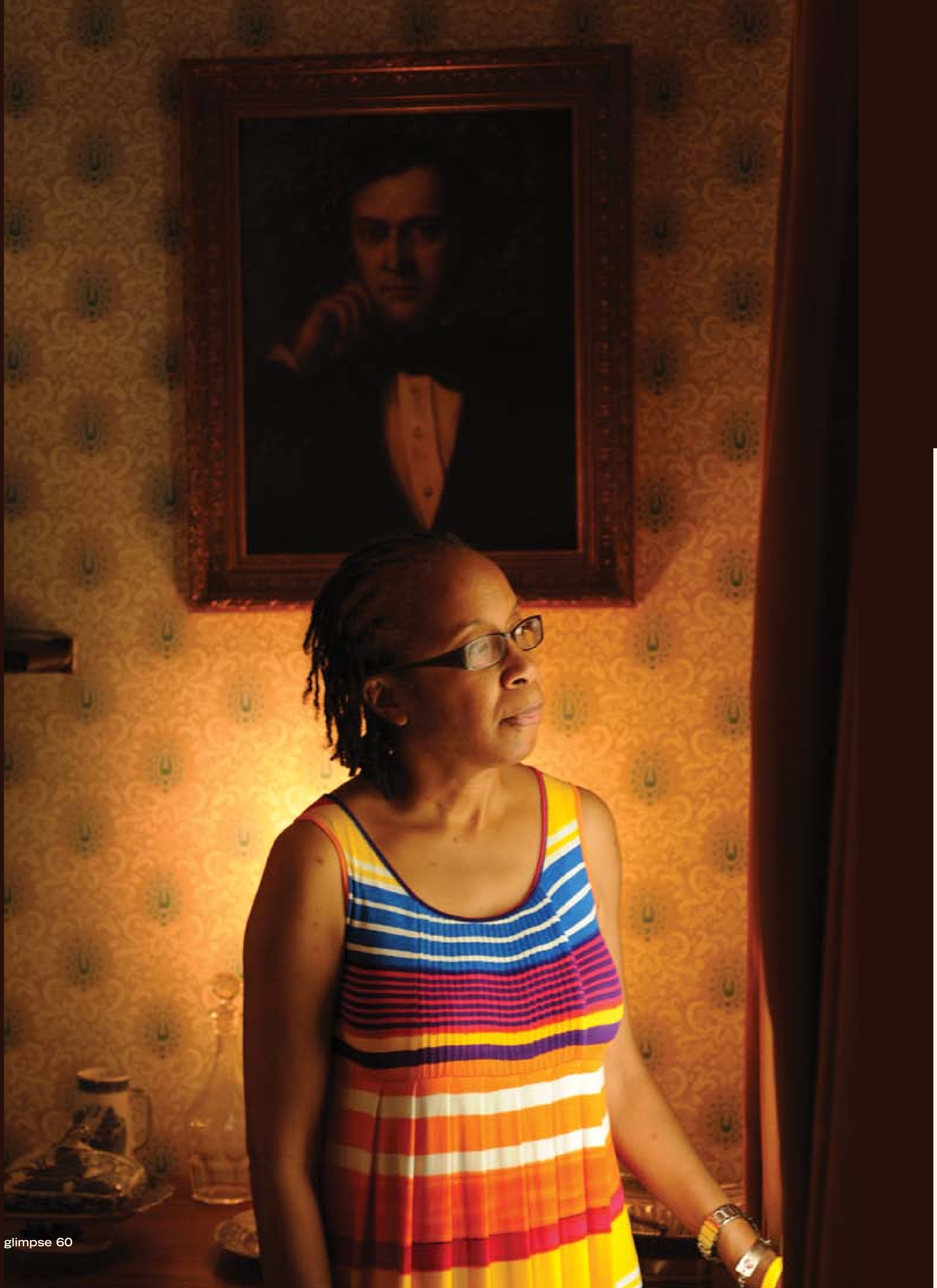
Next stop is Godley-Snell Research Center, where the squirrels become data points—sex, weight, blood, scrotum and teat observations, tags checked, and whisker samples snipped. Dunn has dealt with a problem the previous researchers struggled with—squirming squirrels. "I found a seamstress who made a handling cone that attaches to the trap door with Velcro," says Dunn. "We open the door, the squirrel runs into the webbing, and is bundled up." After the exam, the cone is reattached and the squirrel returns to the trap.

Dunn will graduate next year. When she finishes, the project will be over. Yarrow has been promoted to college administrator. He is not taking on new graduate students.

Will DiazaCon help with the squirrel problem? Arborist Paul Minerva says he already has seen signs that Dunn's project has reduced the gnawing. Dunn is reluctant to talk about results before she completes her research, but she offers one observation.

"I don't know if squirrels have reached the biological carrying capacity on campus, but they have reached the cultural carrying capacity," she says. "That's the limit society sets when it won't tolerate a species that's a danger or doing damage. It's a value judgment."

Greg Yarrow is the chair of the Division of Natural Resources and a professor of wildlife ecology in the College of Agriculture, Forestry, and Life Sciences. Peter Kent is a news editor and writer in Clemson's Public Service Activities.



close focus

Struggling toward *the Promised Land*

How the Exodus narrative helped sustain generations of blacks seeking freedom and equality.

by Jeff Worley

Rhondda Thomas knows the power of a good story. One story in particular, the Exodus narrative, captivated her when she was a girl in Sunday school making her first voyage through the Bible. As she grew into her teens, went to college and then to graduate school, Exodus began to take center stage in her academic life.

"When I started my graduate studies and did research on the Exodus story, I found that scholars had taken a very limited view of the story's potential and the power of this narrative through many years to drive and nourish blacks in their quest for freedom," Thomas says. Her hunch was that many black writers, especially during the nineteenth century, had mined Exodus for its allegorical power. It turned out Thomas was right.

"I did a search on Exodus stories, and I found them everywhere," she says. "And in the sermons, letters, books and other written materials I researched, I was taken by the multiple ways this narrative was sustained as a way to express the strong desire for freedom."

Thomas continued her search-and-find mission through graduate school with an eye toward writing and publishing a book. *Claiming Exodus: a Cultural History of Afro-Atlantic Identity, 1774-1903*, was published early this year by Baylor University Press.

"Exodus was of course an oral tradition before Moses wrote it down, and sermons are also part of the oral tradition, but in America the print culture is such an integral part of our identity, I wanted to focus on the written, literary convention in this country," Thomas says. "So even the sermons I discuss in the book were written down and widely circulated."

In *Claiming Exodus,* Thomas mentions several dozen black writers who used the Exodus myth to further blacks' struggle for freedom, but she says there are three who played especially important roles in the drama of emancipation and self-realization: Phillis Wheatley, Absalom Jones, and W.E.B. Du Bois.

Facing page: Rhondda Thomas at Fort Hill on the Clemson campus. Especially during the nineteenth century, she says, Exodus had the power to nourish the quest for freedom. Photo by Patrick Wright.

Phillis Wheatley: Include American slaves in the revolution.

Thomas found that the first person in America of African descent to use the Exodus story was also the youngest—Phillis Wheatley. She was eight years old when she was brought to Boston on a slave ship in 1761, and John Wheatley, a prosperous Boston merchant, purchased her as a personal slave and companion for his wife. Phillis received a solid education and, at age fourteen, began to publish her poetry and letters in Boston newspapers. In 1773, John Wheatley emancipated her.

"Being freed from her master may have given the celebrated Wheatley the confidence to evoke Exodus in penning her strong abolitionist statement in 'Letter to Reverend Samson Occum,' published on the eve of the American Revolution," Thomas says. "In her letter Wheatley draws on the rhetoric of the Exodus narrative and Enlightenment theory to elevate Africans from abject bondsmen to rational, spiritual human beings. In doing so, she shifts the objective of the Revolution from the colonists' emancipation to the physical, religious, and political liberation of all Americans—including Africans." Thomas adds that in the closing of her letter, Wheatley invokes biblical precedence, suggesting that Africans' pleas for liberty are equivalent to ancient Israelites' prayers for deliverance from Egyptian slavery.

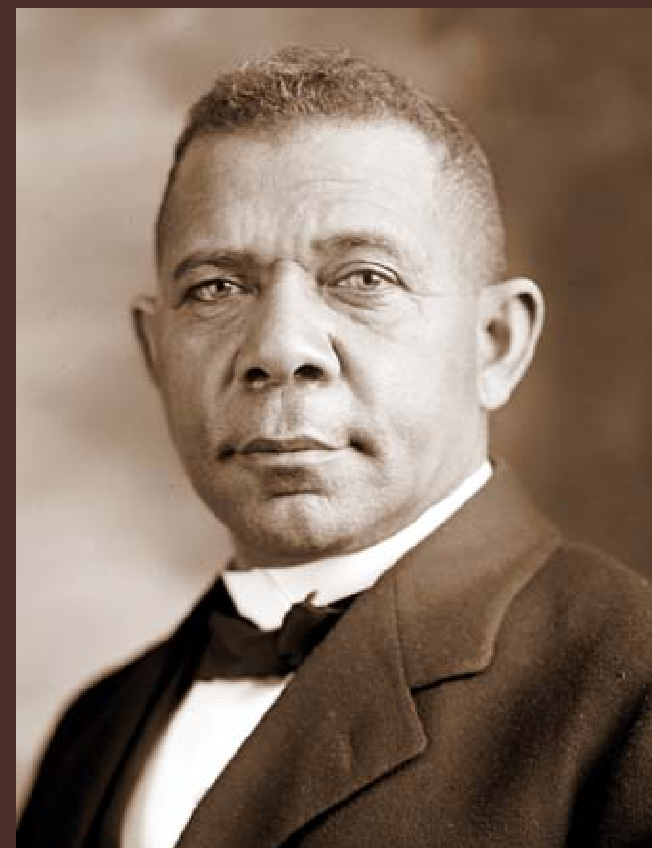
"Basically what Wheatley does in this letter is point out the absurdity of the colonists using the Exodus narrative in their demand for liberty while still believing they should enslave Africans," Thomas says. "This former slave girl was sharply questioning their sense of reason. Wheatley was likely the most prominent African American of her time to publicly demand the abolition of slavery during the American Revolution, which effectively complicated the debates regarding race, citizenship, and freedom."

"It is the story, always the story, that precedes and follows the journey."

Terry Tempest Williams

Photo 1904 by J.E. Purdy. Library of Congress collection.

Photo 1905 by Harris and Ewing. Library of Congress collection.



The Exodus narrative

The Book of Exodus tells how Moses leads the Israelites out of Egypt and through the wilderness to Mount Sinai, where God reveals himself and offers them a covenant: They are to keep his torah (i.e., law, instruction), and in return he will be their God and give them the land of Canaan. The Book of Numbers tells how the Israelites, led by their God, journey from Sinai towards Canaan, but when their spies report that the land is filled with giants, they refuse to go on. God condemns them to remain in the wilderness until the generation that left Egypt passes away. After thirty-eight years at the oasis of Kadesh Barnea, the next generation travels on to the borders of Canaan. The Book of Deuteronomy tells how, within sight of the Promised Land, Moses recalls their journey and gives them new laws. His death concludes the forty years of the exodus from Egypt. According to Exodus, Numbers, and Joshua, after Moses' death Joshua became the leader of the Israelite tribes.

—source: Wikipedia

Leading the way

W.E.B. Du Bois (above left) reluctantly identified Booker T. Washington (above right) as a Moses figure of their time. Absalom Jones (below left), a minister, and Phillis Wheatley, a freed slave, used the Exodus story to urge a young nation toward liberty and equality.

1810 portrait by Raphaelle Peale. Source: Episcopal Archives.

Frontispiece of *Memoir and Poems* (1834). Source: Documenting the American South, UNC-Chapel Hill.

Absalom Jones: gradual emancipation and community building

More than thirty years later, another strong voice in the struggle for liberty extended the Exodus myth: the Reverend Absalom Jones of St. Thomas African Episcopal Church in Philadelphia. On New Year's Day, 1808, Jones preached "A Thanksgiving Sermon" on the occasion of a new law, taking effect that day, that prohibited the nation's participation in the slave trade.

"In his sermon Jones characterized American slaves as ancient Israelites whose cries had moved God to convince politicians in Congress to outlaw the slave trade," Thomas explains. "Jones evoked the Exodus narrative to interpret this legislation as a divine sign portending the emancipation of the slaves, transforming free black Philadelphians into activists who should now continually commemorate their victory and aggressively work for civil rights." Thomas adds that by the time he delivered his "Thanksgiving Sermon," Jones was sixty-two years old, a confident, Moses-like figure in the antislavery cause.

"His sermon was published and distributed and read widely," Thomas says, "and it helped black Philadelphians to become one of the most activist communities in the nation."

W.E.B. Du Bois: Booker T. Washington as a potential Joshua

In *Claiming Exodus*, Thomas discusses a number of writers who used and extended the Exodus narrative in the struggle toward freedom through the nineteenth century's pivotal events: the War of 1812, the great debates of 1820s, Manifest Destiny, the Civil War, and Reconstruction. Championed by black activists, various black leaders through the century came to represent Moses figures or Joshua figures (Joshua became the leader of the Israelite tribes after the death of Moses).

W.E.B. Du Bois, the first African American to earn a doctorate at Harvard and cofounder of the National Association for the Advancement of Colored People (NAACP) in 1909, somewhat reluctantly supported Booker T. Washington as a potential Joshua figure at the turn of the twentieth century, Thomas says, adding that the two men were not always in agreement as how best to accomplish their shared goals. "Du Bois would have wanted a leader who took a more radical approach to white Americans' insistence on second-class citizenship for African Americans but said that to the extent Washington, the builder of the Tuskegee Institute, preached 'thrift, patience, and industrial training' for the masses, blacks should strive with him and glory 'in the strength of this Joshua called of God and of man to lead the headless host,'" Thomas says, quoting her book.

With additional support from Andrew Carnegie, who singled out Washington as the 'modern Moses,' Washington was regularly identified by white newspapers throughout the nation at the turn of the twentieth century as the African Americans' Moses, securing his status as race leader and affirming his more conservative strategy as the solution to the problem of the color line, Thomas concludes.

Logging in lots of library time

Thomas describes the eight years of research and scholarship that led to the publication of *Claiming Exodus* as emphatically not glamorous.

"There were not the online databases there are now, so to try to find these stories I spent hundreds of hours reading bound volumes and painstakingly going through microfilm, despite the fact that whirling through microfilm actually makes me nauseous." Thomas's research took her from Washington D.C. (Howard University) to Atlanta (the Emory University archives) to South Carolina (the Historical Society), and to Charleston, Philadelphia, and Boston. The occasional surprising finding was one of the things that kept her going, says Thomas.

"One of my best finds—this was in the American Antiquarian Society archives in Worcester, Massachusetts—was a letter from Frederick Douglass near the end of his life to Francis Grimké, a Presbyterian Church pastor in Washington, D.C. As far as I know, no one had known of the existence of this letter, which talks about the Promised Land," Thomas says. Grimké was an important racial activist in the early twentieth century.

Another major discovery Thomas made through her research was that the writers she investigated had a far broader concept of the "Promised Land" than she had expected.

"I grew up thinking that either the American North or Canada was the Promised Land for blacks seeking their freedom," Thomas says, "but I discovered through my research that writers also thought of the American West, East and West Africa, and even England and France as the Promised Land. Finding a multiplicity of promised lands was an interesting surprise."

Why is the Exodus story so powerful?

"Every major moment in American history has seen a proliferation of Exodus narratives," Thomas says. "The story is an epic narrative chock-full of drama, suspense, and a tremendous fight between good and evil. It's the dominant narrative used by white and black Americans over and over again to try to keep their quest for freedom and democracy going. Collectively, the Afro-Atlantic Exodus stories sustained the momentum of early civil rights efforts."

Rhondda Thomas is an assistant professor of African-American literature in the Department of English, College of Architecture, Arts, and Humanities. Jeff Worley is a freelance writer and poet who lives in Lexington, Kentucky.

OUR NOT SO FREE WAYS

A futuristic dream carved and recast America.

by Mary Jane Nirdlinger

When Cliff Ellis wants to visit his friends in Tulsa, Oklahoma, he gets in his car, finds a freeway, and arrives about eleven hours later. During that trip, most of us would see an unending ribbon of concrete, overpasses, exits, and, with luck, free-flowing cars. Cliff Ellis sees the results of one of our country's greatest experiments in urban form. His new book, *Changing Lanes*, with coauthor Joseph F. C. DiMento, lays out the history of our freeway system as clearly as a road atlas.

In the beginning, our national system of highways grew out of a desire to connect rural areas with their markets. Dusty roads were replaced with paved routes that could carry farmers' goods in all seasons. Beginning in the 1930s, some limited-access roads were built through urban areas, but urban freeway building didn't really take off until the 1950s and 1960s. Controversy erupted when highway builders ran headlong into the built-up reality of our cities. The solution, as designers inked it into drawings, was elegant motorways with lush edges flowing through tidy landscapes and slicing between the high walls of modern skyscrapers. But it wasn't that easy.

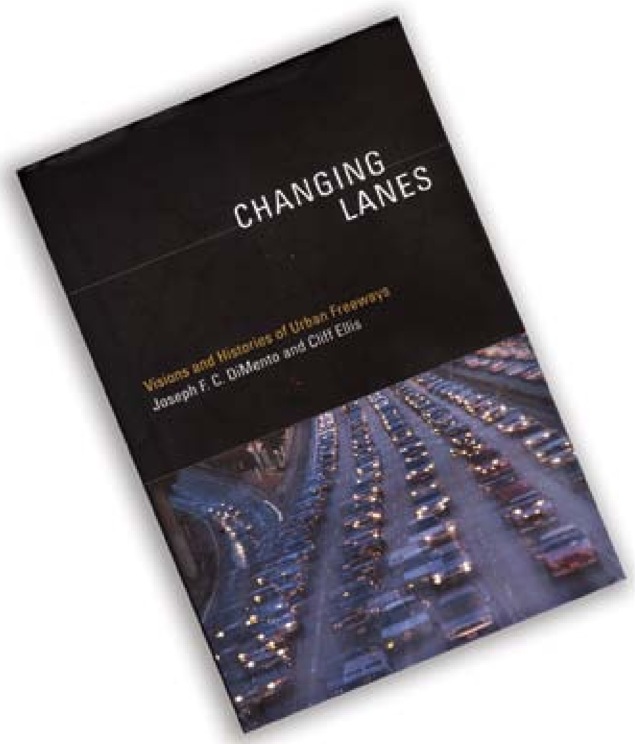
"Highway engineers, city planners, architects, and landscape architects all viewed that huge building task through different lenses," Ellis says. "They go through different educational experiences, they approach problems differently, and they see the world through different perspectives."

These perspectives are still at work today. "We're facing all of the same issues, but now it's even more important; it's worldwide," Ellis says. "The Chinese are building huge freeway systems, and other countries are contemplating huge systems. It's probably not the wisest course to invest everything in freeways."

While Ellis has captured a lot of ideas and lessons from this grand experiment with freeways in America, he respects the good intentions of the people who designed and built them.

"Highway engineers thought that everything they were building was good for cities," Ellis says. "They were working in the public interest." As the visionaries of the time saw it, freeways could help rid urban areas of poverty, congestion, and noise.

It was all about the future. In 1939, industrial designer Norman Bel Geddes worked with General Motors to design and build a one-acre model called Futurama for display at the New York World's Fair. Futurama was a magnificently detailed American landscape of the future. More than five million visitors rode in upholstered seats mounted on a conveyor belt, peering down through a window as though from an airplane. A recorded narration explained the wonders of easy automobile travel on freeways connecting rural areas with towns and dazzling new cities.



Seeing the future

For the time, the vision and the technology were astonishing. "People just said, 'Woah—what a wonderful new world is being created.'" When visitors left the Futurama exhibit, everybody got a button: "I've Seen the Future." And they had.

"The kind of interstate travel we do now would have been astonishing to people in the 1920s," Ellis says. "It's impossible now to imagine not being able to go from city to city in comfort at high speeds."

The system we use today is based on ideas developed in the 1930s and '40s. Construction took off in the 1950s, with new government funding and little opposition.

"People in specific cities said, 'Wait a minute; you're going to build this through a beautiful place,' and it was stopped," Ellis says. "But most of the proposed system was built."

At heart, though, the freeway system was based on a rural model. "It was problematic when you took those standards and tried to smash them through the middle of downtown," Ellis says. "Was that the wisest things to do?"

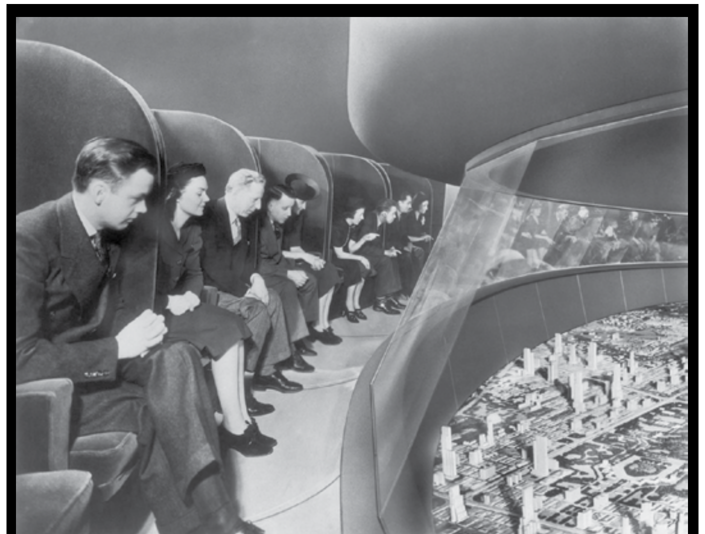
The freeway planners made great promises about how these projects would benefit inner cities. *Changing Lanes* documents the consistent belief that freeways would open up central business districts for reinvestment and economic growth by bringing people downtown and remedying traffic congestion. What they didn't foresee was how those same roads would make it very easy to leave downtown or not go there at all. A whole new place evolved, a place where you could live your entire life on the edge of town.

When the freeways went into the bigger cities such as Boston, New York, and Chicago, their insertion was not a matter of delicate surgery. "They cut large swaths through dense, older neighborhoods without much concern for the people who lived there," Ellis says.

It was this approach that eventually generated opposition to some local freeway projects, shifting the community focus from transportation to social justice and historic preservation.

There were dire predictions for the cities that dodged freeways, but, as Ellis notes, some of the best lessons come from what was *not* done. "Some of the proposals for lower Manhattan are appalling things to contemplate now when you think about having these massive urban freeways cutting across Washington Park," Ellis says, "but the Cross Bronx Expressway went through similar areas."

Some places escaped attention. Greenville, South Carolina, was a relatively small city during most of the early planning, so the major freeway is off to one side. "It has benefitted from the fact that it wasn't really damaged by urban freeways," Ellis says. "So have Charleston and Savannah, where the ramps come down outside the historic districts and then it's just surface roads.



Five million visitors to Futurama, at the 1939 World's Fair, beheld the future of cities and highways.

"It happened. We ran the experiment on urban freeways."
— Cliff Ellis

Imagine if huge freeways had actually been built through the historic districts of Savannah and Charleston?"

Ellis is not saying freeways are all bad. "We need industrial routes and major arterials to get in and out. But there were alternatives that were overlooked."

Tearing them down

Some of those alternatives appear today when freeways are removed. Ellis was in San Francisco in 1989 when the Loma Prieta earthquake collapsed portions of the city's elevated freeway. Eventually, the damaged Embarcadero Freeway was torn down and the area was opened to redevelopment. The waterfront, once hidden under the dark shadow of the freeway, became a beautiful transit boulevard.

The tear-downs are interesting, but they're few and far between. Ironically, we built the freeways in part to accelerate economic development, but in some cities today the fastest route to economic development may be to take the freeway out.

When you compare an atlas of the United States today to the original plans for the freeway system, the achievement is remarkable. Almost all our cities have freeway networks in and around downtown.

One thing that wasn't fully planned for, though, was maintenance. Freeways aren't really free. The long-term cost, to repave, rebuild, and lay them down again, is huge.

Ellis describes three of the factors that keep us going: Gasoline is still cheap, and so far it's had very little impact on shifting us out of auto dependency; we're not yet taking climate change seriously; and our land-use patterns are still dispersed. Our urban form is built around motor vehicles.

"The highway planning profession has evolved, but there still is a pretty big chasm between the highway builders and transportation planners," Ellis says. "When you say 'transportation,' it implies that you're not only going to talk about automobiles, you're going to take transit into account, and walking and cycling."

Decade after decade

Ellis's research details our steady investment of money and resources since the early 1900s into freeways. Regulations, highway and transportation bureaucracy, economic interests, and physical infrastructure all resist change; they have staying power.

The freeway system continues to expand with quite a bit of highway construction on the edges. As the original infrastructure reaches the end of its useful life, there's a lot of reconstruction on the horizon.

Ellis wonders what the future will hold. "I don't know what the energy system and the climate will be in two thousand and fifty, but we probably don't want to build ourselves into a dead end with only one type of transportation.

"We have to imagine the long-term consequences," he says. "At some point you have to think beyond your own personal world and imagine year after year and decade after decade."

And what about all those freeways on the ground today? Ellis sums things up this way: "It happened. We ran the experiment on urban freeways. We didn't have them in the 1930s. We know enough now to look back, and maybe we could have done things smarter, better, differently. We've ended up with a very one-sided, imbalanced system, and it's really probably time to change, and the sooner the better, to a more sustainable and resilient system."

Changing Lanes doesn't offer a Futurama-style fix to our freeway habit.

"We are in a bit of a bind here," Ellis says. "The crisis is not immediate, and we take it for granted that there is no climate catastrophe yet, but a lot of people would say we are heading toward a future crisis and that our children and grandchildren aren't going to be that charitable towards us."

There are some small signals of change. After the recent housing crisis, many of the inner city areas bounced back faster than suburban areas did. Ellis says that research suggests that today's young people do not necessarily want a large single-family home by a freeway on the edge of town.

Maybe, Ellis wonders aloud, "People don't want to live where they have a fifty-minute commute on a congested freeway when they could live downtown and have interesting things to do." But it's too early to say, and Ellis sounds a little wistful on the topic of the future.

"It would be nice if people thought about the well-being of future generations," Ellis says, "but we live in the built environment we inherited, and as long as it doesn't break down, we keep going."

Cliff Ellis is an associate professor and the director of the Graduate Program in City and Regional Planning in the College of Architecture, Art, and Humanities. Joseph F. C. DiMento is a professor in the School of Law and the director of the Newkirk Center for Science and Society at the University of California, Irvine. Changing Lanes *was published in 2013 by the MIT Press. Mary Jane Nirdlinger is a city planner and the director of policy and strategic initiatives for the Town of Chapel Hill, North Carolina.*

CU-ICAR

Introducing Deep Orange 3

If you like cars, this may be the coolest master's thesis ever. Engineered and built by students, Deep Orange 3 features a unique hybrid power train that automatically chooses front-, rear-, or all-wheel drive. And despite its sports car lines, the car seats six, because today's young drivers tend to hit the road with lots of friends.

Clemson students in automotive engineering built the car in collaboration with students at the Art Center College of Design in Pasadena, California. The California students designed the body panels, and Clemson students built the rest, working their way step-by-step through market research, concept sketches, and computer-aided design into assembly and testing at the Clemson University International Center for Automotive Research (CU-ICAR).

Paul Venhovens, BMW Endowed Chair in Systems Integration at CU-ICAR, who leads the Deep Orange program, says the students had free rein to push the boundaries of conventional design and engineering. "We know the future of the automotive industry will require ever more flexible, more cost effective, and more innovative approaches to manufacturing," Venhovens says. "Our manufacturing approach on this project was exemplary of this kind of change."

Deep Orange 3 is a Mazda concept car, and the project received support from Mazda North America Operations.

Above: Clemson student engineers test-drive the frame and working parts of their creation, Deep Orange 3.

Below: The complete vehicle sports sweeping body panels designed by art school students in California. The students' coast-to-coast collaboration produced a truly original design from the ground up.

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Craig Mahaffey

The Secret Book It began as an art project about the struggle of crops and weeds, and the organization of nature. But then the artist lost control. Page 27