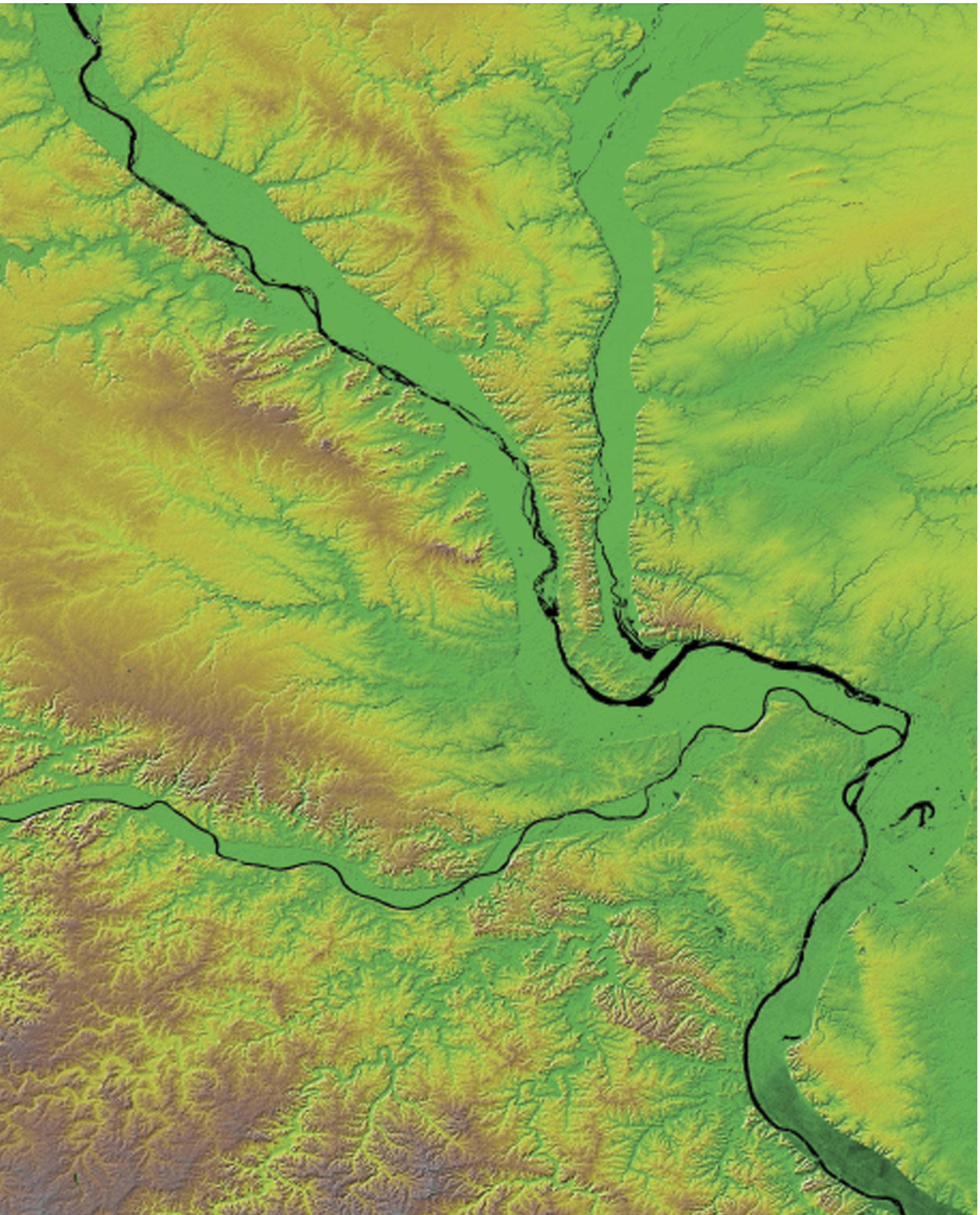
California Institute of Technology

E&S
ENGINEERING AND SCIENCE

Volume LXV,
Number 1,
2002



This view of the St. Louis area generated by the Shuttle Radar Topography Mission (SRTM) shows the Mississippi flowing in from the upper left and meeting first the Illinois, flowing southward from the top right, and then the Missouri coming in from the west. The green-colored floodplains containing—or sometimes not containing—the rivers can clearly be seen. The city of St. Louis is on the Mississippi just below the point where it meets the Missouri. This prime location at the hub of three major American waterways helped establish the city's reputation as the "Gateway to the West." For more about the SRTM, see the story beginning on page 22.

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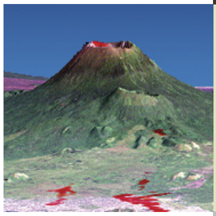

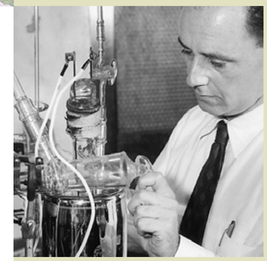

On the cover: Which came first, the bird or the egg? These sushi-quality Japanese quail eggs, obtained from a restaurant supply house, are helping biologists figure out how a complex adult develops from a single cell, and how animals become different from one another. The researchers study the genes that control neural crest cells, which wander far and wide through the embryo to become many widely different cell types in the adult. The story beginnning on page 10 explores how they do it.

Engineering & Science (ISSN 0013-7812) is published quarterly at the California Institute of Technology, 1200 East California Boulevard, Pasadena, CA 91125. Annual subscription $10.00 domestic, $20.00 foreign air mail; single copies $3.00. Send subscriptions to Caltech 1-71, Pasadena, CA 91125. Third class postage paid at Pasadena, CA. Published by Caltech and the Alumni Association. Telephone: 626-395-3630.

PICTURE CREDITS: Cover, 2, 9, 10, 13, 15, 21, 38, 40, 44 – Bob Paz; inside front cover, 29-31 – NASA/JPL/NIMA; 3 – Carlos Lois; 3, 4 – James Hagadorn; 4-5 – NASA/DLR; 5 – M. Cai; 6 – AFI; 7 – Bob Abel, Doug Smith; 9 – NASA/JPL/U. of Arizona, NASA/JPL/Arizona State; 10, 19 – Dan Meulemans; 10 – Tanya Moreno; 13 – Mark Selleck; 14 – Martín García-Castro; 17 – Jeremy Gibson-Brown; 17, 18 – Dave McCauley; 19 – Jordi-Garcia Fernàndez; 22, 23 – Doug Cummings/NASA/JPL/NIMA; 24-28 – NASA/JPL; 28 – Ball Aerospace; 39 – Floyd Clark; 41 – Chris Tschoegl; 42 – Elizabeth Penn

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Stephen Hawking, theoretical physicist and best-selling author, visits his Caltech collaborators once every year or so. During his stay he traditionally gives a public lecture, which invariably overflows Beckman Auditorium. This time, some hardy undergrads showed up in the middle of the night in order to be sure of being first in line for the free tickets required for admission. It's as close as Caltech gets to hosting a rock star—when the box office opened later that morning, the ticket line wrapped all the way around the Gene Pool and extended nearly to Del Mar Boulevard.

You Light Up My Mice

Specially prepared HIV-derived viruses stripped of their disease-causing potential have been harnessed to introduce foreign DNA into animals in a method that could have wide-ranging applications in biotechnology and experimental biology. David Baltimore, professor of biology and president of Caltech, and his team have infected single-celled mouse embryos with the virus, leaving a new gene from a jellyfish permanently deposited into their genomes.

The resulting mice carried at least one copy of the gene in 80 percent of the cases, and 90 percent of these showed high levels of the jellyfish protein. Furthermore, their offspring inherited the gene and made the new protein. (The mice were given the jellyfish gene for Green Fluorescent Protein, which makes the cells containing it glow green under an ultraviolet light—an easy way to verify that the gene had been transferred in good working order.) Such animals that carry and pass on a foreign gene are called transgenic.

"It's surprising how well it works," says Baltimore, whose Nobel Prize-winning research on the genetic mechanisms of viruses 30 years ago is central to the new technique. "This technique is much easier and more efficient than the procedure now commonly in use, and the results suggest that it can be used to generate other transgenic animal species." The current method involves injecting the new gene into the nucleus of an egg cell before it is fertilized.

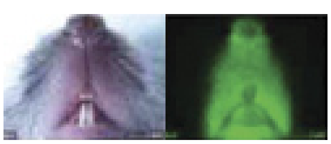
The new technique uses HIV-like viruses known as lentiviruses, which can infect both dividing and non-dividing cells, to insert new genes into the cell's existing genome. Unlike HIV, the lentivirus is rendered incapable of causing AIDS. Baltimore and his team developed two ways of introducing the lentivirus into cells: microinjection of virus under the layer that protects recently fertilized eggs, or incubation of denuded fertilized eggs in a concentrated solution of the virus. The latter method is easier, although less efficient.

Transgenics holds promise to biotechnology and experimental biology because the techniques can be used to "engineer" new, desirable traits in plants and animals, provided the trait can be identified and localized in another organism's genome. A transgenic cow, for example, might be engineered

Right: Warts on a fingertip? No. Craters on Mars? Wrong again. The ripples on this slab of sandstone were left on a shallow seafloor more than 500 million years ago. The rings mark the last resting places of a school of jellyfish.

to produce milk containing therapeutic human proteins, or a transgenic chicken might produce eggs low in cholesterol. In experimental biology, transgenics are valuable laboratory animals for fundamental research. A cat with an altered visual system, for example, might better accommodate fundamental studies of the nature of vision.

According to Baltimore, the procedure works on rats as well as mice. This is a huge advantage to experimentalists because of the number of laboratory applications in which rats are preferable, he says. The paper appeared in the February 1 issue of *Science*. The other authors of the paper are postdoc Carlos Lois; undergrad Elizabeth Hong, a senior this year; Shirley Pease, a Member of the Professional Staff; and postdoc Eric Brown. □—*RT*



Like a Grateful Dead poster under a black light, this transgenic mouse glows in the dark.

Jellyfish in the Sands of Time

And speaking of jellyfish, postdoc James Hagadorn has found an armada of them in a flagstone quarry in Wisconsin. Finding a fossil impression of a soft-bodied creature in a coarse-grained deposit is rare; finding hundreds of them in one spot is almost unheard-of. In fact, this is only the second mass stranding of jellyfish ever found.

Jellyfish (more properly, scyphozoan medusae) used to run aground all the time, of course, just as they do now. "The only reason these were preserved is that there were no higher organisms in this setting," says Hagadorn. "If they washed up on the beach today, the birds would eat them. Or your dog. Or if they did get buried, a burrowing horseshoe crab would churn up the impression. These fossils are from the end of the Cambrian era, about 510 million years ago, just before land animals appeared. So it's not that something caused them to be preserved, but the lack of something that was destroying them."

It's precisely because these jellyfish were at the top of the food chain that makes them so interesting. If they behaved like their modern counterparts, they were free-swimming predators. Yet because they lack the hard body parts that typically make good fossils, they have been sorely underrepresented in previous studies of who was eating whom in the Cambrian world. This has proven to be a big omission. Literally—the few previous finds had been about the size of demitasse saucers, while these guys averaged as big as dinner plates (about par for their descendants today), and some were up to 70 centimeters (about 27 inches) in diameter.

Back in the Cambrian, Wisconsin was just south of the equator, and most of it lay beneath a tropical sea. In fact, this quarry near Mosinee was already famous among fossil hunters for the spectacular jeep-tire-sized tracks left there by giant molluscs. In Cambrian times, it was probably the bottom of a shallow lagoon or bay. The jellyfish were most likely blown in by a storm whose ebb left them high and dry, only to be buried by fresh sediment in succeeding tides.

Hagadorn, who starts as a professor at Amherst this fall, found the fossils purely by accident. His real field is the Precambrian, where he works with Professor of Geobiology Joseph Kirschvink (BS, MS '75) and Kenneth Nealson, head of JPL's astrobiology group. The Precambrian contains the first fossils of creatures that are more than mere agglomerations of cells such as algal mats. But the fossils are very rare. For example, the Ediacarans, the subject of Hagadorn's PhD thesis at USC, are known only from a handful of impressions that their soft bodies left in some exceptionally well-preserved sand- and mudstones. Late in 1999, Kevin Peterson, a postdoc in Chandler Professor of Biology Eric Davidson's lab with an interest in fossils, noticed Ediacarans for sale in a fossil catalog. "He knew I had

worked on them, so he suggested I call the company," recalls Hagadorn. "So I spoke to Dan Damrow, who supplied the fossils, and asked him to send me some pictures. It turned out that they weren't Ediacaran fossils, but some of the photos included things that looked like jellyfish. So after I picked my jaw up off the floor, I called him back and said, 'Do you have any idea how rare those things are? Stop digging!' And then I called Bob Dott, of the University of Wisconsin-Madison, who is the godfather of Cambrian sediments in the midwest. We went out to the quarry in the summer of 2000, and now Bob and Dan are coauthors on the paper," which appeared in the February 2002 issue of *Geology*. □—*DS*

Top: Three jellyfish impressions and part of a fourth. Notice the second set of ripples within one impression, indicating that it was resubmerged under a calmer tide. (The broader the ripples, the more energetic the water that made them.)

Inset: The ridges radiating out from the center of this fossil are sediment-filled cracks that opened in the dead jellyfish as it dried out, so this one was clearly exposed to the air for some time.

Definitely an "E-Ticket"

The prelaunch configuration of GRACE's twin orbiters, which were nicknamed Tom and Jerry, looked like a Borg telephone booth.

Twin satellites took off on the ultimate roller-coaster ride on March 17, when the GRACE (Gravity Recovery and Climate Experiment) blasted into a polar orbit from Russia's Plesetsk Cosmodrome. Like cars on a roller coaster, GRACE will speed up on the "downhill" stretches where concentrations of mass make Earth's gravitational field stronger. The lead spacecraft will feel the effect first, and pull slightly away from the trailing one. And, when the lead spacecraft passes over a lower-mass region later on, it will be the first to slow down as it coasts back "uphill." (The effect is incredibly subtle, of

The Circle of Light

A spherical glass bead, no thicker than this page, makes a highly efficient laser that could be a boon to the telecommunications industry. Professor of Applied Physics Kerry Vahala (BS '80, MS '81, PhD '85) and grad students Sean Spillane and Tobias Kippenberg (MS '00) melted a standard fiber-optic wire to make the bead, which they mated to another fiber-optic wire stretched thin. The laser is especially efficient—1,000 times more so than previous devices—because of the way it stores light inside the microsphere, or resonator, as well as the manner in which the wire permits efficient coupling of light into the sphere.

The light travels around the sphere in a ring-shaped orbit and, over hundreds of thousands of orbits, an extreme concentration of optical power can accumulate. In this way, very weak signals applied to the sphere from the fiber-optic wire can build to enormous intensities within the sphere itself. At these power levels, the atomic arrangements within the glass are distorted, resulting in a process called Raman emission and lasing. Because Raman lasers require enormous intensities to function, they are usually power-hungry devices. Normal Raman lasers turn on "with a shout"—these new devices require "only a whisper."

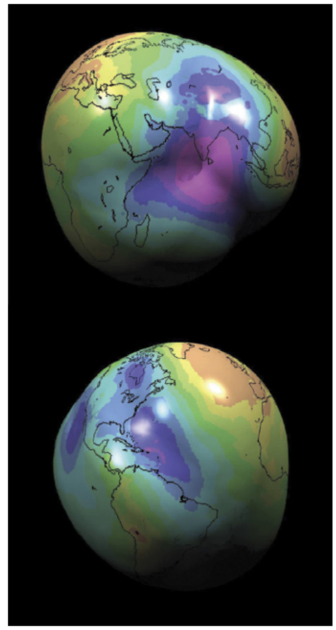
RIDE

course: picture measuring the change in distance between two cars on the 405, one in San Diego and one in L.A., to the accuracy of the diameter of a soot particle from a tailpipe.) The spacecraft do this with JPL-built microwave-based range-finding systems and Global Positioning System (GPS) sensors that will improve existing global gravity maps a hundredfold.

Over GRACE's five-year mission, it will help track melting glaciers in Antarctica, map deep ocean currents, and even measure the seasonal changes in the amount of water stored in underground aquifers. And, of course, it will keep an eye on the flow of molten rock in Earth's mantle, giving us a better insight into the "conveyor belts" that are ramming India into Asia while ripping California apart.

GRACE is a joint project of NASA and DLR, the German space agency. JPL manages the U.S. portion of the project. JPL, the University of Texas, and Germany's Earth Research Center (GFZ) are processing the data. For more info, see http://www.csr.utexas.edu/grace. —*DS*

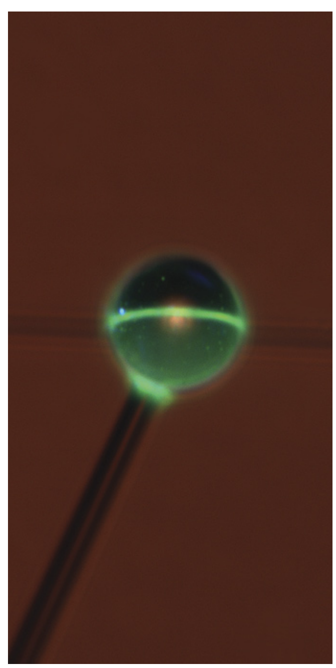
Below: Earth's geoid—the imaginary surface on which the pull of gravity is equal everywhere—resembles a stress-busting squeeze toy.



Central to this breakthrough was the ability to couple directly to the ring orbits, or whispering-gallery modes, of the sphere while preserving its exquisite perfection in terms of its ability to store and concentrate light. The tapered optical fiber achieved near-perfect coupling efficiencies, with negligible loss, both to and from the sphere.

Because Raman lasers and amplifiers can operate over a very broad range of wavelengths, they allow other lasers to reach previously inaccessible wavelength bands. For example, Raman amplifiers are now used widely in commercial long-distance fiber communications systems because of this wavelength flexibility. And, through a process called cascading, one Raman laser can pump another to generate a whole series of wavelengths in a kind of domino effect. More generally, cascading can be used to extend the wavelength range of other lasers into difficult-to-access wavelength bands for sensing or other purposes.

The work appeared in the February 7 issue of *Nature*, and can be found online at www.its.caltech.edu/~vahalagr. —*RT*



Right: A green laser beam whizzes around a microsphere's equator.

MINDING YOUR POLY-P'S AND Q'S

Huntington's disease is a cruel disorder, destroying nerve cells in the brain and, over time, robbing an individual of the ability to walk, talk, and eat. As yet, there is no cure or effective treatment for this hereditary condition. The end result, then, is death, caused by such complications as infection or heart failure. But now Professor of Biology Paul Patterson, postdoc Ali Khoshnan, and research assistant Jan Ko have come one step closer to understanding how Huntington's disease develops and how it can be stopped. In a paper published in the January 22 issue of the *Proceedings of the National Academy of Sciences*, they describe how they used antibodies to block the effects of the disease in cultured cells.

Huntington's disease is caused by a mutation in a protein called huntingtin, or htt, in which a site known as polyQ on the htt protein gets expanded. This mutation normally kills the afflicted cell. Khoshnan and his colleagues made an antibody that binds to the polyQ site, along with another antibody that binds to a different site, called polyP. The idea was to block either of these sites and see whether the toxic effects of mutant htt, which kills nerve cells in the brain, could be blocked.

"We knew that the polyQ site was critical because when it is expanded by mutation it causes Huntington's," says Patterson. "It was also known that the polyP site on htt might be important for interfering with the functions of other proteins." The investigators produced a modified version of the antibodies that would allow them to be produced inside cells that also carry the toxic, mutant htt. They found that cells producing the antibody against the polyP site were unaffected by the mutant protein. In striking contrast, when cells were induced to produce the antibody against the polyQ site, htt's toxicity was enhanced and the cells died even faster.

It may be that the polyQ antibody stabilizes a shape of the mutant htt protein in its most deadly form. Most important, though, says Patterson, is that the survival of the polyP-antibody-producing cells may indicate that it is the polyP site that actually gives mutant htt its cell-killing ability, so covering the site with a molecular Band-Aid saves the cell. "Or, an alternative interpretation is that the binding of the antibody preserves the protein in a non-toxic shape," he says.

The researchers have two goals in mind with their work: elucidating the mechanism of neuronal death caused by mutant htt, and devising molecular strategies for blocking its toxic effects. "Potentially, this knowledge could be useful in designing a therapeutic drug, one that covers up that part of the mutant protein that kills healthy cells," says Patterson. "The next stage of the work will be to deliver this antibody into the brains of mice that carry the human mutant gene and that have developed motor symptoms that are related to the disease. We want to see if this antibody can rescue these mice, even after they show signs of the disease. These experiments are, however, just beginning." □—*MW*

¡Uvas, No; Libros, Sí!

In this, the centenary year of Steinbeck's birth, the California Council for the Humanities, chaired by Associate Professor of History William Deverell, is urging everyone in the state to read and reflect on *The Grapes of Wrath*. The project kicks off in June so that people will be ready to participate in the discussions, screenings, and so on at the Huntington and other libraries statewide come October. "It promises to be great fun and illuminating at the same time," says Deverell.

The Cause of Many Effects

Ray Feeney (BS '75) has five Academy Awards sitting on his desk. You remember his work from *Terminator 2*, right? And *Independence Day*? You don't? Well, that's not surprising. Four are Scientific and Engineering Awards for advances in visual-effects technology, and the fifth is the John A. Bonner Medal of Commendation for his body of work, presented to him this March. He's a little leery of calling the Bonner medal a lifetime achievement award, as he's the youngest person to receive it by a good 20 years or so. But it does give some idea of where the industry would be without him.

When Feeney started working in Hollywood, the art of creating flying saucers hadn't evolved that much beyond hanging scale models on fishing line. The paint jobs were getting more sophisticated, of course, but the models still had to be photographed frame by frame, and the models and the camera manually repositioned between each exposure. So for his summer job in 1974, he and fellow Techer Bill Holland (BS '77) built a motion-control camera system for special-effects wizard Robert Abel. A basic

In other Hollywood news, on March 20 the Museum of Television and Radio hosted a panel, organized by the Sloane Foundation and the American Film Institute, to discuss the manner in which science and scientists are portrayed on film these days. From left are: Brian Greene, author of *The Elegant Universe*; James V. Hart, screenwriter for *Contact*; Caltech president David Baltimore; actor Dustin Hoffman (*Outbreak*, *Rain Man*); moderator Jean Oppenheimer, film critic; Jared Diamond, professor of physiology at UCLA and Pulitzer Prize-winning author of *Guns, Germs, and Steel: the Fates of Human Societies*; Sylvia Nasar, author of *A Beautiful Mind*; Jonah Nolan, author of *Memento*; Sarah Bottjer, professor of neurobiology at USC; and Simon Wells, director of *The Time Machine*.

motion-control system steers the camera along a very reproducible path so that you can make multiple passes with it, each time photographing different elements. When the film is put together, it will look as if everything was shot in a single pass. More elaborate systems coordinate the movements of scale models, two-dimensional art, and the camera—enabling it to fly, for example, through the midst of a fleet of starships orbiting a planet. (Not that the system they built was ever used for that purpose, says Feeney. "In the early days, the primary applications were commercials. Budgets on commercials were $600,000 to $1,000,000 for 30 seconds, whereas movie budgets couldn't sustain that many dollars per frame.") The computer revolution was just getting under way, and Feeney and Holland thought it would be a good challenge to try to use a computer to drive the system. "We were horrified at what they were doing by hand," Feeney recalls. "They had automated the precision and repeatability, but were figuring out all the numbers on a mechanical calculator and writing them down. Obviously computers were ideal for enhancing the process." One thing led to another, and by the next summer they had built two more systems, including one of the first to be entirely controlled by a minicomputer—gotten as surplus from a bankrupt manufacturer called Redcor in Chatsworth. Feeney, Holland, and 10 other people shared an Academy Award in 1988 "for their individual contributions and the collective advancements… in the field of motion control technology."

Holland went to work for Hewlett-Packard after graduation, while Feeney stayed on with Abel. Feeney had always had a career in Hollywood as his goal—

Feeney in the conference room at RFX. Posters (this one signed by Arnold) are common souvenirs in the movie business, but all good Techers prefer toys! Every one of these action figures owes its existence to special effects.

Feeney as an undergrad with one of his and Holland's computer-controlled camera stands. This one was used for animating logos for commercials. The camera (visible at far right over Feeney's shoulder) points at an illuminated glass table, on which artwork and colored gels were placed to be photographed.

"When I was at Caltech I was a photographer for the yearbook and the newspaper, and discovered when I wanted to work in Hollywood that anyone interested in photography started as an intern or a driver, just trying to get in, and I also discovered at Caltech that as an engineering major I got paid very little to work over the summer for a professor. So when I tried to get going in Hollywood, I came in as an engineer, and when I was trying to work around Caltech, I would work as a photographer."

Star Wars came out in 1977, and motion-control technology entered its heyday. At the same time, computer graphics, or CGI, was taking its first significant steps. *Tron* would come out in 1982, and Robert Abel would provide some of the effects for it. Feeney, however, had gone on to found his own company, RFX, Inc., in 1978. "A lot of the work was being done on VAX-sized computers, but in 1983 Silicon Graphics came out with their first workstation, and we got involved with them. They were primarily designing and building equipment for scientific and engineering uses—universities and government projects—and RFX was pretty much responsible for their adoption into the motion-picture industry."

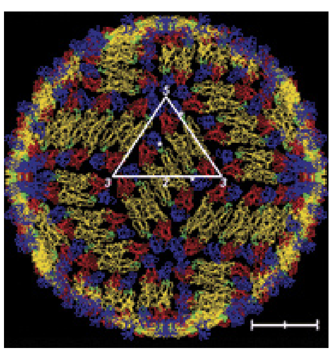
Now people could "sweeten" space battles with digital laser beams, and even create an entire object in the computer. But special-effects scenes were still assembled photochemically in an optical printer. Many strips of film, each containing one or more elements, would be run through the printer in the proper order to create the final composite. So to be able to get that blaster ray out of the computer and into the bad guy's chest, RFX helped to develop the Solitaire Film Recorder, which converted digital data into image frames and then output them on film stock. This resulted in Feeney's second award, shared with Richard Keeney and Richard Lundell of Management Graphics, Inc., in 1991.

Computers, of course, kept getting faster and better, and by the late '80s it was possible to compose an entire scene in silicon rather than on film. This led to the converse problem: now you had to get the live actor, or at least the image thereof, into the machine. This was really two problems, with the second being how to separate the live actor from the live background. The first problem was licked by scanning the film frame-by-frame into the computer, using CCD arrays like those that would become standard in today's digital cameras. In 1994, this netted Feeney his third award, along with Will McCown (BS '77, MS '78) and Bill Bishop of RFX, and with Les Dittert of Pacific Data Images. The second problem was solved by radically expanding the blue-screen technology used to place a weather map behind your favorite meteorologist. The resulting software package, christened Cinefusion, also won in '94, with the Academy honoring Bishop, Feeney, and three people from Ultimatte, the company that originally developed the video blue-screen system.

"We helped to build the computer-graphics department at Lucasfilms for *The Abyss* and *Terminator 2*," says Feeney. "The CGI elements for *The Abyss* were composited in a traditional optical printer. *T2* was entirely digitally composited. It was at that moment that the technology came of age. You could take your favorite producer to that movie and say, 'See, whatever you can imagine, we can do.' Stories that had been languishing on the shelf, because there was just no practical way to visualize them, could now be made. All the rules changed.

"Another watershed event was *Independence Day*. The other projects had one 'key element'—the water snake in *The Abyss*; the silver, molten guy in *T2*; the photo-real dinosaurs in *Jurassic Park*. But in *ID4*, what was different was the sheer number of elements, the complexity. It was like telling the story of the Battle of Britain without actually hiring a bunch of Spitfires. *ID4* was one of the first major movies to use a software package we wrote called Chalice, which was later used on *Titanic* and is the forerunner of some of the compositing tools in use today. Starting at *ID4*, I would say, it became less about the hardware and more about software. *T2* was mainly about hardware problems to be solved—film scanning, film recording. In *ID4* it was more about software tools to manage complexity.

"I find it fascinating to try to follow the evolution of science and technology in other industries, and to try to figure out how those tech-nologies can be brought over to the motion-picture indus-try. Being a technically oriented but motion-picture-driven person, this is the best career for me. The work you do is seen by millions of people; they've never heard of you, but one or two people can change how movies are made." □—*DS*



The glycoproteins on the dengue virus's exterior are arranged in an icosahedral symmetry (white). The scale bar is 100 Ångstroms, or one hundred-millionth of a meter.

Mapping the Envelope

Scientists at Caltech and Purdue University have determined the fine-detail structure of the virus that causes dengue fever. This could lead to newer and more focused strategies for devising a vaccine to protect the world against an illness that causes 20,000 deaths each year.

In the March 8 issue of *Cell*, James Strauss (PhD '67), the Bowles Professor of Biology; Richard Kuhn of Purdue, the lead author and a former postdoc in Strauss's lab; and Purdue's Michael Rossman and Timothy Baker describe the viral structure they obtained with a cryoelectron microscope. The detailed electron-density map shows the inner RNA core of the virus as well as the other spherical layers that cover it. At the surface is the glycoprotein scaffolding whose projections are thought to allow the virus to interact with a receptor and invade a host cell.

This is the first time the structure of one of the flaviviruses has been described, Strauss says. The flaviviruses include the yellow fever, West Nile, tick-borne encephalitis, and Japanese encephalitis viruses. All are enclosed with a glycoprotein outer layer. "Most viruses that cause serious illness are enveloped, including influenza, hantaviruses, West Nile virus, smallpox, and herpes—though not polio," Strauss says.

The dengue fever virus's glycoproteins are arranged in a very unusual manner. Details from the computer-generated images show a highly variegated structure of glycoprotein molecules that are evenly dispersed, but in a surprisingly complex pattern. "The proteins in the envelope are surrounded by their neighbors in more than one way. In most viruses with icosahedral symmetry, each protein always has the same arrangement of neighbors," Strauss explains.

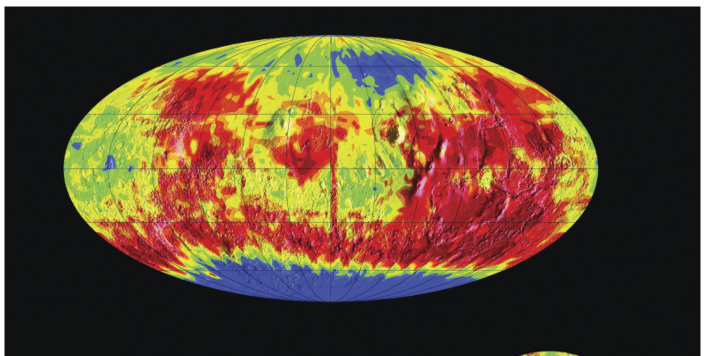
Strauss says it's still unclear what the odd symmetry will ultimately mean for future research aimed at controlling the disease, because the precise function of the glycoproteins' different structural domains are still unknown. Those that have been false-colored blue in the rendering at left are thought to be involved in receptor binding, and thus responsible for the virus's entry into a cell. The yellow structures are an elongated domain thought to be responsible for holding the scaffolding together; the red ones' function is not yet known.

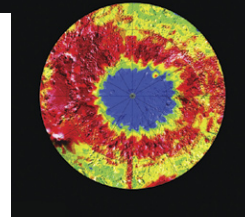
Hello, Rubipy Tuesday

The next time you stop by the Ath, try a Rubipy (pronounced roo-bippy, as in "bet your"). Named in honor of Harry Gray, Beckman Professor of Chemistry, it's a brilliant red organic compound of vodka, Cointreau, watermelon schnapps, and Midori. "Rubipy" is the Gray group's pet name for tris(2,2´-bipyridine) ruthenium(II), an electron-transfer molecule used in their research on artificial photosynthesis. What better way to get lit?

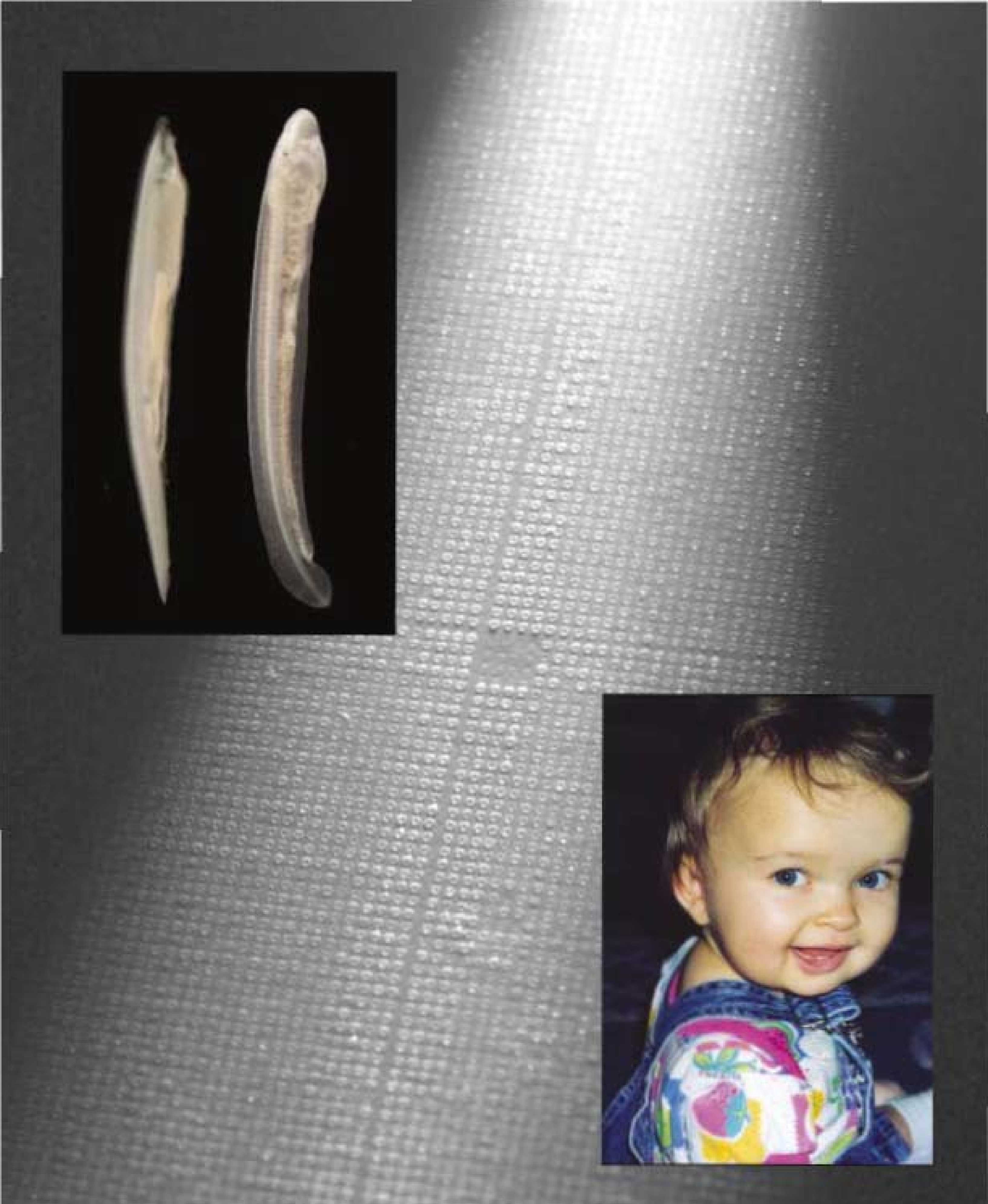
But a more detailed view of these structures is the beginning of a more informed strategy for a focused medical or pharmaceutical attack, Strauss says. "You can think of the protease inhibitors for HIV. Those in large part came from knowing the structure of the HIV enzymes you were trying to interfere with." Thus, the new work could lead to drugs that will bind to the virus to prevent it from entering the cell, or perhaps from reassembling once it is already inside the cell.

Dengue fever is a mosquito-spread disease that has been known for centuries, but was first isolated in the 1940s after it became a significant health concern for American forces in the Pacific theater. A worldwide problem, the disease is found throughout Latin America, the Caribbean, Southeast Asia, and India, and is currently at epidemic levels in Hawaii. Especially serious is a complication of dengue infection called dengue hemorrhagic fever, which is responsible for most of the deaths. The disease is a leading cause of infant mortality in Thailand, where there is an especially vigorous program to find an effective vaccine. □—*RT*





The Mars Odyssey's mapping mission is off to a flying start. Within days of its beginning routine data collection, a press conference was held at JPL to announce that ice probably permeates the Martian subsurface to a depth of at least one meter over a vast area extending from about 60° south latitude all the way down to the pole. Such an enormous reservoir of water ups the chances that life may have existed on Mars. The discovery was made with the Gamma Ray Spectrometer package, which found high levels of hydrogen (shown in blue above) in the soil. Meanwhile, an infrared camera called the Thermal EMission Imaging Sytem (THEMIS), was taking the first "night vision" pictures of Mars. The view at right shows a portion of the Hydaspsis Chaos (2° N, 29° W), which is believed to have formed by the sudden withdrawal of subsurface ice or water, causing the ground above to collapse. The chaos's outflow system encompasses Mars Pathfinder's landing site. In this image, fine-textured dust loses its heat more quickly after sunset and appears dark, while larger rocks hold their heat and appear bright. The mesas and plateaus are covered in dust while the rocks on their flanks are relatively dust-free, which may indicate they are still moving downslope. The inflow channel at the bottom of the image is about seven kilometers wide and 280 meters deep.



Tales of a Travelin' Cell

by Douglas L. Smith

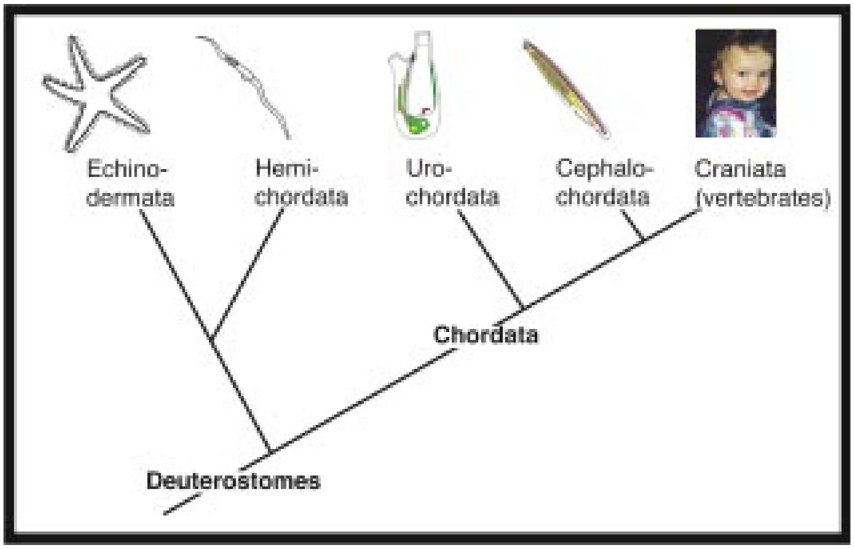
Top left: a juvenile amphioxus (left) and larval lamprey (right) look pretty similar, and very different from a human child. But lampreys are really much more like people than they are like amphioxuses. One big reason for this is a group of cells called the neural crest, some of whose genes (from a chicken) are seen in the background, arrayed in millimeter-sized doughnuts on a nylon filter.

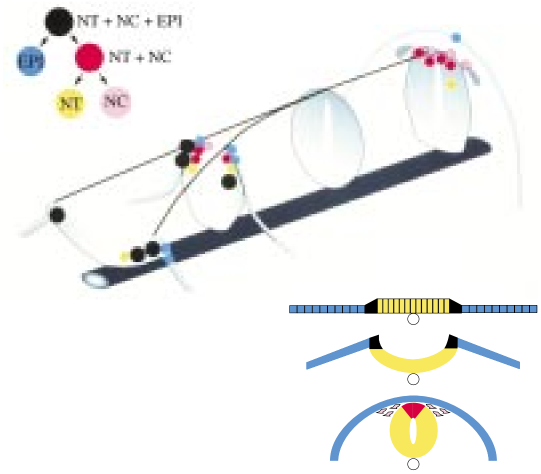
If Danny DeVito and Arnold Schwarzenegger can be twins, so too can the lamprey and the amphioxus—both are snakelike aquatic critters, but lampreys can be several feet long, while your average amphioxus tops out at a couple of inches. And if you looked at them when they were young, you'd swear they *were* twins. But the lampreys are vertebrates, albeit just barely—they are the simplest ones extant, and their backbones aren't even bone, but cartilage—and the amphioxus is the highest example of the next lowest branch of the chordate phylum. (The chordates are all animals with a hollow nerve cord down the back, regardless of whether they have a spinal column to keep it in.) The two species part paths as embryos when a group of cells called the neural crest appears in the lamprey, so Marianne Bronner-Fraser, the Ruddock Professor of Biology, studies those cells to address "two central questions in developmental biology: How do you build a complex adult organism from a single cell? And, how do species become different? Both are very difficult, very interesting questions."

The neural crest cells emerge from the nascent central nervous system—the brain and spinal cord—shortly after its formation. Their progeny fan out through the embryo to become most of the rest of the nervous system. These cells also form most of the skull and jaw bones—if it weren't for the neural crest, we (and cats and dogs and crocodiles and frogs and pelicans) wouldn't have faces. But only the vertebrates have them. "The amphioxus is our closest living invertebrate relative," says Bronner-Fraser. "It has a very nice nerve cord similar to, but much more primitive than, our spinal cord. Its head has structures called gill arches that, in vertebrates, fill with neural crest cells and become the jaws and facial structures. It fascinates me that the two embryos resemble each other so closely, but that the amphioxus lacks this one particular cell type."

Every embryo starts out as a single cell—a fertilized egg—that divides repeatedly to form a hollow ball of identical cells. In animals, the ball grows what looks like a belly button (an innie),

Our branch of the tree of life. The Chordata, or chordates, include fish, amphibians, reptiles, birds, and mammals in the vertebrate class. The amphioxus is one of the Cephalochordata, and the Urochordata include the sea squirts.





The main diagram shows the neural tube zipping itself shut from head to tail, with the embryo's head to the right. The neural fold is just getting started at the tail end of the diagram, while some neural crest cells up by the head have already taken their leave of the neural tube. The color codes show what developmental choices remain available to the cells along the way, with NT standing for neural tube, NC for neural crest, and EPI for epidermis. (Not all cells that end up the same choose their fate at the same time.) The inset at bottom right shows a series of cross sections through a single point along the neural tube as it closes, using the same color scheme.

and then something really amazing happens. The cells in the immediate vicinity of the navel plunge down through it to become a second layer of cells that expands to line the inside of the ball, like a balloon being inflated inside a bottle. This inner layer then subdivides to form a third layer, and the ball elongates to become a hollow cylinder. The outer layer is called the ectoderm, which will form the skin and the nervous system. The middle layer, the mesoderm, will become muscles and some organs, such as the heart and kidneys. The innermost layer, the endoderm, forms the viscera.

The neural crest cells, not surprisingly, come from the ectoderm. While the cells on the ectoderm's outskirts (shown in blue in the inset above) will become skin, the cells in the central region thicken and change shape, morphing from sugar cubes into soda cans (yellow). The soda cans are called the neural plate, and this transformation marks the beginning of the nervous system. Like a rug being pushed up against a wall, the ectoderm begins to fold up into two parallel ridges where the plate cells and skin cells meet, and the line of cells (black) on the crest of each ridge will become the neural crest cells. The flanking sheets of skin cells move toward each other as the neural plate sinks between them, until the neural plate has been rolled up into the neural tube, which will become the brain and spinal cord. The tube zips itself shut from the head to the tail, with the neural fold cells being the teeth in the zipper. But they don't all remain teeth for long—as soon as the tube closes, some of them opt to become neural crest cells and promptly hit the road. "This one group of cells gives rise to cells that are as different as the bone cells in your face and the nerve cells in your guts," says Bronner-Fraser. "How they do it is a fascinating question, and really reflective of what's going on in the fertilized egg, where you have one cell that can give rise to all the cell types in the body. How does a cell decide whether to become a bone cell or a nerve cell? And how does it know where to go?"

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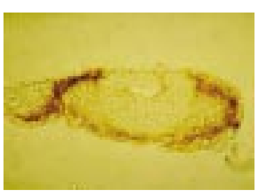
Or, for that matter, how does an ectoderm cell decide to become a neural crest cell in the first place? Since the cells always form at the boundary between the ectoderm and the neural plate, Bronner-Fraser wondered whether a process called induction was at work. Induction is "a kind of conversation between two tissues" that results in the creation of a new cell type, and is a staple of embryology. Signaling molecules from one tissue (the skin) bind to receptors in an adjoining tissue (the neural plate), turning on genes in the receiving cells that transform them into a third tissue (the crest).

To find out whether induction was at work in the neural crest, postdoc Mark Selleck (now a professor at USC) put skin cells and neural plate cells together in a culture dish to see what would happen. And sure enough, neural crest cells formed at the junction. He repeated the experiment on chicken embryos, grafting little slivers of neural plate tissue under the skin in places it didn't belong. Says Bronner-Fraser, "We call this cut-and-paste biology. We do most of our work on chickens, because it's very easy to open up the egg, cut out bits of tissue, and move them around to different places. Then you can close the egg

Left: Postdoc Martín García-Castro demonstrates how to inject a chicken embryo under the microscope.



Above: This piece of neural plate tissue was laid on a piece of skin in a culture dish. Neural crest cells (dark stain) formed wherever the two tissues touched.

back up and the embryo will continue to develop very happily. So we can see if the cells will do something different if they're in a different place." But the result was the same—any time the two tissues met, they made neural crest cells. So the next step was to zero in on the responsible molecules.

Many signaling molecules are proteins, as are the receptor molecules, and a protein is manufactured in any given cell only when that cell's copy of the gene containing that protein's fabrication instructions is turned on. The interplay of protein and gene, stimulating the production of some proteins and inhibiting others, gives rise to the astonishing complexity of cells, and thus of life. Each protein and its corresponding gene share the same name, so to keep them straight, the genes' names are rendered in italics.

"There are basically two strategies available," says Bronner-Fraser. "We can try to discover a brand-new molecule. Or we can just look in the refrigerator and pull out all the molecules that are known to send similar signals in other situations, and see if they're doing the job here as well. It used to be that everyone was finding new molecules right and left. Every journal you'd go to, there'd be reports of proteins with weird names like 'sonic hedgehog,' or called by various initials—BMP, FGF, and so forth. We envisioned that there were thousands of signal paths, each with its own protein, and everyone would get to discover one. I think the most disappointing discovery in the last five years has been the fact that there may be only a small number of signaling molecules that get used over and over and over again. Now every time you look in a journal, you see the same protein doing something different. So maybe a signal that somebody else discovered helps form the ear is important here, too. We call this the 'usual suspects' approach."

However, no jury will convict unless the suspect is in the right place at the right time. One such protein, called Wnt (pronounced "wint"), was found by postdoc Martín García-Castro to hang out in skin cells. The Wnts are actually a family of closely related molecules that are the vertebrate equivalents of a fruit-fly signaling molecule called "wingless." (Three guesses what goes wrong when you tamper with it.) The people who found the vertebrate version called it "int," and when the fruit-fly connection was made, the "W" was added to the name.

But Wnt could be an innocent bystander—it might be doing something else, or nothing at all. So García-Castro tried blocking its signal to see if the neural crest cells would form without it. By flooding the cells with a Wnt inhibitor, he overloaded its receptors and basically crashed the

A gene need only be active at a very low level to be involved in a cellular change, so its mRNA may only show up once or twice. In order to be sure of finding such a needle, you have to pitch a ton of hay.

system. And behold, no neural crest cells.

Just one more piece of evidence was needed to nail down the case—was Wnt on its own sufficient to make neural crest cells? To find out, García-Castro added it to bits of neural plate tissue in a culture dish. The neural crest cells appeared and promptly set out for a stroll, just as if they were back home in the embryo. And to be sure he wasn't falling victim to cellular identity fraud, he checked their IDs with several molecular markers.

The fact that Wnt is both necessary and sufficient to make neural crest cells doesn't mean that it is the only thing involved in an actual organism. "This is just the tip of the iceberg," says Bronner-Fraser. "To generate a different cell type, all kinds of changes must occur within that cell." Each of those changes is reflected by changes in the inventory of proteins found in the cell, each of which is the product of some gene. So postdoc Laura Gammill is trying to catalog the lot of them, using techniques developed for genomics.

Right: Neural crest cells (dark) are springing into being along this chicken embryo's neural tube, except for where a Wnt inhibitor was applied. The cells were made visible with a dye molecule attached to a DNA sequence that was designed to bind to the mRNA for *slug*, a gene known to be active in neural crest cells. Whatever cells have that gene turned on will produce that mRNA and take up the dye. Below: Adding Wnt to neural plate tissue in a culture dish (right) was like firing a starter's pistol: a whole bunch of cells suddenly took off for parts unknown. No Wnt, no wanderlust (left); the cells remained neural plate cells and stayed home. Both samples were stained with HNK-1, a non-specific agent that binds to many tissue types.

Genomics, also called the "new biology," uses highly automated equipment to look at thousands of genes at a time and analyze their sequences or figure out their functions. In this case, Gammill collected all of the mRNA from some chicken embryos that were forming the neural crest. (Messenger RNA, or mRNA, is the molecule made by an activated gene that carries the gene's instructions to the cellular machinery.) She then made DNA copies of each piece of mRNA, and inserted each copy into a bacterium. Each bacterium was separated out into its own culture dish, and grown until its zillions of offspring had churned out usable amounts of that mRNA copy. Then a robot in the Genomics Technology Facility at the Beckman Institute daubed a little dollop from each dish onto hybridization filters, which are nylon membranes $8\frac{1}{2}$ inches square. Biologists call this a "macroarray," and they're not kidding—the Q-Bot can do 15 filters at a time (it takes several hours), and each one holds 18,432 spots. Gammill used eight filters, or 150,000 spots.

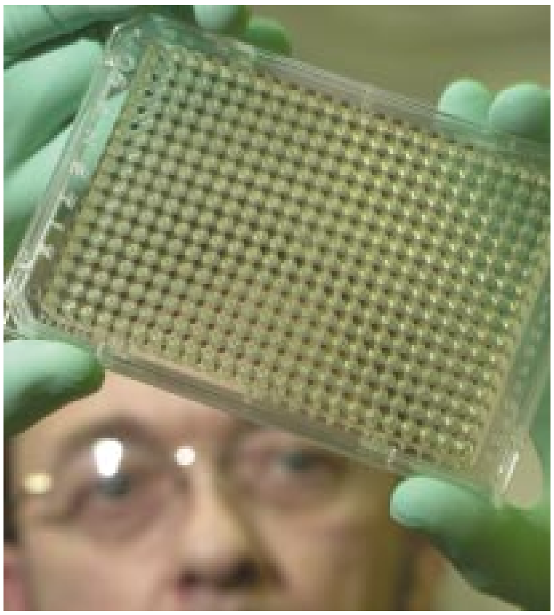
Only a few of these spots will hold anything interesting. You'll get several thousand spots containing a copy of a gene that does some vital but irrelevant thing like enabling the cell to divide, for example. That gene is turned on full blast, and the cell is cranking out its corresponding mRNA. But a gene need only be active at a very low level to be involved in a cellular change, so its mRNA may only show up once or twice. In order to be sure of finding such a needle, you have to pitch a ton of hay.

Thankfully, there's a way to toss out most of the hay. DNA is a double-stranded molecule, with the letters that contain the genetic information arrayed in sequence along one strand. Each letter on this strand will bind only to its complementary letter on the other strand—As with Ts, and Cs with Gs. So Gammill sandwiched some skin and neural plate tissue together to induce neural crest cell formation, extracted the tissues' mRNAs, and made single-stranded DNA copies of them. Then she made a separate pool of single-stranded DNA molecules whose letters were complementary to mRNAs she had taken from skin cells and neural plate cells that were not in contact with each other. Any gene active in both the neural crest cells and the skin or neural plate cells—the common, uninteresting genes—would have a DNA strand in each pool. Stirring the two together allowed each such strand to find and bind to its mate. This double-stranded DNA was separated out, leaving the single-stranded neural crest DNA, which she then used to search for spots of matching mRNA on the filters.

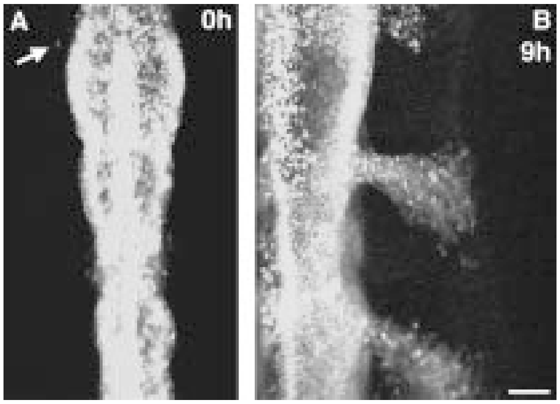
Says Bronner-Fraser, "We went into this thinking, 'Well, when you generate a new cell type, what would you expect? Are 1,000 genes involved in this process, or 2,000?' We had no idea what the scale would be." She now thinks there are considerably fewer genes involved, but nobody really knows for sure.

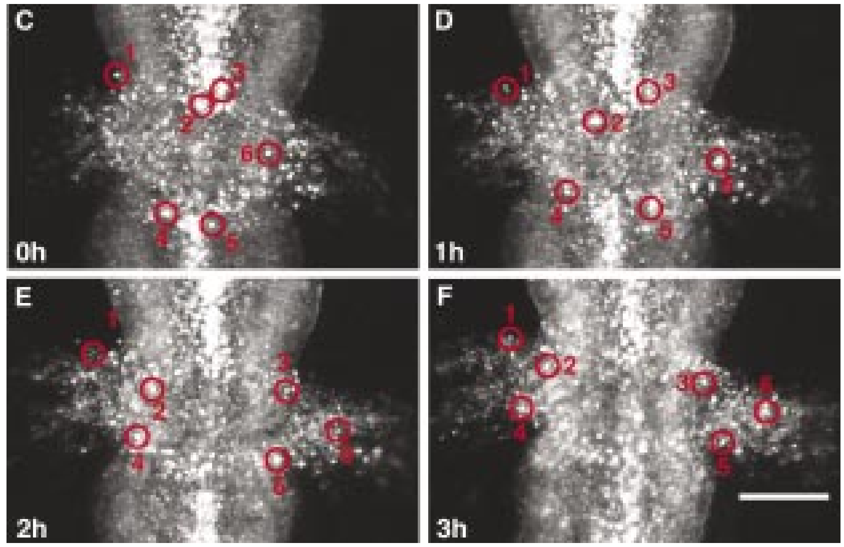
Gammill has found about 100 genes so far, which she is running through a database to see if they resemble ones of known function. She comes up empty about 10 percent of the time, but many of the ones she's identified fall into groups related to cell proliferation and locomotion. Says Bronner-Fraser, "It's as if these cells are being generated so that they can quickly become migratory cells, which makes sense in hindsight, because the first thing they do is leave the neural tube." In other words, they're born with their knapsacks packed. They're good to go.

These itinerant cells thrust out long filipods—literally "thread feet"—but not much is known about how they propel themselves. Says Bronner-Fraser, "The classic way to study how cells move is to put fibroblast cells—a type of cell found in connective tissue—in a flat dish, which probably doesn't relate really well to how cells move in embryos." Some of the genes Gammill found make proteins in the cytoskeleton, which is the scaffolding within a cell that gives it its shape. Changing from a regimented, immobile brick in a wall of tissue to a freewheeling, self-propelled blob in a lava lamp "obviously requires changes in the underlying structure of the cell, but it starts happening much earlier than we realized," Gammill says. Other genes she found encode proteins in the extracellular matrix, which is the gelatinous goop outside the cells that the neural crest cells grab onto in order to pull themselves along. "We do know that if you block some of these interactions, the cells don't do as well, but a lot of times they still get to the end point," Bronner-Fraser says. "So what makes them motile



Right: Research Assistant Ted Biondi of the Genomics Technology Facility prepares plates for the Q-Bot. Each plate has 384 wells, each of which contains mRNA from a different culture dish. The Q-Bot picks up and deposits samples from all the wells at once—still, it takes 48 plates to cover a filter. Below: Postdoc Laura Gammill watches the Q-Bot at work in its sterile cabinet.





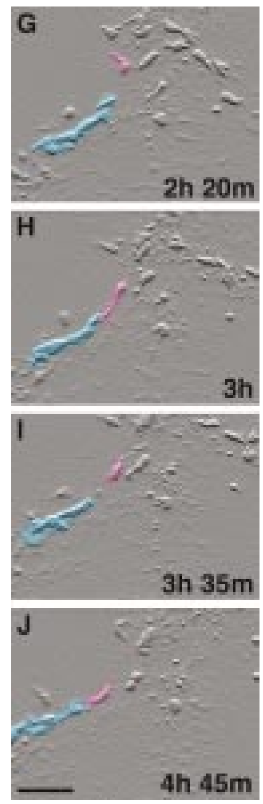
The scale bars are (clockwise, from above) 100, 100, and 50 microns (millionths of a meter), respectively.

is a really big question. I'm very interested in it, but I don't quite know how to get at it yet."

How they find their way is another good question. Bronner-Fraser is collaborating on that one with her hyphenate, Scott Fraser, the Rosen Professor of Biology and principal investigator at the Beckman Institute's Biological Imaging Resource Center, who makes movies of embryonic cells on the march. (In fact, his lab has developed a whole set of techniques for watching cells go about their business deep within opaque embryos, but that's another article.) Any individual cell can be tracked for as long as it remains on screen, and if you watch a lot of these movies, you'll notice that one cell frequently leads the way, making a path that the others follow. Says Fraser, "Sometimes they follow one another in a polite, well-behaved line—in what we call the 'English queue' mode—and sometimes they just climb and claw all over one another to get to the front of the line. We call that the 'professional wrestler' mode." Some of the Fraser lab's movies are on the Web at http://bioimaging.caltech.edu/neuralcrestpk.html; try movies 3 and 4. Says Bronner-Fraser, "Often, you'll see cells link to one another as if they're communicating. We didn't know they did that before." This leads to a whole new set of questions: What happens if you wipe out the leader? Will the next cell in line still know where to go? Will a new leader step in? "We went in thinking, 'These cells are smart. They always go to the right places.' Well, it turns out that a lot of the cues that keep them on track are not things that are saying, 'Hey, come this way,' but things saying, 'Stay away!'"

For example, postdoc Cathy Krull in Bronner-Fraser's lab (now a professor at the University of Missouri) and Rusty Lansford, a senior research fellow in Fraser's lab, have discovered that an inhibitor molecule called ephrin funnels the outgoing neural crest cells onto a set of prescribed paths as they exit the neural tube. Without ephrin (or with an overdose of it), the neural crest cells overrun the surrounding tissue like a horde of lemmings. And Bronner-Fraser postdoc Maria Elena de Bellard has found that another inhibitor, called slit, keeps the wrong set of neural crest cells out of the viscera so that the right ones can enter and become the autonomic nerves in charge of your digestive tract. It now appears that neural crest cells can go anywhere they please unless they are specifically excluded, and, left to their own devices, they go wandering willy-nilly and wind up in all the wrong places. So they aren't smart cells that know where to go, but dumb cells that react to their environments.

In these photo sequences from the Fraser lab, the neural crest cells are bright against the background tissue. What starts with a single neural crest cell (arrowed) in A becomes a mass exodus nine hours later in B. But even then you can track the cell(s) of your choice, as shown by the numbered circles in C through F. In G through J, the cells have been "embossed" to make them easier to see. As a column of cells (blue) marches off, a nearby cell (magenta) reaches out to touch the last cell in line, and then joins the parade.



Postdoc David McCauley wades through a stream in northern Michigan in search of spawning lampreys. The lampreys are less concerned about being caught than finding a mate, so they are easily snagged by hand.

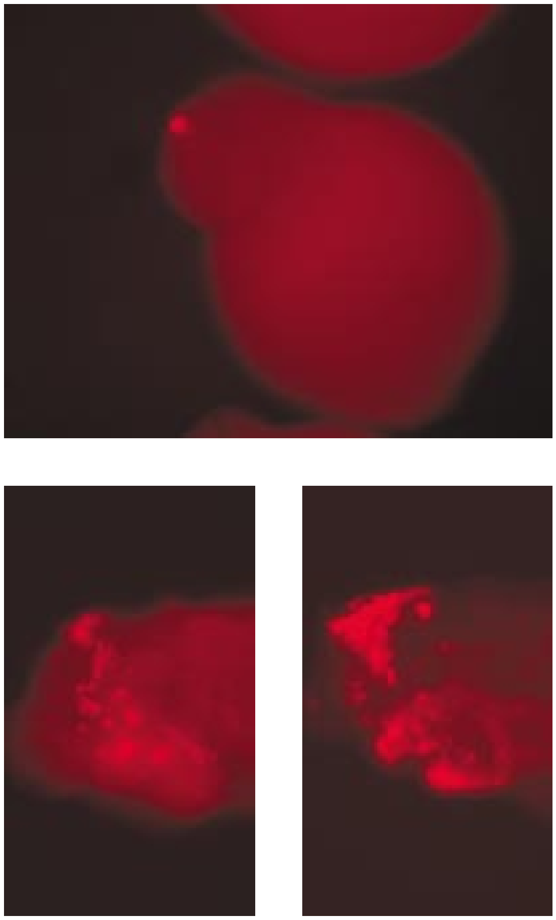
Which may explain what happens when neural crest cells turn bad. "Many invasive cancers arise from cells of a neural-crest origin," says Bronner-Fraser. For example, some neural crest cells form the pigment cells, or melanocytes, in your skin. When they run amok, you get melanoma, which is a malignant cancer with a nasty tendency to spread. And there's neurofibromatosis, which some people think is what the so-called Elephant Man had. "An amazing array of tumors arise from these cells, and the fact that they are so migratory in the embryo makes you wonder if this contributes to their ability to become metastatic later. Some labs are looking at neural-crest-derived tumors and comparing their properties to neural crest cells, and it turns out that the worst tumors are the ones that most closely resemble the embryonic cells. We're doing the basic science on the neural crest cells, providing a point of comparison." Perhaps one reason for those cancers' invasiveness is that the molecular "Keep Out!" signs aren't present in adults. "More happens than that. Tumor cells can actually break down barriers that they may not have been able to as embryonic cells, so they're like superembryonic cells. But the fact that the environment is not embryonic probably contributes."

When the cell *is* in its proper environment, Bronner-Fraser says, "it's very heartening that we're finding a manageable number of genes, because we can now go back and test the function of the most interesting ones using classical biological techniques." In other words, the researchers can inject the gene back into the embryo and see what it does, or block the protein's receptors and see what goes wrong, just as García-Castro did with Wnt. Or they can use various methods to turn the gene on and off and see what happens, like flicking a light switch to see which outlet it controls. And the gene array on a filter can be reused indefinitely, so you can go back to that filter at any time to try something new. Then, when you find a gene that intrigues you, you can go to the corresponding culture dish, where you now have it on tap.

A lamprey and a two-foot lake trout.

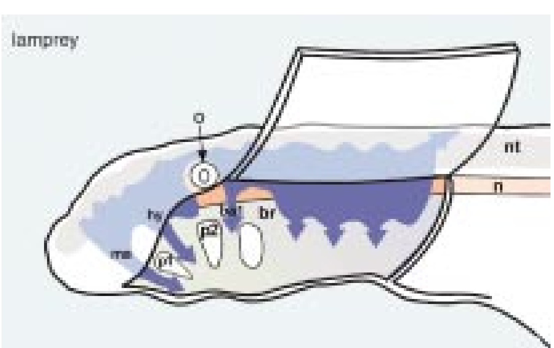
Bronner-Fraser plans to make a series of genomic snapshots spanning the migration process. "We've only looked at the cells as they're getting ready to migrate, but we can ask what happens when they're actively migrating. Or when they're about to stop migrating—that is, how do they know when they've arrived? Maybe the stop receptors are missing on cancer cells. Genomics is an incredible tool that lets us explore the system in a much more complex way than we were able to before. It's very exciting because we can get answers that just weren't available to us even two years ago. So it's a great time to be in biology."

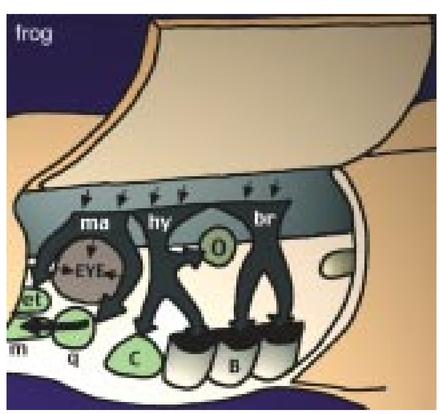
Beyond following the neural crest cells' life cycle, Bronner-Fraser's lab is trying to answer the larger question of how these cells evolved in the first place. This involves looking at the lamprey, which has them, and the amphioxus, which doesn't. Lampreys are the vampires of the high seas—they attach themselves to fish with their suction-cup-like mouths and drink their fill of blood before moving on. Says Bronner-Fraser, "They're slimy and they're horrible and they don't have much of a forebrain and they have this circular mouth, with teeth all around the edges. I wouldn't want to swim with them." But they do have one redeeming quality. "I gave a departmental seminar once," she recalls, "and Seymour Benzer [Boswell Professor of Neuroscience,



Right: In the developmental-biology equivalent of putting radio collars on cells, McCauley injected a dye called DiI into the neural-crest-forming region in the back of the head of a lamprey embryo in the early stages of neural-crest-cell migration (top). Two days' time (bottom left) finds the cells en route to the mouth, which is at the bottom of the picture. Six days after injection (bottom right), some cells have reached their destination—the upper and lower lips, which they fill like a hand in a sock puppet. In higher vertebrates, these cells would become the jaws.

Below: The neural-crest-cell migration routes in lamprey and frog embryos. Both have mandibular (ma), hyoid (hy) and branchial (br) streams, so named for their destinations. The first two streams become facial cartilage in the lamprey and facial bones (green) in the frog. In both species, the hyoid and branchial streams surround the otic vesicle (O), which becomes the ear canal. The branchial streams become the branchial arches, a subset of the gill arches. (The "ba1" stream in the lamprey goes to the first, or headmost, branchial arch, labeled "B" in the frog.) Pouches of tissue, two of which are labeled "p1" and "p2" in the lamprey, lie between the gill arches. The neural tube is marked "nt," and "n" is the notochord, a stiff rod of cells found in all chordate embryos that acts as the backbone. Lamprey drawing by David McCauley; frog drawing by Senior Research Fellow Carole LaBonne after Roberto Mayor et al. "Development of Neural Crest in *Xenopus*," *Current Topics in Developmental Biology*, vol. 43, 1999, Academic Press.



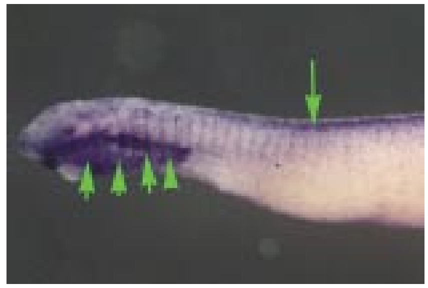


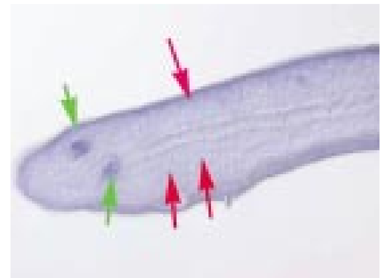
Emeritus] got really excited. He said, 'I didn't know you worked with lampreys. Did you know that they're a delicacy?' It turns out that in Portugal they actually eat these things." Benzer even sent her some recipes, which she hasn't yet had the nerve to try.

Lampreys spawn in cold freshwater streams, and in the early 20th century they invaded the upper Great Lakes, where they've been wreaking havoc ever since. So postdoc David McCauley spends every June at the Great Lakes Fishery Commission's research station at Hammond Bay on the shores of Lake Huron. Says McCauley, "Their mission is to control the lamprey, so it's kind of odd—I'm trying to figure out how to raise them, while they're trying to kill them." Collecting lampreys is easy, he says. "The males build nests by moving rocks on the streambeds with their mouths—it's amazing how big a rock they can move—so you just walk down the middle of the stream and you'll come upon three or four lampreys in this shallow depression, the spawning nest, and you just grab 'em." He shucks all the eggs and sperm into one beaker—it's sort of like milking cows—swirls the beaker a few times and lets it sit for about 15 minutes. The fertilized eggs are about a millimeter in diameter, opaque, white, and yolky, so they're not the easiest things to work with. "But the nice thing is, they develop very slowly," says Bronner-Fraser. "Most organisms studied in developmental labs—zebra fish, for example—develop really fast. So if you're interested in a particular stage, you might have to stay up all night to get to the stage you want. These guys develop so slowly that you could sleep for 12 hours and come back and still be all right."

The progeny of neural crest cells

The green arrows show the different staining patterns for ***ap2*** in the lamprey (left) and amphioxus (right). In the lamprey, ***ap2*** appears in the neural tube (top) and gill arches (bottom). In the amphioxus, these structures are marked with red arrows, and ***ap2*** is found instead in the brain (upper arrow) and the pre-oral pit.





from different places along the neural tube wind up in different parts of the body, so McCauley traced their migration routes by injecting a dye called DiI into various locations down the length of the tube. DiI gets soaked up by the cell membrane from the extracellular fluid, so you can just squirt a tiny droplet under the skin—much easier than trying to get a hypodermic needle into an individual cell! Similar experiments on frog embryos had been done by Andres Collazo (now at the House Ear Institute) when he was a postdoc with Scott Fraser and, says McCauley, "the way lamprey cells migrate is not so different. The structures they give rise to are different—lampreys have no jaws, so lamprey neural crest cells give rise to cartilage in the branchial arches instead—but there are similar populations of cells going to similar places. They just do different things when they get there." In other words, there's no gradual transition to neural-crest-cell-ness. The crest cells in the lowliest vertebrate have all the attributes of those in more sophisticated creatures.

Wading for amphioxuses in Florida. Linda Holland is second from right, with the white eyeshade.

So what happened between the amphioxus and the lamprey? Does the amphioxus also have the neural-crest-forming genes, and, if so, what are they doing? Grad student Daniel Meulemans found that a gene called *ap2*, which is essential to the formation of the neural-crest-derived facial bones and nerves, also shows up in the amphioxus. In fact, in the early stages of development, *ap2* does the same thing in both species—it's turned on in the epidermal cells that will become skin, but not those that will become the neural plate. Then it turns off for a while, and when it turns back on again, its role has changed. It shows up in the amphioxus's cerebral vesicle, which is what passes for a brain, and in the pre-oral pit, says Meulemans, "which is a weird gland that may be the amphioxus version of the pituitary."

"We found this to be true for almost everything that we looked at," says Bronner-Fraser. "It was as if the amphioxus had the whole array of genes that the vertebrates had, but they weren't using them in the same way." In order to make their new tissues, the vertebrates apparently co-opted existing genes and gave them new duties instead of creating new genes from scratch.

Just as lampreys draw McCauley to Lake Huron, Meulemans spends his summers in the wilds of Tampa, Florida, in search of his quarry. Adult amphioxuses live in shallow seawater, where they carpet the bottom, anchoring themselves in the mud by their tails and straining plankton from the murky water. To collect them, you need to filter feed as well—teams of people wade into chest-deep water armed with long-handled shovels, archaeologist-style sieves, and buckets. You shovel the mud into the sieve, and pick out the amphioxuses. "Tampa is the best place to

In 50 days, an amphioxus grows from a ball of cells to a mature couch potato, buried in mud up to its neck. Like a guy with an empty popcorn bowl, it gets up long enough to feed itself, rising to the tailward dashed line. It will even bestir itself enough to swim to a new spot now and then.

FIGURE NOT LICENSED
FOR WEB USE

Figures by Nancy J. Haver from pp. 370 and 371 of *Embryology: Constructing the Organism*, edited by Scott F. Gilbert and Anne M. Raunio, Sinauer Associates, 1997.

collect them in the U.S. because their population density is so high, and Nick and Linda Holland have worked out the ecology and know just where to get them," says Meulemans. "It's a very cool event—the whole U.S. and European amphioxus community shows up to harvest them."

The Hollands, who are at the Scripps Institution of Oceanography in La Jolla, are the deans of amphioxus research, and have developed an electrostimulation method to induce the amphioxuses to spawn on cue. Still, the technique only works during breeding time—at night during the summer. Says Meulemans, "Traditionally, you'd collect them every day, then zap them in the evening and hope they're in the mood. They only spawn once, so if they do, you throw them back into the ocean. And if they aren't in the mood, you try them again the next night." But last year, Meulemans discovered that they would continue to spawn indefinitely every two weeks if he put lights over their tanks on a cycle that mimicked a midsummer's day. "So they do have potential as a lab animal, but it's hard to keep the plankton levels high enough for them to spawn without the nutrients polluting the tank at the same time. That's why they normally only spawn in the summer—there's lots of plankton."

The neural crest cells' reassigned genes are the first tool of war for the vertebrates. "The amphioxus doesn't have that, so all it can do is sit around and filter feed. It retains its pacifist lifestyle."

(Lampreys are easier to raise in the lab, but like the salmon they prey on, once they spawn, they die. So the trick is to make them chill out. Literally. "Spawning is temperature-induced," says McCauley. "So if you keep them very cold—5° C—they won't spawn. Their metabolism shuts down, and you can hold them in tanks for as long as you like." Then, when you're ready for an experiment, you just plop them into 15° water and you're off to the races.)

Amphioxus adults and lamprey larvae are both filter-feeding bottom-dwellers. Says Meulemans, "The crest-cell derivatives become important when the animal becomes predatory. They go into making things like the jaws, the muscular pharynx, and a better peripheral and sensory nervous system for faster movement and heightened senses." In other words, the neural crest cells' reassigned genes are the first tool of war for the vertebrates. "The amphioxus doesn't have that, so all it can do is sit around and filter feed. It retains its pacifist lifestyle."

The thing that allows the lamprey (and the rest of us vertebrates) to beat our gill arches into swords is a stretch of DNA called the *cis*-regulatory region, which lies just ahead of each gene. (See *E&S*, 2001, No. 3/4.) The *cis*-regulatory region contains binding sites for assorted signaling molecules that appear in various combinations in different parts of the embryo at different times and the sum of whose effects turns the gene on or off.

To try to understand how the genes' functions shifted, Meulemans took the *cis*-regulatory region from an amphioxus gene and coupled it to the DNA for a protein that caused the tissue to turn blue wherever the gene was turned on—what's called a "reporter gene" in the trade. He then injected this homemade gene into chicken embryos and applied an electric current across the neural tube in a process called electroporation. The current temporarily opened pores in the cell membranes, letting the DNA in. And because the DNA has a negative charge, it got pulled toward the positive electrode. So the new gene only entered the embryo's crest cells on one side of the tube, while the other side, with its original patrimony of chicken genes, served as the control.

The gene whose *cis*-regulatory region Meulemans borrowed is called *snail*, and it is one of the first neural crest genes turned on. In vertebrates, it's active in the neural-crest-forming region and in the peripatetic neural crest cells. In the amphioxus, it's active throughout the nervous system, not just where the neural crest cells would form, and it's not turned on in any migratory cells whatsoever. Meulemans found that the reporter gene turned on as it would in the amphioxus, confirming that evolution had changed how the gene is used.

So the question now is, what changed in the *cis*-regulatory region? Amphioxus eggs are barely visible to the naked eye and are notoriously hard to work with, but this past summer, the Hollands succeeded in injecting them with a reporter gene that Meulemans had constructed—the first time that foreign DNA had ever been put into an amphioxus embryo. This means that genes from either organism can now be put into the other one, and the problem can be attacked from both sides.

Says Bronner-Fraser, "Evolution is a hard question, because we don't have the ancestors around to look at—we can only look at the organisms that are still alive and try to extrapolate backward. We tend to be very vertebrate-centric as human beings, so we know a lot about a few vertebrates, but vertebrates represent a very small portion of the evolutionary tree. Very little is known about many of the creepy-crawly organisms, but it's really critical to study a lot of different organisms in order to understand their relationships. For example, jellyfish have muscles, but they don't have the layer of cells called the mesoderm that, in most other organisms, muscle comes from. So a lot of people are trying to figure out how that change occurred. Our ability at Caltech to make arrays of all the genes that are turned on at a particular place at a particular time, and then subtract away the common genes, is really exciting. I've been working on this one problem all my adult life—the core problem hasn't changed, it's just that the way we get at it has changed. It's hard to say what I'm going to be doing in five years, because each thing you do changes the next thing. That's why I love science." □

Marianne Bronner-Fraser has been at Caltech since 1996. She got her Sc.B. from Brown in 1975 and her Ph.D. from Johns Hopkins in 1979; both are in biophysics. She is on the NASA Life Sciences Panel for Developmental Biology, has chaired the Gordon Conference on Neural Development, and has been Caltech's faculty chair since 2001.

PICTURE CREDITS: 10, 13, 15, 21 – Bob Paz; 10, 19 – Dan Meulemans; 10 – Tanya Moreno; 13 – Mark Selleck; 14 – Martín García-Castro; 17 – Jeremy Gibson-Brown; 17, 18 – Dave McCauley; 19 – Jordi-Garcia Fernàndez

Two Lamprey Recipes

Cleaning and Marinating the Lamprey (Not for the weak-stomached!):

Immerse the lamprey in hot water. Remove the mucus by scraping the skin with a knife; finish by rubbing with a piece of cloth. Cut off and discard the tail (about six inches). Hang the lamprey by the head over a bowl containing a tablespoon of vinegar. Open the branchial-holes region to allow the blood to drip out, and wash the lamprey with seven ounces of red wine. Stir the blood-wine mixture as needed to avoid coagulation; set aside. Eviscerate the lamprey and remove the notochord, which is dark in color and lies along the back wall of the abdominal cavity. Prepare to remove the head by making a surficial cut all the way around the body. Pull off the head and be sure to get the large piece of associated cartilage. Discard the head and the cartilage. Wash again. Cut the lamprey into $2^1/_2$-inch pieces. Marinate the pieces for at least two hours (five or more is better) with salt, pepper, wine, bay leaf, parsley, and cut-up carrots and onions.

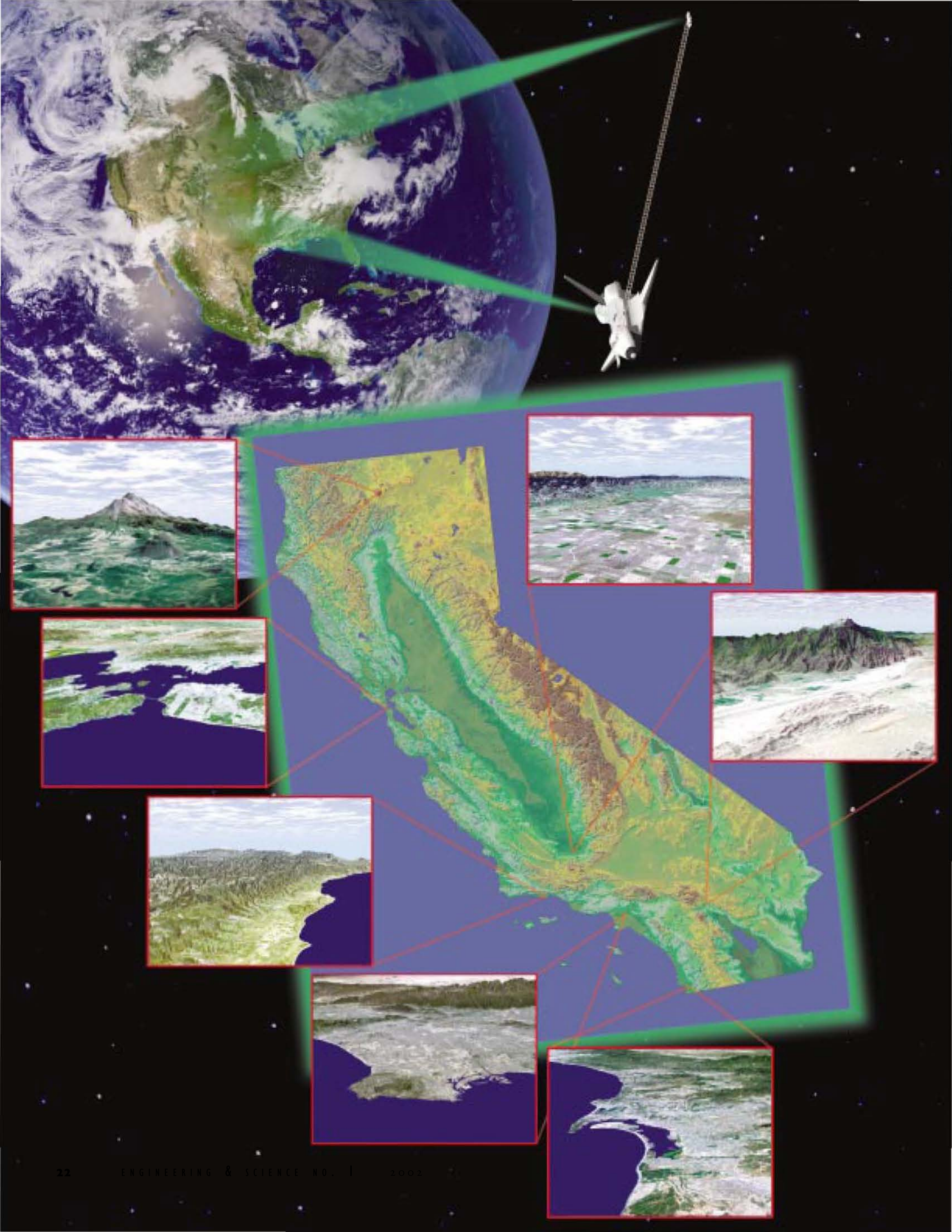
Lamprey "Bordeaux style" (Lampreia Bordalesa):

Heat the lamprey, marinade and all, with butter and crushed garlic in a pan until everything turns color. Add white wine and some fish soup, season and cover. Once the lamprey is cooked, remove the lamprey pieces. Return the sauce to the boil until well cooked. Turn down the heat and add the blood and some lemon juice. Let simmer without boiling. Serve the lamprey and the sauce atop thin pieces of toasted bread. Serve with white rice.

Lamprey Rice (Arroz de Lampreia):

Brown the lamprey pieces in a pan with about six tablespoons of olive oil, crushed garlic, salt, and pepper. Add small portions of water, enough to make one quart of sauce. Let boil for an hour. Taste and adjust seasonings. Add one pound of rice and the lamprey blood. Reurn to boil, then cook slowly until the rice is done. The sauce should remain very liquid. Serve piping hot.

Adapted from translations by Paulo Vaz-Pires from *A Cozinha Ideal* (Ideal Cooking), 9th edition, Manuel Ferreira, Domingos Barreira, Lisbon, Portugal, 1988; and from *Tesouro das Cozinheiras* (Treasures of the Chef), Mirene, Porto Editora, Porto, Portugal, 1993. The translations appeared in *Seiche*, the newsletter of the University of Minnesota Sea Grant Program, in April 1996.



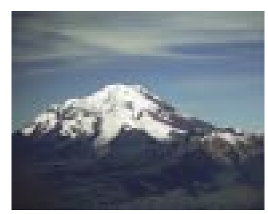
Planetary Phrenology: The Lumps and Bumps of the Earth

by Michael Kobrick

Phrenology is the study of the shape and protuberances of the skull, based on the belief that they reveal character and mental capacity. It was very popular in Victorian times, but has since been discredited as a scientific way of understanding the mind. On the other hand, studying the lumps and bumps of the earth to work out what's going on inside is solid science: the shape of the outside of the earth—its topography—really is the key to what's going on underneath. Topography controls the flow of surface and subsurface water, provides clues to the structure of the earth's crust, gives us places to put antennas, sometimes falls on us during earthquakes, and allowed the invention of skiing.

In February 2000, the Shuttle Radar Topography Mission (SRTM) aboard the space shuttle *Endeavour* measured that topography, and I'd like to tell you something of how the mission was conceived, how it was done, and how the data that we got from it are being used.

But first let me somewhat rescale your thinking about the earth's topography. If you were asked to name the highest point on the earth you'd probably say Mount Everest, which is 29,029 feet (8,850 meters) above sea level. But the top of Everest is not the farthest point from the center of the earth; that's an honor held by a volcano in Ecuador called Chimborazo. Although it's only 20,561 feet (6,267 meters) above sea level, the top of Chimborazo is farther from the center of the earth than the top of Everest, because the earth bulges at the equator. This bulge results from the earth's rotation on its axis, which is pretty fast: if you're reading this at the latitude of Pasadena, California, you're actually speeding toward the east at almost 900 miles per hour—so it's a good thing the atmosphere is going with you. Since the earth is not infinitely rigid, it bulges at the equator (picture a spinning ball of Silly Putty), and by a surprising amount. The difference between the diameter of the earth measured through the poles and the diameter measured through the equator is 25 miles (40 kilometers), almost the length of a marathon.



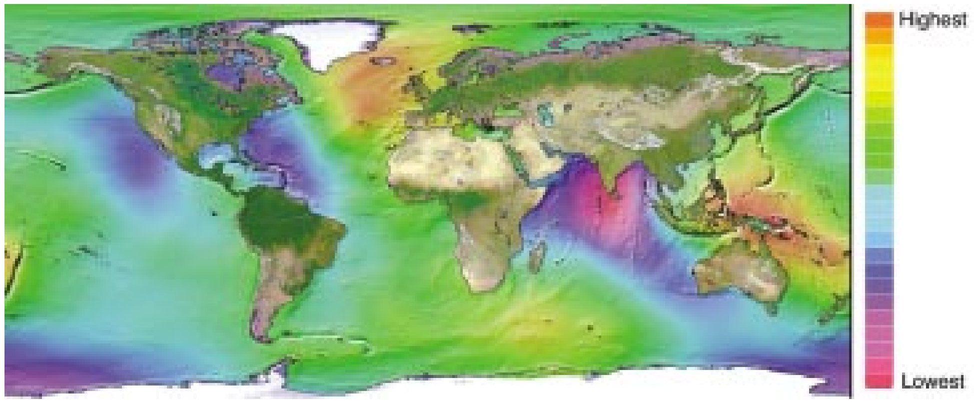
Chimborazo

Since Chimborazo is very near the equator, the top is actually 7,054 feet (2,150 meters) farther from the center of the earth than the top of Everest, up there at latitude 28 degrees north. (This information could be helpful if you're ever a contestant on *Jeopardy*.)

The ocean shares this equatorial bulge, but it also has other lumps and bumps all over the place, resulting from disparities in the earth's gravity field caused by variations in the density of its outer crust. You can see those bumps in the map of the earth at the top of the following page, in which I've color coded the oceans by height according to the earth gravity model. If you sail from the east coast of Africa to Malaysia, you're really sailing down into a hole that's about 100 meters deep and back up the other side.

The oceans cover about 70 percent of our planet, so they hide a lot of the earth's topography. In the picture of the earth at the bottom of the next page, the water has been stripped off and I've added maps of the other planets for which we have

Left: The color-coded, shaded relief map of California is a mosaic of 60 of the over 14,000 "cells" that will ultimately be generated by the SRTM when all the data have been reduced. Each cell covers an area of 1 degree longitude by 1 degree latitude. The flyover views around it are a combination of SRTM topographic data and Landsat photos, and show (clockwise from top right) the southern end of the agricultural San Joaquin Valley, Palm Springs, San Diego, the Los Angeles basin, Santa Barbara, San Francisco, and Mount Shasta, one of the highest volcanoes in the United States.

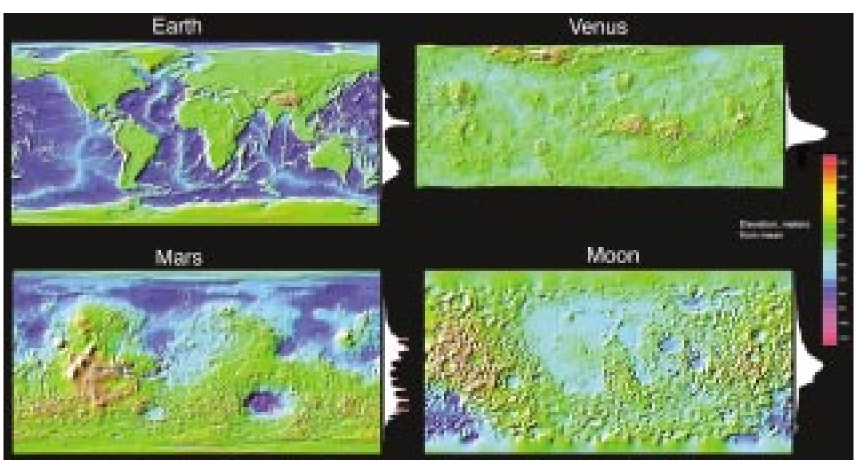


Sea levels are not uniform around the globe because of variations in the earth's gravity field. Color coding sea levels by height reveals "holes" like the 100-meter depression in the Indian Ocean.

reasonably good topographic data for comparison: the moon, Venus, and Mars. I've color coded them all in the same way, and used exactly the same scale for all four surfaces. You can see they look quite different. On the right of each panel is a bar chart showing the percentage of the planet's surface at each elevation, with the highest elevation at the top and the lowest at the bottom. The moon, Venus, and Mars have quite a broad range of elevations (if you ignore the spikes on the Mars bar chart, which are just the result of artifacts in the data set) but the earth is unique—it's split into two. That spike near the top of the bar chart is the range of elevations of the continental surfaces, and as you can see, it's very narrow. There's not much difference in height between one land surface and another—the continents are pretty smooth. You can also see this in the color-coded map—the earth doesn't have as many yellow and orange areas as the other planets, does it? The lower bump in the earth's bar chart, the range of elevations of the ocean bottom, is different. It's much broader, like that of the moon or Venus. And that's because the ocean floor is much more uneven.

The fundamental reason for this dichotomy is age. The continents float around like corks on the outer crust, bumping into each other, moving apart; and they're very old, nearly the same age as the earth itself, about 4.5 billion years. Although new mountains do get pushed up on the continents in various ways, 4 billion years of erosion by rain, wind, and glaciers have weathered them down so much that they're almost flat. The ocean basins, on the other hand, are quite young. In places like the mid-Atlantic ridge, or over hot spots like Hawaii, they're constantly being reborn; stuff is coming up from the upper mantle of the earth, displacing older rocks, and these older rocks eventually plunge back into the mantle. The average age of the ocean basins is only a few hundred million years, which is young in comparison to the elderly continents. And since it doesn't rain on them, they don't erode, so topographically they're very much rougher.

If you could hold the whole world in your hands, would you feel any of this topography? Well, if the earth was the size of a desk globe, Everest would be about three-tenths of a millimeter high. You wouldn't feel it. In fact, at this



The four planet-sized bodies in the solar system for which we have good topographic data, viewed at the same vertical scale and with the same color coding. Bar charts of elevation are on the right of each panel. Earth's continents clearly have the smoothest surface (that we know of) in the solar system.

The volcano Kliuchevskoi on the Kamchatka peninsula erupted in October 1994, and was photographed (far left) by the shuttle astronauts and the Spaceborne Imaging Radar (near left), SRTM's predecessor. The radar saw right through clouds and volcanic plumes, and it didn't matter that the sun was setting at the time.

scale, the earth would feel like a smooth plastic beach ball!

At the Jet Propulsion Laboratory I work on remote sensing of the earth and planets using imaging radar. The word radar usually calls to mind big rotating parabolic dishes and air-traffic controllers staring at round screens with blips on them. Well, we've gone a bit beyond that—we can now use radar to take pictures of the surface of planets. Modern imaging radars take pictures that are often indistinguishable from photographs.

The imaging radar we flew on two space-shuttle missions in 1994 consisted of a phased-array radar antenna made up of many hundreds of little individual transmitters and receivers (called TR modules) distributed around the face of a structure looking a whole lot like a billboard (right). By adjusting the phases of those little transmitters, the direction in which the radar beam points can be changed. The shuttle flew upside down with the "billboard" pointing off to one side, and the radar beam swept out an image swath along the ground. It wasn't a continuous beam, of course, but consisted of a series of pulses. A pulse about 33 microseconds long was emitted, hit the ground, and bounced back. The echo was recorded, and another pulse emitted. This radar pulsed about 1,500 pulses a second, considerably faster than the human persistence of vision; if it were a series of light flashes it would look like a continuous spotlight. Where the ground was rough, as in a city (buildings, corners, and metal things reflect radar very well), a lot of the energy got reflected back toward the antenna, and we coded that as bright in the image. When radar waves hit surfaces that were flat and smooth, like freeways (eight lanes of concrete), they bounced off in a forward direction, and very little got back to the antenna, so they looked dark.

Radars can see right through clouds, dust, and smoke because they use wavelengths of centimeters or longer, in this case 5.6 centimeters. That's about the length of your little finger, much bigger than the particles that make up clouds, smoke, or even the smog that sometimes obscures the Los Angeles basin. When ocean waves hit a rock that's much smaller than the wave, they don't even notice, they just march right on by, and it's the same with radar waves: they go right through the clouds. It also doesn't matter whether the sun is shining or not, because the radar provides its own illumination, and images can be taken day and night. During the second of the two 1994 flights, there was a volcanic eruption on the Kamchatka

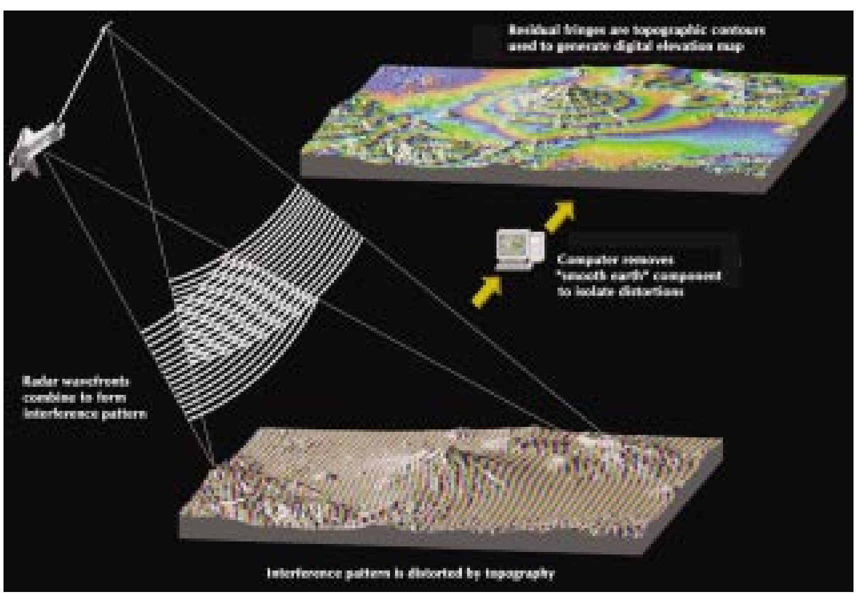
The crew of *Endeavour* visiting JPL's spacecraft assembly facility before the February 2000 mission. Behind them is the huge "billboard" radar antenna, a veteran of two previous flights in 1994.

peninsula. The picture top left is a photograph taken by the astronauts as the shuttle flew over, and next to it is a picture taken by the shuttle radar. The radar could see right through the smoke plume.

The two 1994 missions were very successful, but as is typical with imaging radars, the width of the swath was only between 48 and 64 kilometers (30 and 40 miles), not really giving the sort of wide-angle view that should be attainable from space. So one of the engineering geniuses on our team at JPL thought of a better way to do the imaging, and as we were also running a few research and development experiments on the flights, we tried

This 250-kilometer-wide picture of ice floes entrained in ocean eddies in the Weddell Sea near Antarctica was the first ScanSAR wide-swath radar image ever acquired from space. Taken by the Spaceborne Imaging Radar in 1994, it paved the way for the SRTM.

The SRTM mission astronauts, from left: mission specialist and payload commander Janice Voss, mission specialists Mamoru Mohri (Japanese Space Agency), Janet Kavandi, and Gerhard Thiele (European Space Agency), pilot Dom Gorie, and commander Kevin Kregel.



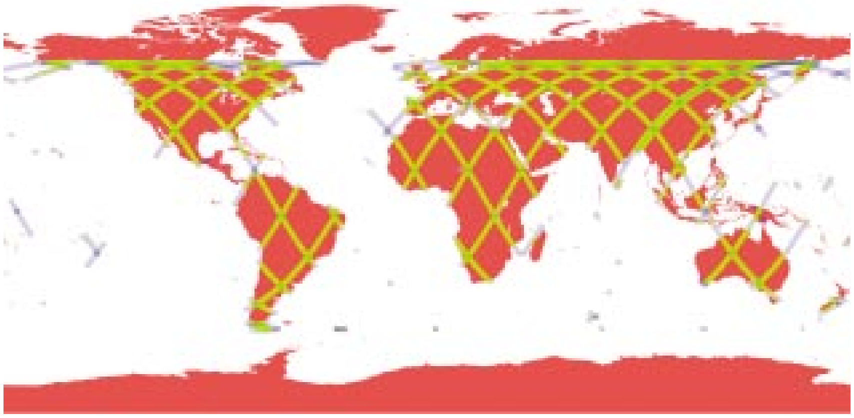
An interferometer can be visualized as two sets of lock-stepped (coherent) radar wavefronts combining to form interference fringes, which overlay the radar image and are distorted by local elevation differences. Isolating and displaying only these distortions produces elevation contours, which can be color coded. Recognize Mount Shasta?

his idea out. Instead of having the beam sweep along in a continuous fashion, we triggered the TR modules to electronically wiggle the beam back and forth, perpendicular to the direction of flight. In the radar world, we call this ScanSAR (Scanning Synthetic Aperture Radar), because the beam scans across the swath the way an electron beam sweeps across the face of a cathode-ray tube to make a television picture. You point the beam at one spot on the ground for about a tenth of a second, then zip it over to another place and point it there for a while, then you zip it over to a third place, then a fourth. By looking at four such subspots, you can sweep out a much wider swath of data. Shown left is the result. It's a historically significant image because it's the first ScanSAR image that we know of ever acquired from space. Instead of a mere 50 kilometers, the image is 250 kilometers across. It's a huge area.

On those 1994 shuttle flights we also experimented with a relatively new technique called radar interferometry, which is not too dissimilar from optical interferometry. Our imaging radar uses "coherent" radar waves, similar to laser light, in which all the electromagnetic waves are in step with one another like marching soldiers. The radar beam can be pictured as a set of concentric wavefronts centered on the antenna on board the shuttle, with a 5.6-centimeter separation between the fronts. If there's a second antenna some distance away with similar wavefronts coming from it, a series of interference fringes is generated where the two sets of arcs overlap, as shown in the diagram on the left. If the surface of the earth were perfectly flat, these fringes would be nice, straight lines. But if there are lumps and bumps on the surface, the fringes get distorted, and by measuring these distortions we can deduce the topography.

With a nontrivial amount of computer processing we can turn these fringes into a digital elevation map, which is like a picture made up of rows of dots, where the brightness of each dot represents a topographical elevation. The brighter the dot, the higher the elevation. If we display this map as a picture on a computer screen, it resembles an X ray, fuzzy and indistinct. But some simple filtering with an image-processing program like Photoshop can turn it into a shaded relief map, and the elevations can also be color coded. Then it starts to look a lot more familiar.

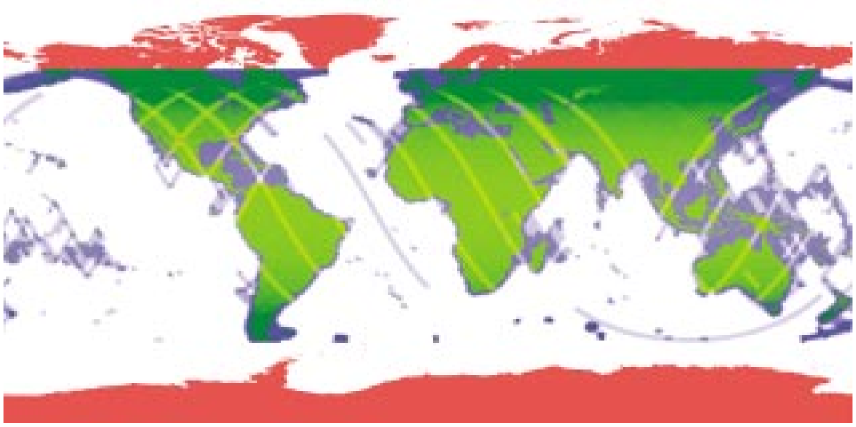
The leftover hardware from the 1994 space shuttle flights was qualified to fly again, but there were no plans to do so and it was sitting in storage down in Carson in an airproof box. As we were casting about for ideas as to what to do with it, one of our more creative engineers at JPL, Ed Caro, had a brainwave: what if we borrowed one of the long, extensible masts that were being built to hold the huge solar panels for the International Space Station? We could attach one end of the mast to our existing antenna structure in the



The radar swath coverage as the shuttle orbits the earth, shown for a single day (day 5), left, and for the entire mission, lower left. Land not mapped is red, which the swath coverage turns light green over land and blue over water, then darker and darker green or blue as terrain or water is covered more than once.

payload bay, and put a second radar antenna at the other end. With both antennas pointed at the ground, we would have a proper interferometer. Now, in principle, you don't need both antennas at the same time: when we did this interferometry in '94 we did it by flying back to almost the same spot in space and repeating the scan on a separate day. But if there are any atmospheric changes in those two days (like wind, rain, or dust storms), the surface "decorrelates" and interferometry doesn't work very well. If both antennas are there at the same time, however, it should work perfectly.

But as bold an idea as that was, it wasn't really bold enough because nobody doubted that it would work. Basically everyone said, Well, so what? We know interferometry works, and there's no need to demonstrate it again. Then I had an idea. This was probably the only good idea I have really ever had, and like most good ideas it wasn't inventive or creative—I just stole two other ideas, interferometry using Ed's mast, and ScanSAR. What if we make that secondary antenna at the end of the mast also a phased array, so that the two beams can scan in unison? Both beams, scanning at the same time, would be doing interferometry over a swath we calculated could be 225 kilometers wide. Now that's an important number I want you to remember.



How much of the earth's total landmass could we measure with that? After resurrecting some software I wrote in graduate school, I calculated all the exact repeat orbits around the earth possible for the highest orbit inclination the shuttle could reach (a repeat orbit is one that brings the satellite back over exactly the same spot again after a certain number of revolutions). Although there were a large number of solutions, some fundamental physics limited the number of choices. The lowest the shuttle could go was about 200 kilometers above the earth; below that, there's too much atmosphere and it doesn't stay in orbit very long. Also, our payload would be fairly heavy, so the orbiter wouldn't be able to get up very high into space, ruling out everything above 250 kilometers. Further, the orbiter could only fly for about 10 to 12 days, after which the astronauts would start to run out of fuel, air, food, and so forth (not a good thing), so with a margin for error, the mission could not go beyond 11 days. This left about half-a-dozen solutions, with the obvious choice being an 11-day mission at a 233-kilometer altitude. It turned out this pattern would repeat exactly in 159 orbits. (To get an idea of what this would look like, imagine wrapping twine around a ball, with the twine perfectly equally spaced, 159 times.)

The key figure I needed to know was how far apart the ground tracks—the tracks of the orbiter projected onto the earth—would be as it went round in those 159 orbits. Would it be more or less than the width of the radar swath? If it were more, there would be gaps between the swaths, and the idea wouldn't work. It's a fairly simple calculation: divide 159 into the circumference of the earth and multiply by the trigonometric sine of the angle at which you cross the equator, which is almost exactly 60 degrees.

Two views of the mast: just starting to deploy from the canister, left, and fully deployed, right—the technician's still in the picture, just too far away to be seen. Below: Our home planet as it's typically seen from space—cloud covered.

The back of my envelope said 218 kilometers. I couldn't believe it! It meant that with our 225-kilometer-wide swath there would be no gaps, and we could completely map all the landmasses between +/- 60 degrees latitude in a single shuttle flight using just leftover hardware. This was so unbelievable, I was sure there had to be something wrong with the idea, so we spent a couple of weeks trying to figure out what that could be—and found nothing. In fact, all the usual bugaboos that make your life miserable in planning a shuttle mission just weren't there, and not by our brilliance, but seemingly by random chance.

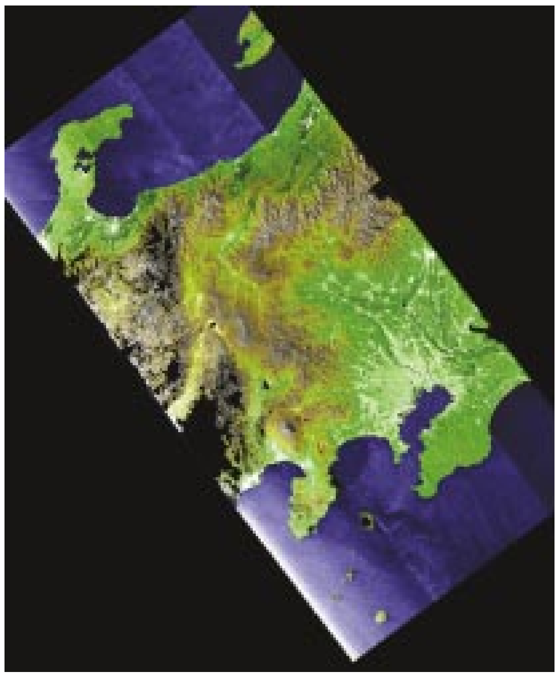
For example, all the land on the earth except Antarctica was north of the southern extent of those ground tracks, so we would only need to have the radar look in one direction—north—which meant we could always stay in the same shuttle attitude. The attitude is the direction the shuttle is pointing as it flies along the orbit. This saves a lot of fuel, which we knew would be in short supply. When we planned the 1994 flights, a coin toss had determined that the onboard antenna would be tilted slightly toward the orbiter's starboard side, which meant that the attitude the shuttle would have to be in to look north on this flight was tail first. Now the attitude of the shuttle is important, because there's a lot of debris floating around in space that could hit the windows and the leading edges of the wings. There are many attitudes NASA won't let you fly in for very long, like nose first. Tail first was no problem, we were told: we could stay there the whole flight. What luck!

So at the end of 1994 we presented our brilliant idea to the Earth Science Enterprise at NASA in the hope that we'd get funding. The cost of the payload would come to about $100 million, about one-fifth of what we figured it would cost to do the same thing with a free-flying satellite. They were impressed, but suggested we search out another sponsor who could help defray the costs. This was pretty discouraging. After all, who has that kind of money and is interested in maps? Well, we got lucky again: the Defense Mapping Agency (DMA), a branch of the Defense Department that makes maps for the military, was looking for a way to make digital maps at high resolution—one data point for every area about the size of a football field for the whole earth. They'd done about 60 percent of the earth using satellite photos and other sources, but now they were stuck, and the main problem was clouds. At any one time only about 40 percent of the earth is covered by clouds, but they're not statistically distributed. Some places are almost always clear, while others such as northern South America, Indonesia, and islands in the Pacific are cloudy almost all the time. Camera-carrying satellites couldn't photograph through it, but our radar could. So the DMA, now renamed the National Imagery and Mapping Agency (NIMA), hopped right on board. Other participants in the project were the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt), who built part of the system, and the Agenzia Spaziale Italiana. The Shuttle Radar Topography Mission was on its way.

Artist's concept of the SRTM in space, as viewed from a nearby UFO. This painting is courtesy of Ball Aerospace, builders of the outboard antenna, who clearly view the SRTM as their antenna attached to some minor associated hardware—the shuttle!

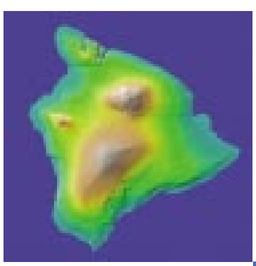
The heart and soul of the project was the huge mast (opposite page, top). At launch it was folded up inside a canister about 3 meters long, and once in orbit the canister started to turn a helical screw mechanism that pulled the mast open and unfurled it one "bay" at a time. It was an engineering marvel: 60 meters long, with 76 bays in all, made of plastic struts reinforced with carbon fiber, with stainless-steel joints at the edges, and titanium wires held taut by 500 pounds of tension. One of our two radar antennas was mounted on the end.

On February 11, 2000, space shuttle *Endeavour*, with a six-person international crew, carried up the SRTM. They returned to Earth on February 22. The mast–orbiter combination was the largest rigid object that had ever flown in space, even bigger than Mir. In one day of mapping, *Endeavour* made 16 orbits, with the radar covering a 225-kilometer-wide swath each time (as shown on page 27). We imaged almost every landmass twice to get a more accurate result, although a few places were imaged only once because the astronauts were running low on fuel and had to stop a few orbits short. But those areas were in the United States, and had already been mapped accurately by conventional means. And, anyway, even once was enough to meet our accuracy specs. The most nerve-wracking aspect was that for the mapping to be successful, everything had to work correctly over the entire mission—and it did. At the end, we'd imaged 99.96 percent of our target.



Section of a typical 225-kilometer-wide SRTM data swath, this one covering central Honshu, Japan. The lighter region around the bay to the right is Tokyo; the black regions are data gaps that will be filled in by adjacent swaths.

The mission collected 12 terabytes (12,000,000,000,000 bytes) of data, about the same as the amount of information contained in the U.S. Library of Congress. The ongoing plan is to process every single byte; we have something like the tenth largest supercomputing facility in the world at JPL, and it's processing these data full time. Even with all that computing power, it's going to take until late 2002 to finish. The intention is to process all the swaths, put them together in a mosaic, chop that into little squares of 1 degree longitude by 1 degree latitude, and deliver them to our users, who are scientists, the public, and NIMA.



Topographical maps of the Big Island, Hawaii (left) and Sicily (below), color coded for height.

We can do quite a lot of interesting things with the data. For instance, we can create perspective views by sandwiching an optical photograph taken from orbit by Landsat with a digital elevation map of the same area. To give more detail, aerial photos can also be superimposed, and the elevations color coded for height. We can also generate video to give the feeling of flying over the area. And this brings to mind one of the prime civilian, nonscientific uses for these kinds of data in the future, enhanced ground-proximity warning systems for aircraft.

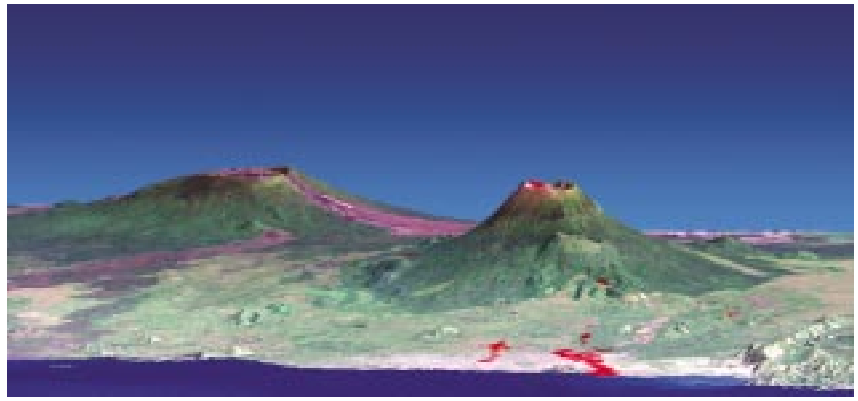
The most common element in plane crashes—so common it has its own acronym—is CFIT, or Controlled Flight into Terrain. This means that even though the plane is working normally and the pilot is in control, for some reason it just gets

Two views of Costa Rica, a country often covered by clouds. On the left, the Caribbean Sea in the foreground is separated from the Pacific by the central mountain range; on the right, the capital, San José, can be seen nestling below the volcano Irazu.

flown into the ground, generally because the pilot couldn't see where the ground was. Well, with the advent of the Global Positioning System (GPS), an airplane can know exactly where it is in three-dimensional space, but the plane also needs to know where the ground is, and that's where the digital topographic map comes in. With such a map a pilot could have a virtual-reality screen in the cockpit showing exactly what it would look like out the window if it weren't for those pesky storm clouds, or just plain darkness. It might not be cheap to install such a system in all existing aircraft, but now that we've produced this data set there's technically no reason it can't be done.

Wireless communication is another important application. I'm sure many of you get annoyed when you're driving around and your cell phone cuts out because the terrain blocks the phone from the antenna. Now, suppose I gave you the task of deciding where to put antennas to get the best coverage of Los Angeles. It would be pretty tough—you'd almost have to do it by trial and error, by going out and doing tests in different places. Well, with the digital elevation map it's easy. Just as an exercise to demonstrate how easy, I sat down and wrote a computer program in about 20 minutes to figure out what the coverage for Los Angeles from Mount Wilson would be. Mount Wilson is one of the highest accessible points overlooking the Los Angeles basin, which is why there's a sizable "antenna farm" up there. But when the illumination pattern from Mount Wilson is overlaid with a Landsat photograph coregistered with a digital elevation map, you can see where the reception shadows are (below). The

Satellite view of Los Angeles without and with the illumination pattern from the antennas on Mount Wilson. The mountains cast "shadows" where television and radio reception are typically not very good. Calculating antenna coverages like this is quite difficult using paper maps, but trivial with SRTM-style digital elevation maps.



Nyiragongo volcano in the Democratic Republic of the Congo erupted on January 17, 2002, sending streams of lava into the city of Goma on the north shore of Lake Kivu. More than 100 people were killed, and more than 12,000 homes destroyed. This picture shows the lava flows (red) by combining a Landsat satellite image, an SRTM elevation model, and image data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on NASA's Terra satellite.

Palos Verdes peninsula casts a big shadow out over the ocean, and the Santa Monica mountains shade many parts of Malibu. I used to live in a place called La Crescenta, only 20 miles away from the transmitters on Mount Wilson, but I got no TV reception at all because that area is in the shadow of Mount Lukens. About 10 years ago I moved over to Pasadena, and now my reception is perfect, just as the map says it should be!

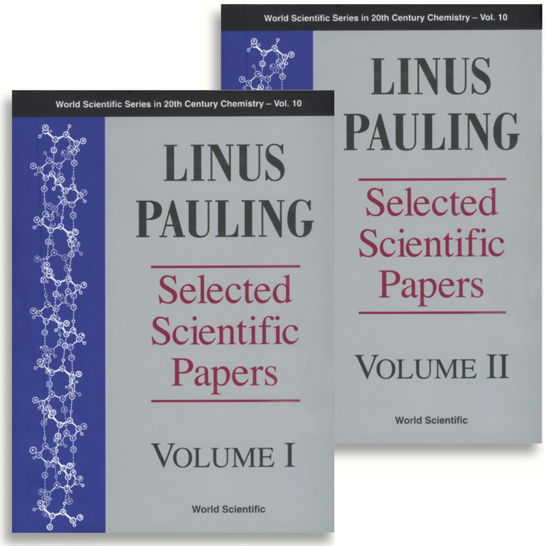
At present, we're still cranking those 12 terabytes of data through the computer and mapping the earth. What are we going to do with this in the future? The hardware that we flew on the SRTM is qualified for a number of additional flights, so it could be flown again, although there's no plan to do so—the 2000 flight was so perfect we can't think of any reason to repeat it. But there's another application of interferometry, called differential interferometry, that is truly amazing. If you know the topography (and that will be true for almost everywhere on the earth now that we have the SRTM data), and you have a radar image taken before and after an earthquake, for example, you can measure the movement of the surface of the earth with almost unbelievable precision. Our vertical resolution in the SRTM is only 10 meters (30 feet), but differential interferometry could detect earth movements of just a few centimeters. Earthquake movements could easily be measured from an orbiting satellite equipped with differential interferometric imaging radar. Some theories predict that the earth does funny things just before an earthquake, like bulging—remember the Palmdale bulge?—so it's possible that differential interferometric remote sensing could actually be used for earthquake prediction. Why not build a satellite that just flies along the San Andreas fault every day or so and checks for earth movements? In my opinion the money saved from predicting just one major earthquake correctly would be more than the cost of such a satellite.

There'll be a lot more interesting results coming out of this mission as we reduce the data. Take a look at our Web page at http://www.jpl.nasa.gov/srtm for updates, more background information, pictures of the world's topography, and flyover animations. □

PICTURE CREDITS:
22, 23 – Doug Cummings/NASA/JPL/NIMA; 24-28 – NASA/JPL; 28 – Ball Aerospace; 29-31 – NASA/JPL/NIMA

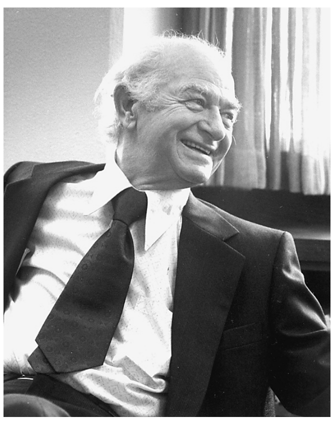
The Caltech campus in Pasadena with the San Gabriel mountains behind.

A specialist in radar remote sensing of the earth and planets, Michael Kobrick has worked at the Jet Propulsion Laboratory for 28 years, ever since earning his PhD in planetary and space physics from UCLA. He also has a BS in physics from the Rensselaer Polytechnic Institute, and an MS in astronomy from the University of Illinois. He was principal investigator in the early spaceborne radar experiments of the Apollo program, science manager for the 1990 Magellan mission to map Venus with radar, and has also spent several thousand exciting flight hours experimenting with airborne imaging radar systems. As project scientist for the Shuttle Radar Topography Mission—his brainchild—he is now in charge of the reduction of the data set and its release to end users. This article is adapted from a Watson lecture given on February 21, 2001.



Linus Pauling: Selected Scientific Papers

World Scientific, 2001; 1,573 pages



Pauling at Caltech in 1974.

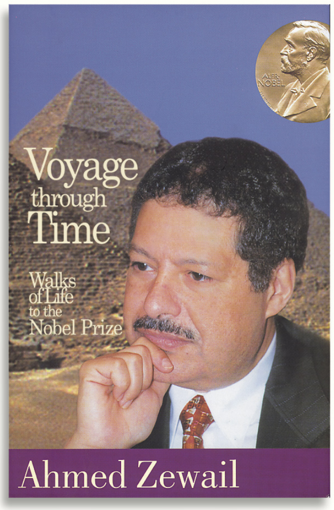
When the World Scientific Publishing Company contacted Linus Pauling shortly before his death to propose publishing a selection of his scientific papers, Pauling is reported to have said (according to his son Peter): "The selection is easy—print them all." Wisely, his children, who had agreed to act as editors, concurred with the publisher that this would generate a daunting number of volumes and a prohibitive price. So the resulting *Linus Pauling: Selected Scientific Papers* contains only 144 of his most important writings (out of about 1,200) produced between 1923 and 1994. Even so, it runs to 1,573 pages in two volumes (and $240).

The project has remained a family enterprise. Editors are Barclay Kamb, the Rawn Professor of Geology and Geophysics, Emeritus, who acted as editor-in-chief; Linda Pauling Kamb, who was the photo editor and curator of the original publications; and Peter Jeffress Pauling, Alexander Kamb, and Linus Pauling Jr., each of whom edited a section. Also involved in the selection of the papers was an impressive bank of advisers (including, from Caltech, chemists Richard Marsh and Ahmed Zewail and biologists Justine Garvey and Ray Owen). The selection, according to the editors, "aims to present Pauling's most important and influential scientific papers and the papers that best convey his imaginative style of scientific thinking and the considerable gamut of scientific subjects that he tackled."

Divided into four parts, the papers are grouped by subject matter: the nature of the chemical bond; the atomic structure of molecules and crystals (along with quantum mechanics); the structure and function of large molecules of biological importance, particularly proteins; and biomedical subjects. Each part is subdivided into chapters; the relationship of the chapters to one another and the significance of the individual papers are explained in the introduction to each part. All the papers are reproduced in facsimile from their original sources.

The volumes also contain a substantial collection of photographs and a short biography originally written for the Royal Society of London by Jack Dunitz (who notes, in addition to a summary of Pauling's scientific achievements, such things as his "seraphic smile"). And if you really want to know *all* the papers Pauling wrote, they're listed in Appendix III; the list alone takes up 58 pages.

Ahmed Zewail, the Pauling Professor of Chemical Physics and professor of physics, wrote the foreword, in which he compares Pauling's stature in chemistry to the Great Pyramid of Cheops. This anthology represents, he writes, "a monumental contribution—a must for chemists, biologists, and scientists in general who want to understand the roots of important concepts in modern science, the foundations for which were laid down by Linus Pauling."



VOYAGE THROUGH TIME:
WALKS OF LIFE TO THE NOBEL PRIZE
by Ahmed Zewail
The American University in Cairo Press, 2002; 287 pages

As he explains in his recent autobiography, Ahmed Zewail has, like Harry S. Truman, "tried not to forget who I am and where I came from." And *Voyage through Time: Walks of Life to the Nobel Prize* tells us. Throughout, the book is infused with the influence of his Egyptian background, which a third of a century in the United States has not erased—the songs of Um Kulthum, which he has loved since childhood; his pride in the contributions of Arab scientists throughout history, particularly the relevance to his own work of Alhazen, who worked with light and optics in the 11th century; and even the point that "chemistry" derives from an Arab root word.

Zewail writes evocatively of his boyhood in Desuq, a Nile town near Alexandria, of his science education at the University of Alexandria (which had a new spectrophotometer but no lasers), and of his decision to attend graduate school in America, following in the footsteps of teachers he admired. He describes the excitement of coming to the University of Pennsylvania in 1969, the culture shock (he wore a suit and tie to the lab at first), his broken English (once ordering a "desert" instead of "dessert"), and the scientific shock of all the new and complex instrumentation. After finishing his PhD in 1973, he almost returned to Alexandria, but could not resist the lure of the "high-powered" labs that were courting him as a postdoc. He landed at Berkeley, where yet another culture shock awaited (hippies, streakers), as well as the unfamiliarity of big science and big funding. But again he assimilated and decided to make his career in America.

Caltech recruited him as an assistant professor in 1976, beating out other big-time suitors. He was a bit concerned about Caltech's "lack of enthusiasm" for chemical physics, but opted anyway for a place he considered the "mecca of science." He was granted tenure after two years.

Plenty of pages are devoted to Zewail's scientific work—the steps leading up to the birth of femtochemistry in 1987 and the Nobel Prize in 1999 for using femtosecond laser pulses to catch chemical reactions in the act, breaking and forming bonds between atoms. But any regular reader of *E&S* probably already knows about Zewail's science. It's the personal side revealed here that makes for fascinating reading.

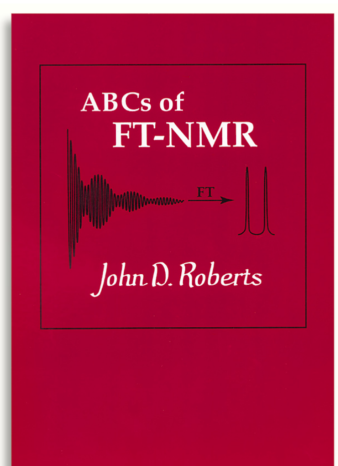
The book is lavishly illustrated. We see not only the much-honored scientist with his family and diverse important people, but also the 10-year-old Ahmed on the beach with his father, the serious boy in primary-school art class, and the scorecard that the young postdoc plotted to choose Caltech over Harvard, Chicago, Rice, and Northwestern.

Zewail feels that as a scientist equally at home in two different cultures (he holds dual Egyptian and American citizenship), he is in a unique position to help foster science for the "have-nots." At the end of the book he makes a "proposal for partnership" between the developed and developing worlds, a sort of Marshall Plan for science. He believes strongly that developing countries must create "centers of excellence" and to that end is intensely involved in planning for the University of Science and Technology in his homeland. The UST sounds a lot like Caltech—a mecca of science. —*JD*

ABCs OF FT-NMR
by John D. Roberts
University Science Books, 2000; 336 pages

Nuclear magnetic resonance (NMR) spectrometers can identify molecular structure, follow reaction kinetics, and study enzyme mechanisms. The Fourier-transform (FT) version is a top-of-the-range model that detects very weak signals by analyzing the spectra of the sample over and over again, the way a camera takes a picture in dim light using a long exposure time. But, cautions the author, don't regard the FT-NMR spectrometer as a "black box" instrument. Relying on the preset FT-NMR analyses could give you the wrong results and you'd never be any the wiser; worse still, they could give you no results at all when they are there to be had.

Aware that for most chemists and biologists the prospect of learning about FT-NMR is a daunting one, the scope of this book has been kept broad rather than deep, the explanations qualitative rather than quantitative, and the math—where unavoidable—simple. The author (now Institute



Professor of Chemistry, Emeritus) was one of the pioneers of NMR spectroscopy over 40 years ago, though he modestly claims to be "a ranking nonexpert." As the set text for the basic FT-NMR course, this book has been tried and tested by 10 generations of Caltech students and teaching assistants and, in response to their feedback, revised almost annually (this is the ninth edition), to make sure that the explanations of complex NMR phenomena are as simple as possible. It's not airplane reading (unless you really want to take your mind off the flight), but it's a gentle guide through a difficult subject written with great charm and delightful humor. If you use FT-NMR spectroscopy in your work, you need to read this book. The good news is, you'll enjoy it.—*BE*

A Hundreth Sundrie Flowres

by George Gascoigne, edited by G. W. Pigman III
Clarendon Press, Oxford University Press, 2000; 781 pages

George Gascoigne (c. 1534–77) is not exactly a household name. A perennial wannabe at the court of Queen Elizabeth, he spent a dissipated youth, was trained in the law (which came in handy for the many lawsuits—bigamy, debt, theft—that pursued him), failed at farming, sat briefly in Parliament, went to war in the Netherlands to flee his creditors, and finally, in the last years of his life, was hired by the members of the court to write a couple of masques and pageants for the queen. He also wrote the first Italian-style comedy in English, as well as the first English adaptation of a Greek tragedy, and some of the first English sonnets and a "proto-novel." He was a literary pioneer, but was unlucky to be overshadowed by the famous Elizabethans who studied (Sidney and Spenser) and plundered (Shakespeare) his work.

Gascoigne never vanished completely from the radar screen, and editions of his work appeared sporadically in the 18th and 19th centuries. A *Complete Works* was published in 1907–10. Now, Professor of Literature G. W. (Mac) Pigman has published an edition of Gascoigne's major achievement, *A Hundreth Sundrie Flowres*, which contains a collection of plays (*Supposes*, the Italian comedy, and *Jocasta*, after Euripides), prose (*The Adventures of Master F. J.*), and poems, many of them purportedly written by "sundrie gentlemen," but all, in fact, by Gascoigne himself. His own description on the title page reads: "A Hundreth Sundrie Flowres Bounde up in One Small Poesie. Gathered partely (by translation) in the fyne outlandish Gardins of Euripides, Ovid, Petrarke, Ariosto, and others: and partly by invention, out of our owne fruitfull Orchardes in Englande: Yielding sundrie sweete savours of Tragical, Comical, and Morall Discourses, bothe pleasaunt and profitable to the well smellyng noses of learned Readers."

This new edition, wrote a reviewer in the *London Review of Books* "is the best piece of luck Gascoigne has had in the four hundred and fifty years since his birth." And the *Times Literary Supplement* noted: "If anything deserves to bring George Gascoigne back into the spotlight of serious attention, it is this judicious and scholarly edition. . . . G. W. Pigman's *A Hundreth Sundrie Flowres* is a worthy addition to the Oxford English Authors series and is a reminder of just how valuable responsible editing can be."

Pigman's responsible editing includes 277 pages of learned, line-by-line commentary on sources, meanings, allusions, translations, and history. And his textual introduction tackles a problem that has vexed scholars for centuries (Gascoigne's book "is one of those bibliographical eccentricities which it seems hopeless to explain," said one): that is, which edition of the work, the 1573 one (which was "deemed lasciviously offensive") or the cleaned-up, reorganized, and supplemented 1575 version, should be recognized as the authoritative copy-text. With sound textual arguments, Pigman opts for the earlier, while paying all due respect to the later one.

Again from the *London Review of Books*: "Here, almost spotless, is almost anything a reader of Gascoigne could desire to know, in what must be one of the best editions of an early modern text produced in the last decade."

Unjust Seizure
Conflict, Interest, & Authority in an Early Medieval Society

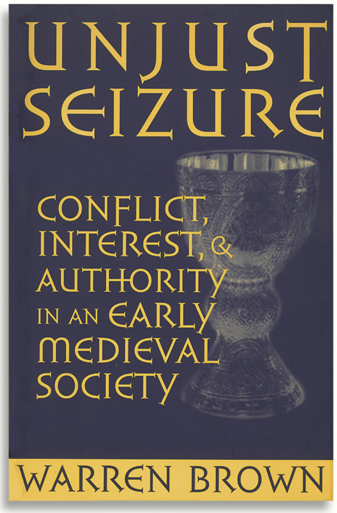
by Warren Brown
Cornell University Press, 2001; 224 pages

This book is about political power and how it functions in the affairs of a feudal society before and after a new government takes over. No, it's not about 21st-century Afghanistan, but 8th- and 9th-century Bavaria, where Warren Brown, assistant professor of history, has focused his research on conflict resolution—on the authority claimed by rulers to settle disputes, the institutions established, and the reaction of the populace to a change in those institutions.

His research was aided by a rich trove of documents in the Bavarian town of Freising. There, in the middle of the 9th century, a priest collected and copied the cathedral archives of the previous hundred years—archives that recorded all the local property disputes, many of which involved the church and its monasteries. Over those hundred years, the Bavarian ducal authority gave way to conquest by the Franks under Charlemagne, who tried to introduce a central authority to rule over a land that was a long way down the legal supply route. The stories from the cathedral archives leave a clear written record of real-estate wrangling before and after the arrival of "the new sheriff in town."

The local dukes were the Algilofing family, who had ruled with quasi-royal authority since the 6th century. Brown describes several cases from the mid-8th century, in which feuding landowners, who had resorted to violence, were required to deed property to the church—perpetrators and victims alike. Inheritance of property was another source of conflict in which the church often ended up the winner. Things sometimes got sticky for the church, however, because Bavarian law still allowed aristocrats a substantial amount of control of donated property, a custom the bishops did not have the power to challenge.

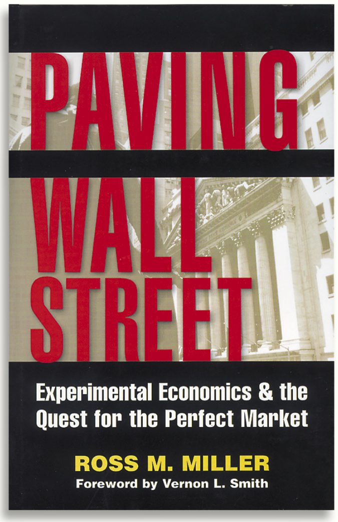
This cosy arrangement changed with the Carolingian takeover, beginning in 791. The duke was no longer a player, bishops gained much more clout, and officials of a formal Carolingian judicial system entered the picture. Suddenly (even without lawyers) the disputes recorded in Freising mushroomed. This was not primarily due to a centralized judicial apparatus



exported by the Franks, says Brown, but rather to a couple of powerful bishops who assumed the mantel of Charlemagne's prestige and gave the appearance of centralized authority to which the populace could appeal. After Charlemagne died in 814, disputes over real estate reverted to a more informal mode, and Brown's final chapter is entitled "The Art of the Deal."

Lively case studies from the Freising archive throughout the book paint a vivid picture of medieval life. "The Tale of Kyppo's Pig" and the intrafamily bickering over deeds to the church from a landowner named Toto and his sons, Scrot and Wago (there's a new wife involved), make for an enjoyable read. And the story of the bishop who took the blame for impregnating a duke's daughter to spare her lover, and then was mutilated and slaughtered by her brother, has enough gory detail for any modern movie. At least the bishop was ultimately proclaimed a saint.

An article by Warren Brown, "What's 'Middle' About the Middle Ages?" appeared in *E&S*, No. 2, 2000.



PAVING WALL STREET
EXPERIMENTAL ECONOMICS & THE QUEST FOR THE PERFECT MARKET
by Ross M. Miller
John Wiley & Sons, Inc., 2002; 314 pages

How do financial markets work? And if we knew, would we all be rich? Probably not, as demonstrated by the 1998 Long-Term Capital Management debacle involving a hedge fund that operated on the arbitraging theories of economics Nobel Prize-winner Robert Merton (MS '67, applied mathematics).

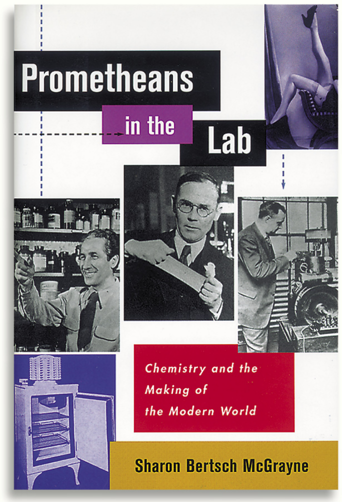
But academic economists want to know anyway. Ross Miller's book *Paving Wall Street: Experimental Economics & the Quest for the Perfect Market* traces the attempts over the last half century to determine precisely how Adam Smith's "invisible hand" moves its fingers and why markets behave the way they do. Along the way he examines and explains such phenomena as bubbles, the stock market crash of October 1987, derivatives, options, California's energy deregulation—and hedge funds.

Miller earned his BS ('75, mathematics) from Caltech, where he participated in Vernon Smith and Charles Plott's pioneering 1974 seminar "Laboratory Methods in Social Science," when he wasn't hanging out at a local brokerage. He admits in his preface that "because Vernon, Charlie, and their Caltech colleagues got to me first, everything that I have seen in the academic and corporate worlds has been filtered through the lens of experimental economics."

Smith (BS '49, electrical engineering, and Distinguished Alumni Award '96) and Plott are generally recognized as the founders of this field, which overturned the assumption that economics was, like astronomy, a purely observational discipline. Smith first encountered rudimentary experiments (in which "living, healthy, human subjects" simulated a competitive market) in graduate school at Harvard, and then took them to a new level in 1956 in his own courses at Purdue, where he met Plott. In testing the laws of supply and demand, Smith also used real cash, sometimes his own, to provide a genuine economic incentive. In his double oral auction, student "buyers" and "sellers" bid amounts that quickly converged to an equilibrium price.

Caltech became the center of experimental economics in the early '70s, Plott (currently the Harkness Professor of Economics and Political Science) having joined the faculty in 1971 and Smith returning as a Sherman Fairchild Distinguished Scholar in 1973. "The two of them, along with many of Caltech's other social scientists, soon turned Caltech into a hotbed of experimentation on how groups made decisions." Miller describes his own and others' work on speculation and bubbles in a controlled laboratory, before routing the rest of his narrative to Wall Street (in a chapter entitled "Bubbles in the Wild") and taking readers on an entertaining and enlightening ride with not a single equation in sight.

Toward the end of the book, the author travels beyond financial markets to describe experimental work in other markets, such as allocating landing slots at airports, dividing up the broadcasting spectrum, and assigning space on the Space Shuttle—all of them problems studied in Caltech's laboratories by former and current faculty members, including Professors John Ledyard, David Grether, Tom Palfrey, and Colin Camerer. Says Camerer, the Axline Professor of Business Economics: "The style [of the book] is a refreshing combination—dramatic and fun to read, but also historically and scientifically accurate. So, I can send one to my dad, a salesman, and another to my girlfriend, a patent attorney."



PROMETHEANS IN THE LAB
CHEMISTRY AND THE MAKING OF THE MODERN WORLD
by Sharon Bertsch McGrayne
McGraw-Hill, 2001; 243 pages

Sharon Bertsch McGrayne tells the stories here of nine chemists whose discoveries changed the way we live our lives—the mundane things, like soap, dyes, sweets, nylon, and refrigerators, that are the conveniences of modern life. But this isn't just "Better Living Through Chemistry"; she also describes the dark side of the chemical revolution, the cost of some of those conveniences to the environment and human health. And intertwined with the chemistry and with the author's even-handed cost-benefit analysis, are colorful and entertaining accounts of the lives of some very human scientists.

Take Thomas Midgley Jr., who was single-handedly responsible for two of the late 20th century's most dangerous pollutants. Midgley found a safe and efficient refrigerant in chlorofluorocarbons, which led to ubiquitous air conditioning and, later, the ozone hole. He also discovered in the 1930s that adding tetraethyl lead to gasoline made automobile engines run more smoothly, without knocking. No matter that 15 workers in tetraethyl lead factories died of lead poisoning; Midgley publicly poured some over his hands to prove it safe.

In her last chapter, McGrayne gets to the hero of her collection of stories, the man who dedicated much of his scientific career to negating Midgley's contribution to civilization: Clair Patterson, a member of the Caltech faculty for more than 40 years. Patterson, a geochemist, determined the age of the Earth at 4.5 billion years by analyzing tiny amounts of lead isotopes. In the process, he learned that everyday life on Earth was far more contaminated with lead, a neurotoxin, than anyone had realized—or was willing to admit.

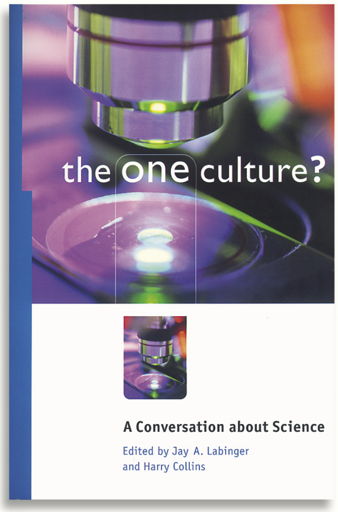
"Over the next 30 years, Patterson used mass spectroscopy and clean laboratory techniques to demonstrate the pervasiveness of lead pollution," McGrayne writes. "He traced the relationships between America's gas pump and its tuna sandwiches, between Roman slaves and silver dimes, and between Native American Indians and polar snows. He forged as close a connection between science and public policy as any physical scientist outside of medical research. He made the study of global pollution a quantitative science. And marrying his stubborn determination to his passionate conviction that science ought to serve society, Patterson never budged an inch."

Patterson's social conscience, says McGrayne, arose out of penance for his war work at Oak Ridge separating uranium isotopes for the Manhattan Project. But facing down powerful industrial interests fitted him well; it fed his natural cantankerousness and iconoclastic spirit, which the author captures as she traces his lonely campaign to rid the world of lead pollution. Often derided as a fanatic, he was directly responsible for passage of the Clean Air Act of 1970; the automobile industry responded with catalytic converters, which are inactivated by lead, and leaded gasoline became a thing of the past. By 1980 the average lead level in American blood had dropped 40 percent, and in the '90s to just a third of that. The amount of lead fallout onto Greenland's ice cap had declined 90 percent by 1989.

Patterson was frequently nominated for the Nobel

Peace Prize (by Saul Bellow, who featured a Patterson-like character in his novel *The Dean's December*). He died from an asthma attack in 1995, a disease first contracted collecting gas samples from a Hawaiian volcano a dozen years earlier. —*JD*

1980: Clair Patterson exhibits lead-soldered tuna cans, which he fought to remove from grocery



THE ONE CULTURE?
A CONVERSATION ABOUT SCIENCE
Edited by Jay A. Labinger and Harry Collins
The University of Chicago Press, 2001; 329 pages

Language authority H. W. Fowler wrote that English speakers who neither know nor care what a split infinitive is "are the vast majority, and are a happy folk, to be envied" by those who do know and care. The same might be said of scientists and their awareness of the so-called science wars. According to Jay Labinger, coeditor with Harry Collins of *The One Culture? A Conversation About Science*, "very few scientists are interested, let alone involved," in a debate that has its roots in Thomas Kuhn's publication of *The Structure of Scientific Revolutions* in 1962, and that broke into the open in 1996 when physicist Alan Sokal published his hoax—purporting to be a critique of science—in the "cultural studies" journal *Social Text*. The majority of scientists, apparently, are not even aware that a war is on.

In an effort to generate some light from the heat and fog of war, Labinger, administrator of Caltech's Beckman Institute, and Harry Collins, a British sociologist, have brought together representatives from both sides. The editors admit their focus is narrow: "We concentrate primarily on issues that have arisen out of the field called 'sociology of scientific knowledge' (SSK) and the critical responses thereto." No proponents of literary theory or cultural studies are represented, and all but one of the active contributing scientists are physicists.

The result is an excellent book whose intended audience is unclear. The editors' goals of seeking "a little convergence" between the two sides, of reintroducing complexity into the debate, and of at least clarifying some of the unresolved differences, will certainly resonate with those familiar with the issues, but may have little meaning for those who are not. This is unfortunate, since the matters being discussed are important.

Why important? The ultimate issue under debate is that of who speaks for science. Is it practicing scientists themselves, or the "SSKers," who study science by utilizing a relativism that "brackets out" any notion of science discovering facts about the real world (as opposed to socially constructing them), or postmodernists for whom science is "just another story," or some combination of these? Where do people who are not scientists or sociologists or literary theorists fit in?

Contributors—particularly on the SSK side, though to a certain extent on both sides—claim that their debate over the nature of science has had little impact on the world at large, whether in terms of affecting science funding or the way the public perceives science. Perhaps so, but reading these essays I wonder whether that could change. Several of the SSK contributors seem to believe that showing science to be socially constructed will increase public understanding of science and aid policymakers in dealing with issues involving science. As neither a scientist nor a sociologist, I have my doubts. When it comes to issues like global warming or genetically modified foods or mad-cow disease, I want to feel that scientists are working to discover what is really going on. That reaching a scientific consensus is a social process goes without saying. The question is whether that process is genuinely—if provisionally—finding out things about the natural world in a way that other processes don't.

SSK, as presented here, reminds me more than anything else of classical behaviorism, which "bracketed out" phenomena such as emotion, instinct, and mind. Behaviorism produced some interesting work, but in the end proved to be a dead end. Contributor Trevor Pinch writes of so-called science studies: "Rather than treating science as the 'exotic other' or just as a different animal, it levels the playing field—all animals are really the same, and they are not all that exotic." Perhaps. But while studying, say, humankind as just another animal may be necessary, it is surely not sufficient for understanding what is essentially human. Similarly, bracketing out the scientific "facts of the matter" may keep science studies from ever finding out all that much about science. (It is ironic that, after repeated SSK assertions that science has no unique essence, Harry Collins refers us to "the kind of assiduous study done in the field or in laboratories," to distinguish science from, for example, creationism. Collins, I'm sure, didn't intend trying to define science, but what he says does bring to mind the definition G. G. Simpson offered nearly half a century ago: "Science is an exploration of the material universe that seeks natural, orderly relationships among observed phenomena and that is self-testing.")

I've said little about the contributions by Labinger, Sokal, and the other scientists, mainly because their essays are so clearly thought out and written. Reading the book is a bit like riding a boat on a choppy sea: a rise into clarity followed by a plunge into obscurity. Not uniformly, of course. Interestingly, the scientists most opposed to the methodology of SSK seemed the clearest; the scientists with some sympathy for SSK somewhat less so; and the majority of SSKers and allies less so yet, with Peter Dear's offering re "epistemography" particularly difficult going, encompassing a turgidity and hair-splitting worthy of a medieval theologian.

The book is well indexed, and the editors have usefully provided bracketed numbers when important topics are introduced, referring the reader to other chapters where the same topics are discussed by other contributors with differing viewpoints.

I hope *The One Culture?* finds an audience, especially among scientists, who—as this book makes clear—are being studied by a group that claims for itself an objectivity it would deny to those it studies. I think the public at large could find it interesting, perhaps even helpful, as well. I did. —*MF*

The 16th annual meeting of the Society for Literature and Science, which seeks to strengthen bridges between the two fields, will be held October 10–13, 2002, in Pasadena, with support from Caltech and the Huntington Library. Proposals for panels and papers are due June 1. For more information, see the conference Web site at http://SLS-2002.caltech.edu/ or contact Jay Labinger, jal@its.caltech.edu. □

Lyman G. Bonner
1912 – 2002

Lyman Bonner, who served Caltech in a number of administrative positions between 1965 and 1989, died in Pasadena on March 22 at the age of 89.

Bonner was born in Kingston, Ontario, on September 16, 1912, the second of seven children. His first encounter with Caltech came in 1929 as a 17-year-old transfer sophomore, while his father, head of the chemistry department at the University of Utah, was on sabbatical here. Bonner finished his degree at Utah in 1932 and followed his older brother James back to Caltech as a graduate student. He earned his PhD in chemistry in 1935, the second of four Bonner brothers to hold Caltech doctorates.

His dissertation work on molecular structure led to an interest in infrared spectroscopy, which at Princeton, where he went next as a National Research Council fellow, had its home in the physics department. It was there that, as Bonner says in his 1989 oral history, "I decided I enjoyed physics and physicists more than I enjoyed chemistry and chemists, and I quietly made a switch." In 1937, he became an instructor and then assistant professor of physics at Duke, where he taught young naval officers in the wartime V-12 program.

When that program began to phase down in 1944, Bonner took a leave of absence for more hands-on war work and joined the Allegany Ballistics Laboratory, which was developing solid rocket propellants for the Navy under the Office of Scientific Research and Development. When ABL reverted to civilian life after the war and was taken over by Hercules, Inc., Bonner resigned his position at Duke and stayed on as technical director. In 1953 he was awarded the Navy's highest civilian honor, the Distinguished Public Service Award, and from 1955 to 1965 was director of development in the explosives and chemical propulsion department at Hercules.

By 1965, Bonner had become itchy to change directions, away from industry and government. On inquiring what might be available at Caltech (brother James was professor of biology here), he was offered the new post of director of foundation relations. A new fundraising campaign was about to begin. "After thinking it over for a day or two, it seemed to me very much the sort of thing I would like to try," he said later. "It was an entering step in the administration, a chance to learn what the administrative roles of a university were. On that basis I was glad to take it, at a 40 percent cut in salary, but I'd expected at least that. It wasn't money I was looking for, but a little more satisfaction. And I've never regretted it."

Because the campaign intended to raise money for 30 new buildings (that didn't quite happen), Bonner became interested in what the buildings were to be like—how big, how much they would cost, what they were to do. So in 1967 he found himself with a new job: assistant to the president (Lee DuBridge) for facilities planning. He was also named an associate in chemistry, but again gravitated toward physics instead; he taught recitation sections of freshman and sophomore physics for many years.

In late 1968, Bonner tried on yet another hat, that of director of student relations, another new position created by DuBridge, with responsibility for "maintaining and promoting good communications and good relations among students, faculty, administration and trustees." As such, he presided over the admission of female undergraduates, as well as the not-very-turbulent times of student "unrest" at Caltech. The campus was fully mobilized for an invasion of the Students for a Democratic Society in 1969, but only about 35 people showed up, Bonner said in his oral history. Always rather laid-back himself, he thought the campus had overreacted. "We have more problems finding activists than having too many activists," he wrote to then-president Harold Brown.

The closest thing to violent activism that Bonner remembered occurred after the Kent State shootings in 1970, when the administration refused to lower the flag to half mast. Students broke the lock and lowered the flag anyway. Then, he said, we sat around in the Winnett clubroom and talked about it.

"Lyman was a lovable chemist—a contradiction in terms," said J. Kent Clark, professor of literature, emeritus. "He was Caltech's chief troubleshooter and problem solver, and he was not afraid of change. His versatility and his amiability helped Caltech make some very interesting transitions. He did Caltech a tremendous amount of good."

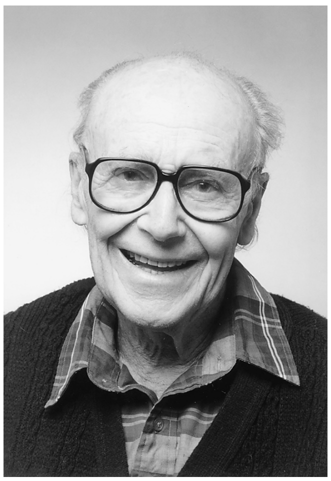
Bonner liked dealing with the students and remained director of student relations until 1980, when his title was changed to administrator for student affairs, a post he held until 1984. He was principally responsible for establishing the Student Health Center as it exists today. In addition he took on the post of registrar from 1977 till 1989, when he retired.

He loved words ("Lyman was also a literate chemist," said Clark) and was still solving crossword puzzles long after his Alzheimer's disease was diagnosed.

Bonner is survived by his wife, Jackie Bonner of Pasadena, who joined *Engineering & Science* magazine in 1967 and was its editor from 1979 to 1984; a daughter, Lynn E. Bonner of Seattle; two sons, Allen G. Bonner of Philadelphia and Philip H. Bonner of Lexington, Kentucky; five grandchildren; and four great-grandchildren. □ —*JD*

When the area between Thomas and Guggenheim was marked off for relandscaping in 1974, students parked their cars (with "for sale" signs on them) there as a prank in honor of Bonner (right), who was then director of student relations. The campus police were not amused and ticketed all the cars.

Norman R. Davidson
1916 – 2002



Norman Davidson, whose groundbreaking work in molecular biology led to a better understanding of the genetic blueprint of life, died February 14 in Pasadena, after a brief illness. He was 85.

Davidson was the Norman Chandler Professor of Chemical Biology, Emeritus, at Caltech, where he had been a faculty member since 1946. He took emeritus status in 1986, but served as executive officer for biology from 1989 to 1997 and remained active in research until his death.

"It was with the deepest personal regret that I heard of the death of Norman Davidson," said Caltech president David Baltimore. "Norman was a friend long before the prospect of my being president of Caltech arose, and he symbolized for me the essence of the Institute.

"His movement into biology from a background in chemistry allowed him to play a special role in the development of molecular biology. He saw imaginative ways that structural understanding could illuminate functional questions. He trained some of the finest and most imaginative people in the field. And he was deeply loved by all with whom he came in contact because of his unalloyed commitment to pushing the frontiers of understanding.

"Caltech is diminished by the loss of this great man who, undaunted by infirmity, almost to the end drove himself around the campus in his cart, asking questions, making suggestions, and still fully contributing to the institution to which he had given so much of his life," Baltimore said.

1955

Davidson was born April 5, 1916, in Chicago. He earned a bachelor's degree in chemistry at the University of Chicago in 1937, and completed another bachelor of science degree at the University of Oxford in 1938 as a Rhodes Scholar. In 1941 he completed his doctorate in chemistry at the University of Chicago.

During the war he worked at USC for the National Defense Research Committee, and at both Columbia University and the University of Chicago for the Division of War Research. From 1943 to 1945, he worked in the University of Chicago's metallurgical laboratory on the plutonium separation project for the Manhattan Project.

After the war and a brief stint as a researcher at the Radio Corporation of America, Davidson joined the Caltech faculty as a chemistry instructor and remained on the faculty for the rest of his life. He became a tenured professor of chemistry in 1952, a full professor in 1957, executive officer for chemistry in 1967, and the Norman Chandler Professor of Chemical Biology in 1982. He also served briefly as interim chair of the Division of Biology in 1989.

Davidson was known in the scientific community particularly for his innovative methods in bridging the gap between the physical and biological sciences. He pioneered new methods in physical chemistry and electron microscopy, the latter proving especially useful for genetic mapping and exploring the information properties of DNA and RNA.

On the reaction to his move from physical chemistry into molecular biology, Davidson said in his 1987 oral history: "I can recall a number of questions about how I was going to do it. But the important point is that Caltech is an environment that understands and appreciates interdisciplinary science. Even people who don't know anything about it appreciate people moving into new and exciting areas."

In 1996, when he was awarded the National Medal of Science by President Clinton, Davidson was working on new methods for studying electrical signaling in the nervous system and the ways in which the system changes during learning and memory formation. He was cited by the White House "for breakthroughs in chemistry and biology which have led to the earliest understanding of the overall structure of genomes."

"For example," the White House statement continued, "Davidson's research on DNA established the principle of nucleic acid renaturation, one of the most important principles in molecular biology and a primary tool for deciphering the structure and function of genes."

Davidson was also a founding member of the advisory council to the Human Genome Project.

"Norman was a major figure in both chemistry and biology for more than half a century, and one of the people who helped bring the two together, not just at Caltech, but in the subject as a whole," said Caltech provost Steve Koonin.

Henry Lester, the Bren Professor of Biology, noted the importance of Davidson's work in neuroscience since the late 1970s. "Norman made contributions in several important fields," said Lester, who began working with him in 1983 and shared laboratory space with him until Davidson's death. "His laboratory helped define the molecular biology of membrane excitability, including ion channels, transporters, and receptors."

Davidson's many awards included his designation as the 1980 California Scientist of the Year, the Robert A. Welch Award in Chemistry (1989), the Dickson Prize for Science (1985), and the Peter Debye Award by the American Chemical Society (1971). He was a member of the National Academy of Sciences for 42 years, a fellow of the American Academy of Arts and Sciences since 1984, and holder of an honorary doctorate from the University of Chicago.

Davidson is survived by his wife, Annemarie Davidson, of Sierra Madre, California; four children, Terry Davidson of Poway, California, Laureen Agee of Mammoth Lakes, California, Jeff Davidson of Cayucos, California, and Brian Davidson of Walnut Creek, California; and eight grandchildren. □ —*RT*

John R. Pierce
1910 – 2002

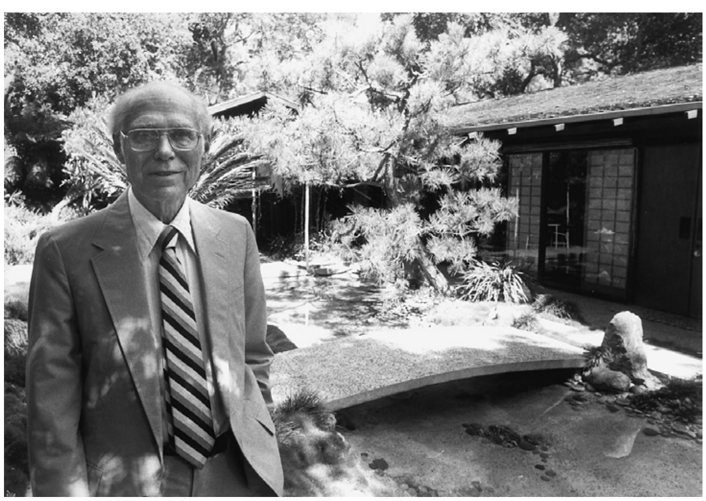
John R. Pierce, pioneer of satellite communication, science fiction writer, and musician, died April 2 in Sunnyvale, California. He was 92.

Born in Des Moines, Iowa, in 1910, Pierce later moved with his family to California and graduated from Woodrow Wilson High School in Long Beach. He earned three degrees from Caltech: his BS in 1933, MS in 1934, and PhD in 1936, all in electrical engineering. He started off planning to be a chemical engineer, but freshman chemistry, he said in a 1981 profile in *E&S*, cured him of that. A language requirement dissuaded him from physics. He had built and flown his own glider in high school and was briefly attracted to aeronautical engineering, but "we drew endless beams with rivets. So I looked for some sort of engineering that wasn't full of rivets. I became an electrical engineer." Much later he reflected that perhaps what he did was really physics after all.

He began his first career in 1936 at Bell Telephone Laboratories in Murray Hill, New Jersey, eventually to become executive director of research, Communications Sciences Division, in charge of work on mathematics and statistics, speech and hearing, behavioral science, electronics, radio, and guided waves. He was first put to work on vacuum tubes; he claimed to know nothing about them when he started but went on to invent a vacuum tube used in radar during the war and headed a team that developed traveling-wave tubes for amplifying microwaves. Pierce also coined the name "transistor" at the request of his friend Walter Brattain, one of three men who won the Nobel Prize for its invention.

Pierce is best known as the father of satellite communication. His ideas, inspired by a 1945 proposal of science fiction writer Arthur C. Clarke, led to the launch, in 1960, of Echo 1, a mylar balloon that bounced radio waves back to Earth. Pierce told the *New York Times* that he felt he had done "something of practical value." Telstar, a direct product of his work, transmitted the first transatlantic television broadcast two years later.

As "J. J. Coupling," Pierce wrote science fiction stories, the first in Hugo Gernsback's *Science Wonder Stories* in 1930. Many of his stories appeared in *Astounding Science Fiction*, and it was this magazine that carried his 1952 story "Don't Write: Telegraph!" which foreshadowed his satellite communication work. The pen name comes from atomic physics; "I didn't know what it meant when I chose it, and I'm a little uncertain now," he said in 1981. He took it from the letterhead of William Shockley's mock



Pierce stands in front of his Japanese-style home in Pasadena in 1981. He had been fascinated with all things Japanese ever since Professor of English Harvey Eagleson suggested, in 1928, that he read *The Tale of Genji.*

Institute for Useless Research; the "institute's" president was Isaac Neutron and the secretary was J. J. Coupling.

From the '60s on, Caltech tried to lure Pierce back to campus. Finally, Francis Clauser, chairman of the Division of Engineering and Applied Science, was shocked one day in 1971 to get a phone call from Pierce announcing, "You know, I think I'd like to come to California." So, after more than 35 years at Bell Labs, Pierce embarked on his second career as professor of engineering at Caltech. He took emeritus status in 1980 but continued in the post of chief technologist at JPL until 1982.

In that year, at the age of 72, Pierce began a third career as visiting professor of music at Stanford's Center for Computer Research in Music and Acoustics, a post he held for the next 12 years. Although he claimed not to be able to carry a tune, he had become interested in music while at Bell Labs. He composed some of the first computer-synthesized music, made two recordings, and wrote several books on music, sound, and speech and hearing, including *The Science of Musical Sound*.

Pierce was awarded the National Medal of Science in 1963 for his work on communication satellites, and the prestigious Charles Stark Draper Prize in 1995. He received one of Caltech's first Distinguished Alumni Awards (1966) and many other honors, including the Engineer of the Year award of the Institute for the Advancement of Engineering, the Medal of Honor of the Institute of Electrical and Electronics Engineers, the Marconi Award, and numerous honorary degrees. He was a fellow of the National Academies of Sciences and of Engineering, the American Academy of Arts and Sciences, and a member of the American Philosophical Society. He was the author of 20 books and held about 90 patents.

Pierce is survived by his wife, Brenda Woodard-Pierce, of Sunnyvale, a son, John J. Pierce of Bloomfield, New Jersey, and a daughter, Anne Pierce, of Summit, New Jersey. □ *—JD*

The material quoted above comes from articles in Engineering & Science*, October 1971 and November 1981.*

NEW HUMANITIES AND SOCIAL SCIENCES DIVISION CHAIR

She has traveled alone in a war-torn area of Africa and listened to lions pad around her tent at night, but now Caltech professor of anthropology Jean Ensminger takes on a different challenge, as the new chair of the Division of the Humanities and Social Sciences.

In making the announcement, Caltech provost Steve Koonin commented, "Jean brings a distinguished record of teaching and research, fine judgment, and demonstrated management skills to an important position of academic leadership within the Institute. We are very fortunate that someone of her talents is willing to take on this important responsibility."

Ensminger will be the first woman to serve as division chair at Caltech, and will take the helm on June 15, replacing John Ledyard, professor of economics and social sciences, who will be returning, he says, to "the best position in the world: full professor at Caltech." He will redirect his energies to his research in market and organization design, or focus on a new, unrelated area, or "go sailing, if my boat is still afloat."

For her part, Ensminger is enthusiastic about the prospects for the division, and hopes to build on its successes over the last two decades. "The division has transformed the study of political science and political economy in ways now emulated and dominant in virtually every major university in America," she says, "and is currently incubating several areas of expertise that have the same potential for transforming disciplines as we know them today."

Specifically, she notes that the absence of disciplinary boundaries at Caltech is spawning research that will "reshape the philosophy of mind, behavioral economics, and the frontier between neuroscience, psychology, and economics, while the division's uniquely seamless boundary between literature and history, together with proximity to the Huntington Library, affords us another opportunity to blossom in the humanities."

Ensminger is an uncommon anthropologist: her line of research is in an area known as experimental economics, a field, she notes, that the division has played a pivotal role in shaping. She is interested in how people make economic decisions, and her work involves running experiments—described to the participants as games—that use real money in order to learn something about real behavior. Unlike most experimental economists, however, Ensminger takes the method out of the university laboratory and into small-scale communities in Africa and elsewhere.

The simplest game she uses plays for fairly high stakes, usually a day's wages, whether the game is played in Hamilton, Missouri, or Wayu, Kenya, two places where she has conducted her research. Ensminger will bring a group of people together to play in pairs. Player one is told he or she has, say, $50 to divide with the other person; both will remain anonymous to one another, and player one can give player two any amount or nothing. How is the money divided? More fairly than one might guess, often as high as a 50-50 split.

Even more counterintuitive to conventional economic theorizing, says Ensminger, is that the more involved a society is in a market economy—that is, working for wages, or raising something (crops or cattle) and selling it in order to live—the fairer people tend to be. Across 16 small-scale societies studied around the world, the U.S. is the most fair-minded reported to date, while hunter-gatherers are the least.

For almost 25 years, Ensminger has traveled to Africa, living and studying with the Orma tribe, partially nomadic cattle herders in northeastern Kenya near the Somali border, where she will return this summer for five weeks. In the beginning, she would live in a tent on the grounds of a local school, in a place that was frequented by roaming lions at night. Now she stays in the compound of the local chief, but there is a greater danger—banditry.

"My field site became very dangerous in the 1990s because of the collapse of the Somali state," says Ensminger. "There is an ethnic conflict between the Orma and the Somali, who want to take over Orma territory. A phenomenal number of people I know have either been shot or killed by the bandits. It's not a war; it's like the Wild West with armed bandits on the loose."

As a woman traveling alone, carrying cash, and in one of the few cars in the area, she is obviously a target for bandits. And while she feels safe in the Orma villages, she admits to being "unabashedly terrified whenever I go on the roads in and out of that area." Still, that is where 20 years of her research is, and she is not willing to give it up.

It is that kind of perseverance she intends to bring to working with her colleagues as division chair. "I'm honored and delighted to have the opportunity to work with faculty of the extraordinary quality found here, and I look forward to the possibilities and challenges that lie ahead." □ —*MW*

Honors and Awards

David Baltimore, president of Caltech, has been named an honorary member of Art Center College of Design's Board of Trustees.

Barry Barish, Linde Professor of Physics and director of the Laser Interferometer Gravitational-Wave Observatory Laboratory, is the 2002 recipient of the American Association of Physics Teachers (AAPT) Klopsteg Award.

Andrew Benson, Caltech Prize Fellow in Astronomy, has been awarded the 2001 Michael Penston Prize, which is presented annually by the Royal Astronomical Society to honor the best astronomy PhD thesis in the United Kingdom.

David Chan, assistant professor of biology and Bren Scholar, has been selected to receive a 2002 Beckman Young Investigators award, intended to "help provide research support to the most promising young faculty members in the early stages of their academic careers in the chemical and life sciences." A graduate of Harvard Medical School, Chan joined Caltech in January 2000.

Thomas Caughey, Hayman Professor of Mechanical Engineering, Emeritus, has been selected by the Engineering Mechanics Division of the American Society of Civil Engineers to receive the 2002 Theodore von Kármán Medal in recognition of "his pioneering developments and sustained leadership in developing tools for dealing with challenging problems in engineering science".

John Eiler, assistant professor of geochemistry, has been awarded the 2002 James B. Macelwane Medal by the American Geophysical Union (AGU) in recognition of his scientific accomplishments.

Thomas Everhart, president emeritus, has been named the 2002 recipient of the Founders Medal by the Institute of Electrical and Electronics Engineers (IEEE).

Robert Grubbs, Atkins Professor of Chemistry, has been selected by the American Chemical Society to receive the 2002 Arthur C. Cope Award.

Sossina Haile, associate professor of materials science, and Denise Nelson Nash, director of public events, have been selected as 27th Congressional District Women of the Year. Along with seven others, they were honored by Congressman Adam Schiff for having "played a critical role in improving the quality of life" in the 27th District and having "made a difference in our community in a significant manner."

Wilfred Iwan, professor of applied mechanics and director of the Earthquake Engineering Research Laboratory, was awarded the 2002 Alquist Medal by the

Joe Kirschvink, winner of the Feynman Prize for Excellence in Teaching.

California Earthquake Safety Foundation in honor of "his lifetime of service to the profession of structural engineering and its application to the safety of the people of California and the world."

Joseph Kirschvink, professor of geobiology, has been awarded the 2002 Richard P. Feynman Prize for Excellence in Teaching. Kirschvink was specifically selected for "his innovative teaching style and outstanding mentorship, which have inspired a generation of Caltech students."

Steve Koonin, provost and professor of theoretical physics, has been elected a member of the Council on Foreign Relations. Dedicated to increasing America's understanding of the world and contributing ideas to U.S. foreign policy, the council "aims to enhance the quality of study and debate on world issues, develop new generations of thinkers and leaders, and help meet international challenges by generating concrete and workable ideas."

Shrinivas Kulkarni, MacArthur Professor of Astronomy and Planetary Science, will deliver the 2003 Salpeter Lecture at Cornell University.

Andrew Lange, Goldberger Professor of Physics, has been chosen by the Manne Siegbahn Institute in Stockholm, Sweden, to deliver its annual Manne Siegbahn Memorial Lecture.

David MacMillan, associate professor of chemistry, was selected by AstraZeneca Pharmaceuticals as a recipient of the 2001 AstraZeneca Excellence in Chemistry Award. In addition, he was chosen by the Pfizer Global Research and Development Academic and Industrial Relations Committee as a recipient of the 2001 Pfizer Award for Creativity in Organic Chemistry.

Carver Mead, Moore Professor of Engineering and Applied Science, Emeritus, was awarded Carnegie Mellon University's Dickson Prize in Science.

Ned Munger, professor of geography, emeritus, has received the Gandhi-King-Ikeda Award from the Martin Luther King, Jr. International Chapel and the Gandhi Institute for Reconciliation, Morehouse College, Atlanta. The award reads: "In the tradition of Mohandas K. 'Mahatma' Gandhi, Dr. Martin Luther King, Jr. and Dr. Daisaku Ikeda, you have served your community and the world through your dedication to peace and unity, your commitment to nonviolence, and your persistent efforts to establish justice for all humankind."

Michael Roukes, professor of physics, was selected to give one of the 2002 Lillian M. Gilbreth Lectures from Frontiers in Engineering at the National Academy of Engineering's national meeting in February.

Anneila Sargent, professor of astronomy and director of both the Owens Valley Radio Observatory and the Interferometry Science Center, has been invited to deliver the Graham Lecture at University College, Toronto.

Re'em Sari, Sherman Fairchild Senior Research Fellow in Astrophysics and lecturer in planetary science, has been awarded Case Western Reserve University's 2002 Michelson Postdoctoral Prize Lectureship.

Barry Simon, IBM Professor of Mathematics and Theoretical Physics and executive officer for mathematics, has been invited to be a Distinguished Visitor at UC Irvine.

P. P. Vaidyanathan, professor of electrical engineering, was selected by the Institute of Electrical and Electronics Engineers Signal Processing Society to receive the 2001 Technical Achievement Award.

Erik Winfree, assistant professor of computer science and computation and neural systems, is a recipient of the Presidential Early Career Award for Scientists and Engineers.

Ahmed Zewail, Pauling Professor of Chemical Physics and professor of physics, has been selected to join the Welch Foundation's scientific advisory board. He has also received a Distinguished Alumni Award from the University of Pennsylvania and the G. M. Kosolapoff Award in chemistry from the University of Auburn. □

Celebrating the sale of the Aston Martin are, from left: Lee and Nick Begovich; Jeff Ricketts, Begovich's financial adviser, who conceived the car/trust plan; and David Sydorick, the car's new owner. (Photos and text by Carolyn Swanson.)

CAR. BOND CAR.

A 1960 Aston Martin DB4GT Zagato has been converted into a $1 million charitable remainder trust that will provide a lifetime income stream for the donor—and a great benefit for Caltech. The donor was Nicholas Begovich (BS '43, MS '44, PhD '48, all in electrical engineering).

"As a kid, one of my neighbors was constantly working on cars, and I got to help him. That's how it all started, I think—that and my hobby in radio," Begovich explained. "The two went together, so the cars became a hobby, and electronics became a profession."

On the professional side, Begovich spent most of his career with Hughes Aircraft. Starting in 1948 as a research physicist, he served as a vice president from the late 1950s until joining Litton Industries in 1970 as a corporate vice president and president of its Data Systems Division. In 1976, he left to become a consultant to the Applied Physics Laboratory at Johns Hopkins, as well as to various defense electronics companies and the Department of Defense. He is a member of the American Physics Society and a fellow of the Institute of Electrical and Electronics Engineers.

He began collecting postwar foreign sports cars in the early 1950s. He would typically acquire a car, drive it a few months, then tear it apart and begin "tinkering" with it. Begovich's collection, which features some very rare vehicles, is housed in two garages in an industrial area near his home.

The Aston Martin is the first of his collection to be sold, as a means of removing highly appreciated assets from his estate. It's very rare indeed—a British car with a body designed by the Italian company Zagato. Only 19 were manufactured, and just three are in the United States. Begovich negotiated with the owner's fiancée in 1969 to purchase the car for about $5,000. Musing on his good fortune, he admitted, "I often wonder if they ever got married."

Converting car to trust was very easy. First, the trust was established, then a buyer for the Aston Martin was identified (a collector who owns a number of cars with Zagato coachwork), and the sale price was set at $1 million. Begovich acted as a trustee until the car was sold, and then Caltech became the successor trustee, releasing him from further responsibility with regard to administration of the trust. The trust provides a lifetime annuity for Begovich and his wife, Lee; upon termination, the remaining trust assets will be used to establish either a Caltech professorship or postdoctoral fellowship in any of the fields of electrical engineering, physics, mathematics, or biology.

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