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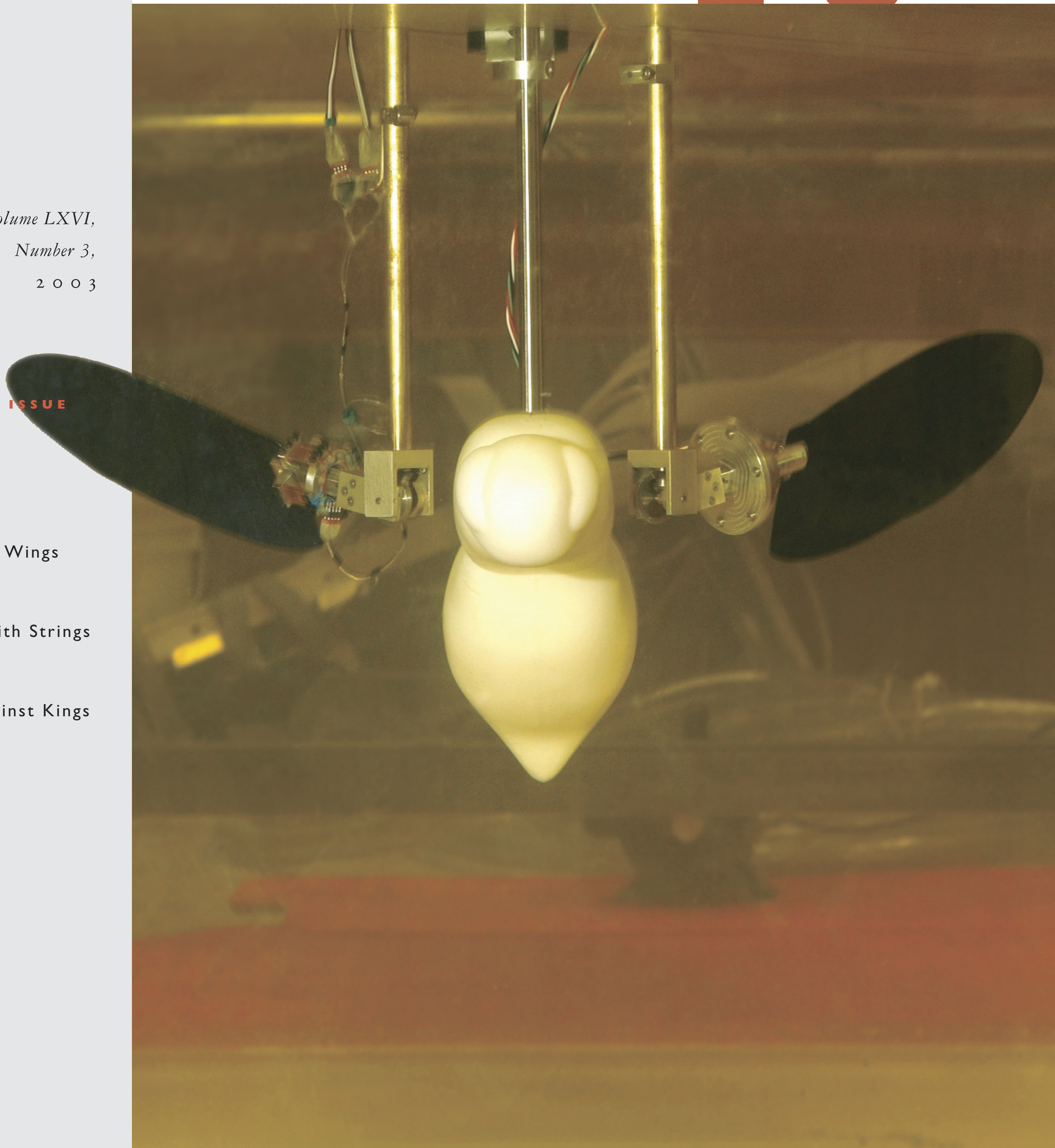
E&S

Engineering and Science

Volume LXVI,
Number 3,
2003



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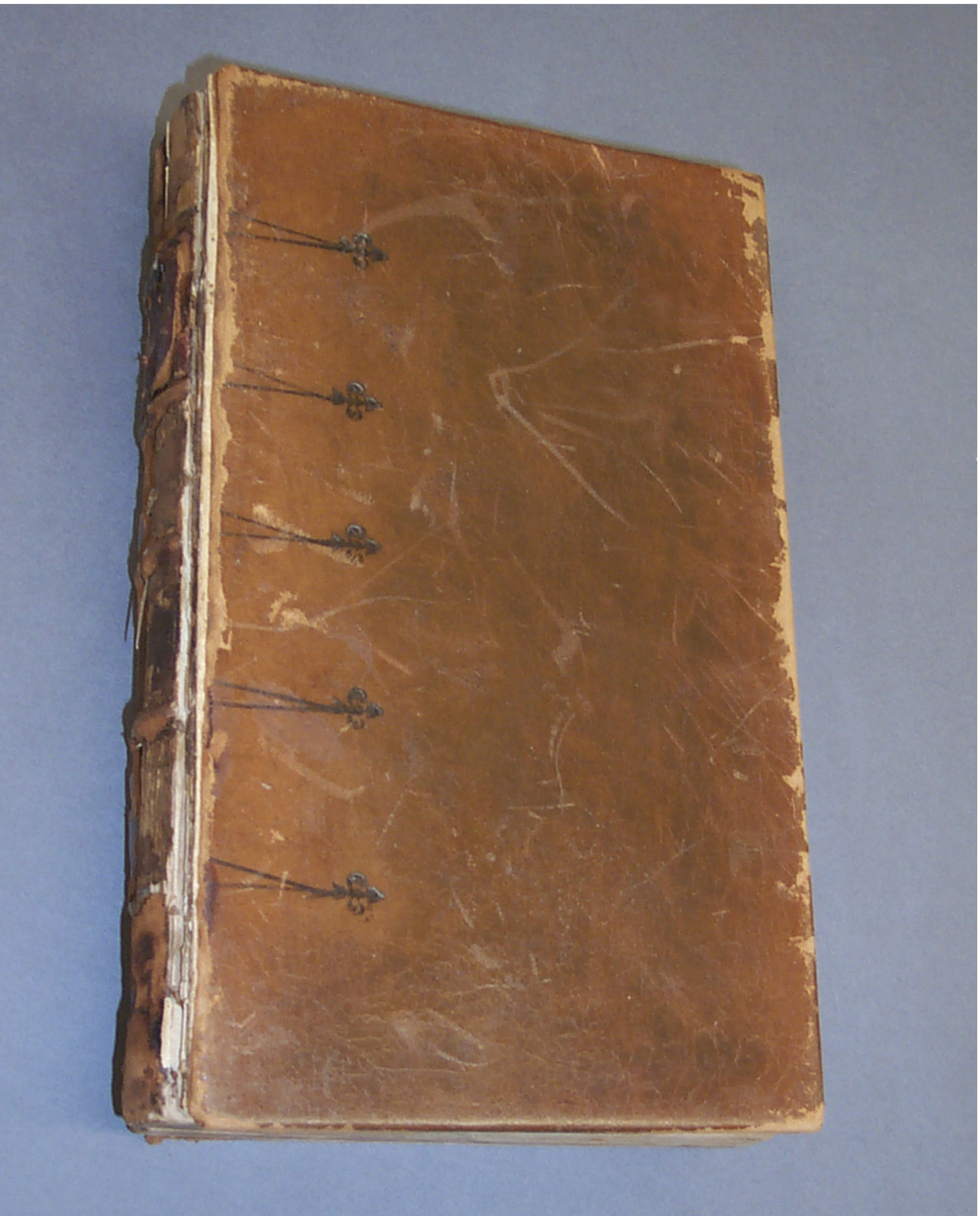

Looking very innocent but harboring proof that you can't tell a book by its cover, this 1674 edition of Samuel Butler's *Hudibras* hides a handwritten manuscript of a seditious Catholic tract, bound into its now crumbling spine. When George Housner, the Braun Professor of Engineering, Emeritus, donated it along with the rest of his book collection to the Caltech Archives, curious staff members set out to try to discover who wrote the mysterious tract and what it was doing bound up with a satirical epic poem. To read about what they found, see the story beginning on page 32.

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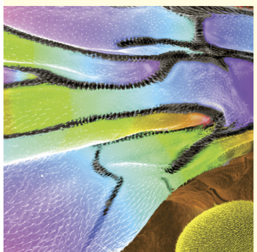

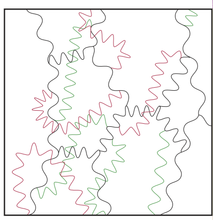

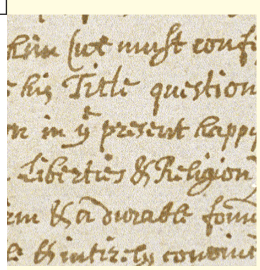

On the cover: Robofly has a 60-centimeter wing span, but relax—your fruit salad is safe. Robofly's wings flap five times per second in a tank full of mineral oil whose density and viscosity is such that the system exactly reproduces, on a much larger scale, the aerodynamic forces on a real fruit fly's wings as it maneuvers in midair. To find out how the fly exploits these forces with its tiny muscles and even tinier brain, see the story on page 10.

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, 10, 14-16, 32, 33, 36, 37, 40, 44 – Bob Paz; 4, 25, 26, 30, 31 – Doug Smith; 6 – NASA; 6 – NASA/JPL/MSSS; 7 – JPL; 9 – David Werntz; 10, 24, 28, 29, 30, 31, 38 – Doug Cummings; 11, 19 – Ron Fearing, UC Berkeley; 11 – Joseph Yan, UC Berkeley; 15 – Wai Pang Chan, UC Berkeley; 19 – Srinath Avadhanula & Rob Wood, UC Berkeley; 32 – Floyd Clark; 41 – Marianna Plott

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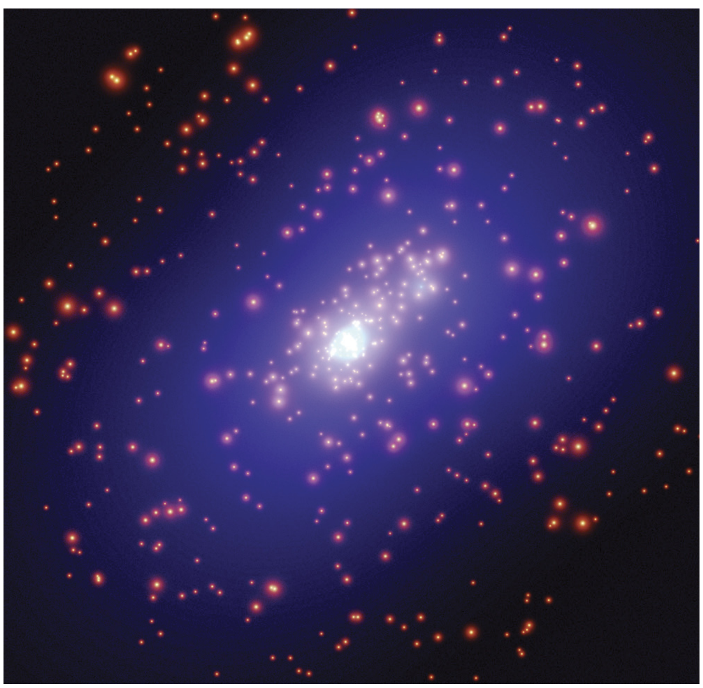
Through a Lens, Darkly

European Space Agency, NASA, and Jean-Paul Kneib (Observatoire Midi-Pyrénées, France/Caltech)



This mass-distribution map of the galaxy cluster known as Cl0024+1654 was created by feeding Hubble and ground-based observations into advanced mathematical models. The galaxies' mass is shown in red, and the mass of the dark matter in blue. The lighter and brighter the color, the more mass there is at that point. The dark matter is densest where the galaxies clump, holding them together like glue. The dark matter is not uniformly distributed in a nice sphere, and a secondary blob can be seen to the upper right of the main mass.

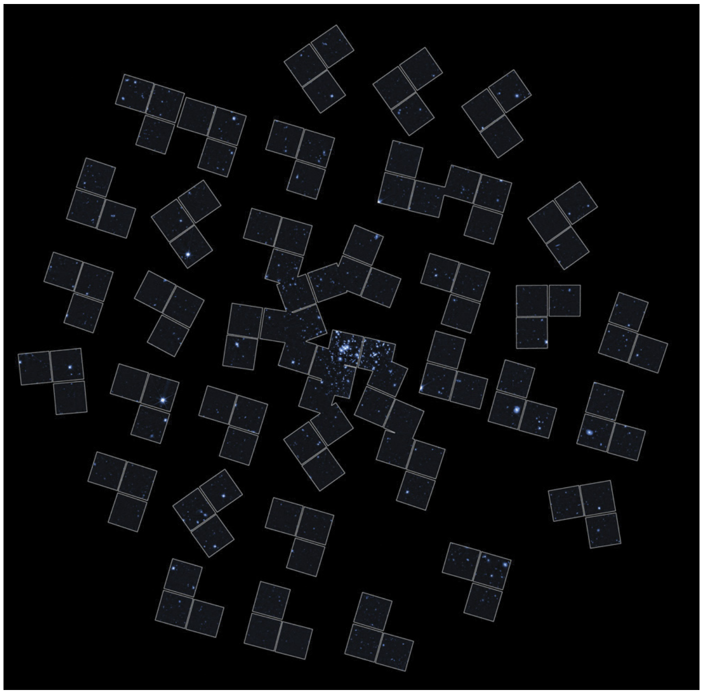
Astrophysicists have had an exceedingly difficult time charting how the mysterious stuff called dark matter permeates the universe because it's—well—dark. But a new "mass map" of a gigantic cluster of galaxies about 4.5 billion light-years from Earth shows in unprecedented detail how dark matter is distributed, and indicates how it figures into the grand scheme of the cosmos. An international group of astronomers led by Caltech Visiting Associate Jean-Paul Kneib; Richard Ellis, the Steele Professor of Astronomy and director of the Caltech Optical Observatories; and postdoc Tommaso Treu plotted how the cluster bends the light from more than 7,000 more distant galaxies behind it, distorting their shapes. This phenomenon, known as gravitational lensing, allowed the dark matter's mass contribution to be inferred by subtracting out the distortions that are caused by the matter that can be seen. About 80 to 85 percent of all matter in the universe is invisible, a fact realized by Caltech's Fritz Zwicky in 1937, based on studies of the motions of galaxies in the nearby Coma cluster.

Making over 120 hours of observations on the Hubble Space Telescope, the researchers surveyed a patch of sky almost as large as the full moon. The study achieved a new level of precision, not only for the cluster's center, which had been done for many clusters, but also for the previously uncharted outlying regions—as far as 15 million light-years from the center, a much larger range than in previous investigations. The result is the most comprehensive study to date of the distribution of dark matter and its relationship to the shining galaxies.

The study, to be published soon in the *Astrophysical Journal*, reveals that the dark matter's density falls off fairly sharply as one moves out from the cluster's center, defining a limit to the dark matter's distribution and hence the total mass of the cluster. "Although theorists have predicted this from numerical simulations based on the effects of gravity, this is the first time we've had convincing observations on large scales to back them up," says Ellis. "Some astronomers had speculated clusters might contain large reservoirs of dark matter in their outermost regions. Assuming our cluster is representative, this is not the case."

The new level of detail

European Space Agency, NASA, and Jean-Paul Kneib (Observatoire Midi-Pyrénées, France/Caltech)



European Space Agency, NASA, Jean-Paul Kneib (Observatoire Midi-Pyrénées, France/Caltech), and the Canada-France-Hawaii-Telescope

Above, left: It took five days of observations and 39 Hubble Wide Field and Planetary Camera 2 (WFPC2) images to make the map. Each WFPC2 image is about 1/150 the diameter of the full moon. This composite is 27 arc-minutes across, slightly less than the moon's diameter.

Above, right: The galaxy cluster as seen by the Canada-France-Hawaii Telescope on Mauna Kea. The group of yellow galaxies at center is the cluster's heart, but cluster galaxies actually extend to at least the photo's edge. This image measures 21 × 21 arc-minutes.

also revealed localized concentrations of dark matter associated with galaxies known to be slowly falling into the system. Overall, there's a striking correspondence between features in the dark-matter map and the visible galaxies—another important finding.

"The close association of dark matter with structure in the galaxy distribution is convincing evidence that clusters like the one studied built up from the merging of smaller groups of galaxies, which were prevented from flying away by the gravitational pull of their dark matter," says lead author Jean-Paul Kneib.

The Hubble's new camera, the Advanced Camera for Surveys (ACS), will be trained on a second cluster later this year. ACS is 10 times more efficient than the Wide Field and Planetary Camera 2, which was used for this study, and will allow finer clumps of mass to be studied in order to investigate how the clusters were assembled in the first place.

The other team members are Patrick Hudelot of the Observatoire Midi-Pyrénées in France, Graham P. Smith of Caltech, Phil Marshall of the Mullard Radio Observatory in England, Oliver Czoske of the Institut für Astrophysik und Extraterrestrische Forschung in Germany, Ian Smail of the University of Durham in England, and Priya Natarajan of Yale University. □

Deuterium, Dirt, and Ozone Damage

Two months after a pivotal study on the potential impact of a future hydrogen-based economy on the environment, further evidence is emerging on what would happen to hydrogen released by human activity. In the August 21 issue of *Nature*, a group of researchers from Caltech and other institutions report on a study of the reactions that produce and destroy hydrogen molecules in the stratosphere. The results indicate that most of the hydrogen removed from the atmosphere winds up in the ground, so the scientific community will need to focus on the destruction of hydrogen in the soil in order to accurately predict whether human emissions will accumulate in the air.

The researchers reached this conclusion through careful measurements of a rare isotope of hydrogen known as deuterium. It has long been known that atmospheric molecular hydrogen is anomalously rich in deuterium, but it was unclear why. The best explanation was that the hydrogen was being destroyed by airborne chemical reactions that were relatively slow for deuterium, causing it to accumulate like salt in an evaporating pan of water. This would mean that hydrogen-oxidizing trace gases controlled the natural hydrogen cycle, and that soils were relatively unimportant. But the Caltech group discovered that one of the main natural sources of atmospheric hydrogen—the breakdown of methane—is actually responsible for the deuterium. This implies that reactions with atmospheric oxidants are relatively unimportant to the hydrogen cycle, and that uptake by soils is really in the driver's seat.

The issue is important because of the potential for a future hydrogen economy to leak hydrogen into the air—a scenario explored in the earlier study. If such leaks are not mitigated by natural processes that destroy hydrogen, the leaked hydrogen will accumulate and inevitably find its way into the stratosphere, where it will participate in chemical reactions that damage the ozone layer. The key to predicting how this chain of events will unfold lies in knowing what natural processes destroy hydrogen, and to what extent they might counteract increases in human emissions.

Hydrogen is highly reactive, but the question of when and where it reacts, and under what circumstances, is difficult to answer precisely. This question is simplified in the stratosphere, where it's easier to single out and understand specific reactions. According to John Eiler, associate professor of geochemistry and a coauthor of both papers, the new data were gathered in the stratosphere with one of the high-flying ER-2 planes operated by the NASA Dryden Flight Research Center in the Mojave Desert. The ER-2, a reconfigured U-2 spy plane, is part of NASA's Airborne Research Program and is crucial to atmospheric chemists interested in directly collecting stratospheric samples for air-quality research.

"We wanted to look at hydrogen in the stratosphere because it's easy to study the production of hydrogen from methane separate from other influences," Eiler explains. "It may seem odd to go to the stratosphere to understand what's happening in the ground, but this was the best way to get a global perspective on the importance of soils to the hydrogen cycle."

The air samples, collected in various locales, showed extreme deuterium enrichment. With precise information on the deuterium content of hydrogen formed from methane, the researchers were able to calculate that the soils' hydrogen uptake is as high as 80 percent. It is suspected that soil-dwelling microbes use the hydrogen, but their biological processes are poorly understood.

It seems likely that the hydrogen taken up by soils is relatively free of environmental consequences, but the question still remains of how much extra hydrogen can be consumed. If there is a significant amount of leakage, then soil uptake must increase dramatically or it will be inadequate to cleanse the atmosphere, Eiler says. "An analogy would be the discovery that trees and other plants get rid of some of the carbon dioxide that cars emit, but by no means all of it. So the question as we look toward a future hydrogen economy is whether the microbes will be able to eat the hydrogen fast enough."

The research was funded in part by the National Science Foundation. Bruce Doddridge, program director in the NSF's division of atmospheric science, said, "This carefully conducted research has resulted in the most accurate information to date, and appears to account for the deuterium excess previously observed. A more accurate molecular hydrogen budget may have important implications as global fuel technology shifts its focus from fossil fuels to other sources."

The paper's lead author is Thom Rahn, a postdoc of Eiler's now at the Los Alamos National Laboratory. The other authors are Paul Wennberg, professor of atmospheric chemistry and environmental engineering science; Kristie Boering and Michael McCarthy, both of UC Berkeley; Stanley Tyler of UC Irvine; and Sue Schauffler of the National Center for Atmospheric Research in Boulder, Colorado. Other supporters of the research were the Davidow Fund and General Motors, the David and Lucile Packard Foundation, the NASA Upper Atmosphere Research Program, and the National Center for Atmospheric Research. □—*RT*

GALILEO'S WAKE

The Galileo spacecraft signed off on Sunday, September 21, and hundreds of project alumni and their families spent the day at JPL bidding it farewell. The spacecraft was plunged into Jupiter's atmosphere in order to avoid possible contamination of its moons in the distant future. An overflow crowd in Von Kármán auditorium listened to panelists recounting Galileo's triumphs over launch delays, stuck antennas, balky tape recorders, and enough other obstacles to kill several lesser missions; heard a rundown of the 14 years' worth of stupendous science that resulted; and then counted down the last five seconds to "impact" (actually, the crossing of the 1-bar depth in Jupiter's atmosphere) New Year's Eve style at 11:57 a.m. PDT. But Galileo would

The Not Ready for Real-Time Players presented *Survivor: Jupiter*, in which such things as the high-gain antenna, the probe, the flight team, and finally Galileo itself got voted off one by one. In a remarkable stroke of timing, their parodic tribute ended just when the signal did. (With apologies to the Rolling Stones, the lyrics on the screen behind them read, "They said/ You can't record the science that you want. . . .")

enjoy an afterlife of sorts for more than an hour as its signals sped to Earth.

Fittingly, it was the Deep Space Network's Goldstone station, only about 100 miles from JPL as the photon flies, that received Galileo's last transmission, at 12:43:14 p.m. The spacecraft once again defied the odds, transmitting engineering data at 32 bits per second right up to the moment it passed behind Jupiter's limb without going into "safe" mode because of the radiation. And there may be one last gift in the data, even though the instruments had been shut down: on a previous pass by the moon Amalthea in November 2002, the star scanner picked up stray flashes of light that were not cosmic-ray hits to the electronics. If the flashes turn up again this time, they could be glints from a previously unknown ring in Amalthea's orbit. The data may be hard to tease out, but, says former sequence integration engineer Bruce McLaughlin (BS '77), "It's all been recorded on tape and shipped to JPL, and if we have to sit down and scratch out the ones and zeroes with paper and pencil, we'll do it." □—*DS*

This photograph of Gilbert McCann sitting at the console of the analog computer he designed ran in his obituary in the previous issue. The unidentified man standing behind him is the late Charles Wilts (BS '40, MS '41, PhD '48), professor of electrical engineering, who was McCann's close collaborator in building the machine. Wilts's obit appeared in the Spring '91 issue of *E&S*.

Oschin's One-Twelve

A major new sky survey has begun at Caltech's Palomar Observatory. The Palomar-QUEST survey, a collaborative venture between Caltech, Yale, the Jet Propulsion Laboratory, and Indiana University, will explore the universe out to the most distant quasars, more than 10 billion light-years away.

The survey is being done using the newly refurbished 48-inch Sam Oschin (pronounced "Ocean") Telescope, first used to produce all-sky atlases on photographic plates in the 1950s. Today, the telescope's eye is a camera containing 112 digital imaging detectors known as charge-coupled devices, or CCDs. (The largest astronomical camera until now had 30 CCDs.) Designed and built by scientists at Yale and Indiana Universities, the QUEST (Quasar Equatorial Survey Team) camera captures the entire field of view of this wide-field telescope.

The survey will generate astronomical data at the unprecedented rate of about one terabyte per month. A terabyte is a million megabytes, or approximately equivalent to the amount of information contained in two million books. In two years, the survey will generate an amount of information about equal to that in the entire Library of Congress.

Unlike past surveys, Palomar-QUEST will make many observations of each portion of the sky, enabling researchers to find not only objects that move, like asteroids or comets, but also objects that vary in brightness, such as supernova explosions, variable stars, quasars, and cosmic gamma-ray bursts—and to do so at an unprecedented scale. "Previous sky surveys were essentially digital snapshots," says Professor of Astronomy S. George Djorgovski. "Now we're starting to make digital movies of the universe."

Djorgovski and postdoc Ashish Mahabal, in collaboration with the Yale group, plan to use the survey to discover large numbers of very distant quasars—highly luminous objects believed to be young galaxies with massive black holes at their centers—and to use them to probe the early stages of the universe.

Richard Ellis, the Steele Professor of Astronomy and director of the Caltech Optical Observatories, will use QUEST to search for exploding stars known as supernovae. He and his team, in conjunction with the group from Yale, will attempt to confirm or deny the recent finding that our universe is accelerating as it expands.

Shri Kulkarni, the MacArthur Professor of Astronomy and Planetary Science, studies gamma-ray bursts. A gamma-ray burst is the most energetic explosion in the cosmos. It is short-lived and unpredictable, and when first detected its exact location in the sky is uncertain. The automated Oschin Telescope, armed with the

QUEST camera's wide field of view, can pin down its position, allowing astronomers to catch and study its fading glow. (See *E&S*, 2003, No. 1.)

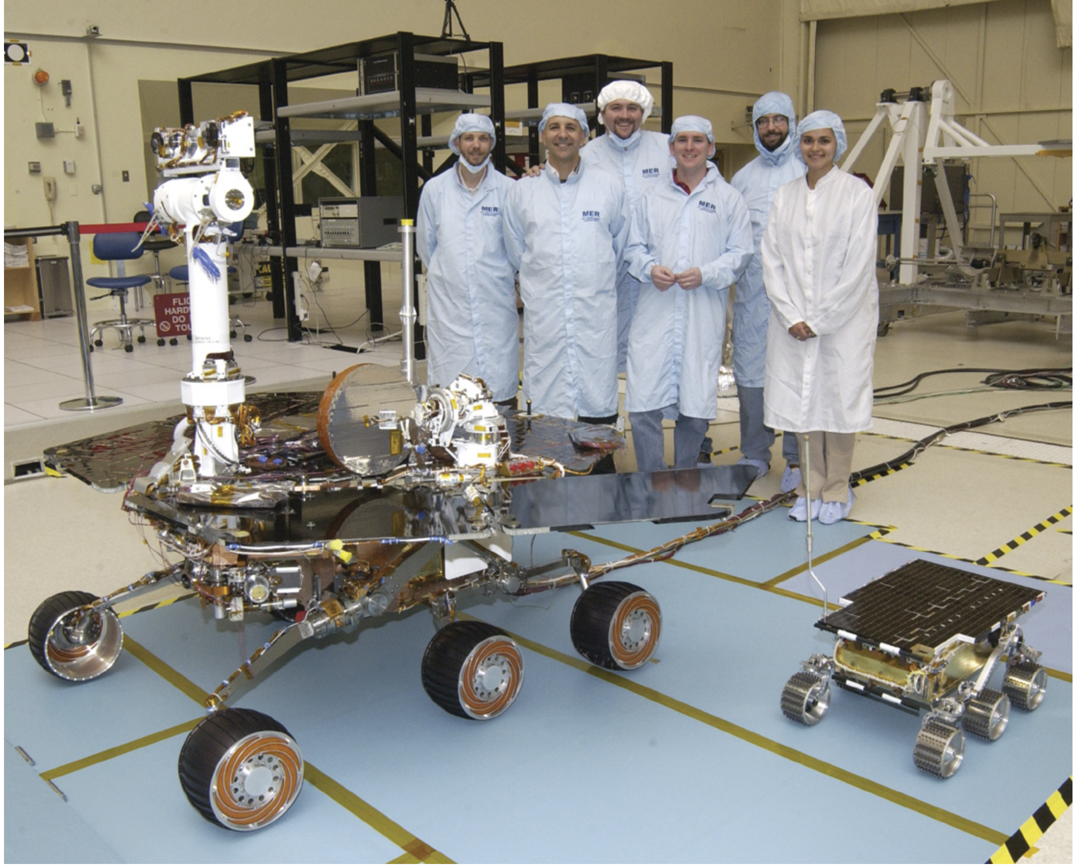
Closer to home, associate professor of planetary astronomy Mike Brown is looking for objects at the edge of our solar system, in the icy swarm known as the Kuiper Belt. Brown is convinced that there are big objects out there, possibly as big as the planet Mars. He, in collaboration with Yale's David Rabinowitz, will use QUEST to look for them.

Steve Pravdo, project manager for the Jet Propulsion Laboratory's Near-Earth Asteroid Tracking (NEAT) Project, will use QUEST to continue NEAT's search for asteroids that might one day approach or even collide with our planet. (See *E&S*, 2001, No. 1.)

The Palomar-QUEST survey will undoubtedly enable many other investigations in the years to come. The intent is to make all of the copious amounts of data publicly available in due time on the Web, as a part of the nascent National Virtual Observatory. Roy Williams, member of the professional staff of Caltech's Center for Advanced Computing Research, is working on the National Virtual Observatory project, which will greatly increase the scientific impact of the data and ease its use for public and educational outreach as well.

The QUEST team members from Indiana University are Jim Musser, Stu Mufson, Kent Honeycutt, Mark Gebhard, and Brice Adams. Yale University's team includes Charles Baltay, Rabinowitz, Jeff Snyder, Nick Morgan, Nan Ellman, William Emmet, and Thomas Hurteau. The NEAT team consists of Raymond Bambery, principal investigator; and coinvestigators Daniel McDonald, Michael Hicks, Kenneth Lawrence, and Pravdo. The camera's installation was overseen by Robert Brucato, Robert Thicksten, and Hal Petrie (BS '68). □—*SK*

Left: The Space Infrared Telescope Facility (SIRTF), the fourth and final installment of NASA's Great Observatories program, lifted off from Cape Canaveral at 1:35 a.m. EDT August 25. Now en route to an Earth-trailing orbit well away from our planetary warmth, the spacecraft is being checked out by ground controllers. So far, all systems are go to begin doing serious science sometime around Thanksgiving Day. SIRTF is managed by JPL, and its data-processing and control center is located at Caltech. The next issue of *E&S* will feature an in-depth look at the mission.



Above: Spirit and Opportunity, JPL's twin Mars Exploration Rovers, were launched on June 10 and July 7 respectively and will reach Mars three weeks apart in January 2004. The direct descendants of the 1997 Mars Pathfinder mission's Sojourner rover (*E&S* No. 3, 1997), these two robot geologists will be able to traverse more ground in a few days than Sojourner did in its entire lifetime. Along with updated versions of the camera and instruments that Sojourner and Pathfinder carried (plus two brand-new spectrometers and a microscope), these rovers have something no human geologist would leave home without—a rock hammer, or in this case an abrasion tool to remove the surface patina from specimens and expose the minerals beneath. Perhaps not surprisingly, the rovers will search for hints of ancient water. Opportunity will explore an area of the Meridiani Planum where the Mars Global Surveyor discovered signs of hematite (*E&S* No. 3/4, 2001), a mineral that on Earth typically forms in hot springs. Spirit will land on Mars's opposite side, in Gusev Crater, which appears to have once been the bed of a lake slightly smaller than New Jersey. In this photo taken in November 2002 in JPL's Spacecraft Assembly Facility, some project members pose with Spirit and Marie Curie, a Sojourner flight spare.

Opposite: At 1300 GMT (6:00 a.m. PDT) on May 8, as Earth and Mars were en route to their closest encounter in some 60,000 years, the Mars Orbiter Camera on JPL's Mars Global Surveyor snapped this shot of a half-Earth and its moon hanging in the Martian sky—the first time we have looked up from another planet and seen our home as a sphere, not a speck of light. Below: In the same field of view were, from left, Callisto, Ganymede, Jupiter, and Europa. Io is behind Jupiter, as is the Great Red Spot. Both images have been processed to allow the planets to be seen with their much-dimmer moons, and color has been added.

The Quiet Zone

In trying to predict where earthquakes will occur, few people would think to look at Earth's gravity field. What does the force that causes objects to fall to the ground and the moon to stay in orbit have to do with the unpredictable ground trembling of an earthquake? Caltech researchers have found that within subduction zones—the regions where one of the earth's plates slips below another—areas where gravity is relatively high are less likely to experience large earthquakes than areas where the gravitational force is relatively low. The study, by grad student Teh-Ru Alex Song and Associate Professor of Geophysics Mark Simons, appeared in the August 1 issue of *Science*.

Until now, says Simons, researchers studying earthquake behavior generally took one of four approaches: 1) analyzing seismograms generated by earthquakes, 2) studying frictional properties of various types of rock in the laboratory or in the field, 3) measuring the slow accumulation of strain between earthquakes with survey techniques, and 4) large-scale dynamic models of earthquakes and tectonics.

Song and Simons instead considered variations in the gravity field as a predictor of seismic behavior. A gravity anomaly occurs when gravity is stronger or weaker than the regional average. For example, a mountain or an especially dense rock would tend to increase the nearby gravity field, creating a positive anomaly. Likewise, a valley would tend to create a negative anomaly.

Song and Simons examined existing data from satellite-derived observations of the gravity field in subduction zones. Comparing variations in gravity along subduction trenches with earthquake data from two different catalogs going back 100 years, the team found that, within a given subduction zone, areas with negative gravity anomalies had more large earthquakes. In addition, most of the energy released in earthquakes was in areas of low gravity. The team looked at subduction-zone earthquakes with magnitude greater than 7.5 since 1976. They found that 44 percent of the total energy released in those earthquakes came from the regions with the strongest negative anomalies, even though these regions made up only 14 percent of the total area. Song and Simons also compared the location of large earthquakes with the topography of the subduction zones, finding that areas of low topography, such as basins, also corresponded well to areas with low gravity and high seismic activity.

So why would gravity and topography be related to seismic activity? One possible link is via the fault's frictional behavior. When plates rub up against each other, friction makes it harder for them to slide. If the friction is great enough, they'll stick. As the stuck plates continue to push against each other over long periods of time, they may deform and create spatial variations in topography and gravity. Friction also causes stress to build up until the strain is released in an earthquake. So in subduction zones, areas under high stress are likely to have greater gravity and topography anomalies, and are also more likely to have earthquakes. Simons hopes to use Global Positioning System measurements, which can show where strain is accumulating, to test the prediction that areas with high gravity will have low strain, and vice versa.

These gravity anomalies take a long time to build up, and change very little over scales of a million years or so. (Earthquakes do change the gravity field, but those variations are small compared with the long-term anomalies.) Because the topography and gravity variations persist over periods much longer than the typical time between earthquakes, which is generally 100 to 1,000 years, large earthquakes should be consistently absent from areas with large positive gravity anomalies, say Song and Simons. "This study makes a strong connection between long-term tectonic behavior and short-term seismic activity," says Simons, "and thereby provides a new class of observations for understanding earthquake dynamics."

The team points out that there are low-gravity areas in subduction zones with no seismic activity. Furthermore, the research concentrates on subduction zones, and so makes no predictions about other types of faults. Nonetheless, within a subduction zone known to be earthquake-prone, high-gravity areas do tend to have few earthquakes. So while the research does not offer a way to predict where earthquakes will happen, it can predict where they won't happen, says Simons. □—*ET*

Fall Watson Lectures Set

This fall's Watson lecture series opened with Caltech President and Professor of Biology David Baltimore talking about "Viruses, Viruses, Viruses" on October 15. Then on November 5, Thomas Sterling, a visiting associate in Caltech's Center for Advanced Computing Research and inventor of the Beowulf method for turning clusters of PCs into supercomputers, takes us on a tour "From PCs to Petaflops—The Future of Really Big Computers." Jean Ensminger, professor of anthropology and chair of the division of the humanities and social sciences, will be "Experimenting with Social Norms" on November 19. And finally, James Heath, the newly arrived Gilloon Professor and Professor of Chemistry, will chart the future of "NanoSystems Biology" on January 14, 2004. All Watson Lectures are at 8:00 p.m. in Beckman Auditorium; no tickets or reservations are required. The lectures also become available online at Caltech's Streaming Theater, http://today.caltech.edu/theater/, about a week after the event.

On Sunday, September 28, the Caltech/JPL Flying Club (more properly the Aero Association of Caltech, or AACIT) hosted a barbecue at the El Monte airport, where their fleet of two club-owned and five leased airplanes lives. The club ran a shuttle to campus, some eight miles away, and nearly 100 people were treated to aerial tours of the Rose Bowl, JPL, Caltech, and the Santa Anita racetrack. AACIT membership is open to the entire Caltech/JPL community and their families—for more information, see http://aacit.caltech.edu. At least three past members have gone on to become astronauts: Jay Apt, formerly at JPL, flew four shuttle missions before leaving NASA for the Carnegie Museum of Natural History; John Grunsfeld, late of Caltech's Space Radiation Lab, has also flown four missions, including two service calls to the Hubble in which he made five spacewalks; and Garrett Reisman (MS '92, PhD '97) has completed training and awaits assignment.

Voices of Vision: A Couple of Books, a Movie, and Some TV

The Voices of Vision series, which "brings innovative thinkers to campus who explore ideas in an inspiring fashion and express themselves through different media," in the words of Denise Nelson Nash, director of Caltech Public Events, returns for its second season. Leading off was Garrison Keillor, reading from his latest novel, *Love Me*, on Monday, October 6, 2003. Keillor, author of nearly a dozen books, is founder and host of *A Prairie Home Companion* and *The Writer's Almanac*, both on National Public Radio, and is a regular contributor to *Time* magazine. Then on Wednesday, October 22, 2003, Al Franken read from *Lies and the Lying Liars Who Tell Them: A Fair and Balanced Look at the Right*. Franken's previous books include *Rush Limbaugh Is a Big Fat Idiot and Other Observations*; *Oh, the Things I Know!*; *Why Not Me?*; and *I'm Good Enough, I'm Smart Enough, and Doggone It, People Like Me!* Book signings followed both readings, which were presented in collaboration with Vroman's Bookstore and Caltech's Words Matter series.

Next, Howard Rosenberg will examine "Media Ethics" on Thursday, November 6. A Pulitzer prize–winning television critic for the *Los Angeles Times* until this past August, Rosenberg was named one of the nine national media critics "with clout" by the Freedom Forum Media Studies Center at Columbia University in 1995. And for those of us who will never get a 3:00 a.m. telephone call from Stockholm, Marc Abrahams, founder of the Ig Nobel Prizes and cofounder of the science-humor magazine *Annals of Improbable Research*, will appear on Tuesday, January 27, 2004. Ten Igs have been given each year since 1991 for "achievements that cannot or should not be reproduced."

On Tuesday, March 2, Josefina Lopez, the author of *Real Women Have Curves*, discusses "Real Women and Other Unseen Images in Hollywood." Be sure to arrive in time for the 6:00 p.m. screening of *Real Women Have Curves* that precedes her talk. And finally, David Silverman will appear on Tuesday, April 6. From 1990 to 1997, Silverman was the supervising animation director for the runaway TV hit *The Simpsons*, overseeing one of five directing teams that supervised the work of nearly 100 animators.

The season is cosponsored by the Caltech Employees Federal Credit Union and the San Gabriel Valley Newsgroup, publishers of the *Pasadena Star-News*. All events except the screening begin at 8:00 p.m. in Beckman Auditorium. Admission is free on a first-come, first-served basis. No tickets or reservations are required. □

Come Fly with Me

by Michael H. Dickinson

Michael Dickinson (at the head) rides a fruit fly with some of his team—graduate student Seth Budick, postdoc Titus Neumann, and postdoc William Dickson—behind him. Although seeing the world the way a fly does is still a dream, the lab's innovative approach to studying fly flight behavior is bringing them a little closer.

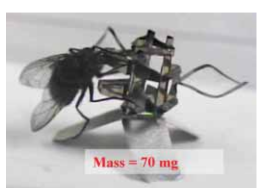
If the goal is to reverse-engineer an insect, and incorporate its design into a miniature flying device, flies are an excellent choice.

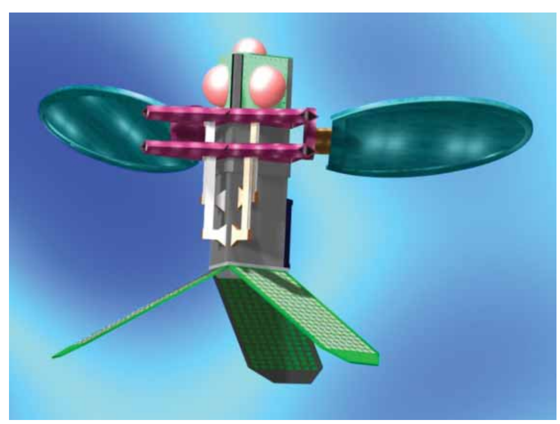
This article is adapted from a talk given to an audience of academics and representatives from a variety of industrial research labs at CNSE Industry Day 2003 in May. Organized by the Center for Neuromorphic Systems Engineering, the theme of the meeting was Machine Awareness and Learning.

The Division of Engineering and Applied Science might seem an odd home for someone with a PhD in zoology who studies flies. Engineers are more likely to view flies as an annoyance than as a topic of study. There are several reasons, however, why one might pause before swatting a fly with a surplus slide rule. In my own research and that of many biologists interested in understanding important problems such as locomotion, engineering approaches are now much more common and powerful than they used to be. Government funding agencies such as NASA, the Defense Advanced Research Projects Agency (DARPA), and the Office of Naval Research (ONR)—not known for their generous support of zoology—have demonstrated a keen interest in insects in recent years, in the hope that a better understanding of aerodynamics and control in these highly successful creatures might provide insights for the design of micro air vehicles (MAVs). These small flying devices would weigh less than a ballpoint pen and fit comfortably in a coffee cup—a description that also fits most of the six million or so species of insects on the planet.

The insect I chose to study is the common fruit fly, *Drosophila melanogaster*, which is famous for its role as a model organism in genetics, developmental biology, and molecular biology. However, it was not its genes that attracted me, it was the sophisticated flying behavior. Flies represent about one out of every 10 species known to science. Distinguished from all other insects in having only two wings and possessing gyroscopic organs called halteres, the fly order Diptera includes mosquitoes, fruit flies, houseflies, gnats, and horseflies. The success of flies is due in part to their many specializations for flight—fast visual systems, powerful muscles, wings capable of generating unsteady aerodynamic forces, and those specialized gyroscopes, the halteres, capable of sensing the rotations of the body during flight. If the goal is to reverse-engineer an insect and incorporate its design into a miniature flying device, flies are an excellent choice.

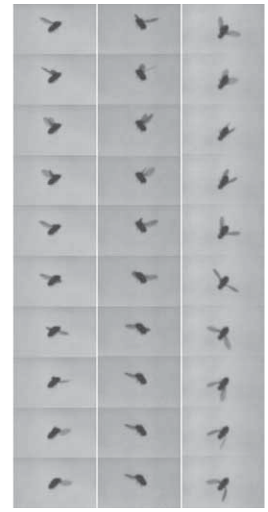
Consider, for example, a routine behavior of the common housefly. Next to mosquitoes, houseflies probably suffer more from the angry swats of rolled newspapers than any other insect. One of the reasons houseflies are so annoying is that the males are territorial and occasionally may claim our bedrooms as suitable cruising grounds. To succeed in mating, males must constantly patrol



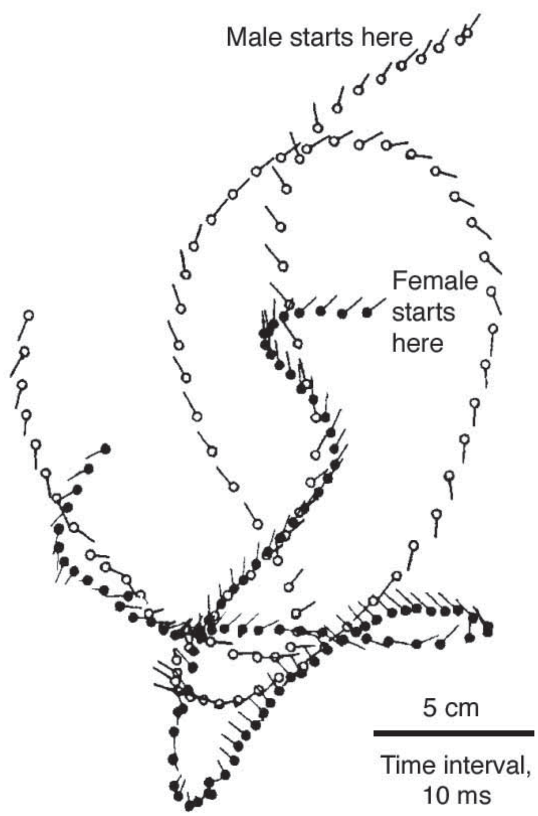


A housefly checks out a prototype micromechanical flying insect (MFI) developed by Ron Fearing's lab at UC Berkeley, above. At right is an early concept drawing of what the MFI would look like. **To see what it looks like now, turn to page 19.**

their territories looking for both interloping males and potential mates. If an object enters his territory, the male must quickly decide whether it is a predator, another male attempting to usurp the territory, or a receptive female. The animal's behavior depends on his correct classification of the target. If he perceives a predator, he flies away. If it's another male, he must chase and expel the would-be interloper. If it's a female, he must chase, intercept, and catch her to initiate courtship. Just such sequences were first captured, using high-speed film, in the pioneering work of Tom Collett and Michael Land a quarter of a century ago. An example of similar work, a rapid mating chase filmed and analyzed by Hermann Wagner, is shown below. The positions of the male and female every 10 milliseconds are indicated by white and black lollipops, respectively. At the start of the sequence, the male gives chase as the female enters his field of view. Initially, he does a remarkable job of tracking her flight path, but loses her trail when she performs an evasive maneuver. After a long loop, he regains his composure and continues the chase. An analysis of such sequences shows that the male can adjust his flight behavior in less than 30 milliseconds after a change in the trajectory of the female.



Ultra-high-speed video cameras capture stages of a single forward wing movement from three different angles, something extremely difficult to film, as the wings beat up to 250 times a second.



High-speed photography makes it possible to follow a male housefly's attempt to capture a female. This can't be seen with the naked eye because it happens so quickly—the entire chase shown here took just 1 second. The lollipops (white for the male, black for the female) show the flies' head and body angles at 10-millisecond (ms) intervals.

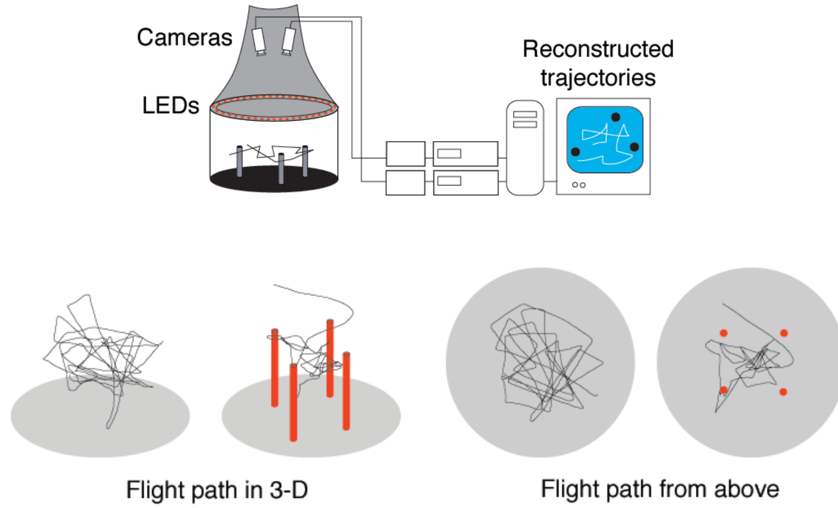
Wagner, H. (1985): Aspects of the Free Flight Behaviour of Houseflies (*Musca domestica*) in *Insect Locomotion*, eds Gewecke, M. & Wendler, G., p. 223. Paul Parey Verlag, Berlin.

This is extraordinarily fast processing, and illustrates why the flight system of flies represents the gold standard for flying machines. Over the short term, flies may teach us about the design of robust control systems, while in the long term, it may eventually be possible to construct a flying robot with a fly's agility.

In order to build a mechanical fly we must first understand how a real fly works. How does one go about characterizing a system that is so complex? Although I was trained in neurobiology and zoology, it became clear when first thinking about fly flight that it would be difficult to understand what the nervous system was doing without understanding the mechanics of the fly's muscles and skeleton—the "physical plant" of the organism. It would also be difficult to reverse-engineer these elements without understanding how the limbs, appendages, and wings interact with the external environment. Further, as the fly moves through space, it receives a stream of sensory information that adjusts the circuits within its tiny brain. So to understand the performance of the system as a whole we have to take a systems-level view that does not isolate the analysis of any one individual component from another.

As flies explore, they move in straight flight segments interspersed with rapid changes in direction called saccades. Each saccade is faster than a human eye blink—the animal changes direction by 90 degrees within about 30 to 50 milliseconds. To study the mechanics of this behavior in greater detail, we track the motion of fruit flies in a large flight arena dubbed Fly-O-Rama by my students. In this arena, we can change the visual landscape surrounding the fly and measure the

In Fly-O-Rama, free-flying flies are filmed with two CCD cameras, and software reconstructs their trajectory as they investigate obstacles in the arena. What looks like a drawing done on an Etch A Sketch is the characteristic fly way of getting around, which is to move forward in a straight line interspersed with rapid changes in direction called saccades.



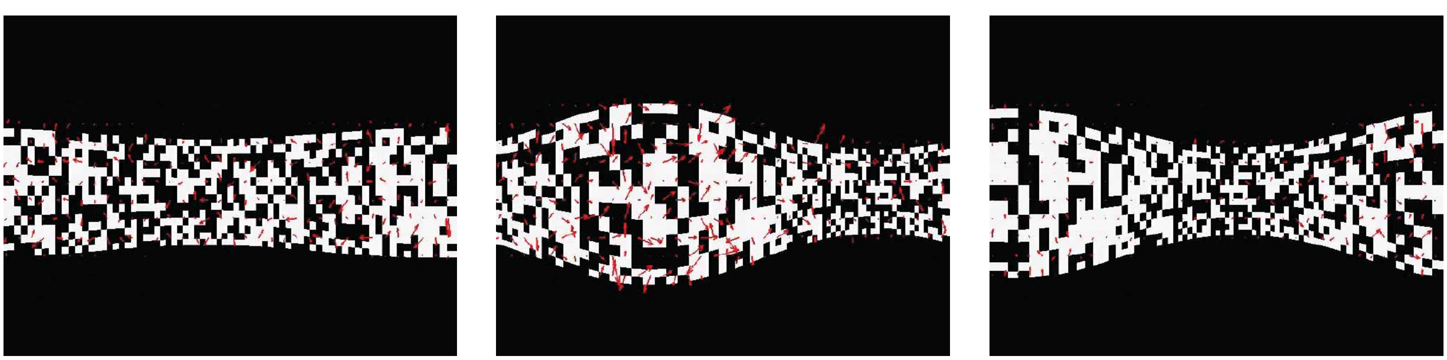
effect on its flight behavior. We've captured saccades on high-speed video shot at 5,000 frames per second in three fields of view, and these images indicate that the fly performs the entire saccade in about eight wing strokes. I'll use our research into this rapid, yet graceful behavior as an example of how we use a systems analysis approach to study fly flight.

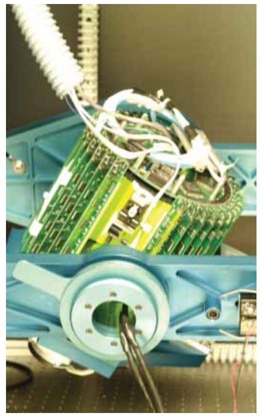
The saccades are so regular that they look as though they're triggered by an internal clock, but this isn't the case. By changing the patterns on the wall of the arena, we have been able to show that the animal's visual system triggers each turn. Insects have quite sophisticated visual systems, and approximately two-thirds of their brain (about 200,000 neurons) is dedicated specifically to processing visual information. Fruit fly's eyes have poor spatial resolution (each eye has a resolution of about 25 × 25 pixels; in comparison, a cheap digital camera has a resolution of 1000 × 1000 pixels), but they have excellent temporal resolution and can resolve flashing lights at frequencies up to 10 times faster than our own eyes can. This means if you take a fly on a date to the movies it will think you brought it to a slide show.

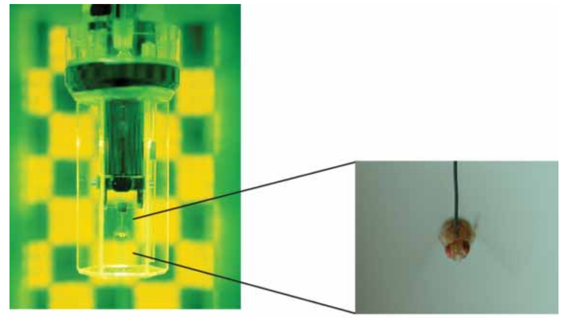
By carefully measuring the animal's flight path in Fly-O-Rama, we can reconstruct the visual world from the fly's perspective—the equivalent of sitting on the back of the fly as it zips around the arena (below). In addition to gaining some sense of what it feels like to be a fly, such reconstruction allows us to ask what goes through the fly's brain just before it turns. After much analysis, the answer has emerged—each saccade is triggered by an expansion of the fly's visual world. The fly travels in a straight line until it perceives an expansion of the visual world, then it veers 90 degrees to the left or the right. These saccades are collision-avoidance reflexes that keep the animal from crashing into objects.

Free-flight studies in Fly-O-Rama are useful because they make it possible to examine the fly's behavior in near-natural conditions, but they don't permit rigorous experimental control. To further

These stills from a movie show what you would see if you were riding on the back of a fly as it heads toward a computer-generated crossword-puzzle landscape on the wall of the arena (left). When the program makes part of the landscape expand (center), the fly immediately saccades to the right, and when you recover your posture, you see you're heading toward the other side of the arena (right).







The flight simulator is the green cylinder at far left. Inside, a tethered fly, wings flapping, waits for the virtual reality ride to begin.

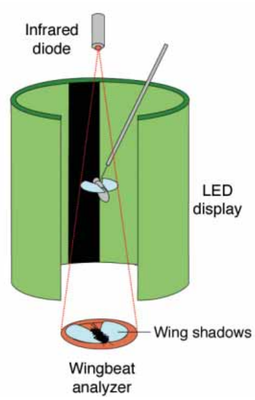
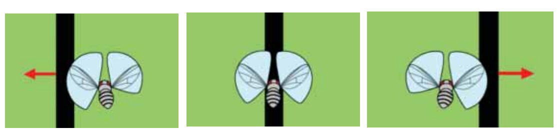


Diagram of the flight simulator showing how the wingbeat analyzer works. The flies try to keep the stripe right in front of their eyes, and adjust their wing strokes to steer it back into place when it moves.

refine our analysis of the sensory features that trigger and control saccades, we built a flight simulator that tricks a tethered animal into "thinking" that it is flying. We carefully glue the fly to a fine wire and place it inside a cylindrical arena whose walls are lined with a computer-controlled electronic display. Twelve thousand independently controlled LEDs produce a constantly varying pattern of squares and stripes that give the little fruit fly the feeling of flying in a real landscape. We can measure the fly's intended flight behavior by tracking the motion of its wings with an optical wingbeat analyzer, or by fixing the fly to a sensitive torque meter. The arena can be configured in an open-loop mode, in which we present the animal with a visual stimulus and



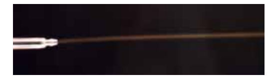
measure its response, or a closed-loop mode, in which the fly itself can control the arena.

For example, in a closed-loop configuration, the fly is allowed to control the angular velocity of a dark stripe on the arena wall by changing the relative amplitude of the left and right wing strokes. It steers toward the stripe—fruit flies are attracted to vertical edges—and whenever the stripe moves away to the left or right, the animal can steer it back into the center of its field of vision by adjusting its wing strokes. It's like a child playing a video game: The flies seem to enjoy this "fixation" paradigm, and they'll happily fly toward the stripe (like a dimwitted horse following a carrot suspended in front of it) for about an hour until they run out of energy.

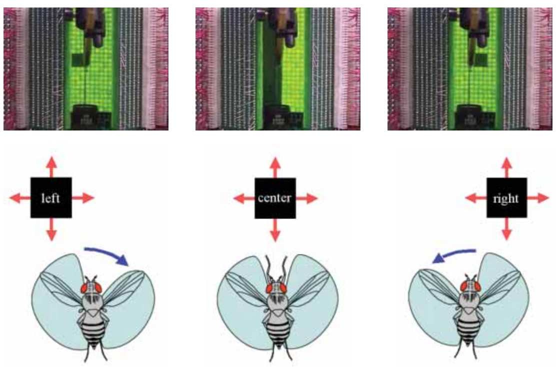
When we place the fly in the arena at the start of an experiment, we give it a little piece of paper to cling to. When we're ready to start, we blow the paper away. Tiny touch sensors on the legs detect the loss of terra firma, and the fly begins to fly. We can stop each experiment by carefully replacing the piece of paper. The fly's legs sense the contact and trigger the wings to stop. If we place sugar water on the paper, taste cells on the feet activate a feeding reflex, and the fly extends its proboscis and refuels for the next flight.

One informative experiment that is possible in the flight simulator is the fly-swatter paradigm. Under closed-loop control, we let the tethered fly fixate on a little black square that is programmed to expand at random times. Each time the square expands, it triggers a saccade. Because we know precisely where the square was when it began expanding, we can construct a precise spatial map of the collision-avoidance behavior (facing page). The results indicate that the fly is clever, but not too clever. It doesn't carefully calculate the size of the turn depending on the direction or speed of the impending impact. Rather, an expansion to the left of it triggers a 90-degree turn to the right, and an expansion on the right-hand side triggers a turn to the left. If the fly sees an expansion directly in front, it saccades either

Clinging to a scrap of sugar-watered paper, this fly is taking a refueling stop before starting the next sortie.



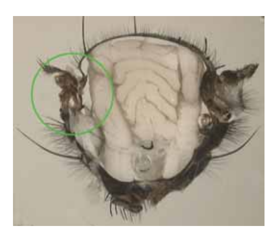
Graduate student Seth Budick uses a wind tunnel to study how fruit flies search for food, and what they do when they find it. A thin plume of smoke with the delicious odor of rotting fruit is released from a nozzle (top right) into a 0.4-meters-per-second wind. A free-flying animal enters the tunnel and makes its way upwind to the odor source, while cameras keep track of the fly's progress.



In the fly-swatter experiment, a black square expanding on the left of the fly prompts it to make a saccade to the right. If the square expands on the right, there's a saccade to the left. And if the expanding square is straight ahead, the fly saccades either left or right, and also stretches out its legs in preparation for landing.

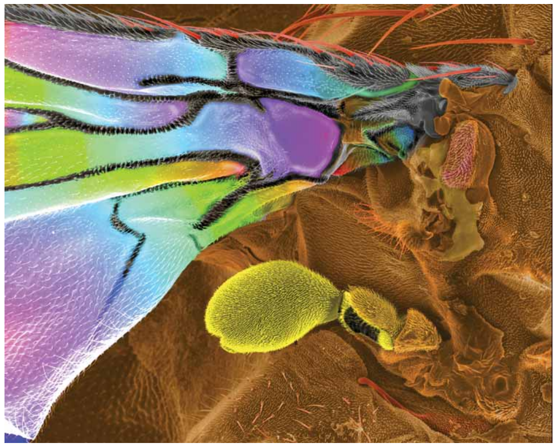
to left or right with equal probability. Central expansion also triggers an additional behavioral response—the fly reflexively sticks out its legs and prepares for landing. Such results suggest that the search algorithm of this tiny organism consists of stereotyped "all-or-nothing" reflexes. Although simple, this algorithm works elegantly, and when modulated by a sense of smell, enables the fly to search and locate small targets such as rotting bananas in a fruit bowl.

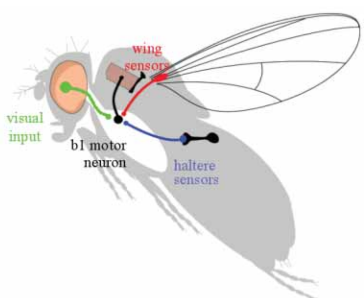
Keeping with the spirit of the systems-level analysis, we would also like to understand how the fly mechanically alters its wingbeats to perform these different visually elicited behaviors. Here things get rather humbling, because it's the mechanical component of this biological system that we, as engineers, are the furthest away from being able to replicate. Flies don't have an internal skeleton consisting of individual bones or cartilage. Instead, they're surrounded by an external skeleton, the cuticle—a single, topologically continuous sheet composed of proteins, lipids, and the polysaccharide chitin. During development, complex interactions of genes and signaling molecules spatially regulate the composition, density, and orientation of protein and chitin molecules. Temporal regulation of protein synthesis and deposition allows the construction of elaborate, layered cuticles with the toughness of composite materials. The result of such precise spatial and temporal regulation is a complex, continuous exoskeleton separated into functional zones. For instance, limbs consist of tough, rigid tubes of "molecular plywood" connected by complex joints made of hard junctures separated by rubbery membranes. Perhaps the most elaborate example of an arthropod joint, indeed one of the most complex skeletal structures known, is the wing hinge of insects—the morphological centerpiece of flight behavior. The hinge consists of an interconnected tangle of tiny, hard elements embedded in a thinner, more elastic cuticle of a rubberlike material called resilin, and bordered by the thick side walls of the thorax. In flies, the muscles that actually power the wings are *not* attached to the hinge. Instead, flight muscles cause small strains within the walls of the thorax, and the hinge amplifies these into large sweeping motions of the wing. Small control muscles attached directly to the hinge enable the insect to alter wing motion during



The wing hinge is the part circled in green in this cross-section of a fly thorax. The white tissue is the flight muscle.

The hindwings of flies have evolved into halteres, small knobs that beat antiphase to the wings and act like gyroscopes to help maintain balance in flight. In the colorized close-up of a fly's thorax (courtesy of MicroAngela) at right, the haltere is the green drumstick below the wing. How the sensory organs, eyes, and brain are wired to the wings and halteres is shown below.





steering maneuvers. Although the material properties of the elements within the hinge are indeed remarkable (resilin is one of the most resilient substances known), it is as much the structural complexity as the material properties that endows the origami-like wing hinge with its astonishing properties.

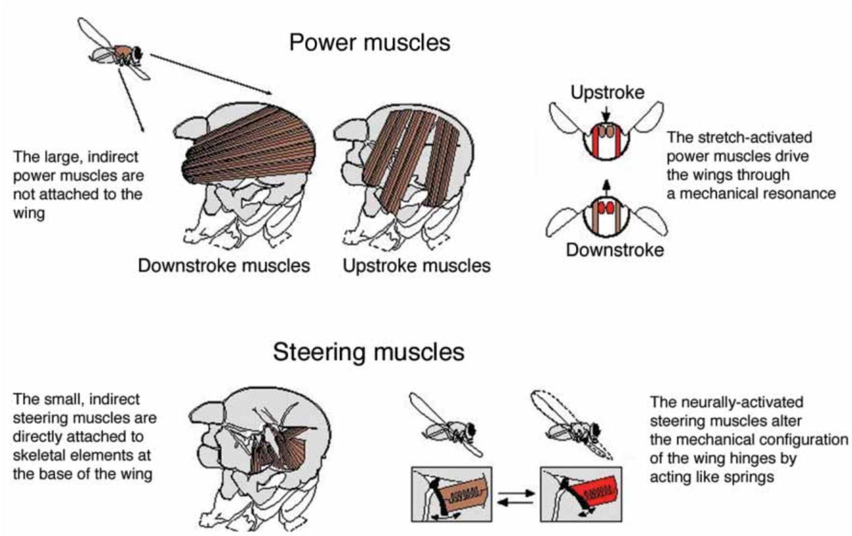
By controlling the mechanics of the wing hinge, the steering muscles act as a tiny transmission system that can make the wing beat differently from one stroke to the next. Electrophysiological studies indicate that this is a phase-control system. Most of the fly's steering muscles are activated once per wingbeat, but the phase at which they're activated is carefully regulated by the nervous system. This is important, because the stiffness of these muscles changes depending on the phase in which they are activated within the stroke. Even when the steering muscles are not actively contracting under the control of a motor neuron, they're still being stretched back and forth by other muscles around them. If a muscle is activated by its own motor neuron while it is lengthening, it becomes stiff; if activated while shortening, it's relatively compliant. The fly uses the steering muscles as phase-controlled springs to alter the way the large strains produced by the power muscles are transformed into wing motion.

If all the sophisticated flight behavior that flies exhibit boils down to subtle changes in the activity of tiny steering muscles, what controls the steering muscles? The nervous system must activate each muscle at the appropriate phase in each cycle and modulate that phase during steering maneuvers. The regular firing pattern of the steering muscles would suggest that they are controlled by an internal clock (such circuits are common in locomotor behaviors), but it turns out that the fly's steering muscles fire in phase with the wing stroke because they're activated by sensory reflexes. During each wingbeat, sensory cells on the wings and halteres send timing signals into the brain that are used to tune the firing of the muscles.

The information coming from the haltere, a hindwing modified by evolution and resembling a very small chicken drumstick, is particularly important because it is essential in stabilizing reflexes. Beating antiphase to the wings, the halteres function as gyroscopes during flight. When the fly rotates, each haltere is deflected from its beating plane by Coriolis forces, which are pseudoforces present when an object has a velocity in a rotating frame of reference. Sensors at the base of the haltere detect Coriolis-force deflections and activate appropriate compensatory reflexes.

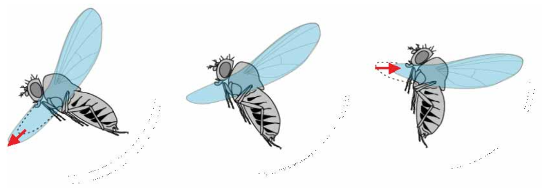
We study haltere-mediated reflexes by placing one of our flight simulators inside a large three-degree-of-freedom rotational gimbal, called the

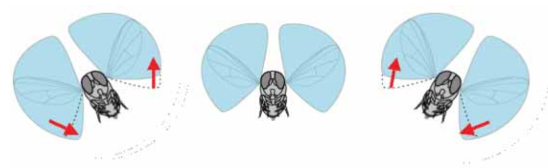
The fly thorax is packed with two sets of antagonistic power muscles that move the wings up and down, but are not attached to the wing hinge. The much smaller steering muscles are attached to tiny elements at the base of the wing and work as springs that can vary in stiffness.

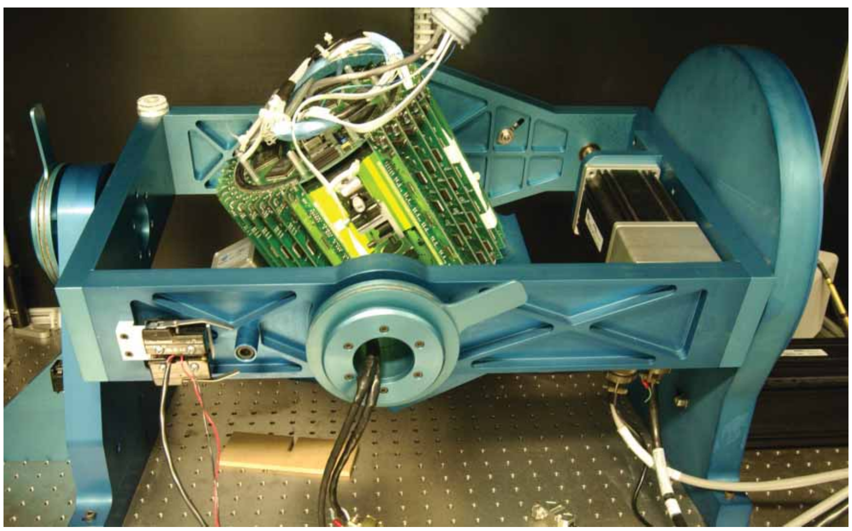


Rock-n-Roll Arena. As the animal steers toward the stripe, we can rotate the apparatus at up to 2,000 degrees per second about the yaw, pitch, or roll axes of the fly. The animal detects these rotations with its halteres and responds with compensatory changes in wing stroke. These reflexes are extraordinarily robust—if the fly pitches forward, the haltere detects it, and the stroke amplitude of both the left and right wings increases. If the fly pitches backwards, the stroke amplitude decreases. Similar reflexes act if the fly yaws (a sideways turn about the vertical axis) or pitches. The changes in wing motion occur because the haltere sensors shift the activation phase of the steering muscles—and thereby their stiffness—which in turn changes the way the wing beats, altering the production of aerodynamic forces. The halteres are essential elements of the fly's control system. Cut them off, and a fly rapidly corkscrews to the ground.

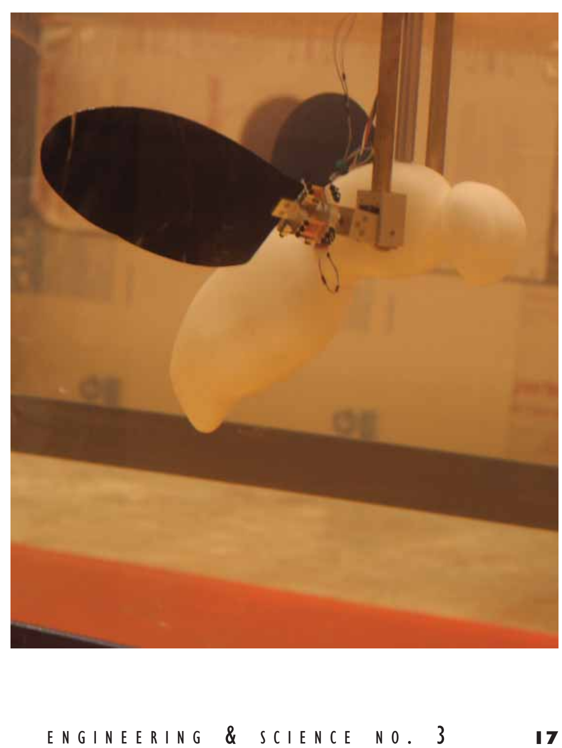
But if the fly possesses such a robust autonomous control system, how does it ever do anything voluntarily? What if it's a male fly and it really *wants* to turn left toward a female? Or a female who wants to steer away from a male? Although we don't know the full answer to this complicated question, one possibility is that the fly can actively steer by fooling its own gyroscope. In addition to having control over the steering muscles of the wing, the visual system and higher brain centers can control tiny steering muscles of the halteres. By actively manipulating the motion of the haltere, the fly's brain might initiate compensatory reflexes in the haltere that make the insect change its flight path.



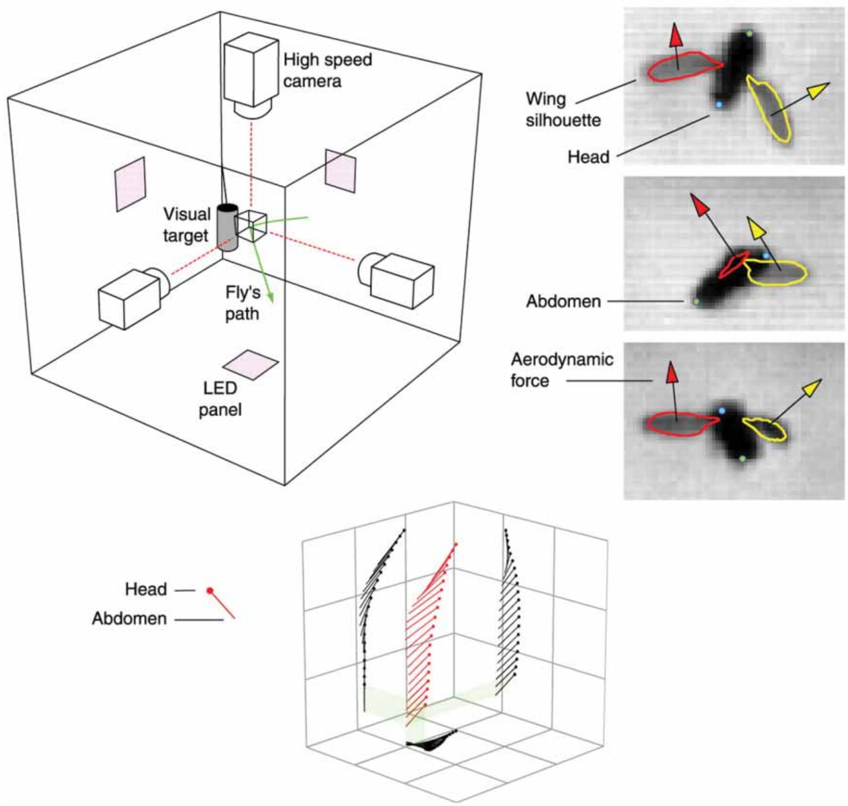




Because of the complexity of fly aerodynamics, understanding wing motion does not necessarily translate into an understanding of flight forces. It is a common myth that an engineer once proved a bumblebee couldn't fly, and while the true story is really much kinder to the engineer, it underscores the difficulties of studying fly aerodynamics. At present, even brute-force mathematical computations on supercomputers cannot accurately predict the forces created by a flapping wing. For this reason, my lab has constructed Robofly, a dynamically scaled insect with a wingspan of half a meter, on which it is possible to directly measure aerodynamic forces and flows. Most aeronautic engineers take large airplanes and model them as



A Rock-n-Roll Arena is used to analyze how a fly keeps its balance during flight. The flight simulator is attached to a rotational gimbal that pitches, yaws, and rolls the animal around as it steers toward a stripe. The diagrams above show how the fly changes wing stroke to stabilize itself when pitched forward or backward, or rolled sideways. The blue areas show the wingbeat envelopes. Robofly, right.



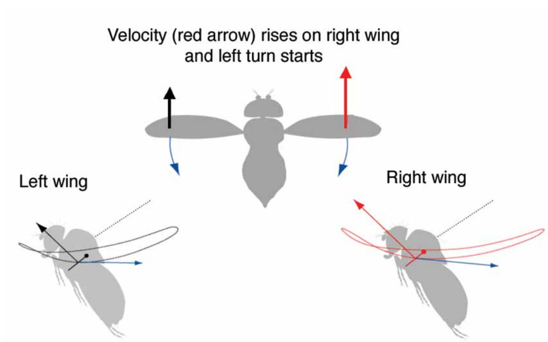
Fruit flies were imaged with high-speed cameras at 5,000 frames per second as they flew freely around an enclosed chamber (diagram, left). Their 3-D body and wing positions were extracted from each frame and fed into Robofly to calculate wing forces, which were then superimposed on the wings as vectored arrows. The next diagram, below, shows one of the sequences analyzed, in which a fly climbs vertically and performs a saccade at the top. The red lollipops correspond to the body orientation every 5 ms; black lollipops, the corresponding orthogonal projections.

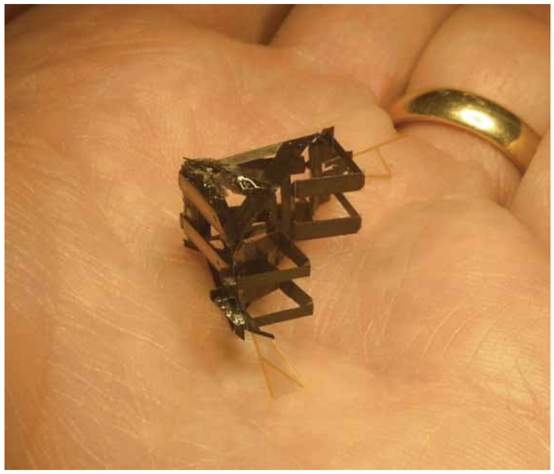
small things in a wind tunnel. We take a tiny fly and model it as a giant thing in 200 metric tons of mineral oil. Although a bit messy, Robofly has proven to be a scientifically very productive instrument.

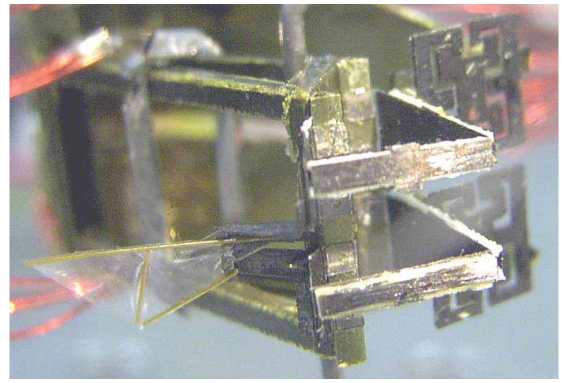
One application is to use high-speed video to take the patterns of wing motion measured in freely flying fruit flies, and play them out directly on Robofly to study how the fly alters flight forces during a maneuver such as a rapid saccade. Once we measure the forces generated by Robofly and scale them down appropriately, we can superimpose the aerodynamic force vectors onto the original video sequences.

In one such example, shown above, we found that the animal ascended with almost zero horizontal velocity, rotated its body by precisely 90 degrees, and then accelerated forward. We were surprised to find that it accomplished this rapid maneuver with very minute and barely detectable changes in wing motion—which explains in part why the fly needs such a well-tuned control system. Another surprise was that the body dynamics of these tiny flies is not dominated by the viscosity of the air (which, to

Above: Robofly in action. Bubbles have been injected into the mineral oil to visualize the fluid flow created by the wingbeats. Right: To make a turn to the left, the fly creates a torque by increasing stroke amplitude on the right wing, and by tilting the stroke plane backward.







MFI, the micromechanical flying insect being developed by Ron Fearing's lab at UC Berkeley is about the size and weight of a large housefly. It has two functioning wings and a carbon-fiber thorax. The close-up above right shows the ingenious wing hinge and flapper.

a fly, has the consistency of mineral oil), as was previously thought, but rather by inertia—the need to stop the body from continuing to spin. This means that during each saccade they must first generate torque to start the turn, but after only four wingbeats they must quickly generate countertorque so that they can stop turning. The fly's brain must regulate the timing between turn and counterturn to generate the precise 90-degree rotations. Recent evidence suggests that while a visual signal triggers the start of the saccade, it's the haltere that detects the initial rotation and triggers the counterturn.

So what can we do with this emerging blueprint of a fly? Do we know enough to build a robotic insect? In a collaboration with Ron Fearing at UC Berkeley, we're working on a five-year project jointly sponsored by ONR and DARPA, to build a micromechanical flying insect (MFI). The aerodynamics of this device, which is the size and shape of a housefly, are all based on what we've learned about these little insects. Ron and his students have designed an ingenious flexure joint that can replicate the flapping and rotating motion of the wing and, so far, they have a two-winged fly that can generate about 70 percent of the force required for flight. With a few improvements they should soon have a configuration capable of supporting its own weight. The next challenge will be to design a control system that enables the device to hover stably.

In the end, it's just a fly. Is such an insignificant little organism really worth all this effort? The natural world is filled with complex things, like immune cells, the human brain, and ecosystems. Although we've made great progress in deconstructing life into its constituent parts such as genes and proteins, we have a ways to go before we have a deeper understanding of how elemental components function collectively to create rich behavior. The integrative approach that we are using to study fly flight is an attempt to move beyond reductionism and gain a formal understanding of the workings of a complex entity. The fly seems a reasonable place to start, and if successful, I hope such work will stimulate similar attempts throughout biology. The lessons learned along the way may provide useful insight for engineers and biologists alike. Even if you don't buy such grand visions, I hope you will at least think before you swat. □

PICTURE CREDITS:
10, 14-16 – Bob Paz;
10 – Doug Cummings;
11, 19 – Ron Fearing, UC Berkeley; 11 – Joseph Yan, UC Berkeley; 15 – Wai Pang Chan, UC Berkeley; 19 – Srinath Avadhanula & Rob Wood, UC Berkeley

A zoologist with a fine grasp of engineering, Michael Dickinson, the Zarem Professor of Bioengineering, has equipped his lab to study fly flight in a multidisciplinary way. Trained as a zoologist (ScB in neural sciences from Brown University in 1984; PhD in zoology from the University of Washington in 1989), he began his transition toward engineering while a postdoc at the Max Planck Institute for Biological Cybernetics in Tübingen, Germany, studying insect flight aerodynamics. In 1991, he started his own lab as an assistant professor at the University of Chicago. He moved to UC Berkeley in 1996, and was named the Williams Professor of Integrative Biology. Dickinson joined the Caltech faculty in Engineering and Applied Science and Biology in 2002. He was a recipient of a prestigious MacArthur Fellowship in 2001, and was awarded the George Bartholomew Award of the American Society of Zoologists in 1995, and the Larry Sandler Award of the Genetics Society of America in 1990. The lecture on which this article is based can be viewed on Caltech's Streaming Theater Web site, http://today.caltech.edu/theater/list?subset=science.

This article was selected by the E&S *staff as one of the best written for the Core 1 Science Writing course, a requirement for all undergraduates to gain experience in communicating science to the general public.*

The Genetic Roots of Language

What SLI and Williams Syndrome Can Teach Us About the Roles Played by Genes in the Development of Language and Intelligence

by Andrea McColl

I'm sitting here in the student lounge, listening to my friends discuss their physics homework, tonight's dinner, and whether the "big ass party" someone put up fliers about is going to be a very big party, or a party for large-bottomed people. While the physics itself is proving difficult, something else they're doing is effortless—the sharing of ideas, abstract concepts, and common experiences through the production and interpretation of a complex pattern of sound waves. Surrounded by people with whom we can communicate in this manner, we don't question our own language abilities, yet we base judgments about others' intelligence on their language ability. We (consciously or not) rank those who speak in complicated, fully grammatical sentences as more intelligent than those who use only short sentences or make frequent grammatical errors. This apparent connection can be deceptive, and looking at where it breaks down reveals especially important pieces in the jigsaw puzzle that is language.

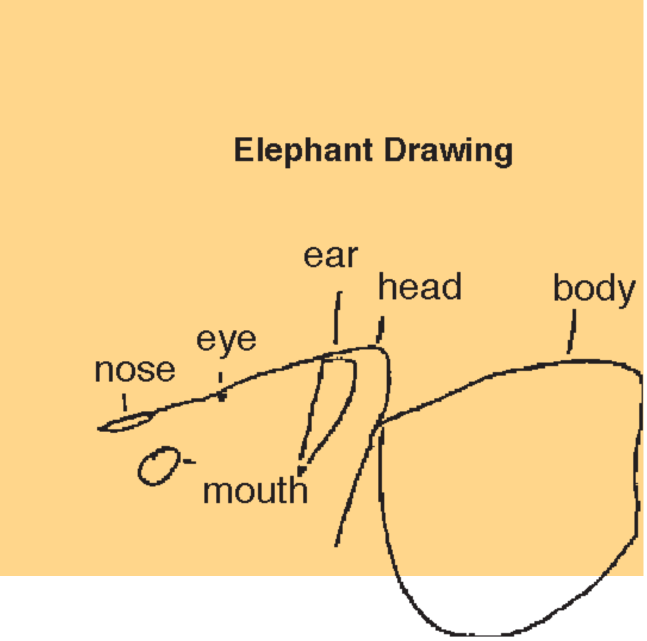
Six-year-old Hannah Gadlage (she's now eight) has the characteristic elfin features of Williams Syndrome. (Photo courtesy of the Gadlage family.)

Goo-Goo Genes?

Although born not knowing language, most of us are born with the ability to acquire it. Babies come prepared to learn language, and they will easily acquire the intricate structures of a fully developed language even when their environment is deficient. For example, there are many recorded cases of deaf children whose hearing parents learned sign language. Being second-language learners, these parents didn't achieve fluency—and yet their children, learning only from them, became completely fluent, with a grammar more complex and accurate than that used by their parents. This suggests a genetic predisposition to acquiring language.

Some argue that humans are born with a universal grammar, a framework into which the details of one's native language are placed. Since all languages contain, for example, nouns and verbs in some form, it can be argued that nouns and verbs are part of the structure of this universal grammar. However, this still is just a theory; the definitive proof depends on genetic evidence. More specifically, were it to be shown that identifiable genetic changes lead to identifiable linguistic problems (ideally, for example, that a mutation in chromosome 13 affects only verb conjugating abilities and nothing else), that would be enough proof for most researchers.

There are two disorders that suggest particularly compelling links between genetics and language: Williams Syndrome and Specific Language Impairment (SLI). In brief, with Williams Syndrome, individuals have incredibly low intelligence and unexpectedly fluent speech; with SLI, individuals have otherwise normal intelligence and significant language difficulties. While this in itself is a striking contrast, it is even more significant that individuals with Williams Syndrome are missing roughly 20 consecutive genes on one copy of their chromosome 7. (Humans have 23 pairs of chromosomes and at least 20 to 30 thousand genes.) SLI patients show strong patterns of inheritance as well. Many researchers herald these



This illustration of an elephant, drawn by an individual with Williams Syndrome, is indicative of the visuospatial deficits common to this disorder. (© Dr. Ursula Bellugi, The Salk Institute)

disorders as proof of the independence of language and intelligence. Some suggest that these disorders show a link between genes and language. Is the evidence sufficient?

Elephants and Elves: Williams Syndrome

When a 15-year-old with Williams Syndrome was asked to draw an elephant, she produced the drawing shown above, unidentifiable without the verbal description she produced while drawing (as described by Ursula Bellugi). "And what it has, it has long grey ears, fan ears, ears that can blow in the wind. It has a long trunk that can pick up grass, or pick up hay . . . If they're in a bad mood it can be terrible." Her sentences are nearly as complex as her drawing is simple, and are far more complex than one would expect from an individual with an IQ of 49.

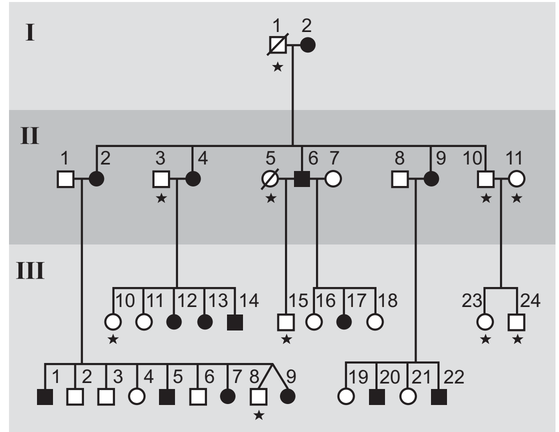
In addition to this extreme disparity between linguistic and visuospatial abilities, people with Williams Syndrome show other distinctive characteristics, both intellectual and biological. They generally have a strong affinity for music and show remarkable musical abilities, being able to write and sing songs, and to play songs by ear after hearing them only once. Perfect pitch also appears to occur more frequently in the Williams Syndrome population than in the general population. Physically, they have very distinctive "elfin" facial features, heart problems (such as aortic narrowing), high blood-calcium levels, and difficulty producing elastin, a protein that normally works with collagen to regulate the ability of joints and tendons to stretch. It was these last two biologic characteristics that enabled researchers to isolate the exact genetic problem that leads to the disorder. In 1993, the gene for elastin was identified as one of those in the region of chromosome 7 that is missing in Williams Syndrome individuals. With this discovery came the question: What role does this missing information play in producing the symptoms of the syndrome? While it is clear that losing one copy of the gene for elastin could affect its production, the other missing genes have not yet been mapped to the other characteristics of Williams Syndrome.

With recent sequencing of the human genome, it is becoming far simpler to identify the genetic source of various syndromes. Scientists are using this knowledge to figure out which genes affect which proteins. Moving from this microscopic evidence to a particular physical trait is a much more difficult leap: Would a missing gene have produced a protein essential to the developing brain, therefore making the effects of its absence irreversible? Would the missing gene have produced a protein that leads to lower levels of, for example, sodium in the blood, leading to an effect that can be easily treated by adding sodium to an affected child's diet? Is there still some other, more complex connection that has yet to be determined?

While the discovery of the genetic causes of Williams Syndrome is significant, it does not tell the whole story about the disorder. What we have learned about Williams syndrome strongly supports the idea that intelligence and language are not irrevocably interconnected, as had previously been thought, and this has further reinforced the theory that our ability to use language is based in our biology, not in our training.

Missing the Miscellaneous: SLI

Williams Syndrome is a very specific diagnosis that includes particular physiological and biochemical symptoms, as well as the more visible ones, and occurs in roughly one out of every 30 thousand births. In contrast SLI, Specific Language Impairment, is a much less well-categorized disorder. SLI is a title used to describe a family of related language disorders, occurring in approximately 7 percent of the population. An SLI



The pedigree of the KE family shows a dominant inheritance pattern, as roughly half of the children of affected individuals also have the disorder. Circles are females; squares are males. A shaded box represents an individual with language problems. In level II, numbers 2, 4, 6, 9, and 10 are siblings.

diagnosis requires that a patient have normal (or higher) IQ (as measured in a series of nonverbal tests), and score significantly low on several language tests that verify lower-than-normal language ability. There can be no external factor that potentially contributes to the language deficit: Hearing must be normal, speech must be physically and developmentally possible (SLI cannot be diagnosed in pre-language infants), and there must be no significant neurological damage.

Some individuals with SLI appear to be merely linguistically delayed, starting out a few years behind their peers with respect to language acquisition but eventually catching up and developing normal speech. Others never achieve full normalcy, suffering with their particular linguistic problems throughout their lives. Among the patterns found in SLI patients (although no single patient had every symptom) are:

• frequently pluralizing nouns improperly;
• frequently omitting the verb to be, as in "That man in a dark room."
• never using the past-tense marker "-ed";
• comprehending metaphors with difficulty (even when other comprehension of speech is normal); and
• using pronouns incorrectly, as in "Her eat. And her get clothes on."

These and other problems have been seen in both spontaneous and prompted speech.

Most English-speaking SLI individuals have a unique weakness in their grammatical morphology. They are unable to add necessary bits to words in order to indicate that they are plural (cat – cat**s**), have been done by someone (climb – climb**s**), happened in the past (walk – walk**ed**), and so on. In English, the words without these fragments added on are still legal words; however, this is not always the case in other languages. For example, in Italian, most words never appear in their stem form, but always have something added to provide more information. It is acceptable to say *parlo* (I speak), *parlate* (y'all speak), and *parlano* (they speak), but no Italian speaker would ever say the bare stem, *parl*. Although Italian-speaking SLI children have problems with morphology, they never eliminate modifiers. Instead, they substitute another word form, following a relatively standard pattern, such as using the third-person singular form of the verb instead of the third person plural, as in *vende* (he or she sells) instead of *vendono* (they sell). One theory is that, instead of changing the words to their proper form, they have memorized one or two forms of the words, and produce those whenever any form of the word is needed.

This may also be a learning deficit due to difficulties in processing fast sounds; and if so, in hearing the small sounds that make up these grammatical morphemes. Some studies have shown that individuals with SLI are worse at sequencing fast sounds, but this theory is not widely accepted. What *is* known is that there is still a great deal to learn about SLI, and this theory suggests a way in which genetic problems could impact language acquisition—through the hearing pathway. Without being able to properly receive or distinguish the sounds heard, making it to the next steps in language processing becomes far more difficult.

Several trends suggest the influence of genetics on SLI: Males are more likely to have SLI, and children with SLI are more likely to have at least one parent with a language problem. Many of this latter group of children have nonimpaired siblings. Additionally, studies of identical and fraternal twins have revealed that, especially among the fraternal twins, a statistically significant number of pairs consist of one impaired and one non-impaired twin. This in particular indicates that "nurture," or the role of environment in development, is not the sole cause of language problems, as there have been many studies showing that twin children receive essentially the same linguistic input.

One large family, the KE family (whose pedigree is shown in diagram on the opposite page), in which many members have the same speech disorder, provides striking evidence of the role of genetics. This family is especially significant because the disorder exhibits the very clear inheritance patterns of a dominant gene. For example, individual II 10 in the pedigree is the only child of I 1 and I 2 not to have the disorder, and did not produce any children (III) with this disorder. However, half of his siblings and nephews were impaired. This inheritance does not appear linked to gender. It is also significant to note that impaired individuals produced both normal and impaired children; thus the environment in which these children were raised was the same, and likely had little influence on whether or not they developed the disorder.

The genes responsible for this particular family's disorders have been mapped to a particular area on chromosome 7, and genetic analysis of an unrelated patient who exhibited similar language problems revealed a mutation in this same region. While further studies are necessary, it may be that this mutation leads to a lack of a particular protein

Intelligence doesn't require language. There are thousands of recorded cases of acquired aphasia, where a subject has lost language ability due to some physical or physiological cause, such as a stroke or other nonintellectual brain damage.

that affects the development of neural structures important for speech and language, the way similar proteins have been shown to influence neuronal development in other organisms. The overall genetic pattern exhibited by the KE family, especially with the discovery of the gene deletion, strongly suggests that a gene, or a small set of genes, has a major impact on language development.

Current studies are attempting to divide SLI patients into distinct subgroups, based on the details of their impairment, so that testing can determine more precisely the causes of the impairment. Perhaps one day, as with Williams Syndrome and the KE family, other types of SLI can be linked to specific chromosomes and genes and tell us more about the language acquisition pathway.

Broken Brains

Intelligence doesn't require language. There are thousands of recorded cases of acquired aphasia, where a subject has lost language ability due to some physical or physiological cause, such as a stroke or other nonintellectual brain damage. Well over a century ago, studies of brain-damaged individuals concluded that language ability resides almost entirely in the left hemisphere of the brain, which is also the case for most normal individuals. A few have right-hemisphere language; these people are commonly also left-handed and show other signs of hemisphere role-reversal. Among the most famous of these studies were those done by Pierre Paul Broca in 1861. One of his patients was so severely aphasic that he could utter only one word, "tan." An autopsy revealed that neurosyphilis, a degenerative disease, had damaged a very specific zone in this patient's brain (subsequently called Broca's area), a region later determined to be very important for control of speech production. Damage to Broca's area leads to great difficulties in speaking, but does not affect understanding of speech. Although it takes great effort for a Broca's aphasic to articulate words, when they do manage to name items, they do so correctly.

Damage to another region of the brain produces essentially the opposite effect. Patients with damage to Wernicke's area retain fluent and grammatically correct speech—but cannot understand what they are saying, or what anyone is saying to them. (Noam Chomsky, a famous linguist, once illustrated the separation between meaning and grammar in this completely grammatical yet meaningless sentence: "Colorless green ideas sleep furiously.") The speech of a Wernicke's aphasic is filled with nonsense words and incoherent trains of thought. While Broca's aphasics have very slow, stilted speech (when they can speak at all), Wernicke's aphasics talk a great deal, but when asked to name words, they either use a completely incorrect name, or select a related but incorrect word (such as knee for elbow).

Modern studies, especially those using magnetic resonance imaging, or MRI (a fast and non-intrusive technique that uses powerful magnetic

Contrasting the SLI and Williams Syndrome studies neither proves nor disproves a genetic basis for language acquisition. However, it does show that language and intelligence are in fact independent.

fields to image the inside of a living body, which can be used to observe a brain in action and take pictures of the brain regions activated during various tasks) have verified the diagnosed function of these regions, as both Wernicke's and Broca's areas show distinct activity as impaired and nonimpaired patients perform a variety of linguistic tasks.

The distinct localization of these two areas of language in very specific regions of the brain is further evidence of a biological basis for language. That these target regions serve the same purpose in everyone shows that these areas must form during brain development; thus, genetic mechanisms must shape their creation.

Is the Evidence Enough?

Contrasting the SLI and Williams Syndrome studies neither proves nor disproves a genetic basis for language acquisition. However, it does show that language and intelligence are in fact independent. Since there exist people with normal intelligence who cannot speak properly, and people with dramatically low intelligence who speak normally, it is illogical to use language alone as a sign of intelligence. Rather, the origins of each should be explored separately.

SLI research is an especially promising source for information about language-specific genetic disorders. By identifying a group of unrelated SLI patients with the same particular language problems, researchers may be able to isolate a genetic marker for their particular variant of the syndrome. Imaging studies are being used to pinpoint the brain locations used in performing different linguistic tasks, and these studies may help divide SLI patients into different categories. A brain that does not activate along normal patterns could lead to some of the problems observed in SLI, and thus it might be possible to categorize some varieties of SLI based on patterns of brain activity. This would make it possible to examine each category, looking for common traits not found in either normal individuals or in other SLI categories. Such imaging studies may reveal whether SLI is more a hearing or linguistic deficit, or even perhaps two different disorders, one with each cause, that coincidentally appear similar to linguistic researchers.

Research continues on the linguistic front as well. Linguists are looking at the details of particular language deficits and are trying to characterize them. Then, using these deficits to characterize the essentials of language, they are seeking universal, separable properties of language that are coded in the DNA. If, for example, the ability to pluralize words can be "broken" genetically (by deleting a gene) without impacting the individual's other language, it would be plausible that this ability is an inherent structure, somehow separable from the rest of language. Cross-linguistic studies (such as the Italian one mentioned previously) have added more depth to this research; finding speakers who exhibit the same pattern of broken structures, regardless of native language, will add support to the independence of that structure.

The basic set of assumptions are that language is more than just a learned skill, that humans are either biologically predisposed towards language acquisition or have a built-in universal grammar framework upon which to build an acquired language, and that language is not tied to intelligence. These assumptions seem simple, but that is only because researchers have uncovered evidence such as the striking contrast between SLI and Williams Syndrome. These findings have led to far greater understanding of language and intelligence, as discussed here, and also of genetics, the structure of the brain, and the unexpected roles of various proteins in development.

So the next time you're talking with someone, take a moment to appreciate the complicated set of factors that enable you to communicate. And take a moment to thank your parents, as well, because it was their genetic contribution that made it possible for you to get your friends to help you finish your physics homework in time to go to that very large party. □

Andrea McColl

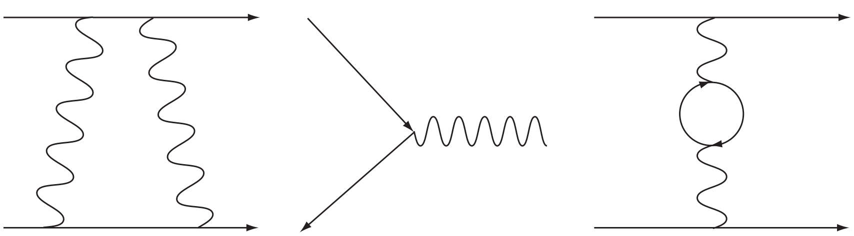
PICTURE CREDIT: Doug Cummings

Andrea McColl majored in biology and is now a first-year grad student in linguistics at the University of Southern California, where she will be working on a project on semantic deficits in Alzheimer's patients. As a Caltech undergraduate, she was a member of the fencing team and choreographed sword fights for several Theater Arts productions. Her faculty mentor on the Core 1 paper was Fiona Cowie, associate professor of philosophy, and the editor was Dian De Sha.

Like Chocolate for String Theory

by Douglas L. Smith

PICTURE CREDITS:
25, 26, 30, 31 – Doug Smith; 28, 29, 30, 31 – Doug Cummings



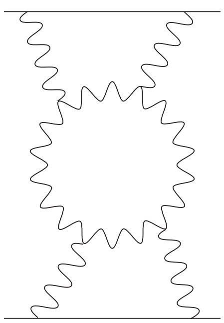
In Feynman diagrams, time moves from left to right. Every line is a particle, and every junction is an interaction. Straight lines are protons, electrons, and the like; wavy lines are force-carriers like photons and gluons. The diagram shows the manner in which a set of particles interact, not their actual directions or speeds. So in the diagram above left, two electrons (arrows) exchange a photon, and then a while later exchange another one. In the center diagram, an electron and a positron (denoted by a backwards arrow, since it is the electron's antiparticle) annihilate one another, producing a photon. And in the right-hand diagram, a photon emitted by an electron produces an electron-positron pair that recombines into a photon before being absorbed by the other electron. As the processes get more and more complex, a picture can truly be worth a thousand words.

Gravity glues galaxies together, while deep within the atom other forces reign supreme. Do galaxies and protons play by the same rules? Professor of Theoretical Physics Hirosi Ooguri and Harvard's Cumrun Vafa, fresh off a six-month visit as a Moore Distinguished Scholar, are trying to find the common ground between the two realms. On the atomic scale, the so-called Standard Model explains three of the universe's four basic forces—electromagnetism, and the strong and weak nuclear forces—in terms of quantum mechanics. And string theory is hot with folks trying to come up with a quantum treatment of gravity and enfold the Standard Model into a "Grand Unified Theory of Everything." The two theories just don't mesh, but Ooguri and Vafa have managed to nudge them into a closer alignment. In the process, they've cleared a mathematical minefield in the Standard Model using techniques they'd developed for working with strings.

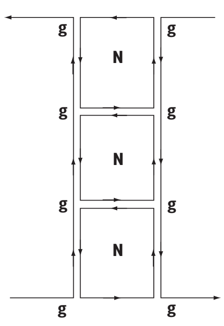
According to the Standard Model, protons and neutrons contain three quarks each. So you'd think that if you hit a proton hard enough you ought to be able to knock one loose, but try as we might, we've never seen a free quark. That's because quarks are held together by the "strong interaction," which increases with distance, so a proton is essentially wrapped in rubber bands. The more you stretch them, the harder they snap back. This strong nuclear force is carried by particles called gluons, the swapping of which makes quarks clingy.

Physicists normally work with such exchanges by drawing little cartoons called Feynman diagrams, showing all the possible things the particles could do. Say you have two electrons. Every now and then, one of them might emit a photon that gets absorbed by the other. In very rare cases, the photon could split in midflight, turning into an electron and a positron, which then recombine to turn back into a photon.

The harder you pull quarks apart, the more gluons they will exchange as they try to keep their grip. The reason more gluons get exchanged is because the coupling constant grows, and the coupling constant grows because the gluons interact. It's a chicken-and-egg problem.



In the Feynman diagram above, two quarks emit a pair of gluons that then exchange another pair of gluons among themselves. The diagram has eight vertices, labeled g, and three complete loops, labeled N, as shown below. Its contribution to the overall process is proportional to g^8N^3.



And in extremely rare cases . . . you get the idea. You can calculate each diagram's individual effect, add them all up, and eventually derive an overall description of the particles' behavior. In general, the more complicated the diagram, the less likely the process depicted in that diagram is to happen, so you can cut off the calculation at any level of complexity and get a corresponding level of accuracy. "That's how things work when we apply the Standard Model to high-energy collisions, as shown by Professor of Theoretical Physics David Politzer and others, or to the various precise computations in quantum electrodynamics that Feynman studied so successfully," says Ooguri.

Each diagram is represented by a single term in the expansion, or overall calculation, and every term contains two key parameters. The first, called *g*, is the coupling constant, which is a measure of the strength of the particles' interaction. It's raised to the power of the number of vertices, or places where lines meet, in the diagram. The second, called *N*, is raised to the power of the number of closed loops in the diagram. So, for example, the odds of the Feynman diagram at upper left happening are governed by g^8N^3.

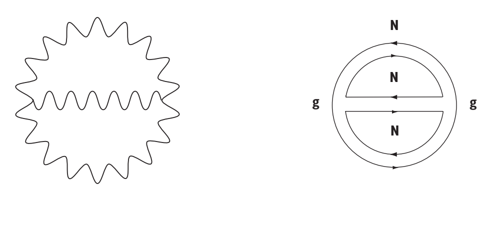
N is always a positive integer, and in the Standard Model, *N* equals three because quarks come in three "colors." More generally, *N* is the rank of the matrix in the SU(*N*) gauge-symmetry group—don't ask: all you need to know is that the Standard Model is a gauge theory. In gauge theories, forces are carried by particles, such as gluons and photons; the elusive quantum-gravity particle is called the graviton.

If you're dealing with electricity, magnetism, or the weak nuclear force, the coupling, *g*, is very small—for electromagnetism at atomic distances, it's about 0.1—and the high-power terms fade rapidly into oblivion. "If each vertex costs you *g*, then the more complicated the diagram becomes, the higher the power of *g* you get, and that suppresses the diagram," Ooguri explains. "So if *g* is small, then you need only worry about the relatively simple Feynman diagrams."

Unfortunately, the harder you pull quarks apart, the more gluons they will exchange as they try to keep their grip. The reason more gluons get exchanged is because the coupling constant grows, and the coupling constant grows because the gluons interact. It's a chicken-and-egg problem. The method gets stood on its head—the more complex the Feynman diagram, the more likely it is to occur. You get stuff that looks like fine French lace, and the calculation spins wildly out of control. So successive terms get bigger and the calculation never settles down on an answer.

But Gerardus 't Hooft, who shared the 1999 Nobel Prize in physics with Martinus Veltman "for elucidating the quantum structure of electroweak interactions," saw a way out. Since the calculation depends on *N* as well as *g*, and *N* is always greater than one, he figured out a way to expand the equations in terms of 1/*N*. You still have to consider all the Feynman diagrams, but now the more complicated the diagram, the better—as you divide by higher and higher powers of *N*, the terms get smaller and smaller.

't Hooft's approach allows you to add up infinitely many Feynman diagrams by classifying them by their topologies rather than their number of vertices. To see what this means, consider the case of three lines meeting at two vertices, like the international "do not" symbol. This diagram



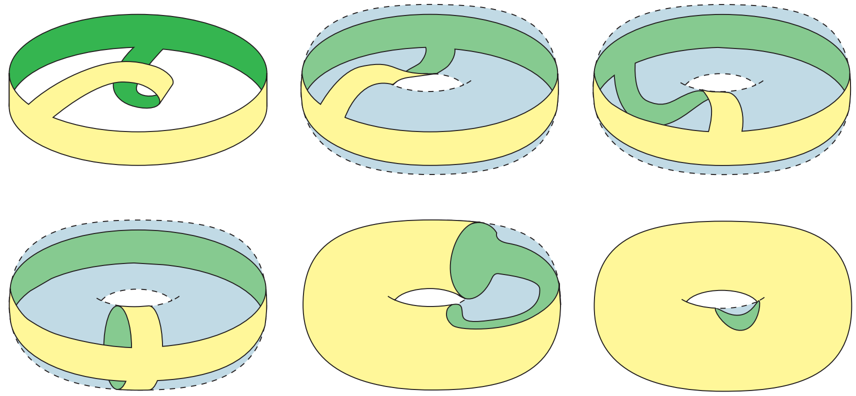
This three-gluon exchange (left) has two vertices and three complete loops (right).

You can make your own one-loop, two-vertex unflat surface. Cut out the three strips at right. Lay them out in a T, green side up, and staple them together. Staple the arms' free ends together, forming a ring that's yellow outside and green inside. Insert the T's leg through the ring from below, bring it out the top, give it a half-twist, and staple it to the front of the ring. If you've done this correctly, you'll have one all-yellow surface and one all-green surface. To show that there's only one edge, run a marking pen along it—you can color all the edges and return to the starting point without lifting the pen.

represents a "vacuum" exchange of three gluons—in other words, a triple-gluon swap between two particles that aren't there; in quantum mechanics, empty space is filled with "virtual" particles that pop into being from nothingness and promptly disappear again. The diagram's two vertices give you g^2, and there are three closed loops for N^3. And if you think of the diagram as being made of flat strips, so that each loop is an edge, you get a disk with two holes in it. So far, so good—but now if you take the central strip, give it a half-twist and connect it to the outer edge of the circle instead of the inner one, the new disk will have a single, continuous edge. (Without going into details, the half-twist can happen because N is related to the colors of the quarks.) The two vertices remain, but now there's only one loop, for g^2N, as you can prove to yourself by using the strips of paper at right. You can't draw this up-and-over diagram on a sheet of paper, but you can on the surface of a donut, as we will discover. Mathematicians would say that the two disks have different topologies.

A donut is topologically equivalent to a coffee mug because each has one loop. If you stood the donut on edge and very carefully dimpled it with your thumbs, you'd create a depression that could hold coffee, albeit briefly.

Topology, or rubber-sheet geometry, deals with the invariant properties of objects—things that don't change when the object itself is stretched, bent, or otherwise distorted; poking holes or tearing off pieces is not allowed. Thus a donut is topologically equivalent to a coffee mug because each has one loop. If you stood the donut on edge and very carefully dimpled it with your thumbs, you'd create a depression that could hold coffee, albeit briefly. Our twisted "do-not" symbol is equivalent to a somewhat different mug—one



Above: You can transform the twisted "do-not" symbol into a bitten-out donut shell by gently stretching and deforming it. You start by bringing the far end of the center strip around to its near end, forming a loop that encircles the donut like a cigar band. Then stretch the horizontal and vertical loops until they cover most of the surface, leaving one small hole.

with a hollow handle that's open to the mug's interior. In other words, if you filled this cup with piping-hot coffee, it would go up inside the handle as well. This could be a popular design in Alaska, but there's a large finger-burning, lap-scalding lawsuit potential in the Lower 48. And the twisted "do-not" donut is equally unsatisfactory—imagine a chocolate-shelled donut from which a bite has been taken and the donut itself scraped out, so that only the chocolate remains. Homer Simpson would not be happy.

His daughter Lisa would be ecstatic, however, because that's how you draw a twisted disk on a donut. The intact chocolate shell is the donut's surface, and the bitten-into shell is the drawing on that surface of the twisted "do not" symbol. In fact, any Feynman diagram can be drawn on a shell made from the right number of donuts. Picture a whole bunch of them, some perhaps standing on edge, possibly in a big, jumbled pile, all touching one other and completely drenched in quick-hardening chocolate. After the scraping-out, you'd get a hollow shell that looks like one of Henry Moore's sculptures. (Particles that enter or leave the diagram are represented by open-ended tubes—half-eaten donuts—sticking out from the shell.) In 't Hooft's formulation, if you start with n donuts, any diagram drawn on—or bitten out of—that shell comes with a factor of $1/N^{-2n}$. "The number of donuts is a topological invariant," says Ooguri, "and the power of N keeps track of it."

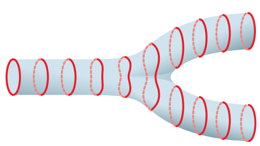
Well, then, why not forget about Feynman diagrams altogether and recast the Standard Model as a theory of chocolate shells? Ooguri and Vafa have shown this is indeed possible—not for the Standard Model itself, not yet—but for a large class of supersymmetric gauge theories in four dimensions. (Remember, gauge theories describe forces in terms of particles; supersymmetry is something required to explain why most particles have mass.) Ooguri and Vafa adapted the language of string theory to describe the donut shells, and it works very well.

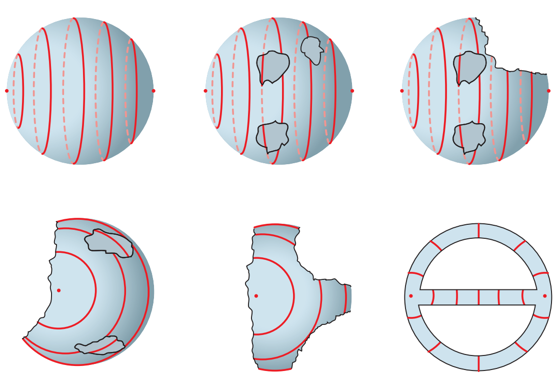
String theory had been rescued from obscurity in 1974, when John Schwarz, now the Brown Professor of Theoretical Physics, and his collaborator, the late Joel Scherk of the Ecole Normale Supérieure in Paris, realized that it could be a candidate for the long-sought Theory of Everything. (It had originally been invented for an altogether different purpose that didn't work out, but that's another story.) But while it handled quantum gravity quite nicely, it predicted a universe that didn't match ours in one important respect. Explains Ooguri, "Nature is not symmetric under the exchange of left and right. The world in the mirror is not the same as our world." This effect, known as parity violation, could not be reproduced—the string-theory universe remained stubbornly ambidextrous. Undaunted, Schwarz kept plugging away almost single-handedly until 1984, when he and Michael Green (then at the University of London, now at the University of Cambridge) found the fix that kept the theory internally consistent while allowing parity to be violated. The field took off, and nowadays you can't pick up a popular-science magazine without reading about superstrings, 10- or 11-dimensional universes, M theory, branes, and the like.

Strings can be thought of as flexible Os. As time passes, a string sweeps out a "world sheet," as shown at left. If the string is moving, the sheet—a cylinder, really—leans in the direction of motion. If the string emits another string, the cylinder forks. As more strings interact, their collective world sheet becomes a network of fused donut shells.

But it's not enough for the world sheet to look like a shell. It has to taste like chocolate, or in this case it has to reproduce the adding-up of the Feynman diagrams. Ooguri and Vafa have shown that one particular variant of string theory does just that. Says Ooguri, "When we did the computations, the world sheet started generating some exotic domains because of its internal dynamics. It tore open here and there to create a new phase in which space-time decayed into nothing." Such behavior tends to be the death of theories, as the math generally breaks down, but Ooguri and Vafa were thunderstruck to discover that the strings stayed in the sheet's normal regions, flowing around the exotic domains like water around rocks in midstream. That is, the strings developed gaps as needed to avoid entering these uncharted zones, and then magically closed up again when the danger had passed. "It turns out that this corresponds exactly to a Feynman-diagram computation. The exotic domains create holes in the world sheet, and if you throw them out, you recover the computation from gauge theory. This provides a way to generate open strings out of closed strings, and once you have open strings, you almost have a gauge theory."

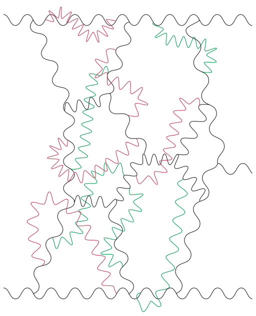
Why not forget about Feynman diagrams altogether and recast the Standard Model as a theory of chocolate shells?

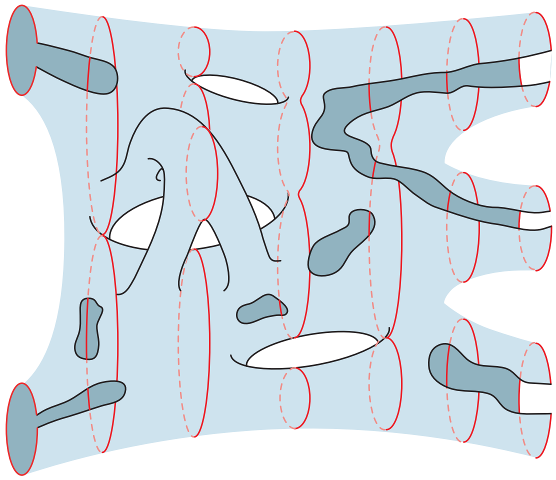




Top left: As in a Feynman diagram, time moves from left to right. Here a string (red) emits another string, causing the world sheet (gray) to fork.

Left: If a string comes into existence briefly and then vanishes, its world sheet is a sphere. Ooguri's and Vafa's exotic domains tear the sphere's surface open, and by stretching three openings in just the right way, you can get the flat disk with two holes. The bottom two spheres have been rotated to show how one hole engulfs nearly an entire hemisphere before the flattening.





Above: If you make a world sheet from enough donuts, you can reproduce any Feynman diagram, no matter how complicated. The Feynman diagram at left has 30 vertices and a tangle of gluons. The red lines are half-twisted paths that rise up out of the page, while the green lines are half-twisted ones that hang under the page. This diagram can be drawn on the five-donut surface at right. (The forked bridge, when squashed flat, becomes three donuts.)

Ooguri and Vafa were working in four dimensions; the current universe-explaining superstring theory operates in 10. (The other six are curled up on themselves, so we don't experience them.) Ahead lies the job of twiddling with those other six dimensions until the Standard Model comes tumbling out. The clincher will come when the calculations predict the masses of the proton, neutron, and so on that are actually observed, and to the same level of precision.

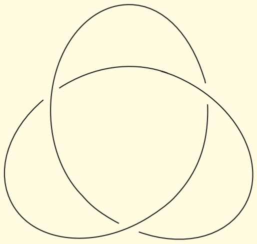
"There's already a string theory that approximates the strong interaction pretty well, but it's not exact," says Ooguri. In this regard, the string theorists are in the same boat as everybody else. Because the Feynman diagrams are so intractable, the other folks have resorted to something called lattice gauge theory, in which space-time is divided into a finite set of points, called a lattice. Then a computer calculates all the fields at each lattice point. Says Ooguri, "The technique has gotten to the point where we can compute particle masses fairly well. But it is not very illuminating.

"We want to do much better. By transforming the calculations into string-theory problems, the techniques Vafa and I, and other collaborators, have worked out over the last 10 years give us a way to compute various quantities *exactly* for a large class of gauge theories. These are calculations we couldn't even approach before, and that's very exciting."

To date, nobody has found a general analytical method capable of handling the strong interaction. In fact, it's such a tough nut to crack that the Clay Mathematics Institute has named it one of seven "Millennium Problems," and has offered a million bucks to the person or persons who succeed. And while the money would be nice, "if we get a handle on this," Ooguri says, "we'll surely learn tons of new things about gauge theory. That's our aim." □

The Number of the Knot

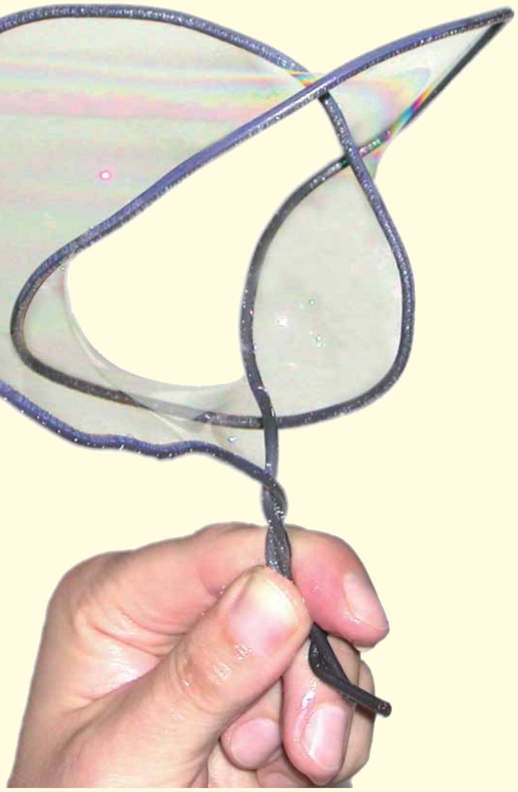
The work also has mathematical applications, particularly in three-dimensional knot theory. A knot can be thought of as a length of rope with its two ends attached to each other. The simplest knot is a circle or ellipse, the so-called unknot; in nontrivial knots the line is wrapped around itself. So in the next-simplest knot, you cross the line over and under itself once, as if you were preparing to tie your shoelaces, before you join the ends. This is called a trefoil knot. And truly complicated knots have loops stuffed through other loops and lines twisted around themselves like the Gawd-awful tangle that that 150-foot, bright-orange outdoor extension cord in your garage is in.



One of knot theory's fundamental problems is to determine whether one knot is equivalent to another—whether the one can be transformed into the other without forcing the line to pass through itself like a magician's linking rings. Mathematicians eventually hope to be able to classify all knots in this manner. A related question is that of deciding whether a given knot is trivial, that is, if it can be disentangled into a circle. Say you have a flat loop of rope—a very long, thin oval. If you treat the tips of the oval like the ends of an ordinary piece of cordage, you can tie the doubled-up rope into additional knots. The result sure doesn't look trivial, but it is—you can get back to the original oval without cutting and splicing anything.

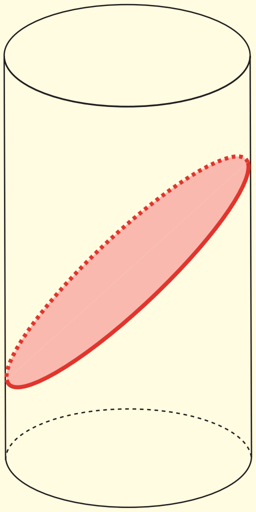
In their quest to classify knots, mathematicians have come up with several invariants, or mathematical expressions that remain unchanged as you pry the knot's loops apart. If the invariants for two knots are different, then, clearly, so are the knots. But nobody has yet come up with a

Surface tension drives soap films to span the minimum possible area, so here's the minimum surface of a trefoil knot, wire-loop and soap-film style. The saddle-shaped surface curves gracefully to connect adjoining turns of the wire, leaving a void in the middle analogous to a donut hole on a closed surface.



formulation for a "complete" invariant—a formulation that says that two knots must be the same if their invariants are the same.

One nearly complete class of knot invariants is called the Jones polynomials, discovered by UC Berkeley's Vaughn Jones. This work won him the Fields Medal, often called the Nobel Prize of mathematics, in 1990. Says Ooguri, "Jones's work initiated a proliferation of knot invariants in the 1980s. Unfortunately, these invariants have not provided much insight into knot theory itself. In particular, the relationships between these invariants and the intrinsic geometric properties of the knots remain obscure."



An unknot (red) extended into two dimensions creates a cylindrical surface. The unknot's minimum, or soap-bubble, surface in the three-dimensional space containing the cylinder is the slanted ellipse shown in pink.

But, he adds, "while we were trying to figure out the equivalence between gauge theory and string theory, and the physical consequences of that equivalence, we came up with a surprising prediction: for every knot, you can extract an infinite set of integers from the Jones invariant and its generalizations, and these integers have clear geometric meaning. Mathematicians like integers. They think integers are more noble than real numbers. So when we found integers in an unexpected place, it got their attention." In fact, some aspects of Ooguri and Vafa's conjecture have already been proven mathematically.

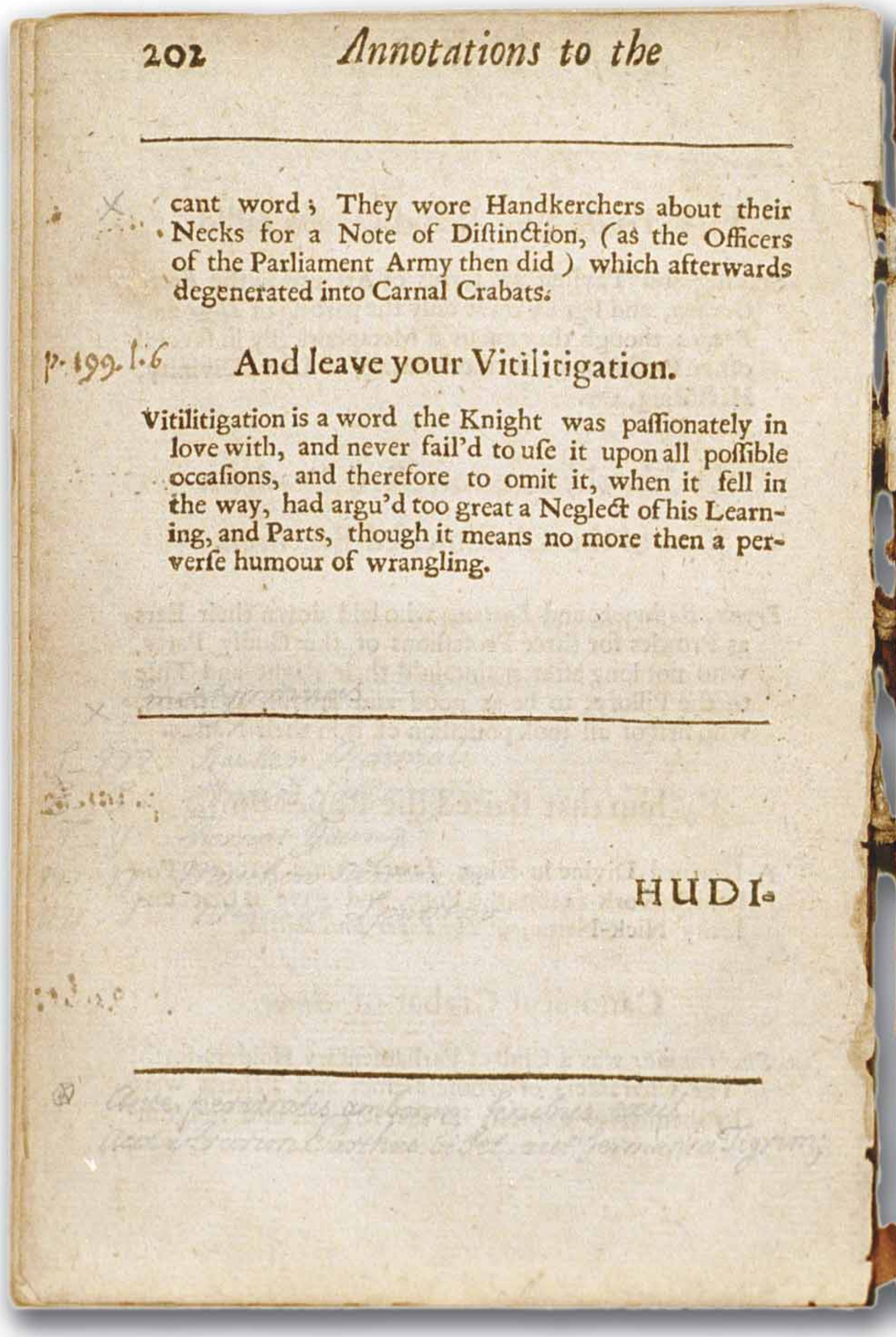
"Mathematicians like integers. They think integers are more noble than real numbers. So when we found integers in an unexpected place, it got their attention."

The conjecture arose by analogy to 't Hooft's method for adding up Feynman diagrams drawn on chocolate surfaces. A knot is a one-dimensional object, but it's embedded in three-dimensional space. So Ooguri and Vafa added two dimensions to the knot to make it 3-D, and then placed this 3-D knot in six-dimensional space—six-dimensional because they were trying to work out what happens in those six extra dimensions that come along with string theory. Says Ooguri, "We then looked for minimum surfaces—surfaces of minimum area, like a soap film on a wire loop—that are bounded by the 3-D knot." That's pretty mind-bending, but it's easier to follow in fewer dimensions. For example, take a cylinder and slice it on the bias to make an oval. This oval is an unknot. If you extend the unknot into two dimensions, you get the cylindrical surface. And the unknot's minimum surface in three-dimensional space is the diagonal disk that lies within the cylinder and whose edge is the oval. Moving up the food chain, a trefoil knot can have a fluted minimum surface with a donutlike hole in the center.

"The surfaces come with various topologies," says Ooguri, "so we count up the number of surfaces in each topological class. There are infinitely many topological classes—basically the number of donuts again—so we have infinitely many integers." (Of course, a lot of those integers can be zero.) "And the way you count them has close ties to other branches of mathematics, so I hope that insights from those branches will give fresh perspectives to problems in three-dimensional topology." —*DS*

Bookish Plots

by Charlotte E. Erwin


202 *Annotations to the*

cant word; They wore Handkerchers about their Necks for a Note of Diſtinction, (as the Officers of the Parliament Army then did) which afterwards degenerated into Carnal Crabats.

p. 199. l. 6 And leave your Vitilitigation.

Vitilitigation is a word the Knight was paſſionately in love with, and never fail'd to uſe it upon all poſſible occaſions, and therefore to omit it, when it fell in the way, had argu'd too great a Neglect of his Learning, and Parts, though it means no more then a perverſe humour of wrangling.

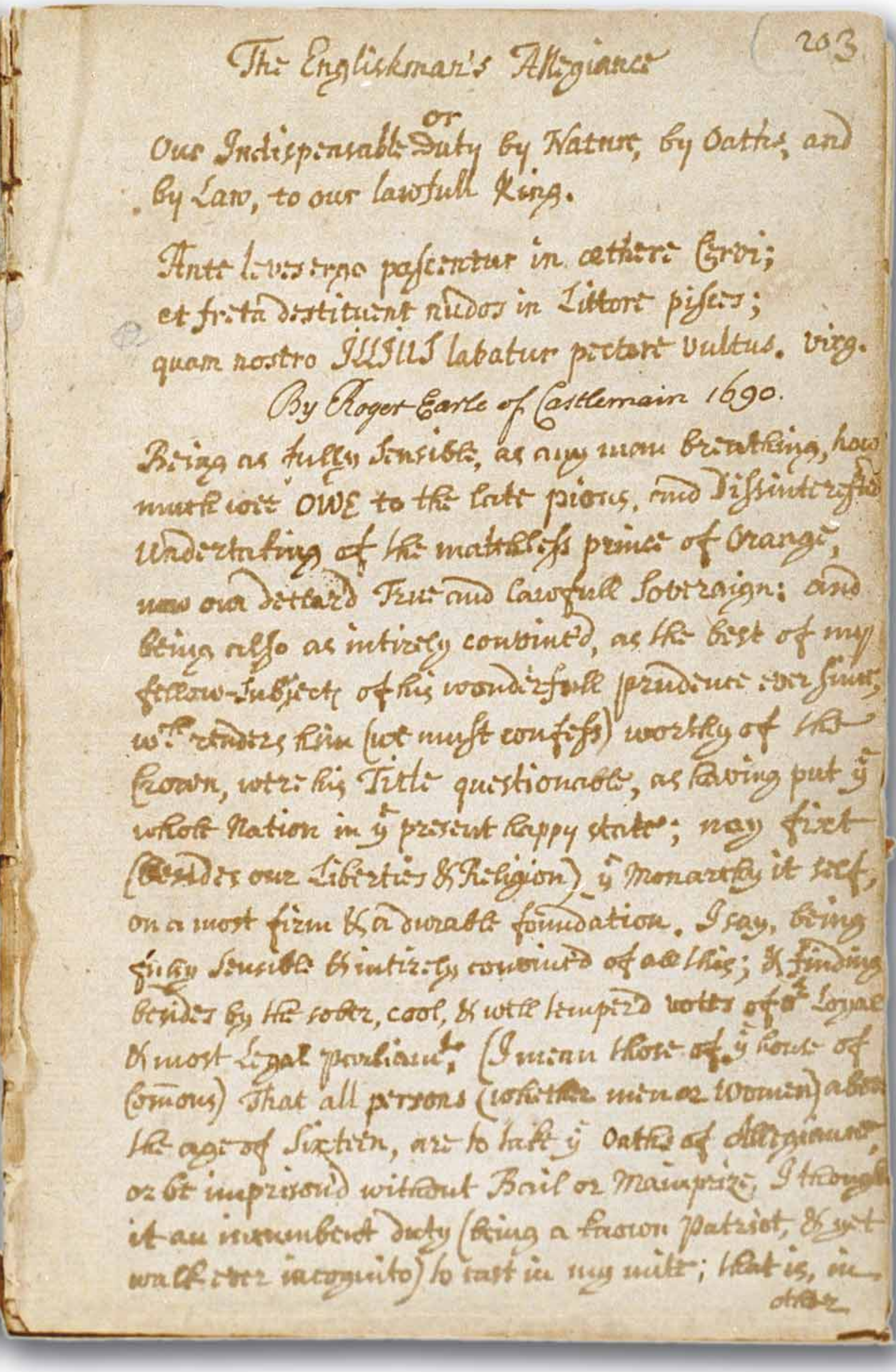
HUDI-

"A known Patriot, and yet walk ever Incognito." So the anonymous author of a Jacobite pamphlet describes himself. These English partisans had special reason to walk incognito, as their undertakings, written and otherwise, were usually seditious and frequently treasonable. They remained loyal to the deposed Catholic monarch, James II—in Latin, Jacobus—after he was ousted in the Glorious Revolution of 1688. At that time, Parliament, not God, chose to hand off the crown, and the first English Bill of Rights was written. The succession had gone to the Protestants William and Mary, but their legitimacy was hotly debated. England was awash then in anonymous pamphlets and tracts on the rights and obligations of subjects and the limitations of the monarchy. Our anonymous pamphleteer titled his treatise "The Englishman's Allegiance, Or, Our Indispensable Duty by Nature, by Oaths, and by Law to our Lawful King." It was composed in the aftermath of the 1688 crisis and published around 1690. So well was its authorship suppressed that it was missed even by the indefatigable creators of the 20th-century *English Short Title Catalogue*, the bibliographic authority on early English books.

"The Englishman's Allegiance" is known today through just 13 copies, of which only two are in the United States. One resides at the Huntington Library in San Marino, California, the other at the Folger Library in Washington, D.C. Now, with the discovery and identification of a new, manuscript source in the Caltech Archives by cataloger Barbara Rapoport, the elusive author has been unmasked. In December 2001, the Archives received a magnanimous gift of close to 300 rare and valuable books from George W. Housner, the Braun Professor of Engineering, Emeritus (and widely known as the father of earthquake engineering). The Housner collection comprises a mix of early scientific (including early earthquake literature), historical, and literary works dating back to 1531, as well as more contemporary landmark and collector's editions. Among them is a real mystery piece, a 1674 edition of Samuel Butler's *Hudibras*, which Housner thinks he must have purchased in England sometime after World War II. Lodged inside is a handwritten copy of "The Englishman's Allegiance." A second hand has written on the manuscript: "By Roger Earle of Castlemain 1690."

The unveiled "Allegiance" manuscript poses a challenging literary puzzle: as one piece drops into place, all others assume new and compelling forms. Who was Roger "Earle of Castlemain," and did he *really* write this pamphlet and under what circumstances? How does the published pamphlet compare to the manuscript version? Is the

George Housner, rare-book donor and father of earthquake engineering, in 1972.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The Englishman's Allegiance
or
Our Indispensable Duty by Nature, by Oaths, and by Law, to our lawfull King.

Ante leves ergo pascentur in aethere Cervi;
et freta destituent nudos in littore pisces;
quam nostro Illius labatur pectore vultus. Virg.

By Roger Earle of Castlemain 1690.

Being as fully sensible, as any man breathing, how much wee OWE to the late pious, and disinterested Undertaking of the matchless prince of Orange, now our declared True and lawfull Soveraign: and being also as intirely convinced, as the best of my fellow-subjects of his wonderfull prudence ever since, wch renders him (we must confess) worthy of the Crown, were his Title questionable, as having put ye whole Nation in ye present happy state; nay fixt (besides our Liberties & Religion) ye Monarchy it self, on a most firm & a durable foundation. I say, being fully sensible & intirely convinced of all this; & finding besides by the sober, cool, & well tempered votes of or Loyal & most Legal parliament, (I mean those of ye house of Comons) That all persons (whether men or women) above the age of Sixteen, are to take ye Oaths of Allegiance, or be imprisoned without Bail or Mainprize, I thought it an incumbent duty (being a known Patriot, & yet walking incognito) to cast in my mite; that is, in other

Bound in between Parts I and II of Samuel Butler's *Hudibras* (actual size), this seditious 17th-century manuscript was spotted by an alert cataloger in the Caltech Archives, setting off a search for the author's identity. Was he indeed "Roger Earle of Castlemain," as this mysterious document claims?

manuscript in the author's own hand? How and why did it get bound into a seemingly unrelated book, and who wrote the attribution of authorship and date on it? The story of the "Allegiance" text, as it has begun to unravel in the Caltech Archives, answers some of these questions and in the process yields some satisfying conclusions about the durability of both books and authors.

Our authorial masked man turns out to be Roger Palmer, the first Earl of Castlemaine (1634–1705). He was a contemporary of Isaac Newton and earned the admiration of both the poet laureate John Dryden and the Quaker William Penn. Most of what is known about him is summarized in the venerable *Dictionary of National Biography* (London, 1900). He was born in 1634, educated at Eton and King's College, Cambridge. Though admitted to the study of law at the Inner Temple, he was not called to the bar. In 1659, against his family's wishes, Roger married Barbara Villiers, at which point he secured for himself a humiliating notoriety and fulfilled his father's prediction that if he married her, he would be one of the most miserable men in the world. Within a year, Barbara became the favorite mistress of King Charles II, coincident with his restoration to the throne in May 1660. She bore the king five children and had several more besides, none fathered (it is thought) by her husband, from whom she parted for good in 1662. In a gesture calculated largely for her own advantage, she obtained for her husband the title of Earl of Castlemaine and Baron of Limerick, an Irish honor for which he showed little enthusiasm. Notably unrestrained in her personal conduct, Barbara was rudely dubbed "the royal whore" by the poet Andrew Marvell. As Lady Castlemaine and later Duchess of Cleveland, she was the talk of the court and often of the town; the diarist Samuel Pepys mentions her frequently.

The unfortunate husband, meanwhile, was ostensibly marginalized. Or was he? In the course Roger Palmer charted from this point, two factors remain constant: his unwavering and public devotion to Roman Catholicism, in spite of heavy legal and social penalties; and his staunch support of the Stuart monarchy. There was no way out of his marital dilemma: his religion forbade divorce, and he would therefore have no legitimate children of his own. His loyalty to the throne forced his acquiescence to his wife's position.

Nonetheless, in spite of scandal and aggressive anti-papist intrigue, Roger Palmer did not fade quietly from view. On the contrary, in the course of a turbulent career, during which he was imprisoned in the Tower of London at least five times, he tenaciously continued to speak out on

The Palmers didn't have much in common, maritally or politically. The flamboyant Barbara was the mistress of Charles II, while the more sober Roger devoted himself to the cause of religious freedom. Roger's portrait, printed in *The Earl of Castlemain's Manifesto* (1681), comes from the Huntington Library. The oil painting of Barbara (née Villiers), Duchess of Cleveland (after Sir Peter Lely, ca. 1666) is reproduced by courtesy of the National Portrait Gallery, London.

behalf of English Catholics and to argue for religious toleration. When not engaged in polemics, he had time to invent a new type of globe, whose description, amply illustrated, was published in 1679 by Joseph Moxon, the royal hydrographer. His contemporary, Bishop Burnet, called him an unlucky man, but all things considered, his case might be the opposite. During the fevered days of the Popish Plot in 1678, when upwards of 25 Roman Catholics were executed for conspiring to kill King Charles II and to restore Roman Catholicism as the state religion of England, Lord Castlemaine was not one of them. He was tried at the King's Bench Bar in Westminster on June 23, 1680, for "high treason in the highest nature," which included alleged "approbation" of the king's death. Before a jury of 12 men, he conducted his own defense and was acquitted. Two accounts of his trial were published, one written by himself. The Popish Plot was later determined to be a fabrication. Some years afterwards, upon James II's accession to the throne in 1685, Lord Castlemaine and other Catholics saw their stars rise dramatically. Castlemaine was appointed the king's ambassador to the Vatican. According to contemporary accounts, he made a dreadful mess of his embassy by flouting decorum and by bringing an unseemly pressure to bear on Pope Innocent XI in a matter of ecclesiastical appointments. Recalled to England, he was consoled with a place on the Privy Council. But his fortune was short-lived. On the heels of James's fall he was arrested and charged with high treason, for endeavoring to reconcile England to the See of Rome and for other high crimes and misdemeanors. After enduring almost 16 months in the Tower, he was freed on bail. He died quietly in the country some years later at the age of 70.

Castlemaine's authorial career began in 1666 with a short treatise which later became known as "The Catholique Apology." In its original form, it appeared anonymously under the long title "To all the Royalists that suffered for his Majesty, and to the rest of the good people of England. The humble apology of the English Catholicks." This was an appeal for recognition of Catholic loyalty during the Civil War. It finishes with a "Bloudy Catalogue," flamboyantly printed in red ink, of those Catholics who died in the war. Somewhat intemperate and theatrical, the pamphlet earned for Castlemaine the epithet "the Apologist." It was answered, rebutted, and refuted several times, until in its last edition of 1674 the whole set of interchanges had swollen enormously in size from a mere 14 to 608 pages. Lord Castlemaine continued his pro-Catholic writings with *The Compendium* (of the Popish Plot trials, 1679) and *The Earl of Castlemain's Manifesto* (1681).

Although it was dangerous to be known as the writer of politically subversive tracts, the author of the "Allegiance" pamphlet wanted *some* people to know who he was. Otherwise why write at all? To this end, he provided some "Who-am-I" riddles in his opening pages. First, he says who he is not: "I am not a Quaker, for I can swear, and have both sworn Allegiance, and am also very fully resolv'd to keep it." Quakers were forbidden to swear oaths on religious grounds. They and the English Catholics had been sorely pressed in the matter of oaths, principally the oath of allegiance to the monarch and the oaths imposed under the Test Acts (1672, 1678), which essentially nullified the pope's authority. Like many Catholics, Castlemaine had sworn the oath of allegiance to the Stuarts, and he did not fancy being required to swear it again to the newly installed William and Mary, whom he regarded as usurpers.

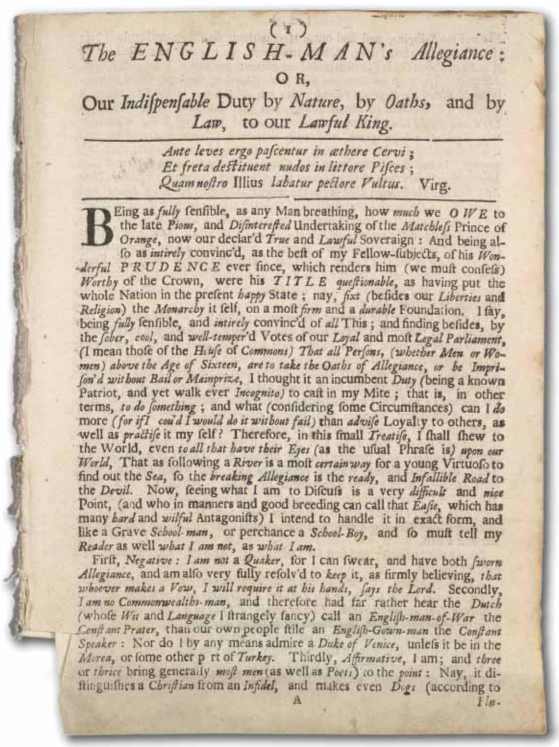
The author avers he is no "commonwealthsman." Around the time of William and Mary's Glorious Revolution, this term was applied to Dissenters, that is, those Protestants who were not Anglicans, and those who favored a limited monarchy. Castlemaine was certainly neither of those. The Palmer family were royalists and, almost as surely, Anglicans. Roger's father, Sir James Palmer, served as a gentleman of the bedchamber under King Charles I and advised him in the matter of a shared passion—art collecting. Roger was the son of James Palmer's second marriage, to Catherine Herbert, daughter of Sir William Herbert, first Lord Powis. It is from his mother's side that Roger apparently gained his religious persuasions, for the Herberts were among the most powerful of the Catholic aristocrats. Although previous biographers fail us on this point, Roger was probably a convert to Catholicism. The "Allegiance" author claims to have been born and bred in the Church of England, but then roundly castigates that church for its worldliness and hypocrisy. It was of course the Anglican establishment, not the Dissenters, that made life miserable for Catholics.

The author tells us further that he is "of the long Robe," meaning that he is a lawyer. This accords with Castlemaine's biography. He also professes admiration for the Dutch and respect for a Duke of Venice in "the Morea or some other part of Turkey." Castlemaine had published under his own name two detailed histories, first, on the wars between the Venetians and the Ottoman Turks in the Mediterranean (where he had traveled widely); and second, on his own participation in the second Anglo-Dutch War (1665–67). From these pointed clues, those who knew him, his family, and his occupations had an excellent chance of identifying his authorial voice and heeding his message. That message, like the identity riddles, squares with Lord Castlemaine's character and conservative views. It passionately defends divine-right monarchy and direct hereditary succession. "Our Lawful King," he writes, "sits always on a Hill, and is as conspicuous as the Pyramids of Modin, the Tombs of the Maccabees, which might be seen by all that sail'd on the Sea. The Inscription on his Throne is in such legible Characters, that he that runs may read it: Nor can any Native of England, or Scotland, possibly mistake his Royal and Sacred Person." An Englishman's allegiance, it follows, can only be to the legitimate sovereign, and that is James II.

These were politically charged times. Castlemaine was in prison for all but a few weeks of 1689 and for four or five more months in 1690. Did he compose his "Allegiance" essay while incarcerated? He gives a broad hint on that matter by noting a certain limitation on his sphere of action: "I thought it an incumbent Duty (being a known Patriot, and yet walk ever Incognito) to cast in my Mite; that is, in other terms, to do something; and what (considering some Circumstances) can I do more (for if I cou'd I would do it without fail) than advise Loyalty to others, as well as practise it my self?" Whether "The Englishman's Allegiance" was composed in the Tower or in the months in 1690 when the Earl was at large, its preservation and circulation had to be effected. This was a clandestine effort, and parts of the story will remain untold. But we know some essential facts: the text was printed in pamphlet form without title page or author in the latter half of 1689 or in 1690 (events mentioned in the text lead to this conclusion); and a handwritten copy was made and intentionally stowed in a printed book—the book that George Housner purchased some three centuries later.

The Earl of Castlemaine's handwriting can be established from his autograph letters (one can be viewed at the Huntington Library), and it is certain that *he* did not pen the manuscript copy. It is a handsome fair copy in a neat contemporary hand, in ink on paper that, by its type and watermark, would be typical of the late 17th century. The text corresponds almost exactly with the pamphlet version. Variants between the two are slight, and there is no clear evidence of the priority of either one. It would be tempting to suppose that the manuscript served as the "copy" from which the compositor set type, but this could not be the case unless the whole book served as the cloak beneath which the subversive text was transmitted to the printer—an intriguing possibility. The manuscript was certainly written *after* its pages were inserted into the binding where it resides today.

How do we know this? First we need to tackle some book history. Old books frequently have interesting provenance, but the details of these histories can be elusive. The record is often patched together from physical evidence, such as book plates, dedications, and inscriptions of various sorts. The book that holds the "Allegiance" manuscript is an intriguing case. Samuel



(1)

The ENGLISH-MAN's *Allegiance*:

OR,

Our *Indiſpenſable* Duty by *Nature*, by *Oaths*, and by *Law*, to our *Lawful King*.

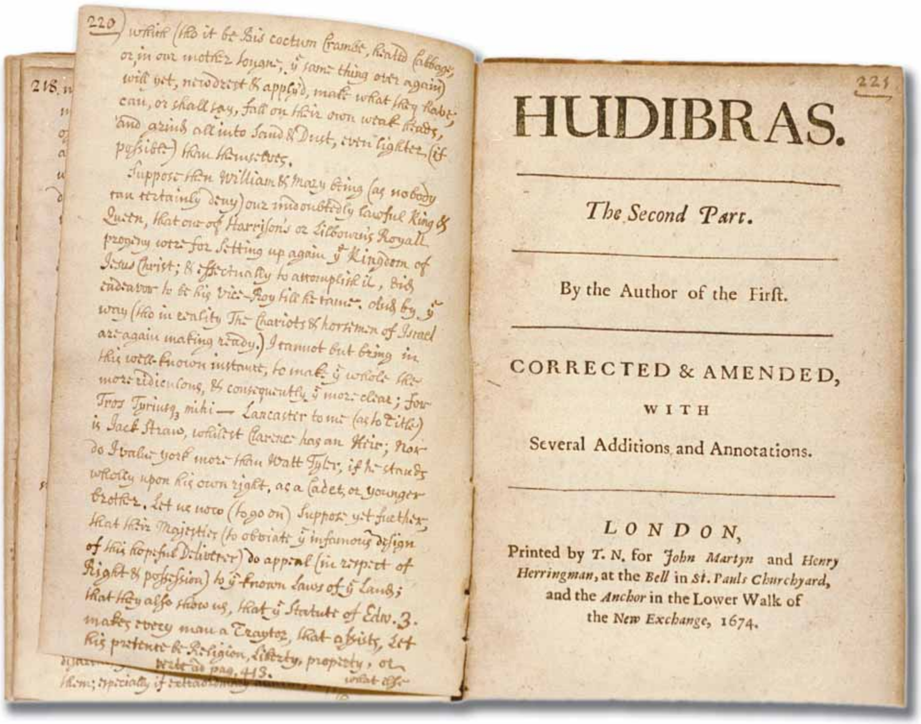
Ante leves ergo paſcentur in æthere Cervi;
Et freta deſtituent nudos in littore Piſces;
Quam noſtro Illius *labatur pectore Vultus.* Virg.

BEing as *fully* ſenſible, as any Man breathing, how *much* we OWE to the late *Pious*, and *Diſintereſted* Undertaking of the *Matchleſs* Prince of *Orange*, now our declar'd *True* and *Lawful* Soveraign: And being alſo as *intirely* convinc'd, as the beſt of my Fellow-ſubjects, of his *Wonderful* PRUDENCE ever ſince, which renders him (we muſt confeſs) *Worthy* of the Crown, were his TITLE *queſtionable*, as having put the whole Nation in the preſent *happy* State; nay, *fixt* (beſides our *Liberties* and *Religion*) the *Monarchy* it ſelf, on a moſt *firm* and a *durable* Foundation. I ſay, being *fully* ſenſible, and *intirely* convinc'd of *all* This; and finding beſides, by the *ſober*, *cool*, and *well-temper'*d Votes of our *Loyal* and moſt *Legal Parliament*, (I mean thoſe of the *Houſe* of *Commons*) *That all Perſons, (whether Men or Women) above the Age of Sixteen, are to take the Oaths of Allegiance, or be Impriſon'd without Bail or Mainprize*, I thought it an incumbent *Duty* (being a known Patriot, and yet walk ever *Incognito*) to caſt in my Mite; that is, in other terms, *to do ſomething*; and what (conſidering ſome Circumſtances) can I *do* more (*for if I cou'd I would do it without fail*) than *adviſe* Loyalty to others, as well as *practiſe* it my ſelf? Therefore, in this ſmall *Treatiſe*, I ſhall ſhew to the World, even *to all that have their Eyes* (as the uſual Phraſe is) *upon our World*, That as following a *River* is a moſt *certain way* for a young Virtuoſo to find out the *Sea*, ſo the *breaking Allegiance* is the *ready*, and *Infallible Road* to the *Devil*. Now, ſeeing what I am to Diſcuſs is a very *difficult* and *nice* Point, (and who in manners and good breeding can call that *Eaſie*, which has many *hard* and *wilful* Antagoniſts) I intend to handle it in exact form, and like a Grave *School-man*, or perchance a *School-Boy*, and ſo muſt tell my *Reader* as well *what I am not*, as *what I am*.

First, *Negative*: *I am not* a *Quaker*, for I can ſwear, and have both *ſworn Allegiance*, and am alſo very fully reſolv'd to *keep* it, as firmly believing, *that whoever makes a Vow, I will require it at his hands, ſays the Lord.* Secondly, *I am no Commonwealths-man*, and therefore had far rather hear the *Dutch* (whoſe *Wit* and *Language* I ſtrangely fancy) call an *Engliſh-man-of-War* the *Conſtant Prater*, than our own people ſtile an *Engliſh-Gown-man* the *Conſtant Speaker*: Nor do I by any means admire a *Duke of Venice*, unleſs it be in the *Morea*, or ſome other p rt of *Turkey*. Thirdly, *Affirmative*, I am; and *three* or *thrice* bring generally *moſt men* (as well as *Poets*) to the *point*: Nay, it diſtinguiſhes a *Chriſtian* from an *Infidel*, and makes even *Dogs* (according to

A *Illu-*

Only 13 copies of the anonymously published pamphlet "The English-Man's Allegiance" still exist. This one is in the collection of Caltech's neighbor institution the Huntington Library and is reprinted with permission.



When the copyist came to the end of the 16 pages bound between Parts I and II of the book, he jumped to the pages bound at the end and finished there. Note the continuous pagination as "The Englishman's Allegiance" segues into *Hudibras*.

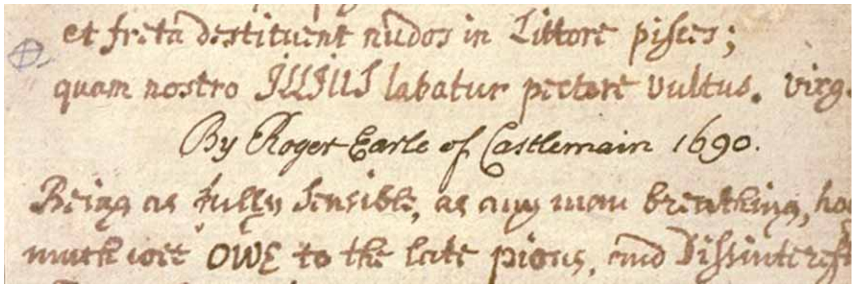
Butler's *Hudibras* is a verse satire on the English Civil War and the Cromwell era. Parts I and II were published in 1663 and 1664, respectively; Part III did not appear until 1678. *Hudibras* is part mock heroic epic, part political allegory. It became a true bestseller, "in greatest fashion for drollery," reported Pepys in his diary for December 10, 1663, although he personally thought it "silly." Even King Charles II read it, reportedly "with great delight." The title character is a Presbyterian knight who, somewhat in the manner of Don Quixote, goes forth adventuring. From the well-known opening lines—"When civil Fury first grew high, / And men fell out they knew not why"—the poem broadly satirizes everything from religion to government to the Royal Society. In 1674 Butler made a new edition of Parts I and II together, and this is the edition that comes into our story. In this revised version, the text was altered through excisions and additions. The author also wrote explanatory notes called Annotations to clarify some of his obscure topical allusions which by 1674 referred to events that were rapidly receding into the past. The bigger format of the new edition, along with a series of actions by an expanding cast of characters—printer, owner, copyist, and bookbinder—made *Hudibras* physically adapted to the concealment of a small manuscript.

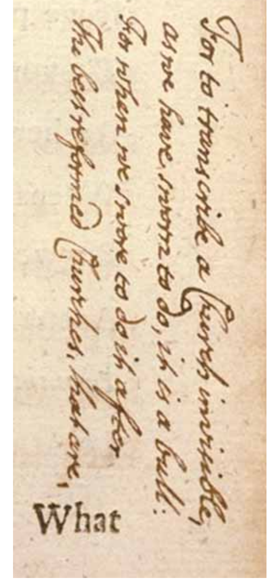
Most deserving of our attention after Lord Castlemaine is the person who owned Caltech's *Hudibras* around 1690 or sometime after, and who made the attribution of the manuscript text to the Earl. This was a person with a zeal for truth and an appetite for detail. Unfortunately, he remains unidentified, having covered his tracks even better than the Earl. The attribution bespeaks a direct or at least close knowledge of the "Allegiance" text and a desire both to protect it and to make it known, if only to the chosen few or posterity. Based on his preservation efforts, we may suppose him to be, at the very least, a sympathizer to the Jacobite cause and willing to take a risk on its behalf. He could have been a friend of Castlemaine and might be sought within the relatively small circle of the Catholic peerage, among the aristocratic companions who had recently shared the Earl's ill-fated embassy to Rome, or among those to whom he considered applying for bail in 1690 who are named in the Huntington Library letter. The owner was probably not young, as he recognizes events several decades past. He was most certainly a gentleman with scholarly inclinations and fond of books, in addition to being neat in his writing and meticulous in his habits.

Here is what seems to have happened: the *Hudibras* owner had access to a copy of the "Allegiance" text—a dangerous item, but something he wanted to keep. He noted that his copy of *Hudibras* happened to have a blank page between Parts I and II—a result of the printing practices of the day. One blank page suggested a likely spot for the interpolation of additional pages. Paper was selected, of a quality and thickness to take ink without bleed-through. One sheet was folded into an octavo format to match the size of *Hudibras*—three folds would yield 8 leaves, 16 pages. This gathering—to use the proper book-making term—was trimmed and inserted to follow the blank page in *Hudibras.* The book would have had to be in an unbound state, but that was common. Owners rather than booksellers frequently saw to the binding of a book sold in wrappers or pasteboard covers. But this insertion would not produce enough pages for the "Allegiance" text. So a second gathering of blank pages of the same type of paper was added at the end of the book. And then, for good measure, more blank pages were added at the beginning. All of the added pages are of the same paper, distinguishable by its texture, weight, and characteristic watermark. Partitioning the blank pages into three segments made them less noticeable. Also, blank pages at the front and back of bound texts were used quite innocently for strengthening a binding. At this point, the owner had altogether 18 blank leaves (36 pages) inserted at three points—front, middle, and back—into his copy of *Hudibras.* Now he could have the book properly bound in leather and made ready for his shelf.

Enter the sympathetic copyist. He was ready to write out the seditious text. But he made a mistake—fortunately for later book historians. Instead of beginning to write on the paper insert, he started copying the text on the one blank leaf of the *Hudibras* text. Then a problem appeared, as the paper was thin and his ink bled through, forcing him to leave the overleaf blank, even though he had already paginated it. He then

The hand that entered the attribution "By Roger Earle of Castlemain 1690" is clearly not that of whoever copied the rest of the tract. But it is very similar to the hand that neatly scribbled remarks in the book's margins, presumably that of the book's owner, who was well up on current affairs, as his marginalia reveal. Note the resemblance of the "C"s in "Castlemain" and "Church."


By Roger Earle of Castlemain 1690.


What

skipped to the first inserted leaf and continued to write without difficulty. When he came to the end of the blank pages, he jumped to the back of the book and finished the job. He had two and a half blank leaves left over.

By his blundering beginning, the copyist left evidence that he was writing on pages already bound into *Hudibras*. This establishes a crucial physical and temporal link between book and manuscript. The *Hudibras* owner also reinforces this link by writing on both manuscript (the attribution to Castlemaine is in his hand) and book pages. He glosses the Butler text in a thorough and lively manner, constructing his own scholarly edition by restoring in the margins all of the bits of text that were dropped by the author in his second edition. He has keyed Butler's Annotations to their relevant pages, accurately anticipating by almost 300 years Oxford's critical edition of 1967. The owner was in the know, too, on some of Butler's obscure allusions, dating back before at least 1663. In his inked note "Lord Munson," he recognizes and identifies the unlucky gentleman so violently subdued by his wife, here described in Butler's gawky, comic lines (Part II, Canto I, 885-90):

Did not a certain Lady whip
Of late, her husband's own Lordship?
And though a Grandee of the House,
Claw'd him with Fundamental blows,
Ty'd him stark-naked to a Bed-post;
And firk'd his Hide, as if sh'had rid post.

Did poor Lord Munson dare to show his face in Parliament after this escapade? That is certainly another story.

The satirical *Hudibras* and the seditious "Englishman's Allegiance" have traveled together for many years. Both authors, though far apart in point of view and method, join in the common purpose of ridicule. Theirs was an age of violent unrest, and each strove to come to terms with it in his own way. One is detached and skeptical, the other a fervent partisan. The latter sought redress, the former was content to look and laugh. By strange and chancy events, their writings were bound together, one sheltering the other, but each in some way promoting the other's survival. Now having been delivered by a conscientious collector, George Housner, into Caltech's institutional hands, the companions are assured of a secure future together. □

Several people contributed to this article. To Barbara Rapoport goes the credit for the identification of the Castlemaine manuscript and for research on the Earl's handwriting. Kevin Knox in the Caltech Archives contributed much helpful advice on the 17th-century historical context. Mary Robertson and Stephen Tabor of the Huntington Library and Bruce Whiteman of UCLA's Williams Andrews Clark Memorial Library examined and commented on the physical characteristics of book and manuscript. Robertson also drew attention to the letter of the Earl of Castlemaine in the Huntington Library.

Charlotte (Shelley) Erwin has worked at Caltech for 15 years, as associate archivist since 1990, and became a member of the Academy of Certified Archivists in 1997. She holds a bachelor's degree in English from Vassar and a PhD in music history from Yale. Her current interests are in history of science, in modern European cultural and intellectual history, and in rare books.

Barbara Rapoport holds a bachelor's degree in English from the University of London and a master of library science degree from UCLA, where she spent most of her professional life. Since 1994 she has worked quarter-time at Caltech, cataloging maps for the geology map library, and recently took on cataloging the Housner collection as a special assignment.

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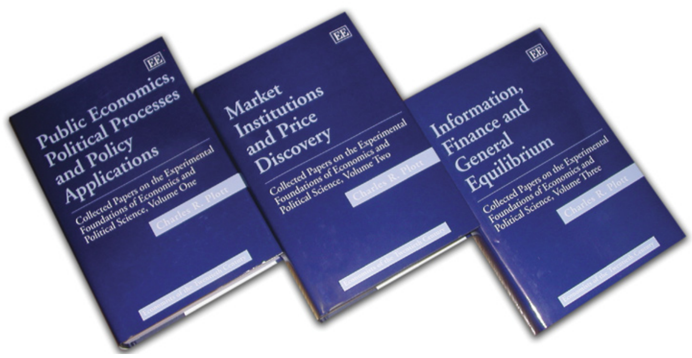


Collected Papers on the Experimental Foundations of Economic and Political Science:
I. Public Economics, Political Processes, and Policy Applications;
II. Market Institutions and Price Discovery;
III. Information, Finance and General Equilibrium
by Charles R. Plott
Edward Elgar, 2001.
Volume I: 608 pp.; Volume II: 688 pp.; Volume III: 656 pp.

by Andreas Ortmann

Andreas Ortmann is on the faculty of the Center for Economic Research and Graduate Education at Charles University in Prague, and is a member of the Economics Institute of the Academy of Sciences of the Czech Republic. He has no affiliation with Caltech; in fact, he's never even set foot in Pasadena.

This review was excerpted from the Journal of Economic Psychology*, Vol. 24, No. 4, pp. 555–575, © 2003, with permission of Elsevier.*

As everyone reading [the *JEP*] knows, the 2002 Nobel Prize in Economic Sciences went to Daniel Kahneman and Vernon Smith [BS '49]. The Economics Prize Committee of the Royal Swedish Academy of Sciences credits Smith as being "the most influential figure in launching experiments as an empirical methodology in economics" and "establishing standards for what constitutes a good experiment. Other researchers have furthered this tradition. Charles Plott, in particular, has written several important papers, further developed the experimental methodology, and spearheaded experimental research in new areas."

I argue that these statements play fast and loose with the historical facts and sloppily and incorrectly assess the scope of Plott's work and his "pioneering influence" (as Smith put it graciously in his Nobel Banquet speech). Specifically, Smith, after acknowledging Kahneman's contributions, noted "I wish to celebrate . . . the pioneering influence of Sidney Siegel, Amos Tversky, Martin Shubik, and Charles Plott on the intellectual movement that culminated in the economics award for 2002."

How influential a pioneer was Plott? Plott's introduction to these volumes, and Smith's "Autobiography: the Early Years to 1975," which he wrote upon the request of the Nobel Foundation, agree on many aspects of their collaboration in the late 1960s and early 1970s. It is undisputed, for example, that Smith, inspired by classroom experiments his teacher Edward Chamberlin conducted at Harvard, developed what he called the theory of induced valuation, sometime between 1963 and 1965 at Purdue. (Purdue was Smith's first teaching post and a place where he spent the overwhelming part of the years 1955–67, partially overlapping with Plott who, after having graduated from the University of Virginia, started his career at Purdue in 1965. After a one-year stint as visiting professor at Stanford during the academic year 1968–69, Plott moved in 1971 to the California Institute of Technology.)

As Plott describes it, "My introduction to the use of laboratory experimental methods in economics was in the late 1960s, resulting from the fact that Vernon Smith and I both enjoy fishing. We frequently fished together and while fishing we always talked about economics.

From right: Miller, Plott, and Stefan Feuerabendt (BS '85) in 1983. At the time, Miller and Plott were working on a paper on information in markets. Then a professor of economics, Plott is now the Harkness Professor of Economics and Political Science.

From time to time, Vernon would tell me about some of his experimental work. He had actively conducted experiments in the late 1950s and early 1960s, but by the late 1960s he was doing other things. Professional acceptance of his work had not been overwhelming. In fact, it had been substantially ignored and his research interests had long since turned elsewhere. That is not to say that his enthusiasm and capacity to talk about the topic had diminished."

According to Smith's account, while he continued to think about experimental economics, and while he used it in his teaching, in the late '60s and early '70s he had focused his energies on the economics of uncertainty, corporate finance, and natural resource economics, with considerable success. Smith then spent two years at Caltech, as a Sherman Fairchild Distinguished Scholar in 1973–74 and a visiting professor of economics in 1974–75. All the indications are that by the time Smith arrived at Caltech, a full-fledged and fully financed experimental program was under way, with many public-economics experiments completed, in which [Assistant Professor of Political Science] Morris Fiorina and Plott were the main contributors.

Like the question of whether John Lennon or Paul McCartney was the main musician and songwriter for the Beatles, the question of the relative contributions of Vernon L. Smith and Charles R. Plott to experimental economics strikes me as irrelevant. The Beatles were, probably in most people's view, the joint effort of Lennon and McCartney, and similarly a good case can be made for the symbiotic interaction of Plott and Smith, if only for a limited amount of time.

There is, in particular, agreement that Plott and Smith "talked experiment . . . on many bass fishing trips" during those years and that the two ended up teaching a seminar for student credit that was attended by "three paying customers (including an undergraduate, Ross Miller [BS '75]), and several faculty." (Both quotes are from Smith's "Autobiography.") There was no looking back for either of them, nor for experimental economics, from that spring semester in 1974 on. While efforts to keep Smith in Southern California failed—he chose instead to make the University of Arizona into one of the premier centers of experimental economics in the world—Plott continued to build the experimental program at Caltech into a center whose influence can hardly be overestimated. As David Warsh, editor of economicprincipals.com and formerly of *The Boston Globe* and *Forbes* magazine, put it in his online essay "The Vital Many," "Caltech, despite the tiny coterie of barely fifteen social scientists on its faculty remains the discipline's spiritual home."

Apart from being the catalyst for Smith's renewed attention to matters experimental, and apart from being the driving force behind the Caltech experimental program, Plott made a number of significant contributions, some of them with Smith and some of them with the students and faculty who attended that seminar in the spring of 1974. (Miller recently published an insightful and deservedly acclaimed book, *Paving Wall Street*, which traces modern finance and modern institutions such as frequency auctions and derivatives back to those simple experiments at Caltech.) I list some of Plott's contributions below.

Plott recognized that the use of laboratory methodology—back then applied exclusively to markets (by economists) or games (by political scientists)—could be applied to public economics, public choice, and indeed political science, i.e., on topics such as voting on which he had worked theoretically. His papers on committee decisions under majority rule and on the impact of agenda-setting on committee decisions—"a stunningly powerful tool to use if one is interested in manipulating voting groups," as he called it—had tremendous impact and remain highly readable and entertaining pieces for everyone who wonders about the usefulness of experimental economics, or those who wonder about the ways faculty meetings transpire.

In the April 2003 issue of the *Southern Economic Journal*, Charles Holt of the University of Virginia tells the following story about the real effects of one early agenda-setting study. "[Luce Professor of Law and Social Change in the Technological Society Michael] Levine and Plott had been members of a flying club that was to meet and decide how to spend a large sum of money on a collection of airplanes to be used by the membership. After being appointed to serve on the Agenda Committee, they distributed a survey of members' preferences to assist in structuring the discussion at the meeting. The survey results were used to design an agenda that the authors believed would yield a fleet of new aircraft that they [the authors] preferred. The president of the club had different preferences and repeatedly tried to deviate from the agenda during the meeting, but was ruled out of order in each case. The authors were asked to resign from the club after an account of the agenda strategy was published in the *Virginia Law Review*."

{Plott, however, says, "The Holt story is incorrect. I was not a member of the flying club. Levine was, and he came to me because he knew that I was an expert in committee decisions and he was responsible for a very large committee that had a very difficult and controversial decision to make. He wanted to know how to find the "best" decision, and I told him there was no such thing as a "best" or "fair" decision, and that the outcome was a function of the agenda's design. Interested in the application of known science, I then talked him into letting me design a set of procedures that would be "fair" but also lead to the decision that he liked best. The survey was distributed afterward, and allowed us to test the agenda's influence by revealing the preferences that were actually in place during the meeting. The club generally liked the agenda, congratulating Levine on a job well done, and there was certainly no asking for resignations—I have no idea where that came from."—ed.}

Plott appears to have been the first experimentalist to intervene in a regulatory dispute. Plott and James Hong {BS '76} (reading 5, volume II), reported experiments conducted for the U.S. Department of Transportation to "shift the burden of proof in a policy debate." The relevant debate involved the railroads and the dry-bulk barge industry. The railroad lobby wanted the barges to post their prices with the Interstate Commerce Commission, and claimed to want so for altruistic reasons (e.g., that it would lower prices, increase efficiency, and help the independent barge-owners). Apart from the alleged concern for consumer welfare on the part of the railroad lobby not being particularly credible in the first place, its claims clearly contradicted the so-called posted-price effect Plott and Smith had earlier identified: In a market where prices cannot be changed once they have been posted, prices get pushed up if sellers post them and pushed down if buyers post them. Sure enough, the general theory used by the railroads failed to predict what was observed in a simple and scaled-down version of the industry.

The very first multinational market experiment, run in December 1995 over the Web with participants in Australia, Canada, France, Germany, Japan, the Netherlands, Spain, Sweden, and elsewhere in the United States. From left are Hsing Yang Lee, the lab's technical manager; Paul Brewer (BS '89, MS '92, PhD '95); and Plott.

Plott, more than other experimentalists in the '70s, seems to have realized the potential for what is now becoming known as "design economics." This insight is likely to have been the result of Plott's work in public choice (agenda setting) and of his work on regulatory issues, both of which invited thinking about counterfactual scenarios. The problem, as Plott says, was "to design institutions that perform a particular task, as was the case in the study of agendas. . . . The experiments are used as 'test beds' in which the performance qualities of the institutions are assessed and the reliability of the model that led to the design in the first place is ascertained." Besides the barge study already mentioned, Plott and various collaborators did experiments that informed policy-making on, to name a few reprinted in these volumes, the allocation of airport landing slots; the right to use railroad tracks; price-setting policies for the use of space-station resources; FCC auctions; and the EPA's new emissions-trading mechanism. Plott appreciated the importance of institutions—a theme acknowledged in his "fundamental equation" that related outcomes to various ways in which preferences, physical possibilities, and institutions could interact. It needs stressing that this insight today is second nature to all experimentalists, and even the better theorists, but back then in the dark ages of economic theorizing the importance of institutions was mysterious to most economists.

Plott pioneered with Smith and Miller a methodology for the study of assets, bubbles, futures markets, and other aspects of financial markets. As Smith comments, "this must have been the first scientific paper in economics with an undergraduate coauthor." That paper initiated numerous experimental studies on rational expectations and the ability of markets to aggregate information. Plott himself was involved in several influential papers that constitute a convincing exercise in persuasion about the astonishing ability of markets to, as he wrote in the *Southern Economic Journal* in 2000, "collect information that is dispersed across the economy, aggregate it like a statistician, and publish the findings in the form of prices." And all that without publication delay, I cannot resist adding!

Plott pioneered the multiple-unit double auction, which permits multiple-unit or "block" trades and thus allows within the classic double-auction framework the study of markets with large volumes and many traders. This, preparing as it did the study of more complicated general-equilibrium and international-trade experiments, marked not only another important conceptual step—a major generalization of the double auction—but also yet another technological innovation. {It allowed as many as 20 markets to operate simultaneously in real time, allowing complex, interdependent systems to be studied. Even more importantly, it was designed to run over a Local Area Network, or LAN, rather than requiring specialized hardware, meaning that it could be (and was) set up by almost anyone almost anywhere. Its descendants are still in use today.—ed.} I should note that the multiple-unit double auction had perplexed both Plott and Smith for a long time.

While Plott rarely wrote explicit pieces about methodology, his oeuvre is pervaded by important methodological ruminations. In fact, pretty

Plott's fishing trips continue—last summer found him with this beauty of a barramundi that he caught and released on the Bullo River some 400 miles southwest of Darwin, Australia.

much every paper in these volumes contains them—clearly a reflection of the considerable hostility that pioneers such as Plott and Smith encountered. Writing in the mid-'90s, after Plott rightly claimed that experimental economics had become an experimental science, Lola Lopes of the University of Iowa still observed that "[a]lthough every major economic journal now regularly publishes experimental work, the field is still not mainstream and experimental economists have their work cut out to convince theoretical economists about the feasibility and value of subjecting economic ideas to empirical tests." Even now, as Harvard's Alvin Roth put it so memorably, "we've won the battle for the journals, but not yet the battle of departments."

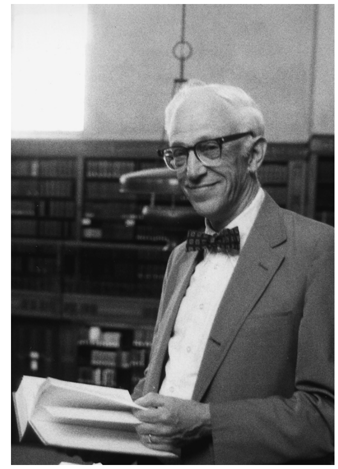
The Economics Prize Committee of the Royal Swedish Academy of Sciences identified Smith's major successes as his contributions to market mechanisms, tests of auction theory, the use of the laboratory as a "wind tunnel," and experimental methodology. Clearly, Plott has contributed his fair share to all of these, and then some. The present volumes are a most impressive testament to his accomplishments. How influential was he? Highly, if the measuring rod is the number of ISI citations, or the number of influential students, or his impact on issues of regulation, deregulation, or antitrust, or the allocation of airport slots, or resources on space stations, etc. As Warsh observed, "Had the Swedes chosen not to combine the honors for experimental and behavioral economics [Kahneman's field] in a single award, presumably Plott would have shared the prize with Smith."

Kahneman is a follower of the heuristics-and-biases school of thought, which, in contrast to earlier schools, has argued that the "apparently universal quirks in human judgment that routinely affect economic behavior" (Warsh) demonstrate that ordinary people, and even experts, are cognitive misers whose reasoning, judgment, and decision-making abilities are an embarrassment to the picture of human beings as rational actors. Indeed, throughout the Nobel documents runs an undercurrent that suggests behavioral and experimental economics have jointly put to rest "homo oeconomicus"—that self-interested and rational beast with which neo-classical economists have been so enamored.

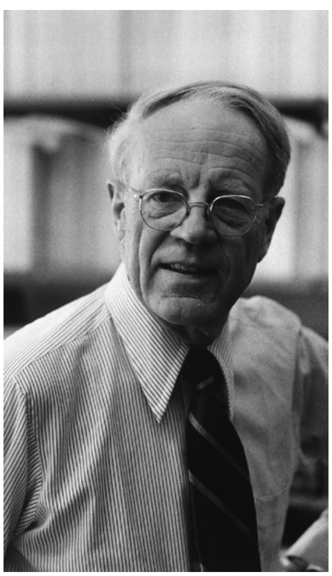
The heuristics-and-biases program has been the dominant paradigm in research on human reasoning, judgment, and decision-making over the past few decades. In light of its rapidly growing acceptance among economists and other scholars, it is therefore interesting to note that it has been under attack for some time by a large number of psychologists. Drawing on notions of bounded rationality, these critics argue that humans have evolved surprisingly effective simple decision rules that in many contexts serve them well, and that this redefines what constitutes rationality by taking into account constraints on resources such as time, knowledge, and cognitive processing ability. I am convinced that future researchers in the philosophy and sociology of science will have a feast in tracing how an entrenched program such as heuristics-and-biases was able to take over another market while it was losing slowly but surely on its own turf. It has been fascinating to watch how economic theorists, often blissfully unaware of the disputed status of the heuristics-and-biases program, have taken the results of its advocates at face value.

It is notoriously difficult to make assessments about the influence of academic researchers, especially if they are pioneers. For that reason, the Royal Swedish Academy of Sciences is an important, if not the most important, current writer of the history of thought. While every reconstruction is to some extent a rationalization that smoothes the course of history to construct a compelling narrative, the selection of what *Business Week* online called "the odd couple" of Kahneman and Smith not only has slighted the pioneering influence and accomplishments of Charles R. Plott, it has brushed away—and therein lies the real danger for all of us—the controversial conceptual and methodological issues that have made, and continue to make, for some of the most promising recent advances in both economics and psychology. □

Plott, however, is philosophical about not having been given a share of that prize. "Of course, I was disappointed. However, the real disappointment was that the institutions that supported the research when no one else would, Caltech being the case in point, did not get the recognition."



Leverett Davis, Jr.
1914–2003



Leverett Davis, Jr. (PhD ’41), professor of theoretical physics, emeritus, died June 15, 2003, after a long struggle with Alzheimer’s disease. He was 89.

A native of Illinois, Davis earned his BS degree at Oregon State College in 1936, before coming to the Institute to pursue graduate work in physics. He joined the Caltech faculty in 1946, after several years on campus as an instructor, and taught for nearly four decades, before retiring in 1981.

At Caltech, his research interests included cosmic rays, solar physics, and the characteristics of interplanetary space. He was involved in planning the magnetometer experiment on the Pioneer spacecraft that passed Jupiter and was coexperimenter for the magnetometers aboard the Mariner spacecraft.

Davis was also a fellow at the Rockefeller Institute for Medical Research in 1940–41 and an NSF Fellow at the Max Planck Institute in Göttingen, Germany, in 1957–58. He was a consultant with Aerojet, the Space Technology Laboratories, and NASA, as well as serving as a member of the 1969 National Academy of Sciences study group on the exploration of the outer planets, and on the 1970 National Science Foundation study group for the exploration of Venus.

In 1970, Davis was presented with NASA’s Exceptional Scientific Achievement Award for his research into interplanetary magnetic fields, and he served as president of the International Astronomical Union from 1967 to 1970. He was a fellow of the American Physical Society, the American Geophysical Union, and the American Astronomical Society.

Davis is survived by his wife, Vicki, and three children. A memorial service has been set for Monday, November 11, at 3:00 p.m. in the main lounge at the Athenaeum. □

Martin Ridge
1923–2003

Martin Ridge, professor of history, emeritus, died September 22, 2003. He was 80.

A native of Chicago, Ridge graduated from Chicago Teachers College with a bachelor of arts degree in 1944, and then earned his master’s degree and doctorate at Northwestern University. After serving on the faculty at Westminster College, San Diego State University, and Indiana University, he joined the Caltech faculty in 1980, where he remained until his retirement in 1995.

Ridge was an authority on American history and the Westward expansion. He was author of several books, including *Ignatius Donnelly: Portrait of a Politician, California Work and Workers* (with Vanza Devereau), *The American Adventure* (with Walker Wyman), *Westward Expansion: A History of the American Frontier* (with Ray Allen Billington), and the first two volumes of *Liberty and Union: A History of the United States* (with Raymond J. Wilson and George Spiero).

He wrote introductions to several books, including the 1985 University of Wisconsin edition of *The Significance of the Frontier in American History*, by Frederick Jackson Turner, as well as to the 1974 edition of Francis Parkman's *The Oregon Trail.* He also edited and revised several works on American history.

In addition to his faculty position at Caltech, Ridge was also a senior research associate at the Huntington Library.

Among his honors were the Ray Allen Billington Prize, the Best Book Award from the Pacific Coast Branch of the American Historical Association, the Best Book Award from Phi Alpha Theta, and the Gilberto Espinosa Prize from the *New Mexico Historical Review*. He was a former president of the Western History Association and the Pacific Coast Branch of the American Historical Association, and former editor of the *Journal of American History.*

He is survived by his wife, Sally Ridge, of San Gabriel; and two sons, Wallace and Drew Ridge. A memorial service will be held on Saturday, November 22, at 2:00 p.m. at the University Club of Pasadena. □

Honors and Awards

Jess Adkins, assistant professor of geochemistry and global environmental science, has been awarded the European Association for Geochemistry's 2003 Houtermans medal, which is given to outstanding young scientists for their contribution to geochemistry.

Barry Barish, Linde Professor of Physics and director of the Laser Interferometer Gravitational-Wave Observatory (LIGO) Laboratory, has been chosen to be the Hiroomi Umezawa Distinguished Visitor at the University of Alberta, where he will present a seminar and a public lecture.

Christopher Brennen, professor of mechanical engineering, has been selected by the Japanese Foundation of Fluids Machinery Research to receive the Fluids Science Research Award. The first non-Japanese recipient of this award, Brennen is being recognized for his work on cavitation and multiphase flows, and he will travel to Japan to receive the award in December.

John Brewer has been named the Eli and Edye Broad Professor of Humanities and Social Sciences. He joined Caltech in 2002 as professor of history and literature, a title he retains.

Emmanuel Candès, associate professor of applied and computational mathematics, and his coauthor, former grad student Franck Guo, have received the 2003 Best Paper Award of the European Association for Signal, Speech and Image Processing (EURASIP). The award—in recognition of "New Multiscale Transforms, Minimum Total Variation Synthesis: Applications to Edge-Preserving Image Reconstruction," published in the November 2002 issue of *Signal Processing*—will be presented at the EUSIPCO-2004 conference in Vienna.

André DeHon, assistant professor of computer science, has been named to the 2003 TR100, a list of 100 top young innovators in technology. Chosen from around the world by *Technology Review*, the nominees "are recognized for their contributions in transforming the nature of technology." DeHon was cited for work toward building practical molecular computers, including figuring out how to arrange nanowires into working circuits, and inventing a reprogrammable architecture based on such circuits.

Kenneth Farley has been named the W. M. Keck Foundation Professor of Geochemistry.

Michael Hoffmann, the Irvine Professor of Environmental Science and the dean of graduate studies, Hui-Ming Hung (PhD '00), and Joon-Wun Kang, a former visiting associate, have been awarded the Water Environment Federation's (WEF's) Jack Edward McKee Medal. The medal, named for the past WEF president and Caltech professor (1949–1980), was given for their article, "The Sonolytic Destruction of Methyl tert-Butyl Ether Present in Contaminated Groundwater," published in the December 2002 issue of *Water Environment Research*.

Andrew Ingersoll has been named the Earle C. Anthony Professor of Planetary Science.

Jerrold Marsden has been named the Carl F Braun Professor of Engineering and Control and Dynamical Systems.

David Politzer, professor of theoretical physics, is corecipient of the European Physical Society's 2003 High Energy and Particle Physics Prize, which he shares with David Gross of UC Santa Barbara and Frank Wilczek of MIT. The trio "are best known for their work on QCD—the theory of the strong force. In particular they showed that the force between two particles in certain types of gauge theories is strong when they are far apart and weak when they are close together." (For more on this subject, see page 25 of this issue.)

Demetri Psaltis, Myers Professor of Electrical Engineering, and colleagues Karsten Buse and Christophe Moser (PhD '01) have received the

Best Application Award at the Ninth International Conference on Photorefractive Effects, Materials, and Devices. The award, presented annually for novel and significant advances in photorefractive systems, recognizes the trio's work on holographic filters.

Axel Scherer, Neches Professor of Electrical Engineering, Applied Physics, and Physics, has been selected to receive a Senior U.S. Scientist Award from the Alexander von Humboldt Foundation.

Peter Schröder, professor of computer science and applied and computational mathematics, has been named this year's winner of the Computer Graphics Achievement Award by the Association for Computing Machinery and the Special Interest Group on Graphics and Interactive Technology (ACM SIGGRAPH) for his contributions to multiresolution modeling and digital geometry processing of curved surfaces.

Brian Stoltz, assistant professor of chemistry, is a recipient of the 2003 Amgen CR&D Young Investigator's Award, which "has been created to recognize the scientific contribution and commitment to academic excellence of rising young investigators" in the field of chemistry.

Ahmed Zewail, Nobel Laureate in chemistry, Linus Pauling Professor of Chemical Physics and professor of physics, has been named a member of the Royal Swedish Academy of Sciences. The Royal Academy awards the Nobel Prize in physics, chemistry, and economics. Besides noting his illustrious research career, the academy cited his active contribution to "promoting research and education in the Third World." □

Carver Mead Wins National Medal of Technology

Carver Mead (BS '56, MS '57, PhD '60), the Moore Professor of Engineering and Applied Science, Emeritus, has been named by President George W. Bush as a recipient of the National Medal of Technology. The medals will be awarded at a White House ceremony on November 6.

Mead is known for many contributions in microelectronics and information technology. His major innovations include pioneering work on the very large-scale integration (VLSI) design for complex circuitry at the microscopic level; and an amplifying device known as the high electron mobility transistor (HEMT), which is used in microwave communications and is also an integral component of the Internet. He has also been a pioneer in computer animation, microchip design, neuromorphic electronic systems, and other computer interfaces.

His laboratory led an effort to create silicon models of specific areas of the nervous system, and showed that the elementary operations of the nervous system could be emulated by analog circuits. The devices included a cochlear chip, which is modeled after human hearing, as well as devices modeled after vision and learning.

Mead holds more than 50 U.S. patents, and has written more than 100 scientific publications.

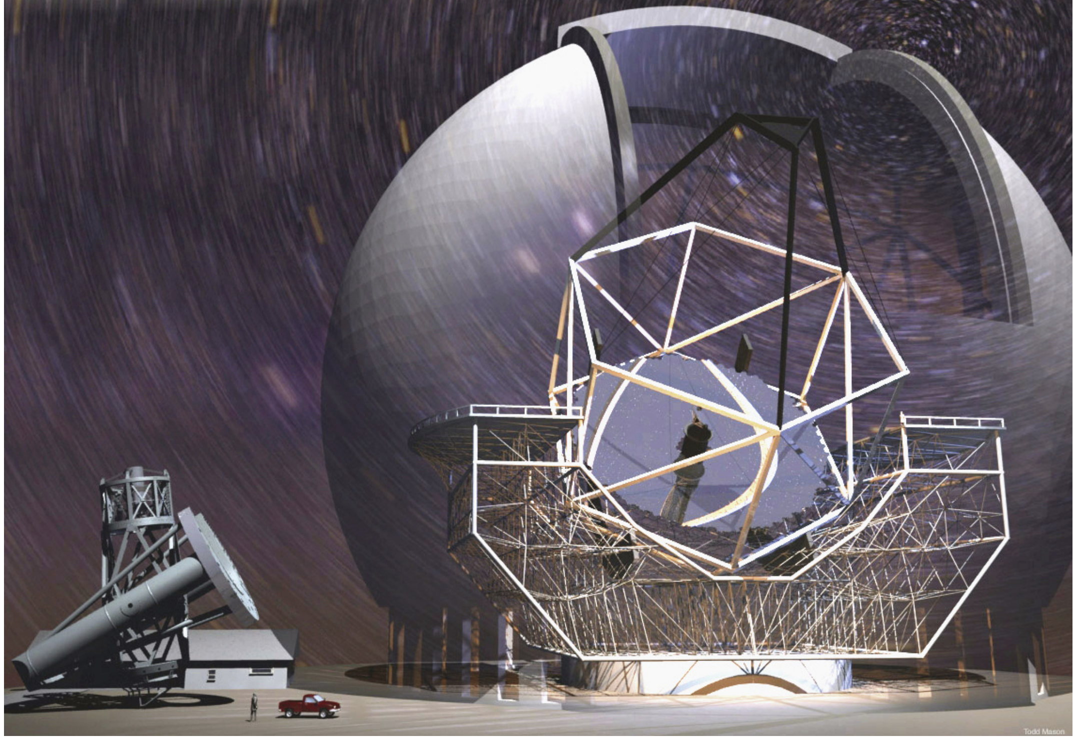
The National Medal of Technology recognizes people and organizations that "embody the spirit of American innovation and have advanced the nation's global competitiveness. Their groundbreaking contributions commercialize technologies, create jobs, improve productivity and stimulate the nation's growth and development."

The award was established by Congress in 1980, and complements the older National Medal of Science. The National Medal of Technology is administered by the Department of Commerce. To date, there have been 146 recipients of the honor, 12 medals having gone to Caltech faculty, alumni, and trustees.

And on October 12, Mead received the 2003 Founders Award from the National Academy of Engineering "for visionary contributions in the field of microelectronics, including VLSI technology and computational neural systems." □

Mead working on a silicon retina design in 1987.

Thirty–Meter Telescope Design Funded



The proposed Thirty-Meter-Telescope will dwarf the 200-inch Hale Telescope (left) on Palomar Mountain, which was the largest successfully operating optical telescope in the world from 1949 to 1993. (Todd Mason, Mason Produc-

The California Institute of Technology has a distinguished history of launching and operating some of the best observatories in the world. For example, the 200-inch Hale Telescope on Palomar Mountain was both a bold undertaking in 1949 and the era's greatest achievement in telescope design. Another significant advancement came in 1993 with the first light captured by the 10-meter segmented-mirror Keck I Telescope atop Mauna Kea, followed by the completion of its twin, Keck II, in 1996. Built by Caltech and the University of California, these twin telescopes stand as the current state of the art in optical and infrared instrumentation.

Now, the dream of a 30-meter optical telescope has moved one step closer to reality, thanks to a $17.5 million grant from the Gordon and Betty Moore Foundation awarded as part of the foundation's 10-year commitment to the Institute. The grant will fund the design development phase of the Thirty-Meter Telescope (TMT) project, allowing the Caltech and its partner, the University of California, to proceed with formulating detailed construction plans for the proposed instrument.

"This project takes Caltech's success in ground-based astronomy to the next level of ambition," said Richard Ellis, director of optical observatories at Caltech. "The TMT will also build logically on the successful demonstration of the segmented primary mirrors of the Keck telescopes, a major innovation at the time but now recognized as the only route to making a primary mirror of this size."

"The key new capabilities promised by the Thirty-Meter Telescope will include unprecedented angular resolution—necessary to resolve detail in early galaxies and newly forming planetary systems—and, of course, the huge collecting area for studying the faintest sources, which are often the most important to understand, but are beyond the reach of current facilities," adds Chuck Steidel, professor of astronomy, who chaired a science committee charged with making the case for the proposed facility. The TMT, complete with adaptive optics, will provide images more than 12 times sharper than those of the Hubble Space Telescope and will have nine times the light-gathering ability of one of the 10-meter Keck telescopes. The telescope also will, for the first time, permit a physical understanding of how normal galaxies grow in the underlying fabric of dark matter, which governs cosmological evolution.

The birth of the TMT—formerly known as the California Extremely Large Telescope—began in 1999 with the idea of a 30-meter optical and infrared instrument. To further the project, Caltech faculty approached colleagues at the University of California to combine scientific and technical expertise to develop a conceptual design, which was completed in 2002.

According to Ellis, the major goals of the design development phase will include an extensive review and optimization of the telescope design, addressing areas of risk, for example by early testing of key components, and staffing a project office in the newly acquired St. Luke's facility. Following the design study, the final phase of the project, not yet funded, will be construction of the observatory at a yet undetermined site in Hawaii, Chile, or Mexico. Regular astronomical observations could perhaps begin by 2012.
☐ —*Vannessa Dodson*

For more information on Caltech's strategic priorities and the campaign to support them, visit the web site at http://www.one.caltech.edu.

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