Although blustery winds added some excitement—the chief flyer, kite-surfing instructor Eric May (middle of picture, dark shorts), got lifted off the ground on the first attempt—the obelisk went upright in just 25 seconds on the second try. Graff (plaid shirt) handles a control line. The obelisk was provided by Daniel Correa (center, foreground) of Incablock, which makes concrete blocks.

California: Wine, Movies, Avocados, and Nobel Laureates

Not only does the State of California have the fifth largest economy in the world (having recently passed up France), it also has the largest concentration of Nobel laureates. And, because the year 2001 marks the 100th anniversary of the Nobel Prize, California will be celebrating and paying tribute to its laureates and to the significance of science and technology in the state. Which no doubt has something to do with its economy.

Of California's 94 Nobelists, Caltech counts 27 among its faculty and alumni (that's actually 28 prizes, since Linus Pauling won two). Three of the four faculty members still active on campus will be taking part in the Nobel Centennial Symposium in Beckman Auditorium on the afternoon of October 24. President David Baltimore (physiology/medicine '75), Rudy Marcus, the Noyes Professor of Chemistry (chemistry '92), and Ed Lewis, the Morgan Professor of Biology, Emeritus (physiology/medicine '95) will introduce speakers at the symposium. (Ahmed Zewail, the Pauling Professor of Chemical Physics and professor of physics, who won the chemistry Nobel in 1999, will unfortunately be out of town.) Other Caltech speakers at the event include Richard Andersen, the Boswell Professor of Neuroscience, and Professor of Physics Andrew Lange. A reception at the Athenaeum will follow.

Caltech's symposium is only a portion of the California Nobel Prize Centennial 2001, which will be attended by members of the Swedish royal family and the Swedish ambassador. It's preceded by a morning symposium at UCLA, which has a few Nobel laureates of its own. On October 25 a Centennial Celebration luncheon will be held at the California Science Center in downtown Los Angeles, chaired by Gayle Wilson, the state's former first lady and a member of Caltech's board of trustees. On October 26, the celebration moves northward to San Francisco, where there will be a symposium at the Exploratorium. A banquet at City Hall follows on the 27th.

The Nobel Centennial is also sponsoring an essay contest for junior- and senior-high-school students and establishing Centennial Scholarships. □

Fly Like an Egyptian

When you think about building the Egyptian pyramids, you probably have a mental image of thousands of slaves laboriously rolling massive stone blocks with logs and levers. But as one Caltech professor is demonstrating, the task may have been accomplished by just four or five guys who flew the stones into place with a kite.

On June 23, Professor of Aeronautics Morteza (Mory) Gharib (PhD '83) and his team raised a 6,900-pound, 15-foot reinforced-concrete obelisk into a vertical position in the desert near Palmdale, using nothing more than a kite, a pulley system, and a support frame. The team eventually hopes to show that even 300-ton monuments—not to mention the far-less-massive building blocks of Egypt's 90-odd pyramids—could have been raised with a fraction of the effort that modern researchers have assumed.

Gharib, whose primary research interest is the nature of fluid flow, has been working on the project since local business consultant Maureen Clemmons contacted Caltech two years ago. Clemmons had seen a picture in *Smithsonian* magazine in 1997 of an obelisk being raised, and thought that the Egyptians could have used kites to accomplish the task more easily. All she needed was an aeronautics expert with the proper credentials to field-test her theory. It is a credit to her determination that the tests are occurring—with no scientific or archaeological training, she has managed to marshal the efforts of family, friends, and fellow enthusiasts.

Even today, moving heavy stones without power equipment is quite labor-intensive. In 1586, the Vatican moved a 330-ton Egyptian obelisk to St. Peter's Square. Lifting the stone upright took 74 horses and 900 men. For Gharib, the idea of accomplishing heavy tasks with limited manpower is appealing from an engineer's standpoint because it makes more logistical sense. "It's one thing to send thousands of soldiers to attack another army on a battlefield," he says. "But an engineering project requires everything to be put precisely into place. I prefer to think there were relatively few people involved."

The concept Gharib developed with SURF (Summer Undergraduate Research Fellowship) student Emilio Graff, a senior in aeronautics, is to build a simple tower around the obelisk, with a pulley system mounted somewhat forward of the stone's tip. That way, the base of the obelisk will drag the ground for a few feet as the kite lifts the stone, and it will be quite stable once it reaches the vertical. If the obelisk were raised with the base as a pivot, the stone would tend to swing past vertical and fall the other way. The kite rope is threaded through the pulleys and attached to the obelisk's tip. A couple of fliers steer the kite with guide ropes, moving it in figure-eights for maximum sustained lift.

Of course, no one has any idea if the ancient Egyptians actually moved stones or anything else with kites and pulleys, but Clemmons has found some tantalizing hints that the project is on the right track. On a building frieze now displayed in a Cairo museum, there is a wing pattern in bas-relief that does not resemble any living bird. Directly below are several men standing near vertical objects that could be ropes. And she has discovered that a brass ankh—long assumed to be merely a religious symbol—makes a very good carabiner for controlling a kite line.

Gharib next plans to raise a 10-ton stone, then perhaps a 20-ton one. Eventually, they hope to receive permission to raise one of the obelisks still lying in an Egyptian quarry. "The whole approach has been to downgrade the technology," Gharib says. "We first wanted to show that a kite could raise a huge weight at all. Now that we're raising larger and larger stones, we're also preparing to replace the steel scaffolding with telephone poles and the steel pulleys with windlasses like the ones that may have been used on Egyptian ships. In fact, we may not even need a kite. It could be we can get along with just a drag chute." Steady winds of up to 30 miles per hour are not unusual in the areas where the pyramids and obelisks are found. The wind in Palmdale gusted to over 20 m.p.h., although a 12-m.p.h. breeze would have sufficed. □—*RT*

Put Some Cesium in Your Tank

Gasoline averaging $3 per gallon? Oil drilling in an Alaskan wildlife reserve? A need to relax air quality standards? It seems the long-term future of fossil fuels is bleak. One promising solution scientists have been studying is fuel cells, which have their limitations too. But in the April 19 issue of *Nature*, Caltech Assistant Professor of Materials Science Sossina Haile reports on a new type of fuel cell that may resolve these problems.

Unlike an automobile engine, where a fuel is burned and expanding gases do the work, a fuel cell converts chemical energy directly into electrical energy. Fuel cells are pollution-free, and silent. The fuel cells in today's prototype cars are usually based on polymer electrolytes. (An electrolyte is a nonmetallic substance that conducts electricity.) Polymer electrolytes must be humidified in order for the fuel cell to function, and can only operate over a limited temperature range. Thus these fuel cell systems require many auxiliary components and are less efficient than other types of fuel cells.

Haile's laboratory has developed an alternative type of fuel cell based on a so-called "solid acid." Solid acids are chemical compounds, such as $KHSO_4$ (potassium hydrogen sulfate), whose properties are intermediate between those of a normal acid, such as H_2SO_4 (sulfuric acid), and a normal salt, such as K_2SO_4 (potassium sulfate). Solid acids can conduct electricity at rates similar to polymers, they don't need to be hydrated, and they can function at temperatures up to 250 °C. They are also typically inexpensive and easy to manufacture. But until now solid acids had not been examined as fuel-cell electrolytes because they dissolve in water; worse, they can lose their shape at even slightly elevated temperatures. To solve these problems, Haile and her colleagues operated the fuel cell at a temperature above the boiling point of water, and used a solid acid, $CsHSO_4$ (cesium hydrogen sulfate), that is not very prone to shape changes.

The next challenges, says Haile, are to reduce the electrolyte's thickness, improve the catalyst's performance, and, most importantly, prevent the reactions that can occur upon prolonged exposure to hydrogen. Still, she says, solid-acid fuel cells are a promising development. "The system simplifications that come about [in comparison to polymer electrolyte fuel cells] by operating under essentially dry and mildly heated conditions are tremendous. While there is a great deal of development work that needs to be done before solid-acid-based fuel cells can be commercially viable, the potential payoff is enormous." □—*MW*

In mid-May, the Division of Geological and Planetary Sciences commemorated the 75th anniversary of its founding (as the department of geology and paleontology under John Buwalda) with a reunion. About 100 alumni came for two days of talks by division faculty on their current research, as well as other sorts of celebrating, including this spectacular cake with a very literal "ring of fire." The following month, on June 24, Bob Sharp (BS '34, MS '35), the Sharp Professor of Geology, Emeritus, celebrated his 90th birthday. Sharp has been a member of the faculty since 1947 and was chair of the division from 1952 to 1968.

2001—A Mars Odyssey

As the Red Planet looms large in the midnight sky this summer, another JPL spacecraft has set out to meet it. The 2001 Mars Odyssey lifted off from Cape Canaveral on April 7, and is slated to arrive on October 24. Its primary mission, to run from January, 2002 through July, 2004, is to map the composition of the planet's surface, to detect water and shallow subsurface ice, and to study the radiation environment. The spacecraft carries three primary instruments.

THEMIS (Thermal Emission Imaging System) is a visible/infrared camera provided by Arizona State University that by day will map the distribution of minerals, particularly those that can form only in the presence of water. At night, it will look for active thermal regions that are warmer than their surroundings—potential "hot springs," at least by Martian standards.

The GRS (Gamma Ray Spectrometer), provided by the University of Arizona, will scout out 20 chemical elements, including silicon, oxygen, iron, magnesium, potassium, aluminum, calcium, sulfur, and carbon, on the Martian surface. A pair of neutron detectors in the GRS package (built by the Los Alamos National Laboratory and Russia's Space Research Institute) will allow the amount of hydrogen present in the top meter of soil to be calculated, which in turn acts as a proxy for determining the potential amount and distribution of Mars' water ice.

And MARIE (Mars Radiation Environment Experiment), led by NASA's John-

Not featured at the GPS reunion was the fine vintage at right, bottled for the neighboring Division of Physics, Mathematics and Astronomy in honor of SIRTF (the Space InfraRed Telescope Facility; see page 26). Infra Red wine comes in three "wavelengths"—3.6 microns, 30 microns, and 160 microns—indicating a range from light bodied to full bodied. It's reportedly "pretty good." Professor of Physics Tom Soifer (BS '68), director of the SIRTF Science Center, has enough Infra Red in his wine cellar to last until the satellite's launch in 2002.

son Space Center, will assess the radiation hazards to future human explorers. Cosmic rays emitted by the sun and other stars can trigger cancer or damage the central nervous system; similar radia-tion monitors have been flown on the Space Shuttles and on the International Space Station, but none has ever ventured beyond Earth's protective magnetosphere, which shields us from much of this radiation.

The orbiter is also designed to act as a communications relay for future Mars landers, including JPL's pair of Mars Exploration Rovers, to be launched in 2003. □

A Really NEAT Discovery

JPL's NEAT (Near-Earth Asteroid Tracking) program's newest telescope, the just-refurbished 1.2-meter-diameter (48-inch) Oschin telescope at Caltech's Palomar Observatory, officially bagged its first asteroid on May 16. Better yet, the catch was a Potentially Hazardous Asteroid—one of about 300 now known whose orbit crosses Earth's. Provisionally named 2001JV1, it is about 0.7 kilometers (0.4 miles) in diameter, so it could leave a nasty welt. But don't get out the tinfoil hats or the beach umbrellas just yet—"potentially hazardous" means it would have to be significantly deflected from its current orbit to do us any harm.

Since its inception in December, 1995, NEAT has found roughly 100,000 asteroids, including about 100 near-Earth asteroids; NASA's goal is to find all of the estimated 700 to 1,500 asteroids larger than 1 kilometer (0.6 mile) that approach within 48 million kilometers (30 million miles) of Earth, and to do so by 2008. About 500 have been detected so far. The vast majority of these are harmless, but a tiny percentage have orbits that could eventually put them on a collision course with Earth.

The Oschin telescope, built in 1947, has been used for two landmark sky surveys, the second of which was completed in 2000. Its half-million-dollar upgrade, sponsored by NASA/JPL, has turned it into a fully automated facility with a computerized pointing system and a state-of-the-art CCD camera. □

Binocular Vision: "First Fringe" at the Kecks

Astronomers' vision got a whole lot sharper on March 12, when at 10:40 p.m. Hawaiian Standard Time the W. M. Keck Observatory became an interferometer. The two 10-meter Keck telescopes atop the summit of Mauna Kea successfully pooled the light received from a star in the constellation Lynx known as HD 61294, attaining what astronomers refer to as "fringes." Interferometry, which has long been a staple of radio astronomy, means that the signals from two or more telescopes are combined to create a virtual telescope whose dish—or in this case mirror—is the size of the separation between the instruments, enabling you to discriminate between objects that are exceedingly close together. In this case, the telescopes are 85 meters (93 yards) apart, and the goal is to see warm, Jupiter-sized planets orbiting around nearby stars directly, rather than inferring their existence from the wobbles their gravitational tugs induce on their parent stars. This doesn't mean we'll be able to take the planet's picture, but with luck, the distinction between the star and the planet will be clean enough that the planet can be studied spectroscopically, giving information on its temperature, pressure, and atmospheric composition.

An interferometer has to align the incoming signals so that their peaks and troughs match up to within a very small fraction of a wavelength. This is easy enough with radio waves, which are a centimeter or more in length, but a very tough challenge with light, where the waves are measured in millionths of a meter. And it's further complicated by atmospheric turbulence, which causes the star (and its thousandfold dimmer companion) to shimmy disconcertingly. Each image wanders around on its detector independently from its twin at the other telescope, continuously altering the baseline separation.

The Keck Interferometer sends an image of the target star (or a bright, nearby guide star) from each telescope to a fast-readout infrared camera called the Keck Angle Tracker that sends commands back to adaptive-optics systems to compensate. The two star images are thus kept centered on a fiber-optic line that feeds another fast readout IR camera called the fringe tracker. The fringe tracker adjusts the "fast delay lines" that bounce the light through a system of adjustable prisms and mirrors to align the waves, while simultaneously compensating for the earth's rotation. A peak occurs in the fringe tracker when the paths are identically matched, and a minimum occurs when the paths are different by one-half the wavelength of the light. When the peak-to-minimum ratio exceeds a certain threshold value, fringes have been seen.

HD 61294 was the first of about 20 stars that were locked on to during the engineering run, which consisted of the first halves of the nights of March 12 to 14. The fringes would last for up to 10 seconds at a time, and for about 10 percent of the total duration that each star was tracked, which varied from 10 to 30 minutes. Now the challenge is to fine-tune the system to lock onto the fringes for long enough to make useful measurements, a teething period that is expected to take the rest of this year. Limited science operations, including looking at these planets and the dust rings from which planets condense, may begin early next year.

The Keck Interferometer is funded by NASA's Origins program, and is a collaboration between Caltech, the University of California, and JPL/NASA. ☐—*DS*

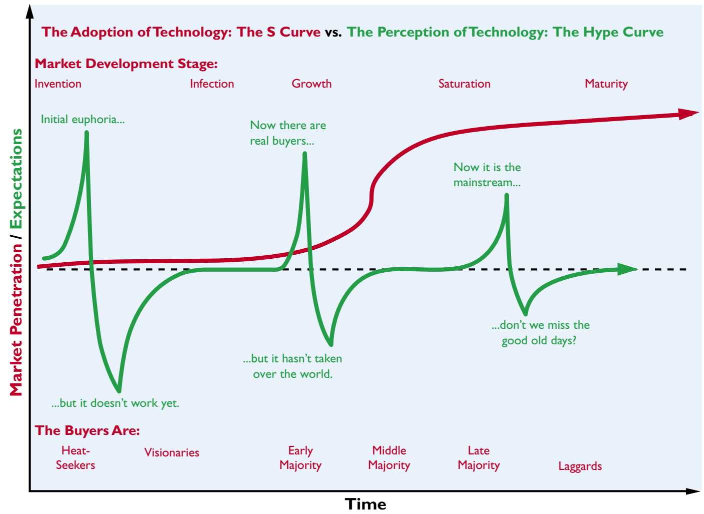
As new graduates sweltered under a broiling sun and parents and other wellwishers huddled under a sea of parasols, speaker Gordon Moore, PhD '54, former chair of Caltech's board of trustees and Intel Corporation, provided some advice from snowboarding: "Stay low and be confident as you move forward." At Caltech's 107th commencement on June 15, 204 new owners of BS degrees, 120 MS degrees, one Engineer, and 159 PhDs were ushered out into the real world.

From Punch Cards to Palm Pilots

Caltech's computer-science option turned 25 this year. At Caltech, a birthday party means a symposium, so there were two days' worth of speakers on fields where Caltech has left its mark: chip design, parallel supercomputers, networking, and computer graphics, as well as a peek at what may lie beyond silicon. Here are some highlights.

Option cofounder Ivan Sutherland (MS '60), then Jones Professor of Computer Science, now vice president of Sun Microsystems, talked about the early days. In the Caltech tradition, the fledgling program had to "pick one thing and do it well." They opted for VLSI, or Very Large Scale Integration, because cofounder Carver Mead (BS '56, MS '57, PhD '60), Moore Professor of Engineering and Applied Science, Emeritus, was one of its fathers and would shortly write The Book on the subject. VLSI, which allows you to put an entire circuit—or, these days, millions of transistors—on a silicon chip, is now such a basic part of life that it doesn't merit a second thought. But back then, it was revolutionary, and the notion that grad students could actually design, build, and test several generations

One of the symposium's sessions was a panel discussion on "Entrepreneurship and Computer Science," at which Phil Neches (BS '73, MS '77, PhD '83), founder of Teradata Corporation, compared the standard business model's S-shaped curve of market penetration to the EKG-like "hype curve" of expectations typically found in the technology sector.

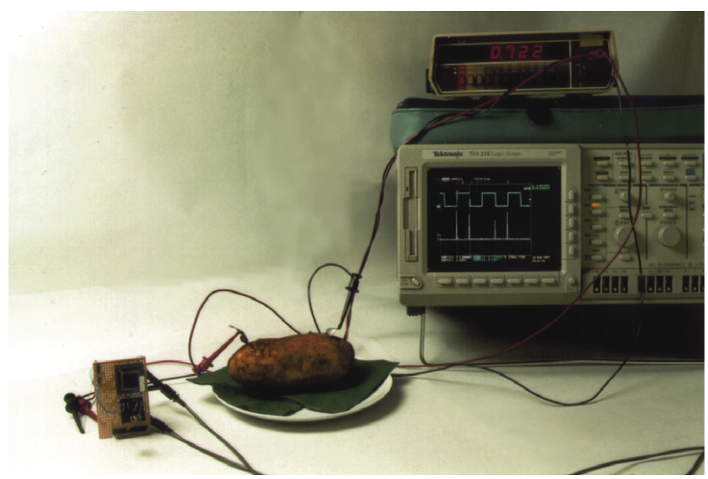


of chips in time to write a thesis was even more so.

At the dawn of the computer age, said Sutherland, logic elements (in the form of vacuum tubes) were expensive and unreliable. Wires, on the other hand, were cheap and reliable. Today, logic (transistors) is cheap and very reliable, but wires are expensive and very, very bulky. But "we're still tied to the mindset of 1950s programming, using detailed instruction sets. Instead, we need to put the programmer in charge of moving the data around. Addition is simple. Getting the operands to the adder is the hard part." He drew an analogy to another technological transition: "What we're doing now is copying the Roman stonemason's arched bridges in wrought iron. We need to begin building suspension bridges."

Most of the rest of the speakers talked about these suspension bridges. Stanford's William Dally (PhD '86) discussed designing chips based on a "parallel stream architecture." Such chips are broken up into many self-contained regions, each with its own memory and processor units. The idea is to handle as much of the computation as possible as locally as possible, by breaking the data up into streams and assigning each stream to its own region or regions; all the regions can then chew on pieces of the problem simultaneously without having to talk to each other very much. This reduces the torrent of data through the wires (both within and between chips) to a manageable flow, alleviating the traffic jams that would otherwise occur as more and more components are packed on a chip. Dally is building a one-teraflops (trillions of floating-point mathematical operations per second) machine that fits on a single shelf and draws less than a kilowatt of power. In contrast, the teraflops supercomputers up at Lawrence Livermore National Laboratory are the size of Beckman Institute Auditorium and use many megawatts of electricity. "These days, most of the power consumption isn't in the processing, it's in data movement." By 2011, he predicted, using such parallel stream architectures, we could have five teraflops on a chip and "a machine that won't require its own [power] substation." A handful of those chips could get you 100 teraflops, easy—a staggering amount of computing power. (When asked what home or business applications he anticipated for such a monster, he replied, "*Really* cool video games.")

Asynchronous chips, in which each circuit operates at its own pace rather than to the tick of a master clock, offer another way around the wiring bottleneck by leveling out the communications traffic, said Professor of Computer Science Alain Martin. Each asynchronous processor forwards its results the moment it finishes, rather than flooding the network when the clock says "SEND." Such chips also draw less power—as much as a quarter of the power consumed goes to running the clocks. Asynchronous chips are inherently faster, because the chip's speed is the average of all the processors' speeds instead of the speed of the slowest one. The downside is that since each processor is primed to accept a message all the time, any "glitch," or spurious signal, will be interpreted as data. (Synchronous systems are immune to this, as only a glitch at the exact moment that data is due would be taken seriously.) Clever communications protocols are needed to keep the data real and to manage the data flow in general. In fact, Martin titled his talk "Delays Have Dangerous Ends"—a quote from *Henry VI*—and was going to subtitle it, "A Shakespearean Approach to VLSI Design," but "decided it would not be appropriate for a Frenchman to do so."



In the lower left corner of the picture above is a silicon potato chip. It's also the world's first asynchronous microprocessor—a 16-bit chip with roughly 23,000 transistors, designed in Martin's lab in 1989. It ran at a then-respectable 17.5 MHz with a 5-volt power supply, drawing 230 milliwatts of power. But it will also run happily, albeit some 500 times more slowly, on the 0.9 volts and 40 microwatts obtainable from a nice, fresh, juicy potato, as Mika Nyström (MS '97, PhD '01) demonstrated.

To which an audience member replied, "So is it a tragedy or a comedy?"

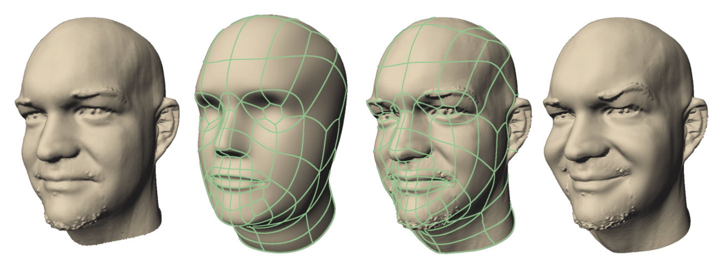
It was actually a history, beginning with the 1979 Caltech Conference on VLSI, where concurrent processing emerged as a discussion topic; Martin's lab built the world's first asynchronous microprocessor a decade later. A demonstration chip built in 1998 ran four times faster than the commercial two-million-transistor chip it was mimicking, and his lab still holds the record for the fastest working asynchronous circuits. (He quoted Carver Mead: "There is nothing more useless than a fast circuit that doesn't work.") He's trying to make them even more efficient. "If you track how the variables move—the atomic structure of the program, if you will—and then do a spectral analysis to see which operations 'cluster,' according to some measure, you can optimize your design based on the clustering." Martin, Dally, and a host of others are creating programming and chip-design tools that automatically deal with the complex details, leaving the humans free to draw the big pictures.

Another session covered how you link devices, asynchronous or otherwise, together. Caltech has been a pioneer in distributed computing since the early '80s, when Charles Seitz (a CS faculty member until 1994, when he left to found Myricom, a high-speed networking company) wired together a boatload of off-the-shelf PC processor boards to attain supercomputer performances at Radio Shack prices, and Geoffrey Fox (then professor of theoretical physics and dean of educational computing, now at Florida State) used it to tackle a gnarly quantum-field problem whose immensity had previously deterred all comers. Called the Cosmic Cube because its processors were connected like the vertices of an *n*-dimensional cube, it spawned an industry.

In the early '90s, JPL Senior Scientist and Caltech Faculty Associate (at CACR, Caltech's Center for Advanced Computing Research) Thomas Sterling, then at NASA Goddard, and his colleagues went one better by using commercial network technology and operating systems as well to create Beowulf—the model for today's teraflops computers. Sterling foresees a petaflops (quadrillion flops) machine by 2010. He proposes using Beowulfs—on a slightly smaller scale—in spacecraft. "NEAR [the Near-Earth Asteroid Rendezvous mission] sent back some 160,000 pictures. But the data product the scientists really wanted was a 3-D map of the asteroid. What if the spacecraft could do the advanced processing and you could just download the map? That would be equivalent to a 10^6 data compression."

The new frontier lies in linking computers that need to share some data, but don't want to get too intimate, in networks that evolve as the task dictates. Mani Chandy, Ramo Professor and professor of computer science, has come up with one such system, called Infospheres, which he plans to donate to humanitarian agencies doing disaster relief. Red Cross field workers could use their palmtop computers to coordinate food and clothing shipments, for instance, by tapping into various donors' inventory systems, railroad and airline schedules, and the truckers' dispatch centers. "Even poorer countries like India are heavily wireless," says Chandy. "Technology leapfrogs, so they've skipped right past telephone lines." The system employs what Chandy calls "screen scraping"—reading data from someone else's Web display that isn't formatted the way your computer likes it, but interpreting it anyhow and replying appropriately. Warming to that theme, Hewlett-Packard's Rajiv Gupta (MS '87, PhD '91), a protégé of Chandy's and Mead's, talked about having a chip in your car determine that your transmission is about to blow and automatically using your cell phone to make an emergency appointment at the closest dealership, displaying directions to it on your in-dash GPS unit, and booking a taxi to be there when you arrive so that you still get to your Very Important Meeting on time. "You don't know or care how the other components work, or even whose they are. You just need their output. The industrial revolution removed people as the bottleneck in the production of goods; this removes people as the bottleneck in the production of services."

Yaser Abu-Mustafa (PhD '83), professor of electrical engineering and computer science, designs systems called neural networks that

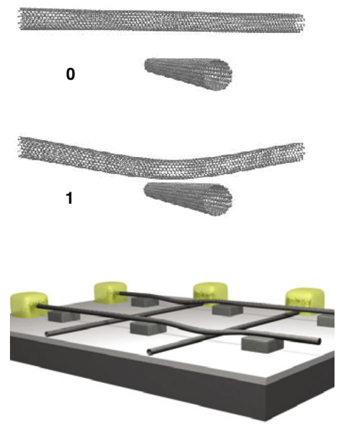


Schröder's lab develops methods for compressing and manipulating 3-D geometric information. Once properly encoded, you can treat the data like any other kind of signal, filtering out noise or changing some aspect of the object. Here, pushing up two critical grid points at the corners of the mouth puts a smile on someone's face. Schröder sees geometry as the fourth wave of multimedia, following on sound, still photos, and video, all of which are now routinely transmitted over the 'net. Fields as diverse as archaeology and biomedicine will benefit, and let's not forget the ubiquitous e-catalogs.

learn from hint and example rather than having to be programmed. For years, Abu-Mustafa has been training them to predict trends in the foreign-exchange market—a task chosen because "it is rich in data, is very noisy, and for which there is no mathematical model," thereby inadvertently launching the discipline of computational finance. "If I get a good system, you'll hear about it. If I get a *very* good system, you won't hear about it," he joked, going on to note that the results have, in fact, been published.

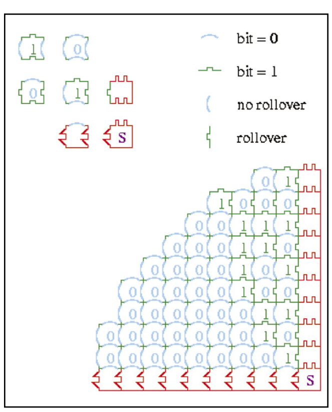
Jim Kajiya, a CS professor from 1978 to '94 and now assistant director of research at Microsoft, spoke of the emergence of computer graphics as a medium in its own right. "Applied computer sciences extend human capabilities: robotics, our muscles; memory and computation, our brains; and graphics, our imagination. So are graphics just for games for 14-year-old boys?" No. The confluence of computer vision and computer graphics becomes computer video—malleable, editable objects you can manipulate on your screen. Peter Schröder, professor of computer science and applied and computational mathematics, picked up the theme in describing his 3-D modeling research. How do you store and transmit geometric information so that a coarse but usable rendition of the object shows up almost immediately, with progressively finer detail filling in afterwards? How do you search a collection of shapes for common themes—to find all the animals, perhaps, or to recognize a face? And can you put digital objects that were scanned as separate entities together, reassembling a vase from its shards?

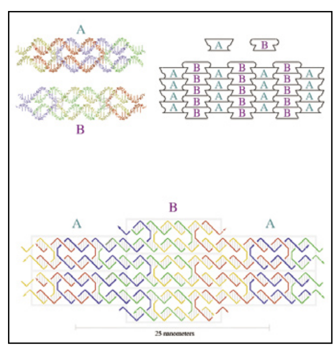
The final session looked at means of computing beyond silicon. According to Assistant Professor of Computer Science Andre DeHon, a silicon wire slated for production around 2005 is about 100 nanometers, or 200 silicon atoms, wide; about 44,000 square nanometers will be needed to encode one bit of information. But a variety of other technologies offer the possibility of building molecular wires and switches one nanometer wide; a bit might occupy 400 square nanometers. DeHon's own work centers on carbon nanotubes, which with the right electrostatic charge will flex to form binary (on/off) logic elements. "This will require a paradigm shift from the top-down methods of bulk carving and etching to bottom-up strategies for self-assembly, taking into account the specific characteristics of individual atoms." Even more exotically, quantum computing will attempt to exploit the bizarre properties of quantum-mechanical systems to solve problems that ordinary computers can't crack, said Associate Professor of Computer Science Leonard Schulman. The NSF recently established an Institute for Quantum Information at Caltech, to which Schulman and several colleagues, including one of Caltech's two most recent MacArthur "genius" Fellows, Assistant Professor of Physics Hideo Mabuchi (PhD '98), belong. And finally, Caltech's other MacArthur Fellow, Assistant Professor of Computer Science and Computation and Neural Systems Erik Winfree (PhD '98), described the first steps toward computing using DNA molecules whose structures encode a "program," and whose self-assembly into an array reads out the "answer." Look for more on Mabuchi and Winfree in a future issue. ☐ —*DS*

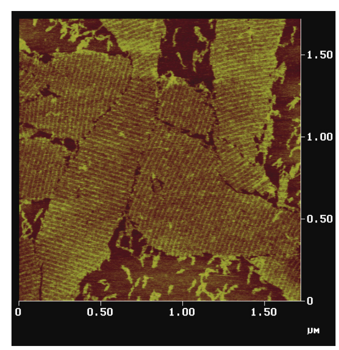


After Lieber, et al, *Science*, volume 289, page 95, July 7, 2000.

Single-walled carbon nanotubes are essentially soda straws whose walls are one carbon atom thick. Two perpendicular tubes, suspended two billionths of a meter apart, can flex under the influence of static cling to encode zeroes and ones (top). Chips built from arrays of such junctions (bottom) would be more compact than silicon ones. Computer architect DeHon is collaborating with Harvard chemist Charles Lieber to try to build practical circuits this way.







Left: A DNA computer would use "tiles" that interlock like puzzle pieces. In this example, the computer counts upward from 1 (in binary numbers) as the tiles fall into place, beginning from the one labeled "S" in the bottom right corner. Above, left: The first step is to create a lexicon of rigid, two-dimensional tiles that act as logic elements by binding to one another only in specific configurations. Here, four bits of single-stranded DNA self-assemble into double-crossover units that can take either of two forms, "A" or "B." A and B, in turn, fit together only one way to form a repeating pattern. Above, right: An atomic-force microscope scan of the actual A-B crystal. The B tiles stick up higher, giving it a corduroy look.