California Institute
of Technology

Engineering & Science

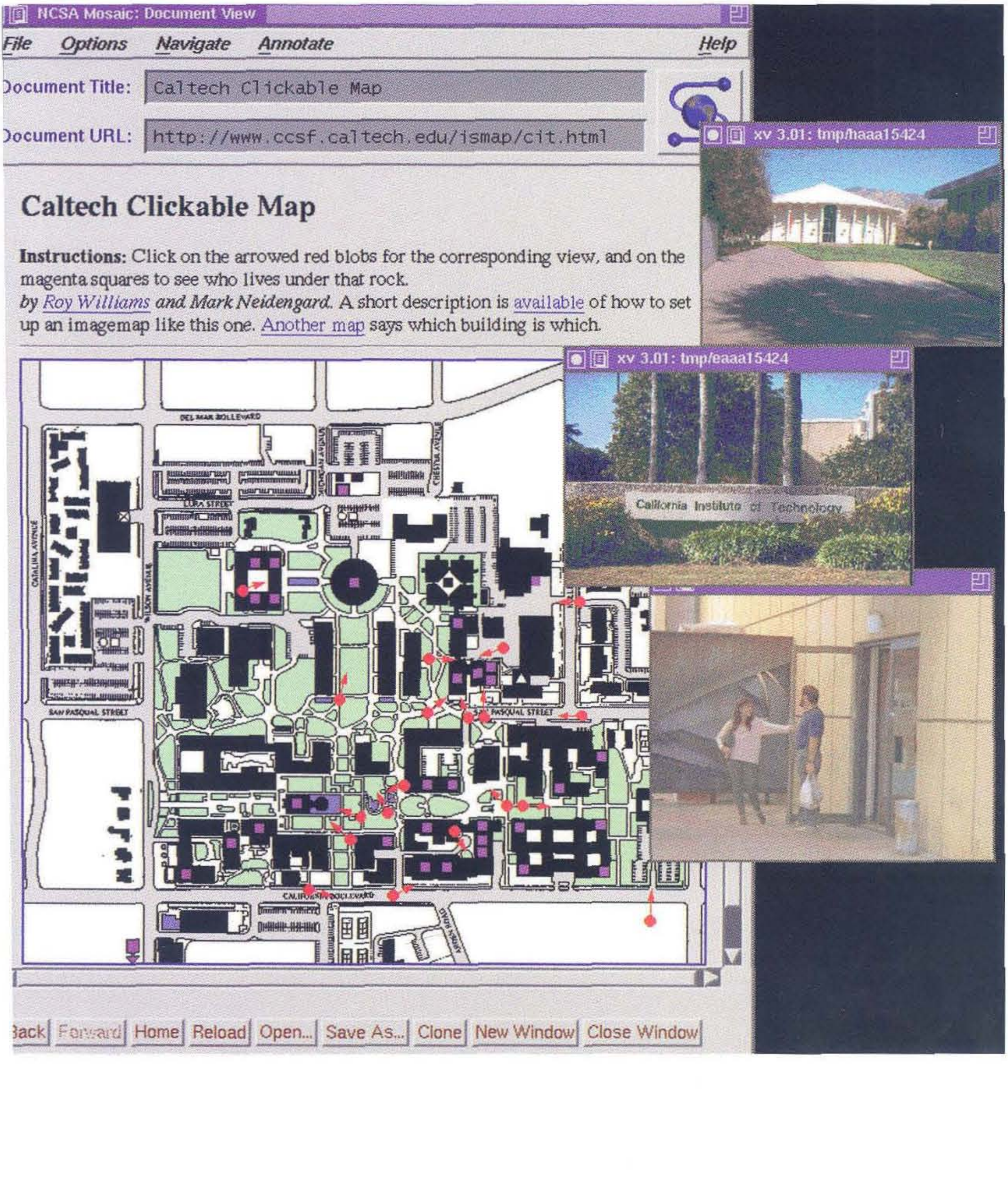
Winter 1995

In this issue

Linus Pauling

The SSC

The Internet



This is a "clickable" map of Caltech, available on the Internet through the World Wide Web. The map allows people to "visit" the campus without setting foot on it. Each magenta square corresponds to a departmental Web server in the surrounding building (the black shapes); clicking your cursor on that square brings up information about that department, its people, and its programs. Clicking on a red circle gives you a view of the campus from that point in the direction of the arrow. Starting on page 26, the creator of this map shows us around the Internet.

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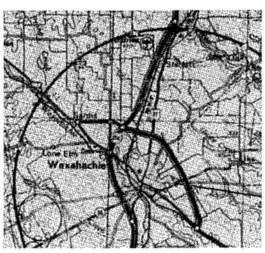

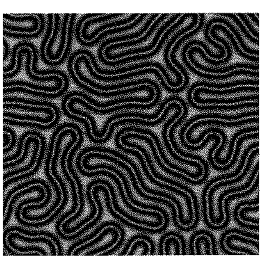

On the cover: Linus Pauling, on his return to campus in 1991 for a symposium in honor of his 90th birthday, joined old colleagues and new at the institution where he had spent 37 years on the faculty. Pauling died last August at the age of 93. At the memorial service, held in Beckman Auditorium on November 18, colleagues and family members paid tribute to one of the most creative scientists of the 20th century; their remarks begin on page 2.

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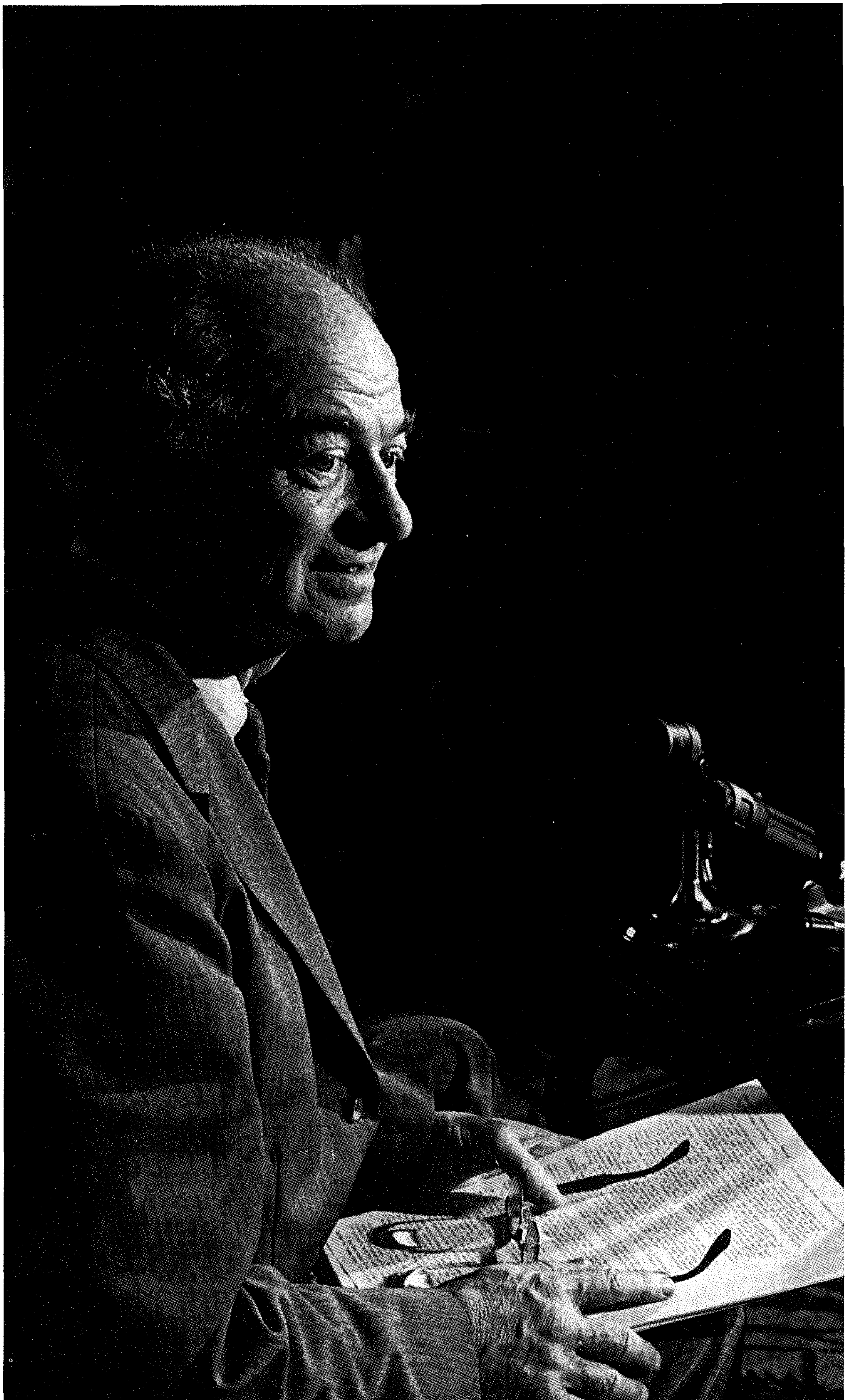


Linus Pauling 1901–1994

He was a genius, a pathfinder, whose scientific courage allowed him fearlessly to cross the boundaries of physics, chemistry, biology, and human medicine.

At a press conference in his Pasadena home on October 18, 1963, Linus Pauling announces his appointment to the Center for Democratic Institutions in Santa Barbara and the end of his 41-year association with Caltech. Eight days earlier he had won the 1962 Nobel Prize for Peace.

Linus Pauling, Nobel Laureate and professor of chemistry, emeritus, died August 19, 1994, at his home in Big Sur. He was 93. He had spent most of his scientific life at Caltech, from his arrival as a graduate student in 1922 to his departure in 1963 after winning his second Nobel Prize, the prize for peace.

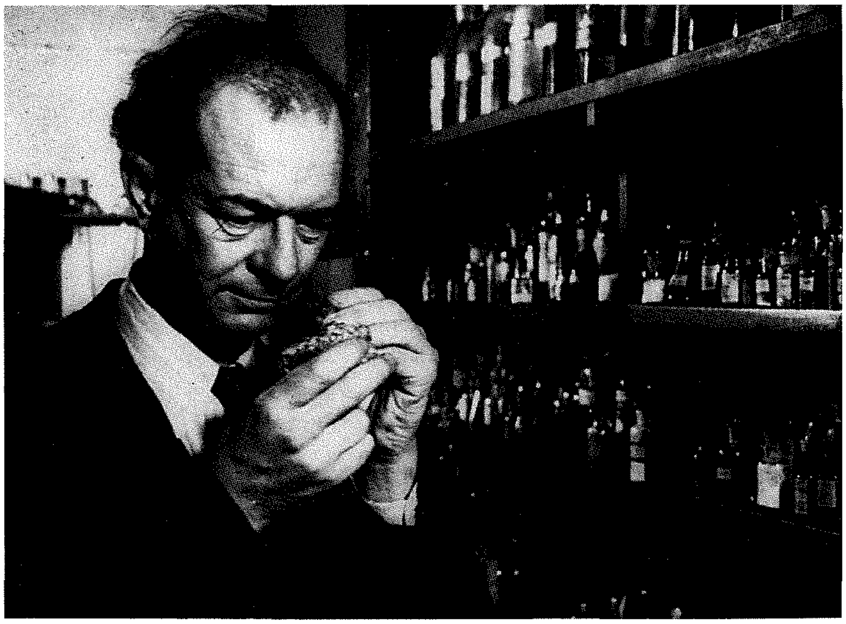
At the campus memorial observance on November 18, Caltech President Thomas E. Everhart welcomed the large crowd that filled Beckman Auditorium to "remember a man some have called the greatest scientist of the 20th century." Peter Dervan, chair of the Division of Chemistry and Chemical Engineering, a post Pauling had held for 21 years, delivered the closing remarks, referring to Pauling as "a genius, a pathfinder, whose scientific courage allowed him fearlessly to cross the boundaries of physics, chemistry, biology, and human medicine." Dervan thanked the speakers "for their eloquent, warm, and very honest remarks about the life and work of Linus Pauling."

Verner Schomaker
Professor of Chemistry, Emeritus
University of Washington
Faculty Associate in Chemistry, Caltech

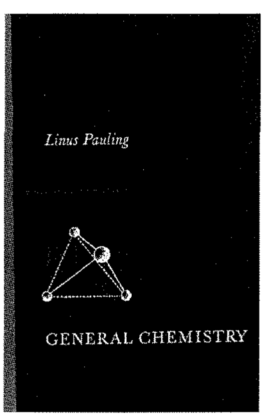
(Verner Schomaker commented on the award established in 1966 by the Oregon and Puget Sound sections of the American Chemical Society, "named after Dr. Linus Pauling, a native of the Pacific Northwest, because of the inspiration of his example. The nominee shall have made outstanding contributions to chemistry of the character that have merited national and international recognition." Schomaker pointed out that in the 29 years between Pauling, the first recipient, and Jim Ibers (BS '51, PhD '54), the latest, nearly half of the recipients of the award had had some connection to Caltech. This says a lot, said Schomaker, about what A. A. Noyes started when he appointed Pauling a graduate fellow in 1922. Schomaker went on to cite Pauling's interest in education in chemistry.)

Some years ago Dr. Pauling mentioned to me that he had given a talk somewhere about why the molecular orbital picture of electronic structure should not be used in elementary chemistry courses, and why he shouldn't be teased so much, ridiculed, and even condemned for sticking with the valence bond language and method. He clearly felt strongly about it, and he promised to send me a reprint, but it never came. This week I found the article in vol. 57, 1980, of the *Journal of Chemical Education*—the talk "Prospects and Retrospects in Chemical Education" given at a symposium in Honolulu in April 1979. In part, he said:

"I think that it is a tragedy that the writers of elementary textbooks decided to discuss the molecular orbital method, because the introduction of such a discussion in the teaching of elementary chemistry has served to confuse students. Only one system for treating valence, valence bonds, and molecular structure should be used for the elementary student in order that he build up a sound picture of molecules and the chemical



Pauling in his Caltech lab, probably in the early forties. His 2-lb. classic textbook (below) was first published in 1947.



bond and not be confused. The valence bond treatment is much simpler than the molecular orbital treatment, and it is also more powerful, so far as elementary non-mathematical discussions are concerned. The molecular orbital method ought to be X-rated, so that only after they had reached a certain age would students be allowed to learn about it.

"The authors of these textbooks discuss ethylene on the basis of the molecular orbital method by stating that in order to apply this method you must first know how the nuclei are arranged. They then say that it is known that in ethylene the nuclei all lie in the same plane, with two hydrogen atoms near each carbon atom, and that therefore we can discuss sigma bonds between carbon and hydrogen, and that therefore we can discuss sigma bonds between the two carbon atoms. There is accordingly a disadvantage right at the start. With the valence bond treatment, planarity follows directly from the concept of the tetrahedral carbon atom, with two bent bonds between the two carbon atoms. It seems to me to be pretty poor that the molecular orbital method does not even permit the derivation of the conclusion that the nuclei in ethylene lie in the same plane. Instead this has to be introduced as an assumption.

"My criticism of the molecular orbital treatment of valence and molecular structure has nothing to do with molecular quantum mechanics. The molecular orbital starting point for quantum mechanical calculations is a very good starting point."

Pauling was also keenly interested in the facts, in descriptive chemistry. For example, Derek A. Davenport, of Purdue, who introduced Pauling at the symposium, reproduces several of Pauling's letters to his Oregon Agricultural College instructor, F. J. Allen. One of them, written October 1924, from Caltech, includes the statement: "The faculty seems to emphasize physics and thermodynamics and statistical mechanics and atomic structure rather than chemistry." He later recalled those impressions: "My idea of chemistry at the time was that one developed a familiarity with chemical substances, and chemical substances to me meant inorganic substances, because all organic substances seemed to be about the same. I remember some 20 years later I met a man who had a PhD in chemistry from Berkeley, and I said to him that I was interested in bonds between metal atoms, that is, inorganic compounds that contain metal-metal bonds. I mentioned that there is, of course, one well known one, the mercurous ion in calomel. It turned out that he, with his PhD in chemistry, did not know that there is a mercury-mercury bond in calomel. I doubt that he knew anything about calomel. I was shocked to find that there could be people with a PhD in chemistry who knew so little about descriptive chemistry."

At the recent Pauling award, Jim Ibers contrasted one of the typical present-day textbooks very unfavorably with Pauling's 1947 edition of *General Chemistry (An Introduction of Descriptive Chemistry and Modern Chemical Theory)*, which he had enjoyed as a freshman here at Caltech. The former weighed 5.7 lbs. versus 2.0 lbs. for Pauling's classic; many dozens of mostly pointless *colored* illustrations versus none; half as much descriptive chemistry; lots of molecular orbitals versus none; physical chemistry, including thermodynamics, versus hardly any; and a triple or quadruple dose of Supplementary Material versus none. Pauling would have been pleased, especially since he didn't like thermodynamics anyhow.

(Schomaker went on to protest statements in some of Pauling's recent obituaries, primarily that Pauling thought he had cured his near-fatal bout with nephritis in 1941 with massive doses of vitamin C, and that the preoccupation with vitamin C that had "spoiled his great reputation as a chemist" in the last 25 years of his life was due to "his greatest failing, vanity." Schomaker noted that Dr. Thomas Addis of Stanford had cured the nephritis with a diet that ran counter to the usual treatment, and that Pauling always credited Irwin Stone with interesting him in vitamin C in 1966. As for his vanity, Schomaker said that in his own private poll, 9 out of 10 respondents agreed with

Before the symposium for his 90th birthday celebration, Pauling is greeted outside Beckman Institute by Walter Schroeder, senior research associate, emeritus.

him that Pauling was "supremely confident, yes, but not a bit afflicted by undeserved self-esteem." Countering an obituary statement about Pauling's lectures—that "he would reel off the top of his head atomic radii with the gusto of an organist playing a Bach fugue; afterward he would look around for applause"—10 out of 10 of Schomaker's respondents agreed that he was "a marvelous showman," but 9 out of 10 thought that he was "never so corny as to look around for applause.")

If Pauling were still living and in reasonable comfort, he would still be enjoying people, minerals, sea lions and otters, birds and flowers. He would still be hoping that physicists would attend his continuing string of papers on nuclear structure; that chemists would pay more attention to his ideas on the metallic bond, and that more physicians would join ever more ordinary people in wholesome interest in good nutrition and orthomolecular amounts of vitamins, especially ascorbic acid. He would be looking for more evidence that quasicrystals are multiple cubic twins after all and he would still be contributing new insightful gems of understanding of chemistry and biology.

I cannot end without reminding myself of the central fact that Linus Pauling was the most original and creative mind in chemistry of the 20th century.

Norman Davidson
Norman Chandler Professor of Chemical Biology, Emeritus, Caltech

In early 1946, when I was working in New Jersey, I received a letter offering me a job as an instructor at Caltech at the princely salary of $3,600 per year. The letter was in Linus's strong, legible handwriting, characteristically on a laboratory data pad, and written from a hotel in St. Louis. I was probably one of the last of the tenure-track faculty members who entered the system with the now-obsolete title of instructor. My teaching assignment was to assist Linus in Caltech's general chemistry course, for which he was just finishing the book that Verner alluded to. I remember on my first day in September 1946 wandering around sightseeing. I looked into Gates Laboratory—that beautiful room in the Annex with the very high ceiling and bookstacks that you reach by a ladder. And there standing precariously, it seemed to me, at the top of a ladder, with his glasses low on his nose, and balancing a gigantic volume of the *Journal of Physical Chemistry*, was Linus. I knew he was recuperating from a serious illness, and I thought to myself, "There is one of the world's greatest brains balanced on two of the world's frailer legs."

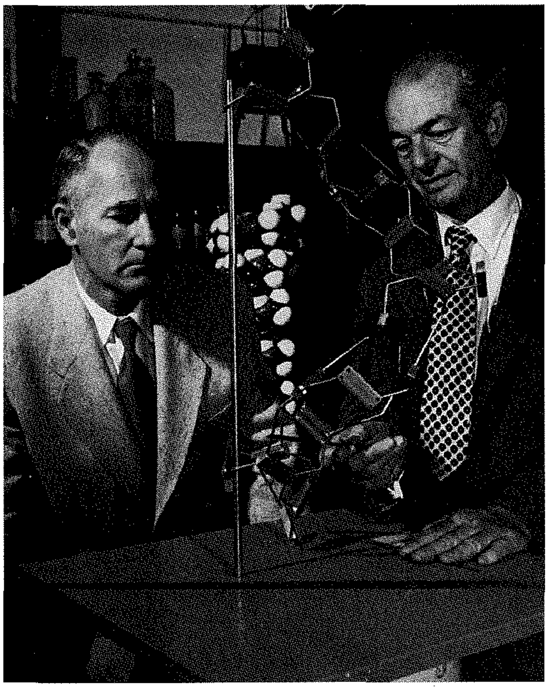
I remember meeting a new graduate student, Harvey Itano, an American born in California of Japanese parents, who, after a period of internment, had gone to medical school in St. Louis during the war. He told me he had come to Caltech after the war to fulfill his prewar ambition to study for a PhD in chemical biology under Linus Pauling. Linus had suggested as a project that he look for a molecular difference between normal hemoglobin and the hemoglobin of people who had the sickle cell disease. I was an ignorant chemist, but I remember thinking to myself that that sounds like a crazy idea. In a few years the team that included Harvey, John Singer, and Bert Wells described sickle cell anemia as the first clear example of a human molecular disease, involving a change in the charge of the hemoglobin molecule (later shown to be a single amino acid change). The point of this story is not that Norman Davidson was not far-seeing, but that Linus Pauling was an audacious, brilliant visionary who created new ideas and new fields.

Part of my job as Linus's assistant was to tell him what he was scheduled to lecture about. This was usually at his desk in the chairman's office on the first floor of Crellin, just where it is now. But sometimes, when he had just returned from a trip, I would meet him as he walked into the lecture hall at 11 a.m. in the Gates Annex (the lecture hall now refurbished and renamed the Linus Pauling Lecture Hall) and asked me what it was he was supposed to talk about. He always proceeded to give a very well-organized and, of course, interesting lecture. Few of us can do that.

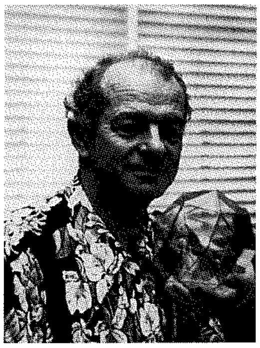
But on the occasions when I visited him in his office he would also tell me about his latest ideas—big ones such as the alpha helix structure, and little ones about the unexplained factlets of descriptive inorganic chemistry that fascinated him. Why is HF a weak acid? Why does sulfur form S_8 gas molecules? He told me his ideas about the answers, ideas that came to him, as he said, "with my feet higher than my head for convenience."

Linus was a courageous, compassionate person. There are quite a few cases where he protected and helped relatively powerless victims of McCarthy persecution and hysteria that were then sweeping the country.

Although I'm supposed to limit my remarks to a few of my many personal recollections, I cannot end without reminding myself of the central fact that Linus Pauling was the most original and creative mind in chemistry of the 20th century. From the structure of minerals to the nature of the chemical bond, the structures of complex intermetallic compounds, the structures of proteins, the essential role of complementarity in biological specificity, and molecular medicine, his discoveries opened new vistas and shaped the way we think. To paraphrase another great American, the world will little note nor long remember what we say here today; it will never forget what he did during his life. I was privileged to have worked with him and to have some personal feeling for how that genius was expressed.



Right: George Beadle, chairman of the Division of Biology and later also a fellow Nobel Laureate, admires Pauling's helical model of protein structure. This photo was probably taken in the early fifties. Below: Pauling was also known for his Hawaiian shirts.



Alexander Rich
Sedgwick Professor of Biophysics
Massachusetts Institute of Technology

My own experience with Linus stems from his invitation to come as a postdoctoral fellow in 1949, a few years after Norman Davidson arrived. I came from the East Coast, having just graduated from Harvard Medical School, and arrived suitably adorned with coat and tie. I walked into Linus's office, and there I saw this man with a flowery Hawaiian shirt and a big smile. I thought to myself, "Gee, this is different." The shirt didn't remain constant, but the warm smile did. And the five years I spent as a postdoctoral fellow was really a great experience.

I became interested in seeing how Linus operated. In his autobiographical sketches, Linus has said that he became interested in chemistry at 13, and by 18 had mastered most of conventional chemistry. Now, that's very important because it means that he already understood the qualitative nature of all these changes that constitute chemistry, and then was prepared to look more deeply into why things occur. When he went abroad in 1926 as a Guggenheim Fellow, he wrote in his application that he proposed to apply quantum mechanics, which had been discovered only a few months earlier, to the problem of the structure of molecules and the nature of the chemical bond. What remarkable foresight! He accomplished it, too.

He had the ability to see things in a general way, where many people could only see the particulars. This was strikingly illustrated in 1928, when he began looking at the structure of ionic minerals. These are rocks that are made of units that have positive and negative charges. Instead of looking at these three-dimensional structures one at a time, he asked himself why they have the form they have. He formulated a fairly simple set of rules that made it possible to predict all of these structures. In one statement, essentially, he answered the question of why minerals are the way they are, which was an enormous accomplishment.

Linus said he started to learn something about biology in the late twenties, when Thomas Hunt Morgan came to Caltech, bringing with him a number of younger members of the new biology division. In 1931 he had become interested enough to present a seminar describing the crossing over of chromosomes. From this beginning his work began increasingly to move in the direction of biological molecules. Linus began to develop great insight into what was one of the major puzzles of the day, namely the nature of proteins, the complex machinery of the cell. His

Some of the faculty of the Division of Chemistry and Chemical Engineering in 1937, the year after Pauling was named chairman: Pauling is seated in front between Roscoe Dickinson (left) and William Lacey; standing (from left) are Howard Lucas, Arnold Beckman, Bruce Sage, Stuart Bates, James Bell, and Don Yost.

description of proteins, developed in the late thirties and early forties, is essentially the way we see proteins today—that is, long chains of polypeptides held together by a number of weak forces and with some structural motifs on the inside. In 1937 he laid down what he thought was the basic geometry of how the polypeptide chains coil, but it wasn't until 1948 that he discovered (while in bed with a cold and playing with a sheet of paper) what is now known as the alpha helix, the most important element in the structure.

Linus was in a very real sense the first molecular biologist—before the term molecular biology was invented.

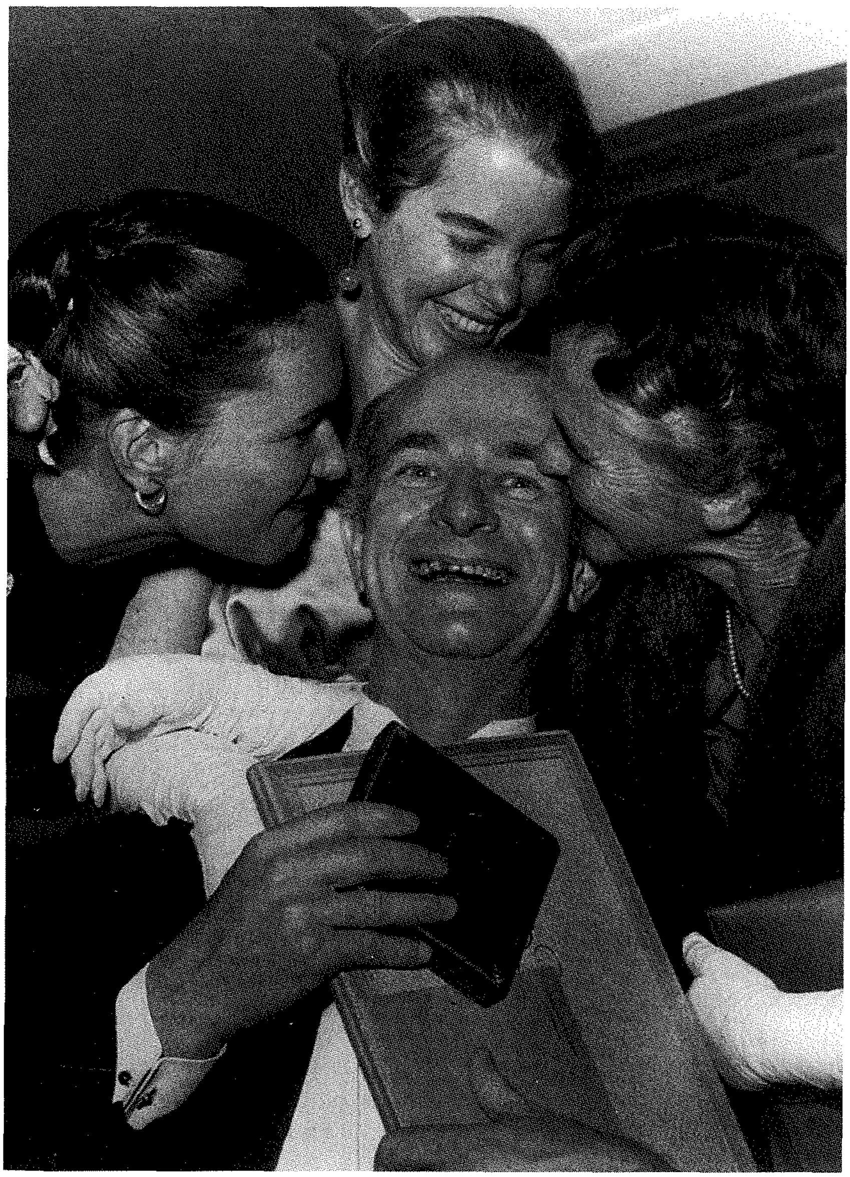
Linus's insights came from many sources, often serendipitous ones. For example, many of us go to committee meetings; they're usually a waste of time. But in 1945 Linus was a member of a committee on medical research, whose report became part of the influential Vannevar Bush report, "Science: The Endless Frontier." One of the members of this group was Dr. William Castle from Harvard Medical School, who described his work on sickle cell anemia; when you remove oxygen from these red blood cells, the hemoglobin within them crystallizes. Linus thought about this and concluded that the molecule has to develop a complementary surface; there must be a change. This led to the suggestion that Harvey Itano try to see if there was a difference. Although today the discovery of a new molecular disease is almost commonplace, then it was revolutionary. This was the first one, and, as such, it laid the pattern for all subsequent work. So Linus was in a very real sense the first molecular biologist—before the term *molecular biology* was invented.

(Rich also described Pauling's method of writing a book on college chemistry—"just dictating it" and then correcting the secretary's mistakes—which illustrated the intuitive depth with which he understood his subject. Rich also defended Pauling's interest in vitamin C and expressed the wish that Pauling could have read a recent paper showing that vitamin C protected animals exposed to cigarette smoke from 90 percent of the damage. "Linus's insight and intuition were very profound. . . . Clearly, he understood something that the rest of us are only beginning to understand.")

I'll end with a quote from Linus. He was working on the question of molecular disease and the evolution of the genetic code. He and Emil Zuckerkandl had developed the concept that there is with time a gradual change in the DNA sequence and likewise a gradual change in the proteins that they encode. He says, "Once more biology will show what it can do without any élan vital. . . . This experience and my other experiences during my last 50 years involving the ever-increasing understanding of the world on the basis of rational principles have led me to reject all dogma and revelations, all authoritarianism. It is possible that the greatest contribution of the new world view that has resulted from the progress of science will be the replacement of dogma, revelation, and authoritarianism by rationality, even greater than the contribution to medicine and to technology." This summarizes what for Linus was a very important thread in the work that he did. He was a man who understood the way nature worked, and from that he learned a great deal about the nature of life itself.

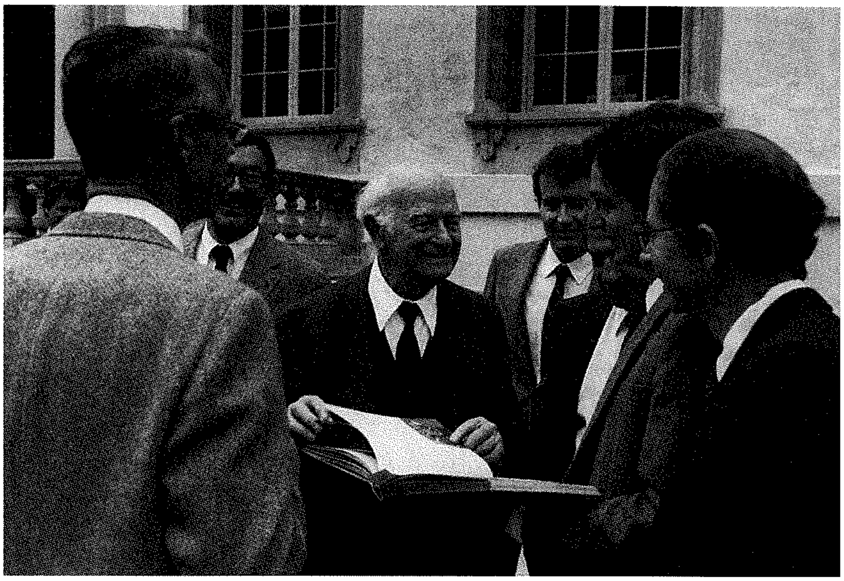
John D. Roberts
Institute Professor of Chemistry, Emeritus, Caltech

After receiving his Nobel Prize in Chemistry in Stockholm in 1954, Pauling is congratulated by, from left, daughter-in-law Anita, daughter Linda, and wife Ava Helen.



Linus Pauling will surely be remembered as the most influential chemist of the 20th century. He showed true genius in transmuting difficult quantum-mechanical principles into a set of simple concepts that could be used to provide a common basis for dealing with the properties of chemical bonds, molecular structures, and reaction mechanisms. Known as Pauling's Theory of Resonance, it fulfilled a need for chemists frustrated by mountains of information on seemingly unrelated chemical phenomena. So they used it. But if you asked if they understood it, that was something else again. Like its underlying quantum-mechanical principles, resonance is not easy to truly understand. But not many cared. The important thing was that it worked. And perhaps I should say here that, even though I wrote the first book popularizing molecular orbital theory for organic chemists, Linus never complained to me about it.

Pauling's genius is also clear from the remarkable breadth of his interests: from his establishment of the basis for protein structures, to studies of amino acids and the ways which they link together as peptides to form helixes and sheets. This work alone would have made him famous, but he went on to study the magnetism of blood, the chemical bases of immunology, sickle cell anemia, the structures of metals and alloys, as well as the structures of atomic nuclei. Pauling's research achievements, along with the wonderful spirit of Caltech, both in the Division of Chemistry and Chemical Engineering and the Institute as a whole, made Caltech compellingly attractive when Linus offered me a professorship in January 1953. Some of my friends suggested that Linus, as chairman of the division, might run over me, but that did not happen. He was generous with startup funds and strongly supportive of what turned out to be a successful initiative to change the Institute's rules to allow admission of a woman who had started graduate work with me at MIT. Further, after some intensive salesmanship in 1954, he agreed to an approach to the Trustees for purchase of a nuclear magnetic resonance spectrometer, an instrument that enabled Caltech to get a head start in applications of this still burgeoning technique to chemistry. We were all excited in 1954 when Pauling received the Nobel Prize in Chemistry. From my perspective, the prize changed Linus's life by enhancing both his credibility and his visibility with nonscientists. This gave him a greater opportunity to be heard on social issues, notably a prodigious



Surrounding Pauling on his return to campus for his 85th birthday are (clockwise from left) John Hopfield, Harry Gray, Terry Collins, Rudy Marcus, Dan Weitekamp, and John Baldeschwieler.

Many think of Richard Feynman as THE California genius. Pauling was more than comparable in a different way, perhaps in the way of Leonardo da Vinci.

and courageous effort to stop nuclear bomb testing. Some scientists and engineers, including ones at Caltech, were skeptical of or even opposed to Pauling's effort, most because they sincerely believed it might endanger our national security. But the effort was successful and led to the 1962 Nobel Peace Prize.

It was unfortunate that the Institute was not unanimous in its support of Pauling's work on the nuclear test ban. This fact, combined with a major concern in the division about the progress of research programs that Linus had under way to study the action of anesthetic gases and chemical factors in mental health were surely important factors when he resigned his professorship in 1964. We were greatly pleased, however, that he was willing to remain associated with the faculty as a research associate until 1971, and after that as professor of chemistry, emeritus.

Linus Pauling was an extraordinary leader in chemistry and molecular biology at Caltech. He had amazing foresight and intuition as to important areas that the Institute should be involved in. He was enormously supportive of and enjoyed participating in undergraduate and graduate teaching. For students, for faculty, he favored doing what is best for the individual situation at hand, rather than following bureaucratic regulations. He both encouraged and personally enlivened our chemical research conferences. Linus set an extraordinary example of broadness of thought and concern for humanity. Many think of Richard Feynman as THE California genius. Pauling was more than comparable in a different way, perhaps in the way of Leonardo da Vinci. Linus was broader, more focused on, more willing to deal with, and more willing to speak out on the impact of science on the world. Linus was a great man. We shall miss him and we shall not forget his genius, nor his contribution to science and our individual lives.

Ahmed Zewail
Linus Pauling Professor of Chemical Physics, Caltech

The last time I spoke with Linus was one week before he passed away. Linda was at home and she was kind enough to let me speak to him on the phone when he was in bed. This was in connection with the publication of his collected work in one volume. With a clear mind and vivid memory he said to me, "Ahmed, my contributions will need more than one volume." Linus was absolutely correct. Indeed, his contributions to chemistry, biology, physics, medicine, and humanity deserve many volumes.

I had the privilege of getting to know him over the past 10 years. I was happy to be part of a celebration to bring him back to campus on the occasions of his 85th and 90th birthdays. I even have a special copy of his book *The Nature of the Chemical Bond*, which I treasure, autographed, "To my friend Ahmed." Throughout my interactions with Linus I observed his unique style, his passion for science, and his brilliant intuition. He had a feeling that he could solve any problem. I noticed on several occasions when we spoke about problems related to my science, he would say, "Well, in 1931 I wrote a paper in the *Journal of the American Chemical Society*, volume so and so, page so and so, that dealt with this problem." What he really was saying to me was that he had solved this problem 60 years ago.

Linus's contributions to chemistry are awesome. He was a pioneer in the application of quantum mechanics to chemistry, a central figure in the use of x-ray and electron diffraction, especially in this country, and the one responsible for introducing chemical-molecular concepts to biology—what we know nowadays as modern molecular biology. Besides his contributions to science, he made contributions to world peace. Essentially all of those contributions, including the writing of the monumental book, *The Nature of the Chemical Bond*, were made here, while Linus was on the faculty of the California Institute of Technology.

Caltech and Pauling were *covalently* bonded. Pauling had an enormous impact on Caltech's chemistry and biology, not only through his science, but also through his leadership. As chairman of the Division of Chemistry and Chemical Engineering for 22 years (from 1936 to 1958), he was instrumental in hiring many of the faculty who have continued Caltech's reputation. He was also a superb teacher in the classroom and in guiding the work of Caltech students and postdocs. He inspired a generation of students and postdocs, many of whom are in leading American universities and institutions; a number of them are Nobel laureates. Caltech, on the other hand, offered Linus a unique scientific atmosphere—outstanding students and colleagues and a leadership role.

If Caltech had been a firmly established hide-bound institution, like Harvard or Berkeley, he wouldn't have been able to do the things that he could do in a new institution as this was.

As happens in any family, there were some times of disagreements, but one must integrate these over time and appreciate reasons and changes. When Linus came back to campus on the occasions of his 85th and 90th birthdays, he told me, as he told others, that the best time of his life was spent at the California Institute of Technology. In fact, he said, and I don't know if he was joking or not, that the best thing that had happened to him was that he did not go to Harvard or Berkeley. Likewise, I believe that Caltech is proud of Linus Pauling and his contributions. In his honor, our division and the Institute have established the Linus Pauling Lectureship, the Linus Pauling Lecture Hall, and the Linus Pauling Professorship.

Linus Carl Pauling died at the age of 93. He died, but the contributions of this giant to Caltech, to science, and to the world will never die. Linus is survived by a wonderful family and by generations of chemists and biologists. He is surely one of the greatest scientists of the 20th century.

Linus Pauling, Jr.

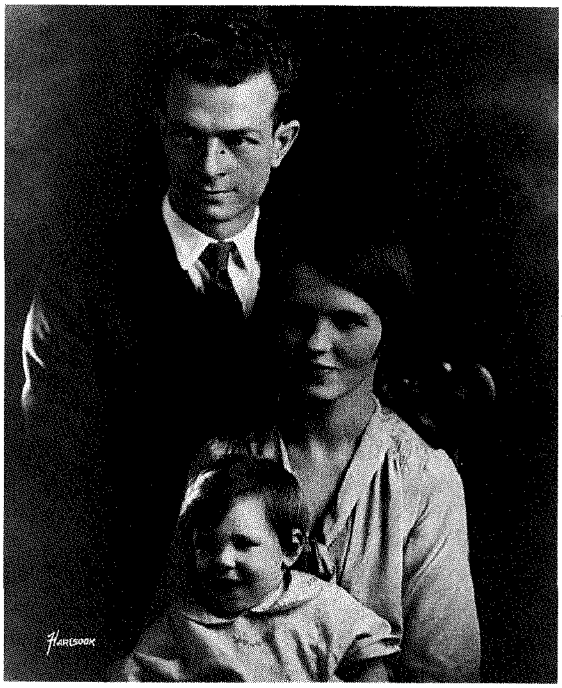
When he finished college, Pop applied to Caltech, Harvard, and Berkeley. Harvard offered him a half-time teaching assistantship and the possibility of earning his PhD in five years. At Caltech, A. A. Noyes offered him a full fellowship and the possibility of a PhD in three years. G. N. Lewis at Berkeley didn't reply at all, and Pop found out from Lewis later that his application had gotten lost underneath a pile of journals—unfortunately for Berkeley, but fortunately for Caltech.

Pop frequently said that he was very thankful that he had come to Caltech. It was a felicitous symbiosis. June next year will be the 70th anniversary of my father's receiving his PhD from Caltech, a ceremony that I was able to watch from my mother's arms. In those days Caltech

was very young. In spite of its 1891 origins as Throop University, the modern Caltech had only started about four years before Pop got here. So it was wet behind the ears too, like Pop. And he was quite wet behind the ears. He was uncultured, coming from the western frontier of Oregon, from a cow college. He often wondered what it was that made Noyes select him, sight unseen, to come here.

Pop and Caltech grew together and were mutually beneficial. He has said to me that if Caltech had been a firmly established hide-bound institution, like Harvard or Berkeley, he wouldn't have been able to do the things that he could do in a new institution as this was. He enjoyed his life here. He worked hard and achieved success. Caltech also achieved success. I think that Pop was an extremely bright star in Caltech's firmament, that he helped make Caltech what it is today.

Pop had another aspect to his personality, and that was a deep sense of ethics, of morality. He felt strongly that scientists who played a role in the development of some of the evils in this world should be responsible for establishing social controls. Following World War II, the evil was radiation. Attitudes were different in those days. The public's attitude, and certainly the government's, was that a little radiation was not bad for you; it might even be good for you, and, in any case, we needed to be willing to suffer this burden in order to keep ahead of the game. Pop wasn't willing to go along with that. Although he wasn't a participant in the development of the atomic bomb, he knew enough about



Pauling as a grad student in 1923 (left); with Ava Helen and Linus Pauling, Jr. in 1926 (right); and at his Caltech graduation in 1925 (below).

it to come to conclusions. So he felt that it was his moral responsibility to campaign for greater understanding of the dangers of radiation. And he set about this, to the displeasure of a great many people, particularly people in the U. S. government.

It's astounding to me that he had the courage to do this, to risk the opprobrium of his government, the people, and his colleagues here. But he went ahead with it, and was, I think, successful in educating the people, not only of the United States but of the world, in the dangers that would come from unrestricted bomb testing. The result was the Nuclear Test Ban Agreement of 1963.

Caltech and its faculty were not much different from the general population. Scientists are people after all, although when I was a kid I thought scientists were gods. When my father saw me out in the audience in my mother's arms, when he got his PhD, he may have thought he was looking at the next generation of scientists. Unfortunately, the gene mix that I got pushed me under the crown of the curve of probability, so I couldn't have followed him even if I'd wanted to. I became a psychiatrist instead. I understand about as much about quantum mechanics as my father did about psychiatry—namely nothing.

But, getting back to scientists as people, when news of his 1962 Nobel Peace Prize came, there was not the spontaneous demonstration of joy on campus that had occurred in 1954. People even crossed the street in order to walk down the other side when they saw Pop coming. It was strange. But it reflected the attitude of the times. He was a very sensitive person, and I believe that he felt really hurt by his Caltech colleagues' abandonment. Some colleagues did celebrate this achievement, of course. He managed to accumulate 11,000 signatures of scientists from around the world to present to the United Nations before the test ban. But Caltech as a campus seemed to feel somewhat ashamed, and a short time later Pop resigned. One could argue that he may have resigned because his laboratory space, office space, and prerogatives were being whittled away, but I suspect that underneath those more logical, public reasons was the hurt he felt at the lack of approval by his colleagues.

His kindness, sweetness, and sensitivity went deep. I never heard my father say a bad word about his enemies or about Caltech. After that, he became an itinerant scientist, going to the Center for the Study of Democratic Institutions in Santa Barbara, to UC San Diego, to Stanford; he didn't really have a home until he established the Linus Pauling Institute in Palo Alto 21 years ago. But his first love, and the institution to whom he gave credit for his development, was Caltech.

Linda Pauling Kamb

I want to say a bit about what it was like growing up with Linus Pauling as my father. In recent interviews my father said that he had pretty much ignored his children as they were growing up. I guess that is partly true, since he was working so much of the time, either at Caltech, at home, or traveling. But there are numerous wonderful times with him to remember. And I'll tell you some of these.

For instance, he used to read the Sunday comics to us, the newspaper spread out on the living room floor, and with Peter, Crelly, and me sitting around. Linus was too old for that. My father had such a wonderful sense of humor. He loved the *New Yorker* cartoons, although much later in life he complained that the modern ones weren't funny anymore. We loved it when he entertained us with some of his tricks, such as wiggling his big ears. He could also wiggle his nostrils. None of us could do that. And he could flip a dime laid on his wrist by turning his hand in a certain way from one side to the other and closing his fingers at the same time, causing a tendon to pop and flipping the dime. I remember we kept trying and trying to do that. I could get a slight wiggle of the dime but never a full flip.

Occasionally we went camping at Painted

In 1937 the Pauling family had grown to include Peter, Linda, and baby Crellin, in addition to Linus, Jr., not pictured here.

We loved it when he entertained us with some of his tricks, such as wiggling his big ears. He could also wiggle his nostrils.

Canyon in the desert near Indio, continuing a tradition that was introduced to my parents by Arthur Amos Noyes, who would take the chemistry graduate students out for camping trips in his legendary touring car. I remember with great pleasure the times we had camping. We children had our own sleeping bags and cots and we would make our own fire pits with rocks. My father taught us how to shoot, using his .22 rifle with tin cans as targets (remember this in light of his antiwar activities). This helped me once later, when I was able to shoot from the open living room window a gopher that was decimating my ajuga plants. That was using Barclay's .22. Actually I had to call Barclay to get directions over the telephone for loading it.

When my father was ill with nephritis and had to spend most of his time in bed resting, he took up dictating his letters at home into a dictaphone, rather than to his secretary. I believe that secretary was Judy Rook, now Mrs. Verner Schomaker. You could hear him in there doing his correspondence. I also need to explain that my father was known for his insistence on correct grammar and punctuation, and he did not leave anything up to the discretion of his secretary. Thus, when dictating a letter he would start, for example: "Dear Dr. Jones comma." Once my mother asked Crellin, my younger brother, who was four at the time, where Daddy was; Crelly answered, "Oh, he's in there talking to Comma again."

Recently my father spoke again of his getting ill with nephritis, as Verner has described to you, when he was visiting Princeton in the winter of 1941. His hands and feet were very swollen. He went on to an engagement at the Rockefeller Institute in New York City, and there they told him not to go on to the Mayo Clinic as scheduled but to cancel that; go directly home and call up Dr. Thomas Addis, a kidney specialist at the Stanford Medical School. This my father did, and Dr. Addis, with my father's input also, put him on a salt-free, meatless diet, with only 37 grams of protein a day. My mother weighed all the food and calculated the number of grams of protein in everything he ate. And, unable to get salt-free bread at that time, during the war, she started baking her own. That was something we all loved, her wonderful bread, salt-free or not. This was not the conventional treatment for kidney disease, which was to give lots of meat and restrict the water intake. Most if not all such patients died, and my father was not expected to live either. He told us recently that Dr. Addis had said to him later that if he had gone as planned to the Mayo Clinic they would have given him something to get rid of the swelling, which would have worked, but he would have been dead within six months. The treatment of putting as little stress on the kidneys as possible is what allowed him to recover completely.

It will be three months tomorrow since my father died. During this time I have received many beautiful letters and cards. I'm grateful to everyone for their love.

Barclay James Kamb

My grandfather came to Caltech 40 years before I was born, so I really missed a lot of his achievements. My first recollection of him is as a white-haired icon, powerful and strong, sharp, witty. He was the center of the family, he and Ava Helen, and brought my brothers, my cousins, my mother, and my uncles along in a family tradition that I will always thank him for. We continue to share something that you can't have without having someone as warm and caring as he was.

What I first noticed as a kid, when I started to pay attention to something more than what was within six inches of my nose, was just how incredibly sharp and insightful he was. My appreciation of how his mind worked grew over the years. Once, he and Ava Helen invited me to spend the summer with them, the summer of 1980. He had offered me a job to help out with some quantum mechanics—as if I were really in a position to help him. I think he thought this would give me a good opportunity to learn that

Pauling at his home in Big Sur in 1983.

chemistry was a good grounding for doing biology. Once we were spending the evening, as we often would, catching up on some news on the television. He would recline on this huge recliner, the size of a double bed, in the shape of a sine curve and covered in fur (I've never seen anything like it, before or since). He would lie on this thing with his feet up—he did like to think with his feet up. I'd sit on a chair and we'd watch the news on TV. Like most people, I'd watch the news and think about the news. But in the middle of some broadcast, he turned to me and said, "Have you solved that problem I gave you yesterday?" I said, "Well, I'm watching the news." This moment was inspirational for me. He really could think about many things at once. I've tried to do that without success, but unfortunately, if I want to learn what's happening on the TV news, I have to pay attention to it.

He probably said many times that he didn't think that he was blessed with an ability to divine the truth. What he thought he could do was come up with many ideas and just throw out the bad ones. I suppose we all ought to just relax our minds and try to think as many thoughts as we can.

At the age of 90 he stayed very current and engaged with people. About four summers ago I suggested bringing some of my 30-something friends around for cocktails at his Big Sur home; my grandfather liked to have a little vodka in the evening, and I thought this would be a good opportunity for me to spend some time with him. He, of course, thought that was a great idea. So we sat on the porch of his house overlooking the Pacific and drank cocktails out of little 100-ml or 250-ml beakers that he had around. He immediately dominated the conversation, which was wonderful for my friends. He could entertain anybody, be it a 20-year-old or a 70-year-old. This is what was charming and what I loved about him—he was so interesting and warm and engaging. But this occasion struck me in particular. He went on about a *Saturday Night Live* program he'd seen the night before, a very funny sketch about the *Time-Life* books—"48 hours in Grenada." And he proceeded to tell the story funnier, I suspect, than the *Saturday Night Live* cast had done it, and he kept us all in stitches. That someone 90 years old could be interested in *Saturday Night Live*, watch it and understand it, and then retell it better than the original—this was a part of him, aside from his science, that we can all cherish and remember.

One of my most powerful early memories of him was not of him directly, but of a photograph. I spent a lot of time as a child thumbing through books in the house where I grew up (which my grandfather had built). I particularly liked books with photographs. In one of these I discovered a picture of him and grandmother at a dinner party honoring Nobel laureates, given by President and Mrs. Kennedy at the White House back in the early sixties. It was a lovely, grainy, black-and-white photograph of Linus and Ava Helen dancing alone on this beautiful parquet floor. What was more stunning to me, however, was that right next to it was a picture of my grandfather taken earlier in the day: he was out on a sidewalk holding a big placard that read, "We

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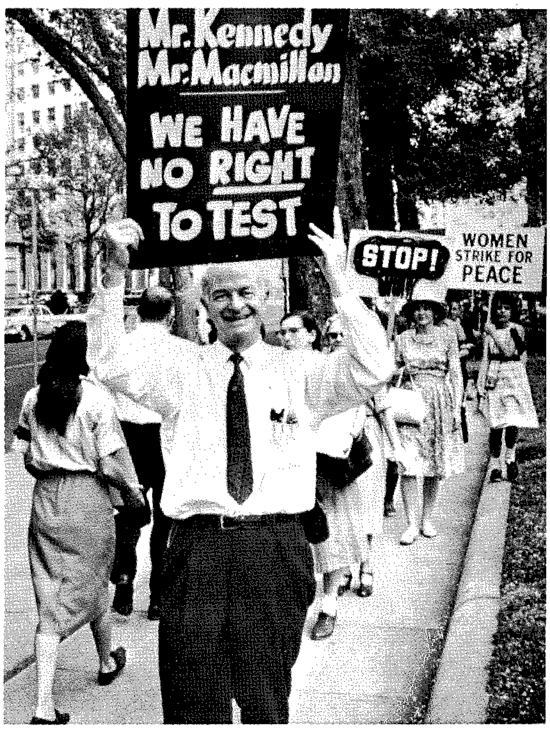


Dancing inside the White House and demonstrating outside in 1962.

Perhaps I didn't understand it consciously at the time, although the two pictures together certainly struck me. I think what it brings home to me now is that you can do a lot of things with your life if you care about it.

have no right to test." Perhaps I didn't understand it consciously at the time, although the two pictures together certainly struck me. I think what it brings home to me now is that you can do a lot of things with your life if you care about it. There are a lot of different things to enjoy about this world, and he certainly did many, many things. I hope this has inspired us all to chase down what it is we like and to not let anything get in the way of pursuing what we want to do.

Alexander (Sasha) Kamb

I once asked my grandfather which Nobel Prize most pleased him, his chemistry prize or his peace prize. He answered, surprising to me, that he was happiest about the peace prize, because with chemistry he was doing exactly what he always wanted to do and what he did naturally. It was never any strain at all. He had to be goaded into the peace effort by his wife, and it was a struggle for him, at least initially. But he took it up, as we all know, with tremendous vigor, and was in the end as successful at that as he was at everything else that he tried to do. I really don't know much about his activism. I've seen some old film footage of his being harassed by various congressional committees and by the press, and his charisma, personal power, and integrity came across very clearly. But what struck me most was his great courage, and I marvel at a man with so much confidence and courage that he could take on these people with impunity, with tremendous will and energy, and with no fear at all.

I've wondered why he got interested in nutrition. It seems a somewhat fuzzy discipline to those trained in physical science, but this interest was typical of him. He did things partly based on his own experiences, and also based on very sound, logical, simple principles. I think the role of dietary restrictions in his recovery from nephritis might have served as the basis for his developing interests in nutrition and health, and also led him to speculate that very simple compounds like salt and protein could change a person's health in dramatic ways. I've been sort of wounded over the years by some of the attacks on him; I'm sure he was somewhat wounded himself. His critics gave the impression that maybe Linus Pauling didn't really have it any more as a scientist. Nothing could be further from the truth. Up to the very end of his life he was extremely sharp, and the arguments he made in favor of vitamin C, for example, were compelling, lucid, clear, and very smart. I think the

I want to remember him like his crystals—as a man who was very solid and deep himself, very lustrous and, if not perfect, about as close to being perfect as a man can be.

On his 93rd birthday Pauling celebrated with two (and possibly three) more Caltech generations of his family: his son-in-law Barclay Kamb, BS '52, PhD '56, the Rawn Professor of Geology; grandson Alexander (Sasha) Kamb, PhD '88; and great-grandson Alexander Kamb.

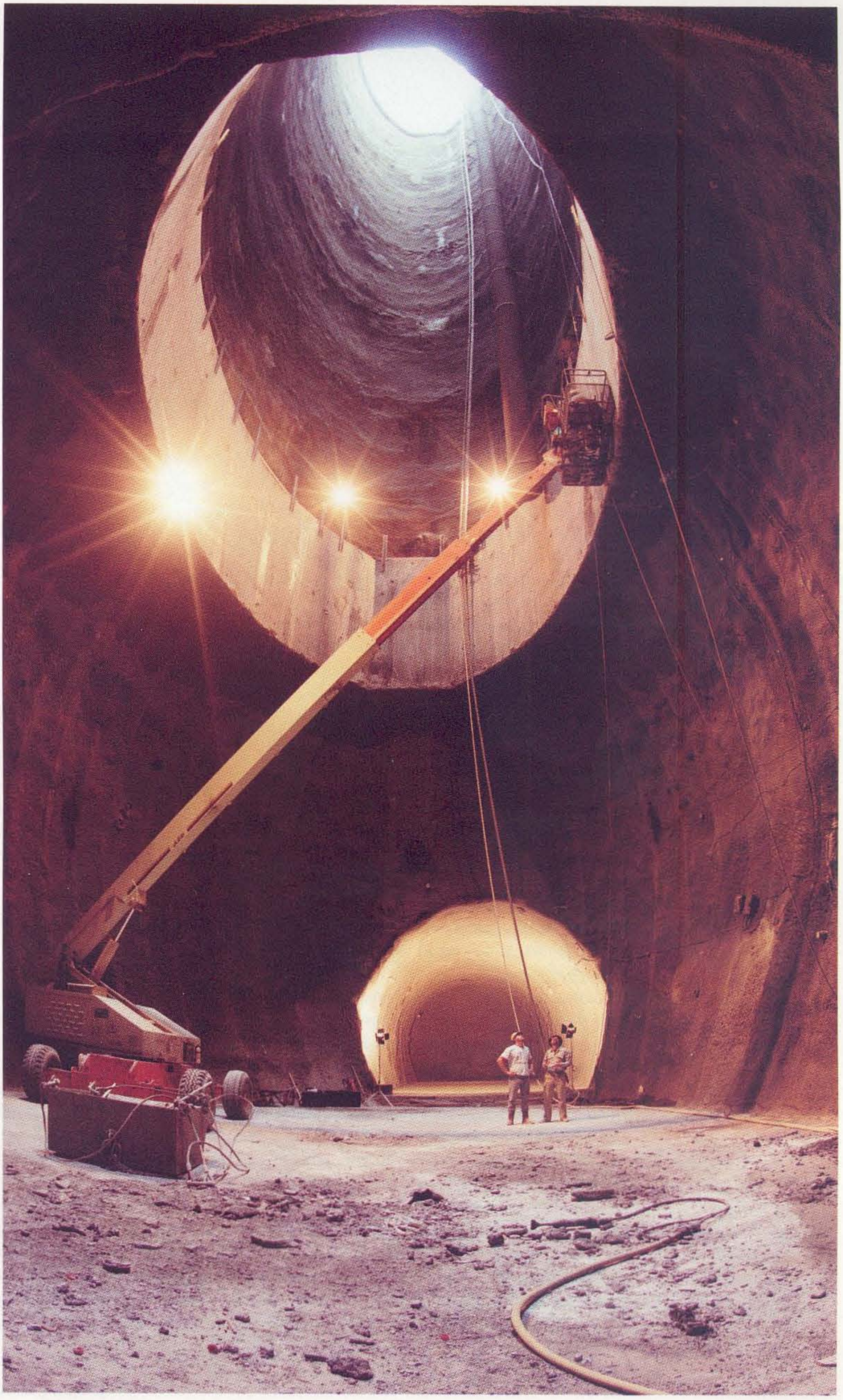
mainstream of scientists now are coming around to the idea that intake of this type of nutrient—vitamin C, vitamin E— is very beneficial, at least in terms of its protective effects against disease.

I'm proud to be a relative of Linus Pauling, and it pleases me to think that I share a quarter of his genes and that perhaps some of the great traits he had might, although somewhat diluted, have been passed on to my son. But I think everyone here can appreciate that being Linus Pauling's grandson has been a little difficult as well. By going into the field that I've gone into, I didn't discourage the inevitable comparisons. But it seems odd to me that he never understood that this made me uncomfortable.

To give you an example, in the last couple of years we started to correspond. One of the letters he wrote began, "Dear Sasha, I've been thinking a lot about you lately"; and I thought, "Gee, I didn't know he thought much at all about me, and that's really nice." But then it went on: "I've been thinking about why you haven't reached your potential (you were a smart kid), and I think I know why. It's because you never took your work seriously enough. And the evidence I have for that is a conversation we had seven years ago where I told you that I'd gotten my PhD in three and a half years, and I asked you why you hadn't gotten yours yet. And you said, 'Well, the average PhD at Caltech takes six years, so I'm even ahead of schedule.'" He went on for another paragraph in this vein.

I was distressed by this letter. By that point I'd gotten used to these kinds of things, but I was hurt that he would be unhappy about me and perhaps about other members of his family as he was reaching the end of his life. I wanted to set him straight about that, and I was also annoyed that he didn't understand. So I went up to see him in Big Sur about a year ago, and I said to him, "Grandpa, I'm pretty unhappy about that letter. I've been trying for a good part of my life not to compare myself to you, and I really don't appreciate your undermining my efforts to do that." He just set his jaw and looked off into the distance, which is something he did when he thought there was nothing to be done—the equivalent of throwing up his hands.

But though he had a somewhat harsh way of treating his family at times, that's not the way I'm going to remember him. The way I will remember him is as the generous and gentlemanly host to me and my friends, other young scientists, when I was living in San Francisco during the last couple of years of his life. My friends would be awestruck—actually dumbstruck. He wasn't a great one at making small talk, but nevertheless he would make an effort to fill the awkward silences. He would lead these young scientists around and show them things in his house that he enjoyed. One of the things he liked to show people was his little collection of crystals, really beautiful ones. And I can see him now, holding a crystal of amethyst, or a big, lovely cubic crystal of pyrite—heavy and solid and lustrous and perfect—and pointing out its various features. I want to remember him like his crystals—as a man who was very solid and deep himself, very lustrous and, if not perfect, about as close to being perfect as a man can be. □



Good-bye to the SSC: On the Life and Death of the Superconducting Super Collider

by Daniel J. Kevles

Particle accelerators have been called the cathedrals of the modern era.

The collider ring's 14-foot-diameter tunnel was blasted about 250 feet deep through Texas rock. This large shaft connects the tunnel to the surface near the injector area and was designed for lowering the long superconducting magnets into the tunnel.

After the atomic bombings of Hiroshima and Nagasaki in 1945, American physicists became a kind of secular establishment, with the power to influence policy and obtain state resources largely on faith and with an enviable degree of freedom from political control. What brought them to power is, to a considerable degree, what kept them there for most of the last half century—the identification of physics with national security. Throughout the Cold War they were crucial figures in maintaining American superiority in arms, advising upon defense policy in relationship to technical possibilities, training students who populated university, industrial, and federal laboratories, including weapons establishments, and contributing to the high-technology postwar economy—both indirectly, through military spin-offs, and directly, through research in myriad fields such as transistors, computers, lasers, and fiber optics.

The most prominent and influential physicists were in elementary-particle research, which is occupied with exploring the fundamental structure of matter and energy and uses high-energy accelerators as its primary experimental tool. Constituting about 10 percent of the American physics community in the 1980s, high-energy physicists had won many of the Nobel Prizes awarded to Americans and had been key figures in the nation's strategic defense and science policy-making councils. During the postwar decades, elementary-particle physics prospered handsomely, not least from a reading of history: seemingly impractical research in nuclear physics had led to the decidedly tangible result of the atomic bomb; thus, research in particle physics had to be pursued because it might produce a similarly practical surprise. In the context of the Cold War, particle physics provided an insurance policy that if something important to national security emerged unexpectedly, the United States would have the knowledge ahead of the Soviet Union.

Particle accelerators have been called the cathedrals of the modern era. Those of recent vintage are huge machines, with dimensions measured in miles. Many work by sending charged particles repeatedly around a circular track, adding energy to them at every pass. (The measure of energy is the electron volt, which is what an electron gains by crossing an electric potential difference of one volt.) The United States' flagship accelerator, with a circular track four miles in circumference, is at the Fermi National Laboratory—Fermilab—in Batavia, Illinois. At the end of the seventies, a project was initiated to double the energy of that machine by using superconducting magnets to keep the particle beam on its circular course. (Certain materials, when cooled to close to absolute zero, become superconducting, which is to say that they conduct current with no resistance and, hence, no energy loss.) The doubling would endow the Fermi machine with an energy of one trillion electron volts (Tev), making it a tevatron and one of the most powerful particle accelerators on earth.

In 1983, however, American high-energy physicists called for the construction of the Superconducting Super Collider (SSC)—a

The SSC's acceleration energy would be 60 times greater than the CERN collider's, making it by far the most powerful proton accelerator in the world.

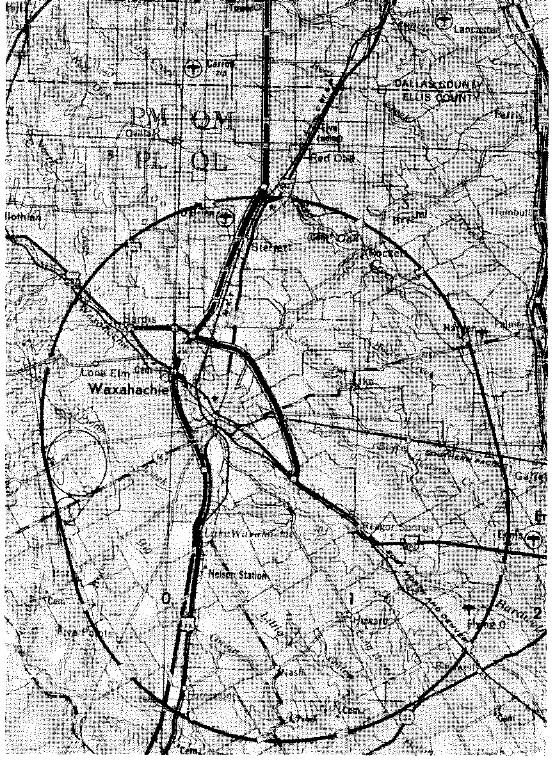
gargantuan machine that would accelerate two beams of protons, each in the opposite direction from the other, through a circular tunnel some 52 miles in circumference to a kinetic energy of 20 trillion electron volts and a collision energy of 40 trillion electron volts. Allowing for inflation, the SSC was estimated to cost roughly $6 billion to construct over 10 years. Although federal funding for all of physics had declined through the seventies, following the Vietnam War, it had been rising dramatically with the Reagan administration's defense buildup, particularly its embrace of the Strategic Defense Initiative, and with the national absorption with economic competitiveness. In that high-technology climate, the SSC was endorsed by the Department of Energy, the agency that funds almost all high-energy physics in the United States, and, in January 1987, by President Ronald Reagan.

Steven Weinberg

High-energy physicists wanted the SSC partly because they saw it as indispensable to further development of the overarching structure of elementary-particle theory that they call the Standard Model. The Standard Model holds that all matter is formed of particles called quarks and leptons, that the existence and behavior of these particles is governed by different types of force fields, and that the interactions of these fields are mediated by the exchange of elementary particles. The Standard Model theoretically unifies three of the fundamental natural forces—the electromagnetic, the weak, and the strong—though the fourth, gravity, has remained beyond its reach. In 1983 experimental evidence was obtained in confirmation of one of the Standard Model's major triumphs: the theoretical analysis that at sufficiently high energies a deep symmetry characterizes both the electromagnetic and the weak forces so that they operate as a single "electroweak" force. By then, too, the Standard Model was being advantageously exploited to understand the behavior of the universe close to the time of its origin in the Big Bang, when enormous energies were concentrated in a very small volume, indicating, for example, that as the universe cooled, the deep symmetry of the electroweak force was broken in a way that generated the electromagnetic and weak forces.

Nevertheless, the Standard Model posed a number of unanswered questions, including some in its electroweak sector. High-energy physicists were particularly interested in probing for evidence of what they call the Higgs force field (named after Peter Higgs, of Edinburgh University, who had most clearly postulated it in 1964), which was believed to play a role in the shattering of electroweak unification and to be necessary to account for why the particles in electromagnetic and weak interactions possess the masses they do; indeed, why they have any mass at all. On theoretical grounds, it was expected that the SSC would reveal the presence of an exchange particle called the Higgs boson, which was predicted to have a mass so large that a machine operating at the SSC's energy would be needed to produce it. The SSC meant a great deal to the theoretical physicist Steven Weinberg, who had independently codevised electroweak theory in 1967 and shared the 1979 Nobel Prize in physics for his contributions to it. In eloquent testimony to Congress and in elegant prose for the public (in a book called *Dreams of a Final Theory*, published in 1992) Weinberg emphasized that physicists were "desperate" for the machine because they were "stuck" as physicists in their progress toward what he called "a final theory" of nature—a complete, comprehensive, and consistent theory that would account for all the known forces, fields, and particles in the universe.

Yet high-energy enthusiasts also wanted the SSC because they worried that the United States was losing its leadership in elementary-particle physics to Europe, which was supporting the grand multinational accelerator installation called CERN (for *Conseil Européen de Recherche Nucléaire*), on the French-Swiss border. The SSC's acceleration energy would be 60 times greater than the CERN collider's, making it by far the most powerful proton accelerator in the world. It would restore the United States' preeminence in high-energy physics, and, in the view of Leon Lederman, the director of Fermilab, reestablish



The SSC's 52-mile tunnel was designed to ring the Texas town of Waxahachie, just south of the Dallas County line. The location of the accelerators (a linear accelerator and three boosters), which would provide protons to the collider, is drawn as two circles on the west side of the ring, where Highway 66 crosses it.

its "national pride and technological self-confidence."

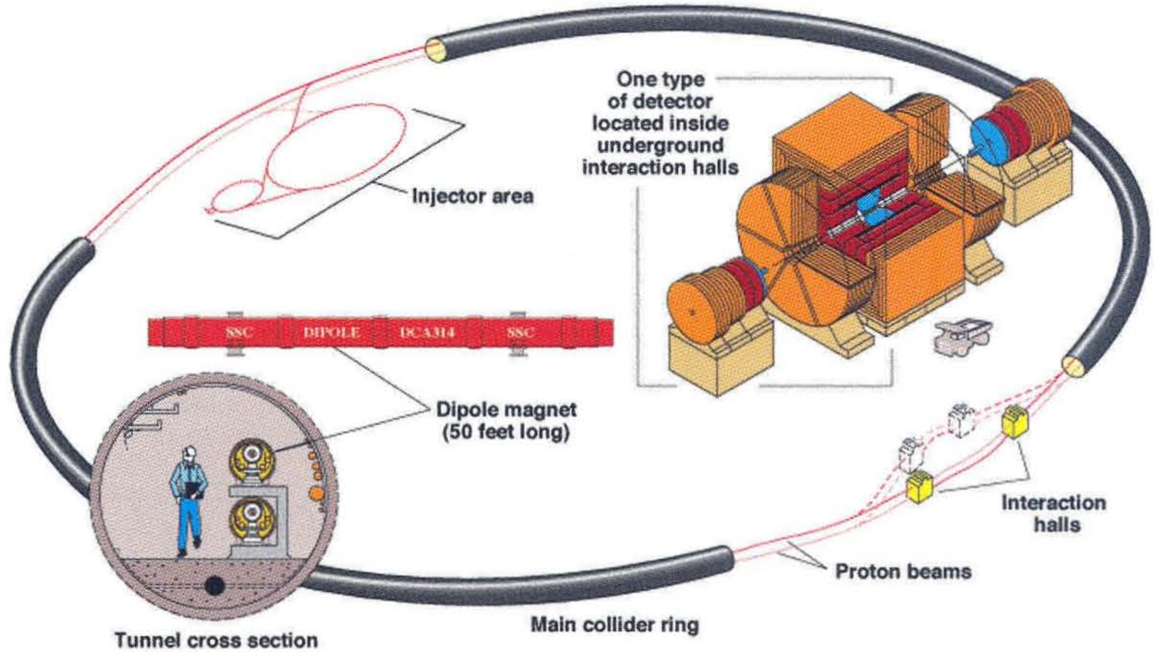
Lederman, one of the principal spokesmen for the SSC, was an accomplished high-energy experimentalist who had made Nobel Prize–winning contributions to the development of the Standard Model during the 1960s (although the prize itself did not come until 1988). He was a fixture at congressional hearings on the collider, an unbridled advocate of its merits who frankly avowed that the primary justification for the collider was intellectual curiosity. Yet neither Lederman nor his fellow enthusiasts minded claiming that the SSC would pay considerable practical dividends to the American political economy. Enlisting the historical record of particle physics in their cause, they pointed to its past spin-offs and extrapolated from them to sketch the SSC's practical promises. Although the knowledge of nature that high-energy accelerators revealed had not been in and of itself practically relevant, the machines themselves had yielded useful dividends—radiation used in the processing of foods and materials and in the treatment of cancer; powerful light beams that etch integrated circuits onto semiconductor chips at much greater densities than could otherwise have been achieved; and computerized methods and sophisticated technologies that screen and analyze superabundant data.

Leon Lederman

Advocates of the SSC declared that protons from one of its low-energy injector accelerators would be diverted to cancer treatment in a facility on the site. They stressed that the SSC would yield advances in superconducting technologies that would contribute to innovations in power generation and transportation in the form, for example, of magnetically levitated trains. Lederman testified before the House Budget Committee that work on superconducting magnets for Fermilab and other accelerators had already "enabled" the deployment of the "powerful medical diagnostic tool called magnetic resonance imaging." Deputy Secretary of Energy W. Henson Moore III, a lawyer and former congressman from Louisiana, went further, indicating to a congressional committee that magnetic resonance imaging had been made possible by the work on superconducting magnets for the SSC itself.

It did not take a physicist to recognize that the SSC, with its $6 billion price tag, would produce an abundance of industrial contracts and, as one congressman put it, "an awful lot of jobs"—some 5,000 to 8,000 of them alone where the SSC would be built. More than half the states in the Union took steps to enter the site-selection competition, which began on April 1, 1987, and which the *New Republic* called an invitation to "quark barrel politics." On November 10, 1988, the day after George Bush was elected to the presidency, Secretary of Energy John S. Herrington announced at a press conference that the winner was Waxahachie, Texas, a town of 18,000 people about 25 miles southwest of Dallas, which had been ranked outstanding on every major criterion by a site-selection committee of the National Academy of Sciences. Texas had also promised the project one billion dollars, a sweetener offered by no other state. Observers could not help but notice, however, that the president-elect called Texas home and that the Texas congressional delegation was a powerhouse. In 1989 Congress voted decisively to fund the construction of the SSC, accepting a total cost for its construction of $5.9 billion.

While physicists, like other American scientists, have embraced political engagement in arenas of technological policy such as arms control, they have tended to resist it on behalf of their science, fearing that it would undercut their social authority, not to mention their self-image, if they behaved like just another interest group in American society. But, among physicists who did not work in elementary particles, the SSC inflamed long-simmering resentments against the power, authority, and budgetary leverage of those who did. Once the collider became a serious public-policy initiative, opposition to it from within the physics community was openly expressed in a variety of forums, especially hearings before the House Committee on Space,



How the world's biggest collider would have worked (not to scale): Protons are collected and accelerated in a string of accelerators in the injection area; proton beams are hurled in opposite directions around the ring at energies of 20 trillion electron volts through two pipes containing superconducting magnets; the beams cross and the protons collide in the underground interaction halls, where huge detectors wait to observe the results.

The budgetary caps made R&D funding into a zero-sum game, which . . . turned the super collider project into what a high official of the American Physics Society called "perhaps the most divisive issue ever to confront the physics community."

Science, and Technology. The dissenters were not, as Senator Dale Bumpers, a leading enemy of the collider, remarked, "people who just fell off the turnip truck." They included former presidents of the American Physics Society and Nobel laureates. Most of them respected and admired particle physics, but, like Nobel Laureate J. Robert Schrieffer, who called himself a "loyal opponent" of the initiative to build the machine, none of them thought it a justifiable use of public resources at its multi-billion-dollar price tag.

The opposition fire intensified after the passage, in 1990, of the Omnibus Budget Reconciliation Act, which imposed caps on defense, nondiscretionary spending such as social security, and discretionary expenditures, including research and development. It limited increases in each area to the rate of inflation while prohibiting the transfer of any savings achieved in one to either of the others. By then, changes in the design of the SSC had been made that would raise its quality and reliability but would also increase its total cost—to $8.249 billion (in 1990 dollars), according to the official estimate of the Department of Energy. The budgetary caps made R&D funding into a zero-sum game, which sent a frisson of apprehension through the American physics community and turned the super collider project into what a high official of the American Physics Society called "perhaps the most divisive issue ever to confront the physics community."

The budgetary claims of the SSC particularly exercised physicists who, like Schrieffer, worked in condensed matter, a branch of physics that deals with matter in the messy aggregate of the solid state and is related to such practical arenas as superconductivity and semiconductors. According to Philip Anderson, also a Nobel Prize winner for his work in condensed-matter physics, high-energy research took a disproportionately large share of the federal basic physics research budget—receiving some 10 times more money per capita than did other fields. Its practitioners also appeared to consider their enterprise intellectually more profound. Although solid-state physics has basic conundrums to be explained, it has been mocked by Murray Gell-Mann, the brilliant particle theorist and Nobel laureate, as "squalid state" physics. Anderson told Congress that the laws of solid-state physics were every bit as fundamental as those of elementary-particle theory and, more important, that fields like condensed matter served society at far lower cost and with far greater payoffs than did elementary-particle research. "Dollar for dollar," Anderson testified in 1989, articulating the conviction of many of his colleagues, "we in condensed-matter physics have spun off a lot more billions than the particle physicists . . . and we can honestly promise to continue to do so."

Condensed-matter physicists were, to say the least, annoyed by the spin-off benefits that had been claimed for high-energy accelerators, especially the alleged decisive contributions to the development of magnetic resonance imaging (MRI) that had been implied by Lederman and explicitly declared by Deputy Secretary Moore. Nicolaas Bloembergen, who had won a Nobel Prize for his research on a precursor to lasers, testified in 1991 that neither superconducting

Sherwood Boehlert

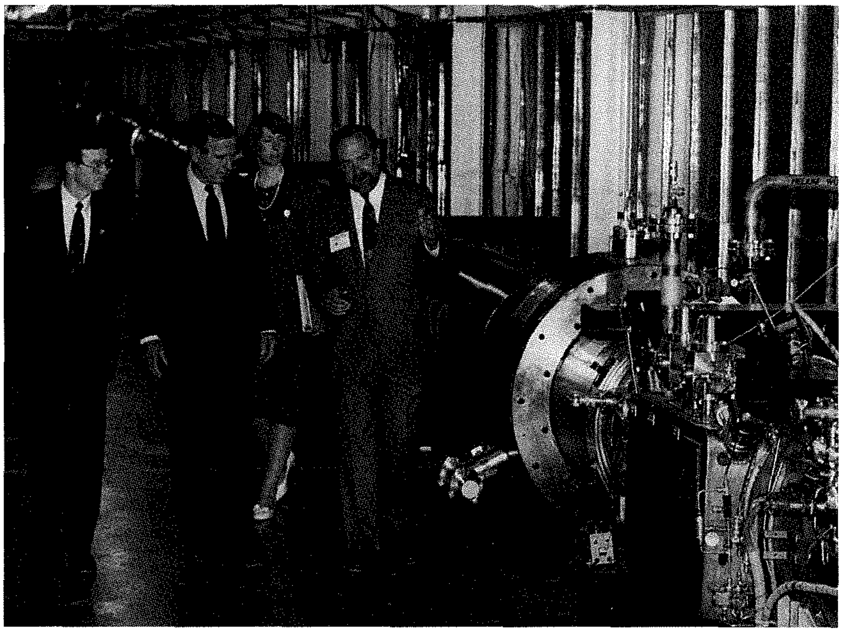
"Contrary to all the hype, the SSC will not cure cancer, will not provide a solution to the problem of male-pattern baldness, and will not guarantee a World Series victory for the Chicago Cubs."

magnets, the superconducting magnet industry, nor magnetic resonance imaging had come primarily from the development of accelerators, adding in a follow-up letter to an official at Fermilab that was entered into evidence in a congressional hearing in the spring of 1992, that "MRI would be alive and well today even if Fermilab had never existed." To Anderson, "the saddest sight of all is to see officials of the department responsible for our energy supply deliberately misleading Congress and the public with these false claims, and to see my particle-physics colleagues, many of whom I admire and respect, sitting by and acquiescing in such claims."

In the spring of 1992, amid the deepening economic recession, the attacks against the SSC were drawing blood on Capitol Hill. The Reagan and Bush administrations had assured Congress that fully one third of the collider's total construction costs would come from nonfederal sources, which now meant, at the elevated price of the machine, $2.7 billion. A billion dollars would come from Texas, leaving $1.7 billion to be provided by foreign countries; much of that was expected to come from Japan. Yet by 1992 nothing had been pledged from abroad except $50 million of in-kind contributions by India. On the night of June 17, 1992, the House voted to terminate the SSC by the hefty margin of 232 to 181, stunning its advocates everywhere into a frantic effort to reverse the decision in the Senate. The effort was successful, but early in 1993 Washington insiders were saying that, with a new Congress and a new administration in office, the prospects of the SSC's surviving another year were problematic. Voters had sent 113 new members to the House, refreshing more than a quarter of that body, with the message to cut spending. President Bill Clinton reiterated a campaign endorsement of the SSC, but his first budget called for stretching out the project by an additional three years—a ploy that would reduce its annual cost but raise the total to almost $11 billion, according to a report from the General Accounting Office, in May 1993, which declared the SSC behind schedule and already over budget.

In the House, now as in 1992, the SSC faced unremitting opposition from its chief critic, Sherwood Boehlert, a moderate Republican of independent mind and pungent tongue from the Oneida district in upstate New York. The year before, he had derided the SSC as a medley of endlessly increasing costs, threats to other sciences, and unwarranted predictions of spin-offs for competitiveness, declaring, "Contrary to all the hype, the SSC will not cure cancer, will not provide a solution to the problem of male-pattern baldness, and will not guarantee a World Series victory for the Chicago Cubs." On June 24, 1993, Boehlert and Jim Slattery, a middle-of-the-road Democrat from Topeka, Kansas, introduced an appropriations amendment to slay the SSC once and for all, with Boehlert summarily averring, "In short, the costs are immediate, real, uncontrolled, and escalating; the benefits are distant, theoretical, and limited. You don't have to be an atomic scientist to figure how that calculation works out. We can't afford the SSC right now."

The defense of the SSC was led by Waxahachie's congressman, Joe Barton, a smart, arch-conservative Republican, who in 1992 had spearheaded an unsuccessful fight for a balanced-budget amendment to the Constitution. (This prompted Congressman Lawrence J. Smith, an outspoken liberal Democrat from Florida and an enemy of the SSC, to gibe that Barton, the budget balancer, was "obviously a contortionist, being on two opposite sides of fiscal policy at the same time.") Barton's case was strengthened by allies from California, hard hit by defense cutbacks, and nearby districts in Texas, who pointed out that the SSC had already provided hundreds of millions of dollars for defense conversion, creating thousands of jobs and awarding some 20,000 contracts to businesses in most states of the Union, more than 10 percent of them to firms owned by women or members of minority groups. Congresswomen Carrie P. Meek, from Miami, Florida, and Eddie Bernice Johnson, from the Dallas area—both black and both newly elected to the House—praised the



Roy Schwitters (right), director of the SSC Laboratory, escorts President George Bush on a tour of the SSC in 1992. Here they view the test facility for the strings of superconducting magnets designed to accelerate the beam of protons through the collider tunnel.

SSC, with Meek declaring, "It gives us a chance, the minorities in this country . . . to get into jobs that are developed by technology and science."

The House nevertheless voted once again, on June 24, to end the SSC, by a strongly bipartisan vote of 280 to 150, which was so lopsided as to make the project's friends wonder whether this time it could prevail in the Senate. The SSC's most important friend in the upper chamber was J. Bennett Johnston, of Louisiana, a Senate insider who chaired the Energy and Natural Resources Committee and also the Energy and Water Development Appropriations Subcommittee, both of which had jurisdiction over the collider project. Originally an opponent of the SSC, Johnston had turned into a formidable ally after General Dynamics committed itself to producing superconducting magnets for the accelerator at a large factory in Hammond, Louisiana. An outspoken opponent of the Strategic Defense Initiative, he counted the collider as important to the post-Cold War, high-technology economy. He had also developed a genuine intellectual enthusiasm for the quest after the Higgs boson, providing the Senate with several rare moments of attempted instruction in theoretical physics, including the observation that particle physics, with its cosmological extensions, touched "the hand of God."

Johnston worked his magic again, guiding the Senate on the morning of September 30 to reject an attempt to kill the SSC by a bipartisan majority of 57 to 42. The SSC cleared a House-Senate conference with its full appropriation embedded in a multi-billion-dollar energy and water appropriations bill, but it was decisively and irrevocably turned back in the House, on October 19, by the overwhelming vote of 282 to 143. "The SSC has been lynched, and we have to bury the body," Johnston snapped.

Johnston, like a number of analysts, blamed the execution on the House freshmen, typically describing them as "the product of an angry electorate that wants to cut projects and cut perks." True enough, the 113 House freshmen voted against the collider by almost three to one and, in the charged economizing atmosphere, it did not help matters that not a single yen had been pledged for the SSC. Yet the incumbent House voted against the SSC by a margin of 200 to 111, almost two to one. And from the beginning the House, as well as the Senate, had been of divided mind on the issue of foreign cost sharing—on the one hand wanting the money but, on the other, not wanting to relinquish any of the project's jobs or control of its technological spin-offs to the nation's economic competitors. Besides, the Congress of the United States is selective in its economizing, tending to be tolerant of expenditures for high national purposes, especially if they are reinforced by important local political and economic interests. Far more important than the freshman effect or the foreign deficiency in shaping the fate of the SSC was the fact that the SSC failed to qualify on national or local grounds.

Missing at the national level was what had made physics, including its high-energy branch, so important since World War II—real or imagined service to national security. Several times both the House and the Senate debates made the point advanced at summary length in a report that the General Accounting Office prepared for Senator John Warner, a conservative Democrat from Virginia, who presented it to the Congress on May 18, 1993. The point was that the SSC had no direct bearing on national security, though its indirect benefits, such as more powerful superconducting magnets and conversion awards to defense contractors, could assist the military indirectly. Indirect defense benefits no longer sufficed. The SSC was disadvantaged by the general outlook, which went almost without saying but which was made explicit by Senator Dave Durenberger, a Minnesota Republican: "If we were engaged in a scientific competition with a global superpower like the former Soviet Union, and if this project would lead to an enhancement of our national security, then I would be willing to continue funding the project. But . . . we face no such threat."

Dissociated from national security, the SSC was subject to the play of domestic politics, presidential as well as congressional. Clinton was far less active in its support than Bush. The clout of the Texas congressional delegation had been weakened. To be sure, SSC expenditures reached almost everywhere: by 1991, more than $100 million in grants and contracts for SSC research had gone to scientists and engineers at 90 universities and institutes in roughly 30 states. But the vast majority of procurement contracts (the big money) had gone to only five states—Massachusetts, New York, Illinois, California, and, of course, Texas, which took the lion's share. Besides, as Slattery pointed out to the House, most states would pay far more for the project than they would receive from it. Boehlert summarized, with only slight exaggeration, the political dynamic of the SSC: "My colleagues will notice that the proponents of the SSC are from Texas, Texas, Texas, Texas, and Louisiana, and maybe someone from California. But my colleagues will also notice that the opponents are . . . from all across the country."

Respectful of the science or not, the opponents of the SSC considered the project simply too expensive, yet its opponents were not all simply economizers as such. The congressional debates revealed that while many wanted to kill the collider solely for the sake of cutting the budget, many other enemies of the SSC insisted that expenditures for it were unwarranted when appropriations for social programs such as Medicare, nutrition, vaccination, education, and inner-city redevelopment were being cut. Analysis of the 1993 House SSC vote in light of the voting record of incumbents on other issues shows that its opponents comprised a coalition of conservatives and, in greater proportion, liberals. Its defenders included a higher proportion of conservatives, a tendency echoed by the vote in the Senate that year, where the collider won only a bare majority of Democrats but prevailed among Republicans by more than 2 to 1. In 1993, Congressman Ralph M. Hall, of Texas, wondered wistfully whether the SSC might not "bring us back one more time to the financial position that we had in the early 1950s and the geopolitical strength that we had." The SSC tended to receive support from the minority of House members who, following a more specific but similarly wishful preference, voted for the Strategic Defense Initiative. In the end, the collider resolved into a creature of Cold War conservatism at a time when the majority of Congress—both liberals and conservatives—was undergoing a fundamental change to a post-Cold War political order.

The death of the SSC exacerbated a broad contraction of opportunities in physics that had begun with the defense cutbacks and economic downturn around 1990.

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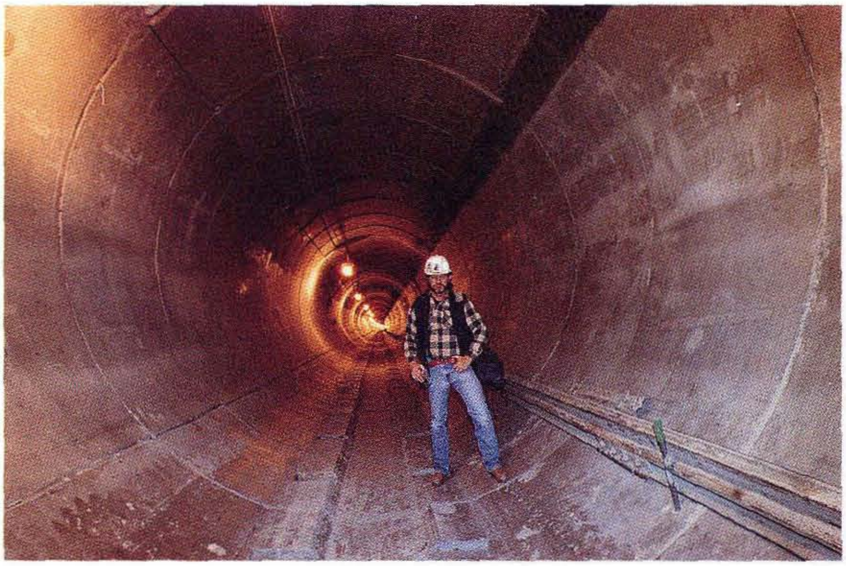
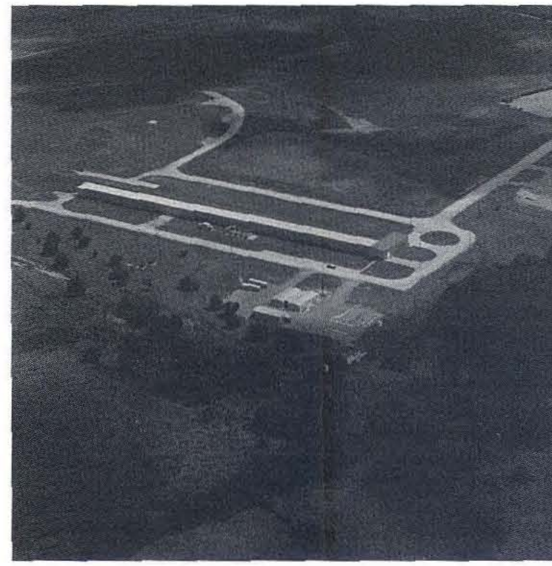
As far as many pro-SSC physicists saw it, the collider's fate defined one of the chief features of the new order: that, as Roy Schwitters, the head of the project, remonstrated, "curiosity-driven science is somehow frivolous, and a luxury we can no longer afford." Leaders of American physics variously declared the collider's death to mean that high-energy physics had no future in the United States, that the country was relinquishing its role as a scientific leader, and that the half-century-old partnership between science and the federal government was ending. At the level of grand interpretation, Murray Gell-Mann called the cancellation "a conspicuous setback for human civilization." At the level where scientists worried about jobs and opportunities, the killing of the collider was proclaimed in a letter to *Physics Today* to have sent a clear message: "Physics and physicists are not valued in this country! Enter this profession at your peril!"

The death of the SSC exacerbated a broad contraction of opportunities in physics that had begun with the defense cutbacks and economic downturn around 1990. By every measure, the supply of physicists exceeded demand in most fields and in every sector—government, industry, and academia—and predictions were that prospects would worsen as new physics PhDs continued to pour out of the graduate schools and emigré Russian physicists sought work in the United States. Young physicists applied by the hundreds for single faculty positions, even at liberal arts colleges with limited research programs. Those who did land jobs reported that competition for funds was so intense that they





When construction halted, about 15 miles of tunnel had been dug (photographer John Bird stands in a section of the empty collider tunnel above), and the facility for housing the linear accelerator (above, right) was almost complete. The Linac was finished after the vote and will remain to provide protons for cancer treatment. The facility was built by a disadvantaged small-business contractor from Fort Worth.

spent more time trying to raise money, often without success, than doing research. Some theorists left physics to deploy their analytical skills on Wall Street. Asked about the job market in 1994, one young physicist, quoted in *Science,* called it about average: "worse than last year, but better than next year."

The physicist Walter E. Massey, director of the National Science Foundation at the opening of the 1990s, observed a "growing perception that the research community considers itself exempt from the pressures of competition and accountability and 'entitled' to public funding." The impression of entitlement left by high-energy physicists—their tendency to measure the quality of society by how generously it supported their enterprise—irritated many people and infuriated some. Rustum Roy, a distinguished materials scientist at Pennsylvania State University who considered high-energy physicists "spoiled brats" for wanting a multi-billion-dollar accelerator when the country was running up \$200-billion annual deficits, was gleeful at the death of the SSC and told a *New York Times* reporter that "this comeuppance for high-energy physics was long overdue." During the 1970s, observers had warned that exponential growth in physics, measured by PhD production or any other indicator, could not continue indefinitely; the warnings had been forgotten amid the defense-driven resumption of expansion in the 1980s. Now, to resolve the emerging crisis, Lederman proposed a restoration of the golden age of autonomy and opulence that had characterized science in the United States in the quarter century after World War II, urging a doubling of the funding for all of academic science, which meant enlarging its annual budget by 10 billion federal dollars. Frank Press, who had been President Jimmy Carter's Science Adviser and was president of the National Academy of Sciences, reminded Lederman and his allies that "no nation can write a blank check for science" and that, if the number of scientists had doubled in 20 years, there was no reason why taxpayers should come to the rescue, or why science should take precedence over other meritorious demands on the federal treasury.

The vote against the SSC was not a vote against science or for an end to the longstanding partnership of science and government; rather, it signified the kind of change in federal scientific research that occurred a century ago, when hard times came to the earth sciences. During the years following the Civil War, federal support of research in the earth sciences had expanded enormously, supplying unprecedented patronage to disciplines relevant to one of the major national missions of the era: the exploration, settlement, and economic development of the Far West. Yet the degree of expansion in federal science generated suspicion among a number of fiscal conservatives that the government was spending too much money for seemingly impractical work, and among populist-oriented congressmen who did not see why funds should be spent for research on the slimy things of the earth when human beings were earning too little to keep their farms. During the depression of the 1890s, the conservatives and reformers formed a

The vote against the SSC was not a vote against science or for an end to the longstanding partnership of science and government.

coalition that sharply reduced the government's support of impractical science and forced the federal scientific agencies onto bare-bones budgets. The depression was the immediate occasion for the cutbacks, but there were other reasons also: the geographical frontier had closed, the country was emphasizing the agenda of its urban industrial order, and the earth-science agencies were no longer at the top of it.

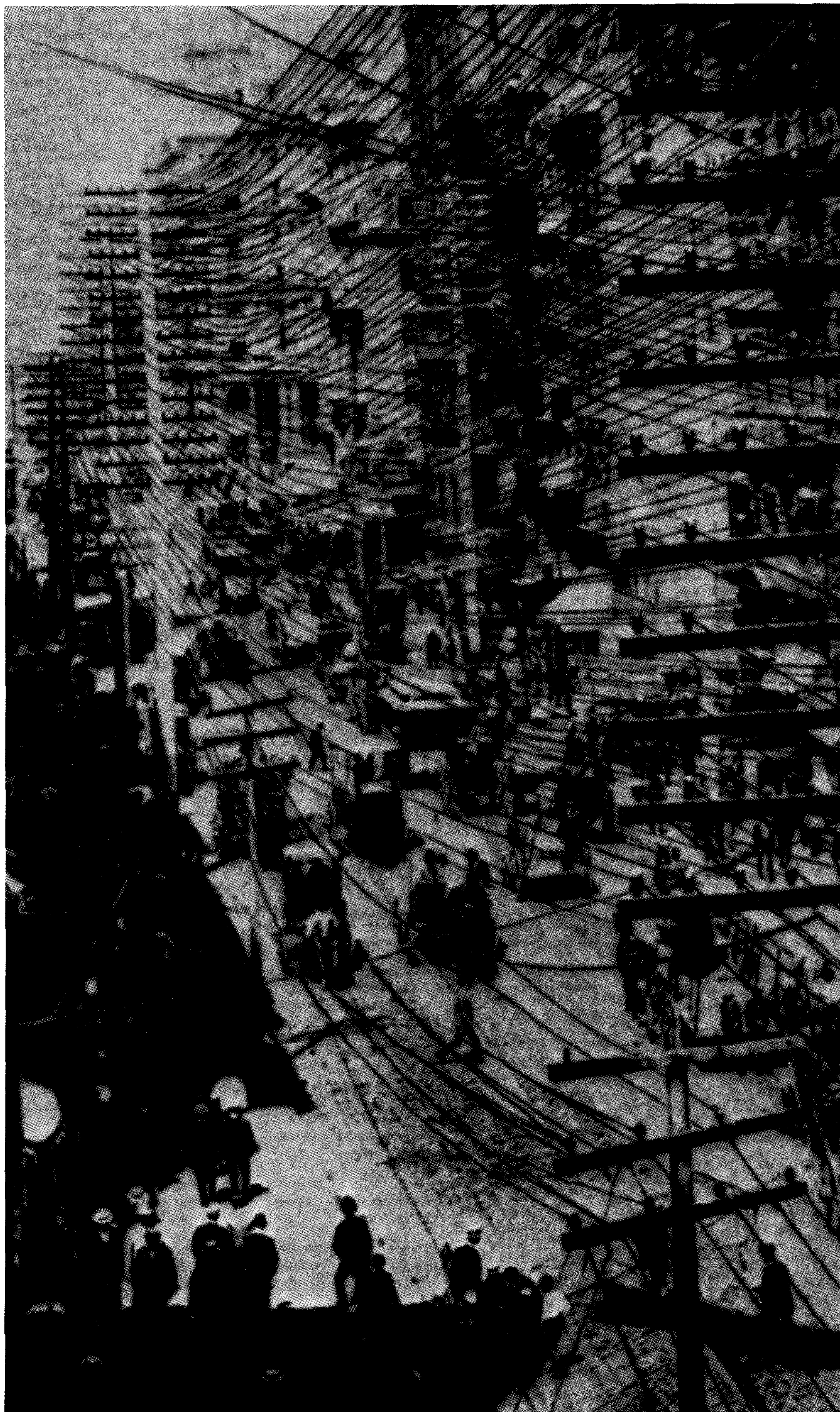
The economic downturn of the early 1990s was, similarly, the occasion for a fundamental shift in the longstanding orientation of federal policy for the physical sciences, a redirection of the science-government partnership's aims in line with the felt needs of post-Cold War circumstances. Emphasis would go to what policy makers were calling "strategic" or "targeted" areas of research—fields likely to produce results for practical purposes, such as strengthening the nation's economic competitiveness or its ability to deal with global environmental change. Emphasis would also be given to science education, and to efforts to diversify the social composition of the scientific professions so that they would better mirror the increasingly multicultural makeup of American society. (American physics remained predominantly white and male, with women accounting for only 10 percent of its yearly crop of doctorates, and blacks and Hispanics less than 2 percent.)

Yet the vote against the SSC was not a vote against all curiosity-driven research either. Virtually no significant policy maker at either end of Pennsylvania Avenue urged that all undirected, untargeted basic research be denied federal largesse. The Congress maintained appropriations at a substantial level for many areas of basic physics, awarding even high-energy research dispensation for several new initiatives in the same year that it killed the SSC. Physics continues to be recognized as a mighty source of innovation and, as such, essential to sustain in a high-technology society.

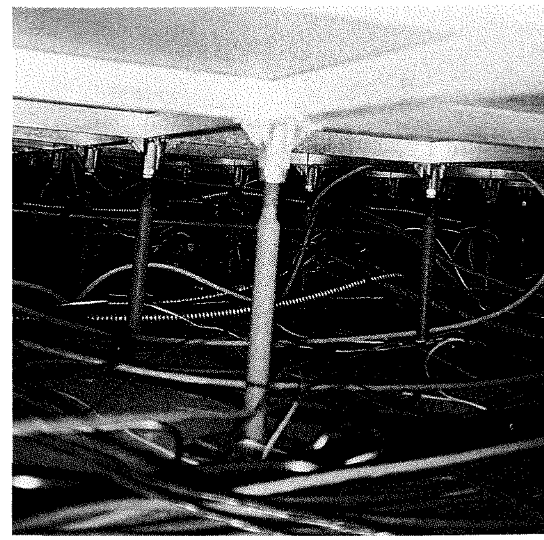
But not at any price. Observers in and out of government agreed that in the new era the big-science effort required to pursue the questions that the SSC would have addressed had to be genuinely international. During the hearings on the collider, the further internationalization of high-energy physics had been called for by critics like Anderson and Schrieffer, who remarked, "Not to build the SSC is conceivable. Not to pursue particle physics is totally unacceptable to those who are concerned with and depend upon the health of science." In 1994, high-energy policy makers were giving serious consideration to the United States' joining CERN, if CERN would accept a formal American contingent, and to participating in the development of a new accelerator, called the Large Hadron Collider, likely to be built there. The machine would smash protons and antiprotons together at only 40 percent of the SSC's energy but was thought to have a chance, albeit a small one, at finding the Higgs boson. When Sherwood Boehlert was told about the prospect at a congressional hearing, he responded favorably, calling the idea "a thoughtful specific blueprint for how to pursue this most basic of basic sciences."

Whether the federal government would commit substantial funds to CERN would be a matter for political decision—political in the best sense, that is, that politics is the means by which the state resolves conflicting claims for the allocation of resources. So, similarly, would politics determine the country's mix of investment in targeted and untargeted research. The scarcity of resources for research provoked competing interests in physics to resort to the political process in the SSC controversy, and it will likely prompt them to make a habit of the practice. With the end of the Cold War, American physics has been disestablished; its claims to a share of the public purse are no longer taken largely on faith or fulfilled with little obligation to accountability. Physics in the United States has been irreversibly incorporated into the conventional political process, become a creature of political democracy, its fortunes, like those of other interest groups, contingent on the outcome of the fray. □

Dan Kevles adapted this article from a new preface to his 1978 book, The Physicists: The History of a Scientific Community in Modern America, *which has been rereleased this month by Harvard University Press. Kevles has been a member of the Caltech faculty since 1964, after receiving his AB and PhD degrees from Princeton. Appointed professor of history in 1978, he was named the J. O. and Juliette Koepfli Professor of the Humanities in 1986. He is also the author of* In the Name of Eugenics: Genetics and the Uses of Human Heredity *(1985) and coeditor of* The Code of Codes: Scientific and Social Issues in the Human Genome Project *(1992). Kevles is head of Caltech's program in Science, Ethics, and Public Policy.*



"Infinite" Information on the Internet



by Roy D. Williams

Opposite: If the Internet is the information superhighway, then the proliferation of telephone service in the 1880s must have been the information macadam street.

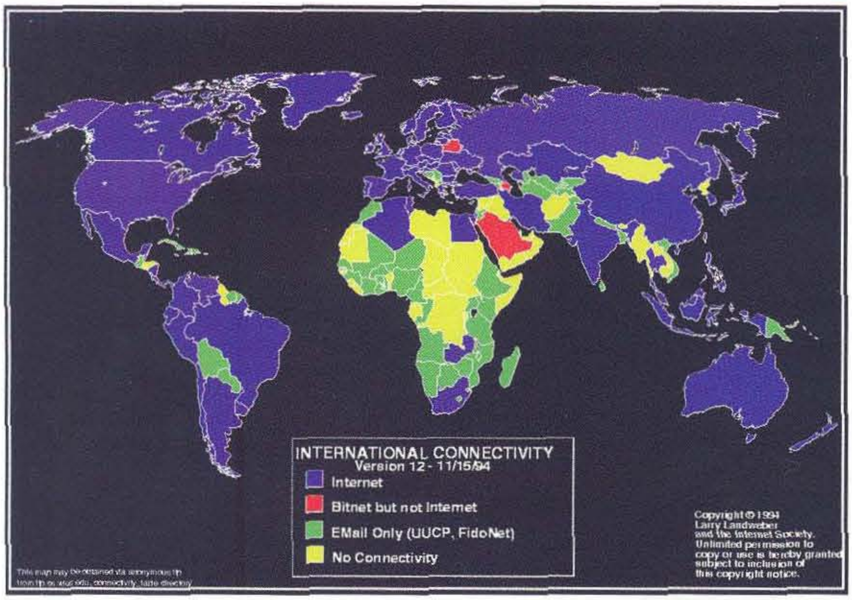
One might find the Internet worthwhile because it connects millions of computers, so that any one of them can exchange data with any other: but the really important thing is that it connects millions of *people,* enabling them to communicate with one another in ways they never could before. Like the telephone and jet aircraft, it will change our lives. The Net is a tool you can use to enhance your professional, social, and perhaps even spiritual lives. Don't expect the miracles proclaimed by the media, but don't be afraid of it either.

Like many new technologies, the Internet started out as something for the elite, but now it's becoming ordinary, and soon it will be necessary. In 1878, when the telephone was a new technology, it was very elite, very special, to have a telephone; it was a beautiful, expensive object of wood and brass—but now we take cheap, plastic telephones to the beach. The Net is still special, but it's getting less so—I'll bet that some people reading this haven't just taken a laptop computer to bed, but have taken to bed a laptop connected to the Internet! It's getting integrated into the fabric of everyday life—ubiquitous computing, ubiquitous Internet. (But some things never change: at left are phone cables along Broadway in Manhattan in 1889; above is a look beneath the machine-room floor in the Booth Computing Center.)

In this article, I'll talk briefly about the Internet's infrastructure—the hardware and how it works. Then I'll describe some of the services that are available on the Net, and give a feeling for cybersurfing—the art and recreation of exploring the Net. And finally, I'll mention some implications for the future—issues of publishing, commerce, advertising, and privacy.

The number of machines on the Internet has exploded in the last year—it's doubling every 18 months—and if it were possible for this rate of increase to continue unabated, there will be a computer on the Net for every human being in the world by the year 2010! There is no center to the Internet, except in certain minor ways, and there is no hierarchy of control. It is a radical decentralization that works, and I think this is something unusual in human creations. Indeed, this lack of a center is vital to the robustness of the Internet; it was built during the Cold War to resist nuclear attack, and yet it's ironic to contrast the military parent with the free-spirited child to which it has, perhaps inadvertently, given birth. From its conception 25 years ago at UCLA until fairly recently, the Internet was run by ARPA (the Advanced Research Projects Agency, an arm of the Defense Department). Commercial activity was first allowed just a few years ago, and now that the technology is mature and demand assured, the private sector has taken over completely. Although the Internet is worldwide, the United States has a large and very clear lead in the computer-networking industry, which will bring in many billions of dollars to this country over the next few years. In my opinion, this lead exists because the government has had sufficient vision to encourage the relevant research since the early days, together with the foresight to give up control when necessary.

The Internet is actually a network of computer



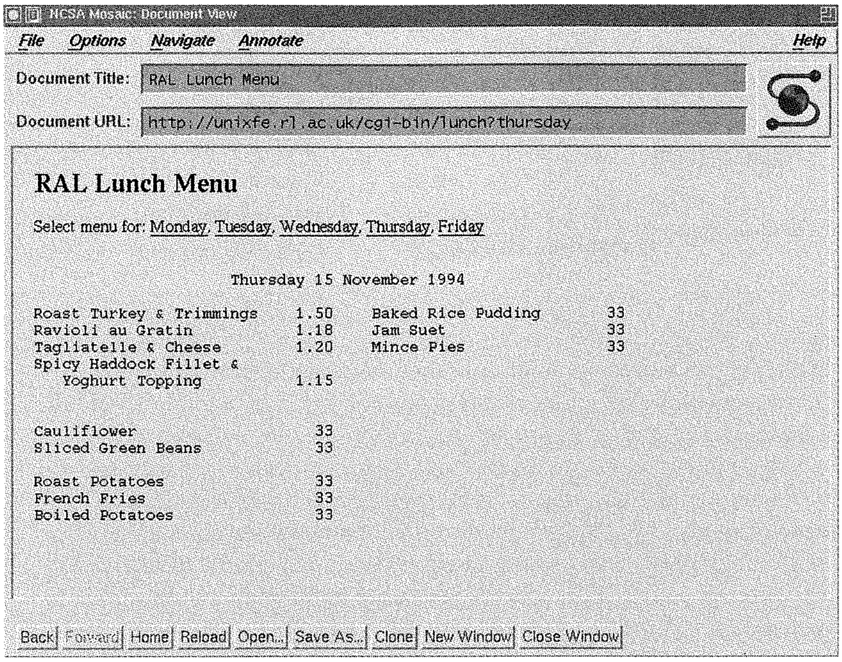
Speed (bits per second)	Device	Time to transmit Complete Works of Shakespeare (5 Megabytes)
1,200	old modem	9 hours
14,400	new modem	45 minutes
128,000	double ISDN	5 minutes
1,544,000	T1	26 seconds
45,000,000	T3 (NSF backbone)	1 second
155,000,000	ATM	0.25 second
800,000,000	HIPPI	0.05 second

Top: The world according to Internet. (Bitnet is a more cumbersome cousin of the Internet.)

Data transmission speeds (above) depend on your equipment. Caltech's campus network runs at T1 speed over fiber-optic lines—the orange cables in the steam tunnels (right). The Internet's "backbone," or main transmission lines, run at T3. (By comparison, a CD-ROM delivers one million bits per second.) Another frequently used unit of information is the "Library of Congress," which is 10^{15} bits, or one million billion bits. It would take almost 35 hours to transmit a Library of Congress at HiPPI speeds.

networks connected by data links, the speed of which determines the user's frustration level. A telephone line equipped with a fast modem can transmit data at perhaps 20,000 bits per second; if we take the complete works of Shakespeare (about 40 million bits) as a unit of information, then it would take less than an hour to be transferred at that speed, which is clearly less time than it would take to recite! But this transmission rate is not satisfactory to today's cybersurfer. It may be that we only want a small quote from Shakespeare, and if we need to get the complete works before we can see the quote, then an hour is definitely too long. Furthermore, images, sounds, and moving pictures take an inordinate number of bits to represent: one full-color image can easily require millions of bits, and compressed TV-quality video needs five million bits per second. (The dedicated Net user might be tempted by ISDN, a service offered by the phone company that is about ten times faster than a normal telephone.) Paul Messina, Caltech's assistant vice president for scientific computing, and I are working on a superfast channel called HiPPI (High-Performance Parallel Interface), which runs at 800 million bits per second. This type of channel allows supercomputers to exchange huge volumes of data at the fastest possible rates, and can also be used as a backbone service, simultaneously transmitting many customers' much smaller volumes of data over a shared trunk line.

Most of the strands connecting the Internet are fiber-optic cables, such as these at left in Caltech's fabled steam tunnels. (Fiber-optic cables are faster, and carry more signals at once, than copper wires.) These cables connect computers to one another and to switching machines called routers. In order to get sent across the Net, your data is broken up into "packets," each of which carries your computer's return address and the address of the recipient computer. A router reads the address and sends the packet to another router to which it is physically connected, and which is (hopefully) closer to the destination. To make this decision about which machine might be closer, the router needs some knowledge of its local environment; this knowledge is updated without human intervention, so that when part of the Internet is damaged, data automatically flows around the crippled link. Thus two messages from one machine—or even two packets from the same message—may reach the same destination by very different routes. The Net's protocol (known as TCP/IP) also assumes that packets may get lost, so each time a destination machine receives a packet, it sends an acknowledgment



Eating a virtual lunch at the Rutherford-Appleton Labs in Oxfordshire, England (above) required a 17-stop journey (right). The top line of each entry is the Internet address of a computer, followed in parentheses by its IP (for Internet Protocol) address, which is what the router actually reads. The second line of each entry shows the machine's type and location. The three columns of numbers have to do with the delay times, in milliseconds, at each step. But use of technology doesn't necessarily imply literacy—somebody at Sprint can't spell "Anaheim."

```
% traceroute unixfe.rl.ac.uk
traceroute to unixfe.rl.ac.uk (130.246.12.16)
sampson-151 (131.215.151.254)                  2 ms    2 ms    1 ms
        Caltech Concurrent Supercomputing Facilities
cisco (131.215.145.254)                        5 ms    4 ms    5 ms
        CALTECH CCSF/CCO cisco box
cerfnet-cit-gw.ln.net (130.152.104.1)          5 ms    3 ms    4 ms
        CERFnet Caltech Backbone Cisco Router
134.24.120.100 (134.24.120.100)               21 ms   25 ms   23 ms
        Dr. Zog CERFnet SDSC CISCO Router
mobydick.cerf.net (198.17.46.153)             18 ms   10 ms   14 ms
        (San Diego)
ucop-sdsc.cerf.net (134.24.52.112)            45 ms   46 ms   43 ms
        UCOP-SDSC CERFnet Cisco Router
sl-ana-3-S2/6-T1.sprintlink.net (144.228.73.81)   59 ms   61 ms   57 ms
        (Anaheim)
sl-ana-2-F0/0.sprintlink.net (144.228.70.2)   58 ms   74 ms   64 ms
        SprintLink DS-3 Backbone Router in Annaheim, CA.
sl-stk-6-H2/0-T3.sprintlink.net (144.228.10.25)   127 ms  181 ms   61 ms
        SprintLink DS-3 Backbone Router in Stockton, CA.
sl-stk-5-F0/0.sprintlink.net (144.228.8.233)  177 ms  147 ms   68 ms
        Sprint SL-STK-5 router in Stockton, CA
sl-dc-6-H1/0-T3.sprintlink.net (144.228.10.1) 149 ms  122 ms
        (Washington DC)
icm-dc-1-F0/0.icp.net (144.228.20.101)       129 ms  132 ms  121 ms
        Sprint ICM-DC-1 router in Washington, DC
icm-london-1-S1-1984k.icp.net (192.157.65.114)   219 ms  224 ms  204 ms
        Sprint ICM-LON-1 router in London, UK
smds-gw.ulcc.ja.net (128.86.1.12)            216 ms  207 ms  213 ms
        (University of London Computing Center)
smds-gw.rl.ja.net (193.63.203.65)            218 ms       *  265 ms
        (Rutherford Lab)
gw.cc.rl.ac.uk (130.246.4.1)                 214 ms  242 ms  227 ms
        (Rutherford Lab)
unixfe.rl.ac.uk (130.246.12.16)              205 ms  216 ms  215 ms
        (Rutherford Lab)
```

back to the sender. If the sender doesn't get the receipt back, it waits a while and sends the same packet again, and again; however, the time between these repeated packets gets longer and longer in order to avoid saturating the system with packets sent to a machine that may be broken. At the destination, the recipient machine collects all the packets and throws out any duplicates. It also puts the packets back together in the right order, if necessary, since they can arrive out of sequence after their journey.

I'll give you an example of routing. At left is a lunch menu for the Rutherford-Appleton Laboratories in Oxfordshire, England, where I used to work. (You can see that the famous jam suet is available. It's a quintessential British pudding—a great solid steaming lump of cholesteric calories and hot custard that stays in your belly for hours.) I connected to the Rutherford Lab to download that menu, and I used a utility called `traceroute` to show where the packets went, as shown in the lower figure. So from Caltech, a router owned by a company called CERFnet sent packets to the San Diego Supercomputing Center. Another router in San Diego took us to Anaheim, where we got on a line owned by Sprint, a long-distance phone service, that took us to London via Stockton, California, and Washington, DC; thence to the University of London Computing Centre and finally through a couple of machines at the Rutherford Lab.

Once your computer is on the Internet, you can use it in four basic ways:

• **Electronic mail**, or e-mail, is like a letter written on paper. You can write and respond to letters, forward them, send copies to others ("cc" the letter), receive form letters from mass mailing lists, and do all the other things you can do with paper letters.

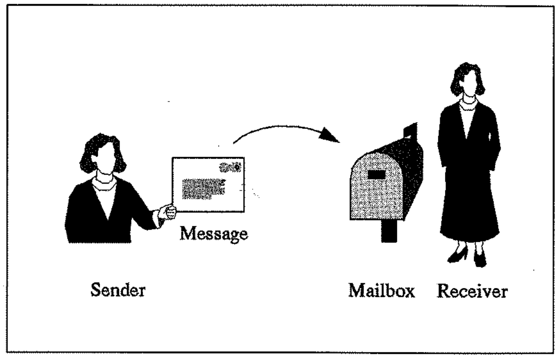
• **Usenet and the "chat" groups**, where one person informally talks to many people, is like addressing a meeting, sitting at a dinner table with others, or standing on a soap-box.

• **Telnet and FTP** services have the feeling of a person talking to a computer: to access a database such as a library catalogue, for example, or to connect to a supercomputer on the other side of the world.

• **The World Wide Web** is like going to the library, except that it's a single, incredibly heterogeneous global library where millions of people have the opportunity to publish whatever they want. You can browse, and get caught up by other topics, and find something that you didn't even know you were looking for. More difficult is to set out on a search and actually find what you were looking for!

Right: Sending e-mail is identical, in concept, to sending physical mail, also known as "snail mail." Only the addresses are different.

Below: When you're typing an e-mail message, it's very easy to make a wisecrack that the recipient may not recognize as a joke because your intonation and facial expression don't transmit over the Net. Thus a whole vocabulary of "Smileys" have evolved to convey your state of mind. Other Smileys are just for fun. Smileys are read by tilting your head to the left.



Some Domain Names

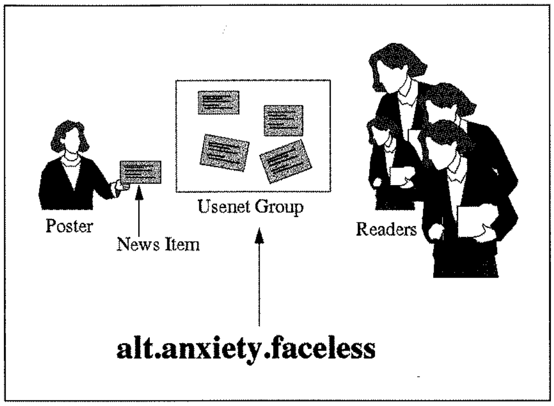
.edu	U.S. Educational Institution
.mit.edu	Caltech of the East
.com	U.S. Commercial
.mil	U.S. Military
aol.com	America Online
.ac.uk	Academic, in the U.K.
.jpl.nasa.gov	JPL (part of NASA)
.edu.au	Educational Institution, Australia

```
:-)     smile
:-D     grin
;-)     wink
:-x     kiss
:-X     big, wet kiss
:-(     frown
;-(     going to cry
:'-(    crying
%-(     confused
:-S     nonplussed
:-O     surprise
8-O     astonishment
:-]     forced smile
         (sarcasm)
:-P     aside
:-|     apathy
:-||    tight-lipped
         anger
:-b     sticking out
         tongue
:-(O)   shouting
:-@     cursing
!-(     black eye
%+{     lost a fight
@-S     cybersurfed
         too long

/:-)    beret
d:-)    baseball cap
<:-)    dunce cap
8-)     wears glasses
=:-)    punk rocker
&:-)    curly hair
:-)>    goatee
':-)    toupee
y:-(    bad toupee
*<:-)   party hat
*<%*}   partying too
         much
@%-\    hung over
         (ice bag)

=):-)   Uncle Sam
5:-o    Elvis
   )    Cheshire Cat
```

With electronic mail, the sender writes a message and mails it via the Internet to a mailbox on another computer, where it waits for the addressee to read it. The address to which a piece of mail is sent consists of a person's name followed by an "at" sign (@) and a number of words separated by dots. (They are not called *periods*, but *dots*—if you learn anything from this article, you'll learn how to pronounce an e-mail address.) As you read the address from left to right, the words refer to increasingly larger domains, just as when you read down the lines of a snail-mail address, the lines refer to larger and larger domains. So, in the address "`jill@rabbit.uea.ac.uk`", "`rabbit`" is the name of the computer containing Jill's mailbox, "`.uea`" is the University of East Anglia, "`.ac`" is the academic part of the United Kingdom Internet, and "`.uk`" is the United Kingdom. In the United States, "`.edu`" refers to educational institutions, "`.com`" is commercial organizations, "`.mil`" is the military, and "`.gov`" is government. Traditionally, e-mail addresses in the United States have no national domain. You may have noticed that British postage stamps do not have "Great Britain" printed on them, which is because it was the British who first made postage stamps. In exactly the same way, at Caltech we are "`.caltech.edu`", not "`.caltech.edu.us`", because the United States invented the Internet.

E-mail is trendy now, but soon it will become necessary. *"You don't have an e-mail address yet?"* is a disdainful question increasingly heard by the have-nots. For the haves, it is increasingly difficult to bother to communicate with the one member of the collaboration who does not have e-mail. In science, at least, e-mail makes long-distance collaborations easy. I collaborate with a colleague in Atlanta, for example, and we exchange e-mail two or three times a day. It's a nice interpolation between the formality and solidity of a paper letter and the undocumented ad-libbing of the telephone. You have time to compose the message carefully, but it is then delivered very quickly. And you don't have to talk to answering machines!

The Internet's second aspect, the Usenet, consists of newsgroups, also known as bulletin boards, each of which is devoted to a specific subject. You send a message to the newsgroup, where it gets posted, and anybody who subscribes to the newsgroup can read it. Your posting disappears after days or weeks; otherwise the system would fill up. Newsgroup names look somewhat like e-mail addresses, except that the words get more specific as you go from left to right—for example, "`alt.clothing.sneakers`". This is a real newsgroup—just one of some 5,000 accessible from Caltech. There's a newsgroup for everything, it seems. There's one for *The Simpsons*—the cartoon—and one for O. J., too. There's a Newt Gingrich newsgroup. There's even one called "`alt.tv.dinosaurs.barney.die.die.die`". Others are more serious—"`comp.sys.intel`" has been bursting with the Pentium brouhaha. Readers of a newsgroup will frequently follow a "thread," or topic of discussion, that continues



One person can reach many people by posting on an electronic bulletin board, or newsgroup, like "alt.anxiety.faceless" at left. This bulletin board, a support group for featureless cartoon characters, is fictitious, but isn't much more specialized than some of the real newsgroups (below, left) available through Caltech's computers.

```
alt.adoption
alt.angst
alt.books.reviews
alt.clothing.sneakers
alt.education.home-
 school.christian
alt.fan.letterman
alt.finals.suicide
alt.movies.silent
alt.music.naked-
 barbies
alt.pantyhose
alt.politics.usa
 .newt-gingrich
alt.privacy.clipper
alt.scottish.clans
alt.sports.baseball
 .sf-giants
alt.support.tourette
alt.tv.dinosaurs
 .barney.die.die.die
alt.tv.simpsons
ca.earthquakes
caltech.announce
 .alumni
caltech.class.math2a
clari.biz.economy
clari.biz.industry
 .construction
clari.feature
 .miss_manners
clari.news.flash
clari.world.mideast
 .turkey
comp.infosystems.www
 .misc
comp.parallel
comp.society.privacy
comp.sys.intel
de.alt.fan
 .haraldschmidt
de.market.jobs
fr.petites-annonces
 .vehicules
k12.chat.elementary
la.eats
misc.kids.vacation
rec.arts.startrek
 .current
rec.bicycles.racing
rec.crafts.textiles
 .quilting
rec.gardens.orchids
rec.woodworking
sci.math.num-analysis
sci.physics.cfd
```

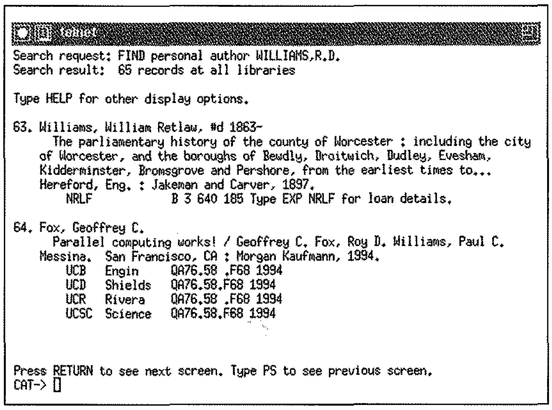
through several messages; angle brackets along the left margin of a message are used to mark material that has been included from somewhere else, generally from a previous posting on the same subject, and you can get many layers of angle brackets. Also, a lot of scientific conferences are planned and advertised through the Internet: agendas are set and speakers recruited electronically—it's only when you arrive that you get deluged with paper. And the Net isn't just for grown-ups—a 10-year-old girl in New Zealand can become key pals with a nine-year-old in Springfield, Virginia, through a group called "`k12.chat.elementary`".

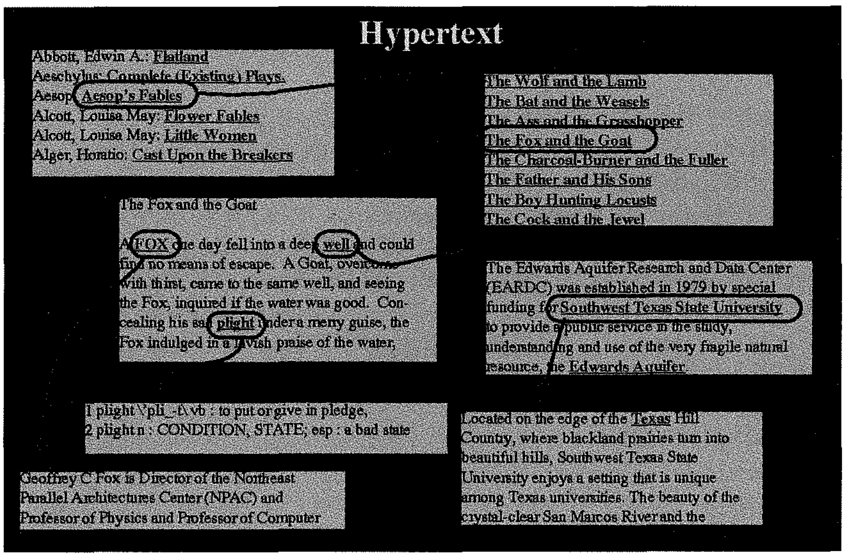
Because they put so many people in touch at the same time, newsgroups can produce adult friendships as well in a way that paper letters and the telephone cannot. For example, two years ago, before my wife and I went to Moscow, I sent a posting to the Usenet group on Russia, "`mlist.russia`", asking, "How do I get from the Moscow airport into the center of the city?" The replies ranged from "You just get on the bus" to "Don't do this—you will be shot." But one reply was from a biochemist at MIT who has a sister in Moscow, and who asked me if I would deliver some medicine because the Russian mails are so unreliable. She sent the medicine to us in California, and we met her sister in Moscow, enjoyed her company, and made friends. This relationship was formed because of the Net.

Similar to the Usenet, but real-time, is the idea of "chat." Chat means that whatever you type immediately appears on the screens of all the other people in the chat session. And you don't have to type anything—you can be a "lurker," which is somebody who listens but does not contribute. Chat is more like a pub than a town meeting—sometimes it's a party, sometimes it's a fight. We have gotten used to having a relationship with someone by telephone without ever seeing them—travel agents, for example. Now we can meet people by Internet without hearing them either, which has had the beneficial side effect of making racism, ageism, sexism, and other types of discrimination more difficult!

The third use of the Internet is Telnet and a related program called FTP, which are methods for exchanging files between computers. For example, some of the world's fastest supercomputers are here at Caltech, but people all over the country use them via Telnet. A Telnet connection allows you to load your software and data files into someone else's computer and run them, even if it's thousands of miles away. People can even fix your software from their office, without an expensive housecall. Telnet can be used for searching databases, such as MELVYL, which is the on-line catalogue for all of the University of California's libraries.

The last—and currently the most talked-about—feature of the Internet is the World Wide Web and the similar services such as Gopher. You can look up almost anything on the Web—today's Senate calendar, how to make an origami frog, weather forecasts for Siberia, a history of the vacuum cleaner. Even the *Encyclopedia Britannica* is on-line, but that you have to pay for. The Web is based on the idea of hypertext, in which multimedia documents—images, Right: A Telnet search for authors named Williams in the MELVYL database yielded, among other things, a parliamentary history of Worcester, as well as this excellent book on parallel computing.





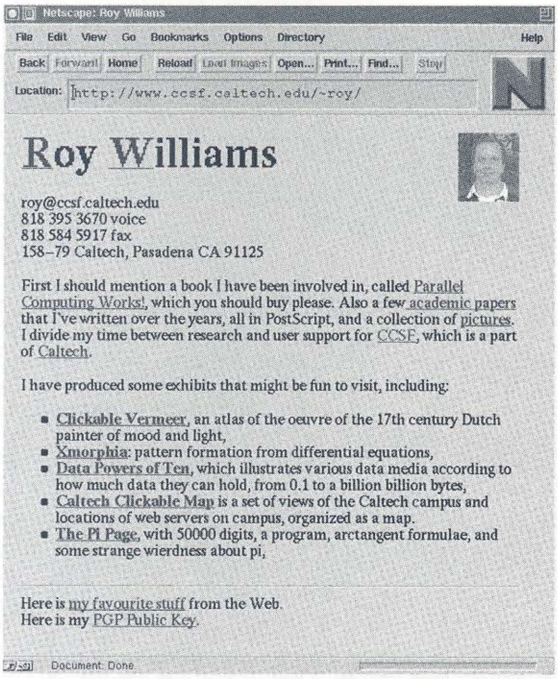
Hypertext (above) provides a way of navigating an ocean of information. The underlined words mark links (red arrows) to other documents; selecting a link and clicking on it brings the document on the arrow's other end up on your screen. Some links are short hops—looking up the word "plight," for example—while others are strides in seven-league boots.

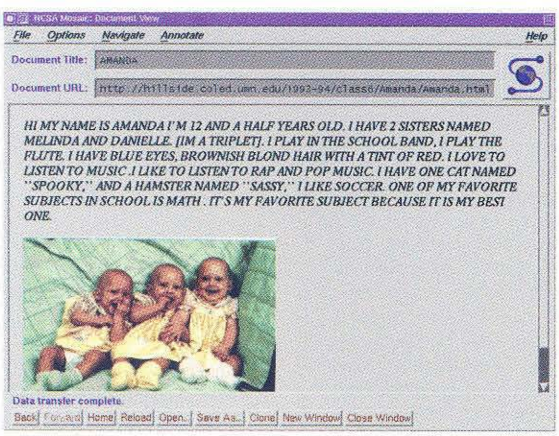
sound, and video clips, as well as text—are linked to other documents. Links can appear on your screen as underlined words or phrases, as push buttons, as icons, as images, or even as different parts of the same image. When you point your cursor and click on a link, the document you're viewing is replaced by the one at the other end of the link. A link can lead to a document on a machine anywhere in the world, which is how the World Wide Web got its name. The Web is growing even faster than the Net itself—doubling every three months, versus every 18 months for the Internet. Every human on the planet will be on the Web within five years at this rate, and every cockroach by 2002!

Hypertext is not really different, in principle, from a footnote or an endnote in text. With a footnote, you go to the bottom of the page for more information. With an endnote, you go to the end of the document. With a link, you jump to another document. An example of this is shown at left. Suppose we start with a list of books, and we want to look up Aesop's fables. We click on Aesop, and our screen is replaced with a list of Aesop's fables—fairly quickly, we hope. Now we click on the fable we want to see, for example, "The Fox and the Goat," and the text comes up. We can make significant jumps very easily. For example, "Fox" might point to Geoffrey Fox, the director of the Northeast Parallel Architecture Center at Syracuse University, which is a long way from the fable of the fox and the goat. Links are an associative way of moving through information, similar to the way human memory works by jumping from concept to associated concept. The old way of using the Internet involved remembering long, complicated addresses in order to find things. Now you can just follow your nose—even if you only vaguely remember how you found something before, you can probably find it again by following the same path.

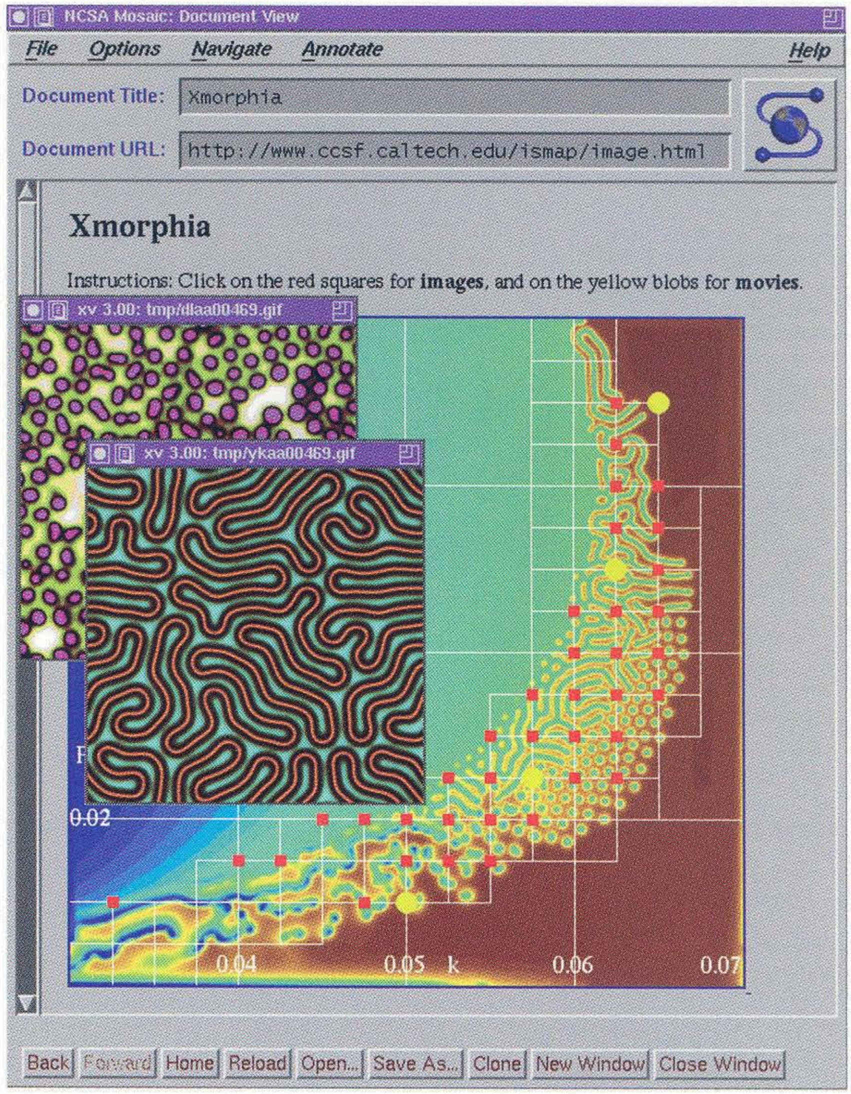
To use the Web, you use a program called a browser, such as Mosaic or Netscape. When the browser is started, it brings up your "Home Page." The Home Page is your point of entry to the Web, and you can always jump back to it by pushing the Home button on your browser, so you can't get too badly lost. You can use an institutional Home Page, such as the Caltech one, or you can create your own personal Home Page. You can put all sorts of personalized stuff on the Web, including links to whatever you think is interesting. Somebody once said, "I didn't know what to do with it, so I put it on the Web." Having said that, let's look at a few of the pages we can find on the Web...

This is my Home Page, which links to academic papers and Web exhibits that I have prepared.





Here is Amanda's Home Page. She attends an elementary school in Minnesota that's connected to the Web.



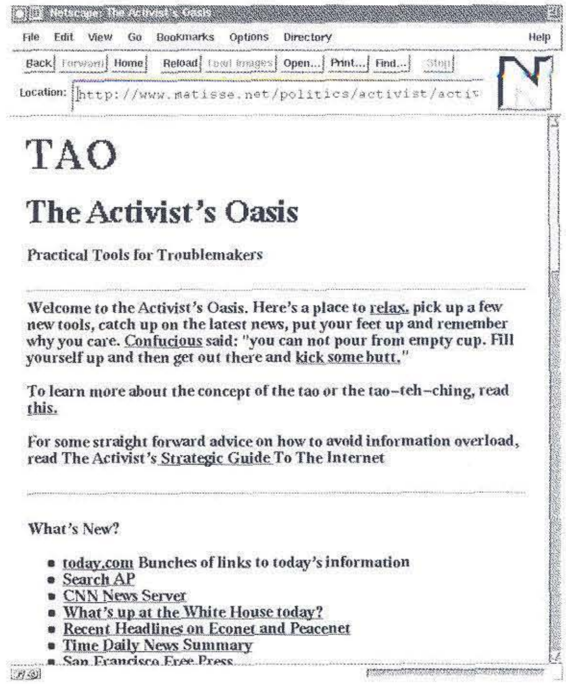
This is Xmorphia, an interactive Web exhibit that I created to show the variety of patterns that can be generated by the reaction-diffusion equations:

$$\frac{\partial U}{\partial t} = D_u \nabla^2 U - UV^2 + F(1-U)$$

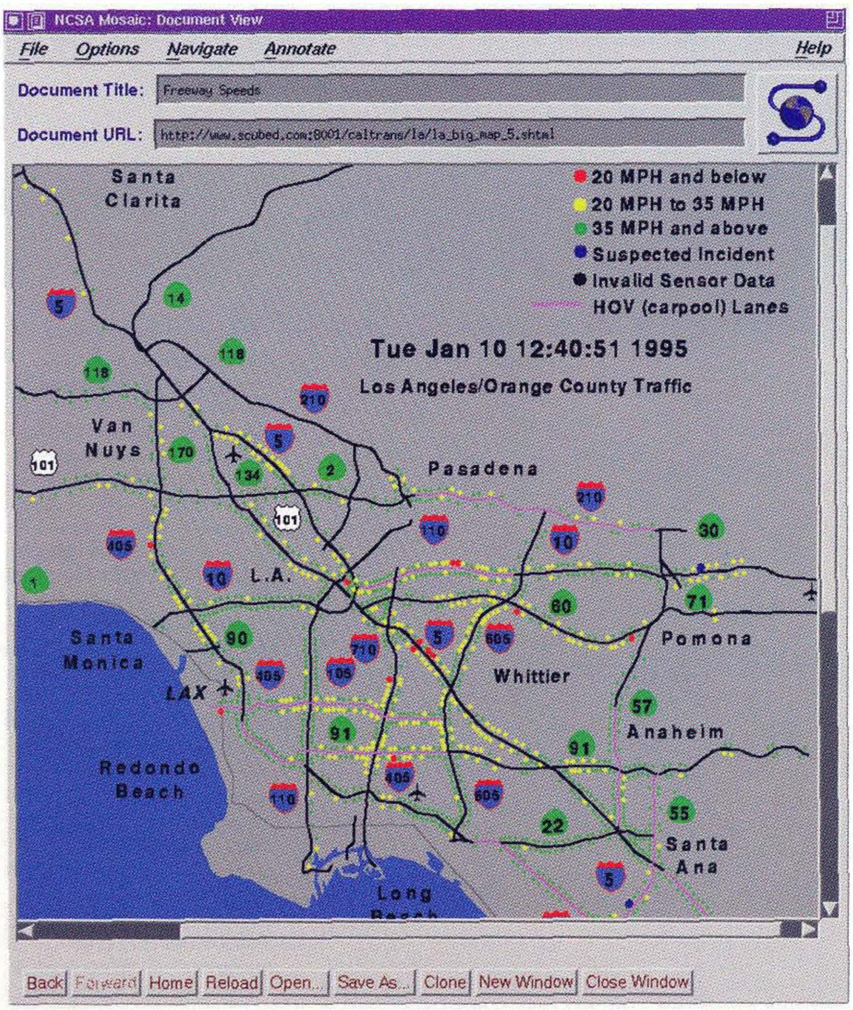
$$\frac{\partial V}{\partial t} = D_v \nabla^2 V + UV^2 - (F+k)V$$

As the parameters F and k are varied, different patterns of stripes, blobs, lines, and turbulent chaos can all be found. If you click on a red dot, you can see the pattern for those parameters. The yellow dots give you a movie of the behavior.

This is the White House Home Page. Among other things, you can get a picture of the President with Socks, the First Cat. The Clinton/Gore administration has been responsible for making a great deal of Federal information accessible by Internet.

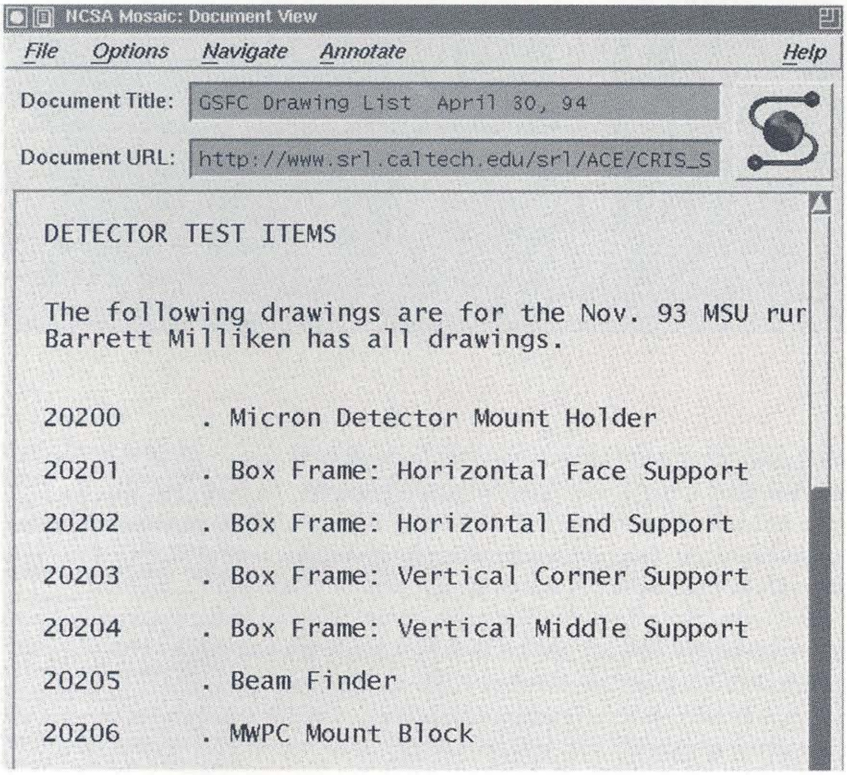


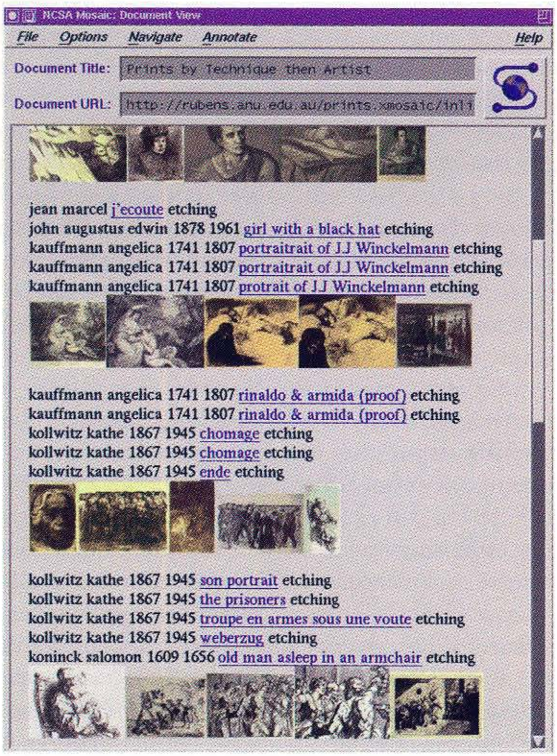
Here is a page devoted to political activism. The free flow of information makes it much easier and cheaper for groups to lobby Congress.



This page, created by Caltrans, shows freeway speeds in the Los Angeles area and is updated every five minutes. This particular image came from the noon hour on a day when we had three inches of rain. Each dot represents a set of sensors embedded in the roadway; the dot's color indicates the traffic flow there. This page was really handy when it came into being a few months ago, but now so many people use it that the connection gets easily overloaded.

The Cosmic Ray Isotope Spectrometer is a collaboration by Caltech, Johns Hopkins, NASA Goddard, and others. They use the Web to manage the project and keep track of how various tasks are progressing.





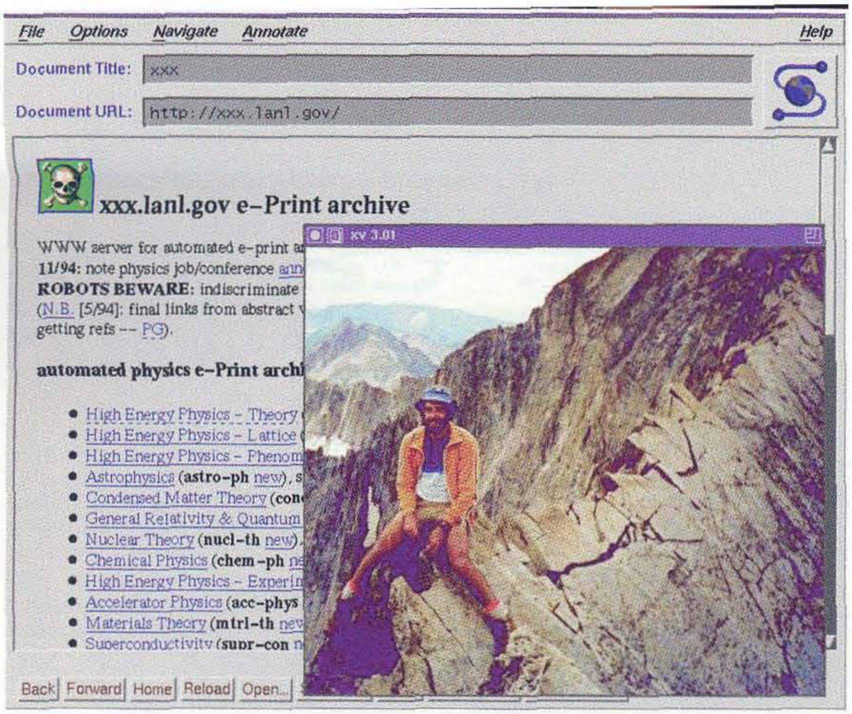
The Australian National University maintains a large selection of prints and drawings on-line, so you can visit the museum virtually. How does the existence of a virtual museum affect attendance at the real museum?

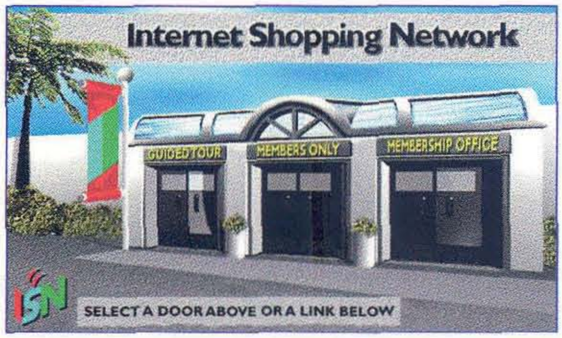
American Demographics
Daily Texan
Boston Review
Buzz
Electronic Antiquity
Federal Communications Law Journal
Internet World
Mother Jones
New Perspectives Quarterly
New Republic
Policy Review
Postmodern Culture
Quanta
Review of Early English Drama
Revue de Presse
Sand River Journal
Technology Review
The Chronicle of Higher Education
The Drama Review
The Nation
The New Yorker
The Reader
The Times Higher Education Supplement
The Times Literary Supplement
USA Today
Verbiage Magazine
Whole Earth Review
Wired

A small sample from the Net's newsstand.

In order to get connected to the Internet, you call a service provider—America Online, CERFnet, CompuServe, Netcom, Psi, or a host of others—who will charge you a fee and give you a phone number for your modem to call and software to let your computer talk to the Internet computers. (The Net is in some sense free, but you've got to pay both for the phone use and for your service provider to connect you to it.) Levels of service vary, but so far *Consumer Reports* hasn't done Internet Service Providers—I'm sure it's just a matter of time! Your service provider may offer on-line help, which the Net doesn't. Service providers may also offer extras like access to Sabre, the airline-ticketing database; legal databases such as Lexus; the world's magazines and newspapers through Nexus; specialized stock-market databases; and so on. You can get censorship from your service provider, if you want it—you can have a separate account with restricted access for the kids, which is like having the phone company prevent 976 calls being made from your phone.

Many magazines and newspapers are available on the Internet; there are even e-zines, as they are called, that exist only on the Net and aren't published on paper. A lot of publishers are transferring their paper offerings en bloc to the Net, even though they're not quite sure what they're doing or why. An on-line clone of a magazine is easy to read—there's no advertising, no perfume samples, no bits of paper dropping out on the floor when you turn the page (what does that tell us about how long this kind of service is likely to last?). An example of a more thoughtful





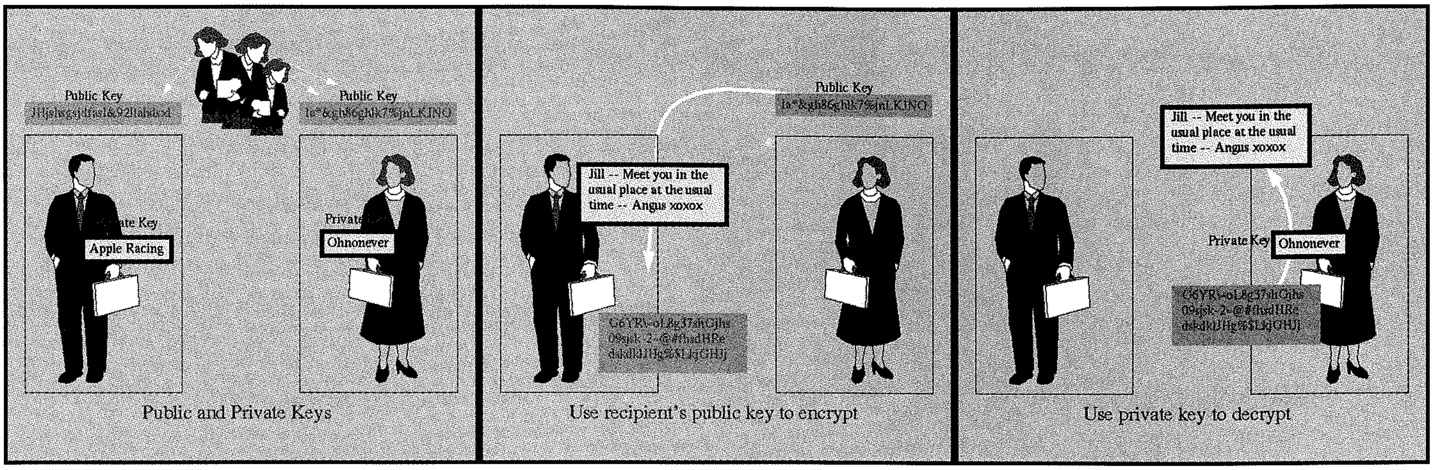
Above: Paul Ginsparg maintains a database of electronic preprints of high-energy physics papers.
Above, right: Click on the appropriate door of the Home Shopping Network's Home Page to get a demo, go shopping, or join the club.

approach is *Mother Jones Interactive*, which is a set of discussion groups and a database promoting grassroots activism. The magazine itself, *Mother Jones*, was one of the first to go on-line—you can download the cover picture if you're willing to sit and wait a few minutes, but besides that, it's all text and looks just like any other Web page. It doesn't matter whether you think the visual layout of a publication is important or not—it's simply not there in the Internet version, especially over a slow telephone link, with images switched off. It's difficult to retain brand identity under such circumstances. But new software, for example a product called Adobe Acrobat, is now available to recreate faithfully the original look of the printed page—even to the ads, which should make the publishers happy and the software popular.

There are books on the Internet: the great classics certainly, but also modern, copyrighted works. The publisher hopes that people who see the book on the Net will go out and buy the real thing, but cheapskates can simply read it on-line or print it on a laser printer instead of buying it. Will we wind up reading more things directly from the machine, without printing them? I think the era of the bedside computer is not so far away.

Scholarly articles are not just appearing on-line, but their on-line "publication" is squeezing out the importance of paper journals. Paul Ginsparg, at the Los Alamos National Laboratory in New Mexico, runs a system called "`xxx.lanl.gov`", which contains a database of preprints of high-energy physics papers. People download about 30,000 preprints per day from his system, and roughly 10 new preprints are added per day. This is really catching on because paper journals take a year or more to publish something, but when you send a paper to Ginsparg's system, it's available to the global scientific community immediately. Many high-energy physicists don't even look at the paper journals anymore, only the Internet sources. But on-line papers are not peer reviewed, and peer review is the quality assurance of the scientific enterprise; furthermore, peer-reviewed papers are what get you tenure! The future of on-line journals is a big question—how do you combine the rigorous prepublication scrutiny of peer review with the instant dissemination of your work? After-the-fact reviewing might be possible if it were true that the number of times a paper is downloaded is a useful measure of the quality of the paper.

You can shop on the Web, through many companies that have been set up in the last year or so for this purpose. Even the Home Shopping Network is available! You can buy all kinds of computer products, of course—you can even get free software demos. But you can also buy cookies, or even lingerie. To buy these products, a credit card is generally used—not because it's the most efficient payment method available, but because it's the only one. Credit cards do not provide sufficient security, they don't facilitate microbilling, nor do they provide anonymity. There's a problem with security because, unfortunately, the Internet is quite a leaky channel: the skills needed to tap into somebody else's Internet



Left: Jill's private key—"Ohnonever"—is converted by her computer into a string of gibberish that can be posted publicly for all to see.
Center: If Angus wants to send Jill a private message, his computer combines his text with her public key to produce an encrypted message that can be transmitted openly.
Right: Jill's computer then combines her private key with Angus's public message to retrieve the private message.

transactions and steal credit-card numbers aren't very rare. And you might want to buy a lot of very cheap things—if you look up something in the *Encyclopedia Britannica* on-line, for example, they might charge you a few cents, and credit cards don't work well with such small transactions. Anonymity will be increasingly important; the problem with electronic transactions is that people are going to figure out who you are, put you into a database, and sell you to marketers. Along with measures to make U.S. currency more difficult to counterfeit, the government is thinking of printing bar codes on our money. I, for one, don't like the idea of somebody scanning my bills and finding out everywhere I go and everything I buy. Several companies are trying to market the idea of electronic digital cash, known as cryptocash, that's secure, comes in small denominations, and is anonymous. Once there's trusted electronic cash, people will be able to start businesses on the Internet very easily, selling custom products to a global market with very little start-up cost.

Closely related to the question of security of information is the issue of encryption, which is a topic of heated discussion these days. The essential question is whether the government has the right, when sanctioned by a judge, to "wiretap" a computer in the same way that the law allows telephone taps. We have to decide this soon, because technology is rapidly taking over. Software to produce military-grade, unbreakable encryption is already available on the Internet for free. The system works like this: you make up a "private key"—a phrase that you never tell anyone, that's between you and your computer. Your computer then converts this private phrase into a public phrase, or "public key," which is a sequence of apparently random characters. You can't go backwards—you can't turn a public key back into a private key, even using all the computing resources in the world for the age of the universe. The public keys are available to everybody. Now, let's suppose that Angus wishes to send a message to Jill. Angus looks up Jill's public key and his computer combines that with his message to produce the encrypted text. The encrypted text is sent to Jill, who uses her private key to decrypt it and get the message back. The private keys never move across the Net, so nobody can intercept them. The only way for someone to get your private key is to look over your shoulder as you type, or to steal it if you're foolish enough to write it down. The government is trying to outlaw this kind of software—it's treated as munitions under some circumstances—precisely because they can't break it. But as the more anarchic citizens of the Net like to say, "If privacy is outlawed, then only outlaws will have privacy."

There are other legal issues as well. When Gutenberg invented the printing press in the 16th century, one of its first uses was to produce large quantities of pornographic woodcuts. The same vulgar objectives are fulfilled by any new medium, including, of course, the Internet. In October 1994, Carnegie Mellon University decided to censor the Usenet feed, some of which contains obscene material. There was an uproar in the campus community, and talk of free speech

"On the Internet, nobody knows you're a dog."

and so on. The question here is whether the Usenet feed is like a telephone company or a television station. Ma Bell is a common carrier and isn't expected to censor its traffic—you can say anything you like on the phone. Whereas a television station partakes of the limited resource of radio bandwidth, and therefore is held responsible for its content.

It's also possible to send e-mail and contribute Usenet postings completely anonymously, which can lead to very frank discussions—people can say things on the Internet that they don't say anywhere else. But it can also lead to antisocial behavior, and I think the Usenet is starting to suffer a bit from this anonymity. People don't take any responsibility for what they say anymore, and the few are spoiling it for the many. In so-called flame wars, people try to be as vicious to each other as they can with just words. In an extreme case, last Thanksgiving two journalists on Long Island not only had their e-mail "bombed"—that is, their e-mail mailboxes were filled up with rubbish—but the attackers also got into the phone company's computers and redirected the victims' incoming calls to an answering machine containing an obscene message. The Internet operates on the honor system, and if you flout that you can do people a lot of harm. But preventing this sort of thing is difficult when there's encryption and anonymity. If you can't see what's being moved across the Net, and you don't know who sent it, how can you possibly decide whether it should be there or not, and, if not, how to stop it?

In conclusion, in my opinion cybersurfing is much more fun than watching television. You can go where you want to go, look at the information that you want to look at. You can be your own publisher: it is becoming easier and cheaper every month to set up a Web server.

The Internet will make disseminating individual artistic expression easy, and we will have access to information that can empower us. It is, perhaps, the gateway to a great new virtual culture.

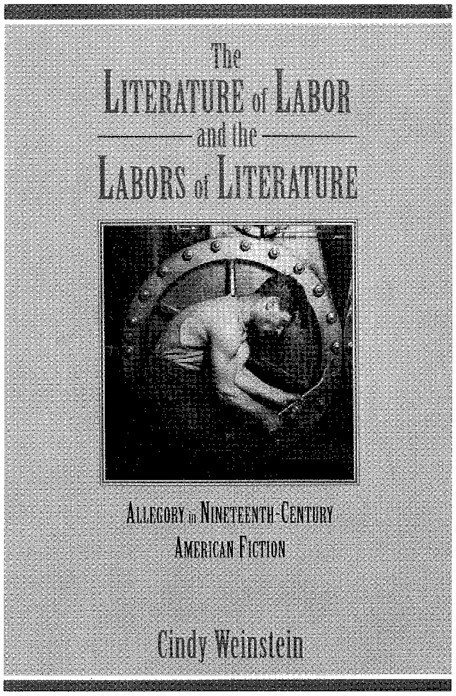
We can expect journalists—and ordinary citizens!—to report on their findings from raw data, rather than predigested information. The bright light of media attention will become more penetrating, causing honesty in reporting the facts, but also more scope for fallacious statistical arguments. Retailers will adjust to the new medium, enticing us into their cyber-stores with giveaways of information, "frequent-visitor programs," and advertisements with ever-fresh "eye-candy" pictures.

The less-exciting alternative is that we'll be forced to spend time in some awful virtual space where we won't meet anybody, and every now and then our path will be blocked by an advertisement for laundry detergent or a feminine-hygiene product, and we'll have to wait for it to finish before we can continue.

Individuals who have the technical and creative abilities to do so should try to put something of themselves on the Internet, before it gets taken over by relentless corporate agendas. We must not simply cocoon behind security gates, with our computers and lots of software, having nothing to do with the nasty cold real world outside. We must use the Internet to build a virtual community and explore what it can do. But we must make sure that it enriches the physical community and real meetings between people, rather than replacing them. □

Roy Williams is a senior staff scientist at Caltech's Center for Advanced Computing Research. He earned his bachelor's in mathematics at Trinity College, Cambridge University, in 1979. His PhD in physics followed at Caltech in 1983, and he has been a research fellow here, at Oxford University, and at the Rutherford-Appleton Laboratory in Britain. He has been working with parallel computers at Caltech since 1986, researching fluid-flow algorithms, differential equations, parallel software, high-speed networking, and the presentation of information using the Internet. He may be found by e-mail at `roy@caltech.edu` *or on the Web at* `http://www.ccsf.caltech.edu/~roy/`.

Books



by Ronald Bush

Fictional characters, E. M. Forster famously said, are either round or flat. The round ones are complex, unpredictable, capable of development and change. The flat ones are one-dimensional. They can help fill out a novelist's grand scheme, and they are sometimes amusing (the obsessiveness of johnny-one-notes is the very stuff of comedy), but they are not what we read novels for.

Forster's prejudices can be traced back to categories advanced by the poet and critic Samuel Taylor Coleridge in the early part of the 19th century. Coleridge, thinking of medieval masterpieces like Dante's *Divine Comedy* and more recent ones like Bunyan's *Pilgrim's Progress*, recognized that many great works of literature once portrayed human beings not in the round but allegorically—as organized reflections of a reality (Christian providence) that was to the author more real than everyday life. In Coleridge's opinion, though, allegory had lost its justification and allegorical characters had become unacceptable to modern readers. And, as one can see from Forster's *Aspects of the Novel* and hundreds of less intelligent counterparts, he persuaded almost everybody.

But not quite. In *The Literature of Labor and the Labors of Literature: Allegory in Nineteenth-Century American Fiction*, Cindy Weinstein, assistant professor of literature at Caltech, asks some interesting questions about why the most famous of America's writers continued to populate their fictions with flat characters: why Nathaniel Hawthorne, whom Henry James called "the most valuable example of the American genius," dabbled in allegory for his entire career; why Herman Melville ruined his sales by writing books that people considered heavy-handed; why Mark Twain, who gave us Tom Sawyer and Huckleberry Finn, also created a character named #44; why Henry Adams, probably the most insightful commentator on American culture between de Tocqueville and Robert Lowell, styles himself at the beginning of his landmark autobiograpy, *The Education of Henry Adams*, a manikin with "the same value as any other geometrical figure."

Were the great 19th-century American writers behind the times? Hardly. They are now regarded as pioneers of 20th-century European sophistication. Why then, in an age when the fashion and conditions for religious allegory had passed, did they insist on presenting artificially simplified personifications of human life?

Weinstein's predecessors had given the beginnings of an explanation. Leo Marx, in a groundbreaking book entitled *The Machine in the Garden: Technology and the Pastoral Ideal in America* (1964), pointed out that the age of the American

Our defining literature, therefore, was suffused with a horror that American life was becoming mechanical, and its anxieties increased with every innovation in technology.

Renaissance saw the rise of industry in a culture that still imagined itself, in Jeffersonian terms, an agrarian society and that still prided itself on the farmer's virtues of autonomy and closeness to nature. Our defining literature, therefore, was suffused with a horror that American life was becoming mechanical, and its anxieties increased with every innovation in technology. (And increased also, as Leo Marx's successors showed, with every new sign that America had changed from an agrarian to an industrial economy.)

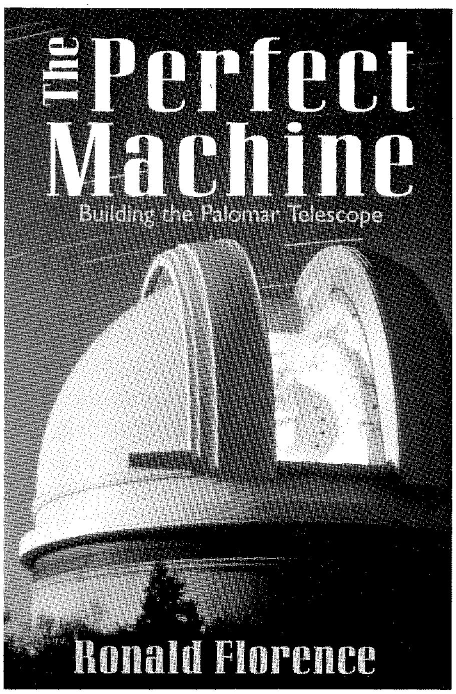
One explanation, then, of the puzzling flatness of the fictional characters of the American Renaissance was that novelists were trying to show us what, if we were not careful, we might become: machine-made, less than human. So, in a story such as Twain's *A Connecticut Yankee in King Arthur's Court*, a school is called the Man-factory, and it molds medieval boys into 19th-century automatons with all the verve and efficiency with which a few years later Henry Ford would produce Model T's. Twain clearly was writing social satire.

Or was he? Weinstein intelligently notices that *A Connecticut Yankee* delights in the success of the Man-factory at least as much as it disapproves. Nor was Twain alone in his ambivalence. In fact, as Weinstein shows in a fascinating piece of cultural history, the American writer's "weakness" for allegory had to do not simply with the rejection of machines and technology but with the way machines had provoked an ongoing and anxious redefinition of human life and work in which all the old categories had become unstuck. For example: work, Benjamin Franklin held, builds character and makes us better human beings, but factory work was beginning to look like mechanically repetitive activity that corroded feeling and judgment. Many Americans believed the former, but instinctively hated factories anyway; just as (to take another of Weinstein's examples) scientific management theorists like Frederick Winslow Taylor tried to remake workers into perfectly efficient cogs in a factory system, yet continued to appeal to the worker's sense of individualism while they did it. Such contradictions were left for American writers to worry the way one worries a toothache with one's tongue: people who blindly held to both sides of the contradictions could feel there was something wrong but couldn't see it. Making them think through it became the novelist's job.

As Weinstein shows, writing stories with flat characters was one way to foreground these contradictions—to make readers uncomfortable and start them asking about what an individual really is. And the contradictions of identity and work were just as pertinent to the writers themselves. Post-Romantic literary creation, it was said, was a matter of genius, and writing was supposed to realize the largest self of the writer in an activity more like flowering than labor. Everybody knew, though, that writing demanded more perspiration than inspiration, and that writers were as conditioned by the marketplace as were factory hands. Were they, too, in danger of becoming human caricatures? Or was there something wrong with the commonplace wisdom about genius and creation? Making allegories, which stripped some of the magic from fiction and let the writer's work show, sometimes seemed more honest.

Weinstein's study adopts the method of so-called literary New Historicism, which in her introduction she defines as trying "to illustrate a discursive field rather than the force of historical evolution." That is to say, she wants to show not how historical reality generates literary style, but to look at the ways people tell stories and fashion images of themselves in and out of fiction, and then show how each affects the other as we produce the reality we live in. There is no question but that her work refines the method and (as the early praise on the jacket cover has it) "puts Weinstein at the forefront of a new generation of Americanists." To me, the study is especially valuable because of the tact with which it conducts such an interdisciplinary investigation without losing sight of the nuances of literary narrative. To the general reader, the interest of the book will be its presentation of the dark corners of ordinary American life, in which we suddenly realize that the images we have invented of ourselves to get through the day don't quite hang together. The elements she examines perplex us still (we are still carrying around some of the same contradictions).

Ron Bush is professor of literature at Caltech, where he has been a member of the faculty since 1982. He is currently a visiting fellow at Exeter College, Oxford.



HarperCollins Publishers, 1994
$27.50
451 pages

by Ronald Brashear

It took a quarter-century to plan, design, construct, and implement the telescope. It was a state-of-the-art instrument, pushing technology to the limit. There was plenty of infighting within the project. The cooperation between science and industry rarely went smoothly. The entire project was fraught with difficulties, and there were a number of major setbacks that might have ended everything. Of course, I am referring to the Hubble Space Telescope. But the Hubble was not the first telescope to endure such birthing pains. This scenario is also applicable to the 200-inch (or 5-meter as it is known today) Hale Telescope on Palomar Mountain.

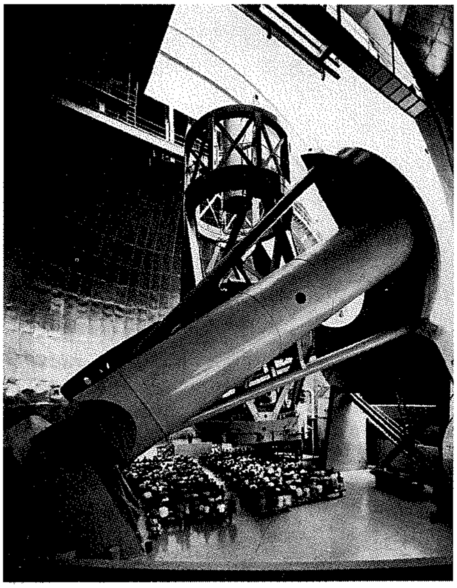
The building of the Hale Telescope is quite a story, and Ronald Florence tells it well. He does a good job in eliciting the drama, not of the Indiana Jones type, but of clashes in personality, the agonizing over the solution to engineering problems, and the intensity of the effort to produce a suitable mirror blank. You can even sense the anxiety during the long stretches while we wait for the mirror blank to cool and while it is being ground to the proper shape. Although this approach may not make for a scholarly history of the project, it does make for good reading.

There have been many tellings of the building of the Palomar telescopes, starting with David Woodbury's unfortunate 1939 attempt, *The Glass Giant of Palomar*. As Florence points out, Woodbury and his book are actually a part of the story, even helping to get a major figure on the project fired. There have been a number of recent articles on Palomar, but *The Perfect Machine* is the only full-length treatment of the Palomar story since Helen Wright's 1952 book, *Palomar, The World's Largest Telescope.*

The 200-inch telescope is the last in a line of world's-largest-telescopes that were the product of George Ellery Hale's activities. Hale, a solar astrophysicist with a talent for separating large sums of money from wealthy men, saw the value of large telescopes in solving the riddles of stellar evolution and cosmology. After constructing the 40-inch Yerkes refractor, the 60-inch reflector, and the 100-inch Hooker Telescope (the latter two on Mount Wilson), Hale and his engineer/astronomer colleague Francis Pease felt confident by 1923 that an even larger telescope could be built—provided they had the money, of course, which they estimated would have to be on the order of 5 million dollars. What proved valuable for Hale was the "old-boy" network of which he was part. He impressed Wickliffe Rose, head of the Rockefeller Foundation, with the telescope idea and by 1928 the funding for the construction of the 200-inch telescope was in hand.

Florence also does a good job in placing the 200-inch telescope project in the context of its time. He notes the key items that impinged on the lives of both the project staff and the public at large. Florence begins his book with an overview of the Shapley-Curtis "Great Debate," a defining moment in the controversy over whether nebulae were within our galaxy or were galaxies of their own. He then discusses the status of cosmology, the importance of a large telescope to the field, and the background of George Ellery Hale, the father of the 200-inch. Fortunately, he spends some time in discussing the impact of the two most significant events that affected the progress of the telescope: the Great Depression and World War II. The 200-inch project provided jobs during

His management style got the telescope built, but he won few friends with his concept that building the telescope was no different from building a huge battleship gun turret.



The 200-inch Hale Telescope was dedicated on June 3, 1948.

the Depression and allowed a number of companies to concentrate more manpower and effort onto special research for the project than they might have during a period when business was better. On the other hand, the war slowed the telescope's construction to a halt by siphoning off manpower and resources.

The most intriguing parts of the book are the depictions of the individuals involved in the making of the telescope. Of note are, first, George Ellery Hale whose frenetic pace led to his undoing. His efforts as a scientific entrepreneur, combined with his strenuous research style and direction of Mount Wilson Observatory, were the equivalent of burning the candle at both ends and led to his complete breakdown in 1910. After that Hale would alternate bouts of intense work with periods of intense exhaustion. The 200-inch telescope proved to be his final project and the one for which he would be best remembered.

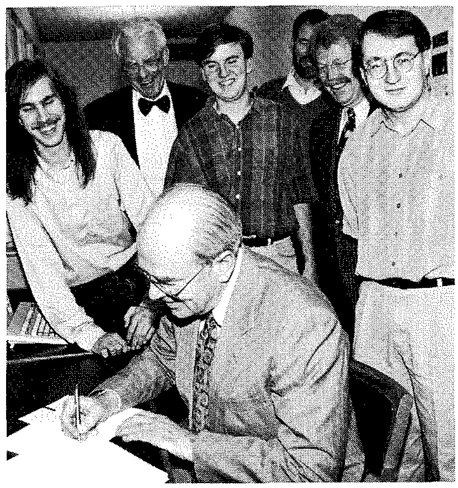
Then there were the former military figures like Captain Clyde "Sandy" McDowell, the Leslie Groves of the 200-inch. McDowell retired from the Navy and gave up a chance at admiral in order to manage the construction of the telescope. His management style got the telescope built, but he won few friends with his concept that building the telescope was no different from building a huge battleship gun turret. McDowell hired retired Army Colonel M. L. Brett to run the construction camp on Palomar. Brett ran the camp like a military operation, even serving one deliberately horrible meal a week to make the workers look forward to the others.

Florence depicts the scientists and engineers as by far the most heroic figures in the drama. It is easy to sympathize with men like George McCauley of Corning and his heroic efforts to fashion a suitable piece of Pyrex for the telescope mirror. Everything seemed to go wrong for McCauley, from a superior taking credit for his work to a flood that threatened to destroy the second attempt at a 200-inch mirror blank. Florence has also done a service by bringing to light a figure who has received very little credit: Rein Kroon, a young Dutch engineer who had been hired for the project by Westinghouse, the builders of the telescope mounting. Kroon solved most of the difficult problems involved in the telescope mounting: how to use oil-film bearings for the mounting, the internal design for the north "horseshoe" bearing, and the design of the declination bearings. The efforts of these men and many others discussed in the book resulted in the completed 200-inch Hale Telescope which entered service in 1949.

Florence spent a good deal of time researching the story (his endnotes show that he has spent much time in archives looking at primary sources), and for this he is to be commended. He has not, however, grappled with some of the significant historical issues regarding the 200-inch and so I still await a scholarly treatment of the Palomar Observatory by a historian of science and technology. A true scholarly history was probably not Florence's intent (there is no preface and, alas, no bibliography other than the works mentioned in the endnotes), but fortunately we are left with a well-researched and well-written story.

Ron Brashear is curator of the history of science and technology at the Huntington Library in San Marino, California.

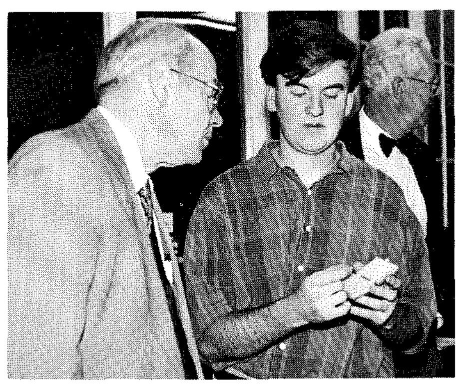
Random Walk



GAMCIT Update

Above: Some five year's worth of NASA-required paperwork culminated on February 17, when President Everhart signed the GAMCIT launch agreement on Caltech's behalf. Looking on are (from left) McCall; Maarten Schmidt, Moseley Professor of Astronomy and the project's faculty advisor; Mike Coward, a senior in electrical engineering; Daniel Burke, electronics design engineer for Caltech's high-energy physics group and GAMCIT's technical advisor; Tom Anderson, vice president for institute relations; and Ratner.

Below: Coward, who designed, built, and tested much of the project's circuitry, shows Everhart one of GAMCIT's avalanche photodiodes, which detect X rays at lower energies than CGRO can measure.



GAMCIT, an instrument designed and built by a group of undergraduates to probe the mysterious origins of certain gamma-ray bursts (*E&S*, Spring '94), has gotten the final go-ahead from NASA and will fly on the space shuttle *Endeavour* on July 20. This is a "hard" launch date, in NASA parlance, because an instrument called SPARTAN, which is also on that flight, is supposed to observe the sun at the same time that the Ulysses spacecraft passes over the north solar pole on July 31. "This launch won't slip," explains senior Albert Ratner. "Other missions will slip past us."

GAMCIT carries a gamma-ray detector and a camera to look for flashes of visible light coincident with gamma-ray bursts. If such a flash is detected, it would support a theory that says the bursts originate from within our own galaxy, as opposed to a competing theory that says these bursts come from billions of light-years away. This is a debate of some consequence, because if the bursts do come from outside our galaxy, then whatever causes them must be stupendously energetic, even by cosmological standards. But the project should return valuable data even if no flashes are seen, because *Endeavour's* orbit is different from that of the Compton Gamma-Ray Observatory (CGRO). Thus GAMCIT will see bursts that CGRO would miss.

GAMCIT is what NASA calls a Getaway-Special Canister, or GAScan. GAScans are self-contained, self-sufficient payloads that must weigh less than 200 pounds and fit into a standard canister somewhat smaller than a 55-gallon drum. On this flight, GAMCIT will be one of 12 GAScans mounted on a "bridge" across *Endeavour's* cargo bay.

GAMCIT has undergone some design changes since last heard from. "In late November, we did a total mass check and ended up 80 pounds overweight," recalls senior Benjamin McCall. "We knew we had to use fewer batteries and lose the big aluminum box." (At that time, the design called for the payload to be powered by 282 size-D flashlight batteries packed in an aluminum case that occupied the payload's bottom half.) The slimmed-down version gets by with 190 D batteries—enough juice to power a string of 16 miniature Christmas lights—packed 10 to a sleeve in custom-extruded PVC pipe. The sleeves go around the payload's periphery, where, it turns out, they actually make the structure stronger.

In order to make its launch date, the GAMCIT payload must be delivered to the Goddard Spaceflight Center in Maryland by April 17. Fabrication of the structural components is well under way up at JPL, and the students hope to complete the final assembly and have the payload ready for testing by March 15.

Random Walk continued

OK, Everybody Move One Office to the Right

On February 20, Professor of Theoretical Physics Steven Koonin (BS '72) became vice president and provost, succeeding Professor of Civil Engineering and Applied Mechanics Paul Jennings (MS '60, PhD '63), who has held the post for the past five years. On that same date Jennings became acting vice president for business and finance, assuming some of the responsibilities of former Vice President for Business and Finance and Treasurer David Morrisroe, who remains vice president and treasurer.

Watson Lectures

The Earnest C. Watson Lecture Series continues apace. Coming attractions for the balance of the academic year are *March 8*: "The Ocean and Climate: Observations from Space"—Lee-Lueng Fu, senior staff scientist, JPL; *April 26*: "Vortices in Nature and Technology: the Good and the Bad"—Anthony Leonard (BS '59), professor of aeronautics; and *May 10*: "Tall Buildings, Bad Welds, Large Earthquakes, Big Problem"—John F. Hall, associate professor of civil engineering. As is customary, all lectures are at 8:00 p.m. in Beckman Auditorium, and admission is free.

Honors and Awards

Allan Acosta (BS '45, MS '49, PhD '52), the Hayman Professor of Mechanical Engineering, Emeritus, and Professor of Computer Science K. Mani Chandy are two of 77 engineers nationwide elected to membership in the National Academy of Engineering, one of the highest distinctions accorded in the field.

Associate Professor of Mechanical Engineering Erik Antonsson is the second recipient of the Feynman Prize for Excellence in Teaching, presented annually to a professor who has demonstrated "unusual ability, creativity, and innovation in teaching."

Charles Elachi (MS '69, PhD '71), lecturer in electrical engineering and planetary science, and director of JPL's Space and Earth Science Programs, will receive the 1995 Nevada Medal for his leadership role in the nation's space program.

Paul Jennings (MS '60, PhD '63), vice president and provost, and professor of civil engineering and applied mechanics, has been selected by Colorado State University to give the First Willard O. Eddy Lecture.

Senior Trustee Ralph Landau has received the 1994 Founders Award from the National Academy of Engineering. The award honors Landau's outstanding engineering accomplishments and his role in stimulating the study of technology and economics.

Anatol Roshko (MS '47, PhD '52), von Kármán Professor of Aeronautics, Emeritus, has been elected an Honorary Fellow of the Indian Academy of Sciences. A maximum of three people can be named as honorary fellows each year, with the total membership limited to 60 honorary fellows.

Alan R. Sweezy 1907–1994

Alan R. Sweezy, professor of economics, emeritus, died December 24, 1994. He was 87.

A native of New York City, Sweezy received his AB in 1929 and his PhD in 1934, both from Harvard. He stayed on to teach economics at Harvard until 1938, when he moved to Washington, D.C., to work in the Federal Reserve Board's Division of Research and Statistics. He returned to academe in 1940, teaching economics at Williams College until 1947. He first came to Caltech as a visiting professor in 1949, and joined the faculty for good in 1950.

During the Great Depression, Sweezy became interested in the role of population growth in the Keynesian theory of employment and income, and wrote several articles on the subject. In the late 1960s, he returned to the study of the economic and social implications of population and began teaching a very popular course on population problems. He also served as associate director of Caltech's population program, which ran from 1970 to 1977, the year Sweezy retired. This program attempted to deal with various population issues, such as birth control, in their statistical and cultural contexts.

Not content to confine his energies to academia, Sweezy was also active in several off-campus organizations that deal with family planning and population growth. He was chairman of the board of the Planned Parenthood Federation of America from 1972 to 1975, and served on the board of the local chapter of Zero Population Growth.

Linus Pauling celebrated his 93rd birthday last year with his large family—here daughter Linda Kamb, seated next to him, holding Pauling's great grandson, Alexander Kamb. Barclay Kamb, Caltech's Rawn Professor of Geology, stands behind Pauling, along with the Kambs' four sons (from left) Barclay James and his wife, Barbara Kosacz, Linus, Anthony, and Alexander (Sasha), in back of his wife, Grace Wong. Linda, Barclay J., and Sasha spoke at the memorial service; young Alexander toddled around the podium.