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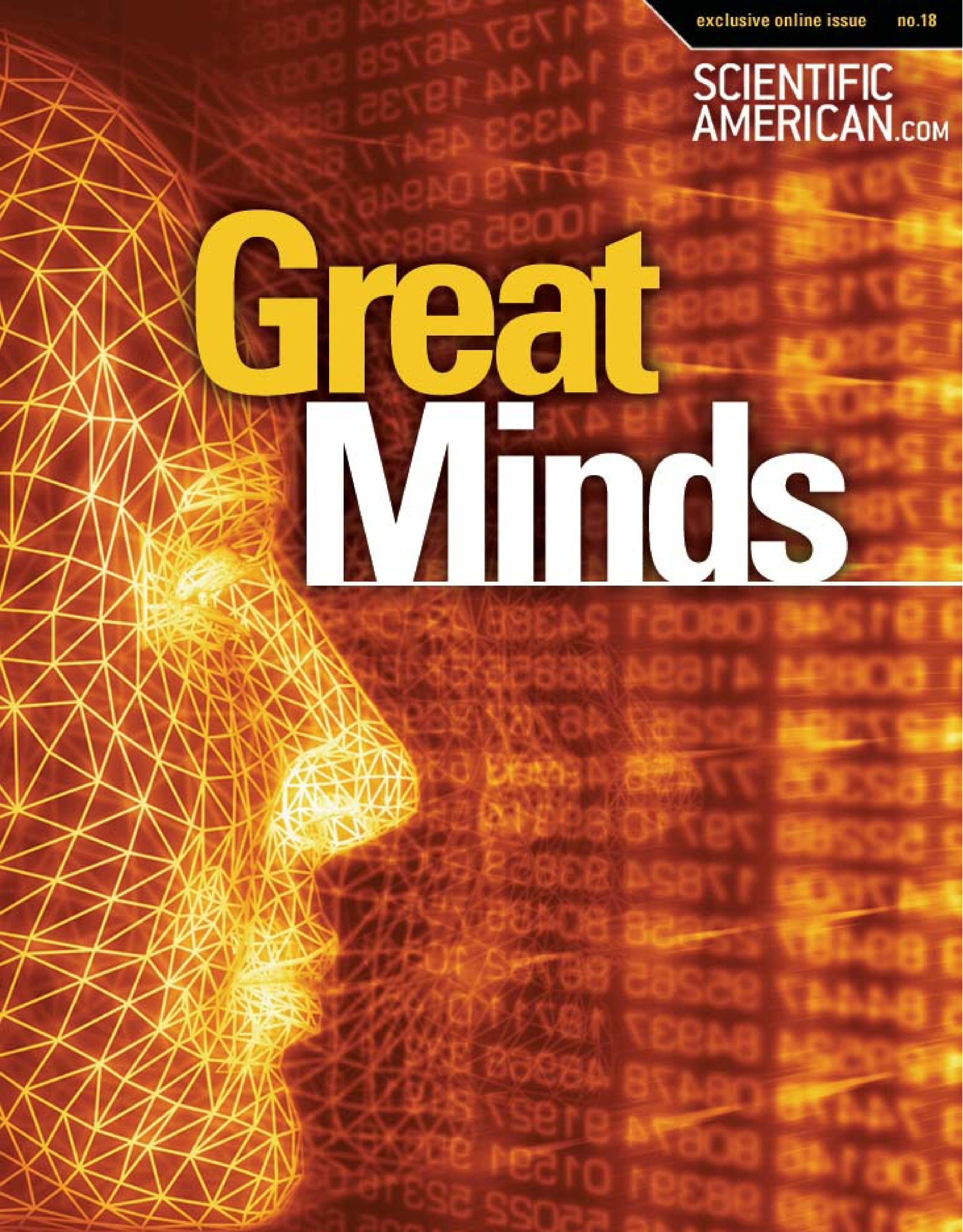

Great Minds

GREAT MINDS

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The inventor of the the World Wide Web, the biographer of chimpanzees, the father of the hydrogen bomb--*Scientific American* has a long tradition of profiling those individuals whose work has made an indelible impact on our lives and the way we view the world around us. This exclusive online issue brings together some of our most memorable encounters.

Unravel string theory with physicist Brian Greene. Find out what dinosaur hunter Paul Sereno does in his downtime. (Hint: it's more than many of us do in our uptime.) Learn how a bout with breast cancer helped astronomer Jill Tarter become a team player in the quest to detect signs of extraterrestrial intelligence. Meet maverick medical researcher Peter Duesberg, who has challenged conventional wisdom on HIV and cancer--and been largely shunned by the scientific establishment as a result. In the pages that follow, these scientists and many others share their discoveries, dreams, motivations and fears. Move over, Barbara Walters--here's *our* list of truly fascinating people.--*The Editors*

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Unearthing History

BY MARGUERITE HOLLOWAY ORIGINALLY PUBLISHED IN OCTOBER 1994

Mary Leakey waits for my next question, watching from behind a thin curtain of cigar smoke. Leakey is as famous for her precision, her love of strong tobacco—half coronas, preferably Dutch—and her short answers as she is for some of the most significant archaeological and anthropological finds of this century. The latter would have hardly been excavated without her exactitude and toughness. And in a profession scarred by battles of interpretation and of ego, Leakey's unwillingness to speculate about theories of human evolution is unique.

These characteristics have given Leakey a formidable reputation among journalists and some of her colleagues. So have her pets. In her autobiography, *Disclosing the Past*, Leakey mentions a favorite dog who tended to chomp people whom the archaeologist didn't like, "even if I have given no outward sign." So as we talk in her home outside Nairobi, I sit on the edge of a faded sofa, smiling exuberantly at her two dalmatians, Jenny and Sam, waiting for one of them to bite me. I quickly note details—her father's paintings on the wall, the array of silver trophies from dog shows and a lampshade with cave painting figures on it—in case I have to leave suddenly. But the two dogs and soon a cat and later a puppy sleep or play, and Leakey's answers, while consistently private, seem less terse than simply thoughtful.

Leakey first came to Kenya and Tanzania in 1935 with her husband, the paleontologist Louis Leakey, and except for forays to Europe and the U.S., she has been there ever since. During those many years, she introduced modern archaeological techniques to African fieldwork, using them to unearth stone tools and fossil remains of early humans that have recast the way we view our origins. Her discoveries made the early ape Proconsul, Olduvai Gorge, the skull of *Zinjanthropus* and the footprints of Laetoli, if not household names, at least terms familiar to many.

Leakey was born in England, raised in large part in France and appears to have been independent, exacting and abhorrent of tradition from her very beginnings. Her father, an artist, took his daughter to see the beautiful cave paintings at such sites as Fond de Gaume and La Mouthe and to view some of the stone and bone tools being studied by French prehistorians. As she has written, these works of art predisposed Leakey toward digging, drawing and early history: "For me it was the sheer instinctive joy of collecting, or indeed one could say treasure hunting: it seemed that this whole area abounded in objects of beauty and great intrinsic interest that could be taken from the ground."

These leanings ultimately induced Leakey at the age of about 17 to begin working on archaeological expeditions in the U.K. She also attended lectures on archaeology, prehistory and geology at the London Museum and at University College London. Leakey says she never had the patience for formal education and never attended university; she never attended her governesses either. (At the same time, she is delighted with her many honorary degrees: "Well, I have worked for them by digging in the sun.")

A dinner party following a lecture one evening led her, in turn, to Louis Leakey. In 1934 the renowned researcher asked Mary, already recognized for her artistic talents, to do the illustrations for a book. The two were soon off to East Africa. They made an extraordinary team. "The thing about my mother is that she is very low profile and very hard working," notes Richard E. Leakey, former director of the Kenya Wildlife Service, an iconoclast known for his efforts to ban ivory trading and a distinguished paleontologist. "Her commitment to detail and perfection made my father's career. He would not have been famous without her. She was much more organized and structured and much more of a technician. He was much more excitable, a magician."

What the master and the magician found in their years of brushing away the past did not come easily. From 1935 until 1959 the two worked at various sites throughout Kenya and Tanzania, searching for the elusive remains of early humans. They encountered all kinds of obstacles, including harsh conditions in the bush and sparse funding. Success too was sparse—until 1948. In that year Mary found the first perfectly preserved skull and facial bones of a hominoid, *Proconsul*, which was about 16 million years old. This tiny Miocene ape, found on Rusinga Island in Lake Victoria, provided anthropologists with their first cranium from what was thought to be the missing link—a tree-dwelling monkey boasting a bigger brain than its contemporaries.

Proconsul was a stupendous find, but it did not improve the flow of funds. The Leakeys remained short of financial support until 1959. The big break came one morning in Olduvai Gorge, an area of Tanzania near the Great Rift Valley that slices East Africa from north to south. Again it was Mary who made the discovery. Louis was sick, and Mary went out to hunt around. Protruding slightly from one of the exposed sections was a roughly 1.8-million-year-old hominid skull, soon dubbed *Zinjanthropus*. Zinj became the first of a new group—*Australopithecus boisei*—and the first such skull to be found in East Africa.

"For some reason, that skull caught the imagination," Leakey recalls, pausing now and then to relight her slowly savored cigar or to chastise a dalmatian for being too forward. "But what it also did, and that was very important for our point of view, it caught the imagination of the National Geographic Society, and as a result they funded us for years. That was exciting."

How Zinj fits into the family tree is not something Leakey will speculate about. "I never felt interpretation was my job. What I came to do was to dig things up and take them out as well as I could," she describes. "There is so much we do not know, and the more we do know, the more we realize that early interpretations were completely wrong. It is good mental exercise, but people get so hot and nasty about it, which I think is ridiculous."

I try to press her on another bone of contention: Did we *Homo sapiens* emerge in Africa, or did we spring up all over the world from different ancestors, a theory referred to as the multiregional hypothesis? Leakey starts to laugh. "You'll get no fun out of me over these things. If I were Richard, I would talk to you for hours about it, but I just don't think it is worth it." She pauses. "I really like to feel that I am on solid ground, and that is never solid ground."

In the field, Leakey was clearly on terra firma. Her sites were carefully plotted and dated, and their stratigraphy—that is, the geologic levels needed to establish the age of finds—was rigorously maintained. In addition to the hominid remains found and catalogued at Olduvai, Leakey discovered tools as old as two million years: Oldowan stone tools. She also recorded how the artifacts changed over time, establishing a second form, Developed Oldowan, that was in use until some 500,000 years ago.

"The archaeological world should be grateful that she was in charge at Olduvai," notes Rick Potts, a physical anthropologist from the Smithsonian Institution who is studying Olorgesailie, a site about an hour south of Nairobi where the Leakeys found ancient stone axes in 1942. Now, as they did then, the tools litter the white, sandy Maasai savanna. The most beautiful ones have been stolen, and one of Leakey's current joys is that the Smithsonian is restoring the site and its small museum and plans to preserve the area.

Olduvai Gorge has not fared as well. After years of residence and work there, and after the death of Louis in 1972, Mary finally retired in 1984. Since then, she has worked to finish a final volume on the Olduvai discoveries and has also written a book on the rock paintings of Tanzania. "I got too old to live in the bush," she explains. "You really need to be youngish and healthy, so it seemed stupid to keep going." Once she left, however, the site was ignored. "I go once a year to the Serengeti to see the wildebeest migrations because that means a lot to me, but I avoid Olduvai if I can because it is a ruin. It is most depressing." In outraged voice, she snaps out a litany of losses: the abandoned site, the ruined museum, the stolen artifacts, the lost catalogues. "Fortunately, there is so much underground still. It is a vast place, and there is plenty more under the surface for future generations that are better educated."

Leakey's most dramatic discovery, made in 1978, and the one that she considers most important, has also been all but destroyed since she left the field. The footprints of Laetoli, an area near Olduvai, gave the world the first positive evidence of bipedalism. Three hominids had walked over volcanic ash, which fossilized, preserving their tracks. The terrain was found to be about 3.6 million years old. Although there had been suggestions in the leg bones of other hominid fossils, the footprints made the age of bipedalism incontrovertible. "It was not as exciting as some of the other discoveries, because we did not know what we had," she notes. "Of course, when we realized what they were, then it was really exciting." Today the famous footprints may only be salvaged with the intervention of the Getty Conservation Institute. "Oh, they are in a terrible state," Leakey exclaims. "When I left, I covered them over with a mound of river sand and then some plastic sheeting and then more sand and a lot of boulders on top to keep the animals off and the Maasai off." But acacia trees took root and grew down among the tracks and broke them up.

Although Leakey steers clear of controversy in her answers and her writings, she has not entirely escaped it. She and Donald Johanson, a paleontologist at the Institute of Human Origins in Berkeley, Calif., have feuded about the relation between early humans found in Ethiopia and in Laetoli. (Johanson set up his organization as a philosophical counterweight to the L.S.B. Leakey Foundation.) And some debate erupted about how many prints there were at Laetoli. Tim White of the University of California at Berkeley claimed that there were only two and that Leakey and her crew had made the other track with a tool during excavation. Leakey's response? "It was a nonsense," she laughs, and we are on to the next subject.

A subject Leakey does not like. "'What was it like to be a woman? A mother? A wife?' I mean that is all such nonsense," she declares. Leakey—like many other female scientists of her generation, including Nobel laureates Rita Levi-Montalcini and Gertrude Belle Elion—dislikes questions about being a woman in a man's field. Her sex played no role in her work, she asserts. She just did what she wanted to do. "I was never conscious of it. I am not lying for the sake of anything. I never felt disadvantaged."

Leakey just did her work, surviving bitter professional wars in anthropology and political upheavals. In 1952 Louis, who had been made a member of the Kikuyu tribe during his childhood in Africa, was marked for death during the Mau Mau uprising. The four years during the height of the rebellion were terrifying for the country. The brakes on Mary's car were tampered with, and a relative of Louis's was murdered. The house that Leakey lives in today was designed during this time: a low, white square structure with a central courtyard where the dogs can run at night.

These pets are very important to Leakey—a source of companionship and safety out in the bush. She admires the traits in them that others admire in her: independence and initiative. (Any small joy that I have about emerging from her house unbitten fades sadly when I reread the section in her autobiography about her telepathic dalmatian and learn that he died years ago.)

We seem to have covered everything, and so she reviews her discoveries aloud. "But you have not mentioned the fruits," she reminds me. One of Leakey's favorite finds is an assortment of Miocene fossils: intact fruits, seeds, insects—including one entire ant nest—and a lizard with its tongue hanging out. They lay all over the sandy ground of Rusinga Island. "We only found them because we sat down to smoke a cigarette, hot and tired, and just saw all these fruits lying on the ground next to us. Before that we had been walking all over them all over the place." She stops. "You know, you only find what you are looking for, really, if the truth be known."

Fighting the Darkness in El Dorado

The embattled researcher answers a book's charges that he incited and exaggerated the violence of the Yanomamö BY KATE WONG

ORIGINALLY PUBLISHED IN MARCH 2001

TRAVERSE CITY, MICH.—In 1964 a 26-year-old graduate student embarked on an expedition that would take him back in time, venturing deep into the Venezuelan jungle to study a primitive Indian tribe known as the Yanomamö. Over the years he would make more than 25 trips into remote regions of Amazonia to study these people, vividly chronicling their way of life in a record-selling book and prizewinning documentaries. Napoleon Chagnon's research catapulted the Yanomamö into the limelight as the fierce people of the rain forest, and as their ethnographer Chagnon became, as one scholar described him, the most famous anthropologist in the world, living or dead.

Today the 62-year-old Chagnon (Americanized to "SHAG-non"), clad in jeans and a khaki shirt, looks the part of the contented retiree. Indeed, the casual observer would hardly suspect that the man seated on the chenille sofa across from me, with his hands behind his head and his feet up on the coffee table, now stands accused of misrepresenting and harming—perhaps even killing—the very people he was studying. Yet in *Darkness in El Dorado*, published last fall, journalist Patrick Tierney claims that Chagnon cultivated violence among the Yanomamö and cooked his data to exaggerate their behavior. He also insinuates that Chagnon and a colleague sparked a deadly measles epidemic. "If you read more than two pages of the book, you think I'm Josef Mengele," Chagnon remarks bitterly.

With such sordid scandal swirling around him, I'm a bit surprised by his relaxed demeanor. But perhaps I shouldn't be. Napoleon Chagnon is no stranger to controversy, and he has a history of rising to the challenge.

The second of 12 children, he grew up in rural Port Austin, Mich., in a house that lacked indoor plumbing. His father, having been discharged from the military, took odd jobs as a painter, police officer, bartender and factory worker to support the family. "Most of my youth was spent with my father off working someplace," Chagnon recollects. "I didn't really get to know him." High school was "stimulus-free," he laments, and after graduating, his father handed him a small sum of money and told him he was on his own.

Chagnon secured a modest scholarship that enabled him to take an intensive eight-week course on surveying. This led to a job with the Michigan State Highway Department, where he worked for a year, saving his money to go to college. As a physics major at the University of Michigan, he had to meet certain distribution requirements, including a two-semester sequence in a social science. All he could fit into his schedule was anthropology, which he had never heard of. But it didn't take long before Chagnon was hooked: "The second week into the second course, I decided that that's what I wanted to be." He stayed on at Michigan for his Ph.D.

Once he decided to study "really primitive people," Chagnon says, he had two parts of the world to choose from: New Guinea or the Amazon Basin. He opted for the latter, as it was the lesser studied of the two, and initially selected a central Brazilian tribe called the Suyà. Just before leaving, however, a revolution broke out in Brazil, making fieldwork impossible. Around the same time, James Neel, a geneticist at the university, was looking into doing research in Venezuela. The two decided to conduct a multidisciplinary study of the Yanomamö—a tribe of about 27,000 Indians who live in some 300 villages spread across an area roughly the size of Texas—about whom there were only a few published accounts. "They were quite unknown at the time, but I did know they lived in both Venezuela and Brazil," Chagnon recalls. "So if Brazil was in a revolution, I would study them in Venezuela, and vice versa." Soon thereafter, the young Chagnon set off with his wife and two small children. His family stayed in Caracas for the 15-month period while he plunged deep into the rain forest in search of "primitive man."

What little Chagnon knew about the Yanomamö beforehand did not prepare him for that initial encounter, which he described memorably in his first book, *Yanomamö: The Fierce People*:

I looked up and gasped when I saw a dozen burly, naked, sweaty, hideous men staring at us down the shafts of their drawn arrows! Immense wads of green tobacco were stuck between their lower teeth and lips making them look even more hideous, and strands of dark-green slime dripped or hung from their nostrils—strands so long that they clung to their pectoral muscles or drizzled down their chins.

He later learned that the men had taken a hallucinogenic snuff, which causes a runny nose, and that he and his missionary companion had arrived just after a serious fight between this village and a neighboring group—a fight that apparently had erupted over women. It was a pattern of violence that Chagnon would observe and report on again and again and one that would ultimately pit many of his colleagues against him.

Chagnon did not expect to see violence among the Yanomamö, nor did he anticipate that he would discover biological underpinnings to their behavior, he says. But in asserting that these conflicts arose over women and not material resources such as food, he broke with the view held by many cultural anthropologists—including those who had trained him. In that view, influenced in part by Marxist economics, material forces drive human behavior.

"Even though it was an unwanted discovery in anthropology—it was too biological—I nevertheless had to confront the fact that they were fighting over women, not scarce material resources," Chagnon recounts. In doing so, he adds, "I basically had to create and invent my own theory of society." Chagnon's Darwinian perspective on culture jibed with Harvard University scientist E. O. Wilson's 1975 treatise on animal behavior, *Sociobiology*. Chagnon—who tends to refer to his detractors as Marxists and left-wingers—thus became identified with that school of thought, which also made him unpopular among social scientists who believe that culture alone shapes human behavior.

In the years that followed, Chagnon took various academic posts and continued to return to Yanomamö territory, conducting censuses and collecting detailed genealogical data. (Appropriately enough, the Yanomamö, unable to pronounce Chagnon's name, dubbed him "Shaki"—their word for a pesky bee.) Then, in 1988, he published a paper in *Science* in which he reported that 40 percent of adult males in the 12 villages he sampled had participated in the killing of another Yanomamö; 25 percent of adult male deaths resulted from violence; and around two thirds of all people age 40 or older had lost at least one parent, sibling or child through violence.

Perhaps most stunning of all, he found that men who had killed were more successful in obtaining wives and had more children than men who had not killed. "The general principle is not so much that violence causes reproductive success. It's that things that are culturally admired and strived for are often correlated with reproductive success," Chagnon explains. "It may be wealth in one society, or political power. You don't have to be violent to have political power. But in the primitive world, where the state doesn't exist, one of the most admired skills is to be a successful warrior."

The *Science* paper came out as the Brazilian gold rush was reaching full throttle in Yanomamö territory, prompting impassioned responses from Brazilian anthropologists and human-rights activists. Portraying the Yanomamö as killers, they warned, furnished miners with a powerful means of turning the public against the Indians. Neither was Chagnon making friends in Venezuela, where his relationship with the Salesian Catholic missionaries who control the region had soured. Indeed, on a 1991 trip to a Yanomamö village he had visited on friendly terms several times before, the headman threatened Chagnon with his ax, claiming that Chagnon had killed their babies and poisoned their water. The headman later revealed that Salesian missionaries had spread these lies.

"The Salesians don't want anybody in with the Yanomamö whom they don't have control over," observes University of New Mexico anthropologist Kim Hill, an Amazon specialist. He further notes that there aren't many researchers in that area who are not openly allied with the missionaries. "Nap was the wild card. He wouldn't play by their rules, and he openly opposed them on some of their policies. I think they just decided they were going to make damn sure that he never came back again." (Raised Catholic, Chagnon recalls with irony that his mother had wanted him to enter the priesthood. "I reassured her that although I hadn't become a priest, I'm very well known in the highest circles of the Catholic Church.")

Chagnon retired in 1999 from the University of California at Santa Barbara after realizing that he probably would not be able to return to Yanomamö territory. On his last three attempts, officials in Boa Vista and Caracas had denied him the necessary permits. So he and his wife, Carlene, moved back to Michigan, into an airy, sun-filled house tucked away in the woods, on the outskirts of Traverse City, a resort town bordering Lake Michigan. There Chagnon figured he would work on a new book and maybe do some bird hunting with his dog, Cody.

That reverie was shattered, however, when a book brimming with explosive allegations leveled against Chagnon and other Yanomamö researchers came out last November. Specifically, Tierney's *Darkness in El Dorado* charges Chagnon with inciting warfare, staging films and falsifying data on the Yanomamö in order to create the myth of "the fierce people." In reality, Tierney suggests, the Yanomamö are generally fragile and fearful. The violence that did occur, he asserts, erupted over the windfall of machetes and axes Chagnon distributed in exchange for their cooperation. He further accuses Chagnon of tawdry activities such as demanding a Yanomamö wife and indulging in drugs. Tierney also strongly implies that Chagnon and the geneticist Neel, who died in February of last year, sparked a deadly measles epidemic among the Indians, claiming perhaps thousands of lives, by using an outmoded vaccine known to have potentially severe side effects.

The famed anthropologist denies it all. The idea that his gifts of steel goods (given to make their daily tasks easier) caused the warfare he observed is preposterous, he says, noting that the Yanomamö have a history of violence that predates his arrival. Gift exchange is par for the course if one wants to study the Yanomamö, he insists. Even so, he adds, his contributions hardly compare to the number of machetes doled out at the missions.

I read Chagnon the passage describing his purported request for a Yanomamö wife. "That's so goddamn crazy," he retorts, explaining that the story is a distortion of his referring to a girl as his cross-cousin—a kinship term also used for "wife" in the Yanomamö language. The claim that he staged his award-winning documentaries is likewise false, Chagnon maintains. And with regard to drugs, he says he took the ceremonial snuff only once—to reassure some Indians who had been threatened by a missionary with being thrown into a chasm of fire if they continued to worship their "demons."

As to mischaracterizing the Yanomamö as fierce, John Peters, a sociologist at Wilfred Laurier University in Ontario who spent 10 years among the Brazilian Yanomamö, notes that the Indians proudly describe themselves that way. "They are a very passionate people," he observes, who are willing to go to extremes in "their anger and fury and their sense of justice." Moreover, according to Hill, who has posted a scathing critique of *Darkness* on the Internet, the only other South American tribes in which Chagnon's hypothesis has been tested—the Waorani and the Ache—appear to link "killers" and reproductive success, too. (Hill, however, interprets the data to indicate that women are attracted not to killers but to men who are big, strong and healthy—traits that also make them more likely to be successful at killing during a raid.)

"Tierney is not a scientist," Chagnon bristles, referring to the journalist's suggestion that he adjusted his data to fit his theory. "No serious scientist has ever doubted my data." Tierney's measles argument has also drawn criticism. Anthropologist Thomas N. Headland of the Summer Institute of Linguistics in Dallas obtained documents from Protestant missionaries indicating that the measles outbreak preceded the arrival of Chagnon and Neel. And various vaccine experts argue that although the side effects of the Edmonston B vaccine may have been severe, without it, many more Yanomamö would have died.

Yet even those who have defended him so vigorously acknowledge that Chagnon does not have a sterling record. Around 1991 he started collaborating with Charles Brewer-Carías, a controversial Venezuelan naturalist and gold miner, and Cecilia Matos, the ill-reputed mistress of Venezuela's then president, Carlos Andres Pérez. Chagnon was being prevented from doing research at the time, and going this route was his last resort, recalls University of Nebraska anthropologist Raymond Hames, who has worked with Chagnon. Still, "it was really unwise," he says. And Hill notes that some Yanomamö with whom he has spoken complain that, considering the fact that Chagnon made his career off working with them, they have received very little in return.

For his part, Chagnon is staunchly unapologetic about the way he conducted his life's work. "I'm not ashamed of what I've done. I think that I've produced one of the most significant and rare sets of archives and anthropological data that could have possibly been collected in this kind of a society," he declares. Although their lands are protected (thanks in large part, Chagnon says, to the influence he and Brewer-Carías had on Pérez), their culture is changing rapidly. "It may turn out that future anthropologists will have to rely entirely on archived materials—the sort I collected—to figure out some of the questions they want answers to about the primitive world. People like the Yanomamö aren't going to be around very long."

As of press time, the American Anthropological Association task force that had been appointed to determine whether the allegations made in Darkness warrant formal investigation was still deliberating. The organization is also reviewing its code of ethics and guidelines for research. In Venezuela, the government has issued a moratorium on all research in indigenous areas.

It is too soon to know if the controversy will be anthropology's Armageddon. But Chagnon himself seems destined to remain the lightning rod. He was one of the first people to explore the connection between biology and behavior, "at a time when it was politically very unpopular to do so," Hill reflects. "And he's still paying the price for that."

Jane Goodall

ORIGINALLY PUBLISHED IN OCTOBER 1997

Gombe's Famous Primate

BY MARGUERITE HOLLOWAY

DAVID S. HOLLOWAY *Apix*

She is standing on the porch of a wooden house in Washington, D.C., just under the thick branch of a tree and just to the side of a tangle of creepers that gives the carefully kept urban backyard a hint of the unkempt, of the vegetative wild, when she does it again. A loud, breathy, nonhuman crescendo silences the garden-party goers and the Goodall groupies, some of whom have driven hours to see her. It is the chimpanzee pant-hoot call, and it has become one of Jane Goodall's signatures. She punctuates most of her speeches and lectures with the wild cry, bringing Tanzanian forests to audiences who have never set foot in Africa and, at least for a few moments, eliminating whatever distinction her listeners were drawing between the scientist and her subjects.

Even as she makes the eerie sound—which is used to establish contact between far-flung members of a troop—Goodall manages to seem completely still. Thirty or so years of sitting quietly, observing the chimpanzees at the Gombe Stream Research Center, have left their mark. Goodall moves without seeming to move; she laughs and turns and gestures while giving the impression of utter calm and stasis. Which is something Goodall has needed a lot of in her dealings with people as well. Renowned and revered today, Goodall's approach to primatology was anything but standard when she started her work. Now that the researcher has moved out of the forest and onto the road, advocating for animal rights and raising money for chimpanzee sanctuaries, she has again met with controversy.

None of that conflict is in the air in this sloping, sunlit garden. Carrying copies of her books, including *In the Shadow of Man* and *Through a Window*, members of the rapt audience listen to Goodall review some of what she has learned about wild chimpanzees. The simian characters—Flo, Flint, Fifi, Pom, Passion—are as familiar to many as family or old acquaintances. Goodall talks about the importance of mothering styles in shaping chimp development, about how a four-year mother-daughter killing spree eliminated all but one newborn chimp and about how it was Louis Leakey who pointed out that chimpanzees, with whom we share 98 percent genetic homology, provide a window into our distant past.

It was, of course, Leakey who sent Goodall out to peer through that frame. It is a famous story by now. Goodall, who was born in London in 1934 and who was always obsessed with animals and with stories of Dr. Doolittle, worked as a waitress and a secretary to raise enough money to get to Africa. Once in Kenya, Goodall called Leakey to say she wanted to work with animals. After informally testing her knowledge of wildlife during a tour of a game reserve, he took her on as assistant secretary and then, in 1960, sent her, untrained, into the field to observe chimpanzees.

Leakey's plan was to find young women—whom he felt would be patient observers and perhaps less threatening to their male subjects than men would be—to study each of the great apes. The other "trimates," Dian Fossey, who studied gorillas, and Birute Galdikas, who studies orangutans, followed soon behind Goodall. The legacy of the legendary paleontologist and his protégés has been far-reaching: primatology is one of the few scientific fields that has equal numbers of men and women. "Jane Goodall has had a profound effect as a role model. Thirty years ago she showed that it was okay for a woman to live in the jungle and watch wild animals," explains Meredith Small, an anthropologist at Cornell University. "I have several young women every year coming into my office telling me that they want to become an animal behaviorist like Goodall. She opened the door for women who dream of doing fieldwork."

Goodall herself initially went into the field accompanied by her mother, Vanne, because the remote forest on the banks of Lake Tanganyika was considered unsafe for an unescorted young woman. The chimps eluded Goodall at first, but months of patience paid off when she observed two previously unrecorded activities: meat eating and the use of long grass as a tool to pluck termites from a mound. By consistently following the apes, Goodall was able to observe their various interactions and to piece together the social structure of her group. She described strong and not so strong mother-infant bonds, sibling loyalty and rivalry, male displays and attacks and dominance, and sexual behavior—all in terms of individuals with humanlike personalities. Flo was a wonderful mother and a very sexually attractive female; her son, Flint, was overly attached and died of grief shortly after his mother died; Passion was cold-hearted, killing and eating the offspring of other females.

Such personal descriptions were not standard fare. "One of the things that was happening in primatology and in evolutionary biology in general as Jane was beginning to influence the field was that people were just beginning to look at individuals. She was already doing that as a matter of temperament," notes Sarah Blaffer Hrdy, an anthropologist at the University of California at Davis. "She was unabashed in her willingness to anthropomorphize and to allow her emotions to inform what she saw the animals doing."

"In 1960 I shouldn't have given the chimps names," Goodall sardonically recalls, fingering the bone Maori talisman she wears as a necklace. "They didn't have personalities, only humans did. I couldn't have studied the chimp mind, because only humans had minds." She goes on to explain in a voice simultaneously soft, hard, strong, calm and passionate that her first paper for *Nature* came back with the words "he" and "she" changed to "it." "How they would even want to deprive them of their gender I can't imagine. But that is what it was, animals were 'it.' Makes it a lot easier to torture them if they are an 'it.' Sometimes I wonder if the Nazis during the Holocaust referred to their prisoners as 'its.'"

Goodall has written that missing a background in science allowed her to view animals in more human terms. Rather than thinking of them as other, she thought of stages of life and of emotion—childhood, adolescence, grief, attachment, rage, play—and because of that, saw animal behavior in new terms. Yet her lack of education could have been a liability as she tried to get her discoveries out into the world, and so Lea-key arranged for her to study ethology at the University of Cambridge. Goodall received her doctorate in 1965, the same year that *National Geographic* introduced "Miss Goodall and the Wild Chimpanzees" to the world.

Fame and scientific imprimatur secure, Goodall continued her work at Gombe, training a stream of students. As the camp grew in size, however, so did the number of interactions between subjects and researchers. Some of the field observations have been criticized as difficult to interpret, such as fights for food. "By changing the environment and feeding them bananas, it skewed results," maintains Robert Sussman of Washington University. "You can't tease apart the effect of humans."

Goodall regrets banana feeding—particularly as it made Leakey skeptical of all her subsequent observations—but she is neither sorry about intervening during a polio epidemic among the chimps nor sorry about threatening Passion and her daughter with a stick so Little Bee could escape with her newborn baby. "I wasn't a scientist. I didn't want to be a scientist, I wanted to learn about chimpanzees," she says emphatically. "So there was this huge outcry: 'You know you are interfering with nature!' But, on the other side, there were all these scientists going out and shooting lots of their study population to examine their stomach contents. Is that not interfering with nature? It is so illogical."

Part of her current work, she explains, is to talk to students about science, to correct the misapprehension that science has to be dispassionate. "I am often asked to talk about the softer kind of science as a way of bringing children back into realizing that it is not all about chopping things up and being totally objective and cold."

Goodall describes this educational effort as her fourth phase of life. The first entailed preparation: reading and dreaming about getting to Africa. "Phase two was probably the most wonderful I will ever have in my life. I was so lucky I spent all of this time in paradise with the most fascinating animals you can possibly imagine." Phase three was getting the work into the scientific community. And her current stage came to her, she recounts, like the vision to St. Paul on the road to Damascus, during a conference in Chicago. "Everybody showed slides of what was happening in their area, and it was like a shock. Then we had a session where people showed videos secretly taken in some of the labs, where chimps are in medical research, and that was like a visit to Auschwitz for me. It was as simple as that. I thought: now it is the payback time."

Payback means speaking out against the unnecessary use of animals in medical research and establishing sanctuaries for illegally captured chimpanzees. Goodall has been attacked for her activism, but she is careful to note that she supports certain uses, that her mother's life was saved by a pig's heart valve. Goodall has also been criticized for saving captured apes, rather than putting money into maintaining habitat in the few places where the estimated 250,000 remaining wild chimps live. Again, the individual is paramount, she says: How could she ignore the starving, bedraggled chimps she has met in markets all over Africa?

Although she spends all her time these days fund-raising, Goodall still ponders chimp behavior. She is particularly interested in female transfer: why some females leave their group and stay away, why others leave, become pregnant and come back. Findings continue to come out of Gombe as well. In an August issue of *Science*, Goodall and Anne Pusey and Jennifer Williams of the University of Minnesota describe the role of hierarchy in female reproductive success. Although female hierarchy is difficult to establish—it is not as blatant as male dominance—the researchers used submission calls recorded between 1970 and 1992 to determine social standing. They concluded that the offspring of high-ranking females have higher survival rates and that their daughters reach sexual maturity earlier.

Finished with her garden talk, Goodall stands on the porch, shaking people's hands before she has to rush off to another talk in a vast, sold-out auditorium. The line is long, and it is filled with young women.

Paleontology's Indiana Jones

From digging to designing, this celebrity scientist has helped map the evolution of dinosaurs

BY KATE WONG

ORIGINALLY PUBLISHED IN JUNE 2000

CHICAGO—Paul C. Sereno can't talk to me when I arrive on a Friday morning in early March. The University of Chicago paleontologist is busy preparing the lecture for a class that starts in 10 minutes. So I sit silently in a chair opposite him, taking in the ferocious-looking saber-toothed tiger skulls, dinosaur claws and other paleontological curiosities that perch atop the bookcases lining his spacious, sunlit office. Moments later he springs out of his seat, collecting the notes and transparencies. "It's been a hectic morning," he says hurriedly, explaining that he forgot his notes at home, as we head downstairs to pick up some slides. Realizing now that he's left something in his office, Sereno dashes back up the stairs two at a time. Within seconds he races down again, and we're off to class at a similarly aerobic pace.

Although it comes with a certain amount of chaos, such abundant energy has served the 42-year-old Sereno well in his prolific career as dinosaur hunter, scholar and popularizer. He has explored remote regions of South America and Africa and turned up numerous dinosaur skeletons (about a dozen of which represent new species)—discoveries that have elucidated such murky issues as the origins of dinosaurs and the effects of continental drift on their evolution.

There was a time, however, when such accomplishments seemed unlikely. Born and raised in Naperville, a western suburb of Chicago, to an artist and a civil engineer, Sereno was the second of six children. But unlike his siblings, he performed poorly in school. In fact, by sixth grade he was nearly flunking. "I couldn't imagine finishing high school," he says.

Fortunately, once Sereno actually entered high school he discovered something he loved, something he was good at: art. Driven by his newfound aspiration, he settled down. "I started studying during my lunch hours to make up the ground," he recounts. Eventually improving his entrance exam scores dramatically, he was accepted at Northern Illinois University, where he planned to become an artist.

He studied painting, favoring the detailed style of the 17th-century Dutch still-life artists. But during his junior year, on a trip to the American Museum of Natural History (AMNH) in New York City with his older brother, who was interviewing for graduate school, Sereno had an epiphany. At the end of their tour of the museum, he says, he knew he wanted to be a paleontologist, realizing he could combine his interests in art, science, travel and adventure. "I walked out of the museum and told them, 'You'll get my application next year.' "

Two years later, in 1979, Sereno entered Columbia University (which is affiliated with the AMNH), embarking on what would become a lifelong effort to understand the evolutionary relationships, or phylogeny, of the dinosaurs. The 1980s was an exciting time, he recalls. It marked the cusp of a revolution in systematics, and researchers were just beginning to sort out dinosaur anatomy and what it said about their family tree.

Then, in 1988, Sereno led his first expedition, to a remote Argentine valley in search of early dinosaurs. After three weeks of prospecting, their paltry research funds dwindling, he chanced on a skeleton that brought him to tears. Eroding out of the rock in a little corner that the team had nearly overlooked was a beautifully preserved specimen of one of the earliest dinosaurs ever discovered—a 228-million-year-old theropod dubbed *Herrerasaurus*. "I couldn't even look at it," Sereno remembers. "I thought it was going to disappear." A second field season at the site yielded an even more primitive beast, which they named *Eoraptor*.

Sereno gained some recognition for these early discoveries, but in recent years his has become one of the most recognizable names in the field. His approachable demeanor and youthful good looks have made him a media darling—even *People* magazine noticed, including the paleontologist in its "50 Most Beautiful People" issue in 1997. That same year *Newsweek* and *Esquire* put him on their own lists. Although he seems quite comfortable in the spotlight, Sereno acknowledges a downside. "Notoriety is a double-edged sword," he remarks, noting that it can convey what one is doing and so help research programs. But it can "engender a knee-jerk reaction on the part of other scientists," who suspect you have "sought every bit of attention that you are getting and are amplifying the importance of your work."

Such accusations may be difficult to substantiate, considering that Sereno's findings are consistently published in prestigious journals. In addition to describing multiple new dinosaurs, his research has called into question several hypotheses concerning the evolutionary history of these animals. For example, one popular theory holds that dinosaurs outcompeted rival groups in their rise to world domination. But after observing that many of the adaptations that served the beasts so well during their reign were already in place millions of years before they became common, Sereno has concluded that they merely took advantage of a vacant ecospace. He adds that he has found no evidence that coevolution between predators and prey, or between herbivores and flowering plants, drove the evolution of these animals, though these were previously thought to have been influential factors. Sereno's work has also shed light on the rate of change in the skeletons of dinosaurs—which started out as meter-long bipedal creatures and later diversified to include 36-ton quadrupeds.

(He is also eager to examine the dinosaur heart reported found in April. Medical imaging seems to reveal a four-chambered heart—bolstering the idea that dinosaurs are related to birds and were warm-blooded. Sereno has publicly expressed doubts that soft tissues could have been preserved in the South Dakota sediment from which the fossil was unearthed in 1993 and would like to look for other coronary features.)

Recent inquiries stem largely from discoveries made in Africa, where Sereno has led four expeditions since 1990. The trips are grueling and often dangerous, because some dig sites are in politically unstable areas, yet paleontology's Indiana Jones remains unfazed: "The question is, How much danger is there relative to the danger we live with on a daily basis?" But he points out that such exotic fieldwork isn't for everyone. "For a lot of people it seems like a romantic thing, but when you get out in the Sahara that romance wears off after about two days. And then you realize, Wow, it's hot! And you've got to dig *that* up?"

"That," in a 1997 expedition to Niger, included 20 tons of bone representing a giant new kind of sauropod dubbed *Jobaria*. "At one point the bone was 151 degrees [Fahrenheit], reflecting up into your face," Sereno remembers, adding that his 18-person team mapped and excavated that material, along with a *Tyrannosaurus rex*–size dinosaur called *Suchomimus* and a few tons of other specimens, loading and reloading the 25-ton cargo five times before reaching the coastal destination.

Sereno is particularly proud of the speed with which he has been able to bring the fossils out of the ground and into publication and displays. "We brought back all that rock [from Niger] at about the same time the Field Museum [in Chicago] bought Sue, the tyrannosaur," he notes. Yet months before Sue was unveiled in May, Sereno's team had already cleaned, cast and assembled three skeletons—comprising 17 tons of fossil material—for exhibition, in addition to publishing its findings in *Science*.

Of course, drive isn't the only requirement. There remains the pesky problem of funding, which the team ran out of before completing the skeletons. As luck would have it, the Chicago marathon was coming up, so Sereno decided to run in it to raise money for his project. And, though he had never run a marathon before, he managed to win the celebrity challenge (which also took an on-line popularity vote into consideration) with a time of three hours and 16 minutes, in the end raising $15,000 for his dinosaurs.

Such close involvement with these projects stems partly from Sereno's belief in the power of presentation. "I consider visual things just as important as the words you put down," he states. "I think that's why people understand as much as they do about what we're doing." But he also seems to delight in these activities. He's currently designing an M. C. Escher–inspired cover for a monograph on *Eoraptor*. "I've been able to fit Pangaea, the home of *Eoraptor*, in between *Eoraptor*s," he enthuses. "I've divided up the space so that if you move in one direction you see *Eoraptor* emerging, and if you move in the other direction you see the continents dividing. It's called '*Eoraptor* and the Division of an Ancient Plane.'"

In his nonacademic time Sereno devotes himself to "getting kids to take themselves seriously." Several years ago he and his wife, educator Gabrielle H. Lyon, started a nonprofit science outreach group called Project Exploration, which aims in part to set troubled children from the Chicago public schools on new trajectories by getting them interested in science. Among the group's programs is a mini expedition out West. Being outside in a totally different place, thinking about the ancient past and finding a fossil bone fragment, Sereno observes, can really have an effect on these kids. "I come from totally believing in the potential of people," he declares. "I'm absolutely, fundamentally convinced that most of us will never understand the various talents we have because we never test ourselves enough."

ASTRONOMY

Father of Spirit and Opportunity

ORIGINALLY PUBLISHED IN OCTOBER 2004

With the success of twin rovers on the Red Planet, Steven W. Squyres and his team are showing how to conduct robotic missions—and setting the stage for human exploration By DAVID APPELL

It's 8 A.M. at NASA's Jet Propulsion Laboratory, and the Mars Opportunity rover team is gathering in a conference room for its daily science kickoff meeting. For "Martian sol 149"—the 149th day on the Red Planet since the start of the rover missions—it is assembling the minute-by-minute plan of what the rover will do: A little spectroscopy. "Ratting" a few rocks—that is, drilling them with the rover's Rock Abrasion Tool, or RAT. "I'm interested in knowing if this stuff is red or not," says Steven W. Squyres of the rocks that the rover is currently rolling over.

A professor of astronomy at Cornell University, Squyres, 48, is the principal investigator for the Mars Exploration Team, which consists of 170 members. He is responsible for all the scientific activities of both the Opportunity and Spirit rovers, leading colleague John Grotzinger to liken him to a "flea on a hot griddle," with his hands in everything.

On this late June day in 2004, the Opportunity team is facing a critical decision about whether to go farther down into Endurance Crater, a 20-meter-deep hole near the landing site on the Meridiani Planum. The team members have been eyeing the crater for weeks. But first they have to figure out if Opportunity can negotiate an inclined rock step right in front of it that drops 30 centimeters along a 25-degree incline. The step is slightly above the rover's design limits, but everyone on the team wants to do it if they can.

"Welcome to the monster truck convention," jokes Opportunity mission manager Matt Wallace at a 10 A.M. traversability meeting. A test rover at the JPL Mars yard successfully went up and down a mock-up of the step; slight slippage and a minor wheelie were the only hitches. After some discussion, the engineering team decides to go ahead and send Opportunity down the step. They will drill several RAT holes on the way in case the rover cannot climb back up, Squyres says.

Departing from the way it normally does business, NASA entrusted the science package of the Mars rovers to a single individual. And unlike many earlier principal investigators, Squyres was heavily involved in the design and engineering of the rovers. In fact, he has been working on them in one form or another since 1987, when he developed the panoramic camera now in use on the rovers. In 1992 he assembled the RAT as well as spectrometers to measure thermal emissions and to detect iron and other chemicals in rocks. Then he spent the next few years writing proposals for the rover project. NASA selected Squyres and his team in 1997, and the Mars Exploration Rover (MER) project came together in its final form in July 2000 [see "The Spirit of Exploration," by George Musser; *Scientific American*, March 2004].

The Spirit and Opportunity landers have proved to be the most complex robotic mission NASA has ever attempted. They have performed beautifully, operating for at least twice their projected lifetimes. Barring mechanical failure—and Spirit has lately been dragging around a bad wheel—the rovers' lives are limited by the buildup of dust on their solar arrays, which cuts the electricity being generated. (Over both rovers, the power loss is about 0.15 percent per sol, slightly less than the 0.18 percent loss per sol of Pathfinder, the rover that landed on Mars in 1997.) With Mars now entering winter, the arrays are taking longer to recharge the batteries, which will most likely result in extended sleep cycles for the vehicles. But there is hope the rovers will survive the Martian winter.

The Mars rovers are about 20 light-minutes from Earth, too far for any type of real-time joystick control. So they are programmed to run one Martian day at a time between code uploads. In the afternoon Squyres sits with the computer jocks who translate the agreed-on strategy into the precise series of wheel and arm movements that will accomplish the tasks. It is tight, detailed code that calls for an in-depth understanding of the vehicles—the kind of difficult day-to-day engineering that Squyres has lived through since the rovers landed in January 2004. Although the rovers have performed beyond anyone's expectations, some small problems have arisen: a heating-element switch remains stuck open on Opportunity, and Spirit had software problems just after emerging from its landing cocoon.

But neither problem has detracted from the science that's been done. "It's fair to say that the rovers would certainly have not been as successful as they are and possibly would never even have happened if it wasn't for Steve," says Jim Bell, lead scientist for the panoramic cameras on both rovers and a close colleague of Squyres' at Cornell. To him, Squyres has set the example for those leading future missions. You not only "have to be a top-notch scientist," Bell states, "but you also have to be willing to get head over heels into the design of the instruments."

The most important discovery is the evidence for great amounts of water at Meridiani Planum. Opportunity detected, for instance, sulfate salts and hematite concretions—small, grayish, iron-containing spherules that scientists have been calling "blueberries." And as Squyres had wondered, shavings of the ratted rock in the crater were indeed brick-red, typical of hematite when it is pulverized. Sulfate and hematite are left in rocks by water, so they suggest that Opportunity is working on what was once the shoreline of a salty sea, although clues gathered so far do not indicate how long, or how long ago, liquid water covered the area. "Not only did we find evidence for a habitable environment at Meridiani," Squyres remarks, "but we've got these wonderful geologic deposits—sulfates and in particular the hematite concretions—that are very good at preserving evidence of whether there was interesting organic chemistry, whether there was life."

It's unlikely the rovers themselves will directly discover signs of life, though. Instead they are laying the groundwork for a sample-return mission, by robots or someday by humans. Squyres is all in favor of a manned mission to Mars. "I'm a huge fan of sending robots to Mars, obviously—that's what I do for a living. But even I believe that the best exploration, the most comprehensive, the most inspiring exploration is going to be conducted by humans."

Although some argue that NASA's many successful robotic missions prove that costly human flights are unnecessary, Squyres doesn't buy it. "I think people who would point to the successes of these two rovers as evidence that you don't need to send humans to Mars are missing the point entirely. I view our rovers not as competitors to humans but as precursors. And they're precursors in the sense of telling us more about the Martian surface and what it's like, what it takes to walk across it, build on it, launch from it, that kind of thing." A human base on Meridiani Planum, now being explored by Squyres and his MER team, would be a good place to start.

An Ear to the Stars

Despite long odds, astronomer Jill C. Tarter forges ahead to improve the chances of picking up signs of extraterrestrial intelligence

BY NAOMI LUBICK

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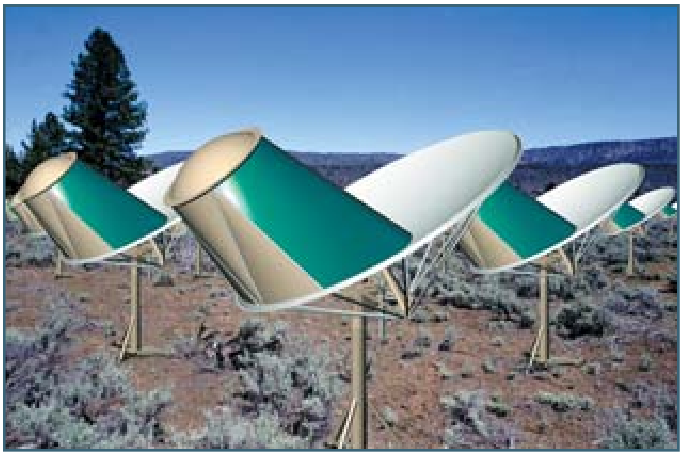
In a photograph hanging outside her office, Jill C. Tarter stands a head taller than Jodie Foster, the actress who played an idealistic young radio astronomer named Ellie Arroway in the film *Contact*. Tarter was not the model for the driven researcher at the center of Carl Sagan's book of the same name, although she understands why people often make that assumption. In fact, she herself did so after reading the page proofs that Sagan had sent her in 1985. After all, both she and Arroway were only children whose fathers encouraged their interest in science and who died when they were still young girls. And both staked their lives and careers on the search for extraterrestrial intelligence (SETI), no matter how long the odds of detecting an otherworldly sign. But no, Tarter says, the character is actually Sagan himself—they all just share the same passion.

In her position as director of the Center for SETI Research at the SETI Institute in Mountain View, Calif., Tarter has recently focused on developing new technology for observing radio signals from the universe. The concept, first presented in the 1950s, is that a technologically advanced civilization will leak radio signals. Some may even be transmitting purposefully.

So far there haven't been any confirmed detections. Amid the radio chatter from natural and human sources, there have been some hiccups and a few heart-stoppingly close calls. On her first observing run at Green Bank Observatory in West Virginia, Tarter detected a signal that was clearly not natural. But it turned out to come from a telescope operator's CB radio.

Tarter's current project is the Allen Telescope Array, consisting of a set of about 350 small satellite dishes in Hat Creek, Calif. The system, which will span about 15,000 square meters and will be one of the first radio-telescope arrays built specifically for SETI projects, is funded by private investors. Its observing speed will be 100 times as fast as that of today's equipment, and it will expand observable frequency ranges.



ALLEN TELESCOPE ARRAY (based on artist's conception) will begin working in 2005. Each antenna has a shroud to block ground reflections.

LY LY SETI Institute

Tarter has often been a lone and nontraditional entity in her environment. Her interest in science, which began with mechanical engineering, was nurtured by her father, who died when she was 12. As with most other female scientists of her generation, Tarter says, a father's encouragement was "just enough to make the difference about whether you blew off the negative counseling" that girls interested in science often got. Her mother worried about her when she departed in the 1960s from their suburban New York home for Cornell University, when women there were still locked in their dorms overnight. She was the only female student in the mechanical engineering department. (Tarter is a descendant of Ezra Cornell, the university's founder, although at the time her gender meant that she would not receive the family scholarship.)

"There's an enormous amount of problem solving, of homework sets to be done as an engineering student," Tarter recalls. Whereas male students formed teams, sharing the workload, "I sat in my dorm and did them all by myself." Puzzling out the problems alone gave her a better education in some ways, she says, but "it was socially very isolating, and I lost the ability to build teaming skills."

Her independence and eventual distaste for engineering led her to do her graduate work in physics at Cornell, but Tarter soon left for the University of California at Berkeley to pursue a doctorate in astronomy. While working on her Ph.D., which she completed in 1975, Tarter was also busy raising a daughter from her first marriage, to C. Bruce Tarter, who has directed Lawrence Livermore National Laboratory for the past eight years. The two had married in Tarter's junior year of college and moved to Berkeley together. Tarter's postdoctoral work there was on brown dwarfs, a term she coined in the 1970s for what was then a hypothetical planetlike body (only recently have they been observed directly).

By chance, an ancient computer led Tarter to SETI. She had programmed a signal-processing machine as a first-year graduate student. When astronomer Stuart Boyer acquired the computer from a colleague several years later for a SETI project—lack of funds forced Boyer into looking for handouts—he approached Tarter, because someone remembered that she had used it.

To persuade her to join the project, Boyer placed a copy of a report on her desk called Project Cyclops, a NASA study conducted by Bernard M. Oliver of Stanford University on possible system designs for detecting extraterrestrial life. Tarter read the hefty volume cover to cover in one night. Hooked on the idea of SETI, she would work with Frank Drake, who in 1960 conducted Ozma, the first American SETI project, and with William "Jack" Welch, who taught her radio astronomy and would become her second husband in 1978. Astronomer John Billingham hired her to join the small group of SETI researchers at NASA, a group that Tarter helped to turn into the SETI Institute in 1984. She became director of SETI's Project Phoenix in 1993, so named because it was resurrected after Congress removed its funding.

The SETI project has always seemed to be NASA's astronomical stepchild, Tarter explains, partly because of the "little green men" associations. But the congressional rejection of the search for intelligent life paradoxically gave new life to its pursuit.

Operating outside the confines of NASA's bureaucracy, Tarter says, the SETI Institute runs like a nonprofit business. The current funding for projects has come from venture capitalists—wealthy scientific philanthropists such as Paul G. Allen and Nathan P. Myhrvold, both formerly at Microsoft. Some contributors also serve with scientists on a board that supervises SETI's business plan, procedures and results.

Tarter's efforts to push SETI forward with private financing impress even skeptics of the enterprise. Benjamin M. Zuckerman, a radio astronomer who began his career with SETI, is blunt in his disbelief in both the search for and the existence of extraterrestrial intelligence. Still, he finds Tarter's work exceptional and notes that by keeping the public interested in SETI, Tarter has enabled astronomers to continue esoteric work.

Tarter, too, has been able to overcome her solo work tendencies. Her SETI collaborators say she has been an indomitable and tireless team leader. Yet a bout with breast cancer in 1995 may have been a defining moment of her ability to delegate authority. Radiation and chemotherapy treatment required that she step down temporarily as Phoenix project manager and cut back on her travel, thereby forcing her to assign tasks to others. She picked up her grueling pace of going to observatories and attending meetings—not to mention consulting for the movie version of *Contact*—as soon as her therapy ended.

The SETI Institute's Allen Telescope Array, to start up in 2005, will be Tarter's largest contribution to instrumentation yet. Thanks to advances in computers and telecommunications, the cost of the array is much lower than that of past setups. For instance, each dish of the Very Large Array in Socorro, N.M., cost $1 million, whereas the SETI Institute paid only $32,000 per dish for the Allen array. Each dish measures 6.1 meters wide and will be set up in a carefully selected, random pattern. The U.C. Berkeley Radio Astronomy Lab and NASA will co-manage it.

The small dishes will be more mobile than the 305-meter-wide stationary dish at Arecibo, Puerto Rico, where Tarter currently does most of her observing. The Allen array will hear frequencies from 0.5 to 11.2 gigahertz, a span 20 times as wide as what most radio telescopes can detect, and results will be high-resolution images of the sky, with thousands more stars observed at once than by Project Phoenix. Plus, the institute will be able to give time to other observers—instead of competing for it elsewhere.

Tarter strongly believes in the search for extraterrestrial intelligence, although unlike Ellie Arroway, she seems to accept that a momentous signal may not come in her lifetime. Meanwhile she is happy to push the technological boundaries of the earth's listening posts and is already planning even larger telescopes for future Arroways to use.

When the Sky Is Not the Limit

In bringing the stars indoors, astrophysicist Neil deGrasse Tyson expands the visitor's universe

BY STEVE MIRSKY

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The Chilean poet Pablo Neruda summed up his view of fate with the comment, "Every casual encounter is an appointment." Astrophysicist Neil deGrasse Tyson has a similar attitude, whether he is considering galactic evolution or the path of his own life. The 41-year-old Tyson's personal encounters have led him to his current appointment, as Frederick P. Rose Director of the American Museum of Natural History's Hayden Planetarium, which reopens this month. Tyson has been the scientific soul behind the renovation, or more accurately re-creation, of the New York City institution that has brought the universe and the night sky to urbanites for generations.

A strictly deterministic outlook could lead to an overly simplistic telling of the Tyson tale: the kid from the Bronx grew up in the Skyview Apartments, and the rest was history. The rooftop of his building, built on one of the Bronx's highest points, did indeed afford a reasonably good look at the heavens in a light-polluted urban environment. More important, however, was his motivation to take advantage of that rooftop. He was in the fifth grade when the universe descended on him, a tale he tells in his soon-to-be-published memoir, *The Sky Is Not the Limit: Adventures of an Urban Astrophysicist*. He also shares the story with this visitor to his office.

"I had a friend," Tyson recalls, "who had a pair of binoculars. And he invited me to look up with them, something I had never done before. I remember thinking to myself, 'If I look at the moon through these binoculars, the moon will simply be bigger.' But no. It wasn't just bigger, it was better." Even through bird-watcher's binoculars, details of the moon's surface leapt out. "What was formerly this gray, shady orb turned into an actual world, with mountains and valleys and craters and shadows," Tyson says. "And I've been hooked ever since."

Tyson quickly points out, though, that "interest alone doesn't get you anywhere. It requires care and feeding." He ravenously digested any astronomy information he could find, a pursuit supported by his parents and actively enabled by his mother. "I like to think of her as an 'astromom,' " he says. "If

ERICA LANSNER

SHARING THE MUSIC OF THE SPHERES with museum visitors is Hayden Planetarium director Neil deGrasse Tyson.

I ever needed a lens or a book, she would work to ensure that I got it." He was soon looking at Jupiter's Galilean moons and Saturn's rings, sometimes at the expense of schoolwork. Fortunately, another Nerudan encounter was nigh.

Tyson's sixth-grade science teacher noted his astronomical interest and showed him an ad for a Hayden evening course called Astronomy for Young People. Although he was even younger than the target age for the class, Tyson enrolled. "It opened my eyes to the study of the universe as an academic pursuit rather than as a weekend curiosity," he says. More Hayden classes followed, and his career trajectory was precociously set. Today Tyson has a special pen with which he signs the same certificates he once received for a successful course completion.

Faithful to his Bronx roots, Tyson went on to attend Bronx High School of Science; at the 20th anniversary reunion of his graduating class, the Hayden director was voted by his fellow alumni as holding "the coolest job." In his teens, Tyson read and creatively employed *Scientific American* to mark his career bearing—by studying the authors' biographies. "I got to read what kind of people they were," he says, "and where they got their degrees. It was my first exposure to the academic pathways that enable someone to become an astrophysicist."

The biography of the late astrophysicist David Schramm, who wrote his first *Scientific American* article in 1974, particularly impressed the young Tyson, who was the captain of the Bronx Science wrestling team. "It said [Schramm] wrestled Greco-Roman," he remembers. "He was a big, strapping fellow—I think they called him Schrammbo. I thought, 'This is cool. I can wrestle and enjoy that and still make a career out of astrophysics.' And so I valued that counterpoint to the articles."

Tyson continued his education at Harvard University and then began his graduate career at the University of Texas at Austin, where he created theoretical models of star formation in dwarf galaxies. He also took a relativity class, taught by John Archibald Wheeler, in which he met fellow student Alice Young. That encounter led to marriage and a daughter, Miranda. Tyson then moved on to Columbia University, just a few miles south of the Skyview Apartments, for doctoral research on the structure and evolution of the center of the Milky Way, the so-called galactic bulge.

While in graduate school, Tyson began another kind of encounter, with laypeople, by reaching out to share the joys of scientific knowledge. Since 1983 he has written a column for *Star Date* magazine, a general readership publication of the McDonald Observatory of the University of Texas at Austin. In it, Tyson takes on the guise of a mythical character called Merlin (not of Arthurian legend), a native of the Andromeda galaxy. Present on Earth since the planet formed, Merlin teaches science to readers in ingenious ways—for example, by recounting conversations with great thinkers of the past. Two compilations of Merlin essays have been published.

In the early 1990s officials of the American Museum of *Natural History* resolved to renovate the Hayden, which had fallen behind the times physically and scientifically. Tyson, who had finished postdoctoral research at Princeton University and had become a visiting faculty member there, was already known within the astronomical community as a strong scientist who could also communicate with just-plain-folks. "And that's when I started getting phone calls," he says.

Tyson came to the planetarium in 1994, became its acting director the following year and permanent director the next, all while maintaining a Princeton position and writing a monthly column for the museum's publication, Natural History. "He came into our field of vision as someone who was extraordinarily talented as a communicator of science," says Ellen V. Futter, president of the museum. "He really is inspirational in his ability to enliven very complex fields and theories in ways that make them not only accessible but fascinating, intriguing and really exciting."

A highlight of the remade Hayden, now one component of the $210-million Rose Center for Earth and Space, is the unparalleled view of the night sky it can serve up. The planetarium has a new $4-million Zeiss projector, the Mark IX, custom-made for this task. "It can put stars on the dome whose images are so precise that they're smaller than the resolution of the human eye," Tyson says. "That means you can put detail on the dome that your eyes can't see." There is method to this seeming madness. "You can now bring binoculars into the dome and see more with them than you could with the naked eye," he explains. "New Yorkers hardly ever look up. They look down. They're worried about what they'll step in. And even if they look up, they see buildings or smog or the lights on Times Square."

The quest for verisimilitude includes scintillation, twinkling of stars caused by atmospheric turbulence. Though charming, scintillation is a reduction in clarity. Including that feature therefore means investing in technology that lessens the view. Tyson wanted it, however, for its teaching potential. "You can put up the stars, flick the switch for twinkling and put on some lights," he says, "and you start the visitor with the same sky that you would see from the streets of New York. And then you take a drive to the country, and you start dimming the lights and removing the scintillation. And the majesty of the night sky as seen from a mountaintop comes into view." Visitors will also be able to leave Earth, from their seats, and see images of the rest of the universe.

From the street, the theater's dome is the top half of a 87-foot sphere, which has been completed and encased in a glass cube. "We're using that sphere in a walkaround exhibit where we compare the sizes of things in the universe," Tyson says. Poet and artist William Blake contemplated seeing the world in a grain of sand and holding infinity in the palm of your hand. Holding the world in one's palm becomes a possibility inside the sphere, where a softball-size Earth leads to realizations about the solar system. "On that scale, Jupiter is about 17 feet in diameter," Tyson notes. "And the sphere is the sun. You can see and feel how much bigger the sun is than Earth. And we go out to stars and galaxies, and the other way, down to the chemistry, down to molecules, atoms and atomic structure." The belly of the sphere also re-creates the universe's first three minutes, where guests can observe the big bang and the formation of the light elements.

With the completion of the new Hayden, Tyson will have the chance to return to his first calling, the research that has been on hold during the intensive final stages of planetarium construction. "I remain interested in the structure of the galaxy," he says, "and what we call the kinematics and the dynamics of the galaxy. Not only do stars have a certain abundance of heavy elements, they're moving in a certain direction." That information can indicate how the galaxy "will continue to evolve, or what it must have evolved from," he reveals. Tyson will resume this exploration as curator of the Hayden's new, academic astrophysics department, which has two other researchers in place and postdocs arriving in the fall. "We're being born whole in a way," he says, "with an infrastructure that will support a scientific research program." Although he will maintain his director's seat, Tyson will also make more time for science by handing over some of his duties to James S. Sweitzer, formerly assistant director of Chicago's Adler Planetarium and now director of special projects for the Rose Center for Earth and Space.

Even ensconced in research, Tyson will no doubt often be as visible as Venus on a clear night just after sunset. He enjoys and feels a particular responsibility to appear before the public, dating back to his first experience watching himself on television. During his time at Columbia, astronomers detected massive prominences and flares on the sun. A local news outlet called the school, and Tyson was asked to discuss the explosions. He watched the taped segment that evening. "I realized I had never before seen a black person on television who was being interviewed for expertise that had nothing to do with being black, other than entertainers or athletes. And at that point I realized there's no greater obligation I have than to continue to be an expert when the media has questions about the universe—thereby possibly exploding stereotypes." Through his study of the entire universe, Tyson has thus been led to the ultimate Nerudan encounter—an appointment with himself.

BIOLOGY

Geographer of the Male Genome

ORIGINALLY PUBLISHED IN DECMEBER 2004

The notion of the Y sex chromosome as a genetic wasteland still entices biologists. David C. Page has spent a good part of his career knocking down that myth By GARY STIX

An English literature student called up David C. Page a few years ago and told him she was thinking of doing a thesis that would rebut feminist criticism and bring back a measure of respectability to him and his work. "I didn't know I was in need of rehabilitation," Page remarks one late September afternoon in his fourth-floor corner office at the Whitehead Institute on the Massachusetts Institute of Technology campus. He retells the incident while resting his "Save the Males" coffee cup on a circular conference table.

Ever since he picked up and inspected a random piece of DNA in 1979 as a young researcher and later learned that the glob contained a piece of the Y chromosome, Page has devoted much of his working life to the study of the genetic package that confers maleness. The very idea of investigating the Y chromosome offends those feminists who believe that it serves as nothing more than a subterfuge to promulgate an inherent male bias in biology. And, in Page's view, some reputable scientists have even pandered to these sentiments by writing books and papers that predict the extinction of men—or the Y's disappearance.

Page has sometimes found himself defending the genome's smallest chromosome against preconceptions that do not necessarily jibe with the science that comes from the 20 researchers in his laboratory. He has helped dispel calumnies such as that the Y chromosome is a decaying, unintelligible mess—the Animal House of the human genome—or that because the Y has a very limited capacity to exchange genetic information with the X chromosome, it is sickly and dying out, a victim of its own masculine social incompatibility.

Bemused and unrehabilitated, Page can point to a long list of scientific papers with his name on them that demonstrate that the Y is an infinitely richer and more complex segment of the genome than ever imagined and one that does not fit neatly into the prejudices of gender-based interpretations of science.

Page seems to be an unlikely candidate to defend maleness. The slim and youthful 48-year-old does not cut a macho figure. At home he is surrounded by females: his wife, three daughters, and a female cat and guinea pig. He only developed an interest in the world of science when he arrived at Swarthmore College in 1974 and spent a few summers doing internships at the National Institutes of Health and Brookhaven National Laboratory. While training in the early 1980s under David Botstein, an M.I.T. geneticist, Page developed a molecular probe that he later used to track down what appeared to be the gene that codes for a protein triggering an embryo to develop into a male. Published with great fanfare in 1987—just after he had received a MacArthur "genius" award and the offer of a tenure-track professorship at Whitehead—the results catapulted him onto national television and the front pages. "The wave of publicity that accompanied that period was something I wasn't quite ready for," he says.

And then the discovery turned out to be in error. Two British groups issued their findings in 1990 about the correct gene on a part of the chromosome just adjacent to the one Page had identified. At the age of 34, the same as some postdoctoral students, Page was cast adrift. In retrospect, the experience had an upside. If he had been the one to discover the sex-determining gene, or SRY, he might have spent way too much time researching just that one gene. For a few years, he struggled with the question of whether more work remained on the Y. Then, in 1995, his laboratory discovered a mutation on the Y chro-

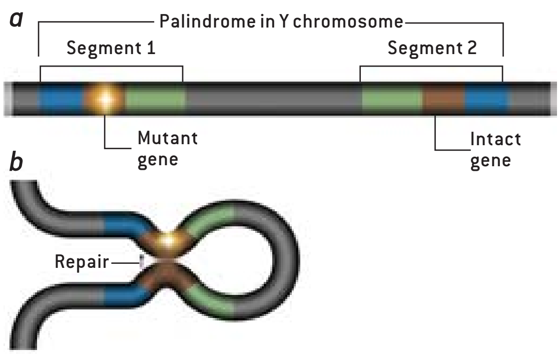
TRACY POWELL

DAVID C. PAGE: THE Y FILES

- **Led what he calls an "anal-compulsive" effort to sequence the Y chromosome, a process akin to drawing a map of a hall of mirrors.**
- **The Y sequence shows that men and women differ as much in their genetic makeup as do, say, human and chimpanzee males.**
- **On the fascination with the "rotting Y": "It has to do with sexual politics—in other words, the implication that men are kind of sloppy and they're not well behaved."**

mosome that causes the most common genetic form of male infertility, accounting for about 13 percent of cases in which men do not produce sperm. "We were on our way again," he says. "We came out of a period of wandering around in the wilderness."

Last year Page's team, along with investigators from Washington University School of Medicine, published the complete sequence of the gene-containing portion of the human Y. It has proved to be the most challenging chromosome to decipher. The other 45 chromosomes, including the X, lent themselves to high-powered industrial reading of the nucleotides of DNA. "It turns out that the one-size-fits-all Wal-Mart approach works everywhere, but not on the Y chromosome," Page explains. The Y poses such a hurdle because its endlessly repetitive series of nucleotides were expected to be nothing more than a collection of garbage DNA. Sequencing required what Page characterizes as "extreme genomics," a search for landmarks among the millions of nucleotides on the chromosome. These guideposts consisted of minute differences among the repeat sections of nucleotides. "It would be as if you had two virtually identical copies of Manhattan, but they differed by the precise placement of some mailboxes and fire hydrants. And if you had been transported from copy A of Manhattan to copy B of Manhattan, the likelihood that you knew you had been moved would be very small. That was the problem we faced," he elaborates.



PALINDROMES—composed of DNA segments that are mirror images—facilitate self-repair of the Y chromosome. The Y can correct a mutation in one of the segments (*a*) by bending and copying the intact version from the other segment (*b*).

The sequencing effort tallied about 80 genes; 20 years ago the prevailing wisdom suggested only a scattering of genes, maybe just one. Both the Y and the X began to evolve from an autosome (a non-sex chromosome) some 300 million years ago. Unlike every other chromosome that comes with a matched pair, including the X in females, the Y has scant ability to trade good genes for defective ones. Over time, most of its 1,000 or so genes that had started in the autosome withered away.

But perhaps the most interesting result attests to the survival prospects for the Y. The myth of the Y as weak and irrelevant has led to ponderings about what will happen in the event that males become extinct. Musings by some biologists have projected the Y's demise anywhere from 125,000 to 10 million years from now. But Page's work shows that the Y may have staying power. The male chromosome contains stretches of DNA that are virtually identical mirror copies of each other, creating huge genetic palindromes (the equivalent of the sentence "MADAM I'M ADAM"). If one of these sections makes a hairpin bend in the middle, it appears capable of donating an intact gene to fix a defective copy on the neighboring section. In essence, the Y seems to have its own self-repair mechanism, a process called gene conversion, making reports of its impending demise highly premature.

Because it is the male chromosome, the seat of human recklessness to some observers, controversy may never fully abate. Biologist Jennifer A. Marshall Graves of the Australian National University in Canberra argues that gene conversion in the palindromes represents a form of "genetic masturbation" that may not only fail to inhibit deleterious mutations but may even speed the process of the chromosome's decline. Page's terse response: "Ah, rhetoric and theory unburdened by experimental data."

At this point, Page has found most or all of the protein-coding genes on the Y—he even shows at conferences a graphic of a whimsical version of the chromosome dotted with genes for channel flipping (*FLP*), spitting (*P2E*) and selective hearing (*HUH*). He is now turning to other questions. He has begun studies of the role of germ cells (egg and sperm) in initiating the process by which an embryo becomes anatomically female.

Yet he still has not lost his affection for the Y. The specialized expertise gained by Page's group may now be used to target other genomes. "To date, hundreds of bacterial genomes and more than a dozen animal genomes have been sequenced, but at present there's only one Y," he says. Page may or may not have rehabilitated himself. But he has gone a long way toward restoring the status of the so-called rotting chromosome.

LUCY READING

Edward O. Wilson

Revisiting Old Battlefields BY JOHN HORGAN

ORIGINALLY PUBLISHED IN APRIL 1994

I've gone from politically very incorrect in the '70s to politically very correct in the '90s," muses Edward O. Wilson. "And I have to add that I wanted neither distinction, because I don't even think in terms of what's correct or incorrect." Wilson, or at least his public persona, has undergone a remarkable transformation over the past two decades. Today he is widely known and admired for his passionate defense of the biota, most recently in his 1992 best seller *The Diversity of Life*. In the late 1970s, however, Wilson was reviled by some scientists and political activists for his espousal of sociobiology, whose premise is that just as the social behavior of ants can be understood by examining their genetic underpinnings, so can that of humans.

When I first meet Wilson in his office at Harvard University's Museum of Comparative Zoology, I have a hard time imagining him at the center of any controversy. The 64-year-old Baird Professor of Science seems too gracious, even eager to please, and he keeps talking about ants—not surprisingly, since he is the world's leading authority on them. This is a man who once wrote that "ants gave me everything, and to them I will always return, like a shaman reconsecrating the tribal totem."

When I ask if science has anything more to learn about the tiny creatures, Wilson cries, "We're only just beginning!" He is now embarked on a survey of *Pheidole*, a genus thought to include more than 2,000 species of ants, most of which have never been described or even named. "I guess with that same urge that makes men in their middle age decide that at last they are going to row across the Atlantic in a rowboat or join a group to climb K2, I decided that I would take on *Pheidole*."

Wilson's "grand goal" is to make *Pheidole* a benchmark of sorts for biologists seeking to monitor biodiversity. Drawing on Harvard's vast collection of ants, he has been generating descriptions and painstaking pencil drawings of each species of *Pheidole*. "It probably looks crushingly dull to you," Wilson apologizes as we flip through his drawings. He confesses that when he peers through his microscope at a previously unknown species, he has "the sensation of maybe looking upon—I don't want to get too poetic—of looking upon the face of creation."

I first detect a martial spirit glinting through this boyish charm when he shows me the leafcutter ant farm sprawling across a counter in his office. The scrawny little specimens scurrying across the surface of the spongelike nest are the workers; the soldiers lurk within. Wilson pulls a plug from the top of the nest and blows into the hole. An instant later several bulked-up behemoths boil to the surface, BB-size heads tossing, mandibles agape. "They can cut through shoe leather," he says, a bit too admiringly. "If you tried to dig into a leafcutter nest, they would gradually dispatch you, like a Chinese torture, by a thousand cuts." He chuckles.

Later, Wilson emphasizes that although he has not written much about sociobiology per se lately, its precepts inform all his work, on biodiversity as well as on ants. Moreover, he still harbors vast ambitions for human sociobiology. He thinks it has the potential to "subsume most of the social sciences and a great deal of philosophy" and bring about profound changes in politics and religion. He scolds Americans for their continued reluctance to confront the role played by genes in shaping human behavior. "This country is so seized by our civic religion, egalitarianism, that it just averts its gaze from anything that would seem to detract from that central ethic we have that everybody is equal, that perfect societies can be built with the goodwill of people." As he delivers this sermon, Wilson's long-boned face, usually so genial, is as stony as a Puritan preacher's.

Ever the biologist, Wilson has described his own career as a series of adaptations to environmental stresses. His father was a federal worker who kept moving from town to town in the Deep South. "Because of the difficulty in social adjustment that resulted from being a perpetual newcomer," Wilson has said, "I took to the woods and fields." At seven he lost most of the vision in his right eye after accidentally stabbing it with the fin of a fish he had yanked from a pond. With acute though myopic vision in his left eye, Wilson focused on animals he could scrutinize from short range, namely, ants.

Wilson pursued his studies at the universities of Alabama and Tennessee and, from 1951 on, at Harvard. He began doing fieldwork in such exotic locales as New Guinea, Fiji and Sri Lanka, discovering ant species that exhibited a fantastic array of social structures. Working in the laboratory, Wilson also helped to show that ants and other social insects exchange information by means of a host of chemical messengers, named pheromones.

Wilson's foray into sociobiology was spurred at least in part by a threat to his scientific tribe. In the late 1950s molecular biologists, exhilarated by their ability to decipher the genetic code, began questioning the value of taxonomy and other whole-animal approaches to biology. Wilson has alleged that James D. Watson, the co-discoverer of DNA, who was then at Harvard, "openly expressed contempt for evolutionary biology, which he saw as a dying vestige that had hung on too long at Harvard." The memory still rankles, especially since taxonomy's status relative to molecular biology may have fallen even further. Wilson deplores that situation. "I think a world biological survey would do more for humanity during the next 20 years than the genome mapping project," he declares.

Wilson responded to the challenge from molecular biologists by broadening his outlook, seeking the rules of behavior governing not only ants but all social animals. That effort culminated in *Sociobiology*. Published in 1975, it was a magisterial survey of social animals, from termites to baboons. Drawing on the vast knowledge he had accumulated in disciplines such as ethology and population genetics, Wilson showed how mating behavior, division of labor and other social phenomena were adaptive responses to evolutionary pressure.

Only in the last chapter did Wilson shift his sights to humans. He argued that warfare, xenophobia, the dominance of males and even our occasional spurts of altruism all spring at least in part from our primordial compulsion to propagate our genes. Wilson has admitted that his style was "deliberately provocative," but he insists that he was not seeking or expecting trouble. "I stumbled into a minefield."

The book was for the most part favorably reviewed. Yet a group of scientists—notably Stephen J. Gould and Richard C. Lewontin, also biologists at Harvard—attacked Wilson for promoting an updated version of social Darwinism and providing a scientific justification for racism, sexism and nationalistic aggression. The criticism peaked at a scientific conference in 1978, when a radical activist dumped a pitcher of water on Wilson's head while shouting, "You're all wet!"

While granting that support for his proposals "was very slim" in the 1970s, Wilson asserts that "a lot more evidence exists today" that human traits can have a genetic basis. To be sure, many scientists, particularly in the U.S., shun the term "sociobiology" because it is still "freighted with political baggage." Nevertheless, disciplines with such "circumlocutory" names as "biocultural studies," "Darwinian psychology" and "evolutionary biological studies of human behavior" are all actually "sprigs" growing from the trunk of sociobiology, according to Wilson.

Ironically, Wilson himself, at the very end of *Sociobiology*, revealed some trepidation about the fruit that the field might bear. "When we have progressed enough to explain ourselves in these mechanistic terms," he wrote, "and the social sciences come to full flower, the result might be hard to accept." Wilson acknowledges that he finished the book "in a slight depression" caused by his fear that a complete sociobiological theory would destroy our illusions and end, in a sense, our capacity for intellectual and spiritual growth.

He worked his way out of that impasse by determining that at least two enterprises represented "unending frontiers." One was the human mind, which has been and is still being shaped by the complex interaction between culture and genes. "I saw that here was an immense unmapped area of science and human history that we would take forever to explore," he says. "That made me feel much more cheerful." He wrote two books on the topic with Charles J. Lumsden of the University of Toronto: *Genes, Mind and Culture* in 1981 and *Promethean Fire* in 1983.

The other endeavor that Wilson realized could engage humanity forever was the study of biodiversity. "With millions of species, each one with an almost unimaginably complex history and genetic makeup, we would have a source of intellectual and aesthetic enjoyment for generations to come." Wilson thinks this quest may be propelled by "biophilia," a genetically based concern that humans have for other organisms.

He explored this theory in his 1984 book *Biophilia*. While compiling statistics on the abundance of species for the book, however, he fell into another depression. Species, he found, were vanishing at an alarming rate; the diversity he so cherished was in mortal danger. That realization catapulted him into his role as a champion of biodiversity.

Wilson's writings on biodiversity have been praised even by some of his former critics. Gould, in a review in *Nature*, lauded *The Diversity of Life* as "a thoroughly successful mixture of information and prophecy." Yet this embrace was not complete; Gould derided the biophilia theory, arguing that humans show as great a propensity for destruction of life as for preservation of it.

"That has been due more to ignorance in humanity's history than desire to wipe other forms of life off the earth," Wilson retorts. Gould, with whom Wilson is "quite friendly," is "allergic to any idea that human nature has a biological basis, and I must say I believe he is nearly alone in that perception now."

knowledge of our evolutionary roots should help liberate us from dangerous patterns of behavior

Wilson intends to take up the banner of sociobiology again in two upcoming books. (A self-confessed "workaholic," Wilson has already written or edited 18 books and more than 300 scientific and popular articles.) One is a full-scale autobiography he has nearly completed and hopes will be published by the end of this year. "I am revisiting all the old battlefields," he remarks.

Wilson's next book will address "natural philosophy," a hoary term he has revived to refer to "the still uncharted and relatively vaguely defined region between biology, the social sciences, moral reasoning and the environment." Perhaps the book's most radical theme will be that findings from evolutionary biology can guide us in resolving moral disputes over topics as diverse as the preservation of species or birth control.

Most philosophers and even scientists believe evolutionary biology "cannot be prescriptive," Wilson states. "That is true to a certain extent," he adds, "but my position is that where we can agree on moral precepts is governed very much by our evolutionary history."

Far from promoting fatalism, knowledge of our evolutionary roots should help liberate us from dangerous patterns of behavior, according to Wilson. A society based on sociobiological precepts would allow us to develop a more rational political system, one that encourages the "maximum personal growth" of humans while preserving the environment.

He points out, for example, that evolutionary biology has shown that sexual intercourse promotes parental bonding and so the stability of the entire family. These findings might persuade the Catholic Church, which believes that the primary purpose of sex is procreation, to drop its prohibition against birth control, thereby aiding efforts to curb population growth. Wilson seeks to "build bridges" rather than to initiate yet another controversy with such arguments. "I don't know exactly where I'm going to end up," he says, "but I hope it's not in the midst of another minefield."

Defender of the Plant Kingdom

ORIGINALLY PUBLISHED IN SEPTEMBER 1999

Botanist Peter H. Raven wants the world to save its plant species. All of them. BY TIM BEARDSLEY

Peter H. Raven, a man used to looking at the big picture, has a big idea. The 63-year-old scientific diplomat and director of the Missouri Botanical Garden in St. Louis was set in August to call on the world's plant scientists, gathered at an international congress, to save the whole plant kingdom from extinction. Raven, for the past two decades a leading advocate for the preservation of biodiversity, predicts that without drastic action, two thirds of the world's 300,000 plant species will be lost during the next century as their habitats are destroyed. Yet he believes that an international commitment to bring vulnerable species into cultivation in botanical gardens, or into seed banks, could avert the catastrophe. "If you are going to give a single valuable present to the people 100 years from now, then saving all the plants might be a very good way of doing it," he says.

Such a grandiose scheme might sound like an idle fantasy. But Raven is a member of 22 academies of science around the globe and has an impressive history of organizing major projects. (His institution provides the headquarters for a network that is already trying to preserve U.S. plants.) He has just stepped down from a 12-year term as home secretary of the National Academy of Sciences, and he chairs the report review committee of the National Research Council, the operating arm of the academies of science, engineering and medicine. In that role he has overseen formal reviews of some 2,200 studies, many on controversial subjects. Raven is "a very good scientific politician and a good negotiator," says Bruce M. Alberts, president of the science academy.

Raven also has a remarkable ability to raise money. In his 30 years as director of the Missouri Botanical Garden, he has transformed it from an academic backwater to one of the leading plant research centers in the world. The 79-acre garden today employs 62 Ph.D.-level botanists, many of them based in other countries, and in collaboration with overseas institutions runs collection programs in numerous regions of botanical interest. The institution has added several new buildings, and a variety of stunning new decorative gardens have made it a renowned tourist attraction.

Raven was for a time on a board that administered George Soros's philanthropy in the former Soviet Union, a position that helped him to raise $1.3 million to restore the decaying headquarters of the Komarov Institute in St. Petersburg, which houses the major botanical collections of the former Soviet Union. He also persuaded St. Louis–based agrochemical giant Monsanto to donate $3 million toward a new herbarium and research center for his own institution, a connection presumably not harmed by the fact that his wife, Katherine E. Fish, is Monsanto's director of public policy. Raven talked to SCIENTIFIC AMERICAN in his elegant office at the Missouri Botanical Garden shortly before the opening of the 16th International Botanical Congress in August. Unlike many scientists, he favors an impeccable business suit and tie. His manner is restrained, although he does not shrink from expressing firm opinions.

His interest in the natural world started early: Raven was eight years old when he joined the student section of the California Academy of Sciences. Within a few years he was collecting plants "fairly seriously." Biology was not offered at his high school in the early 1950s, so the academy provided a social structure and a learning opportunity. In 1950 he was asked to go on a Sierra Club Base Camp outing to the Sierra Nevada. He shared a ride with G. Ledyard Stebbins of the University of California at Davis—who is, according to Raven, the leading plant evolutionary biologist of the century—and became a regular on the expeditions for the next six years.

After earning degrees at the University of California at Berkeley and at Los Angeles, he was recruited by Stanford University in 1962. He was soon making waves: he moved into an office next door to that of Paul R. Ehrlich, who was studying the diets of butterfly larvae. Together they coined the term "co-evolution" to describe the influence that mutually dependent species such as butterflies and plants can exert on each other. The word "crystallized the whole area in a special way," Raven recounts.

During the 1960s Raven's ideas about population, consumption, technology and the environment began to take shape as he came to realize that human stresses on the biosphere were "a whole new factor" in evolution. Raven first became aware of mass extinction in the tropics as an ongoing calamity in 1967, while working as a temporary field course instructor in Costa Rica.

He maintained that interest at the Missouri Botanical Garden from 1972 onward, wielding his academic influence to support research on tropical ecology and plants. Until the early 1980s he was active in plant classification and evolution, especially in connection with the family Onagraceae, which includes fireweed and the evening primrose. But since then he has been "almost exclusively" involved with promoting sustainability and conservation, systematizing knowledge about plants worldwide: he was among the organizers of the conference in Washington, D.C., in 1986 that put the term "biodiversity" into the scientific lexicon. He also devotes "a fair amount of time" to being co-chair of a joint project with the Science Press of Beijing to publish a 50-volume, English-language flora of China.

Raven makes no apologies for playing the dual roles of scientist and activist: he believes people should express their opinions "as broadly as possible." Facts trip off his tongue: world population has increased from 2.5 billion in 1950, when he first explored the Sierra Nevada, to six billion today, he notes, and the world has over that period lost 20 percent of its agricultural land and 25 percent of its topsoil; extinction rates are now about 1,000 times their historic levels and rising. About half the people in the world are malnourished, while the U.S. consumes resources at rates 30 to 40 times that of people in some parts of the world.

Raven points out the irony that although many pontificators project the 21st century to be the century of biology, the soundest predictions foresee a quarter of all species on the earth going extinct in the first 25 years of the new century. "We're acting in a way that is scientifically very irresponsible, and we need to speak out about that," he asserts. He takes issue with blind confidence that human ingenuity will solve the world's problems: unless human populations stabilize and achieve acceptable levels of consumption, he warns, "even the best science and technology can't save us." But he says large corporations can be influential in bringing about constructive change.

Raven is firmly in the camp that believes biotechnology can contribute to solving the world's problems by producing better crops. He has lobbied for the U.S. to ratify the 1992 Convention on Biodiversity, which was intended to protect endangered animals and plants, but is disturbed that it has become embroiled in a protracted examination of the safety of genetically modified organisms. The diversion, he says, has for the most part "nothing to do with biodiversity." He says he understands that many people are fearful about some possible products of biotechnology, such as so-called terminator seeds that could be planted only once, to protect the developers' intellectual property. But objectors are probably reflecting underlying concern about who will control agriculture in the next century, Raven suggests. Likewise, recent public anxiety about the effects of a common bioengineered pesticide, *Bt*, on monarch butterflies reflects a misunderstanding. Monarchs and many other insects are killed by the billions by conventional chemical sprays, he observes, so to suppose that Bt is a big new problem is "absurd"; nothing suggests that monarchs consume significant amounts in the wild. These worries, Raven believes, represent deeper apprehensions about nature.

Raven has been in a position to do something about fears about terminator seeds and what are termed TGurts, seeds that have special properties that are activated by applying proprietary chemicals. He has encouraged the National Research Council to formulate a comprehensive study of intellectual property in relation to crops. One of his frequent opponents in biotechnology debates, Rebecca J. Goldburg of the Environmental Defense Fund, suggests that Raven's connections with Monsanto amount to a conflict of interest. But longtime friend Ehrlich counters that he has faith in Raven's integrity. "It's not where you get the money from," he states, "it's how you spend it."

Although Raven next year will vacate his role as chair of the National Research Council's report review committee, he continues to be a member of the President's Committee of Advisors on Science and Technology, where as chair he helped produce an influential report urging the administration to expand studies of ecosystems and create incentives to preserve them. And he recently became chair of the research and exploration committee of the National Geographic Society. The society "has been searching for ways to express itself in conservation and sustainability," he explains, a direction that puts it in line with his own professional passion of the past 20 years. The society gives away several million dollars each year in grants, publishes its magazine in six languages and operates a TV channel that broadcasts in 55 countries, so Raven will be well positioned to raise public awareness about global issues. He might even manage to save some of the 200,000 plants that could otherwise disappear.

CONSERVATION/ENVIRONMENTAL SCIENCE

The Billionaire Conservationist

Can Ted Turner save threatened species? He is using his private lands and deep pockets to reintroduce animals driven off by development By KRISTA WEST

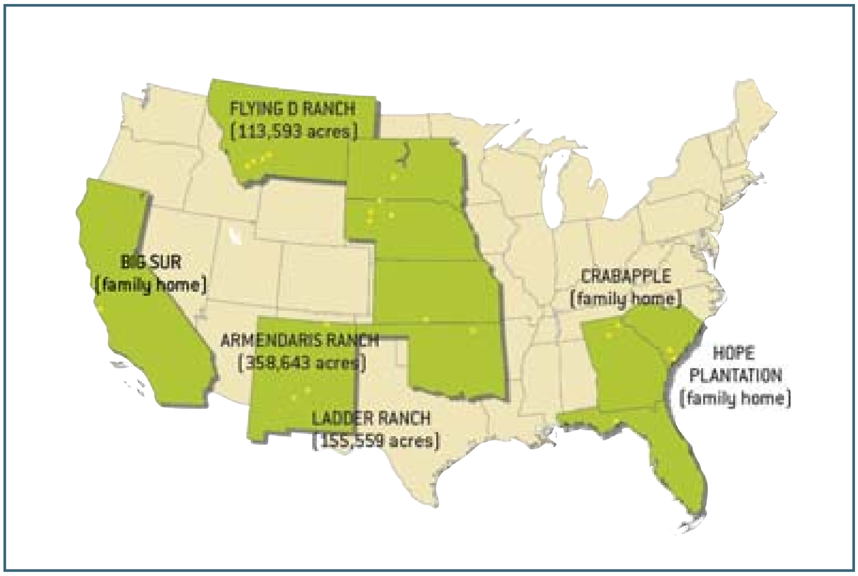
ORIGINALLY PUBLISHED IN AUGUST 2002

As the creator of CNN, the first 24-hour news network, and other cable stations, Ted Turner forever changed the landscape of American television. Now the 64-year-old "media mogul" plans to change the landscape of the American West. He is the ringleader of a giant scientific experiment to restore damaged ecosystems—specifically, to reintroduce species and to reinvigorate Western lands in an economically sustainable way. And he may just have the means and the minds to pull it off.

Turner is the largest private landowner in the nation, controlling two million acres (an area bigger than Delaware) spread across 10 states. He is using the lands as laboratories to apply existing wildlife management techniques and to develop new ones. Since 1997 his staff of traditional ranchers, former government scientists and academic researchers has produced nearly 50 scientific publications, and their impact on the science of wildlife conservation is becoming hard to ignore.

It all started in 1995, when the thrice-divorced father of five visited Yellowstone National Park with his then wife, actress Jane Fonda, to discover more about the federal wolf reintroduction program, an effort of the U.S. Fish and Wildlife Service to transplant wild wolves from eastern Canada to Yellowstone. They met project leader Mike Phillips and, according to Phillips, "learned that restoration could be an alternative to extinction." Two years later Turner, with his son Beau and Phillips, created the Turner Endangered Species Fund (TESF), a nonprofit organization to manage and restore wildlife on Turner's properties and adjacent public lands. Today TESF is working to reintroduce nearly two dozen species of animals, including Mexican wolves, red-cockaded woodpeckers, black-footed ferrets and Rio Grande cutthroat trout, to those lands. "You can already see the difference TESF has made on the overall health of the landscape," Turner remarks.

Of the 14 properties where restoration efforts are taking place, the Armendaris Ranch at the northern tip of the Chihuahuan Desert in south central New Mexico is among the more significant. University, state and TESF collaborations have created more projects than ranch manager Tom Waddell



JOHNNY JOHNSON

LAND ROVER: Ted Turner owns two million acres over 20 properties [dots]; 14, including the ranches listed, host conservation efforts.

can keep track of. “Turner is the artist, but we’re the painters,” Waddell tells me in all earnestness as we rumble around the ranch in his pickup truck. Waddell, who was a biologist for the Arizona Game and Fish Department for more than 20 years, expresses unequivocal loyalty to the self-made billionaire, a trait common to most Turner employees despite the tycoon’s sometimes controversial bluntness.

As we pull up to a flat plot cleared of tall grasses, TESF biologist Joe C. Truett, an expert in desert grasslands, points out where they have been working to reintroduce prairie dogs (similar efforts are also under way on five other Turner properties). Here academic scientists have been experimenting with ways to prepare the land for reintroduction. They have discovered that setting fires and mowing work equally well in getting rid of the long grasses that make the habitat unsuitable for prairie dogs.

For the scientists, the fact that the land is privately owned allows them to experiment on a scale impossible to create in the laboratory—and to do so without the bureaucratic red tape that often accompanies work on public property. “No cookbook exists for restoring land,” Truett explains. “We plan restoration based on scientific knowledge but frequently adjust our plans as experience indicates the need, and Ted’s okay with that.” Such adaptive management is difficult for government agencies, according to Truett and others, because legal requirements and accountability to interest groups and taxpayers make it impossible to change plans even when the need is obvious.

“Our techniques and projects are self-motivated, but we want to publish so that others can use the information,” says Steve Dobrott, manager of Turner’s Ladder Ranch, about 40 miles west of Armendaris. Here the staff works with government researchers to support a federal breeding facility for the Mexican wolf and a state-assisted project to reintroduce native trout. Indeed, anytime TESF wants to work with such protected species, it must seek government approval and cooperation. Technically, the animals are public resources that only happen to live on private lands, and various laws govern their management. “We won’t shy away from tough species,” comments Phillips, now executive director of TESF. “We judge our success by counting publications and heads”—animal heads, that is.

Still, some officials feel that Turner is trying to steamroll the process by “not waiting for the government to act,” notes Wally Murphy, a federal biologist who leads a threatened and endangered species program for the U.S. Forest Service. Murphy himself is generally happy with what the billionaire is doing. “Turner’s motivations may be emotional,” he says, “but he’s taking a very analytical approach. And he’s hired good people.”

For certain projects, self-interest does motivate Turner. “A large part of what we do here is study quail,” Dobrott says, “mainly because Ted likes to hunt them.” Turner visits the Ladder Ranch about 25 times during hunting season, from November to February, according to Dobrott. Another of his favorites is bison—a fascination Turner himself cannot explain but the main reason he began his conservation work. Today he is the biggest bison rancher in the country, with about 30,000 head, at least eight times as many as any other rancher.

More than just harking back to frontier times, the bison serve an economic role. Along with big-game hunts and timber, they are a commodity for Turner Enterprises, a for-profit group. The bison are sold to the North American Bison Cooperative in North Dakota, where Turner’s two-restaurant chain, called Ted’s Montana Grill, buys the meat for its bison burgers.

While Turner Enterprises pulls in the dollars, the nonprofit Turner Foundation gives money away. In 2000 it awarded 683 grants, totaling almost $50 million, to research and conservation organizations. Besides going to TESF, funds also went to the Wildlife Conservation Society and the Nature Conservancy. No other philanthropist targets conservation to this extent. Turner’s one-year contribution is nearly twice what the PGA Foundations, led by Microsoft co-founder Paul G. Allen, gave for conservation from 1990 through 2000. And it is about 90 times the amount awarded in 2000 by the Bill and Melinda Gates Foundation, whose $1.2 billion yearly budget goes mainly to promote human rights, health care and education. Only the federal government spends more on wildlife-related sciences: in 2001 the National Science Foundation doled out $175 million.

Critics say Turner is simply buying the good graces of environmental groups while ignoring the concerns of neighboring property owners. Some ranchers worry that the species being reintroduced on his lands may one day bring federal land-use restrictions. Jimmy Rainey, the mayor of Truth or Consequences, N.M., a town nestled between Turner’s Armendaris and Ladder ranches, doesn’t necessarily agree. He says the local people aren’t really concerned about what Turner is doing—they’re just curious. Certainly they appreciate his financial donation to the town (in the form of a skateboard park), but, Rainey says, “It would be nice if Turner held town meetings or something to let us know what’s going on.”

Turner calls his land stewardship a "serious responsibility," but he isn't one to sit still for such interactions. (He barely made time to be interviewed for this story.) He relies on his staff to engage the local communities.

Turner himself thinks it's too early to judge his conservation efforts. "TESF is a new, innovative entity," he says, "and it will take time before its true impact can be clearly measured." With no other private landowner attempting to make conservation profitable on this scale, there is little by which to gauge his success. But there's no sign of Turner letting up—his staff say that they are always looking for good deals on good land.

Dissent in the Maelstrom

Maverick meteorologist Richard S. Lindzen keeps right on arguing that human-induced global warming isn't a problem

BY DANIEL GROSSMAN

ORIGINALLY PUBLISHED IN NOVEMBER 2001

Adviser to senators, think tanks and at least some of the president's men, Richard S. Lindzen holds a special place in today's heated debate about global warming. An award-winning scientist and a member of the National Academy of Sciences, he holds an endowed chair at the Massachusetts Institute of Technology and is the nation's most prominent and vocal scientist in doubting whether human activities pose any threat at all to the climate. Blunt and acerbic, Lindzen ill-tolerates naïveté. So it was with considerable trepidation recently that I parked in the driveway of his suburban home.

A portly man with a bushy beard and a receding hairline, Lindzen ushered me into his living room. Using a succession of cigarettes for emphasis, he explains that he never intended to be outspoken on climate change. It all began in the searing summer of 1988. At a high-profile congressional hearing, physicist James E. Hansen of the NASA Goddard Institute for Space Studies went public with his view: that scientists knew, "with a high degree of confidence," that human activities such as burning fossil fuel were warming the world. Lindzen was shocked by the media accounts that followed. "I thought it was important," he recalls, "to make it clear that the science was at an early and primitive stage and that there was little basis for consensus and much reason for skepticism." What he thought would be a couple of months in the public eye has turned into more than a decade of climate skepticism. "I did feel a moral obligation," he remarks of the early days, "although now it is more a matter of being stuck with a role."

It may be just a role, but Lindzen still plays it with gusto. His wide-ranging attack touches on computer modeling, atmospheric physics and research on past climate. His views appear in a steady stream of congressional testimonies, newspaper op-eds and public appearances. Earlier this year he gave a tutorial on climate change to President George W. Bush's cabinet.

It's difficult to untangle how Lindzen's views differ from those of other scientists because he questions so much of what many others regard as settled. He fiercely disputes the conclusions of this past spring's report of the Intergovernmental Panel on Climate Change (IPCC)—largely considered to be the definitive scientific assessment of climate change—and those of a recent NAS report that reviewed the panel's work. (Lindzen was a lead author of one chapter of the IPCC report and was an author of the NAS report.) But, according to him, the country's leading scientists (who, he says, concur with him) prefer not to wade into the troubled waters of climate change: "It's the kind of pressure that the average scientist doesn't need." Tom M. L. Wigley, a prominent climate scientist at the National Center for Atmospheric Research, says it is "demonstrably incorrect" that top researchers are keeping quiet. "The best people in the world," he observes, have contributed to the IPCC report.

To Lindzen, climate research is "polluted with political rhetoric"; the science remains weak

Lindzen agrees with the IPCC and most other climate scientists that the world has warmed about 0.5 degree Celsius over the past 100 years or so. He agrees that human activities have increased the amount of carbon dioxide in the atmosphere by about 30 percent. He parts company with the others when it comes to whether these facts are related. It's not that humans have no effect at all on climate. "They do," he admits, though with as much impact on the environment as when "a butterfly shuts its wings."

The IPCC report states that "most of the observed warming over the last 50 years" is of human origin. It says that late 20th-century temperatures shot up above anything the earth had experienced in the previous 1,000 years. Michael E. Mann, a geologist at the University of Virginia and a lead author of the IPCC's past-climate chapter, calls the spike "a change that is inconsistent with natural variability." Lindzen dismisses this analysis by questioning the method for deter-

NASA/SPL/PHOTO RESEARCHERS, INC.

CLOUD COVER over the tropics could reduce global warming—or increase it.

mining historical temperatures. For the first 600 years of the 1,000-year chronology, he claims, researchers used tree rings alone to gauge temperature and only those from four separate locations. He calls the method used to turn tree-ring width into temperature hopelessly flawed.

Mann was flabbergasted when I questioned him about Lindzen's critique, which he called "nonsense" and "hogwash." A close examination of the IPCC report itself shows, for instance, that trees weren't the sole source of data—ice cores helped to reconstruct the temperatures of the first 600 years, too. And trees were sampled from 34 independent sites in a dozen distinct regions scattered around the globe, not four.

Past climate isn't the only point of divergence. Lindzen also says there is little cause for concern in the future. The key to his optimism is a parameter called "climate sensitivity." This variable represents the increase in global temperature expected if the amount of carbon dioxide in the air doubles over preindustrial levels—a level the earth is already one third of the way toward reaching. Whereas the IPCC and the NAS calculate climate sensitivity to be somewhere between 1.5 and 4.5 degrees C, Lindzen insists that it is in the neighborhood of 0.4 degree.

The IPCC and the NAS derived the higher range after incorporating positive feedback mechanisms. For instance, warmer temperatures will most likely shrink the earth's snow and ice cover, making the planet less reflective and thus hastening warming, and will also probably increase evaporation of water. Water vapor, in fact, is the main absorber of heat in the atmosphere.

But such positive feedbacks "have neither empirical nor theoretical foundations," Lindzen told the U.S. Senate commerce committee this past May. The scientist says negative, not positive, feedback rules the day. One hypothesis he has postulated is that increased warming actually dries out certain parts of the upper atmosphere. Decreased water vapor would in turn temper warming. Goddard's Hansen says that by raising this possibility Lindzen "has done a lot of good for the climate discussion." He hastens to add, however, "I'm very confident his basic criticism—that climate models overestimate climate sensitivity—is wrong."

In March, Lindzen published what he calls "potentially the most important" paper he's written about negative feedback from water vapor. In it, he concludes that warming would decrease tropical cloud cover. Cloud cover is a complicated subject. Depending on factors that change by the minute, clouds can cool (by reflecting sunlight back into space) or warm (by trapping heat from the earth). Lindzen states that a reduction in tropical cloudiness would produce a marked cooling effect overall and thus serve as a stabilizing negative feedback.

But three research teams say Lindzen's paper is flawed. For example, his research was based on data collected from satellite images of tropical clouds. Bruce A. Wielicki of the NASA Langley Research Center believes that the images were not representative of the entire tropics. Using data from a different satellite, Wielicki and his group conclude, in a paper to appear in the *Journal of Climate*, that, on balance, warmer tropical clouds would have a slight heating, not a cooling, effect.

Looking back at the past decade of climate science, many researchers say computer models have improved, estimates of past climate are more accurate, and uncertainty is being reduced. Lindzen is not nearly so sanguine. In his mind the case for global warming is as poor as it was when his crusade began, in 1988. Climate research is, he insists, "heavily polluted by political rhetoric, with evidence remaining extremely weak." To Lindzen, apparently, the earth will take care of itself.

Save the Muntjacs

And warty pigs, saolas, zebra-striped rabbits—helping to discover and preserve new animals is this biologist's game BY MARGUERITE HOLLOWAY

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There are few sounds in the forest this late afternoon: only branches up high being lifted by an almost absent wind and the cracking of twigs as Alan R. Rabinowitz, director of science and exploration at the Wildlife Conservation Society, hikes down a slope and through a flat section of forest. There are no animals in sight. We are talking about the pleasure of wandering in woods, of discovery, when Rabinowitz finds an empty shotgun shell. "They won't stay off," he fumes. Hunters have been sneaking onto the posted land, and no amount of discussion or threat has deterred them. "They feel they have a right to it because they have been coming here forever," Rabinowitz says, glowering.

"Here" could well be a forest in Myanmar or Laos or Thailand or Belize or any of the many countries where Rabinowitz has worked for the past two decades to protect wildlife from poachers, among other threats. Indeed, just up the hill sits a cabin filled with some of the items unique to a Rabinowitz-style field station, no matter how remote: weight-lifting equipment and a punching bag. And although we are standing in a mere 25 acres of temperate woods on a small mountain in Putnam County, an hour north of New York City, the issues that excite Rabinowitz—and infuriate him—are the same ones that consume him when he is in real wilderness.

NAJLAH FEANNY *SABA*

CHAMPIONING the cause of threatened animals is a passion Alan R. Rabinowitz developed from childhood stuttering, which drew him to pets: "I couldn't speak, and they couldn't speak."

Rabinowitz—an outspoken, dynamic, charismatic and at times controversial biologist—has been involved directly and indirectly in the recent discoveries of several species of animal. The appearance of sizable mammals unknown to science—one of them, the saola (*Pseudoryx nghetinhensis*), resembles an antelope—in Vietnam, Laos and Myanmar has delighted biologists and conservationists overwhelmed by an era of environmental doom and gloom and extinction. For Rabinowitz, whose work studying large cats in forests largely empty of animals had been depressing him, the finds have restored his optimism and stoked his already intense desire to save creatures. "There are these huge areas of relatively unexplored, unprotected wilderness that we need to go out and find and protect when nobody cares about them," he explains to me as we later sit in the study of his house atop the hill. Most important, adds Rabinowitz, who has recently become a father, is the impact these remarkable discoveries have on the young: "Kids have been getting a totally hopeless message, and we have been doing them a complete injustice by saying it is hopeless and there is no more to discover."

Rabinowitz has been able to get into some of these remote regions and set up programs for the Wildlife Conservation Society (which is based at the Bronx Zoo in New York City) by flying in blind and by passionate persistence. After Laos opened its borders to outsiders in the late 1980s, for instance, he quickly found a way around the government's requirement that only foreigners in tour groups be admitted. "I went to a shady travel agent in Bangkok, of which there are many, and he said, 'We can book a group tour, a tour of about 10 people, but all the names will be fictional except yours,'" Rabinowitz explains. "So I went to Laos, and [a guide] met me at the airport, and I said, 'At the last minute everyone got some kind of bug in their food, and I was the only one who didn't eat the food. Everybody is in the hospital in Bangkok. But I paid all this money, and I just had to go.'"

A short tour and a bribe later, Rabinowitz approached the government and, after months of negotiations, set off to explore the Annamite Mountains in southeastern Laos with colleagues. The Annamites proved to be biologically interesting because they served as refugia during the climatic shifts between 2.5 million and 10,000 years ago, offering animals isolated havens where they evolved distinctly from their relatives in other isolated havens. Exploration in the range had suggested as much: in 1992 scientists surveying terrain in Vietnam near the Ho Chi Minh Trail had found the saola. Soon after, Rabinowitz and other researchers working just across the border in Nakai Nam Theun, Laos's largest protected area, also found the saola. Later surveys revealed a new species of barking deer (the giant muntjac) and a zebra-striped rabbit, as well as the Roosevelt muntjac and the Vietnamese warty pig, which had been thought to be extinct. In Rabinowitz's mind, the mother lode lay in the northern part of Myanmar, in a corner of the Himalayas, and so he set out to convince the government of that. His efforts ultimately led to the creation of Hkakaborazi, a 1,472-square-mile protected area, after an expedition in 1997 revealed yet another species of deer: the leaf muntjac. Rabinowitz and his colleagues subsequently found a black muntjac, blue sheep and a marten, all previously thought to be confined to China.

Rabinowitz will soon return to continue surveying and to bring salt to villagers in an effort to forestall hunting. In northern Myanmar, trade in animals with neighboring China is driven by a desperate need for salt to prevent the devastating consequences of iodine deficiency. Trade in animal parts has emptied many of the forests of Southeast Asia. In Laos, in particular, mile-long walls of thatch and saplings force animals into snares; in many places the forest is completely silent.

Rabinowitz's peregrinations have taken him far from the urban landscape of his childhood. Born in New York City in 1953, he spent his childhood in Brooklyn. His father—a physical education teacher who coached Dodger pitching legend Sandy Koufax in basketball and urged him not to pursue baseball—taught Rabinowitz to weight lift when he was quite young. Being strong and fit has served him well in the jungle, helping him survive disease and many accidents, including a plane crash and a helicopter crash. And it may have earned him his job with the Wildlife Conservation Society, because he was able to set a rigorous pace during a hike with George Schaller, a renowned biologist at the society who had been visiting the University of Tennessee, where Rabinowitz was finishing his Ph.D. thesis on raccoons. After the hike Schaller offered him a job tracking elusive jaguars and assessing the size of their population in Belize. "I immediately said yes," recalls Rabinowitz. "And thought, 'Where's Belize?'"

Strength was especially important when Rabinowitz was younger, because he stuttered: "I could always beat up anybody." Despite the misery often caused by the stuttering—Rabinowitz once stabbed a pencil through his hand to avoid having to give a presentation—he says he is grateful for it: "Now I see it as the greatest blessing. I love stuttering because stuttering put me apart from people." Stuttering drew him to pets, including a turtle, a hamster and some garter snakes. "I would talk to them. And I came to love animals because they allowed me to be me," he says. "I came to champion their cause or associate with them because I saw them as very similar to me. I couldn't speak, and they couldn't speak."

This advocacy has been criticized at times, in part because Rabinowitz has been outspoken against people living in wildlife refuges and scoffs at the idea of "sustainable development" as a fantasy born by armchair philosophers. He clashed with the environmental and human-rights activist group International Rivers Network regarding a dam in Laos, for instance. Rabinowitz believes the dam can be a good idea—if it is constructed according to plans by the World Bank—because the country has no manufacturing base, because the area to be flooded is "completely degraded" and because the people who will be displaced will be getting what they want: schools and housing. "They aren't living in any kind of harmony. They frequently get sick; they have high child mortality," he says. "Go into the field and live with these people and then tell me what kind of a wonderful life they live when you get sick with them."

Despite his oft-repeated claim to prefer animals over humans, Rabinowitz obviously loves and admires the people he works with in the field—something even a quick read of two of his books, Jaguar and Chasing the Dragon's Tail, makes clear. And so he was incensed by a British newspaper's claim that he was colluding with Myanmar's military government to evict members of the Karen tribe from a national park. "We weren't even close to that area," he says, jabbing at a map: Hkakaborazi is to the very north, bordering Tibet; the conflicted Karen region is to the southeast. "I would love to go in the Karen area, but I can't because they are fighting a civil war."

Rabinowitz is already thinking of other places that he can study or protect. "You don't know how many nights when I am burned out or bored or whatever, I pore over maps and look at the places in the world that for political reasons or whatever have now opened up," he says. "Exploration is not just about finding something that nobody has ever seen before or finding a new species. It is also about ways of looking at the world."

NEW SPECIES found in Southeast Asia include the diminutive leaf muntjac (top) and the striped rabbit (taken after it tripped an automatic camera). The forests may harbor other undiscovered creatures.

ALAN R. RABINOWITZ (*muntjac*); LAURIE GRACE (*map*)

Thawing Scott's Legacy

A pioneer in atmospheric ozone studies, Susan Solomon rewrites the history of a fatal polar expedition BY SARAH SIMPSON

ORIGINALLY PUBLISHED IN DECEMBER 2001

Halfway along her chilly walk from the cafeteria to the laboratory, the young woman's pace slows to a crawl. Since her arrival at Antarctica's McMurdo Station 10 days ago, she has acclimatized surprisingly well. She has come to relish the two-mile stroll, even in temperatures as low as –20 degrees Fahrenheit. Yet today the air feels much more intensely frigid. Her legs start to feel numb, and her jeans turn strangely stiff. Ice crystallizes in the corner of her right eye, and the cold tears at her lungs. She suddenly realizes how lucky she is to be so near the warmth of civilization.

That day in 1986 atmospheric chemist Susan Solomon truly understood the unremitting hostility of the earth's southernmost continent. The temperature had dipped to a dangerous –50 degrees F; the windchill was below –100 degrees F. Solomon was visiting Antarctica to study trace gases in the atmosphere, but the experience also inaugurated a 15-year investigation into the tragic expedition of Robert Falcon Scott, the English explorer who perished on the ice in 1912 after narrowly losing a race to the South Pole.

Solomon's historical conclusions culminated in *The Coldest March: Scott's Fatal Antarctic Expedition*, published this past September by Yale University Press. The book offers a compelling new explanation for what doomed Scott and four of his men. It was not the explorer's incompetence, as several popular accounts have suggested. It was lethal cold, more severe than what Solomon had experienced at McMurdo. Her analysis of meteorological records—and a careful reading of the expedition diaries—shows that the descriptions of Scott as a poor and unprepared leader were off the mark. "This is a case where science informs history," Solomon asserts. The polar party died during the coldest March on record, when temperatures plunged as low as –77 degrees F.

As the leader of the research team that confirmed the existence of the Antarctic ozone hole, Solomon, now 45, has long been accustomed to looking at the world in a different way. Examining Scott's expedition became a hobby for Solomon as she pursued the studies that definitively linked the man-made chemicals chlorofluorocarbons (CFCs) to ozone destruction in the stratosphere and made the ozone hole one of the most-talked-about environmental issues of the 20th century.

The year before her 1986 walk in the cold, Solomon was already thinking about ozone. While a researcher at the National Oceanic and Atmospheric Administration's Aeronomy Laboratory in Boulder, Colo., she hypothesized that icy clouds in the heart of the stratospheric ozone layer (about 12 miles above the planet's surface) provide the unusual conditions that activate chlorine from CFCs. The stray chlorine atoms then steal oxygen atoms from ozone (a three-oxygen molecule). As the ozone is destroyed, the earth loses much of its protection against harmful ultraviolet radiation, which can promote skin cancer and damage crops.

Multiple measurements from Solomon's Antarctic ozone expedition in 1986 and another in 1987 proved the theory right—and led many scientists to predict correctly that ozone depletion over the midlatitudes was only a matter of time. Her work led to her election to the National Academy of Sciences in 1993 and to the National Medal of Science last year. At the same time Solomon was implicating CFCs and exploring other aspects of the earth's atmosphere, Scott's expedition began capturing more of her interest. After about 12 years of casually perusing the diaries of Scott and several of his companions, she decided it would be "kind of fun to see what their meteorological data were like," she explains. "That was really when I gained a new level of respect for them." That's also when she first started to find evidence that bad weather, not poor planning, was the greatest factor in Scott's death.

Indeed, Solomon discovered that Scott's team suffered a triple-decker weather disaster while crossing the Ross Ice Shelf, the last leg of their return journey from the pole. That 400-mile crossing should have been the easiest part of their trip. Based on earlier forays and weather measurements, they expected the wind to be at their backs. Expedition meteorologist George C. Simpson also predicted relatively mild temperatures of –10 to –20 degrees F on the shelf. Instead the group encountered average daily minimum temperatures of –34 degrees F, and on only one day of their three weeks on the ice shelf did the temperature rise above –20 degrees F.

"Simpson thought their chances of having weather like that were one in 10," Solomon says. Her analysis of 15 years of meteorological measurements from modern, automated weather stations near Scott's historic path corroborates Simpson's expectations. Just one of those years, 1988, experienced March temperatures persistently that frigid.

Beyond the cold snap, the wind was unexpectedly calm, rendering useless the sails Scott hoped to employ to help move the supply sledges. Each of the men was left to haul a 200-pound sledge through snow that had the texture of gritty desert sand. Again using modern science, Solomon explains why the snow took such a bizarre form: at temperatures below about –20 degrees F, friction no longer melts snow into a slippery layer beneath sledge runners. This trio of conditions was compounded by an unusually long-lived blizzard and a frostbitten foot that eventually halted Scott's ability to walk. He and his last two surviving companions died in a tent only 11 miles from a stash of food and fuel.

Solomon worked nights and weekends for more than three years to weave these and other findings into *The Coldest March*. "It literally poured out because it was with me for so long," she says. She credits her fiction-writing group—which has met every Tuesday for the past 12 years and includes a rancher, a liquor-store office manager and a homemaker—for helping her make the science understandable to a popular audience.

Still happily obligated to her day job as senior scientist at the Aeronomy Laboratory while writing the book, Solomon was also authoring a 41-page review article on the history of ozone research and flying on research planes to study how clouds absorb sunlight, a critical influence on the earth's energy budget. The crushing loss of a dear friend and fellow ozone researcher in a private plane crash in 1999 pushed her through the last months of writing.

"In some ways, it's a matter of principle for her to soldier on in the face of adversity," says Barry Sidwell, Solomon's husband of 12 years. "She can definitely be determined when she sets her mind to it."

As both scientist and historian, Solomon is driven by her desire to carry her message to a broad audience. "One of our shortcomings as scientists is that we don't always communicate well outside scientific circles," she observes. "When you encounter something new or interesting, I think it's a duty to convey that to the public."

MATHEMATICS & COMPUTER SCIENCE

Not Just Fun and Games

Best known for inventing the game of Life, John H. Conway is adept at finding the theorems hidden in simple puzzles BY MARK ALPERT

ORIGINALLY PUBLISHED IN APRIL 1999

Stepping into John H. Conway's office at Princeton University is like stepping into a mathematician's playpen. Dozens of polyhedra made of colored cardboard hang from the ceiling like mirror balls at a discotheque. Dangling among them is a Klein bottle constructed from chicken wire. Several models of crystal lattices sit beside the window, and a pyramid of tennis balls rises from the floor. At the center of it all is Conway himself, leaning back in his chair, his face obscured by oversize glasses and a bushy, gray beard. The eclectic 61-year-old mathematician is clearly in his element.

"What's your date of birth?" he asks me soon after we shake hands.

"April 19, 1961," I reply.

"Tuesday!" he shouts immediately. Then he corrects himself. "No, damn! Wednesday!" Slightly irritated by his error, he explains that long ago he devised an algorithm for determining the day of the week that any given date falls on. Called the Doomsday Rule, the algorithm is simple enough for Conway to do the calculations in his head. He can usually give the correct answer in under two seconds. To improve his speed, he practices his calendrical calculations on his computer, which is programmed to quiz him with random dates every time he logs on.

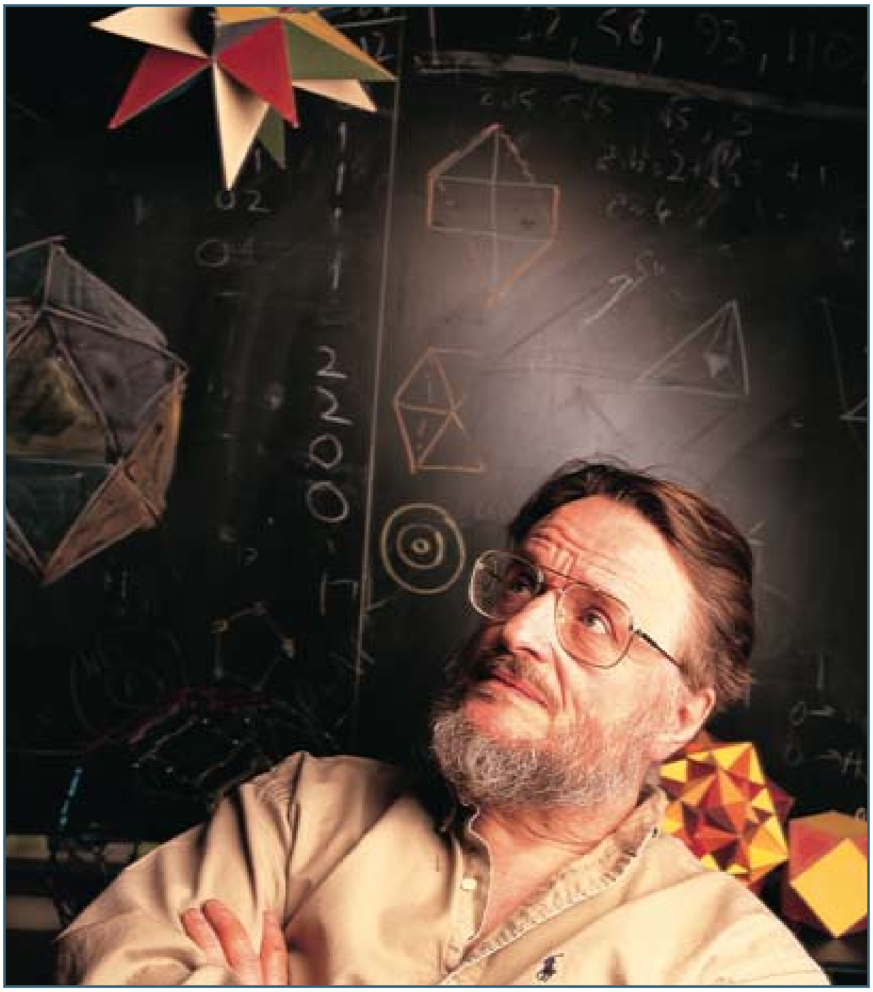
At this point, I begin to wonder why Princeton University is paying this man a salary. But over the past three decades Conway has made some of his greatest contributions to mathematical theory by analyzing simple puzzles. "It's impossible for me to go into the office and say, 'Today I'll write a theorem,'" Conway admits. "I usually have half a dozen things running through my head, including games and puzzles. And every so often, when I feel guilty, I'll work on something useful." Conway's useful work spans the gamut of mathematical disciplines, ranging from theorems about knots and sphere packing to the discovery of a whole new class of numbers—the aptly named surreal numbers.

Born in Liverpool, England, in 1937, Conway showed an early interest in mathematics. At the age of four, according to his mother, he began reciting the powers of two. Liverpool was being bombed by the German Luftwaffe at the time, and Conway has a lasting memory of one of the air raids. "While my father was carrying me to our backyard shelter one night, I happened to look up at the sky. There were spotlights overhead, and I saw the bombs falling from the planes. They were chained together and whirling around. It looked so beautiful, I said, 'Look, Daddy! That's so nice!'"

Conway attended the University of Cambridge, where he studied number theory and logic and eventually joined the faculty of the mathematics department. In his spare time he became an avid backgammon player. "I used to play backgammon in the common room at Cambridge," Conway recalls. "My more sedate colleagues would come in occasionally for a cup of coffee or tea, but I'd be there all day long." Conway's career didn't really take off until the late 1960s, when he became intrigued by a theoretical lattice that extends into 24 dimensions. By contemplating this lattice, Conway discovered a new finite group, which is the set of symmetries of a geometric object. A cube, for example, has 24 symmetries—there are 24 ways to rotate it to an identical position. But the Conway group, as it became known, has more than 1018 symmetries, making it the largest finite group known at the time of its discovery. (It was later superseded by the so-called Monster group, which has more than 1053 symmetries.) Finding a new group is an extraordinarily difficult achievement, and Conway's colleagues soon began to hail him as a genius.

At about the same time, Conway was exploring the idea of the universal constructor, which was first studied by American mathematician John von Neumann in the 1940s. A universal constructor is a hypothetical machine that could build copies of itself—something that would be very useful for colonizing distant planets. Von Neumann created a mathematical model for such a machine, using a Cartesian grid—basically, an extended checkerboard—as his foundation. Conway simplified the model, and it became the now famous game of Life.

In the game, you start with a pattern of checkers on the grid—these represent the "live" cells. You then remove each checker that has one or no neighboring checkers or four or more neighbors (these cells "die" from loneliness or overcrowding). Checkers with two or three neighbors remain on the board. In addition, new cells are "born"—a checker is added to each empty space that is adjacent to exactly three checkers. By applying these rules repeatedly, one can create an amazing variety of Life forms, including "gliders" and "spaceships" that steadily move across the grid.



PETER MURPHY

PONDERING A POLYHEDRON: Mathematician John H. Conway has made important contributions to geometry, number theory, group theory and topology.

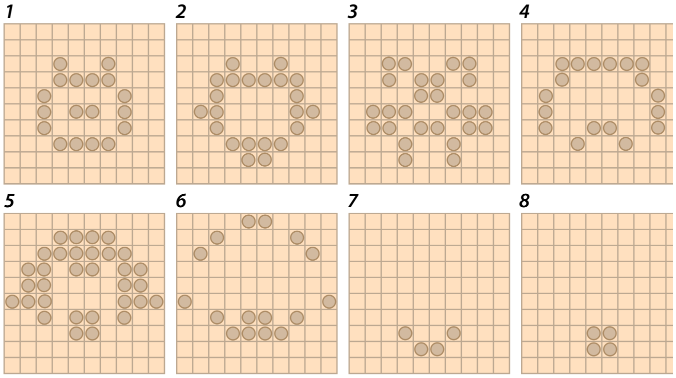
Conway showed the game of Life to his friend Martin Gardner, the longtime author of *Scientific American*'s Mathematical Games column. Gardner described the game in his October 1970 column, and it was an immediate hit. Computer buffs wrote programs allowing them to create ever more complex Life forms. Even today, nearly 30 years after the game's introduction, Conway receives voluminous amounts of e-mail about Life. "The game made Conway instantly famous," Gardner comments. "But it also opened up a whole new field of mathematical research, the field of cellular automata."

Conway, though, moved on to other pursuits. Some of his Cambridge colleagues were skillful at the ancient game of Go, and as Conway watched them play he tried to develop a mathematical understanding of the game. He noticed that near the end of a typical Go match, when the board is covered with snaking lines of black and white stones, the game resembles the sum of several smaller games. Conway realized that certain games actually behave like numbers. This insight led him to formulate a new definition of numbers that included not only the familiar ones—the integers, the rational numbers, the real numbers and so on—but also the transfinite numbers, which represent the sizes of infinitely large sets.

Mathematicians have long known that there is more than one kind of infinity. For example, the set of all integers is infinitely large, but it is smaller than the set of all real numbers. Conway's definition encompassed all the transfinite numbers and, better still, allowed mathematicians to perform the full array of algebraic operations on them. It was a theoretical tour de force: by defining finite and transfinite numbers in the same way, Conway provided a simpler logical foundation for all numbers. Stanford University computer scientist Donald E. Knuth was so impressed by Conway's breakthrough that he wrote a quirky novella, called *Surreal Numbers*, that attempts to explain the theory. In the story, Conway is cast as God—there is a character named "C" whose voice booms out of the sky. Although the comparison may seem a little extreme, Conway acknowledges that he has a healthy ego. "After I make a discovery, my feelings are a bit of a mix," he says. "I admire the beauty of the thing I've discovered, how it all fits together. But I also admire my own skill at finding it."

Conway's interest in games culminated in 1982 with the publication of *Winning Ways for Your Mathematical Plays*, a two-volume work he wrote with Elwyn R. Berlekamp of the University of California at Berkeley and Richard K. Guy of the University of Calgary. The book has become the bible of recreational mathematics; it describes dozens of brain-teasing games, most of them invented by the authors, with outlandish names such as Toads-and-Frogs and Hackenbush Hotchpotch. But the main purpose of the book, Conway insists, is not entertainment. "The book is really more about theory than games," he says. "I'm much more interested in the theory behind a game than the game itself. I got the theory of surreal numbers from analyzing the game of Go, but I never really played the game." In fact, the only game Conway plays regularly is backgammon—a pastime that defies mathematical analysis because it involves the element of chance.

Unfortunately, Conway's personal life has not been as orderly as his mathematical theorems. He has endured bouts of depression and a heart attack. In the mid-1980s Conway moved from Cambridge to Princeton, and since then much of his work has focused on geometry. He is currently exploring the symmetries of crystal lattices—which explains the presence of the lattice models in his office. He is also pursuing what he calls his "grandiose project," a rethinking of the fundamental axioms of set theory. Conway recognizes, however, that he is slowing down. "I used to go through these white-hot phases when I couldn't stop thinking about a problem," he admits. "But now those phases are not so common. It's been ages since I had one."



LAURIE GRACE

CHESHIRE CAT: A LIFE pattern, transforms into a grin (7) and finally a paw print (8).

Among mathematicians, though, Conway's reputation is already assured. "It's hard to predict which of his many major achievements will most impress mathematicians of the future," says Martin Kruskal of Rutgers University, who has spent years investigating the surreal numbers that Conway discovered. Conway himself worries a little that his work on games and puzzles may overshadow his more significant accomplishments, such as the discovery of surreal numbers and the Conway group. But his career is strong evidence that playful thinking can often lead to serious mathematics. "Games usually aren't very deep," Conway muses. "But sometimes, something you thought was frivolous can turn out to be a deep structural problem. And that's what mathematicians are interested in."

Monstrous Moonshine Is True

ORIGINALLY PUBLISHED IN NOVEMBER 1998

Richard Borcherds proved it—and discovered spooky connections between the smallest objects imagined by physics and one of the most complex objects known to mathematics BY W. WAYT GIBBS

Talking to Richard Borcherds about his work can be unnerving. It is not just the difficulty of trying to keep up with the intellect of someone who, at the age of 38, has already won the highest award in mathematics, a Fields Medal, made of solid gold and bearing a Latin inscription that urges him "to transcend human limitations and grasp the universe." There is also the palpable unease of his movements. I arrive at his office in a nondescript corner of the University of Cambridge precisely when he expected; I knock quietly on the door. Yet my entrance has completely flustered him. He begins pacing like a caged tiger and waving his arms at nothing in particular. He appears to have no idea what to do next. I offer myself a seat.

"I'm not very good at expressing feelings and things like that," Borcherds says straightaway. "I once read somewhere that the left side of the brain handles mathematics and the right side handles emotions and expression. And I've often had the feeling that there really is a disconnect of some sort between the two."

Mathematics research is not, as many believe, an exercise in pure reason—at least not for Borcherds. "The logical progression comes only right at the end, and it is in fact quite tiresome to check that all the details really work," he says. "Before that, you have to fit everything together by a lot of experimentation, guesswork and intuition."

That hints at what is most unnerving about talking to Borcherds: looking through his eyes, through his work, you can get a glimpse of a whole alternative universe, full of wondrous objects that are real but not physical. Borcherds spends his days exploring that deep space of mathematics, and indeed—if his frequent far-off stares and his choice today to dress entirely in wrinkled brown attire are any indication—he seems always to keep one foot over there.

"Some mathematics clearly is a human invention," he says, most notably anything that depends on the fact that we use a 10-digit numbering system. "But I think some mathematics does exist before its discovery. Take the Pythagorean theorem. That has been independently rediscovered several times by various civilizations. It's really there. Presumably if there were small furry creatures doing mathematics on Alpha Centauri prime, they would also have some version of the Pythagorean theorem."

And if they had explored a good deal further into the abstract universe of mathematics, the furry aliens might also have stumbled on three remarkable objects and discovered, as Borcherds did, that they are connected in some profound but still rather mysterious way. They would probably not, however, have called the problem the "monstrous moonshine conjecture," as Borcherds's mentor, Cambridge professor John H. Conway, chose to.

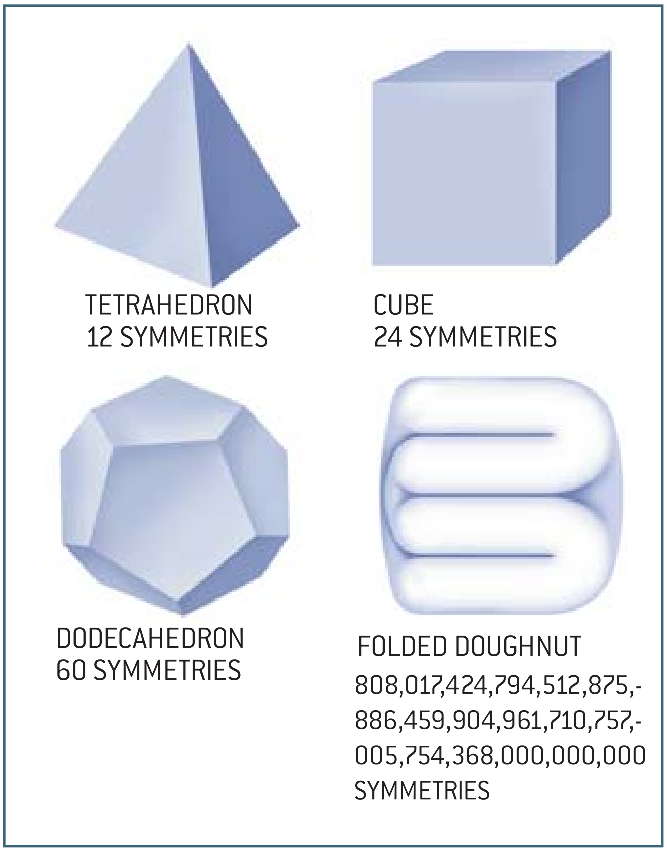
The problem arose in 1978, when John McKay of Concordia University was struck by a rather bizarre coincidence. "I was reading a 19th-century book on elliptic modular functions," McKay recalls, "and I noticed something strange in the expansion of one in particular"—the so-called j function. This elliptic modular function, explains John C. Baez of the University of California at Riverside, "shows up when you start studying the surfaces of doughnuts that are created by curling up the complex plane." On a sheet of graph paper, you can number the columns with whole numbers (1, 2, 3,...) and the rows with imaginary numbers ($1\sqrt{-1}$, $2\sqrt{-1}$, $3\sqrt{-1}$, . . .). Then you can roll up the sheet and join the ends of the tube to make doughnuts of various sizes and shapes. "Roughly speaking," Baez elaborates, "if you give me a shape of such a torus, then I can use the *j* function to convert that shape into a particular complex number." Although the *j* function sounds arcane, it is actually a useful tool in math and physics.

The odd coincidence appeared to McKay when he looked at the coefficients of the j function when it was written as an infinitely long sum. The third coefficient was 196,884. The number rang a bell.

To show me why, Borcherds lifts, with some effort, a book the size of a world atlas from his desk. He opens it to a table of numbers printed so small that they are barely legible. The first number in the table is 1. The next is 196,883. Together they add up to that figure in the *j* function, which is mighty strange, because this table has nothing to do with elliptic functions. "These numbers," Borcherds says, flipping through about eight large pages of tiny print, "make up the character table of the Monster."

The Monster simple group is its full name, because it is the largest sporadic, finite, simple group known to exist. To understand what that means, Borcherds suggests, "suppose an ancient Greek tried to understand the symmetries of ordinary solid objects. He discovered a cube, which is quite easy to construct, and found that it has 24 symmetries"—that is, there are 24 ways to twist it about and end up with it looking the same. Those symmetries make up a finite group of 24 elements.

"Next, perhaps the Greek built a tetrahedron, which generates a group of 12 symmetries," Borcherds continues. "And then he might notice that no geometric object he knew of had a number of symmetries that is a multiple of five—but he could theorize that such an object exists. Later, somebody else might actually construct a [12-sided] dodecahedron, having 60 symmetries, thus proving the first guy right. In fact, it's said that when the Pythagoreans did discover a dodecahedron, they guarded it as such a great secret that they actually strangled one of their members who dared publicize its existence. They took their math seriously in those days."



SYMMETRIES of geometric objects and other mathematical constructs form the elements of so-called finite groups. A particular string theory, when applied to a folded doughnut in 26 dimensions (simplified to three here), has more than 1053 symmetries and produces the Monster group.

Math rarely leads to murder anymore, but quite a few mathematicians have devoted the better part of their careers to solving the mysteries of the Monster group, which was indeed predicted to exist many years before it was successfully constructed. It, too, represents the symmetries of—well, of what exactly, mathematicians hadn't a clue. Something, certainly, that is a bit too complex to call a mere geometric object, because the Monster lives not in three dimensions but in 196,883. And in 21,296,876 dimensions, and in all the higher dimensions listed in the first column of Borcherds's table.

Whatever object gives rise to the Monster group must be exceedingly symmetrical, because "the group has several times more elements," McKay reckons, "than the number of elementary particles—quarks and electrons and such—in the sun": 808,017,424,794,512,875,886,459,904,961,710,757,005,754,368,000,000,000, to be precise.

So far removed are finite groups from modular functions that "when John McKay told people about his observation that the third coefficient of the *j* function matched the smallest dimensions of the Monster, they told him that he was completely crazy," Borcherds recounts. "There was no connection that anyone could imagine." But eventually others noticed that the coincidences ran too deep to ignore. "It turned out that *every* coefficient of the modular function is a simple sum of the numbers in this list of dimensions in which the Monster lives," Borcherds says. Conway and others theorized that the connections were not coincidences at all but reflections of some deeper unity. They dubbed the wild conjecture "moonshine," and a new specialty in mathematics arose to try to prove it.

Borcherds, meanwhile, was barely scraping through a Ph.D. at Cambridge, polishing his Go game when he was supposed to be at lectures, he says. Yet somehow he impressed Conway, who handpicked him to tackle moonshine.

In 1989, after eight years' work on the problem, Borcherds's body was sitting on a stalled bus in Kashmir while his mind no doubt roamed the alternative universe of the abstract. It was then that he found the third piece of the puzzle, the one that joined the other two. The connection, appropriately enough, was string theory, by way of the number 26.

Physicists have been dreaming up various kinds of infinitesimal strings for years in the hope of explaining everything in the universe with one theory. The basic idea is that all elementary particles are not fundamental at all but are really composed of loops of one-dimensional strings.

To keep track of how the laws of nature operate under various theories, physicists have long drawn stick-figure diagrams. Each limb represents the track of a particle, and the intersections, or vertices, are where the particles collide or interact. "In string theory they deal with little loops, not points, so the diagrams are made up not of lines but of tubes connected by bits of plumbing," Baez explains. "The math used in string theories describes what happens where these tubes meet," using a so-called vertex algebra.

One unpleasant fact about string theories, Baez notes, is that "when you try to do calculations in them, you need certain things to cancel each other out, but that only happens when you have 24 extra dimensions around," for a total of 26 dimensions (because time and the string itself take up two).

LAURIE GRACE

"That is bad news for physicists," Borcherds says. "But it is exactly what you need to deal with the Monster. If the critical dimension of string theory were anything other than 26, I couldn't have proved the moonshine conjectures."

But it is, and he did, by inventing a vertex algebra—essentially, the rules of a string theory—all his own. "This vertex algebra," Baez explains, "describes a string wiggling around in a 26-dimensional space that has the unique feature that all 26 dimensions are curled up. It's like a tiny doughnut folded onto itself in the coolest way, using a technique that only works in 26 dimensions."

Complex doughnuts, of course, are what the *j* function is all about. And, Borcherds showed, the Monster is simply the group of all the symmetries of this particular string theory—a theory, by the way, that almost certainly has nothing to do with the universe we live in. But it is now a well-explored land in the alternative universe that Borcherds spends most of his time in.

"There are a whole bunch of very spooky coincidences sitting together that get this to work," Baez reflects. "My feeling is that probably there is something even larger and deeper beneath it, something that hasn't been found. Borcherds has begun to uncover it. But there are still a lot of mysteries left."

Molding the Web

Its inventor, Tim Berners-Lee, says the World Wide Web hasn't nearly reached its potential

BY MARGUERITE HOLLOWAY

ORIGINALLY PUBLISHED IN DECEMBER 1997

The intense Tim Berners-Lee abruptly rolls his chair away from the central table in his bare corner office over to two huge computer screens and starts typing as fast as he is speaking—for the listener, it is akin to a thick hailstorm hitting. The inventor of the World Wide Web is about to demonstrate how he first envisioned his creation and, by extension, how it has not lived up to his expectations.

With amazing speed, Berners-Lee uses his original software to set up a home page, make links to new pages and toggle between them. He shows how easy it should be to insert connections to other Web sites and how any user should be able to save comments into a document—just like writing in the margin of your book, but in this case, your note could transport you to the electronic version of the place you are musing about. "It was to be a very interactive medium; that was the idea. But you ain't got that," Berners-Lee laments.

The disappointment fizzles in a second, though, and Berners-Lee's freewheeling, high-velocity, superhyperlinked brain—the ur-Web itself—returns to thoughts of what the World Wide Web will become. He speaks almost reverently. No matter how many interviews the seemingly shy Berners-Lee agrees to, no matter how often he is asked to give a "vision" talk, no matter how hard he tries to speak slowly, there is a point at which the 42-year-old British physicist cannot contain his enthusiasm. In his world, the Web can empower people and transform society by allowing everyone self-expression and access to all information. "The Web can help people to understand the way that others live and love and are human, to understand the humanity of people," Berners-Lee expounds, almost tripping over his words.

Berners-Lee has been shaping the evolution of this electronic extravaganza from a nexus of quiet, grayish offices in a nondescript building at the Massachusetts Institute of Technology. There Berners-Lee directs the World Wide Web Consortium, or W3C, as it is called. Composed of some 40 staff people scattered around the world and 217 members, including fiercely competing communications and computer companies, the consortium serves as a standards organization for the Web. Just as the Internet Society establishes protocols so that the Internet retains its "inter-ness," W3C tries to ensure that no matter what commercial developments unfold, all the Web's strands remain interwoven.

With his ruffled blond hair and modest manner, Berners-Lee hardly looks like the one person who can get dueling giants Microsoft and Netscape to, if not kiss and make up, at least sit in a room together. Yet every issue arising around and about the Web—from how fast networks can transmit information to how to contend with cyberporn, the threat of censorship and the challenges of safe electronic commerce—is being responded to and molded by the largely hidden hands of Berners-Lee.

It is somewhat hard to plumb the origins of Berners-Lee's global humanism, because he is as protective of his privacy as he is of the integrity of the Web. He declines to answer questions about his wife or his two young children, although a picture of the towheaded youngsters is the only decoration in his office.

Timothy J. Berners-Lee was born and raised in London. His parents, Conway and Mary Berners-Lee, are mathematicians, and both worked on England's first commercial computer in the 1950s, the Ferranti Mark 1. The Berners-Lees occasionally discussed imaginary numbers at mealtime; as a child Tim constructed a Ferranti replica, complete with clock and punch cards, out of cardboard boxes. According to a former colleague, the family was also respectful of spiders: Mary Berners-Lee hung cotton threads down into the bathtub so fallen spiders could scale the smooth sides.

Berners-Lee says he had a Protestant upbringing but rejected literal Christianity as a teenager because it was incompatible with science. He now describes himself as a Unitarian Universalist. "It tackles the spiritual side of people's lives and of values and of the things you need to live your life, but it doesn't require you to believe six impossible things before breakfast," he says wryly.

Berners-Lee graduated in 1976 with first-class honors in theoretical physics from the Queen's College at the University of Oxford. In 1980, after various software-writing jobs, he spent six months at CERN, the European laboratory for particle physics near Geneva, where he designed a calendar program called Enquire to keep track of his own random associations; it later became the basis for the Web. He returned to CERN in 1984 as a software engineer.

The rest is ancient Web history. Berners-Lee wanted to create a means for far-flung researchers to share one another's data and work easily together. So, in 1990, he wrote specifications for HTML (hypertext markup language), HTTP (hypertext transfer protocol) and the precursor of URL (uniform resource locator). The idea of hypertext had been bandied about for a long time. In 1945 Vannevar Bush described the Memex machine, a microfilm-based system that could link associated information or ideas through "trails." Then, in 1965, Theodor H. Nelson, a software designer and writer, aphorized the term "hypertext." Yet no one made it happen. "We had been talking about Web-like things for 20 years in the industry," notes Eric Schmidt of Novell. "Why didn't we invent it?"

The answer may be found by following Berners-Lee's conversation. "He speaks in hyperlinks," notes W3C colleague Sally Khudairi, no sluggish talker herself. She keeps a bottle of aspirin handy for the days when she can't keep up with her boss.

Berners-Lee and his CERN compatriot Robert Cailliau put the free Web software on the Internet in 1991. It didn't take off until 1993, when Marc Andreessen and his colleagues at the University of Illinois, who had seen one of the early Web browsers called ViolaWWW, wrote the now famous Mosaic. Between 1991 and 1994 the number of Web clients grew from about 10 to 100,000. As a research facility, CERN was not the right place for such a fast-moving enterprise. "People started saying, 'Look, this thing is becoming so big that our company is completely orienting itself around the Web. We want to know that it will be stable.' They wanted to know that there will be something keeping it together," Berners-Lee recounts, explaining the birth of W3C, his ever present energy revealed in quick blasts of movement—arms crossed suddenly here, chair lowered quickly there, chin in hand for a moment, a short laugh.

Although the hub of the Web, the offices of W3C are surprisingly quiet. The carpeted hallways are usually empty; doors are pulled shut. The staff lives on the computer, the telephone or the road—working at all hours to endow the Web with whatever technological standards, civility and ethics it maintains. Berners-Lee's egalitarianism informs the modus operandi of the consortium.

Each firm belonging to W3C signs a contract giving Berners-Lee the final say in specifications for the Web. In the three years since W3C was founded, however, Berners-Lee has never ruled by fiat. "Tim doesn't work that way," says Carl Cargill of Netscape. "Tim leads by his vision. And if you disagree with his vision, he will talk to you and talk to you until he agrees with your vision or you agree with his—or both of you come to a new vision." This process is crucial because W3C exists through consensus.

Making sure every Web user and creator can experience exactly the same thing is integral to Berners-Lee's goal of "interoperability." The term simply means that the Web needs to be a system in which everyone, no matter their equipment or software, can participate equally. Interoperability, of course, is the nemesis of the commercial world: witness the tags on sites that say they are best viewed by a particular browser.

"It is important to realize that the Web is what we make it. 'We' being the people who read, the people who teach children how to surf the Web, the people who put information up on the Web. Particularly the people who make links," continues Berners-Lee, picking up speed, as he does whenever he talks about the philosophical underpinnings of the Web. "You should write and read what you believe in. And if you keep doing that, then you will create a Web that is one of value. If other people read it, then your ideas spread. But that is not a prerequisite. The Web doesn't force anything down your throat. If you are worried that your children are going to read low-quality information, teach them. Teach them what to read. Teach them how to judge information."

It is important to realize that the Web is what we make it

Receiving a piece of this vision directly from Berners-Lee is a rare commodity as W3C grows. Even though they are black-belt Webmasters, W3C team members can have a hard time communicating clearly about how to proceed on a topic or how to respond to a crisis with a company. The vision can also erode under constant conversations with company engineers or executives whose interests lie purely in code or markets. "We on the staff have a real need for him to project his vision," Dan Connolly says of W3C. "Some days it seems very important to remember: Should I do what the companies want to do or what is good for the Web?" Connolly adds that certain staffers wish for Berners-Lee to become rather "bold and unapologetic" so that W3C can accomplish its mission—"To realize the full potential of the Web"—with less industry wrestling.

Even as he says it, Connolly knows it is not going to happen. Berners-Lee could have made millions by taking his skills to the private sector; he could be ruling W3C with an iron fist; he could be collapsing his vision under the weight of commercialism; he could find a soapbox. But then he would not be the man who invented the Web.

Although he has neither favorite sites nor time to browse, Berners-Lee says he does use the Web to buy gifts. He even ordered his parents a case of wine for Christmas, expecting that it would be delivered by the local British supermarket—as explained on the Web site. "It ended up being delivered, at what must have been incredible cost, by taxi—all the way across the country," Berners-Lee laughs. The driver finally arrived in the middle of the night with what he must have thought was an emergency delivery. "I have never found out the story," Berners-Lee giggles. "I only paid £7, that's just $10, for delivery."

Pinker and the Brain

Cognitive scientist Steven Pinker plumbs the evolutionary origins of language and behavior while keeping his detractors at bay

BY ALDEN M. HAYASHI

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Steven Pinker does not shy away from fights. Over the years, he has taken on feminists, romanticists, psychoanalysts and fellow linguists, including the brilliant Noam Chomsky. But perhaps his most noted clash has been with Stephen Jay Gould, the paleobiologist. The intellectual feud between the two men, which also involves other leading evolutionary theorists, eventually landed on the front page of the *Boston Globe*.

So it is with some sense of trepidation that I meet Pinker, the 44-year-old professor of psychology and director of the Massachusetts Institute of Technology's Center for Cognitive Neuroscience. Entering his home, a beautifully remodeled Victorian house a short walk from Harvard University, I am expecting a churlish gadfly. But I am immediately disarmed by his soft-spoken and affable manner.

Pinker, who was born and raised in Montreal, recalls that a defining moment in his life occurred in the early 1970s, when he was in junior college (a transition between high school and university in Quebec). He happened to read "The Chomskyan Revolution," an article in the *New York Times Magazine* that described Chomsky's theories—in particular, his assertion that all languages have an underlying universal grammar. "It was the first time," Pinker remembers, "that I had heard of language being an innate ability."

The 1970s also marked the coming of another revolution, that of sociobiology, the study of how genes influence social behavior. Championed by biologist Edward O. Wilson, sociobiology attempted to link biology with the social sciences and humanities. Interestingly, Pinker turned his back on the emerging field, his early interest in the connection between biology and language notwithstanding. "I was probably opposed to sociobiology not for any serious reasons, but because everyone I knew was opposed to it," he recalls. "Especially after the Second World War, anything smacking of genes was suspect because of Hitler and eugenics."

So as an undergraduate at McGill University, Pinker opted for a more traditional route, studying cognitive science. "I found alluring the combination of psychology, computer science, artificial intelligence, the philosophy of mind, and linguistics," he says. In particular, he was impressed with the premise in cognitive science that information—memories, for instance—can be incarnated in matter or, more specifically, neural tissue. He was also attracted to the field's amenability to experimental verification. "Cognitive science," Pinker remarks, "gives you the framework and vocabulary to begin asking questions, and you can then form theories and go out and test them."

He began doing so at Harvard University, where he received a Ph.D. in psychology, and at M.I.T., where he has been since 1982. Pinker poked and prodded at Chomsky's theories, conducting experiments in the laboratory and at day care centers to determine exactly how children acquire language. He observed how toddlers from a very early age make certain errors, for example, in forming the past tenses of irregular verbs ("bringed" instead of "brought"). Such mistakes, Pinker asserted, occurred before the children had processed enough language to have inferred the appropriate rules from scratch. From that and other data, Pinker confirmed that children do indeed have an inborn facility for language, and he developed and tested detailed models for how that mechanism might work. But something was missing. If people have such an innate faculty, how did it get there?

Then, during a sabbatical in the late 1980s, Pinker read Richard Dawkins's *The Selfish Gene* and about two dozen other books on evolutionary biology. "This was the logical next step," he recalls, "going from innate mechanisms such as those for acquiring language and asking, How did those mechanisms get there? And the answer is by the process of evolution." Pinker thus embraced evolutionary psychology, a field that (ironically for him) arose from many of the ideas of sociobiology.

If the human eye is an adaptation—that is, something functionally effective that has evolved through natural selection—then so essentially is the human mind, evolutionary psychologists assert. Thus, various mental faculties, including that for language, and even human behavior might best be understood when viewed in this context, similar to the way in which technicians can reverse-engineer how a VCR works by first knowing what it does. Why, for example, do people fall in love with each other? Rather than a mere social construct, romantic love, evolutionary psychologists contend, evolved biologically as an insurance mechanism to guarantee that both parents stuck around to care for their offspring, thereby assuring continuity of their genes.

Pinker tells me this as we sit at his dining table, which has a full view of his immaculately furnished living room, where every piece of furniture and decorative touch seems to have its place. I suddenly understand how Pinker views the mind: not as a mysterious mess of inexplicable irrationalities but as a system where order and function rule.

In 1994, in his first popular book, *The Language Instinct*, Pinker applied that tidy Darwinism to extend Chomsky's theories into adaptationist territory. Three years later he went much further with *How the Mind Works*, building on the work of anthropologist John Tooby, psychologist Leda Cosmides and others. The 660-page tome is an elegantly written tour de force that pulls together developments in cognitive science and evolutionary psychology, synthesizing them into a coherent and cohesive theory. The book did no less than explain a staggering range of phenomena—why people are disgusted at the thought of eating worms, why they have the proclivity for self-deception, why men buy pornography but women don't—all in evolutionary terms.

less you understand the whole problem, for example, the physical substrate that natural selection acts on, it's senseless to discuss whether language is an adaptation," he says. For these and other reasons, Chomsky, whose work laid the foundation for a biological basis to language, is himself reluctant to discuss whether language is an evolutionary adaptation. "I don't even understand what that means," he replies.

But others, including George C. Williams, one of the great evolutionary biologists of this century, assert that Pinker has indeed made the case for language being an adaptation. In fact, Williams says, "I recall getting annoyed at myself when reading *The Language Instinct* for not having thought of some of the things that Pinker came up with."

> Rather than a mere social construct, romantic love, evolutionary psychologists contend, evolved biologically as an insurance mechanism to guarantee that both parents stuck around to care for their offspring, thereby assuring continuity of their genes

Pinker's persuasive prose aside, it is easy to see why evolutionary psychology elicits ire. Taken to a fanatic extreme, the field paints a bleak picture of people controlled by their genes. (Incidentally, the dark implications of biological determinism plagued Wilson and sociobiology in the 1970s.) Furthermore, biological differences between the sexes have an odd way of quickly becoming twisted into women-belong-back-in-the-kitchen arguments. And popular how-to books such as *Men Are from Mars, Women Are from Venus*, with their tenuous ties to evolutionary biology and their oversimplifications of the human mind, have not helped.

Pinker is quick to point out that "what is" must never be confused with "what should be." In fact, in *How the Mind Works* he bends over backward to make the distinction between science and morals. Nevertheless, "if you're a hostile reader," he notes, "I guess you read [into the book] what you want."

Pinker's battle with Gould might be characterized in the same way: each accuses the other of misrepresenting his views. In a nutshell, Gould asserts that Pinker and other "Darwin fundamentalists" have grossly overemphasized the role of natural selection at the expense of various other considerations—namely, everything from random genetic drifts to wayward meteors. Pinker acknowledges the importance of those factors but contends that a complex functional system such as the human mind must necessarily arise essentially from natural selection.

What irks many of Pinker's critics is the feeling that he and others have pushed their theories far beyond what the scientific data can support. According to biolinguist Lyle Jenkins of the Biolinguistics Institute in Cambridge, Mass., researchers have yet to understand all the individual development mechanisms (genetic, biochemical and so forth) that might have played a role in the biological evolution of the language faculty. "Un-

Weeks after meeting Pinker, as I sort through this debate, I become troubled by other issues. For one thing, why hasn't evolutionary psychology, an arguably powerful paradigm for explaining normal behavior, led to any treatments for mental illnesses such as schizophrenia and manic-depressive disorder? Pinker explains that if such illnesses prove to be physiological (perhaps caused by pathogens), they may be untreatable by psychological intervention, evolutionary or otherwise. For milder disorders, such as depression and phobias, Pinker says that clinical psychologists and psychotherapists are beginning to investigate evolution-based approaches.

Indeed, Pinker concedes that evolutionary psychology's work is hardly done, even for exploring everyday phenomena. Why, for example, do people derive such pleasure in listening to music? "A lot of times there'll be these embarrassing facts that you tuck away, thinking there's got to be an answer to them if only you had the time to look into it," he says. "But what you don't realize is that sometimes those facts are the ones that hold the key to a mystery, and so you've got to take those facts seriously because they change everything."

How such inconvenient facts and unsolved mysteries might muck up Pinker's neat landscape of the mind is unknown. For now, though, evolutionary psychology provides a plausible, if incomplete, approach for understanding the mind, and Pinker has certainly been instrumental in publicizing this paradigm. In the introduction to *How the Mind Works*, he writes, "Every idea in the book may turn out to be wrong, but that would be progress, because our old ideas were too vapid to be wrong."

Flynn's Effect

Intelligence scores are rising, James R. Flynn discovered—but he remains very sure we're not getting any smarter BY MARGUERITE HOLLOWAY

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Just back from teaching, James R. Flynn darts into his office to write down a revelation about Marx, free will, Catholicism and the development of the steam engine that came to him in the midst of his lecture. Busily scribbling, the professor of political science at the University of Otago in Dunedin, New Zealand, declares that extemporaneous talking leads to creative thinking and new ideas. His pronouncement made, Flynn—who, it should be noted, talks for a living—is ready to discuss the insight that made him famous: the observation that intelligence quotients, as measured by certain tests, have been steadily growing since the turn of the century.

Flynn's carefully documented findings have provoked a sort of soul-searching among many in the psychological and sociological communities. Before Flynn published his research in the 1980s, IQ tests had their critics. In general, however, the tests were viewed as imperfect yet highly helpful indicators of a person's acuity and various mental abilities or lack thereof. But after the widespread discussion of the eponymous Flynn effect, nothing has been the same. Debates roil about what the tests really measure, what kinds of intelligence there are, whether racial differences persist and, if IQ truly is increasing, why and what the political and social implications are [see "Exploring Intelligence," the winter 1998 issue of SCIENTIFIC AMERICAN PRESENTS].

"It is transforming work," comments Ulric Neisser of Cornell University, editor of *The Rising Curve*. The recent book, which emerged from a 1996 American Psychological Association symposium, reviews the Flynn effect and the various explanations for it—including better nutrition and parenting, more extensive schooling, improved test-taking ability, and the impact of the visual and spatial demands that accompany a television-laden, video-game-rich world.

Flynn himself doesn't particularly cotton to any of these explanations. Sitting in his office amid swells of books and papers, he looks very much like a wiry, irreverent Poseidon: gray curls, white beard, pale blue eyes and a kindly, contrary demeanor. A trident poses no challenge to the imagination. If the gains in intelligence are real, "why aren't we undergoing a renaissance unparalleled in human history?" he demands, almost irritably. "I mean, why aren't we duplicating the golden days of Athens or the Italian Renaissance?"

Flynn's own humanist beliefs led him to investigate IQ in the first place. During the 1950s, he was a civil-rights activist in Chicago, where he was political action co-chairman for the university branch of the NAACP while getting his doctorate. After that, he taught at Eastern Kentucky University and chaired the Congress of Racial Equality in Richmond, Ky. "As a moral and political philosopher, my main interest is how you can use reason and evidence against antihumane ideologues," he explains. "Prominent among these are racial ideologues because racism has been one of the chief challenges to egalitarian ideals over the ages."

Flynn claims his civil-rights involvement did not prove helpful to a young academic's job search. He and his wife, Emily—whose family had been active in the Communist Party and who, Flynn says, was no stranger to persecution—decided to find a country where they could feel comfortable. They decided on New Zealand: "It seemed to me much more like the sort of social democracy that I would want to live in."

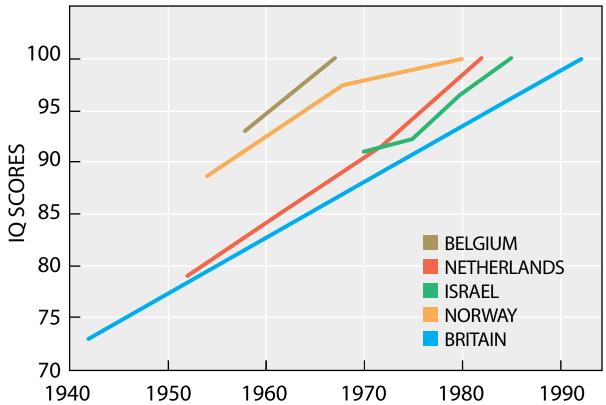
Once they settled into their new home and had started raising their two children, Flynn continued to fight American racism from afar. "I thought that in order to argue effectively with racist ideas, I had to look at the race-IQ debate, the claims that blacks, on average, are genetically inferior." He set out to refute Arthur R. Jensen of the University of California at Berkeley, one of the main proponents of that view. In 1980 Flynn published *Race, IQ and Jensen*, and the duel was on. He decided to follow up with a short monograph on military intelligence tests, because he had a hunch the data had been mishandled and that, in fact, black recruits were making large IQ gains on whites—a trend that would support Flynn's conviction that IQ was linked more to environmental factors than to genetic ones.

Sure enough, Flynn says he found a mistake in the way that some of the military data had been analyzed. But as he investigated further, he realized that Jensen and others would dismiss his findings on the grounds that military intelligence tests were—in contrast to other IQ tests—heavily educationally loaded. In other words, education played a big role in performance. Because black recruits were better educated in the 1950s than they were in the 1920s, any rise in their scores could be attributed to education, not to "real" IQ gains.

Flynn was undeterred. It would be a simple matter, he thought, to find a test measuring "genuine" intelligence that correlated with the military tests, thereby allowing him to use the data from the latter. There was no such correlation to be found, but in the process Flynn unearthed a gold mine. He discovered that certain IQ tests—specifically, the Stanford-Binet and Wechsler series—had new and old versions and that both were sometimes given to the same group of people. In the case of one of the Wechsler tests, for instance, the two versions had been given to the same set of children. The children did much better on the 1949 test than they did on the 1974 one. Everywhere Flynn looked, he noticed that groups performed much more intelligently on older tests. Americans had gained about 13.8 IQ points in 46 years, Flynn reported in 1984.

Although other researchers had noticed different aspects of the phenomenon, they had always explained it away. Flynn did not. "I think the main reason was that since I wasn't a psychologist, I didn't know what had to be true," he muses. "I came as an outsider and didn't have any preconceived notions." (Or, as psychologist Nathan Brody of Wesleyan University points out, there is always the explanation that Flynn, quite simply, "is a very good scholar with a very critical mind.")

Critics, including Jensen, responded by saying that the tests must have higher educational loading than previously suspected. So Flynn looked at performance changes in a test called Raven Progressive Matrices, which measures what is called fluid g: on-the-spot problem solving that is not educationally or culturally loaded. These tests use patterns instead of, say, mathematics or words. "Polar Eskimos can deal with it," Flynn notes. "Kalahari bushmen can deal with it." Amazingly, it turned out that the highest gains were on the Raven. Flynn observed that in 14 countries—today he has data from at least 20—IQ was growing anywhere from five to 25 points in one generation. "The hypothesis that best fits the results is that IQ tests do not measure intelligence but rather correlate with a weak causal link to intelligence," Flynn wrote when he published the data. "So that was the 1987 article," he says, laughing, "and it, of course, put the cat among the pigeons."



WORLDWIDE IQ SCORES have been rising for more than 50 years.

Flynn has recently discovered another dramatic and puzzling increase in the scores of one of the Wechsler subtests—one that measures only verbal ability. Before this new finding, Flynn points out, the explanation that the Raven scores were rising because of video games or computer use had some plausibility. But now, he says, the mystery has only deepened.

Despite two decades of jousting with Jensen, Flynn says he has the deepest regard for the scholar and his scholarship. "There is a temptation on the liberal left not to want to look at the evidence," he remarks. "The fact is that if Arthur Jensen is right, there is a significant truth here about the real world to which we must all adapt." Flynn says he wants humanitarian egalitarian principles to reign "where I have the guts to face up to the facets of the real world. And if one of the facets is that blacks—on average, not individual—are genetically inferior for a kind of intelligence that pays dividends in the computer age, we would do well to know about it."

The next question is, of course, whether he believes such differences exist. In a flash, a sea change: "No! I do not!" Flynn nearly roars.

In addition to his ongoing work on IQ, Flynn has been busy promulgating his ideals on other fronts. Disappointed with New Zealand's slouch toward pure capitalism, he has sought to stem the slide by running for Parliament. He has campaigned, and lost, three times. The most recent and, he adds, final attempt was in 1996 for the Alliance Party: "The only party in New Zealand that still believes in using taxation as a means of redistributing wealth and that still believes in single-payer health and education."

Flynn has also just finished a fifth book, entitled *How to Defend Humane Ideals*, that he has been working on intermittently for many years. "Probably no one will be interested in it because people are much less interested in fundamental contributions than spectacular ones," Flynn rues. It would seem, however, that even merely spectacular results can fundamentally change things.

JOHNNY JOHNSON

Why Machines Should Fear

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Once a curmudgeonly champion of "usable" design, cognitive scientist Donald A. Norman argues that future machines will need emotions to be truly dependable BY W. WAYT GIBBS

Slowly and with care, Donald A. Norman refills his teacup, but the tea drips down the pot anyway. I look down at the small puddles of green tea on the restaurant table and back up at Norman. Here it comes, I think, bracing myself for a classic Norman fulmination on how basic design flaws in ordinary objects are the true sources of most "human error." After all, such cantankerous critiques in his 1988 book *The Psychology of Everyday Things* were what brought him international fame outside the narrow field of cognitive science.

But Norman calmly wipes his napkin over the spill without comment. Although he still calls himself a user advocate, these days he focuses less on the failures of modern technology and more on its potential, envisioning a world populated by well-performing, easy-to-use and even emotive machines.

"This is the new me," the 67-year-old professor at Northwestern University announces the next day in his keynote address to a large human-computer interaction conference in Ft. Lauderdale, Fla. "The old me was critical, always finding fault with things that didn't work." In June 2002, for example, the journal Computer published his excoriation of the consumer electronics industry for the absurd "living-room rocket science" needed to get high-end home theater components to function together.

But in writing *Emotional Design*, his latest work (due out in January from Basic Books), Norman seems to be attempting a metamorphosis from gadfly to oracle. "The new life is about emotion and positive things. So I only say nice things," he avers. "Or rather, I try."

The one picture of a teapot that Norman includes in *Emotional Design*, for instance, is there to illustrate "why lovely things really do work better." The particular teakettle shown has a melodic whistle on its spout, so it blows a harmonious steamy chord when ready to serve. Probably few would argue with the notion that phones and computers would be

JEFF SCIORTINO

DONALD A. NORMAN: EMOTIONAL DESIGNER

- First design project: ham radio station built during childhood from military surplus parts.
- Characteristic obsession: finding out the purpose of the notch in a cuillère à sauce individuelle, a spoonlike utensil in fancier restaurants in Europe.
- Typical job: scientific consultant to firms such as Evolution Robotics in Pasadena, Calif., which has developed a prototype personal robot named ER2.
- Some favorite designs: Cooper Mini automobile; Alessi Te ò tea strainer, which "hugs" the cup; the Ronnefeldt tilting teapot, which holds the leaves on a shelf, immersed when steeping but out of the water when serving.

improved if their bleats and whirrs were less noisome.

But Norman's point goes much deeper. "The cognitive sciences grew up studying cognition—rational, logical thought," he notes. Norman himself participated in the birth of the field, joining a program in mathematical psychology at the University of Pennsylvania and later helping to launch the human information–processing department (now cognitive science) at the University of California at San Diego. "Emotion was traditionally ignored as some leftover from our animal heritage," he says. "It turns out that's not true.

"We now know, for example, that people who have suffered damage to the prefrontal lobes so that they can no longer show emotions are very intelligent and sensible, but they cannot make decisions." Although such damage is rare, and he cites little other scientific evidence, Norman concludes that "emotion, or 'affect,' is an information processing system, similar to but distinct from cognition. With cognition we understand and interpret the world—which takes time," he says. "Emotion works much more quickly, and its role is to make judgments—this is good, that is bad, this is safe."

The two systems are intertwined at a biological level, Norman points out. "The affective system pumps neurotransmitters into the brain, changing how the brain works. You actually think differently when you are anxious than when you are happy. Anxiety causes you to focus in on problems; if something doesn't work, you try it again, harder. But when you're happy, you tend to be more creative and interruptible." So if only for purely utilitarian reasons, devices and software should be designed to influence the mood of the user; they will be more effective because they are more affective.

The idea is more controversial than it may seem. Even Jakob Nielsen, a former user-interface expert at Sun Microsystems who joined with Norman to form a consulting firm five years ago, notes that "there is always a risk that designers will misinterpret this kind of analysis," taking it as carte blanche to elevate form above function.

The problem is that taste varies. Watches, for instance, are designed largely for their visceral, sensual appeal, and for that very reason they come in myriad varieties. Aside from the big hand and little hand, however, there is no standard interface. The more complicated functions of any given watch—its calendar, stopwatch, alarm, countdown timer, and so on—can be maddeningly difficult to operate. Mastering one watch is of scant help in using a different model. So as mobile phones, PDAs and other gadgets continue to morph from tools to fashion accessories, an inherent conflict may arise between the diversity of designs needed to appeal to all customers and the consistency of operation that makes devices easy to use. On that question, "I think Don is an optimist," Nielsen says. Nielsen has studied the usability of Web sites, and the results in that realm are not encouraging. "In many ways, we still don't have the basics settled. Most people can't write a good headline for their Web site, let alone get the information architecture right."

Norman argues, moreover, that machines should not only evoke emotional responses in their owners but should also in some sense feel emotions themselves. Here he parts company with many of his colleagues in human-computer interaction. "I'm not saying that we should try to copy human emotions," Norman elaborates. "But machines should have emotions for the same reason that people do: to keep them safe, make them curious and help them to learn." Autonomous robots, from vacuum cleaners to Mars explorers, need to deal with unexpected problems that cannot be solved by hard-coded algorithms, he argues.

What they need are "weak methods." "Boredom," Norman explains, "is a weak method for getting out of a rut. Curiosity is a weak method for exploring an unfamiliar space. I want my automatic vacuum cleaner to fear heights so that it doesn't fall down the stairs." And, he maintains, if machines have a way of expressing their emotions—grimacing when they are frustrated, say—that would give people a useful glimpse into their internal operation.

Judging by the thousands of designers and researchers who turned out to hear his address at the Florida conference, his ideas carry weight. Yet as Norman held forth on the exhibit floor about the importance of making machines with feelings, Ben Shneiderman of the University of Maryland displayed a clear emotion of skepticism.

"My feelers come out when people use the language of people to talk about machines," he rebutted. "I think that leads down the wrong path." B. J. Fogg, whose research at Stanford University centers on the emotions that users inevitably attribute to their computers, observes that programming pseudoemotions into machines "might make the interaction with users go better. But there is an ethical question: it is a kind of deception."

And in any case, how could emotions be reduced to source code and circuitry? Such technical details are nowhere to be found in Norman's books and speeches, a limitation of which he is quite conscious. "All my life I have tried to develop frameworks, ways of looking at questions that current theories don't address. People say: that's very nice, but how do we realize this vision? You don't give us tools and measures. I guess that criticism is on the mark."

A Greene Universe

The Columbia University theoretical physicist has a simple goal—explaining the universe with strings

BY ALDEN M. HAYASHI

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PETER MURPHY

AT PLAY IN THE FIELDS OF BOHR AND EINSTEIN: Brian Greene's research in string theory aims to unify quantum mechanics with general relativity.

Brian Greene's quest began early. Born in New York City, Greene grew up near the American Museum of Natural History. On rainy days the vast museum became his playground, but Greene was not like most boys his age. "Somehow the dinosaur exhibits, though impressive, never really excited me," he recalls. Instead what ignited his passion was the museum's Hayden Planetarium. "Ever since I can remember, I was always questioning what the universe was made of and how it got to be the way it got to be," Greene says.

Today, three decades later, Greene is still trying to answer those questions. A professor in physics and mathematics at Columbia University, he is one of the world's leading experts in string theory, which promises to explain the entire universe, including its origin and evolution. The theory asserts that all matter and forces are composed of incredibly tiny loops that look like strings. Loops vibrating in different ways become the fundamental particles, such as electrons, gluons and photons. Because of its sweeping potential to describe how everything works, string theory has become the most exciting concept in theoretical physics, and Greene has gotten the buzz as its hottest practitioner, his fame eclipsing even that of Edward Witten of the Institute for Advanced Study in Princeton, N.J.

By all accounts, Greene was destined to leave his mark in academia. At age five, fascinated with the power of the simple rules of arithmetic, he would pass the time by multiplying 30-digit numbers that his father had written down for him. To accommodate the calculations, they taped together sheets of construction paper. In the sixth grade he had exhausted the math resources at his school, prompting one of his teachers to write a note requesting help. Greene and his older sister took the note to Columbia University. "We literally went knocking from door to door," he recounts. After striking out at the computer science department, he found mathematics graduate student Neil Bellinson, who was willing to tutor him for free.

From such auspicious beginnings, Greene entered Harvard University in 1980, majoring in physics. There he first became aware that the two pillars of modern physics—quantum mechanics, which describes atoms and subatomic particles, and general relativity, which explains astronomical phenomena, such as black holes—are mutually incompatible. "It's as if the laws of the small and the laws of the large are in conflict with each other," Greene says. It has been modern physics' embarrassing secret. "The fact that the two theories don't fit together isn't really taught to you," he adds.

But it was not until Greene was at the University of Oxford as a Rhodes Scholar that he learned of a possible fix. It was the mid-1980s, physicists had just tamed several unruly infelicities with string theory, and the concept was experiencing a glorious rebirth as a way to unify quantum mechanics with general relativity. After attending a lecture on the topic, Greene was hooked. His thesis explored a possible way to coax experimentally testable predictions from string theory, and he continued this work at Harvard and later at Cornell University. In 1996 he moved back to New York City to set up a string-theory program at Columbia, coming full circle to the university where he was tutored as a youngster.

Manhattan seems the perfect place for Greene. Partial to chic black clothes, he bears a slight resemblance to the actor David Schwimmer of the TV series Friends, with the same boyish charm and comic timing. Only a touch of gray in his wavy hair hints that he is 38. But although Greene hardly looks the part of the fumbling, disheveled genius, he is no less the academic giant, intimately fluent in the arcane intricacies of string theory.

Ironically, the metaphorical beauty of the theory—the image of an untold number of strings vibrating in a cosmic symphony, all orchestrated by a single, omnipotent law of physics—belies the heinous mathematics involved. String theory requires extra dimensions of space (perhaps seven), in addition to the three that are commonly known. Proponents argue that the additional dimensions are curled up too tightly to see, just as a three-dimensional garden hose would look like a one-dimensional line when viewed from afar. To complicate matters, researchers have uncovered the possibility that one-dimensional strings can stretch themselves into two-dimensional membranes, which themselves can transform into higher-dimensional entities. Physicists such as Greene are having to invent unspeakably complex mathematics to describe this surreal landscape, just as Isaac Newton had to develop calculus to elucidate how forces act on objects.

One of Greene's major contributions to string theory occurred in 1992 while he was on sabbatical at the Institute for Advanced Study. Along with Paul S. Aspinwall and David R. Morrison, both at Duke University, Greene showed how the fabric of space could tear and repair itself—at least according to string theory. Though purely theoretical, the work was intriguing—general relatively prohibits ruptures in space-time—and Witten, the doyen of string theory, had independently arrived at the same result by using a different approach.

Unfortunately, space-time tears are well beyond what physicists can confirm or prove experimentally. In fact, researchers have yet to demonstrate any of the theory's extra dimensions—let alone the very existence of strings themselves. But Greene and other physicists are eagerly awaiting the Large Hadron Collider, a massive particle accelerator currently being built at CERN outside Geneva. If all goes according to plan, the LHC will smash together protons with such tremendous power that the collisions will create some of the hypothetical "superpartners"—selectrons, sneutrinos, squarks and the like—that string theory predicts.

Such proof could have come from the Superconducting Super Collider, had Congress not pulled the financial plug on that gargantuan accelerator in Texas. "If we had built that machine, our understanding of things could have taken a giant step forward," says Greene, who nonetheless can sympathize with the public's lack of support for the multibillion-dollar facility. "I think there's this sense that what we're trying to figure out now are esoteric details only of interest to physicists," he laments. That misconception is one reason why Greene wrote *The Elegant Universe*, the best-seller that explains the cosmic significance of strings and how they could answer some of humanity's deepest questions.

Exquisitely crafted in lucid prose, the book went into three printings in its first month, and Greene was soon whisked into a new role. His uncanny knack for distilling esoteric concepts into simple terms—along with his youthful good looks—has quickly made him the poster boy for theoretical physics. The trappings have been numerous: packed audiences for his speaking engagements; television appearances, most notably on an hour-long *Nightline in Primetime* special on ABC; and a bit part in the upcoming movie *Frequency*, starring Dennis Quaid. Political analyst George Stephanopoulos, who was Greene's running buddy at Oxford, has even joked that Greene, who is single, might be the first physicist to have groupies.

But Greene, who answered all his e-mails until the volume recently became unmanageable, doesn't see himself becoming a full-time popularizer. At this point, he has no plans for a second book. "Writing a book takes its toll on your research," says Greene, who adds that he always wants to remain on the front lines of physics. "I need to be fully engaged in the research to really know what's going on. I need to know all the details, all the subtleties."

The rush of adrenaline is another lure. "What has drawn me to science is the thrill of discovery," Greene says. "There's nothing like that moment of realizing that you've discovered something that has not yet been previously known." His current research investigates quantum geometry, the properties of space at extremely short distances, around the purported size of a typical string, or 10^{-33} centimeter (a hydrogen atom is about 10^{-8} centimeter wide). In this realm, space-time is no longer smooth and curved but stormy and frothy.

Such work could help determine the very essence of space and time. "How did space come into being and how did time come into being, and is there something more basic than space and time?" asks Greene, referring to string theory's postulate that space and time might merely be manifestations of something more fundamental. The answers to those questions might help explain why time, unlike space, seems to run in only one direction—forward.

That and other basic conundrums might be more easily solved if researchers knew the overarching idea behind string theory. With general relativity, that key principle was space-time curvature. Interestingly, whereas most theories develop from the top down, starting with a grand concept from which equations then flow, string theory arose from the bottom up. For Greene, this crucial gap in knowledge—what is the fundamental principle that would make string theory have to be right?—has been as frustrating as it has been tantalizing. "It's as if you had a painting from one of the great masters, but someone had come along and snipped out chunks of it," he says. "From what remains, you can tell that there was a beautiful painting there, but now you want to see the whole thing. And that's what we've been working on."

BRIAN GREENE: EXTRACURRICULAR

- Born New York City, 1962
- Vegetarian
- Father was voice coach to Harry Belafonte
- Running buddies with George Stephanopoulos at Oxford
- Member of Oxford varsity judo team
- Has supplied snippets of dialogue for John Lithgow's character in *3rd Rock from the Sun*
- Favorite *Star Trek* episode: "The City on the Edge of Forever"

Throwing Einstein for a Loop

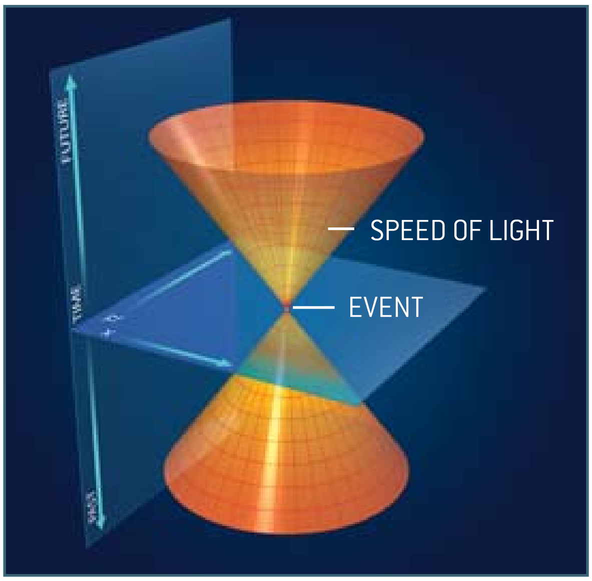
ORIGINALLY PUBLISHED IN DECEMBER 2002

Physicist Fotini Markopoulou Kalamara has developed a way to connect relativity with quantum theory—while making sure that cause still precedes effect By AMANDA GEFTER

She talks about physics like it's cooking. "My strength is to put things together out of nothing," she says, "to take this ingredient and another one there and stick something together." The art is figuring out which ones to use and how to combine them so that when the oven bell dings, the universe comes out just right.

At 31 years old, Fotini Markopoulou Kalamara is hailed as one of the world's most promising young physicists. She recently accepted a position at the Perimeter Institute for Theoretical Physics in Waterloo, Ontario (Canada's answer to the Institute for Advanced Study in Princeton, N.J.). There she works alongside such prominent physicists as Robert Myers and Lee Smolin, hoping to blend Einstein's general relativity with quantum theory to explain the nature of space and time.

This unification is probably the single greatest challenge of modern physics. String theory has been the predominant contender. It proposes that the building blocks of matter are tiny, one-dimensional strings and that various vibrations of strings play the familiar medley of particles as if they were musical notes.



LIGHT CONES, generated by plotting the speed of light against time and three dimensions of space (x, with y and z together), define all past and future connections to an event.

Although string theory finds a way to incorporate gravity into a quantum description of matter, some physicists believe that it has shortcomings that prevent it from being the ultimate theory of everything. For one, the theory presupposes up to 26 spatial dimensions, many more than have yet to be experimentally discovered. More fundamental still, whereas strings are fine for describing matter, they do not explain the space in which they wiggle. Newer versions of string theory may fix this problem. But a small band of physicists, including Smolin, Abhay Ashtekar of Pennsylvania State University and Carlo Rovelli of the Theoretical Physics Center in Marseilles, France, place greater stock in a different approach: loop quantum gravity, or LQG.

In LQG, reality is built of loops that interact and combine to form so-called spin networks—first envisioned by English mathematician Roger Penrose in the 1960s as abstract graphs. Smolin and Rovelli used standard techniques to quantize the equations of general relativity and in doing so discovered Penrose's networks buried in the math. The nodes and edges of these graphs carry discrete units of area and volume, giving rise to three-dimensional quantum space. But because the theorists started with relativity, they were still left with some semblance of a space outside the quantum networks.

That was the state of LQG in the late 1990s, when Markopoulou Kalamara began tackling it. Serendipity actually led her to the subject. "I only decided on physics when I was 16 or 17," says the theorist, who is from Athens, Greece. "Before that, I wanted to be all sorts of things: an archaeologist, an astronaut, a painter." While she was an undergraduate at the University of London, a friend taking theoretical physics recommended lectures being given by quantum-gravity theorist Chris Isham of Imperial College London. "It was on my way home, so I went once a week, and I loved it." She convinced Isham to be her adviser and wound up with a Ph.D. in quantum gravity. She then joined Smolin at Penn State as a postdoctoral fellow.

Markopoulou Kalamara approached LQG's extraneous space problem by asking, Why not *start* with Penrose's spin networks (which are not embedded in any preexisting space), mix in some of the results of LQG, and see what comes out? The result was networks that do not live in space and are not made of matter. Rather their very architecture gives rise to space and matter. In this picture, there are no things, only geometric relationships. Space ceases to be a place where objects such as particles bump and jitter and instead becomes a kaleidoscope of ever changing patterns and processes.

Each spin network resembles a snapshot, a frozen moment in the universe. Off paper, the spin networks evolve and change based on simple mathematical rules and become bigger and more complex, eventually developing into the large-scale space we inhabit.

By tracing this evolution, Markopoulou Kalamara can explain the structure of spacetime. In particular, she argues that the abstract loops can produce one of the most distinctive features of Einstein's theory—light cones, regions of spacetime within which light, or anything else, can reach a particular event. Light cones ensure that cause precedes effect. We can understand this concept by gazing upward and knowing that there are countless stars we cannot see because not enough time has passed since the birth of the universe for their light to shine our way; they are beyond our light cone.

It is not so obvious, though, where light cones fit into the spin networks. Those networks are subject to quantum mechanics. In that wonderland of uncertainty, any network has the potential to evolve into infinite new ones, leaving no trace of a causal history. "We didn't know how, in the language we

SLIM FILMS

were working in, to put in the notion of causality" in LQG, Smolin says. Markopoulou Kalamara found that by attaching light cones to the nodes of the networks, their evolution becomes finite and causal structure is preserved.

But a spin network represents the entire universe, and that creates a big problem. According to the standard interpretation of quantum mechanics, things remain in a limbo of probability until an observer perceives them. But no lonely observer can find himself beyond the bounds of the universe staring back. How, then, can the universe exist? "That's a whole sticky thing," Markopoulou Kalamara says. "Who looks at the universe?" For her, the answer is: we do. The universe contains its own observers on the inside, represented as nodes in the network. Her idea is that to paint the big picture, you don't need one painter; many will do. Specifically, she realized that the same light cones she had used to bring causal structure into quantum spacetime could concretely define each observer's perspective.

Because the speed of light is finite, you can see only a limited slice of the universe. Your position in spacetime is unique, so your slice is slightly different from everyone else's. Although there is no external observer who has access to all the information out there, we can still construct a meaningful portrait of the universe based on the partial information we each receive. It's a beautiful thought: we each have our own universe. But there's a lot of overlap. "We mostly see the same thing," Markopoulou Kalamara explains, and that is why we see a smooth universe despite a quantized spacetime. "I actually think theoretical physics is very much like art," concludes Markopoulou Kalamara, the daughter of two sculptors. "Putting these things together is like taking clay and making something out of nothing, and it should work from every side. I like the creative part, but I also like that you can check."

The time to check is fast approaching. There are details to work out, such as how to derive the usual one-dimensional time from the quantum causality, but she figures that if observations can confirm the basics of spin networks, she'll smooth out the kinks. One experiment could be to track gamma-ray photons from billions of light-years away. If spacetime is in fact discrete, then individual photons should travel at slightly different speeds, depending on their wavelength. Markopoulou Kalamara is trying to decipher the form of that dispersion.

If true, her predictions could forever change the way we think about the structure of space. Several tests of quantum gravity could take place within the next few years. "I always told myself that if it doesn't turn into real physics, if it doesn't get in touch with experiment, I'm getting a really well paying job in New York. For all I know, it may work easily. There's always that possibility," Markopoulou Kalamara says. In the meantime, she's hard at work, and waiting for the oven bell.

Freeman J. Dyson

Perpendicular to the Mainstream BY JOHN HORGAN

ORIGINALLY PUBLISHED IN AUGUST 1993

Some particle physicists think of Freeman J. Dyson as a rather tragic figure. In the early 1950s, they recall, the British-born physicist was at the very center of the field, striving with Richard P. Feynman and other titans to forge a quantum theory of electromagnetism. Dyson, some say, deserved a Nobel Prize for his efforts—or at least more credit. They also suggest that disappointment and, perhaps, a contrary streak later drove him toward pursuits unworthy of his powers. "Freeman always has to be perpendicular to the mainstream," one theorist says.

When I mention this assessment to Dyson in his office at the Institute for Advanced Study in Princeton, N.J., his base for 40 years, he gives a tight-lipped smile. He then responds, as he is wont to do, with an anecdote. The British physicist Lawrence Bragg, he notes, was "a sort of role model." After Bragg became the director of the University of Cambridge's Cavendish Laboratory in 1938, he steered it away from nuclear physics, on which its mighty reputation rested, and into new territory. "Everybody thought Bragg was destroying the Cavendish by getting out of the mainstream," Dyson says. "But of course it was a wonderful decision, because he brought in molecular biology and radio astronomy. Those are the two things that made Cambridge famous over the next 30 years or so."

Dyson has spent his career swerving toward unknown lands. He has veered from mathematics, his focus in college, to particle physics and from there to solid-state physics, nuclear engineering and climate studies, among other fields. Dyson is probably best known now for his books, the first of which, the memoir *Disturbing the Universe*, was published in 1979. His writings celebrate diversity, both in their subject matter—which ranges from the origin of life to the long-term prospects for intelligence in the cosmos—and as a principle in itself. "The principle of maximum diversity," he wrote in his 1988 book *Infinite in All Directions*, ensures that "when things are dull, something new turns up to challenge us and stop us from settling into a rut."

In person, too, Dyson keeps thwarting expectations. At 69, he is slight, all sinew and veins, with a cutlass of a nose and deep-set, watchful eyes. He resembles a raptor, a gentle one. His demeanor is cool, reserved—until he laughs. Then he snorts repeatedly, shoulders heaving, like a 12-year-old schoolboy hearing a dirty joke. It is a subversive laugh, that of a man who envisions space as a haven for "religious fanatics," "recalcitrant teenagers" and other misfits, and who insists that science at its best must be "a rebellion against authority."

Dyson's father, a musician, headed the Royal College of Music, and his mother held a law degree (but never practiced). Their boy displayed his scientific and literary talents early. He calculated the number of atoms in the sun at six and began writing a science-fiction novel at eight. Entering Cambridge in

1941, he quickly developed a reputation as one of England's most promising mathematicians.

A pacifist before World War II, Dyson decided that such a position was politically untenable after Germany overran France. During the war, he spent two years working for the Royal Air Force, seeking ways to reduce casualties among its bomber crews. "I learned everything I know about war in those two years," he says. "The whole bureaucracy was designed so that the commander in chief would hear what he wanted to hear, which is equally true now, of course."

Resuming his studies at Cambridge, Dyson became increasingly attracted to theoretical physics. In a history of quantum electrodynamics that is to be published this fall, Silvan S. Schweber of Brandeis University recounts how Dyson revealed his decision to an acquaintance at Cambridge. As they strolled through the campus, the colleague said, "Theoretical physics is in such a mess, I have decided to switch to pure mathematics." "That's curious," Dyson replied. "I have decided to switch to theoretical physics for precisely the same reason."

In 1947 Dyson traveled to Cornell University to study under the great physicist Hans A. Bethe. There he befriended Feynman, whom Dyson once described as "half genius and half buffoon." Feynman had invented an idiosyncratic method for describing electromagnetic interactions. Meanwhile Julian Schwinger of Harvard University had proposed a seemingly different theory. In a series of brilliant papers, Dyson demonstrated that the two theories were mathematically equivalent. He went on to champion a more lucid version of Feynman's method.

Some physicists have argued that Dyson's contributions were as crucial as those of Schwinger and perhaps even Feynman. Dyson demurs. "I was a clarifier, not an inventor," he says. He insists he has no regrets about not receiving the Nobel Prize, which Schwinger and Feynman shared in 1965 with the Japanese physicist Sin-Itiro Tomonaga (who had derived the theory independently). "I suppose I'm lucky I never succumbed to this Nobel disease that many of my friends seem to have suffered from," he says. "It certainly never played a role in motivating me."

By the mid-1950s Dyson had moved from Cornell to the Institute for Advanced Study, and he decided it was time to change fields. "Particle physics had become the fashionable mainstream, and there were all these piles of pre-prints coming in every day. I felt just adding one more to the pile wasn't really worthwhile." Once he abandoned the search for a unified theory of physics, Dyson never returned. "I'm not really interested in the big picture," he says. "'God is in the details'—that's one of my favorite quotes."

Switching to solid-state physics, he became absorbed in spin waves, the oscillations of atomic spins in a ferromagnet. Saying "I'd like to brag just a little bit," Dyson points out that his 1956 paper on spin waves has been cited at least 675 times and was recently chosen as a "citation classic" by the journal *Current Contents*. "From the point of view of the community at large," he remarks wryly, "you might say spin waves is really the most important thing I did."

In 1956 Dyson also acquired "the delightful hobby" of engineering when he became a consultant to General Atomics, a company dedicated to the peaceful uses of nuclear energy. He helped to invent a miniature reactor that generates radioactive isotopes for research and medical applications. "We designed the thing within two months, built it and sold it in two years." Dyson received his only patent for the reactor, which is still in use throughout the world.

Dyson indulged a long-standing obsession with space exploration by helping General Atomics design a nuclear-powered spaceship called Orion. That project ended unsuccessfully in 1965, and Dyson now thinks nuclear rockets "are probably not much good." He remains interested in alternative approaches to space propulsion. One method he favors calls for using a powerful laser (based on a mountaintop, perhaps) to vaporize water or other propellants in spaceships and accelerate them skyward. "It has this fatal flaw," he admits. "It's only cheap if you have a high volume of traffic."

Unfortunately, in the late 1970s the National Aeronautics and Space Administration cut off almost all funding for research on space propulsion technologies. Instead NASA funneled its resources into one large, expensive machine, the shuttle, violating all the principles Dyson holds dear. "It was just absolute stupidity of the worst sort," Dyson fumes. He notes that "apart from the fact that seven people were killed," he welcomed the destruction of the Challenger, because he thought it would lead NASA to abandon the shuttle once and for all. "It hasn't been that easy, but I still think we will get rid of it."

The best way to revitalize NASA, Dyson contends, is to "cut it off from the octopus in Washington" and dismantle it, much as AT&T was dismantled. He remains confident that one way or another humanity—if not the U.S.—will fulfill its destiny in space. "The rest of the world is doing very well, thank you, particularly France and Japan."

Moreover, the greatest threat to civilization is receding. For several decades, Dyson has been a member of Jason, a group of scientists that advises the U.S. on national security issues. Just five years ago he and other Jason members spent the day with a nuclear-bomber crew at a Strategic Air Command base. "I had my hand on the red switch that arms the bombs," he says. Now the planes have been taken off alert and the bombs placed in storage. "That's enormous progress. Of course, there are still huge problems in destroying weapons."

Dyson's sense of whimsy and romance assert themselves as he peers farther into the future. He is not one of those who believes humans will soon be superseded by robots or computers. "Biological machinery is in so many ways more flexible than computer hardware," he says. In fact, he has speculated that one day genetic engineers may be able to "grow" spacecraft "about as big as a chicken and about as smart," which can flit on sunlight-powered wings through the solar system and beyond, acting as our scouts. Dyson calls them "astrochickens." He has also proposed that very advanced civilizations, perhaps concerned about dwindling energy supplies, could capture the radiation of stars by constructing shells around them.

In 1979 Dyson revealed the depths of his optimism in one of the more exotic papers ever published in *Reviews of Modern Physics*. Dyson had been piqued by a statement made by the physicist Steven Weinberg in his book *The First Three Minutes*: "The more the universe seems comprehensible, the more it also seems pointless." No universe with intelligence is pointless, Dyson retorted. He then sought to show that intelligence could persist for eternity—perhaps in the form of a cloud of charged particles—through shrewd conservation of energy. "No matter how far we go into the future, there will always be new things happening, new information coming in, new worlds to explore, a constantly expanding domain of life, consciousness and memory," Dyson proclaimed.

Dyson is "open-minded" about the possibility that in our cosmic journeys we will bump into aliens. "The closest I will come to an alien intelligence," he says, is an autistic woman he has known since she was a child. When she was 10, another autistic child sent her a letter consisting entirely of numbers. After scanning the list for a moment, the girl shouted, "Mistake! Mistake!" It turned out that all the numbers were prime but one—the mistake. "Although she comes from this totally different universe, mathematics is something she can share with us," Dyson explains. "Maybe that will be true of aliens, too."

Next spring the Institute for Advanced Study plans to hold a festival to honor the official retirement of its most veteran active member. Dyson may harbor some ambivalence about having been there so long. When I remark that the institute is the ultimate ivory tower, he nods solemnly. "I try to get out as often as I can to remind myself there's a real world," he says, and snickers.

For several years, in fact, Dyson has been traveling to colleges around the country talking to students. He prefers undergraduates, since "graduate students are narrowly focused on some rather unimportant problems, and they just don't seem to enjoy life very much." Dyson also likes small colleges in obscure locales. Last fall he visited the Vermillion campus of the University of South Dakota, and there he heard an "absolutely superb" concert of 16th-century music. "Someone who had met me at the airport said, 'Oh, lucky your plane was early, you're just in time for the concert.'" Dyson's seamed face brightens at the memory. Oh, the wonders one encounters, his expression seems to say, once one ventures outside the mainstream.

Infamy and Honor at the Atomic Café

Edward Teller has no regrets about his contentious career BY GARY STIX ORIGINALLY PUBLISHED INOCTOBER 1999

As I'm leaving for John F. Kennedy airport, I tell a colleague that I will be away to interview Edward Teller. "Is he still alive?" she asks in amazement. A day later I sit across the room from a 91-year-old man slumped in his desk chair, his five-foot-high carved wooden walking stick leaning against a desk that has a Ronald Reagan–awarded National Medal of Science hanging above it.

With eyes clouded by ulceration, he stares straight ahead. What may have been the world's bushiest eyebrows have thinned. A cowboy boot covers the prosthesis that replaced the foot he lost in a streetcar accident in 1928. His secretary informs me that his memory of recent events has faded in the wake of a stroke. I wonder if he even sees me or whether I will be able to proceed with the interview.

Almost immediately after I sit down, a heavy, slow voice addresses me in a strong, well-enunciated cadence. "I have been controversial in some respects," he announces in an accent that is part European university professor, part cold war inquisitor and part Bela Lugosi. "I want to know what you know about the controversy and what you think about it." I reach for my tape recorder, but he gestures for me to stop. My flustered, inarticulate answer to his first question only evokes another one: "What do you think about Robert Oppenheimer?" he demands, referring to the head scientist of the Manhattan Project whose government security clearance was revoked after Teller testified against him. "There were clearly differences between Oppenheimer and myself. What do you know about this controversy, and what do you think about it?"

Maybe it is payback time for the three articles that *Scientific American* ran in 1950 that voiced strong opposition to the development of the hydrogen bomb, the weapon for which Teller was an unbending advocate when many other atomic scientists were against it. Teller then demands to see what I write before it is published. I refuse. "You realize that I'm now tempted to cancel the interview, and the best I can do is give you an interview with extreme caution, to make sure that nothing is misunderstood."

This nonagenarian whose capacities I had doubted a few minutes earlier has now set me off balance. I've just experienced firsthand the bluster and resolve that prevailed over presidents, generals and members of Congress. Now that he holds the advantage in our encounter, Teller appears ready to submit to questioning.

What follows in the next few hours is like watching an old movie. Many of the lines in the script are familiar, but the effect of their recitation has only grown through repetition. What would have happened, I ask, if we hadn't developed the hydrogen bomb? "You would now interview me in Russian, but more probably you wouldn't interview me at all. And I wouldn't be alive. I would have died in a concentration camp." Commenting on the ban on nuclear weapons tests: "The spirit of no more testing is the spirit of ignorance; I'm happy to violate it. I don't think we're violating it enough."

Teller's persona—the scientist-cum-hawkish politico—is rooted in the upheavals that rocked Europe during the first half of the century, particularly the Communist takeover of Hungary in 1919. "My father was a lawyer; his office was occupied and shut down and occupied by the Reds. But what followed was an anti-Semitic Fascist regime, and I was at least as opposed to the Fascists as I was to the Communists."

To understand Teller, one must remember that he holds a place at the head table of the atomic café: he was present for many of the major events of 20th-century nuclear physics. He played a bit part in the Manhattan Project's atomic bomb work and became a relentless proponent for and scientific contributor to another weapon that would release unthinkable amounts of energy when atoms fuse together. In 1952 Teller went on to help orchestrate the founding of a second weapons design laboratory, Lawrence Livermore, a competitor to Los Alamos. Livermore succeeded in reducing the size of atomic warheads so that they could fit into nuclear submarines.

Teller conceived a multitude of uses for nuclear explosions, from mining to changing the weather. He campaigned endlessly for nuclear power. He lobbied governor Nelson Rockefeller in the 1960s to undertake programs for the construction of bomb shelters. He was a leading force in convincing presidents Ronald Reagan and George Bush to take on missile defense programs using highly speculative technologies, such as the x-ray laser. More recently Teller has called for nuclear and other explosions to deflect killer asteroids and comets.

What interests me in approaching Teller is trying to understand what he thinks of his own legacy. I ask him what he wishes to be remembered for. "I will tell you in very great detail," he interjects. "I don't care." I wonder whether the father of the hydrogen bomb and the champion of "Star Wars" missile defense has any regrets. "Is there anything that you feel perhaps should not have been done?" I ask. A void of 15 seconds follows. "On the whole, I don't," he replies. I inquire whether he still thinks Project Chariot, the never-realized plan to create a new harbor in Alaska by setting off up to six hydrogen bombs, was a good idea. "Look," he retorts with pedantic emphasis. "With a good harbor, northern Alaska could have been integrated into the American economy more effectively, like Hawaii was."

Teller is also unrelenting about his contribution to devising the hydrogen bomb. Most accounts credit physicist Stanislaw Ulam with a key insight that made a thermonuclear explosion possible—an idea that came only after Teller had pursued an approach to what was called the "classical Super" that led nowhere. Ulam proposed that the mechanical shock of an atomic bomb could compress hydrogen fuel and unleash a fusion reaction. Teller refined Ulam's concept by proposing that radiation from the initial atomic blast rather than the mechanical force of the explosion be used to achieve the necessary compression.

So I ask him who can claim paternity for the ultimate weapon of mass destruction, one whose ignition is often referred to as the Ulam-Teller design. As always, Teller does not mince words. "I contributed; Ulam did not," he says. "I'm sorry I had to answer it in this abrupt way. Ulam was rightly dissatisfied with an old approach. He came to me with a part of an idea which I already had worked out and had difficulty getting people to listen to. He was willing to sign a paper. When it then came to defending that paper and really putting work into it, he refused. He said, 'I don't believe in it.' " But, I reply, most histories report that Ulam suggested compression as a means to initiate a fusion reaction. "I know, and that is a lie," Teller shoots back.

Despite this damn-the-world attitude, Teller acknowledges the emotional turmoil he experienced from his outcast status in the scientific community after testifying against Oppenheimer. In 1954 the Atomic Energy Commission was investigating whether Communist sympathies had prompted Oppenheimer to stymie work on the hydrogen bomb. Teller's action contributed to Oppenheimer's losing his security clearance and his position as an adviser to the commission. "It hurts badly," comes the terse reply when he is asked how he feels today about his isolation.

Nor is Teller fond of the inevitable associations in the public mind with a certain fictional crackpot scientist. "My name is not Strangelove. I don't know about Strangelove," he flares. "I'm not interested in Strangelove. What else can I say?" A few moments later, as I pursue the question, he warns: "Look. Say it [Strangelove] three times more, and I throw you out of this office."

Still, Teller retains an acute awareness of how others see him. After he suffered a stroke three years ago, a nurse quizzed him to probe his lucidity. "Are you the famous Edward Teller?" she queried. "No," he snapped. "I'm the infamous Edward Teller."

After my time with him, I walk the streets of Palo Alto and marvel at how this man's passions have affected anyone who has lived during the past half century. A long-buried memory emerges of my father and grandfather, seated at the dining room table, discussing the materials needed to construct a bomb shelter in our basement that would stop the deadly gamma rays from a nuclear blast hitting New York City, the two men swept into the hysterical maelstrom that Teller helped to fuel. I wonder if Nobelist physicist Isidor I. Rabi wasn't right when he suggested that "it would have been a better world without Teller."

As I walk down University Avenue, amid the twentysomethings in cappuccino bars gazing at laptops and perhaps contemplating e-start-up businesses, I realize that the Manichaean world of good versus evil that still kindles Teller's intensity has faded. His outpost in a modern building at the Hoover Institution, adjacent to the conservative think tank's phallic stucco tower, sits at the epicenter of the Stanford campus that has served as an incubator of the postnuclear world of the electronics and biotechnology industries. The Soviets could never compete with America's electronic weaponry—and even less with the northern Californian economic vibrancy that produced Macintosh computers and Pentium processors. Fidel Castro still muses longingly about turning Cuba into a biotechnology powerhouse. In the end, microchips and recombinant DNA—two foundations of the millennial economy—helped to spur the end of the cold war in a way the fantasy of a Star Wars x-ray laser never could.

But Teller is never finished. Even now, at his age, he refuses to put to rest his grandiose visions of technological salvation. He and colleagues have submitted a paper to *Nature* that suggests dispersing sulfur dioxide or other submicron particles in the stratosphere to block sunlight and thus halt global warming—a cheaper option, he claims, than cutting back on carbon dioxide emissions. The man who imitated the sun by harnessing its fusion fires has never yielded his hubristic belief that knowledge of the physical sciences combined with indomitable willpower can fundamentally alter elemental forces of nature and so save the world.

Dissident or Don Quixote?

ORIGINALLY PUBLISHED IN AUGUST 2001

Challenging the HIV theory got virologist Peter H. Duesberg all but excommunicated from the scientific orthodoxy. Now he claims that science has got cancer all wrong BY W. WAYT GIBBS

SENAGO, ITALY—Three centuries ago cardinals seeking refuge from a plague in nearby Milan stayed here at the Villa San Carlo Borromeo, a grand estate surveying the village from its highest hill. The villa and its inhabitants have fallen on harder times since. The cracked plaster and faded paint on its high walls are covered with modern art of dubious quality. Now it is the private museum of Armando Verdiglione, a once prominent psychoanalyst whose reputation was stained when he was convicted in 1986 of swindling wealthy patients. Today the villa is hosting refugees of a different sort: scientific dissidents flown in by Verdiglione from around the world to address an eclectic conference of 100-odd listeners.

At the other end of the dais from Verdiglione is Sam Mhlongo, a former guerrilla fighter and prison-mate of Nelson Mandela and now head of the department of family medicine and primary health care at the Medical University of Southern Africa near Pretoria. Mhlongo has urged President Thabo Mbeki to question the near universal belief that AIDS is epidemic in South Africa and that HIV is its cause.

Between them sits Peter H. Duesberg, an American virologist who has also challenged that belief. Duesberg is now tilting at a different windmill, however. In a reedy voice clipped by a German accent, he explains why he believes the scientific establishment has spent two decades perfecting an utterly incorrect theory of how cancer arises.

It is an odd speaking engagement for a scientist who isolated the first cancer-causing gene from a virus at age 33, earned tenure at the University of California at Berkeley at 36 and was invited into the exclusive National Academy of Sciences at 49. Today many of his colleagues from those early efforts to map the genetic structure of retroviruses occupy the top of the field. Robert A. Weinberg has a huge lab at the Whitehead Institute for Biology in Cambridge, Mass., with 20 research assistants, a multimillion-dollar budget and a National Medal of Science to hang in his office. David Baltimore got a Nobel Prize and now presides over the California Institute of Technology.

"I could have played the game and basked in the glory" of early success, Duesberg says, and he is probably right. But instead he broke ranks and bruised egos. And so, 10 days before attending this eccentric symposium, Duesberg had to dash off a desperate letter to Abraham Katz, one of the handful of rich philanthropists who have been his sole source of funding since he was cut off from all the normal channels five years ago.

"We're down to our last $45,000," the 64-year-old Duesberg confides glumly as we stand in the dark courtyard of the villa. Katz, whose wife suffers from leukemia, is his final hope; if this grant doesn't come through, Duesberg will have to cut loose his two assistants, close his lab at Berkeley and move to Germany. That is where he was born to two doctors, where he worked through a Ph.D. in chemistry and where he says he still has an open invitation to teach at the University of Heidelberg.

Leaving the U.S., if it comes to that, would thus close the loop on a roller coaster of a career. Although his ascendance is clear enough, it is hard to say exactly when his fall from grace began. Several weeks later as we talk in his small lab—one fifth the size of the facilities he once had—he hands me a paper he published in 1983. "This is the one that started it all," he says.

The paper is not, as I expect, his now infamous 1988 article in *Science* provocatively entitled "HIV Is Not the Cause of AIDS." Nor is it any of the several dozen articles and letters he published in peer-reviewed journals over the next 10 years arguing that the link between HIV and AIDS is a mirage, an artifact of sloppy epidemiology that has lumped together different diseases with disparate causes just because the sufferers have all been exposed to what he calls "a harmless passenger virus."

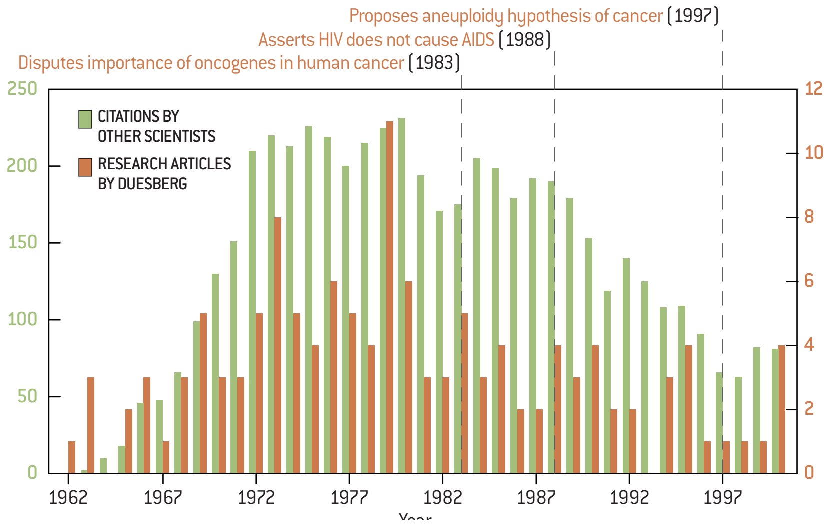
Although these dissenting theories of AIDS did not originate with Duesberg, he soon became their champion—and thus the target of derision for those who feared that disagreement among scientists could confuse the public and endanger its health. When Mbeki, after consulting with Duesberg and other AIDS experts, told the International AIDS Conference last year that he felt "we could not blame everything on a single virus," more than 5,000 scientists and physicians felt it necessary to sign the Durban Declaration, devoutly affirming their belief that HIV is the one true cause of AIDS.

Duesberg's arguments ultimately converted no more than a tiny minority of scientists to his view that "the various AIDS diseases are brought on by the long-term consumption of recreational drugs and anti-HIV drugs, such as the DNA chain terminator AZT, which is prescribed to prevent or treat AIDS." Or, as he puts it more bluntly in Milan, in rich countries it is the toxicity of the very drugs that are prescribed to save HIV-infected people that kills them.

The hypothesis has never been tested directly, although Duesberg claims it could be done ethically by comparing 3,000 HIV-positive army recruits with 3,000 HIV-negative recruits matched for disease and drug use. And so his idea has died as most failed theories do, never fully disproved but convincingly rebutted—in this case by a 40-page treatise from the National Institute for Allergic and Immune Disease—and ultimately ignored by nearly everyone working in the field.

But Duesberg didn't even know AIDS existed in 1983, when he wrote the paper that he says first marked him as a troublemaker. The title seems innocuous: "Retroviral Transforming Genes in Normal Cells?" But in Duesberg papers the question mark often signals that he is about to yank on the loose threads of a popular theory. This time the theory concerned cancer.

He and others had shown that when certain retroviruses insinuate their genes into the cells of mice, the cells turn malignant. Weinberg, Baltimore and others in the field speculated that perhaps similar genes, which they called "proto-oncogenes," lie dormant in the human genome, like time bombs that turn on only if a random mutation flips some sort of genetic switch. This hypothesis spawned a cottage industry to search for oncogenes, so-called tumor suppressor genes and, most recently, cancer "predisposition" genes.



ROLLER-COASTER CAREER of Peter H. Duesberg is traced by the rate at which he has published research articles and the rate at which other scientists have cited his work.

JOHNNY JOHNSON; SOURCE: INSTITUTE FOR SCIENTIFIC INFORMATION *WEB OF SCIENCE*

As two decades passed, human genes with sequences similar to the viral oncogenes were found, and support for this story of cancer's origin solidified. "If you were to poll researchers, I'd guess 95 percent would say that the accumulation of mutations [to key genes] causes cancer," says Cristoph Lengauer, an oncologist at Johns Hopkins University.

But the story also grew steadily more complicated—and, to Duesberg, less convincing. Scientists expected to find some combination of oncogenes and tumor suppressor genes that are always mutated, at least in certain forms of cancer. They did not. Instead the number of putative cancer genes has leaped into the dozens, experiments have shown that different cells in the same malignancy often contain different mutations, and no clear pattern perfectly matches the supposed cause to actual human disease. Cells taken from patients' tumors typically translate their mutant genes into a mere trickle of protein, in contrast to the flood of mutated protein churning in cells transformed by a virus.

Beginning with his 1983 paper, Duesberg has also picked at theoretical weak spots in the orthodox view. Some tumors are caused by asbestos and other carcinogens that are chemically incapable of mutating specific genes, he points out. Mice genetically engineered to lack tumor suppressor genes and to overexpress oncogenes should all develop cancer in infancy—but they don't. Given the measured rate of spontaneous mutations and the number of cells in the human body, the average person should harbor 100,000 cancer cells if even one dominant oncogene existed in the genome, Duesberg calculated in a paper last year. But if simultaneous mutations to three genes were required, then only one in 100 billion people would ever acquire cancer.

In 1997 Duesberg published what he thought was a better hypothesis. There is one characteristic common to almost every malignant tumor ever studied: nearly all the cancerous cells in it have abnormal chromosomes. In advanced cancers the cells often have two or three times the normal complement of 46 chromosomes. In new tumors the gross number may be normal, but closer examination usually reveals that parts of the chromosomes are duplicated and misplaced.

German biologist Theodor Boveri noted this so-called aneuploidy of tumor cells almost a century ago and suggested that it could be the cause of cancer. But that idea lost traction when no one could find a particular pattern of aneuploidy that correlated with malignancy, except in chronic myelogenous leukemia, which is not a true cancer because it doesn't spread from the blood to other parts of the body.

Recently, however, Duesberg and a few other scientists analyzed aneuploidy more closely and argued that it can explain many of the mysteries of cancer better than the current dogma can. Their alternative story begins when a carcinogen interferes with a dividing cell, causing it to produce daughter cells with unbalanced chromosomes. These aneuploid cells usually die of their deformities. If the damage is minor, however, they may survive yet become genetically unstable, so that the chromosomes are altered further in the next cell division. The cells in tumors thus show a variety of mutations to the genes and the chromosomes.

Because each chromosome hosts thousands of genes, aneuploidy creates massive genetic chaos inside the cell. "The cell becomes essentially a whole new species unto itself," Duesberg says. Any new "species" of cell is extremely unlikely to do better in the body than a native human cell—and that may explain why tumors take so long to develop even after intense exposure to a carcinogen, he argues. The aneuploid cells must go through many divisions, evolving at each one, before they hit on a combination that can grow more or less uncontrollably anywhere in the body.

So far Duesberg has only a scattering of experimental evidence to support his hypothesis. In 1998 he showed that there is a roughly 50-50 chance that a highly aneuploid human cancer cell will gain or lose a chromosome each time it divides. Last December he reported that aneuploid hamster cells quickly developed resistance to multiple drugs—a hallmark of cancer—whereas normal cells from the same culture did not.

But it isn't easy to do experiments when every one of his last 22 grant proposals to nonprivate funding agencies was rejected, he says. Although Duesberg maintained a facade of defiance in Milan, he acknowledged in a moment of fatigue that "it is depressing that even private foundations are unwilling to fund research that has high risk but high potential payoff."

His mood had lifted somewhat by May, when I visited his lab. A letter from Abraham Katz tacked to the door stated that his request was approved: he would be getting $100,000, enough to keep the lab running for another nine months.

It seems unlikely that nine months will be enough to persuade other researchers to take his aneuploidy hypothesis seriously. But it is possible. Numerous papers in major journals this year have pointed out the importance of "chromosome instability," a synonymous phrase, in cancer formation. Lengauer and Bert Vogelstein, also at Johns Hopkins, have been particularly active in promoting the idea that aneuploidy—which Lengauer insists must be a consequence of gene mutations—may be a necessary step for any tumor to progress.

Is Duesberg now willing to lay down his lance and play within the rules of polite scientific society? He recognizes that his combative stance in the HIV debate came across as arrogant. "With AIDS, I was asking for it a bit," he concedes. "At the time, I thought I was invulnerable." The experience may have tempered his ego, although he still mentions the Nobel Prize four times in a three-hour interview. Duesberg himself is pessimistic that he will ever be welcomed back into the club. "When you are out of the orthodoxy," he says softly, "they don't recall you."

The $13-Billion Man

Why the head of the Howard Hughes Medical Institute could be the most powerful individual in biomedicine BY CAROL EZZELL

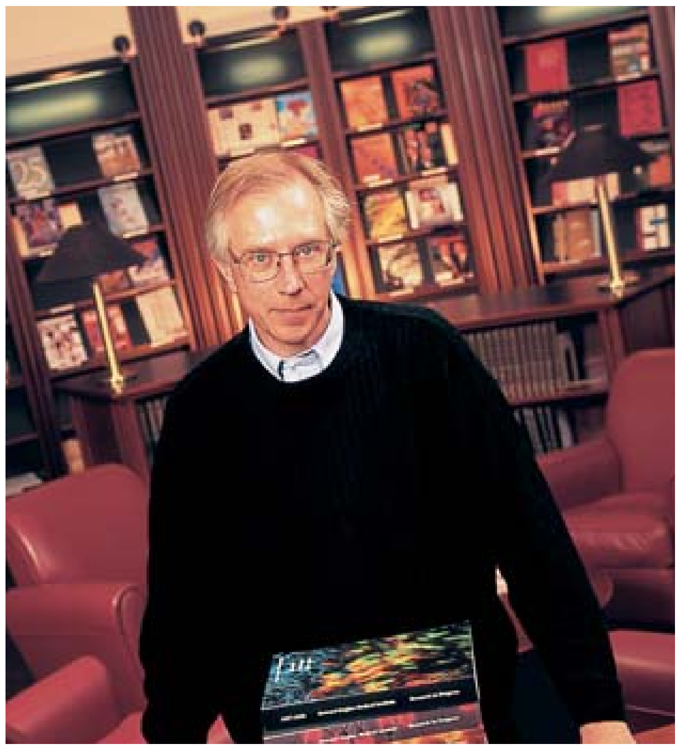
ORIGINALLY PUBLISHED IN JANUARY 2001

CHEVY CHASE, MD.—What's it like to lead the largest private supporter of basic biomedical research in the nation? "Very stimulating," replies Thomas R. Cech with a wry smile. "Sometimes I have trouble sleeping at night because it's so intense."

Last January, Cech (pronounced "check") became president of the Howard Hughes Medical Institute (HHMI), which spends more money on fundamental biomedical science than any other organization in the U.S. besides the federal government. In his post, he commands a research enterprise that includes a select group of 350 scientists sprinkled across the country who are generally considered to be the crème de la crème in their respective fields. He also oversees the distribution of millions of dollars every year in grants, primarily for science education at levels ranging from elementary school to postdoctoral training. Those two responsibilities, plus his own notable scientific findings, arguably make Cech one of the most preeminent people in biomedicine today.

Cech has assumed the stewardship of HHMI at a critical time for biomedicine. There is more funding available for biomedical research than ever before: the National Institutes of Health's annual budget is at an all-time high of $18 billion, and that could double over the next five years based on results of proposals pending in Congress. When added to the $575 million provided in 2000 by HHMI, U.S. biomedical scientists will have a veritable embarrassment of riches. (The London-based Wellcome Trust, with its endowment of $17.9 billion, is the largest medical philanthropic organization in the world and spends $550 million a year on research.)

Cech has also taken over HHMI in an era of rapid change in biomedical science. There are abundant ethical issues that will need to be addressed surrounding new biotechnologies such as cloning and the derivation of stem cells from human embryos. And the increasing ties between academic scientists and biopharmaceutical companies are raising questions about the propriety of such relationships and how they affect the



KAY CHERNUSH

THOMAS R. CECH: FROM BERKELEY TO BIOMEDICAL GURU

- Shared the 1989 Nobel Prize for Chemistry for discovering ribozymes
- Worst job: Worked in a box factory in Iowa as a young man
- Recent book read: The Lexus and the Olive Tree: Understanding Globalization, by Thomas L. Friedman
- Attended the University of California at Berkeley in the 1970s but "never burned anything down"
- Starred as "Mr. Wizard" in science education skits at the University of Colorado
- Met wife, Carol, over the melting-point apparatus in a chemistry lab at Grinnell College

outcome of science.

HHMI officials like to describe the organization as "an institute without walls." Instead of hiring the best people away from the universities where they work and assembling them in one huge research complex, HHMI employs scientists while allowing them to remain at their host institutions to nurture the next generation of researchers. The institute prides itself on supporting scientists' overall careers, not just particular projects, as most NIH grants do. HHMI emphasizes research in six areas: cell biology, genetics, immunology, neuroscience, computational biology and structural biology, which involves studying the three-dimensional structures of biological molecules. HHMI also has a policy of disclosing business interests in research and has forbidden certain kinds of researcher-company relationships.

As one of the world's richest philanthropies, HHMI—which is headquartered in Chevy Chase, Md., just down the road from the NIH—boasts an endowment of a whopping $13 billion. (Founded by aviator/industrialist Howard Hughes, the organization has been funded since 1984 from the sale of Hughes Aircraft following Hughes's death.) In the past the institute sometimes had a hard time just spending enough of the interest its capital generates to satisfy the Internal Revenue Service.

HHMI's strong finances have enabled it to find top-notch researchers. Cech, for instance, won the Nobel Prize for Chemistry (shared with Sidney Altman of Yale University) in 1989 while he was an HHMI scientist. Five other Nobelists are currently on the institute's payroll, including Eric R. Kandel of Columbia University, who shared the 2000 Nobel Prize for Physiology or Medicine.

Despite their relatively few numbers, HHMI investigators also have a disproportionate influence on biomedical research. According to a report in the September/October issue of *ScienceWatch*, which tracks research trends, scientists referenced journal articles written by HHMI scientists more frequently than articles by scientists employed by any other institution. HHMI work was cited 76,554 times between 1994 and 1999, more than twice as often as studies done at Harvard University, which at 37,118 ranked second in overall citations during that period. The same *ScienceWatch* article reported that nine of the 15 authors with the most "high-impact" papers, as measured by the number of citations, were HHMI investigators.

Cech has written some top-cited articles himself. His papers demonstrating that the genetic material RNA can have enzymatic properties—the finding that earned him the Nobel Prize—are becoming classics. The discovery of the enzymatic RNAs, also known as ribozymes, has spawned inquiries into the origin of life.

Before Cech and Altman discovered ribozymes (during experiments they conducted independently), scientists thought that RNAs only played roles in reading out the information contained in the DNA of an organism's genes and using those data to make proteins. The dogma also dictated that the proteins were the sole molecules that could serve as enzymes to catalyze biochemical reactions—that is, to break apart and recombine compounds. But Cech and Altman found that RNAs isolated from the ciliated protozoan *Tetrahymena* and from the bacterium *Escherichia coli* could splice themselves in vitro—a clearly enzymatic function.

More recently, Cech's laboratory has branched out to study telomerase, the RNA-containing enzyme that keeps telomeres, the ends of chromosomes, from shrinking a bit each time a cell divides. Telomerase and its function in maintaining telomeres has become a hot topic in research on aging and is a focus of new-drug development. During his tenure as president of HHMI, Cech is maintaining a scaled-down laboratory at the University of Colorado, where he has spent a few days or a week every month.

Cech was a science prodigy from an early age, although his first abiding interest was geology, not biology. He recalls that he began collecting rocks and minerals in the fourth grade and that by the time he was in junior high school in Iowa City, where he grew up, he was knocking on the doors of geology professors at the University of Iowa, pestering them with questions about meteorites and fossils.

After he entered Grinnell College, Cech says, he was drawn to physical chemistry but soon realized that he "didn't have a long enough attention span for the elaborate plumbing and electronics" of the discipline. Instead he turned to molecular biology and a career that would take him from the Ph.D. program at the University of California at Berkeley to a postdoctoral fellowship at the Massachusetts Institute of Technology to faculty positions at the University of Colorado.

As president of HHMI, Cech says that one of his first priorities concerns bioinformatics (also called computational biology), the use of computers to make sense of biological data. "Bioinformatics is really going to transform biomedical research and health care," he predicts. HHMI has already sponsored new initiatives supporting scientists using bioinformatics to study the structures of biological molecules, to model the behavior of networks of nerve cells and to compare huge chunks of DNA-sequence information arising from the Human Genome Project. "A few years ago biologists used computers only for word processing and computer games," he recalls. "The computer was late coming into biology, but when it hit, did it ever hit."

Cech is also very interested in bioethics. This summer he established a committee to organize a bioethics advisory board to help HHMI investigators negotiate some of the thornier dilemmas of biotechnology. The board, he anticipates, will meet with investigators and develop educational materials. When it comes to cloning, Cech has a specific position. So-called reproductive human cloning—generating a cloned embryo and implanting it into a human womb to develop and be born—is out of bounds for HHMI-supported researchers, he states. But cloning for medical purposes, in which cells from a cloned human fetus would be used to grow replacement tissues for an individual, "would depend on the host institution."

Overall, the 53-year-old Cech cuts quite a different figure from his predecessor at HHMI, Purnell W. Choppin, who retired at the end of 1999 at age 70. Where the courtly Choppin was never seen without a coat and tie, Cech favors open collars, sweaters, and Birkenstock sandals with socks. And where Choppin rarely mingled with his nonscientific employees at HHMI headquarters, Cech hosts a monthly social hour in the institute's enormous flower-trellised atrium. He is also encouraging HHMI investigators to bring a graduate student when they come to the meetings in which HHMI scientists share results. "My style personally," he comments, "is to be open and embracing."

Starving Tumors of Their Lifeblood

No, Judah Folkman probably won't cure cancer in two years. He says he simply hopes to render it a manageable, chronic disease BY CAROL EZZELL

ORIGINALLY PUBLISHED IN OCTOBER 1998

At 9 A.M. on a hot, sticky Friday in the middle of June, the tiny conference room on the 10th floor of Children's Hospital in Boston is packed with the eager faces of an ethnically diverse cast of young people munching bagels. Among the Birkenstocks, T-shirts and jeans of his 30-odd graduate students and postdoctoral fellows, Judah Folkman stands out because of three things: his age (65 years), his necktie and white lab coat, and his courtly but authoritative manner.

At this weekly laboratory meeting, several of the lab members stand to describe their most recent results studying the link between angiogenesis—the growth of new blood vessels—and cancer. Folkman offers everything from detailed remarks on the methods of a particular experiment to advice on how to make the best use of an overhead projector. He's the consummate manager and mentor: one minute he's upbraiding a cocky postdoc for not taking criticism as easily as he dishes it out; the next he's commending the same young man for "good progress" and joking with him that it's not yet time for him to give up and go to business school. The postdoc wraps up his presentation and sits down with a smile.

Folkman and his prolific laboratory hit the news in a major way this past May, when an overenthusiastic, front-page story in the *New York Times* trumpeted results by Folkman's group using naturally derived angiogenesis inhibitors to cure cancer in mice by preventing the growing tumors from attaining a blood supply. The focus of the story was a scientific paper published in November 1997 that had already been the subject of a *Times* news story, though not on page one.

One of the most provocative aspects of the *Times* article was a quote attributed to Nobel laureate—and biology legend—James D. Watson: "Judah is going to cure cancer in two years." Although four days later the newspaper published a letter from Watson saying his "recollection of the conversation" with the *Times*'s reporter was "quite different," the damage had been done. Hordes of people with cancer were already rushing their physicians' offices, demanding access to the impending "cure"—despite the fact that it has yet to be tested in a single human. Folkman's office alone logged more than 1,000 calls a day from cancer patients and their loved ones the week after the *Times* ran the story.

Folkman says he is puzzled over why the *Times* decided to publish such a belated, breathless article on his group's work. "Our published results have all been in mice," he emphasizes. "Many different substances have been shown to inhibit cancer in mice over the years, but unfortunately, so far not all of them have worked as well in people." Most of all, he says, he is concerned that the story might have instilled false hopes in so many of those desperately ill with cancer.

Folkman is a leading pediatric surgeon but shows none of the ego of the stereotypical topflight surgeon. Quite the opposite. He dislikes giving interviews (especially for television) to the point that this summer he even turned down a request by NBC morning anchor Katie Couric—who had recently lost her husband to colon cancer—to appear on the *Today* show. He also hates having his photograph published—not because he is vain about his looks, he says, but because he doesn't want to seem to be taking sole credit for the dogged work of the many scientists who make up his laboratory. In addition, he says, he wants to avoid being thought the leader of the only laboratory in the world devoted to angiogenesis, because many other labs contribute to the field.

A cavernous, elaborate workspace is not for Folkman: his office, which he rarely uses, is small and furnished with tattered, 1970s-era furniture. Every horizontal surface is stacked with books, journals, files and papers, so that the room more closely resembles an attic. Although his office has a computer, Folkman's secretary says that when he needs to write something he usually pulls a chair up to a spare computer next to her desk, in a cramped corner in front of a minirefrigerator, because there is more room there than in his own space.

Folkman's lifework on cancer and angiogenesis began in circumstances not of his own making: he was drafted into the U.S. Navy in 1960. Although he had just finished his assistant residency in surgery at Massachusetts General Hospital in Boston, the navy set him up with a small lab at the National Naval Medical Center in Bethesda, Md., to help in the military's drive to create blood substitutes for use on aircraft carriers, which often spend months at sea.

There Folkman conducted the pivotal experiments that focused him on angiogenesis. While studying the ability of a cell-free blood substitute to keep a rabbit thyroid gland alive in culture, Folkman and navy colleague Frederick Becker placed a few rabbit melanoma cells on the gland's surface. To their surprise, the cells grew but stopped once they formed tumors the size of peas. "Why did the tumors stop growing?" Folkman asks. "That question kept me going for years."

After leaving the navy in 1962, Folkman returned to Mass General, where he became chief surgical resident two years later. As one of Harvard Medical School's brightest young surgeons, by 1967 Folkman had attained tenure, going directly from associate (instructor) to full professor and chairman of the department of surgery at Children's Hospital in just one year. Folkman had distinguished himself as a surgeon through his technical skill and his ability to train others. He had also participated in the early development of implantable drug-delivery devices, which eventually led to the commercialization of products such as the contraceptive Norplant.

Along the way, Folkman kept a small research lab going on the side to pursue his interests in angiogenesis. But when he tried to publish his animal results, he was turned down by dozens of journals. Many scientists scoffed at his idea that devising a way to block angiogenesis might keep growing tumors in check.

It was only through giving a lecture in 1971 that Folkman got his ideas into an important journal for the first time. That year he was asked to give a special seminar at Beth Israel Hospital in Boston that has often been invited for publication in the *New England Journal of Medicine*. Finally, Folkman had a well-read platform for describing his conclusion from the rabbit thyroid gland experiments: that tumors are incapable of growing beyond a certain size unless they have a dedicated blood supply and that finding a way to block the process of angiogenesis might nip emerging cancers in the bud.

But the *NEJM* article simply egged on Folkman's critics. In 1973, for example, when Folkman and his co-workers reported that injecting human tumor cells into the eyes of rabbits prompted angiogenesis, some scientists argued that the observed blood vessel growth was simply part of an inflammatory reaction to foreign cells. One researcher subsequently showed that implanting a chemical irritant, a crystal of uric acid, in rabbits' eyes also spurred angiogenesis. It took years for Folkman and his colleagues to explain this finding by demonstrating that immune system cells called macrophages had entered the rabbits' eyes to destroy the uric acid and had secreted substances that promote angiogenesis.

Folkman's struggles for credibility affected all the factors crucial to the success of a biomedical researcher: his ability to obtain grants from the National Institutes of Health, his chances of publishing his ideas in leading journals and his capacity to attract scientists in training to work for him in his laboratory.

"In the 1970s professors dissuaded their best students from coming to work in my lab," Folkman says matter-of-factly. The only way he could convince outstanding young scientists to join him, he says, was by reminding them that they were so good that even if things didn't work out and they left after a year, their careers wouldn't be harmed.

Throughout the 1980s, Folkman and the other scientists in his laboratory kept adding pieces to the puzzle of angiogenesis and slowly gaining adherents to the idea that inhibiting angiogenesis might be a key to keeping cancer in check. A significant break came in 1994, when Michael S. O'Reilly in Folkman's lab isolated one of the most potent natural inhibitors of angiogenesis, which they named angiostatin [see "Fighting Cancer by Attacking Its Blood Supply," by Judah Folkman; SCIENTIFIC AMERICAN, September 1996]. Folkman, O'Reilly and their co-workers isolated a second natural inhibitor, endostatin, in 1996.

Folkman and his colleagues have now published articles in all the most prestigious research journals, and the list of awards and honors Folkman has received takes up two full pages of his curriculum vitae. Although researchers are not yet clear exactly how angiogenesis inhibitors work, angiostatin is expected to be tested in humans beginning late this year. (Several synthetic angiogenesis inhibitors are already in clinical trials.)

When asked how he persevered despite his early critics, Folkman credits his wife of 38 years, Paula, an alto who sings as a full-time member of the chorus with the Boston Symphony. "I would come home at night so disheartened," he says, "and she would ask, 'Why do you care what they think?' She has always been very supportive."

Does Folkman believe that he will eventually cure cancer? "No, I don't think angiogenesis inhibitors will be the cure for cancer," he answers. "But I do think that they will make cancer more survivable and controllable, especially in conjunction with radiation, chemotherapy and other treatments. I'm very excited to see how they will work in people."

Where Science and Religion Meet

The U.S. head of the Human Genome Project, Francis S. Collins, strives to keep his Christianity from interfering with his science and politics

BY TIM BEARDSLEY ORIGINALLY PUBLISHED IN FEBRUARY 1998

The combination of world-class scientific researcher, savvy political activist, federal program chief and serious Christian is not often found in one person. Yet that constellation of traits is vigorously expressed in Francis S. Collins.

Collins leads the U.S. Human Genome Project, an ambitious effort to analyze the human genetic inheritance in its ultimate molecular detail. A physician by training, he became a scientific superstar in 1989, when he was a researcher at the University of Michigan. There, together with various collaborators, he employed a new technique called positional cloning to find the human gene that, if mutated, can give rise to cystic fibrosis. That discovery quickly made possible the development of tests for prenatal diagnosis of the disease.

Collins has since co-led successful efforts to identify several other genes implicated in serious illness. His tally of discoveries thus far includes genes that play a role in neurofibromatosis and Huntington's disease as well as the rarer ataxia telangiectasia and multiple endocrine neoplasia type 1. In 1993, after turning down the invitation six months earlier, Collins left Michigan to become director of what is now the National Human Genome Research Institute.

In his office on the campus of the National Institutes of Health in Bethesda, Md., the 47-year-old Collins sits at the center of a vortex of medical hopes and fears that is probably unrivaled. He is widely seen as a strong leader for the genome program, which he reports is on target for sequencing the entire three billion bases of human DNA by 2005. And his influence extends well beyond research. Collins's energetic support for laws to prevent people from losing health insurance because of genetic discoveries is perhaps the best explanation for the limitations on gene-based insurance discrimination in the 1996 Kennedy-Kassebaum bill.

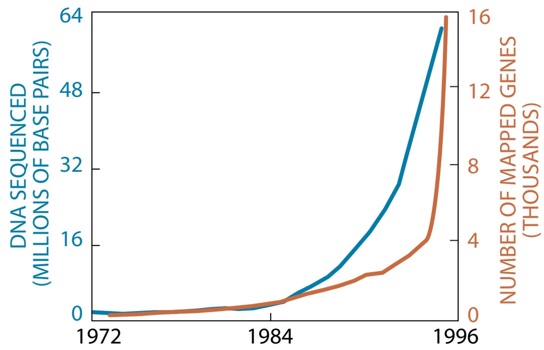
Recently Collins has thrown his political weight behind a new "potentially expensive but very important goal" that he hopes will supplement the genome project's sequencing effort. Collins wants to assemble a public-domain catalogue of subtle human genetic variations known as single nucleotide polymorphisms, written "SNPs" and pronounced "snips." The effort would constitute "a very significant change in the vision of what the genome project might be," Collins says. SNPs are detected by comparing DNA sequences derived from different people.

Unlike positional cloning, analysis of SNPs can readily track down genes that, though collectively influential, individually play only a small role in causing disease. Diabetes, hypertension and some mental illnesses are among the conditions caused by multiple genes. New DNA "chips," small glass plates incorporating microscopic arrays of nucleic acid sequences, can be used to detect mutations in groups of genes simultaneously. By employing this chip technology, researchers should be able to use SNPs for rapid diagnoses.

Collins now spends a quarter of his time building support at NIH for a SNP repository. He bolsters his case by predicting that, absent a public effort on SNPs, private companies will probably survey these molecular flags and patent them. There may be only 200,000 of the most valuable SNPs, so patents could easily deny researchers the use of them except through "a complicated meshwork of license agreements."

Collins the federal official often retains the open-collar, casual style that is de rigueur among scientists, and his preferred mode of transportation (motorcycle) has earned him some notoriety. He is, however, more unassuming than officials or scientists are wont to be. He feels "incredibly fortunate" to be standing at the helm of a project "which I think is going to change everything over the years." Such feelings inspire Collins to musical expression. Last year at the annual North American Cystic Fibrosis Conference, he performed his song "Dare to Dream," accompanying himself on guitar. Yet Collins's easygoing demeanor belies intensity not far below the surface: he estimates that 100-hour workweeks are his norm. He grew up on a farm in Virginia and graduated with a degree in chemistry from the University of Virginia with highest honors. He followed up with a Ph.D. in physical chemistry at Yale University, then went to the University of North Carolina to study medicine. He was soon active in genetics. As a researcher at Michigan, he was doing "exactly what I wanted to do," which is why he turned down the job of leading the genome program the first time he was offered it. He now admits, however, he is "having a very good time."

Large-scale human DNA sequencing was not initiated until 1996, after preliminary mapping had been accomplished. So far only 2 percent of the total human genome has been sequenced. The only cloud on the horizon that Collins foresees is reducing the cost enough to fit the entire project into the budget, $3 billion over 15 years.



NUMBER OF MAPPED HUMAN GENES, located on chromosomes, is rising, but only some 64 million bases have been completely sequenced, about 2 percent of a person's total.

Sequencing now costs 50 cents per base pair. Collins needs to get that figure down to 20 cents. If he could reach 10 cents, the gene sequencers could tackle the mouse as well, something Collins wants to do because comparisons would shed light on how the genome is organized. Cutting against that, however, is the need to ensure reproducibility. This year Collins has enacted cross-laboratory checks to ensure that sequence accuracy stays over 99.99 percent.

Collins notes with satisfaction that today there are people alive who would have died without genetic tests that alerted physicians to problems. Patients with certain types of hereditary colon cancer, which can be treated by surgery, are the most obvious examples. Testing for genes predisposing to multiple endocrine neoplasia type 1 and, possibly, breast and ovarian cancer may in time save lives, Collins judges.

Congress funded the genome project hoping it would lead to cures. But for most of the diseases to which Collins has made important contributions, the only intervention at present is abortion of an affected fetus. Although normally fluent, Collins is halting on this subject, saying he is personally "intensely uncomfortable with abortion as a solution to anything." He does not advocate changing the law and says he is "very careful" to ensure that his personal feelings do not affect his political stance.

He volunteers that his views stem from his belief in "a personal God." Humans have an innate sense of right and wrong that "doesn't arise particularly well" from evolutionary theory, he argues. And he admits his own "inability, scientifically, to be able to perceive a precise moment at which life begins other than the moment of conception." Together these ideas lead to his having "some concerns" about whether genetic testing and abortion will be used to prevent conditions that are less than disastrous, such as a predisposition to obesity.

The recent movie *Gattaca* thrust before the public eye the prospect that genetic research will in the near future allow the engineering of specific desirable traits into babies. Collins thinks it is "premature to start wringing our hands" about the prospect of genetic enhancement. But he states, "I personally think that it is a path we should not go down, not now and maybe not for a very long time, if ever."

Researchers and academics familiar with Collins's work agree that he has separated his private religious views from his professional life. Paul Root Wolpe, a sociologist at the University of Pennsylvania, states that "[Collins's] history has shown no influence of religious beliefs on his work other than a generalized sensitivity to ethics issues in genetics." Leon E. Rosenberg of Bristol-Myers Squibb, a former mentor, says that "the fact that he wears his Christianity on his sleeve is the best safeguard against any potential conflict."

Despite the general approbation, Collins is not entirely without critics. John C. Fletcher, former director of the Center for Biomedical Ethics of the University of Virginia and an

Episcopalian minister before he left the church, faults Collins for not pushing to remove the current ban on using federal funds for human embryo research. Research on early embryos could lead to better treatments for pediatric cancers, Fletcher argues.

In 1996 Collins endured what he calls "the most painful experience of my professional career." A "very impressive" graduate student of his falsified experimental results relating to leukemia that had been published in five papers with Collins and others as co-authors. After Collins confronted him with a dossier of evidence, the student made a full confession. But Collins thinks his feelings of astonishment and betrayal "will never fade."

The fraud was detected by an eagle-eyed reviewer, who noticed that some photographs of electrophoresis gels that appeared in a manuscript were copied. As a result, Collins says that when someone displays a film at a meeting, "instinctively now I am surveying it to see if there is a hint that something has been manipulated." Collins remarks that since the fraud became public, a "daunting" number of scientists have contacted him to describe similar experiences of their own.

Collins still runs his own laboratory, and he continues to press a "very sharp" policy agenda. These involvements keep him busy, but he will soon spend a month with his daughter Margaret, a physician, in a missionary hospital in Nigeria. During his last visit, almost 10 years ago, he saved a man's life in a dramatic do-or-die surgery conducted with only the most basic instruments. These expeditions, to Collins, are an expression of his faith. But they are something else as well, he adds: "It seemed like it would be a wonderful thing to do with your kid."

Terms of Engagement

Irving Weissman directs a new institute dedicated to the cloning of human embryonic stem cells. Just don't call it cloning BY SALLY LEHRMAN

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In a human biology classroom this past March, stem cell biologist Irving Weissman described his Jewish grandparents' flight to the U.S. for religious freedom. He turned to his host, William Hurlbut, a fellow Stanford University professor and member of President George W. Bush's Council on Bioethics, and accused him of attempting to tie American public policy to his own religious beliefs. A student raised his hand and asked, "But once you get rid of religion, do you have any guide other than popular opinion?"

The Hippocratic oath, answered Weissman, who graduated from Stanford's medical school. "You shall not as a doctor allow any of your personal ethical, religious, even moral concerns stand between you and care of the patient," he paraphrased. "I interpolate this to mean not only the patient you might treat but future patients that might be helped by your research."

Weissman, director of Stanford's new Institute for Cancer/Stem Cell Biology and Medicine, has relied on Hippocrates and a careful definition of terms as he navigates the controversy surrounding human embryonic stem cell research. Already known on Capitol Hill for his defense of free scientific inquiry, Weissman found himself a target for attack when he declared that the privately funded Stanford institute would explore human nuclear transplantation—commonly known as cloning.

Weissman's institute, the first of its kind at a university, will not create human clones; rather it will generate new stem cell lines for research. At first, Stanford biologists would most likely derive these from existing lines and use mouse embryos to study ways to "reprogram" transplanted nuclei so that they behave like embryonic nuclei. But a $12-million anonymous donation frees the institute to move into cloning as quickly as it likes. Private funds are also helping sizable programs at the Burnham Institute in La Jolla, Calif., and at the University of California at San Francisco to sidestep the federal funding ban on work with stem cell lines created after August 9, 2001. California has legislation that will provide additional funding.

Despite such backing, scientists here and across the country sit uncomfortably at the focal point for religious and moral qualms about the direction and power of bioscience. This past February the House passed a bill that would impose a $1-million penalty and 10 years in jail for any human embryonic cloning. Several states, including Iowa and Michigan, have enacted bans. Fearing criminalization of their work, some biologists devote a third of their time to lobbying and education. Bioethicist-physicians and the American Association for the Advancement of Science (AAAS) have begun compiling suggestions for self-regulation.

Weissman places his faith in scientists' ability to one day clearly demonstrate the technology's promise. He plans to forge ahead by hiring an expert in nuclear reprogramming. He also wants to explore the possibility of retrieving viable oocytes from oophorectomies instead of using donated eggs. Eventually the institute would combine these two initiatives. But do not consider the transfer of cell nuclei to be "cloning," Weissman insists. Moreover, he states, an "embryo" is not the result.

Weissman hopes to prod the public toward a language that steers clear of dire imagery such as cloned fetuses grown for spare parts. "Whenever we asked people, even scientists, to draw an embryo, they'd usually draw a fetus with legs, head, and so on," he explains. Referring to a National Academy of Sciences cloning panel he chaired, he adds: "Nobody drew a ball of 150 cells." Redefining the terms of the debate won't win Americans over, he thinks. But vague language contributes to a merging of stem cell research with concerns about manipulating human life. "As soon as they start using catchphrases that don't describe what's going on, it's easier for people to say we're cloning human beings," Weissman says. "You're always going to pay if you accept language that is incorrect."

Although two NAS reports press the same point, some researchers worry that Weissman's parsing may be counterproductive. Investigators have toyed with terms over the years, even floating the short-lived "clonote." But "to change the vocabulary now at this point for public consumption—it would be taken badly," remarks John Gearhart, who led the Johns Hopkins University team that isolated human pluripotent stem cells. Scientists are losing the debate, he fears: "'Cloning' is used; 'embryo' is used. Let's try to deal with that and not avoid it."

Indeed, terminology has become a touchstone for both sides. When the AAAS brought together 33 experts in early March to begin discussing a regulatory scheme, the gulf between advocates and opponents included an inability to agree on the definitions of "blastocyst," "embryo" and "viability." When Weissman announced the institute's plans last December, Leon Kass, chair of the president's bioethics council, attacked his words as "artful redefinition." He reminded Weissman that a majority of his committee (including Stanford's Hurlbut) had called for a four-year moratorium on biomedical cloning. Kass went on to chastise the university for attempting to obfuscate the nature of its work and trying to race ahead without public scrutiny.

Nigel Cameron, director of the Council for Biotechnology Policy, which is affiliated with the Christian think tank Wilberforce Forum, suggests that Weissman and others are digging in their heels because they fear a trend of regulation and resistance. Biology's rebellion against public unease, Cameron predicts, will sow distrust for decades to come. "We now have a major university willing to give its name to something many people regard as unethical science," Cameron says. "There seems to be no regard for public conscience."

The 63-year-old Weissman says it would be unethical *not* to proceed. He tells those who would halt embryonic stem cell research that they are responsible for the lives that could have been saved by future therapies. Based on his 20-plus years with stem cells—he was the first to isolate mouse blood-forming stem cells, then those of humans—he is adamant that stem cells from adults cannot evolve into a variety of tissues, as those from embryos can. Further, he points out, the existing embryonic lines came from white, well-to-do, infertile couples and so have limited genetic diversity and utility.

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The institute will not try to create stem cell lines immediately; it will initially explore the machinery that tumor cells share with stem cells. "I believe nuclear transfer for human stem cells is five years away, minimum," Weissman says. In fact, the first American university to transfer the nuclei of human cells may be U.C.S.F., which is building a $10-million graduate training program in stem cell research.

Although Weissman tells students that the potential for scientific advances must sometimes outweigh individual moral, ethical or religious beliefs, he doesn't brush aside social responsibility. At critical junctures he consults with Stanford's bioethicists—most recently, before trying to grow human neurons in mice. He hopes to study learning, memory and diseases such as schizophrenia but wants to stop short of creating a mouse with human characteristics in its brain.

Weissman thinks that reasoned debate will never be enough to settle the stem cell dispute. The general public doesn't have a desire to delve into the issue, he argues, and the Bush administration has religious reasons to remain unconvinced. Words such as "cloning" and "embryo" bolster a hidden quest to redefine human life as beginning at the moment of nuclear transfer or of fertilization, according to Weissman. This is a position that neither a scientist nor a religious person can argue, he says: "You'd have to have an assay for a human soul."