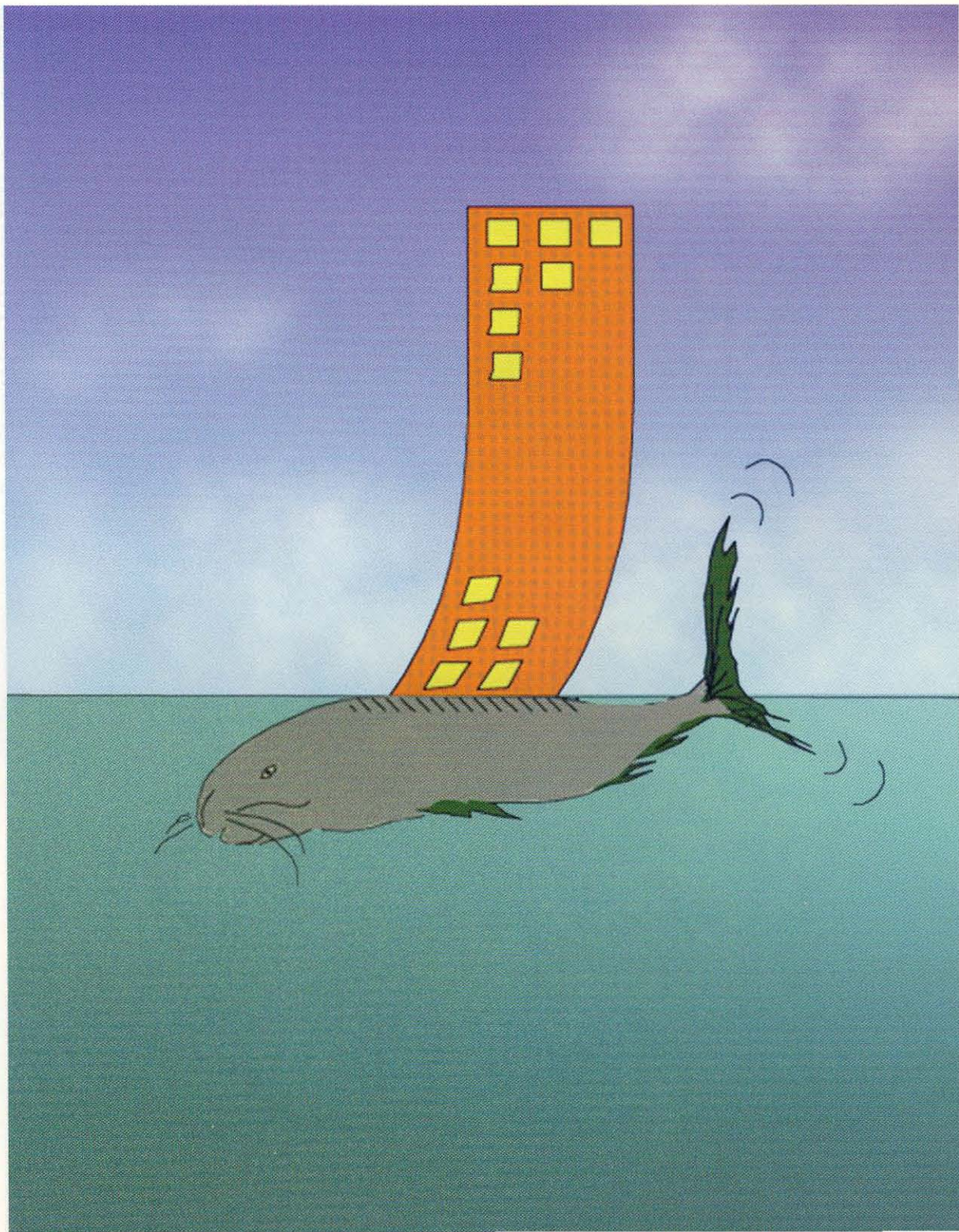
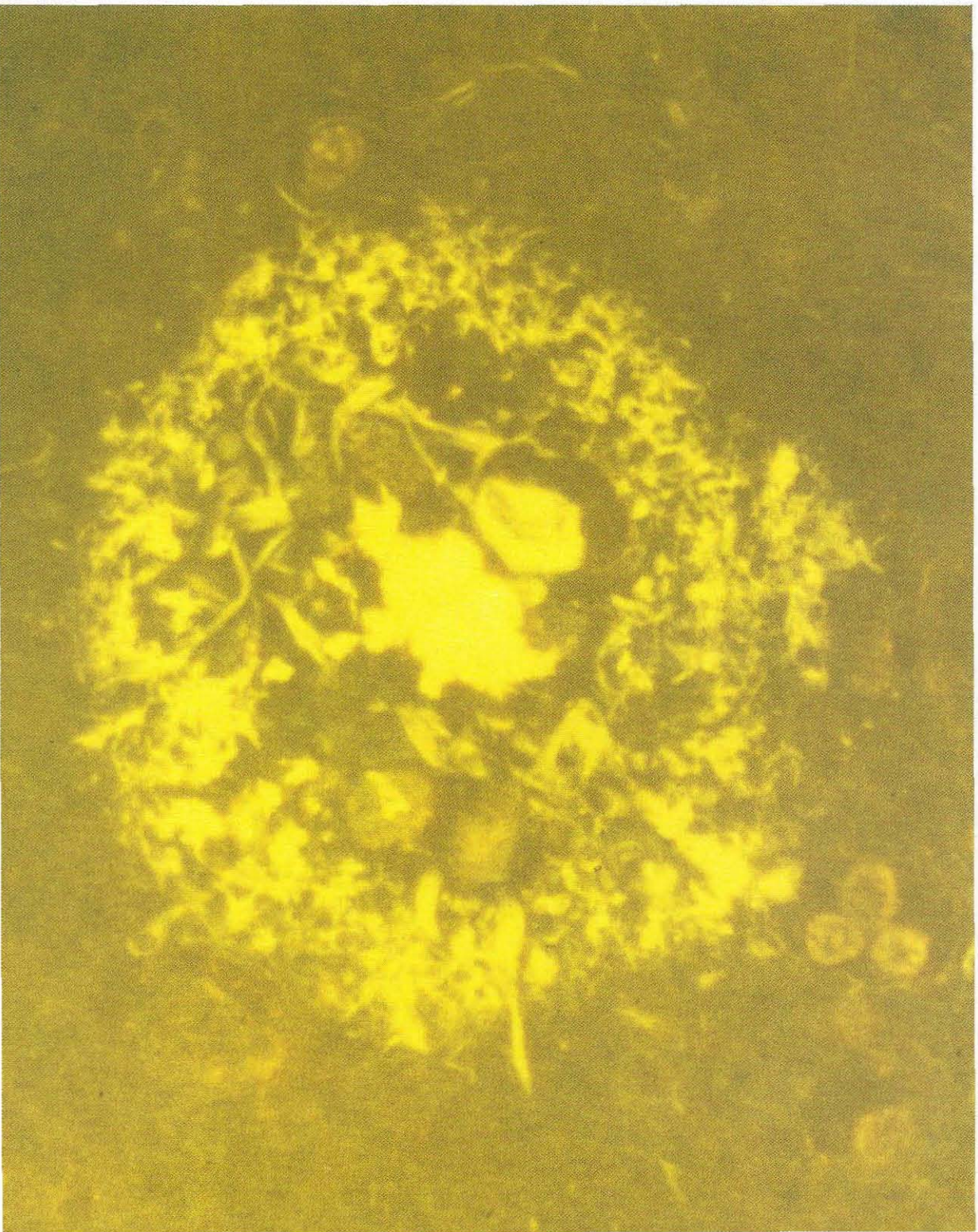
California Institute
of Technology

Engineering & Science

Summer 1995

In this issue



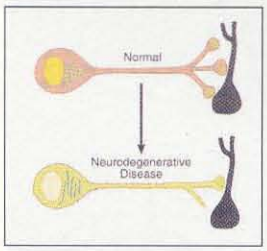


A senile plaque, prepared with a thioflavin stain that binds to amyloid proteins and degenerating neurites, taken from the brain of a patient with Alzheimer's disease. (Neurites are the tendrils that nerve cells use to connect to other nerve cells.) The deep yellow region in the center of the picture is the beta-amyloid-rich aggregate itself. The wreathlike structure surrounding it is made up of degenerating neurites. On May 31, Caltech hosted a forum in which biologists from Caltech and elsewhere described our current state of understanding of the disease and some promising lines of research into potential treatments. A distillation of their remarks begins on page 14.

California Institute of Technology

Engineering & Science

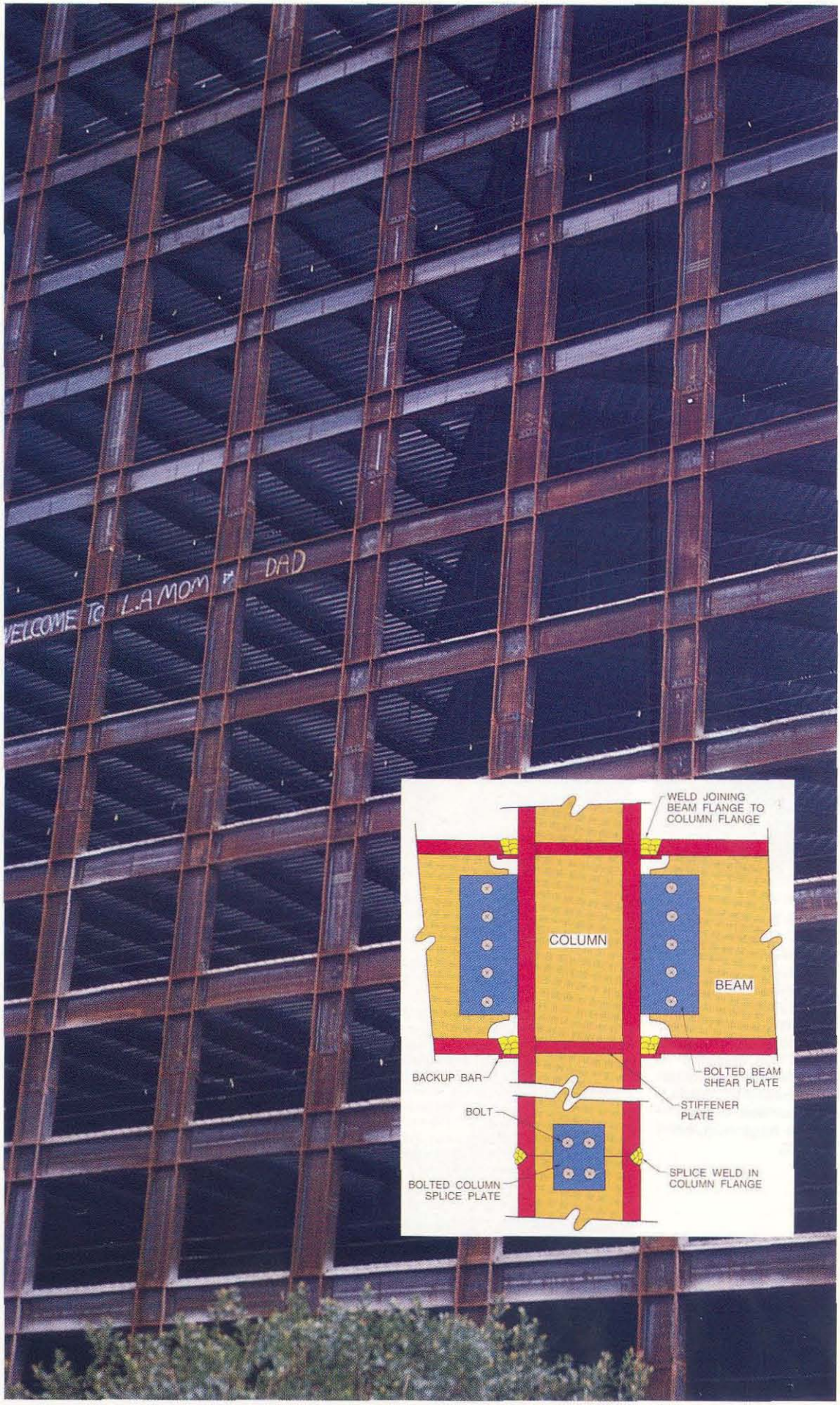
Summer 1995
Volume LVIII,
Number 4



On the cover: The ancient Japanese believed that the wriggling of a giant subterranean catfish causes earthquakes. What happened when this mythical creature shook Los Angeles' steel-frame buildings on January 17, 1994, is described in the article beginning on page 2.

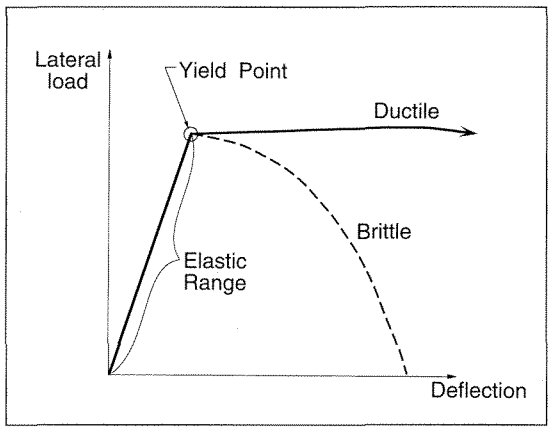
Engineering & Science (ISSN 0013-7812) is published quarterly, Fall, Winter, Spring, and Summer, at the California Institute of Technology, 1201 East California Boulevard, Pasadena, California 91125. Annual subscription $10.00 domestic; $20.00 foreign air mail; single copies $3.00. Third class postage paid at Pasadena, California. Published by the California Institute of Technology and the Alumni Association. Telephone: 818-395-3630. Postmaster: Send change of address to Caltech 1-71, Pasadena, CA 91125.

PICTURE CREDITS: Cover, 2–4, 7, 9 – Cecilia Lin; inside front cover – Robert Terry; 2, 6 – George Housner; 4 – Earthquake Engineering Research Center, UC Berkeley; 6 – 6, 7, 12 – John Hall; 8, 9 – David Wald/C. Lin; 10, 13 – Wayne Waller; 11 – Architectural Institute of Japan; 14, 26, 27 – David Anderson; 16, 17 – Caleb Finch; 18–20 – Erin Schuman; 21–22 – Robert Katzman; 22 – Corder et al.; 23–25 – Paul Patterson; 28, 32 – Norton Simon Foundation; 35 – Royal Picture Gallery; 36 – Robert Paz


WELCOME TO L.A MOM & DAD
WELD JOINING BEAM FLANGE TO COLUMN FLANGE
COLUMN
BEAM
BACKUP BAR
BOLTED BEAM SHEAR PLATE
STIFFENER PLATE
BOLT
SPLICE WELD IN COLUMN FLANGE
BOLTED COLUMN SPLICE PLATE

Tall Buildings, Bad Welds, Large Earthquakes—Big Problems

by John F. Hall



Opposite: The steel frame gives this building its strength and stiffness. (The building is actually in Pasadena, incidentally.) The inset shows the frame's construction in detail. The columns and beams—collectively known as members—are I-shaped in cross section. The web (orange) lies in the plane of the page. The perpendicular flanges (red) resist bending. The beam's web is bolted to the column (blue plates with gray bolts), and the beam's flanges are welded (yellow) to the column's flanges. The backup bars form troughs that contain the molten weld material.
Above: The larger the sideways force applied to a building, the farther it moves, as shown in this load-deflection curve. If the force is less than the yield point, the building will spring back elastically. At larger loads, something gives—either ductilely, in which case the members yield but don't break, or brittlely, in which case they crack.

I'll start by being up front with you: last night I spent most of the evening trying to glue my glasses back together, so you might say I'm not too hot on metal structures at the moment. Having gotten that off my chest, let me begin by giving you a brief introduction to earthquake engineering. In a steel-frame building, the frame supports not only the weight of the building—a vertical load—but also withstands lateral loads from winds and earthquakes. These lateral loads cause the frame members to bend, and the engineering term for the action that causes bending is "moment." Hence these frames are called *moment frames*, or *moment-resisting frames*. The frame consists of vertical columns and horizontal beams, and in order to transfer the bending moments between these members, we need to have very strong connections—usually made with welds.

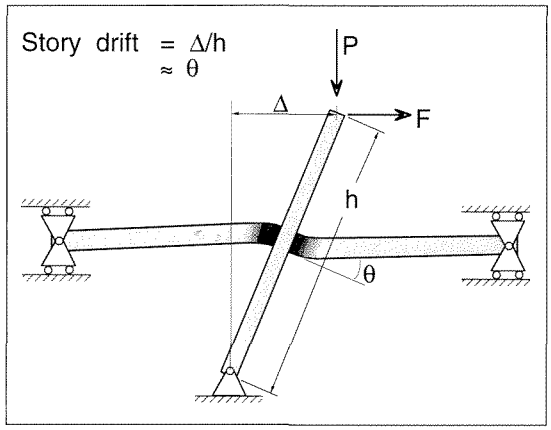
Now, if you apply a lateral force to a building, it will displace sideways in response. Engineers plot this behavior in a load-deflection curve, such as the one above. In the curve's elastic range, from zero load up to the elastic limit, or yield point, you can apply a load on and off and the building always springs back to its original position—it behaves elastically. At loads above the yield point, the building no longer behaves elastically. The postelastic behavior can be ductile, which means that the members deform—they stretch like chewing gum—but maintain the strength of the building. Or, like my glasses, the behavior can be brittle—as the deflection increases, there's a loss of strength as something snaps. Whenever possible, it's best to design structures to have enough strength to carry their loads in the elastic range to avoid the damage associated with yielding. (For example, airplanes are designed to behave elastically while airborne.)

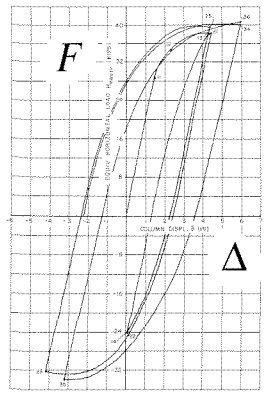
Wind is one lateral load to be considered when designing a building. The wind exerts a sideways pressure on the building, and engineers understand this force pretty well. They treat wind as a constant pressure, and even though the pressure is significant, it's possible and economical to design the building to withstand it in the elastic range. This is fortunate, because if a windstorm came up strong enough to make the building yield, the steady pressure would actually push it over.

An earthquake, like the wind, causes a building to deflect sideways. But unlike the wind, an earthquake is a back-and-forth action. It reminded the ancient Japanese of how a landed fish wiggles, so in their legends, a giant catfish causes earthquakes. This giant catfish can make the ground move pretty violently, and so earthquake loads are larger than wind loads—in fact, it's not economically possible to design a building to respond elastically to a strong earthquake. That means the building is going to yield. How can we get away with that? How can we be sure that the building won't collapse when it yields in a strong earthquake? The answer has to do with the back-and-forth nature of the ground motion. Say the ground moves to the left, causing the building to start to yield to the right. Then, before the building has time to collapse, the ground moves back to the right and gets under the building again, and so on. You can actually try this at home—walk up behind somebody, give him a shove, and before he falls on his face,

Right: Since shaking an entire building on demand is impractial, engineers use a mock-up of a single beam-to-column joint, plus the adjoining halves of the members surrounding it, as a proxy. The column's base is fixed to a pivot and the beam ends are on sliders, closely reproducing the conditions this subassmebly would feel in a building during a quake. Two loads are applied to the top of the column—a vertical load, P, which represents the building's weight, and the back-and-forth horizontal earthquake force, F. The story drift is determined by dividing the resulting deflection, Δ, by the story height, h. The columns are stronger than the beams, so once the elastic limit is exceeded, the beam kinks where it joins the column; this kink angle (θ) is approximately the story drift.

Far right: A typical force-deflection curve from such an experiment. As in the idealized curve on the previous page, the force (F) is plotted vertically and deflection (Δ) horizontally. But here the force is appiled back and forth, over and over again.





run around to the front and push him back.

This explanation's not quite good enough for engineers, without some calculations to verify that it's possible. So back in the 1960s and 1970s, engineers invented computerized methods to calculate the responses of buildings to earthquakes. These mathematical models were pretty simple, and assumed that the buildings would behave in a ductile manner. The engineers used the ground-motion records that were available at the time, and were thought to be representative of strong ground shaking, for the inputs. This led to two conclusions.

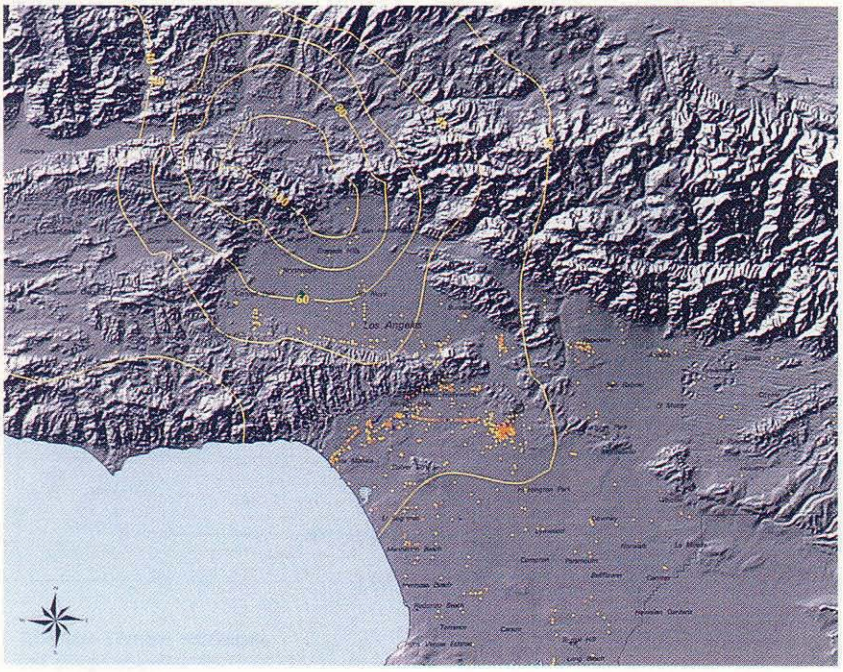
For one, if the building has to yield, it's much better to have the yielding occur in the beams than in the columns. So the engineers started making the columns stronger than the beams. The yielding then showed up as kinks—like in a wire that's been bent too hard—at the ends of the beams where the bending moments are highest. This was good, because the columns held and the building stayed up. The computer programs could also predict the amount of yielding in the structure. I'll quantify that for our purposes by something called "story drift," which is the sideways movement in a story divided by its height from ceiling to ceiling.

This led to the second finding—the engineers calculated that a reasonable story drift for the earthquakes they were using was about 1.5 percent, or a lateral deflection of two inches per 10-foot story. (A building begins to yield at about 0.4 percent, so most of this story drift actually occurs in the yield range.) So they then had to determine whether the actual materials used in a building—the steel beams and columns—could take this kind of drift without losing strength after yielding. In other words, did the members have sufficient ductility?

The only way to determine something like that is in the laboratory, and the easiest method is to build a small piece of the building and apply forces to it to reproduce what it would feel if it were a part of the building during a strong earthquake. Then we measure the story deflection, and the story drift is determined by dividing that number by the story height.

Above is an actual force-deflection curve from such a setup, taken from a report written back in the early 1970s. The curve's bending toward the horizontal is due to the yielding. You can see that the assemblage yields in first one direction, then the other, but you don't see much degradation in strength as the cycles continue. That's very good. That's ductility—the strength is being maintained as the material yields. And if we convert the deflections from this test into story drifts, we get about 4 percent, which is greater than the needed 1.5 percent. So things looked pretty good—the engineers considered their designs to be validated, and the building code was written accordingly. It's important to note that the code is essentially a life-safety document, whose goal is to preserve lives by avoiding building collapses. The code is not intended to prevent damage to buildings.

Now, in the Northridge earthquake, the engineers got a terrible shock of their own—the welded connections in many steel buildings fractured. The fact that the welds failed means



The contours on this map of the L.A. area show peak ground velocities during the Northridge earthquake in centimeters per second. (The green triangle marks the quake's epicenter.) The dots show the locations of steel-frame buildings, as gleaned from the county assessor's records. Red dots are high-rises (six stories or taller), yellow dots are one- to five-story structures, and blue dots are buildings whose height was not recorded. Map prepared by the California Office of Emergency Services.

Many welds failed well within their elastic range. Because they never reached yield, the designed strength of those members was never achieved.

that these buildings are not as ductile as we thought—they're more on the brittle side. (Remember that ductility is the foundation of our design philosophy.) Furthermore, many welds failed well within their elastic range. Because they never reached yield, the designed strength of those members was never achieved. Now, one optimistic point of view says that since the code is a life-safety document, and since Northridge was a pretty good shake and none of the steel buildings fell down, the code was a success. Sure, we had some damage, but the code really doesn't try to prevent damage. This view is actually still held by some engineers, but you can make a couple of points against it.

First, the buildings really didn't get shaken all that hard. In the map above, the dots represent steel buildings, and the contours are the peak ground velocities in the Northridge earthquake. (Peak ground velocity is probably the best single parameter for gauging the damage potential of an earthquake, because even a large acceleration, if applied for a short duration, may not be sufficient to get the building to move.) The map shows that the most damaging ground motions occurred in the Santa Susana Mountains to the north, where there are very few steel buildings—or other buildings, for that matter. So most of the steel buildings got only moderate shaking.

Which leads to the second point: the way in which the code represents an earthquake is deficient. We soon realized that, even for this moderate earthquake, the ground motions and attendant high ground velocities to the north of the epicenter were larger than anticipated by the building code. The records that the engineers used to validate their design procedures back in the 1960s and 1970s didn't show any such velocities. It can be seen in retrospect that California simply wasn't densely instrumented enough back then to catch them. Most of the earthquakes the engineers used, such as the 1940 El Centro (magnitude 6.9) and the 1952 Kern County (7.5), occurred in rural areas where there weren't many strong-motion sensors. The 1971 San Fernando earthquake (6.7), which shook urban Los Angeles, did in fact register a ground velocity of 113 centimeters (about four feet) per second at nearby Pacoima Dam. But this sensor was atop a steep ridge, which was blamed for the strong motions, and so this velocity was discounted as being inapplicable to what a building in the flatlands might feel.

In summary, then, the building code is supposed to be written for larger earthquakes than Northridge, yet the code didn't anticipate the ground motions felt even in this moderate quake. Furthermore, the welds failed in buildings that didn't get the strongest shaking that Northridge had to offer. What does this tell us about what's going to happen in larger earthquakes? I'll come back to that, but first let's take a closer look at what did happen in the Northridge quake.

Most of the steel buildings that were shaken in the Northridge earthquake look fine from the outside. (Remember that no steel buildings collapsed, although other, weaker structures did.) But if you go inside, and uncover some of the beam-to-column connections (which is a lot of

Right: Exposing the beam-to-column connections so engineers can inspect them means cutting through drywall, stripping away insulation, and sometimes dealing with asbestos.

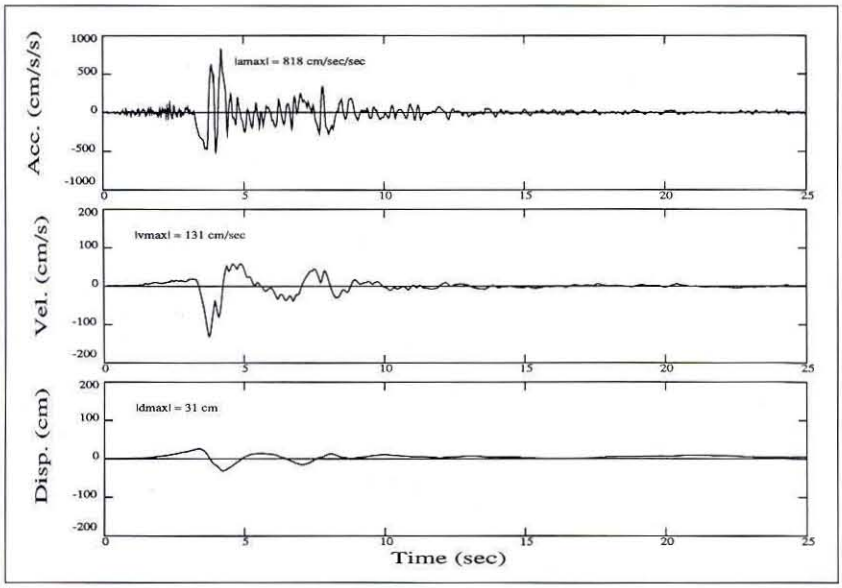
In some cases, more than 50 percent of the welded connections are broken; in a few buildings, nearly every connection has given way.

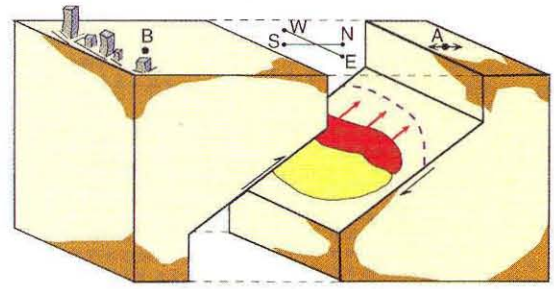
Below: This beam's lower flange is completely severed where it joins the column. The earthquake also sheared off some of the original connecting bolts—these are replacements. Practically all of the welded joints in this building had something similar happen.

work, by the way), you'll see things like the photo at left. The flanges, which carry most of the bending moment, are cracked clear through at the welds. The cracks sometimes extend into the web of the beam or column, and, very occasionally, the member is torn in two. We know that this problem exists in about 100 or so buildings. In some cases, more than 50 percent of the welded connections are broken; in a few buildings, nearly every connection has given way. And there are perhaps another 200 suspect buildings that we haven't really looked at yet.

Why did this happen? Remember that we confine the building's yielding to the beams, causing them to kink at their ends, which is exactly where the welds are. So the welds were highly stressed, and they didn't hold up. Why not? There are at least four reasons. First of all, quality control, to put it bluntly, is often not very good as these buildings are built. There simply aren't enough building inspectors for the volume of construction, and some contractors just aren't well-educated in the importance of following the code—they either don't have the specs on hand at the job site, or they don't follow them. And buildings aren't like airplanes, which provide a good reading really quickly the first time a test pilot takes one up. A badly built building can stand for quite a while before its weaknesses are revealed in an earthquake. So the welds that fractured probably had lots of small defects to begin with. Second, the material used for the welds is not very fracture-resistant. No one was expecting brittle fracture to be a problem, so why pay more for fracture-resistant material when the need is not apparent? Third, there was little or no heat treating done during the welding, which means that the welds cooled very fast, and that tends to embrittle them. The more slowly a weld cools—if you put an electrically heated blanket on it, for example—the more ductile it will be. And finally, the backup bar—which helps retain the molten material as the weld cools—often didn't fuse completely with the column. That gap between the bar and the column often became the notch where the crack started.

One might reasonably ask why the laboratory tests didn't pick this kind of thing up. There are multiple reasons here, too. For one, the tests were generally done at small scales—say, one-third scale—and at slow loading rates, because there wasn't enough money to buy the large equipment and fast actuators necessary to give full-sized connection specimens the shaking they would really feel in an actual earthquake. Also, the quality control on the laboratory welds that the researchers made was probably a lot better than it is at the construction site. These factors worked together to make the test results better than, and not a fair indication of, what might happen in the field. However, if you go back through the old laboratory reports, you do find a fair number of premature fractures caused by the weld-fracture problem, even in those small-scale specimens. The researchers, when asked about this after Northridge, said, "Well, it's all in the reports," and the engineers replied, "We don't have time to read your reports. Why didn't you yell and scream about it?" And so it goes. It's human nature.





Above: These horizontal displacements, velocities, and accelerations (bottom, middle, and top traces, respectively) were recorded near the Olive View Hospital in Sylmar during the Northridge quake. |dmax| stands for peak displacement, |vmax| is peak velocity, and |amax| is peak acceleration.

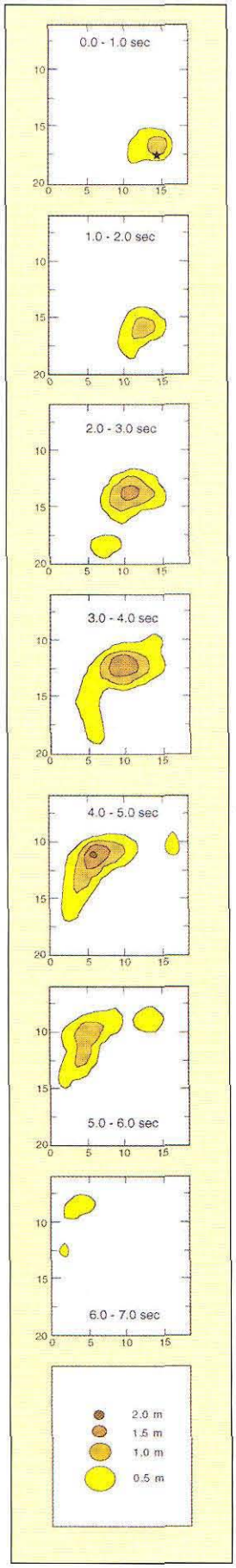
Right: The slip-pulse mechanism tends to focus an earthquake's energy. In the Northridge quake, a south-dipping thrust fault (a fault where one side overrides the other instead of slipping by sideways) ruptured at its base. The slip pulse propagated upward and to the north. At the instant of the sketch, the slip pulse is rupturing the red region and is moving up-fault (red arrows). The yellow region has finished slipping. The slip pulse feeds energy into the shear wave traveling ahead (dashed purple line), which will eventually reach the surface near point A. Thus the region to the north experienced more damaging ground motions than did the built-up area to the south, or even the epicenter (point B).

The Federal Emergency Management Agency is now funding a research program to try to find a solution. Phase I, which I was involved in, is just wrapping up, and Phase II is about to start. The first thing the task force did was investigate the scale effect by testing more nearly full-sized connections in the higher-capacity rigs that are now available. And although the task force improved quality control—they used better weld material, ground off the backup bar, and did heat treatments—the cracks appeared, so it seems that our fundamental design was bad. So we're now trying to reduce the stress the welds must carry by welding cover plates over the joints. The cover plates strengthen the connection of the beam to the column, forcing the yielding out into the beam where there's no weld to break. This method has had some successes, although there are still problems that we hope Phase II will solve. I might add that the solution, when one is found, is liable to be pretty expensive.

In the meantime, some of the buildings damaged in the Northridge earthquake still sit vacant, waiting for a solution to emerge. Others have been torn down. But the majority of building owners can't afford to let their real estate sit idle indefinitely, and are fixing their buildings one way or another. In the absence of a definitive solution, the city of Los Angeles has issued its own guidelines for building rehabilitation, essentially saying, "If you take these suggested actions we'll approve your plans expeditiously now, so that you can put your building back in use, but we may require you to do more things later on."

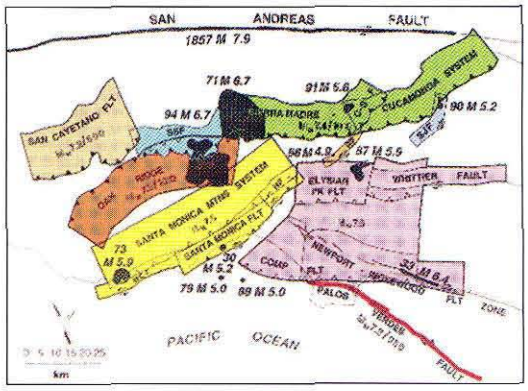
Now let's turn to the ground-motion side of the equation. Above is a record of the ground motion felt in Sylmar during the Northridge earthquake, in a region of strong shaking to the northeast of the epicenter. It shows pretty high accelerations, which are a concern, but I want to focus on the rapid displacement—a roughly 60-centimeter (about two feet) peak-to-trough pulse that happened in less than a second. That kind of motion has a very high damage potential, and it simply wasn't present in the old ground-motion records that the engineers used when they were validating the design procedures.

These large, rapid displacements are what seismologists call "near-source directivity effects"—a very important idea that I want to discuss in some depth. Over the last decade, Professor of Engineering Seismology Tom Heaton (PhD '78) and his colleagues at the U.S. Geological Survey (USGS) and Caltech have discovered some very interesting things about how a rupture proceeds on a fault—namely that, at any given instant, only a small part of the fault is involved in the slip. The slip actually takes place in a pulse that propagates along the fault, as shown above, and the amount of slip within this pulse is quite large. Now, the fault's slip produces shear waves that travel out in all directions. Since the slip pulse travels at a slightly lower speed than the shear wave (a fact also discovered by Heaton, et al.), each successive bit of fault slip contributes more energy to the part of the shear wave being sent out ahead of the rupture, building the wave up to a very large amplitude. So, in general, the largest ground motions are going to be observed in areas toward which the fault is rupturing.



Left, top to bottom: The Northridge quake in one-second intervals, as seen from a vantage point above and perpendicular to the fault plane. The axes are marked in kilometers. The star in the first panel plots the earthquake's hypocenter, or point of origin. From there, the slip pulse travels northward and toward the surface. The darker the color, the larger the slip in meters during that interval, as shown in the bottom panel.

Right: The colored zones are L.A.'s main thrust faults. The sawtooth lines mark the faults' upper edges; those that reach the surface have black teeth. The black blobs represent earthquakes this century (labeled with their year and magnitude). The figures in SHADOWED TYPE show the size earthquake that could happen if an entire fault broke at once, and the recurrance interval in years for that quake. Abbreviated fault names: SSF= Santa Susana, MCF= Malibu Coast, HF= Hollywood, RF= Raymond, C-SF= Clamshell-Sawpit, SJF= San José, COMP= Compton.



But the fault slip is deep underground—how do the seismologists know what's going on down there? They solved what's called an inversion problem. They took strong ground-motion data and geodetic data—surveyor's measurements of surface displacements caused by the earthquake—and back-calculated what must have happened down there in order to give the observed motions up here. Heaton and Dave Wald (PhD '93) of the USGS developed a lot of the methodology used in those calculations, and also generated the set of images at left, which show the Northridge earthquake from start to finish at one-second intervals. The slip pulse's passage along the fault is clearly visible.

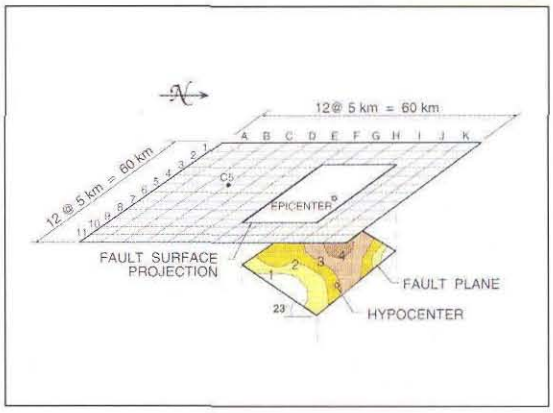
As I said, the Northridge earthquake was only a magnitude 6.7, yet it created stronger ground motions than are represented in the code. But we have even larger earthquakes in California. The San Andreas and the Hayward faults, which are capable of generating large earthquakes, pass close to some of our major cities, which means that we can have very strong near-source effects within our metropolitan areas. This is of real concern. What about Los Angeles?

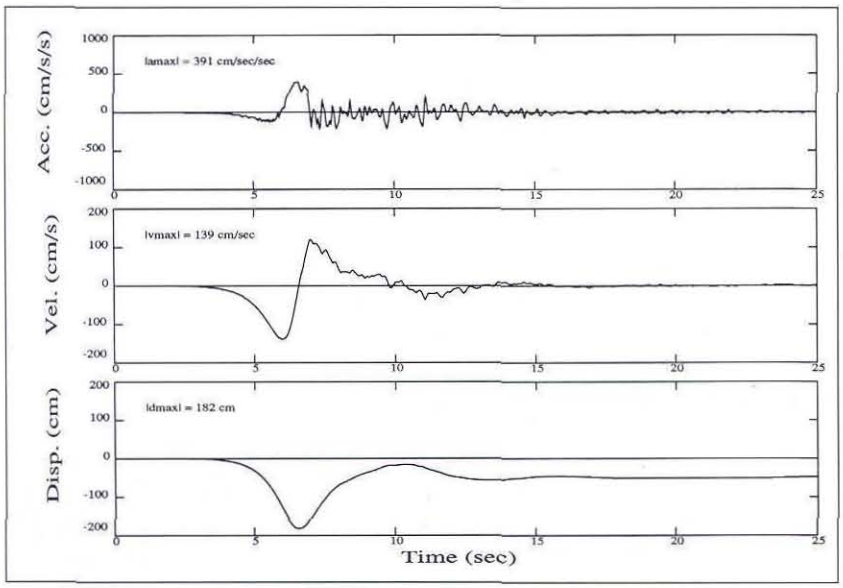
You may be surprised to learn that in the 1920s, the seismic threat to L.A. was quite a lively topic. Robert Hill, a well-known geologist at the time, wrote a book on the subject. He was so proud of his conclusion that he put it on the cover: "This book completely refutes the prediction... that Los Angeles is about to be destroyed by earthquakes. It proves that this area is not only free from the probability of severe seismic disturbances, but has the least to fear from Acts of God of any city under the American flag." I won't talk about the fires and floods we've had of late, but I can say something about earthquakes in the Los Angeles region.

Measurements by many people, among them Ken Hudnut (a Caltech postdoc now at the USGS) and Andrea Donnellan (MS '88, PhD '92) of Caltech's Jet Propulsion Laboratory, have documented a north-south compression of the Los Angeles region by about one centimeter per year, which is thought to arise from the bend in the San Andreas fault to the city's north. Last January, eight geologists associated with the Southern California Earthquake Center, including Jim Dolan (a Caltech postdoc now at USC), and Caltech Professor of Geology Kerry Sieh as lead authors, published a paper that assumed that this compression is accommodated by the system of thrust faults shown in the map above, and calculated how these faults could plausibly release the accumulated pressure, based on their known slip rates and other data. Now we don't know whether this stress is relieved in a few large earthquakes, or a lot of smaller ones, or some mix in between, but this compression by itself is enough to give us one magnitude-7.3 shaking about every 150 years. In the last 200 years, we've only had two magnitude 6.7s, Northridge and the San Fernando earthquake of 1971, so this seems to indicate that there are going to be some large earthquakes sooner or later, and that one such quake might be overdue.

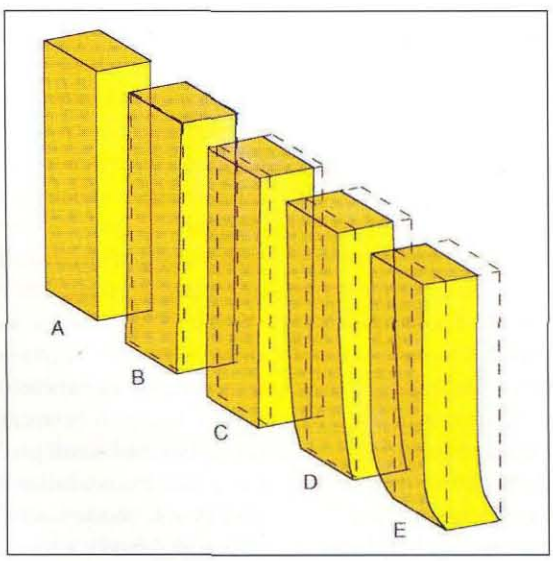
What might this quake do to L.A.'s steel buildings? For the sake of discussion, I'm going to consider a magnitude-7.0 earthquake on the

The hypothetical magnitude-7 earthquake on the Elysian Park fault (right) starts 15 kilometers below the surface and has a peak slip of four meters, as shown by the colored contours. In the grid of observing stations at the ground's surface, the letter indicates north-south location, and the number is east-west position. The ground motions predicted at grid point C5 (below) are plotted to the same scale as the Sylmar ground motions on page 5.





Right: As an earthquake kicks the ground out from under a building (A through C), the lower stories are dragged along while inertia briefly keeps the upper stories at rest. Then by the time the upper stories respond to the initial outward motion, the ground is bringing the lower ones back in, and the two parts of the building are moving in different directions at once (D and E).



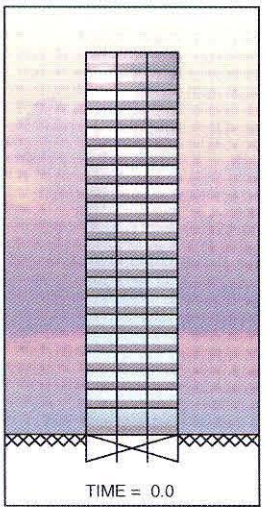
Elysian Park thrust ramp (part of the purple region on the map), which dips to the north and passes directly beneath downtown Los Angeles. Considering that our recent 6.7 was on a blind thrust fault, and that the magnitude-7.5 Kern County quake of 1952 occurred in a similar tectonic setting, this seems pretty plausible.

How do we know how the ground is going to move in a future earthquake, like our hypothetical magnitude 7.0? Well, the seismologists come through again. I've mentioned the inverse problem; this is the forward problem. Through their inverse studies, seismologists have developed a pretty good idea of how ground rupture takes place, so they can impose a reasonable fault-rupture scenario on a mathematical model of a chunk of the earth. From this they can compute the ground motion anywhere, including on the surface. For this hypothetical magnitude 7.0, which Tom and Dave ran for me, the most damaging ground motions occur to the south, in the area toward which the rupture is propagating. In this region, say at location C5, the peak acceleration isn't so big, because we're some distance from the fault. But look at the peak displacement—182 centimeters is about six feet, and this fault doesn't even break the surface! And the accompanying velocity is 139 centimeters per second—about four and a half feet per second—which is a pretty good leap for a piece of solid ground. Needless to say, this is very worrisome.

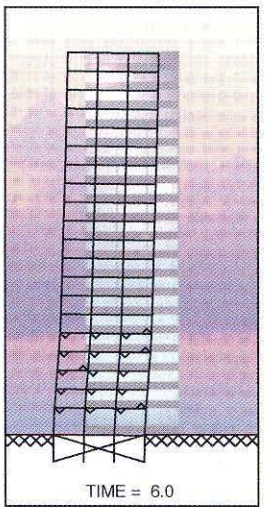
Let's consider how a building could be affected by this leap, which is actually a double leap—out and back. In other words, the moving ground carries the base of the building out with it and then brings it back. The outward movement gets the building going forward at a high velocity; then the ground doubles back (and the lower stories with it), putting the building under enormous stress. Even if the building can arrest its forward motion, it's liable to experience severe deformations in the lower part of its structure. If the welds are popping on top of this, it's going to have a very hard time stopping, greatly increasing the likelihood of collapse.

Now it's time for some engineering analyses. I fed the ground motions—the Sylmar one from the Northridge earthquake and the C5 one from the simulated magnitude 7.0—into a computer model of how a steel-frame building behaves when shaken. This model is a more sophisticated descendant of the ones that the engineers were using back in the 1970s. One improvement is that this program is able to approximately represent weld fracture. But weld fracture is only one of the ways in which a building can lose strength and stiffness. Another way is that, when a beam

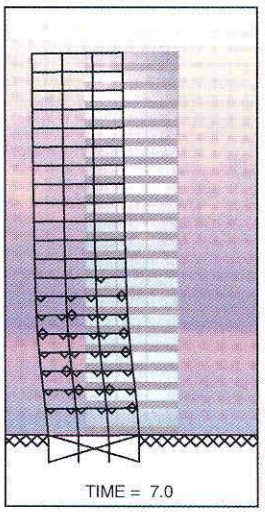
The 20-story building before the C5 ground motion hits. The displacement pulse will be toward the left.



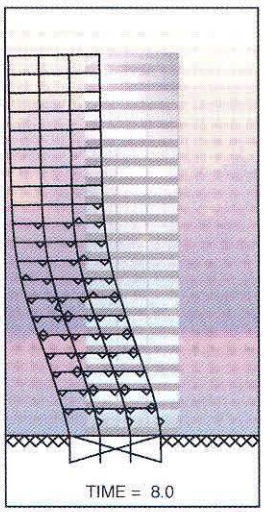
At t=6 seconds, the ground is approaching its maximum horizontal displacement of 182 centimeters.



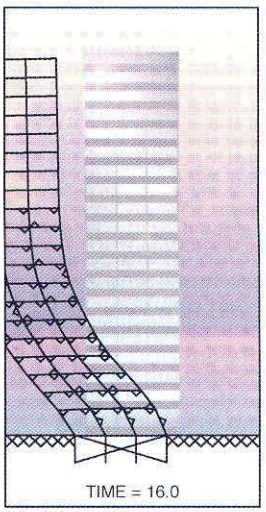
At t=7 seconds, the ground is returning to its original position, causing the building to "crack the whip."



This flexure creates a ripple of breaking welds that travels up the building.



By t=16 seconds, the building is hopelessly overbalanced and on its way to oblivion.



kinks, the flange that's in compression can buckle. Flange buckling can be a very significant type of deterioration, but it's extremely hard to model and my program isn't smart enough to do it. And the base plates, which secure columns to their foundations, can fail; concrete slabs can crack; beams can buckle in torsion; the list goes on and on... So sometimes the program computes very large story drifts, and I'd have to think that if it had included more deterioration mechanisms, the building would have collapsed. We should interpret these large story drifts as actual collapses, even though the output doesn't explicitly say so. The table at left shows the peak story drifts computed for a six-story and a 20-story structure subjected to our two ground motions.

	Sylmar	C5
6-story	3.0	12.4
20-story	2.0	*

Above: Peak story drifts (shown as percentages) calculated for a six-story and a twenty-story steel frame building subjected to the Sylmar and C5 ground motions. The asterisk indicates a collapse predicted by the computer.

The Sylmar numbers are pretty good news. Story drifts of 2 and 3 percent are not unreasonable, especially considering the ground motion's strength and the weld-fracture problem. So even if we'd had more steel-framed buildings hit with near-source directivity effects as measured in Sylmar, we probably shouldn't have seen any collapses. However, the Sylmar record doesn't represent the Northridge earthquake's strongest motion—it's just one of the strongest ones that happened to get recorded. The most damaging ground motions occurred in the mountains north of the San Fernando Valley, and might have caused problems had there been buildings up there to feel them. This is now being studied.

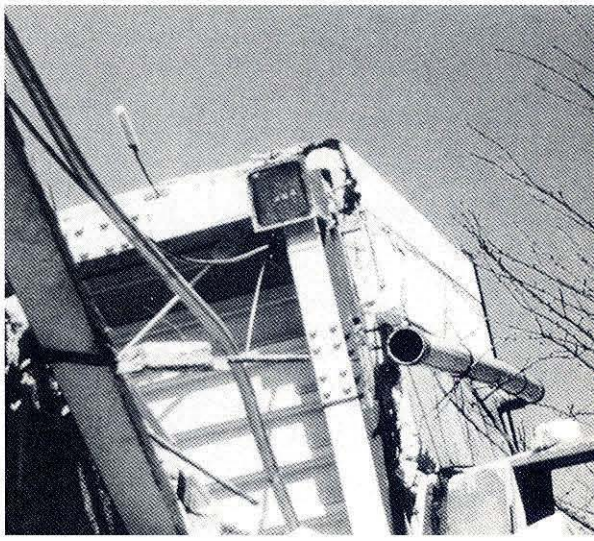
The C5 ground motion is another story. The six-story building has a 12 percent story drift, which is one of those numbers that we have to interpret as a collapse, and the 20-story building collapses outright. The sequences of images across the top of this page are from a computer-animated movie that Wayne Waller of Caltech's Media Integration Lab made from the data generated by my 20-story building model and the C5 ground motion. All of the displacements in these graphics have been amplified by a factor of five for clarity, and the little triangles denote fractured welds. The sequence ends with the building clearly headed for collapse. (Convergence problems in the computer code prevent the model from following the building all the way down.)

So—now that I've shown you these things, here's the big question: Are our steel buildings, which we thought were our most earthquake-resistant type of structure, liable to collapse? We've seen that they're going to behave brittlely during earthquakes, not ductilely as we expected. Also, we can get near-source ground motions from large earthquakes that are considerably stronger than the building code provides for. Furthermore, large earthquakes have duration effects that are not anticipated properly. A magnitude 7.5 can give you 30 seconds of strong shaking, instead of the seven or eight seconds felt in the cases I've shown here, and deterioration is a function of duration. So I think that when we consider these things, we have to admit the possibility that some of our steel buildings will collapse. In Japan, where they build stronger buildings with much better quality control than we do here, they had some problems in the Kobe quake. I've heard from a reliable source that about 30 low-rise modern steel buildings collapsed, although I haven't been able to confirm that.

What about the *real* high-rises? I only looked at a 20-story building; what about the skyscrapers? It turns out that they are actually probably safer, for various reasons. They're relatively stronger than the mid-rise and shorter buildings, because they're designed to carry larger loads—higher wind loading on their bigger surface areas, and, of course, their own heavier weights. Also, skyscrapers like to vibrate back and forth very, very slowly—their natural resonant frequencies are quite low—and only a very large earthquake would have enough low-frequency motion to really grab hold of them and make them move. However, the geologists aren't ruling out such an earthquake, and our experience with Northridge tells us that we have to assume that the welds in these buildings are deficient. So that's something that deserves more study.

By now, if you work in a steel building, you're probably starting to wonder about your chances. Life is full of risks, and there are ways to quantify them. (I think it's something we should do more of.) Let's be blunt—what are the chances of getting killed by a steel building if you work in one? Here's how to figure it out. First, you ask a seismologist what the probability of a large earthquake is, and what the probability is that your building will be in the near-source region, and you multiply those numbers together. Then you ask an engineering researcher what the probability is that your building will collapse. I don't know what answer you'll get, but it may be a fairly modest percentage—not every building is going to collapse. Multiply again, and then you multiply that figure by the fraction of your time that you actually spend in the building. If you work there eight hours a day, five days a week, then you only spend about 23 percent of your time there. (This has been a saving grace for many earthquakes—they hit any hour of the day, any day of the week with equal probability, so the odds are good that you won't be in the building when the time comes.) You can reduce your calculated risk still further because most buildings don't pancake when they fail. Usually, only a few floors collapse—we saw that a lot in Kobe. So you want to also consider the odds that you're going to be on one of those floors. If you work all of that out, you may find a number you can live with, especially if you compare it to some other numbers—the probability of being hit and killed by a drunk driver, for example. It's important to keep these things in perspective.

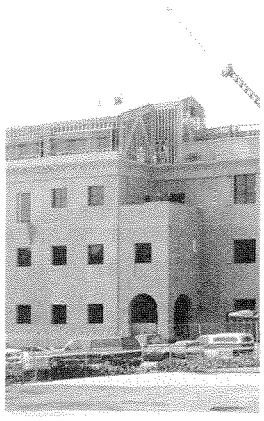
But there's more to an earthquake's toll than lives lost—there's property damage. The Northridge quake cost us about $20 billion at last count; direct property damage from the Kobe quake is currently about $100 billion. An Elysian Park earthquake under downtown Los Angeles would easily cost as much as Kobe. Can our economy take a $100-billion hit? When people were coming up with the building code's philosophy 30 years ago, we weren't having many earthquakes. Therefore it seemed reasonable to design minimal buildings that were just strong enough to avoid collapse (or so they thought), and it wasn't economical to worry about damage control. Today we have a much better idea of the earthquake threat, and things look more ominous. I'd be willing to bet that if it were possible to do a proper economic analysis, it would now make much more sense to design stronger buildings to limit damage. And, of course, stronger buildings would also save more lives.



Steel columns in Japanese buildings are not I-shaped but square in cross section. In the Kobe quake, some columns snapped (below), toppling buildings (right). In this picture of the underside of an upper story, you can see the hollow square of the column that used to support the corner of the building.

For many years now, new buildings on the Caltech campus have been designed by increasing the code forces by 50 percent. This is just smart business practice: we sit on top of the Raymond fault; the Sierra Madre fault is just a few miles away; we're self-insured. I think that such designs will become more common as more people, including the code writers and the government, realize the benefits of damage control. The Moore Laboratory of Engineering, currently under construction, is a very strong building with reinforced concrete walls. That's a good design choice for earthquake country, but what's particularly relevant to our discussion of steel frames is the penthouse. We used bolted flange connections there, even though welding is cheaper, as we just weren't comfortable with the defect potential of the welds. Bolted connections,

Above: This unreinforced masonry building in downtown Coalinga collapsed in the 1983 earthquake. Many California cities still have large stocks of such buildings, and no retrofit programs.



Above: The Gordon and Betty Moore Laboratory of Engineering, currently under construction, has a steel-frame penthouse with fully bolted connections.

however, should behave like perfect, defect-free welded ones.

Now, finally, in an effort to make you feel a little better about steel buildings, and to again put things in perspective, let me remind you that there are a lot worse things out there. Unreinforced masonry—seen in buildings predating the 1933 Long Beach earthquake—is one, as has been demonstrated many times, such as in the 1983 Coalinga quake. Several cities, including Long Beach and the city of Los Angeles itself, have tried to address this problem by requiring the owners of such buildings to do nominal retrofits, such as tying the masonry walls to the floors so that the walls don't pull away and come crashing down. (This is the simplest thing you can do to get obvious benefits. It will avert collapse in medium-sized earthquakes, but it probably won't be enough in large ones. You're reinforcing the weakest point, which means that the failure is just transferred to the next weakest point. This is a general problem with retrofits.) Many other cities haven't done anything yet. Unreinforced masonry buildings remain a real problem, much worse than the steel-building situation.

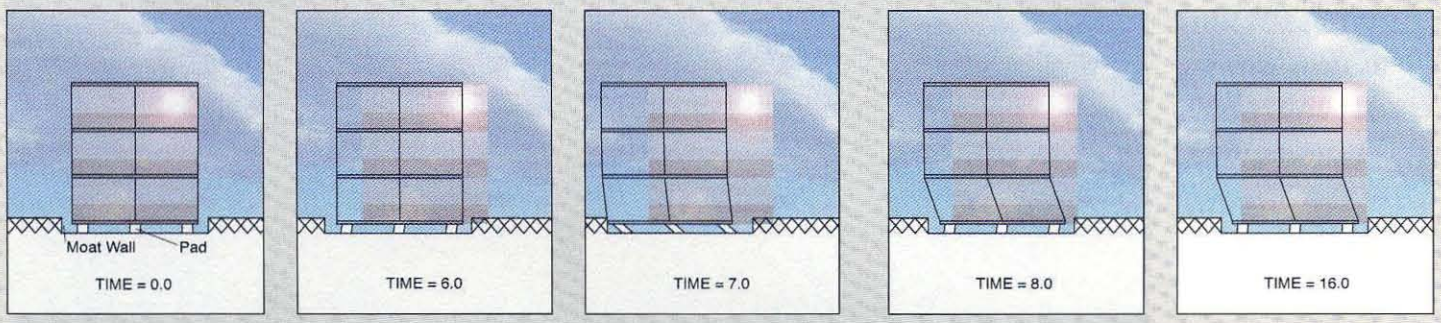
Reinforced-concrete-frame structures built before the early 1970s are also very hazardous during earthquakes. They're very brittle, and the things that seem to go first are the columns, which are bad parts of your building to have fail. (I know an engineer who uses the term "ductilely challenged" to refer to this type of construction.) No cities have yet taken action to address their inventories of these nonductile concrete buildings. Two- and three-story wood-frame apartment buildings with an open first story given over to parking are another problem, as we've seen in Northridge; in general, the damage to multistory, multifamily wood-frame buildings was greater than expected. Again, most of these buildings were built before modern codes. (Even something as seemingly minor as using a smaller-diameter nail than the code calls for can make a significant difference in a structure's strength.) The most infamous example, of course, is the Northridge Meadows Apartments, whose collapse killed 16 people. Even some types of modern structures, namely precast concrete parking garages, are known to be collapse hazards—we lost seven of them in the Northridge earthquake.

It has become traditional, in the months following a damaging earthquake in California, for the governor to call on a blue-ribbon panel to investigate the structural failures caused by that quake. The panel eventually issues a report summarizing the engineering lessons learned, and recommending modifications in the building codes and other precautions that—if implemented—should significantly reduce damage in subsequent earthquakes. A glance at the titles of these reports gives us an unintended insight into California's earthquake problem. After the 1989 Loma Prieta quake, the Board of Inquiry viewed the situation as "Competing Against Time." The Seismic Safety Commission, in its recent report on the Northridge earthquake, sees the need for "Turning Loss To Gain," although someone has said that, following the lead of Loma Prieta's Board of Inquiry, a better title would have been "We Lost." Certainly, if we don't pay serious attention to our earthquake threat, we'll be "Picking Up the Pieces" in a future report. □

Associate Professor of Civil Engineering John Hall was the team leader for the Earthquake Engineering Institute's reconnaissance of the Northridge earthquake, and participated in the Seismic Safety Commission's study of that quake. (He was the secretary to the Board of Inquiry into the Loma Prieta earthquake.) He is also a member of Caltrans' Seismic Advisory Board and the White House Office of Science and Technology Policy's National Earthquake Strategy Working Group. His research combines computer simulations, laboratory models, and field testing, and focuses on the nonlinear response of structures, especially high-rise buildings and concrete dams, to earthquakes. Hall's degrees in civil engineering are a BS from West Virginia University in 1972, an MS from the University of Illinois in 1973, and a PhD (with a minor in seismology) from UC Berkeley in 1980; he also has several years' worth of "real-world" experience in a structural design office. This article is adapted from a recent Watson lecture.

Bodies of Steel on Legs of Rubber

Below: A three-story base-isolated building gets bent out of shape by the C5 ground motion in these stills from another Media Integration Lab movie.



	Sylmar	C5
16-inch	5.0!	*!
20-inch	1.7	19.8!
24-inch	1.1	10.4

Above: The peak story drifts calculated for a three-story base-isolated building with a 16-, 20-, or 24-inch-wide moat, when subjected to the Sylmar and C5 ground motions. An exclamation point indicates that the building hit the moat wall, and an asterisk indicates a collapse predicted by the computer.

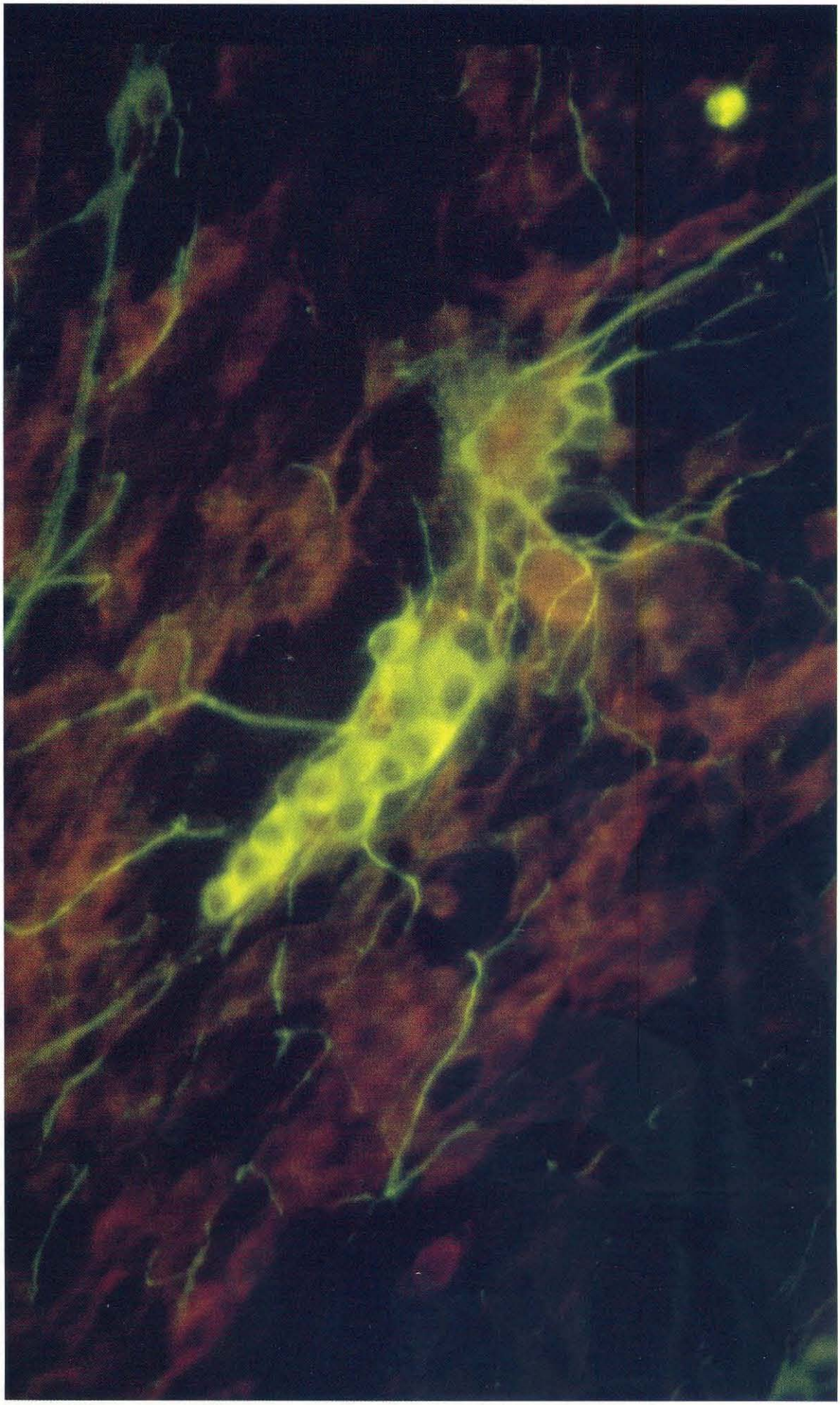
It's a common myth that many buildings in Southern California are on rollers. Not so, but we do have about half a dozen base-isolated buildings, which are built on rubber pads, and we're building more. It's a similar idea to the rollers—put something soft between the ground and the building to try to reduce the ground motion that travels up into the building. This is expensive, so it's only been used so far for critical structures, such as hospitals and emergency operations centers, that need to remain functional after earthquakes. How would near-source ground motions from a large quake affect such buildings?

The designs for base-isolated structures are generally more sophisticated than for fixed-base buildings, and the engineers do usually take some account of the near-source directivity effect—it's the controlling issue, in fact. Consequently, a major design goal is to keep the building's displacements reasonable, so that the structure does not move too far on the pads. Otherwise, the building's weight would squash the pad sideways, and the structure would drop down. So as an added precaution, the engineers often put stops—usually low concrete walls—around the building to act as a barrier. This is just so everyone can sleep better at night, because the building isn't supposed to actually hit them. If that ever happened, it would damage the structure and probably wreck the contents—the building wouldn't exactly be functional any more. The zone of free movement between the building and the stops is called the moat; the moat's width, and ensuring that the pads remain stable within this width, is the critical design issue.

I have another computer program—it's rather crude, but it models a lot of the yielding behavior and other nonlinear features that are important for this problem—with which I've analyzed the response of a three-story base-isolated building to the Sylmar and C5 ground motions. I considered three cases: a 16-inch-wide moat, which is typical of the buildings we've already built; a 24-inch moat, a better design that's typical of several buildings now going up close to major faults; and an intermediate 20-inch moat. The results, as seen in the table at left, aren't encouraging. The building collided with the stops in three of the six trials, and collapsed once. There are also some very high story drifts, which again should be interpreted as collapses.

There are only two cases that might appear satisfactory—the two better-designed isolation systems in the Sylmar ground motion. But even there, we're getting story drifts that tell us that the building yields. This is not good, because in order to ensure that the building and its contents will still be in working order after the shaking stops, the engineer usually makes the promise that the building is going to behave elastically. But that's not true even in our best results—there is some structural damage. Across the top of the page are some stills from a movie we made of the 20-inch moat for the C5 ground motion. The displacements and the moat width are amplified by two, in order to see them better. Note how much the building yields after it hits the wall.

So the near-source ground motions being used in the design of base-isolated buildings could be too small, and the resulting buildings may not, in fact, be "earthquake-proof." □—*JH*



Alzheimer's Disease: Causes and Effects

I think we have the genetic tools and the instrumental tools to understand the fundamental basis of Alzheimer's disease.

After two weeks in culture, the single isolated progenitor cell shown on page 27 had differentiated here into dozens of neurons (stained green, with long fibrous processes) and hundreds of glial cells (stained orange). Grafts of such cells hold great promise for replacing nerves that have died because of Alzheimer's disease or other neurodegenerative diseases.

The following article is condensed and adapted from a forum sponsored by Caltech and the Pasadena Star-News, *in cooperation with the Los Angeles chapter of the Alzheimer's Association. Held on May 31 in a packed Beckman Auditorium, the forum sought to explore the current status of research on this mind-crippling disease and the therapeutic promise that that research holds for the future. In his welcoming remarks Caltech President Thomas E. Everhart noted that "the more we learn about Alzheimer's disease, the better we can fight it." He also expressed his delight in the full house. "It demonstrates the fact that people are interested not only in this disease but in scientific research and how it relates to their lives. At a time when basic research is facing extraordinary pressures, it is heartening to see so many people attending a program based on science and its consequences for human health."*

The program was moderated by physician and journalist Winnie King, and, in addition to the five scientists whose talks are published here, also featured TV actress Shelley Fabares, who spoke on family and social issues surrounding Alzheimer's disease. Fabares spoke of her personal experience as a caregiver for her mother, discussing the progression of the disease, the caregiver's feeling of impotence in the face of its advance, and the overload and isolation that strain the families of Alzheimer's victims. Fabares found help in the Alzheimer's Association and has since become a spokesperson and a member of its national board of directors. She decried the "crippling ignorance" that infects our society with regard to a disease that she said is recognized as the fourth leading cause of death in this country. The number of people with Alzheimer's disease in the United States is expected to reach 9 million by early in the next century. Fabares also spoke out in favor of a long-term health-care policy and "meaningful health-care reform." She hoped that "this forum will enlighten the world about the nature and extent of Alzheimer's disease."

A videotape of the entire forum proceedings (1 hour, 51 minutes) is available from Caltech's Office of Public Events (Mail Code 332-92, Pasadena, CA 91125) for $39.95.

Caleb Finch
ARCO and William F. Kieschnick Professor in the Neurobiology of Aging, and University Professor, University of Southern California

Alzheimer's disease is a very specific kind of dementia that is linked in still mysterious ways to the aging process. Its most widely known characteristic is an impairment of recent memory and a progressive, slow, inexorable course that deprives the brain of its resources of wisdom and capacity for reasoning. Alzheimer's is not to be confused with vascular conditions that can cause another kind of dementia through strokes. In the dementias common in aging, certain types of neurons shrink and die. Even so, many neurons in the brain of someone with deep dementia still seem to function quite normally. A major feature of these dementias is that the incidence increases progressively during aging, particularly after 65 years of age.

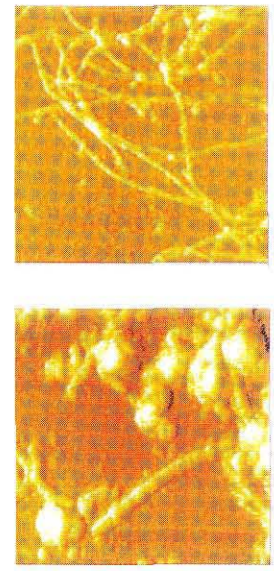
Senile dementias, including Alzheimer's, are

relatively rare before the age of 50. Parkinsonism is another disease whose incidence increases steeply with age; there seems to be no safe age at which one is protected if one hasn't already developed the condition so far. In contrast, two other diseases that affect the nervous system do have safe ages where you are secure from the threat of the disease. One is Huntington's disease, which is the result of a single gene with a dominant effect; the other is the set of diseases called schizophrenias, which may also have a genetic origin, but with strong effects from interaction with the environment. Part of the mystery of these diseases is how one can have inherited a gene at birth that waits so long before it's expressed in its damaging forms. In the case of Alzheimer's disease, there are multiple genetic influences that increase the risk—some of them inevitably, some of them only as risk factors.

One of the major pathological characteristics of the brains of Alzheimer's patients is the senile plaque, a microscopic assemblage of proteins about a hundredth of an inch in diameter. It's found in the vicinity of dying neurons, but there are often other cells in the neighborhood that are quite healthy and active. These are called glial cells, from the Greek word for glue, and they include two types: astrocytes and microglia. The distribution of senile plaques is heaviest in the parts of the brain that are concerned with learning and memory, and the selectivity with which these regions seem to be targeted must in some way be related to the gene activity that determines the particular characteristics of the nerve and glial cells in those areas.

The first protein to be identified with the senile plaque is one called beta amyloid. Now, here is a paradox: each of us has, from birth onwards, in all of our body fluids, traces of this beta-amyloid protein that seem to do us no harm. But somehow in the disease process it aggregates to form these masses that appear to be toxic to neurons. Although it has become the best known of these proteins, amyloid isn't alone in the disease process; there's a long list of other proteins and factors in the brain that are aggregated along with the amyloid in the senile plaques. Some of these are molecules that act like hormones or growth factors that can influence the survival of neurons; others are components of the inflammatory system that troubles our joints with age. A great deal of effort is now under way to understand how these molecules get together and how they influence the toxicity of amyloid.

We can make amyloid fibrils aggregate in a test tube with the same effect as found in the senile plaque. My laboratory is studying another



Atomic force microscopy images show two proteins found in the senile plaques of Alzheimer's disease brains. In this experiment, chemically synthesized, pure beta amyloid aggregated by itself (top) or was aggregated in the presence of the protein clusterin (bottom). Clusterin considerably modifies the extended filaments of beta amyloid, increasing its harmful effects. From Oda et al., *Exp. Neurol.*, in press.

one of the molecules in the plaque, clusterin, and we have found that mixing the two together in a test tube drastically changes the organization of the amyloid, and, moreover, increases its harmful effects. The focus on amyloid is now leading investigators to consider other molecules that interact with it that may modify its toxicity and may suggest an approach to treatment.

The accumulation of amyloid in aggregated form is not unique to humans; it's a biological phenomenon of aging that can be seen in other primates and prosimians. The top figure on the opposite page indicates the part of the lifespan when amyloid begins to accumulate in each of several species—humans, chimpanzees, rhesus monkeys, and lemurs, the latter with a lifespan of only 10 years. It's clear that even short-lived prosimians, which diverged from the rest of our lines more than 40 million years ago, also accumulate beta amyloid in their brains with aging. This may be the molecular equivalent of original sin. The scientific puzzle is to understand why it aggregates, forms senile plaques, and damages nerve cells.

Besides amyloid aggregation, another change found very broadly in the brain during aging is the activation of the glial cells. It appears that virtually everyone on the face of the earth over the age of 50 has astrocytes and microglia that are beginning to wake up and look highly active. This is a basic part of the aging process that may be interrelated with the onset of Alzheimer's, Parkinson's, and other neurodegenerative diseases. These kinds of changes are common to all mammals in corresponding portions of the life-

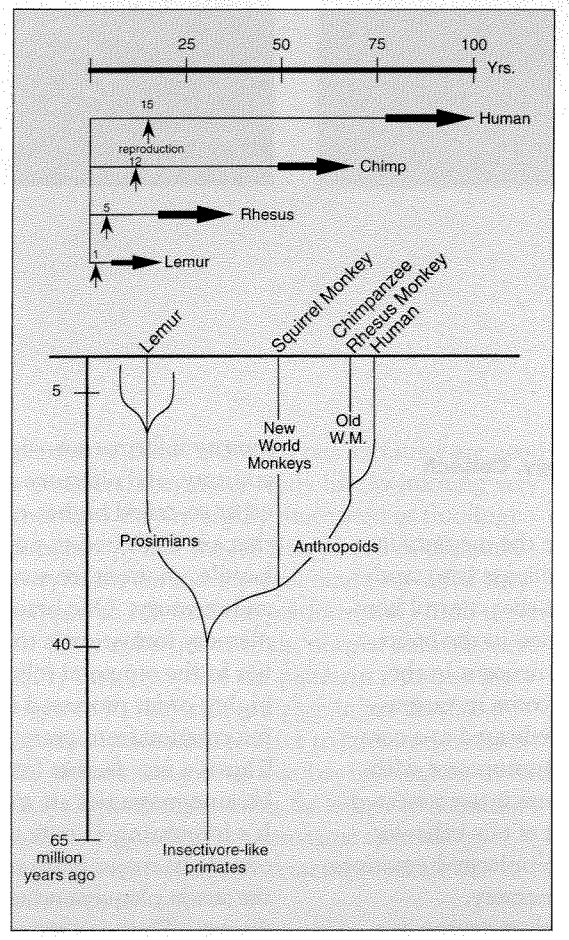
span. The graph at left below shows that the same general processes of neuron atrophy, deposits of amyloid, and increased activity of the glial cells is a broad phenomenon during brain aging in mammals that may precede clinical signs of disease.

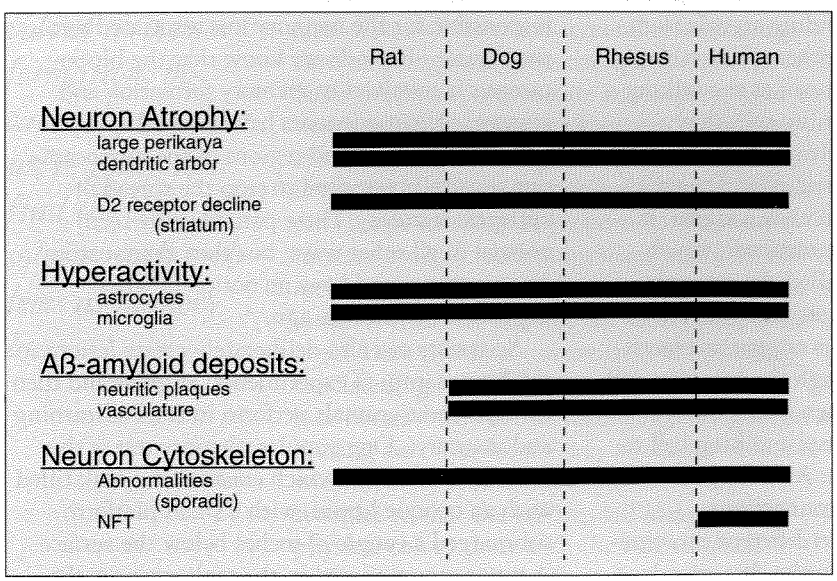
Studies of the genetics of Alzheimer's disease have located genes on at least four different chromosomes. This genetic diversity might ultimately serve as a basis for recognizing which individuals are at risk for the onset of Alzheimer's at a certain age, and which individuals might be treated preventively. As we learn more about the disease, researchers may discover pharmaceutical approaches to Alzheimer's based on the particular mutations and genes that one carries. Other therapeutic targets include devising drugs to influence amyloid metabolism, to modify senile plaque, and to replace neurotransmitters that are lost as nerve cells degenerate. It's a broad field, and the problems are very complicated. We don't expect it to be resolved in a few years. I think that Alzheimer's research is in the same position that cancer research was in about 40 years ago, when one or two forms of cancer could be treated.

I'll close with an optimistic statement: I think we have the genetic tools and the instrumental tools to understand the fundamental basis of Alzheimer's disease. If a person born with a gene for Alzheimer's lives 70 years without any symptoms, it should be possible to suppress that gene's bad effects for the rest of his normal life span. And in the foreseeable future, assuming that reasonable funding is available, much progress will be made.

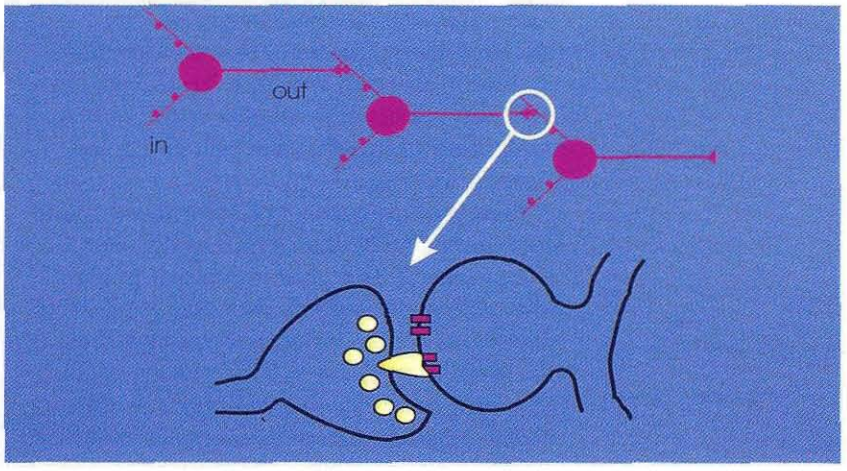
Right: Beta amyloid accumulates during aging in the brains of humans and other primates. The graph shows the age when beta amyloid is first detected (thick arrow) in species with different life spans, according to their positions on hte phylogenetic tree.

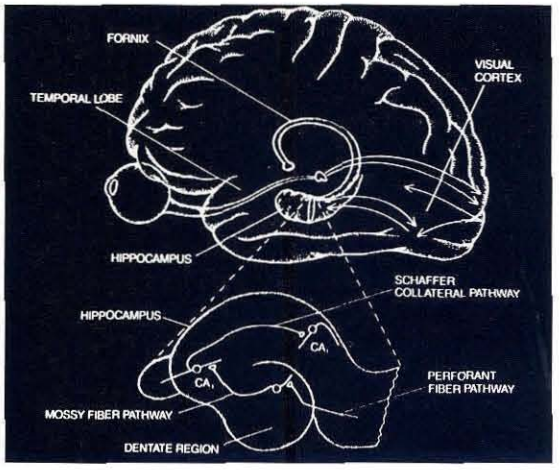
Below: The horizontal bars indicate the occurrance of changes during normal aging in four mammals with different life spans: rat (3 years), dog (15 years) rhesus monkey (30 years), and human (80 years). Note that rats do not accumulate beta amyloid but do show most other changes.





Caleb Finch received his BS (1961) from Yale and PhD in cell biology from Rockefeller University (1969). He has been a member of the faculty at the University of Southern California since 1972, as professor of gerontology and biological sciences since 1978, as the ARCO and William F. Kieschnick Professor in the Neurobiology of Aging since 1985, and as University Professor since 1989.





Above left: Neurons, which can be thought of as having a talking end (left) and a listening end (right), communicate at junctions called synapses. There the talking cell releases a chemical signal (yellow) across the synaptic cleft, which stimulates an electrical signal (pink) in the listening cell, which then "talks" to the next neuron down the line.
Above right: One of the brain's memory-storage sites is the hippocampus, named for its seahorse shape and located in the temporal lobe at the base of the brain.

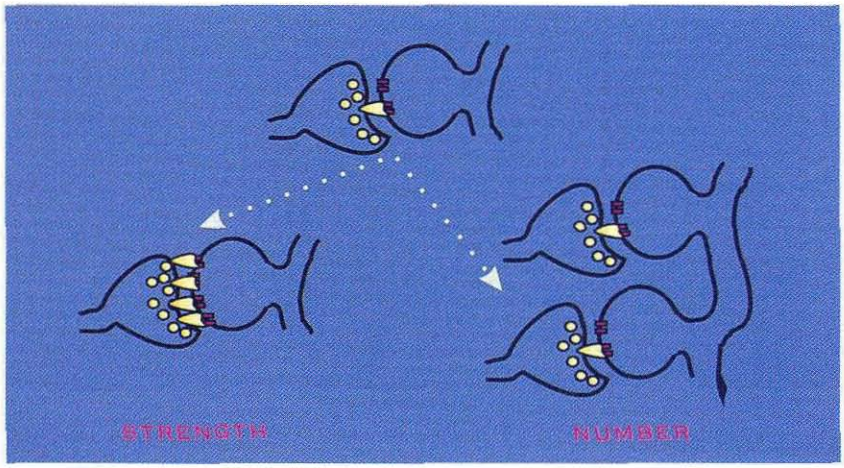
Erin Schuman
Assistant Professor of Biology, Caltech

One strategy to ameliorate the memory loss associated with Alzheimer's disease is to study the fundamental mechanisms that control how and where memories are formed in the brain. We have approximately 10^{11} neurons in the brain, and even though they come in various sizes and shapes, they're all dedicated to a common function, which is to communicate with one another. Networks of these interconnected neurons underlie every aspect of our behavior, from the simplest reflex to complicated emotions, thoughts, and learning and memory.

We can think of an individual neuron as a factory with a receiving end and a shipping end. Neurons communicate by sending signals from one cell's shipping end to another cell's receiving end. Or you can think of one cell as the talking cell and the other as the listening cell; they connect in the synapse. The language of these cells is a combination of electricity and chemistry. When the talking cell receives a signal, it releases a chemical, a neurotransmitter, which travels across a small space called the synaptic cleft to interact with specialized receptors in the listening cell. These receptors trigger an electrical impulse that travels through the listening cell to its shipping end, which then releases a neurotransmitter and thus becomes a talking cell to the next neuron in the chain. An average neuron forms about 1,000 synaptic connections.

The brain is organized into different functional units, beginning with the units that encode sensory information—including the visual, auditory, and olfactory areas. Then there are other so-called higher-order areas of the brain that are dedicated to processing information and handle emotions, reasoning, language, learning, and memory. One brain area important for memory formation is the hippocampus, which lies in the temporal lobe and receives a lot of higher-order processed information, including information from every primary sensory unit. This is a nice feature for a memory-storage site because memories are multi-sensory experiences. It's interesting to note that the hippocampus is one of the major brain areas that's damaged by the senile plaques and tangles of Alzheimer's disease. Thus, it's reasonable to work with the hypothesis that damage to the hippocampus is responsible for the memory loss associated with the disease. How do we know that the hippocampus is involved in memory formation and storage? Neuroscientists have studied epileptic patients who have had regions of the hippocampus surgically removed to stop the spread of epileptic seizures. These patients may seem normal in all other ways, but they cannot store any memories and have no notion of what happened 10 minutes ago.

Scientists can also deliberately create lesions in the hippocampi of experimental animals and then see how these animals perform in tests of learning and memory. One popular memory test is the Morris water maze, which consists of a tank filled with an opaque liquid, with a small platform submerged a couple of inches below the surface. A rat or mouse placed in the tank can't see the



Memories are formed by changing the strength or the number of synapses. The strength of the synapse can be increased when the talking cell sends more neurotransmitter or when the listening cell adds more receptors.

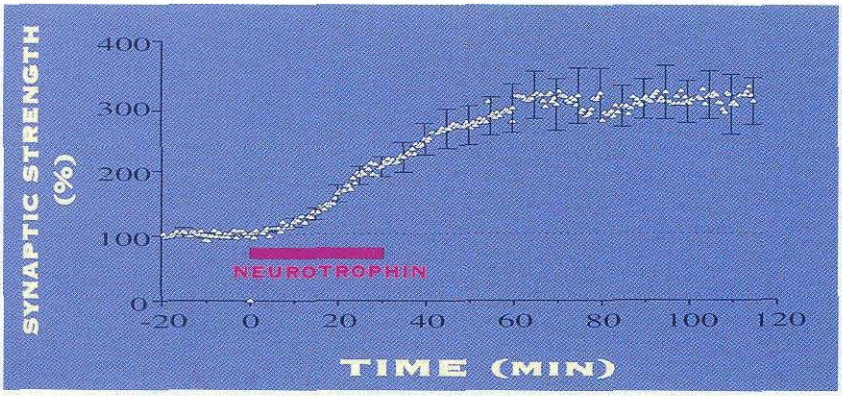
Our ultimate goal is to achieve an understanding of all the molecules, proteins, and genes that are involved in memory formation, because that's where we're going to find the clues to solving such problems as memory loss.

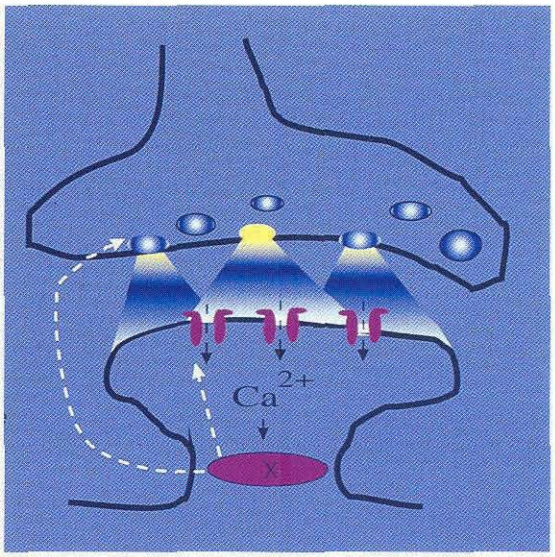
platform. Now, although rats and mice are good swimmers, they don't really like swimming very much, so they're highly motivated to find high ground. When they're first placed in the tank, they swim around the pool randomly until they happen to run into the platform and climb up on it. Over subsequent trials, normal animals learn fairly quickly where the platform is and swim right to it; they still can't see it but they've learned its location relative to cues in the room. In contrast, an animal that has had lesions created in its hippocampus takes far longer to learn the task and spends a lot more time swimming around because it can't remember where the platform is.

What is actually changed about the properties of neurons in the hippocampus or other brain areas when we learn and remember something? And how can we address this question in the lab? Since neurons communicate at synapses, what we want to do is change the properties of the synapses or change the way that information flows in the brain. There are two basic ways the brain can change its synaptic properties. One way to increase synaptic communication would be to increase the strength of transmission at a single synapse, either by making the talking cell shout (send more chemical transmitter) or by having the listening cell add more receptors so it can hear better—sort of like turning up the gain on a hearing aid. The second way to change synapses with memory would be simply to add new synapses so that the talking cell makes more physical connections with the listening cell.

To understand how these changes occur and how memory occurs, we need to understand the process at a molecular level. We can do this by teaching an experimental animal something and then looking in its brain and observing what has changed about the synapses. When scientists have done that, they've seen that usually both of these kinds of changes—increasing transmission strength and adding synapses—occur. We can also take the brain out of the animal and make the changes ourselves, to try to mimic what happens when the animal learns something in its real environment. In my lab, and in many others, researchers remove the hippocampus from rats and then slice it into sections about 0.5 mm thick. Even when we slice the hippocampus up, it maintains its usual properties and the synapses behave normally. We can keep the tissue alive and record the synaptic activity by stimulating the talking cells and recording the size of the listening cell's response, which is always the same over time if stimulated in the same way. If we then stimulate the hippocampus in the right way, by applying strong stimulation to the talking cells, we can dramatically increase the size of the response of the listening cell. This enhanced response, which is called long-term potentiation, can last for long periods of time. Thus, using this technique we can study memory formation in a reduced situation where we have molecular control over the individual cells and synapses.

Our ultimate goal, however, is to achieve an understanding of all the molecules, proteins, and genes that are involved in memory formation, because that's where we're going to find the clues to solving such problems as memory loss. We





Above left: Neurotrophic factors, which promote the growth and survival of developing neurons in the embryo, also appear to increase synaptic strength in the adult brain.
Above right: When memories are formed, the talking cell (here on top) releases its neurotransmitter, which activates a calcium receptor in the listening cell. The calcium then activates a bunch of enzymes that can make the listening cell's receptors more sensitive, as well as prompting the release of more neurotransmitter.

know a fair amount about the molecular mechanisms of long-term potentiation. When long-term potentiation is initiated, a certain receptor is activated that allows calcium to enter the listening cells. Calcium is a very important intracellular messenger that can activate a whole variety of enzymes. These calcium-activated enzymes can do two things: either change the properties of the receptors in the listening cell to make them more sensitive to the same amount of neurotransmitter, or generate a signal that travels back to the talking cell telling it to release more neurotransmitter. We know that these kinds of cellular events underlie short-term memory. It's our guess, and recent work suggests, that for long-term memories signals are actually transmitted up to the nucleus to influence gene expression and change the amount and/or kind of proteins expressed.

The above mechanisms describe changes in synaptic strength. Unfortunately, we don't have a similar molecular understanding of how structural changes—that is, changes in synaptic number, the other way memory could be formed—might occur in the adult brain. We can, however, take advantage of a great deal of work that's been done on structural changes during brain development in the embryo. We know that proteins called neurotrophic factors promote the growth and survival of neurons when the nervous system is developing. In this case, the talking cell releases the neurotrophic factor, which then binds, just like the neurotransmitter, to receptors on the listening cell, and then travels to the nucleus, where it influences gene expression. We hope that the adult nervous system might employ similar mechanisms to change the structure of synapses.

It's quite possible that the same proteins that change structure also change synaptic strength and vice versa. In my laboratory we have determined that these neurotrophic factors that promote neuron growth and survival can also change synaptic strength in the adult nervous system. In the same experiment with the hippocampus slice that I described earlier, when we added the growth-promoting factor we saw an increase in synaptic transmission. This means that the brain may actually use the same molecules to increase synaptic transmission and to promote growth, and shows that the nervous system can use the same sets of molecules over and over again to form these different kinds of memories.

Finally, it is our hope, and it's the hope of basic science, that if we can achieve an understanding of the essentials of synaptic transmission and how memories are formed normally at the molecular level, we will be able to design treatment strategies that may be effective in reversing the memory loss associated with Alzheimer's and other diseases.

Erin Schuman joined the Caltech faculty as assistant professor of biology in 1990. She earned her BA from the University of Southern California in 1985 and her PhD from Princeton in 1990. She's currently a John Merck Scholar and an Alfred P. Sloan Research Fellow.

Robert Katzman, MD
Research Professor of Neurosciences,
University of California, San Diego

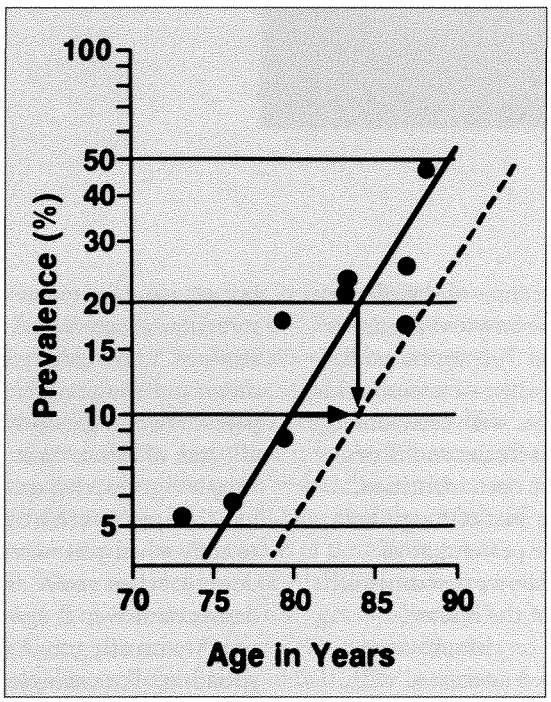
Although dementia is a complex of symptoms that can be caused by more than 70 diseases, Alzheimer's disease accounts for between two-thirds and three-fourths of all cases of dementia. Criteria published in 1980 by the American Psychiatric Association define dementia as characterized by loss of intellectual ability of sufficient severity to interfere with social or occupational function, impairment of memory, and impairment of at least one other area of cognition in individuals who were alert and awake. This definition has enabled us to diagnose dementia very well—in the case of Alzheimer's with 85 percent accuracy, which is remarkable considering that there is no specific biochemical test for it. Unfortunately, this definition does not pick up the early stages of the insidious onset of Alzheimer's disease. Family members will often disagree by years about when the disease began.

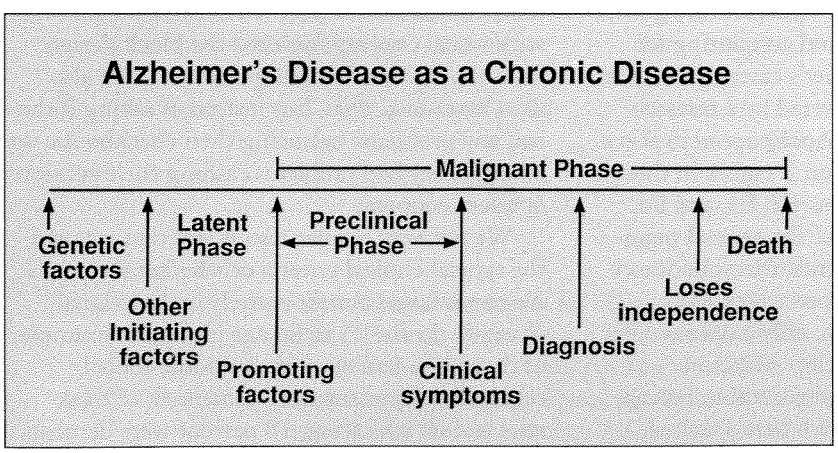
I believe, as do many others, that Alzheimer's can be viewed much like other chronic diseases, such as cancer, where there are initiating factors that occur well before the actual onset of the disease. Recent data suggest that the latent phase may last about 15 years, a phase in which changes could perhaps be picked up with neuropsychological tests but can't be observed clinically. We can't make an accurate diagnosis until a year or two after clinical symptoms appear, which is pretty late in the game.

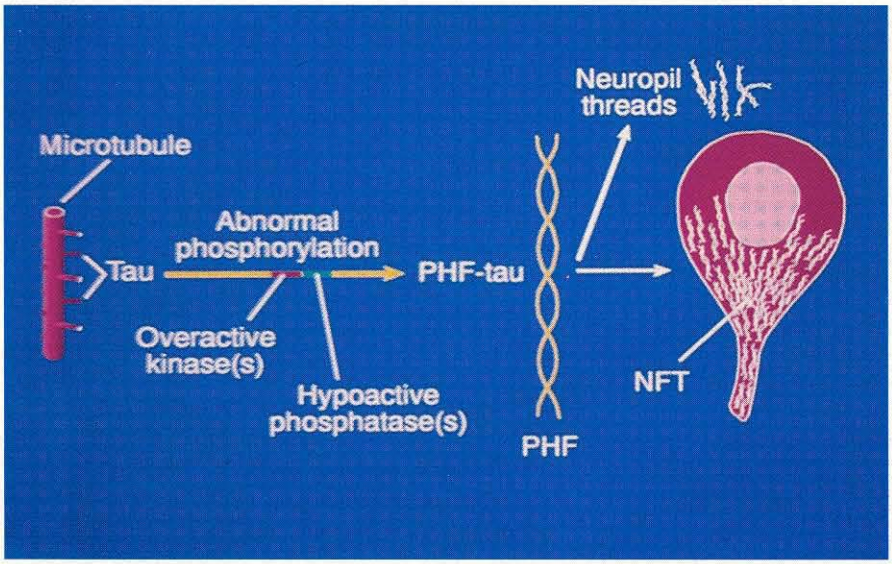
When Alois Alzheimer first outlined the pathology of this disease in 1907, he described the neuritic plaque and the neurofibrillary tangles—abnormal nerve cells that are full of abnormal fibrils. Although most of the investigators today are working on amyloid and the plaque, many of the brain cells in Alzheimer's disease do have these neurofibrillary tangles, which probably contribute to cell death, and we now know quite a bit about their chemistry. A protein called tau, which normally helps stabilize the microtubules that are needed for the transport of proteins in nerve cells, in Alzheimer's somehow gains many phosphorous groups attached to each single molecule. It then separates from the microtubule, forms perihelical filaments and then neurofibrillary tangles. But we don't know whether this tau process is a secondary event or a primary one.

We know quite a bit more about the neuritic

Right: Plotting the log of the prevalence of Alzheimer's disease against age produces a straight line. Approximately 5 percent of the population will have the disease at 75; that increases to 10 percent at age 80. If the onset of Alzheimer's could be delayed by only five years (dashed line) the prevalence of the disease would be cut in half.
Below: Alzheimer's is similar to other chronic diseases, with initiating factors that occur well before onset, a latent phase with no symptoms, then a period in which subtle changes are occurring but are difficult to observe. When symptoms do become obvious, it can still be another year or two before an accurate diagnosis can be made.







Besides discovering the genetic risk factors for Alzheimer's disease, recent studies in a variety of institutions have turned up some apparent protective factors against the disease.

Above: Implicated in the neurofibrillary tangles characteristic of the brains of Alzheimer's patients is a protein called tau, which normally stabilizes microtubules that transport proteins in nerve cells. In Alzheimer's disease, the tau protein acquires phosphorous groups, breaks off, and forms parahelical filaments (PHF), which accumulate, forming neurofibrillary tangles (NFT) that cause the cell to die.
Below: The gene for apolipoprotein E4 increases the risk of Alzheimer's dramatically, particularly if the E4 allele is inherited from both parents. With E4 from only one parent, the risk falls off appreciably. Data after Corder, et al., *Science*, vol. 261, p. 922, 1993.

Probability of Developing AD by the Age of 85 (Familial Cases)	
Allele	Percentage
4/4	91.3
4/3	47.8
4/2	20.0
3/3	20.8
3/2	18.8
2/2	< 15

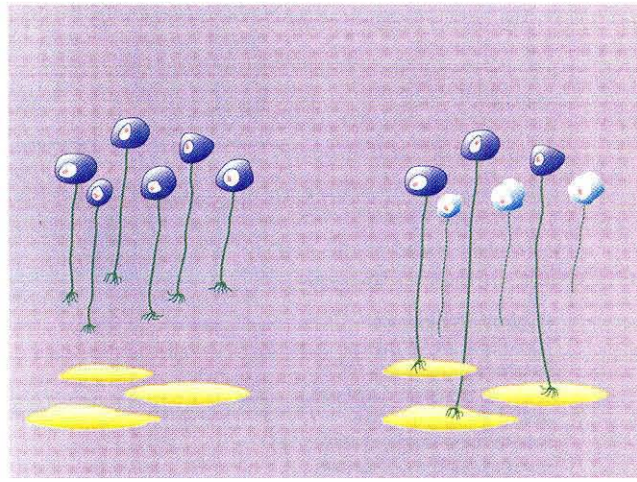
plaque. The amyloid in the center of the plaque is a breakdown product of the amyloid precursor protein, which contains about 700 amino acids. The beta amyloid is formed when 42 amino acids break off. In studying families with early-onset Alzheimer's (patients in their forties and fifties), nine different mutations have been identified, which bracket this particular part of the protein. This doesn't represent a large percentage of Alzheimer's patients, but it shows that amyloid is, in fact, one of the causes of the disease.

Besides the amyloid gene on chromosome 21, early-onset cases have been associated with another gene, not yet identified, on chromosome 14. But the most important susceptibility gene, located on chromosome 19 and accounting for about 30 percent of Alzheimer's cases, is the gene for apolipoprotein E4, discovered by a research group at Duke University. Apolipoprotein E is a low-density cholesterol carrier; it comes in three varieties, commonly known as E2, E3, and E4. Although only two percent of the general population has E4 from both parents, this inheritance accounts for about 15 to 16 percent of Alzheimer's patients. And if you only have one E4, you're twice as likely to develop Alzheimer's as the general population. Apolipoprotein E4 can form complex compounds with beta amyloid, converting it from a soluble peptide to an insoluble fiber very quickly.

Besides discovering the genetic risk factors for Alzheimer's disease, recent studies in a variety of institutions have turned up some apparent protective factors against the disease. Anyone, no matter how intelligent, can develop the disorder, but over the aggregate education appears to be somehow protective. I was involved in a 1987 study of 5,000 elderly individuals in Shanghai to determine the prevalence of dementia. Since 27 percent of this group had never been to school at all, and, of those, most couldn't read or copy simple figures, this created some testing problems. If you haven't been to school and learned to copy when you were a kid, you don't start doing it when you're asked to do it during a dementia survey at age 70. So we adapted the tests we usually use in the United States to this situation. For example, our memory test used actual physical objects that were identified and touched and memorized. Because of the problem with visual copying, we used the block design from the children's intelligence test. We also used functional tests, but instead of asking if they had any problems balancing their checkbooks, we asked if they had problems cashing their pension or salary coupons.

We got very similar results whether we used the typical clinical criteria or whether we used a diagnosis based almost entirely on functional changes. In the 75 to 84 age group, for example, of those who had more than middle-school education, 4 percent were demented; of those who had no education, 18 percent were demented; those with elementary education were in between, at 12 percent.

A number of studies in such places as Bordeaux, France, and in North Manhattan have found the same kind of phenomena. The North Manhattan study found that not only does lack of education, defined here as less than eight years



In the process of embryological development, many neurons (blue) send out their nerve fibers (green) to contact their target cells (yellow). But in this normal competitive process, many neurons don't make it, and they die off.

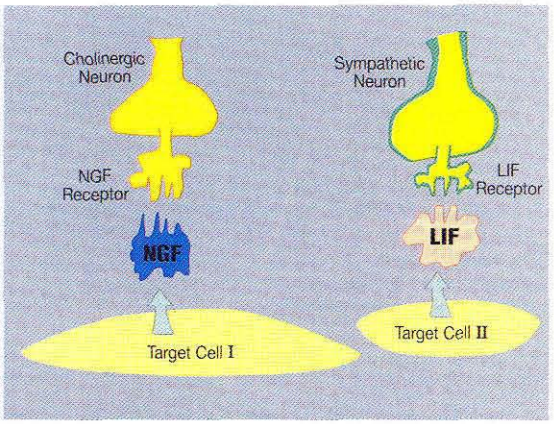
of school, double the risk of developing Alzheimer's-type dementia, but low occupation had the same effect. Individuals with both low occupation and little education had an almost three-fold chance of developing dementia. We interpret this to mean that if you're educated, you may have a five- to seven-year delay in the onset of Alzheimer's, and you'll have half the chance of someone with no education of developing it at all. Since the incidence of Alzheimer's doubles every five years between the ages of 65 and 85, delaying the onset by five years would cut the prevalence of the disease in half. The question of course arises whether late-life education will help. We don't know yet, but it's something worth looking at.

Robert Katzman earned his BS (1949) and MS (1951) from the University of Chicago and his MD from Harvard Medical School (1953). Much of his career was spent at Albert Einstein College of Medicine, where he was chair of neurology and professor of neuroscience. In 1984 he came to San Diego as professor of neurosciences and department chair at UCSD. Since 1994 he has been research professor of neurosciences. He has also held appointments as attending neurologist at the UCSD Medical Center and at the San Diego Veteran's Administration Medical Center.

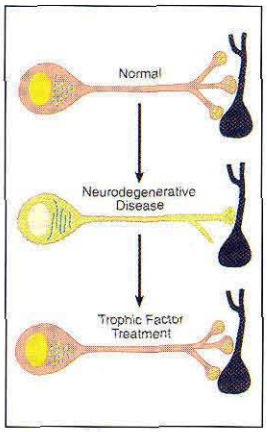
Paul Patterson
Professor of Biology, Caltech

The bottom line on Alzheimer's disease is the death of nerve cells. Neuronal death occurs in other pathological conditions—Parkinson's disease, stroke, and so on—and, in fact, it is a part of normal embryological development. All of us have undergone a massive amount of neuronal death as embryos. Many neurons are born and send out their nerve fibers, or processes, to contact target cells, but only a fraction of those nerve cells actually successfully make contact and live. The rest of the neurons, from one half to two-thirds of them, will die as part of normal development. It is as if the neurons are competing with one another in a kind of Darwinian fight for survival. What they're competing for, in part, are proteins called trophic factors—from the Greek word for nourishment—which are secreted by the target cells. These trophic factors keep the neurons alive.

One family of trophic factors consists of proteins related to nerve growth factor (NGF). NGF is secreted by particular kinds of target cells, and it has a certain molecular shape that allows it to bind very specifically to receptor proteins on the surface of neurons that require it for survival. There are many other families of trophic factors, each produced by different target cells and each acting on different neuronal populations. One type of neuron that responds to and requires NGF is the cholinergic neuron, which is



Right: Different families of trophic factors, such as NGF (nerve growth factor) and LIF (leukemia inhibitory factor) are secreted by different target cells. Each of the trophic factors has a particular molecular shape that allows it to bind specifically to receptors on the surface of the neurons that need it to survive.
Below: After intervention with trophic factors, neurons that have started to shrivel up and lose contact with their target cells (center) are restored and their contacts reconnected (bottom).



among the most prominent cells that die in Alzheimer's disease.

These findings raise the possibility that we could use such trophic factors to interact with the specific populations of neurons that die in various neurodegenerative diseases. If a neuron starts to shrivel up and lose contact with its target cell as the disease progresses, we might potentially be able to intervene with the appropriate trophic factor that could restore this neuron to health, allow it to reattach its connections, and thereby ameliorate the problems (say, memory loss) that its dying was causing.

One of the challenges in such a scheme is delivery: How can we deliver trophic factors to a person's brain? The simplest and most direct way is to implant surgically, in the appropriate part of the brain, a tube connected to a pump of NGF. This is, in fact, actually being tested in humans, and extensive animal research is also being conducted. Rats are one animal model because as they age, they can display deficits at certain learning and memory tasks that are correlated with a loss of cholinergic neurons, as happens in Alzheimer's patients.

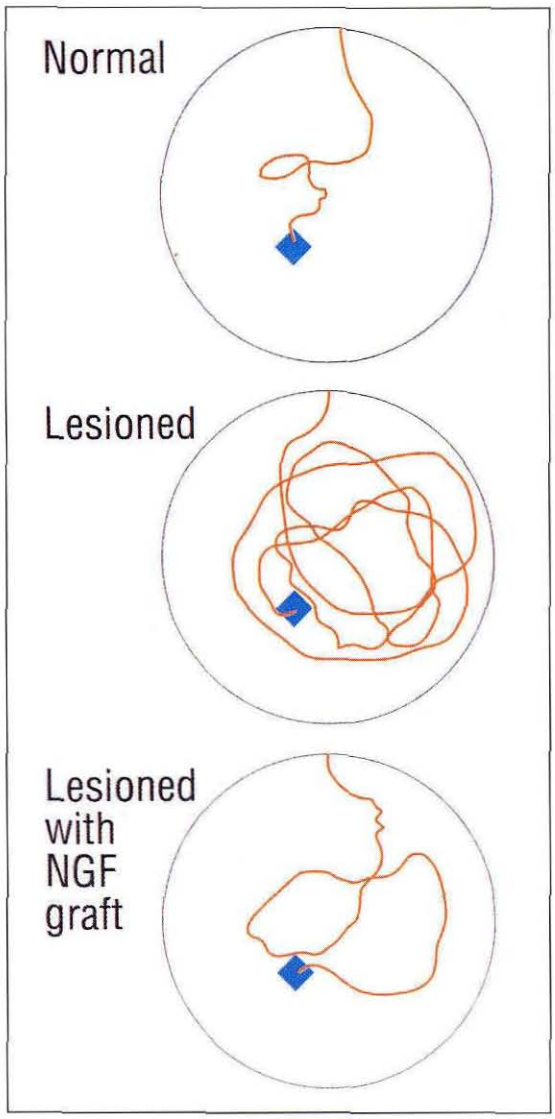
When tissue slices from rat brains are stained to reveal cholinergic neurons, the brains of healthy, young adult rats show numerous such neurons, but the brains of aged rats show very few because the neurons have shrunk and disappeared as they do in Alzheimer's brains. But in an aged rat brain that has been injected with NGF, the neurons are larger and more numerous. Corresponding behavioral tests have shown that in many cases the administration of NGF not only rescues these neurons from death but promotes the ability of these rats to learn and remember new tasks.

There are, as you might imagine, some potential problems with implanting tubes in people's heads. Over months or years it might cause an infection in the brain, or the tube might move slightly, sending the trophic factor to the wrong place, and so on. Therefore, considerable work is focusing on alternative methods of delivery. One on which we are working is a biological method, that is, implanting living cells that secrete large amounts of NGF directly into the brain. Skin cells are isolated from rats, grown in culture in large numbers, and then injected with the gene for NGF (or another trophic factor on which we are working called LIF, for leukemia inhibitory factor). Cells that are producing high levels of the trophic factor are selected for use as a living graft of cells to be implanted into the part of the brain where the neuronal loss is occurring.

In addition to aged animals, other models involve surgical lesions placed in very discrete locations in the brain. In one surgical model, nerve fibers of cholinergic neurons are cut on one side of the brain, leaving the other, intact, side as a control. In this case, the genetically engineered cells producing NGF are grafted into the lesioned side of the brain and the results assessed days or weeks later. When the brains of these animals are examined histologically, the tissue sections reveal that the lesioned neurons survive far better when they are near a graft of cells secreting NGF —they are large and healthy, with many sprouts. When the same experiment is done and the behavior of the rats is tested using the water-maze test that Erin described, the performance of a rat whose cholinergic neurons have been lesioned is very poor. It displays a very poor ability to remember where the platform is located. In contrast, lesioned rats that have received grafts of NGF-secreting cells display a markedly improved spatial learning and memory performance.

A variety of experiments from a number of different labs around the world have shown that NGF and other trophic factors have the capacity to rescue neurons under many different circumstances. It does not seem to make a difference how the neurons have been made to atrophy—whether by aging, surgical lesions, or various toxins; survival and growth can be improved with trophic factor under many toxic conditions. This, of course, has important implications for diseases for which we do not yet know the causes. In addition, some reports have indicated that administering NGF to normal, healthy rats

A variety of basic-science experiments on the normal embryological death of cells and the role of trophic factors provide results that have direct applicability to the clinical study of a number of neurodegenerative diseases.



In the Morris water-maze test, a normal rat quickly learns to find its way directly to the platform (blue square) hidden just below the surface of a pool of water, remembering where it is from clues in the surroundings. The pool is represented here by the circle, and the rat's path is shown in orange. A rat whose cholinergic neurons have been cut cannot, however, remember how to find the platform and swims around in circles (center). But such a rat that has had an NGF-containing graft implanted in its brain can find the platform pretty well (bottom)—not as well as the normal rat but a big improvement over the one with the lesioned brain.

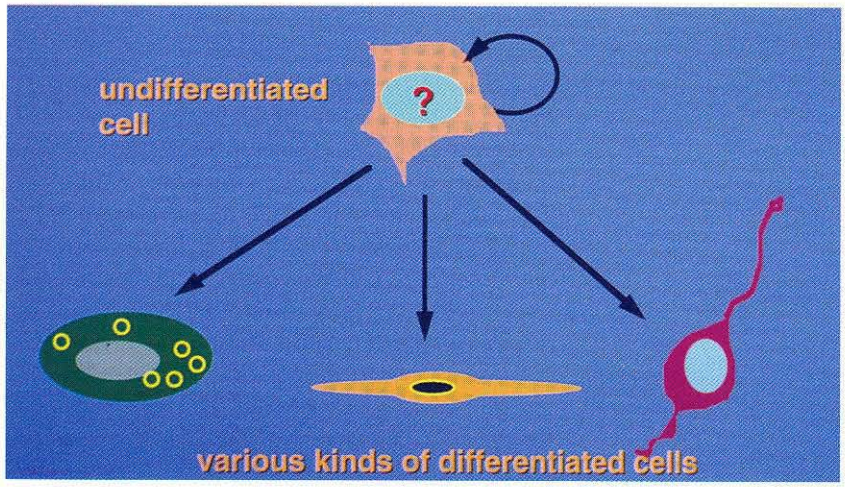
improves their learning and memory capacity. This may give hope to all of us!

A final interesting point concerns another feature of the grafted cells in the brain. An experiment that we've done in collaboration with Fred Gage of UC San Diego involves placing grafts of NGF-secreting cells at some distance from NGF-responsive cells in the brain. In spite of this distance, the NGF-responsive neurons will send processes directly toward the graft, ultimately surrounding and infesting it. The nerve processes do not grow randomly, but directly toward the graft. This means that we can control the direction of nerve outgrowth by where we place the graft. This is experimentally very useful, but it also points out a potential problem in applying this technique in humans. If one misplaces the graft or the tube of NGF even slightly, nerve processes might grow to the wrong location, and the patient could be worse off than before.

Although it is still the early days of this field, one can draw several conclusions at this point: 1) A variety of basic-science experiments on the normal embryological death of cells and the role of trophic factors provide results that have direct applicability to the clinical study of a number of neurodegenerative diseases—not only Alzheimer's disease, but Parkinson's and others. 2) The applicability of such trophic factors to situations in which we do not yet know the cause of the disease is potentially very important. 3) Animal models are essential for the study of these diseases.

Finally, current work in our lab and that of many others is aimed in several different directions. It is critical to find the best form of delivery, and to extend the rodent work into primate disease models. We are also looking for new trophic factors that will work on other kinds of neurons in the brain. Many types of neurons die in these neurodegenerative diseases, including Alzheimer's, and we want to find trophic factors for each of them. Past success in these areas provides hope for currently untreatable neurological diseases.

Paul Patterson has been professor of biology at Caltech since 1983 and executive officer for neurobiology since 1990. He received his BA from Grinnell College in 1965 and his PhD from Johns Hopkins University in 1970. Before coming to Caltech he was on the neurobiology faculty of Harvard Medical School.



A progenitor cell is one that hasn't yet differentiated—that is, it hasn't yet decided what it wants to become. It divides and generates daughter cells, which do differentiate and assume different forms and functions.

David J. Anderson
Associate Professor of Biology, Caltech

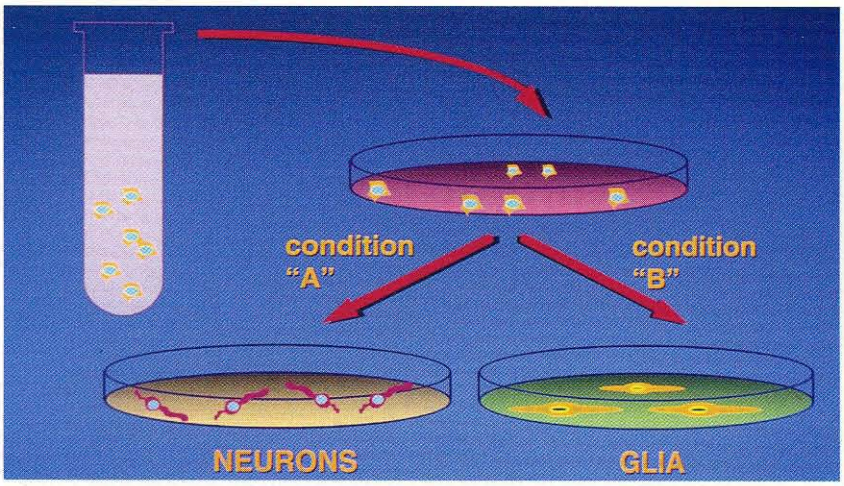
Perhaps the most revolutionary potential kind of therapy for brain diseases is cell-replacement therapy, that is, transplanting cells to replace the function of neurons that have died in diseases such as Alzheimer's disease. In order to develop such a therapy and take it from science fiction to science fact, we need to know, first of all, which type of cell we need to transplant. Since neurons are dying, it would seem to make sense to replace them with more neurons. But another cell, called a progenitor cell, is also being studied as a transplant candidate in my own lab and in others around the world.

A progenitor cell is a cell that we originally thought existed only in the embryonic brain. It's an undifferentiated cell, that is, it doesn't have any particular function except to make more of itself by dividing and to generate other cells—daughter cells—which then differentiate, taking on the specialized form and function that they need, in this case, to make the brain do what it does. Progenitor cells have enormous proliferative capacity; they can divide, which makes them much easier to cultivate in the laboratory than neurons, which can't divide. A particular kind of progenitor cell, called a stem cell, gives rise to the greatest number of daughter cells, and can be thought of as the most primitive of the progenitor cells. Progenitor cells are also easy to grow, and because they are immature, primitive cells, they can adapt more easily than neurons can to a new environment, such as the one they might encounter if transplanted into a brain. Cells are like people: as they get older, they tend to get more set in their ways.

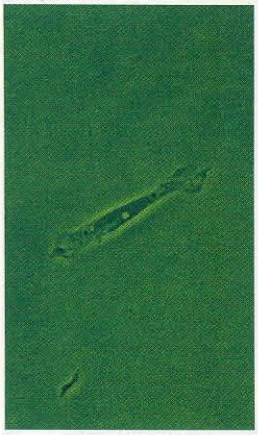
But before we think about transplanting these cells, we need to know more about them, specifically whether there's a special progenitor cell for each type of neuron, or whether a generic type of progenitor cell can give rise to all the different types of neurons that die in various neurologic diseases and therefore can be used to treat them all. In order to determine how many different cell types a progenitor cell can give rise to, we can study them in the laboratory in two basic ways. One is to study them in culture. We put the progenitor cells in petri dishes, and to some of those we add one kind of hormone—or factor, or signal—and then to other petri dishes containing the same kind of cells, we add a different kind of signal. Then we ask whether the progenitor cells differentiate into different cell types in the different petri dishes. And it turns out that they *do*, and we can define the menu of possible fates available to a progenitor cell by these experiments. We don't know ahead of time what conditions, or factors, to use to get the cells to differentiate, but we can use this as a system to search for such conditions. This has the side benefit that once we know the conditions that will turn a progenitor cell into, say, a cholinergic neuron, or a neuron that makes dopamine, we might be able to use that information down the road to supply those factors along with the progenitor cells when they're transplanted into the brain.

Another way to find out what progenitor cells can give rise to is to transplant the cells into experimental animals such as rats. We can transplant these cells, labeled with a dye, into an embryo (or an adult brain), and then follow them to see where they go and what they become. Such transplant experiments in my lab (in collaboration with Fred Gage at UC San Diego) and in several other labs around the country have indicated that these progenitor cells are quite plastic, that is, they have a wide range of developmental capacities, suggesting that they could be used for more than one type of disease. But we still don't know whether there is one single generic progenitor that we could use to treat all neurodegenerative diseases. This is a goal of much current research.

We have two methods of growing progenitor cells for these experiments. One method manipulates the cells from the outside by supplying



Above: Progenitor cells can be isolated and studied in culture to determine what conditions cause them to differentiate into specific daughter cells—neurons, say, or glial cells.
Below: An isolated progenitor cell before it has begun to differentiate. After it had grown in culture for two weeks, it differentiated into the hundreds of neurons and glial cells seen on page 14.



them with nutrient molecules called growth factors, which bind to receptors on the surface of the cells and stimulate them to divide. The alternative way is to manipulate the cell from within—provide the cells with a gene, called an oncogene, whose product increases cell division. Recent experiments with both of these techniques have made it possible to generate large quantities of progenitor cells in the laboratory, starting with very small numbers of cells.

As I said earlier, neural progenitor cells are found in developing embryos. Experiments with animal models have indicated that such fetal cells behave much better than do adult cells when grafted into an adult brain, probably because they're more primitive and, therefore, more plastic. But in order to treat human diseases, we need to start with human cells (animal cells will be rejected by the immune system). In Sweden, where such experiments have been generating a lot of excitement recently, reports have indicated that human fetal cells transplanted into the brains of aged human patients (in this case to treat Parkinson's disease) are actually able to survive, grow, and differentiate over a period of years. In this country, there are moral, political, and practical barriers to doing research with human fetal tissue, but these techniques that allow us to grow large quantities of progenitor cells in the laboratory could allow us to generate an essentially infinite supply from a small sample of human fetal cells obtained on a one-time-only basis. That is, a single sample of fetal tissue could provide a potentially inexhaustible supply of progenitor cells.

Does any of this have a prayer of working?

New research also shows that the adult human brain contains a small reservoir of these progenitor cells or stem cells. This discovery overturned dogma that had been accepted in neurobiology for a century. The existence of stem cells in the adult human brain opens up the possibility that we might be able to transplant a patient's own stem cells from a healthy part of the brain into the part that's diseased. Current research is focusing on ways to accomplish this.

Does any of this have a prayer of working? Although it's not yet clear whether this kind of cell-replacement therapy will work for Alzheimer's disease, dramatic progress has been made using it in Parkinson's disease. This is encouraging, but we're not going to know definitely whether this kind of therapy can work until we have gained more understanding of the fundamental properties of neural progenitor cells. This is the kind of research that we do here at Caltech. Even though it doesn't have a medical school, it's a place where biological research goes on that is relevant to human medicine and human disease. The concept of using replacement cells in therapy for diseases such as Alzheimer's and Parkinson's has emerged directly from the kind of basic research into the fundamental biology of these fascinating cells that we, and our colleagues in other institutions, carry out. □

David J. Anderson earned his AB from Harvard in 1978 and his PhD from Rockefeller University in 1983. Following a postdoctoral appointment at Columbia University, he came to Caltech as assistant professor of biology in 1986 and was named associate professor in 1992. He is also an associate investigator of the Howard Hughes Medical Institute and an adjunct assistant professor of anatomy and cell biology at the University of Southern California School of Medicine.

The *Yang* of Nutrition . . . The *Yin* of Food

We live in a world of fears and phobias—good foods, bad foods; health foods, junk foods. Can't we be good to ourselves?

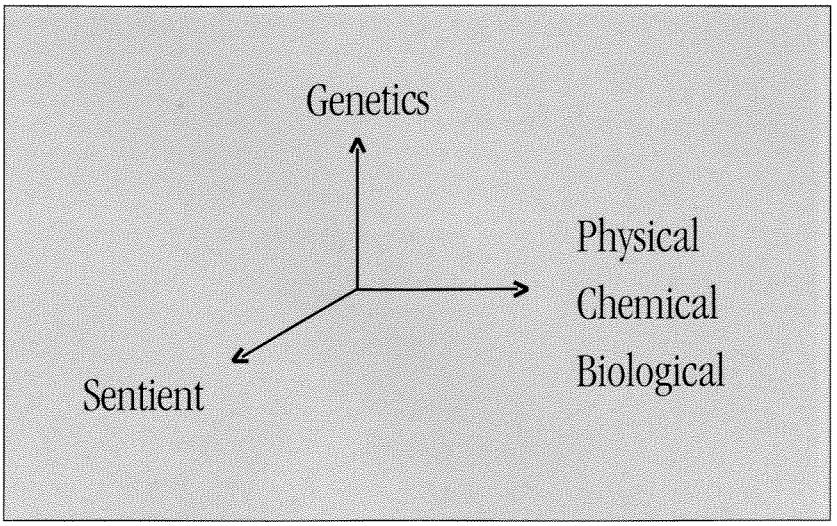
by Paul Saltman

To begin my talk about the science of nutrition and the metaphysics of food, I'll tell you a story. On graduation from Caltech in 1949 I had the opportunity to spend a year in graduate school in Paris. When I got this news I said to my girlfriend, "Barbara, when I get back from Paris, we'll work things out." She said, "Big boy, when you get back from Paris, you ain't going to find *me* here." So we figured out that night that we ought to get married, and I proudly came back to Caltech that evening, because I hadn't quite finished yet, and announced to my colleagues in Fleming House that Barbara and I were going to get married and go to Paris. Dennis Long, who was a great guard on the football team that year, looked at me and said, "Paul, you know, getting married and going to Paris is like taking a ham sandwich to a banquet." Well, as a Jewish kid who was a connoisseur of ham sandwiches, I have to say it was the best thing that ever happened to me.

Detail from *Still Life with Fruit and Vegetables*, Frans Snyders, Flemish (1579–1657); courtesy of the Norton Simon Foundation, Pasadena, California. Fiber isn't everything.

That story could fall into the category of the metaphysics of food. There's also a scientific basis of human nutrition. It's an exact science, almost as good as that of the physicists and the astrophysicists, better than that of the cosmologists. The title of this talk came to me recently when I was invited to the People's Republic of China to talk about national food policy for China. Their whole food policy has changed because of the enormous transformation in the productivity of agriculture and distribution of food in China, and they wanted me to talk about this in the context of nutrition and health. As I thought about what I would say, my mind focused on a symbol out of the Chinese culture, the symbol of *yang* and *yin*. It symbolizes so many concepts, but essentially it's the notion of the synergy of the wholeness of opposites. The *yang*, the black section of the symbol, is in a sense the "maleness" of it—the rigidity, the firmness, the strength, the unambiguous aspects of the universe in which we live. To me that constitutes the scientific dimension of our lives—the boundary conditions established by the laws of nature, which we need to bring into harmony with the *yin*, what the Chinese consider the "feminine," the mystical, the metaphysical, the emotional, the ambiguous, and, above all, the sensual aspects of our lives.

I like to think of all this in the sense of the dimensions of human potential. As I see it, we move in a three-dimensional space, each one of us being at the focus of the three coordinates in the diagram on the following page. You come out with a certain set of DNA; that's a crapshoot at T_0—not a lot you can do about it. We've got faculty here and at UCSD who are cutting genes to measure, and someday, perhaps, we can be fitted for whatever genes we want. But for now our genetics is a given. Then we all have a physical and biological and chemical potential, which we don't brood much about either. The physical forces that can affect the genetic consequences of our birth—the physical dimensions of our lives that compromise our DNA—include radiation of various kinds, various thermal gradients, if you want to think of it that way, and, of course, things like running Ferraris into cement walls. The biological dimension can also affect the potential we're born with. All sorts of



Of the three dimensions of the human potential, genetics is the one you can't do anything about. But you can affect the physical, biological, and, especially, the chemical dimensions (the *yang*), and the sentient aspect (the *yin*).

potentially cataclysmic biological phenomena can threaten us, from AIDS and the Ebola virus to the microorganisms that contaminate water and food.

My talk mainly concerns the chemical dimensions of our lives, not in the sense of, say, smog, which is caused by a chemical reaction and certainly does affect our lives, but rather in the sense of the chemical environment that nourishes us from that moment when we were a single fertilized egg in our mother's womb. What essential nutrients did we receive—or not receive—that promoted or compromised our growth and development? And after we were born, what nutrients fed us, nourished us, and allowed us to manifest our human potential as originally given to us in our DNA?

Remember the first law of thermodynamics, which says, if you eat it and you don't burn it, you sit on it.

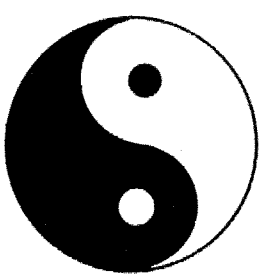
Last, but not least, is the sentient aspect of our lives. What kinds of images, what kinds of projections address our brain from the five senses of our body that shape us as human beings? What do we taste? What do we smell? What do we hear, see, feel? We are all potentially limited or unlimited by those sentient potentials.

I'll come back to the sentient—the *yin*—later, but first let me go back to the chemical dimension of the human potential and the notion of human nutrition. And I'm not going to give you the Saltman diet, but rather *your* own individual and unique diet in the sense that there is an infinite number of perfect diets for each of us. The most important issue in any diet is calories. I know a lot about calories; I got a D in thermodynamics from Stuart Bates [professor of physical chemistry]. God, that was a miserable course!

Actually, it wasn't from Stuart Bates that I really understood calories. It probably came more from a literature course—with Paul Eaton or Harvey Eagleson—when we were reading the poetry of Gertrude Stein and I suddenly realized the importance of her great poem about how a calorie is a calorie is a calorie. I'll bet in your heart of hearts you don't believe that for a minute. You believe that fat calories are bad and carbohydrate calories are good and protein calories are OK. But I'm going to try to convince you that all of them are equal, and that some are not Orwellianly more equal than others. We need a finite number of calories in our body—the number that it takes to maintain the body's energy at its basal metabolic rate, a few more to digest the food we eat, and the rest of the calories to run around, jump up and down, and go skiing and surfing and all those other metaphysical aspects of life. If you consume fewer calories than you are burning, you lose weight. If you consume more, you gain weight. Remember the first law of thermodynamics, which says, if you eat it and you don't burn it, you sit on it.

The number of calories you need is, of course, linked to genetics; we inherit our basal metabolic rate. There are fat rats and thin rats, and there are fat genes and thin genes. But don't wait for the gene fairy to come and give you a transplant. You can't control the situation, but you *can* recognize it. If you've got fat genes, that is, if your basal metabolic rate is very low, you have to eat less and run more. That's the first law revisited. I'm talking lifestyle here, *exercise*. I've done a lot of work with athletes, starting in my old jock

There is no such thing as an empty calorie.



days at Caltech. Some of the numbers freak me out—a Tour-de-France bike rider uses 10,000 calories a day in the mountain runs. You can't eat 10,000 calories a day. They have to go through laborious efforts to get 10,000 calories into their bodies every day, or their bodies start to waste away and burn their own muscle. Your metabolic rate is also dependent on your age (it slows down as you grow older), your sex, your size, and whether you're pregnant.

What does all this say about nutrients? You know, we're nothing more than applied biochemical systems (sounds like a corporation—Applied Biochemical Systems). We need 44—count 'em—44 chemicals. I can define every one of them, give you its structure, talk about its function, and tell you if it's synthetic or natural (it doesn't matter). You need them in finite amounts, which are partly a function of your age, sex, and lifestyle. Where are you going to get them? Well, you should be getting them from the food that has the calories and that is consonant with your lifestyle. This is the chemistry that Harry Gray should have taught you, or Linus Pauling, or Norm Davidson, or whoever taught you.

Let me tell you another story. One night in 1970, a woman named Judith Taylor came into a Toronto hospital with abdominal pains. They opened her up and found she had gangrene throughout her entire intestinal tract; the surgeon had to remove the whole thing. A young Indian physician, Dr. K. N. Jeejeebhoy, who was present that night, came up with an idea, and from then on, Judith Taylor and now tens of thousands of others of all ages have been sustained on an intravenous solution called total parenteral nutrition, or TPN, containing 44 chemicals in six major categories. All TPN bags are the same, in terms of having the same 44 chemicals, but the amounts are a function of the age, sex, and lifestyle of the individual who requires those nutrients.

First and foremost of the major categories is water. We are creatures in a biological world of water. I don't want to go into all the details of it as a solvent, as an ionizing material, as a heat-control mechanism, a chemical reactant—all sorts of beautiful things. You have to have water, eight glasses or its equivalent per day. What do I mean by "or its equivalent?" Does it have to be Evian or Perrier? Can it be Pasadena tap? Of course. Does it matter if it's coffee, beer, tea, or milk? No. How about Coke? Oh, but that's a junk food; won't it kill my kids, rot my brain? No; it's basically water and that's the important thing. The biggest problem with water as a nutrient is that frequently in underdeveloped nations of the world, it's the carrier of disease. But we have to have it.

The second component in the TPN bag is calories. Uh-oh; there's that dirty word again. Why, as the Jews would say, was that night in the Toronto hospital different from all other nights? That was the night that Dr. Jeejeebhoy figured out how to use the technology that the Swedes had developed of putting lecithin, a phospholipid, into a stable suspension. He realized that he could put that suspension in a bag, so that an individual could get adequate numbers of calories to sustain life. You cannot put enough glucose or amino acids to provide a day's ration of calories into human beings without upsetting their electrolyte balance and killing them. But when you put lipids—fats—into that bag, you can get adequate amounts of calories to sustain life and growth.

In most total parenteral nutrition bags, 55 percent of the calories come from fats. And what do the "croakers" tell you, the guys who wear the white coats with stethoscopes and little names over the pocket, the guys with the beards, the Dr. Koops? They tell you 30 percent, don't they? So how come all these people on TPN haven't dropped dead? The French get 45 percent of their calories from fat, and they have half the rate of coronary heart disease and half the rate of obesity that we have. But fat is bad, you say. We *know* that, don't we? There are guys running around up in San Francisco with bean sprouts in their ears telling us we have to get down to 10 percent.

Oh, you say, with the French it's the wine. No, it isn't, my friends; it's the total calories. You want to know what the curse of fat is? I'm going to tell you, even though I'm getting ahead of myself here. It's the metaphysics of the fat. Did you know fat had metaphysics? You bet your ass—literally and figuratively. Fat makes food taste good. Nobody has ever asked for seconds on total parenteral nutrition. Fat makes food taste good, and so we eat more food. And when we eat more food, we get more calories. Very simple. You don't have to have a PhD from Caltech. A simple bachelor's degree will do.

What else in the bag gives you calories? Glucose. My God, that's a sugar! Sugar's bad. We know that, don't we? Sugar rots your teeth; sugar causes hyperkinesis in little children; sugar causes homicidal tendencies in ex-city councilmen from San Francisco. Did you know that sugars—glucose (or sucrose if you, unlike people on TPN, have a gut to digest it)—or complex carbohydrates, are absolutely required for life? There is no such thing as an empty calorie. Sugar

is a precursor for pentose, and for oxaloacetic acid, which runs the Krebs cycle, the series of chemical reactions that oxidizes food to provide energy and release carbon dioxide and water as waste products. Diabetes is a fatal disease, in which the cells don't get adequate glucose. So don't talk to me about empty calories.

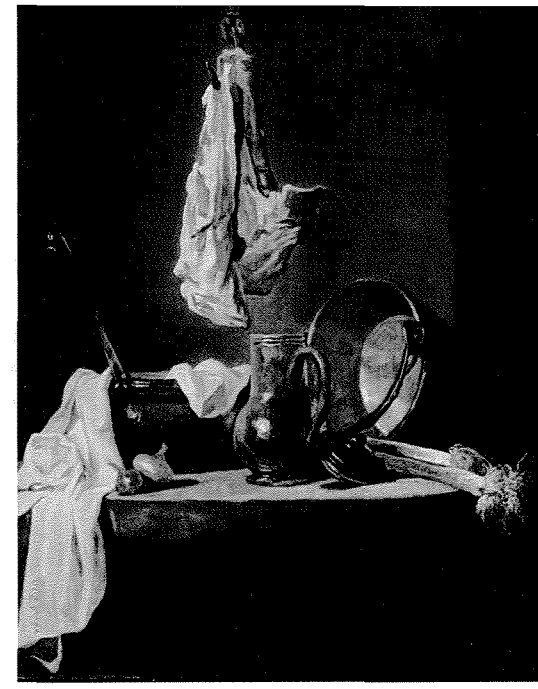
Next on the list come minerals: sodium, potassium, calcium, magnesium, sulfate, chloride, phosphate. Did I say sodium chloride? But we know that sodium chloride is bad for us, don't we? It causes hypertension. For everybody? No, only if your kidneys are rotten. If you've got lousy kidneys then the salt is very toxic. Fifteen percent of the population has lousy kidneys. So tell me, what the hell are the other 85 percent doing running around looking for pretzels without salt? Bad kidneys are caused by bad genes, obesity, stress, smoking, or excessive amounts of alcohol. But salt doesn't cause bad kidneys; salt causes hypertension if you have bad kidneys. If you've got a problem, deal with your problem.

Fifteen percent of the population has lousy kidneys. So tell me, what the hell are the other 85 percent doing running around looking for pretzels without salt?

Calcium is another mineral in the bag. I've published a lot of experiments on calcium; I'm a calcium guru. We were the first ones to show that bone loss in postmenopausal women can be reversed with 1,000 mg of calcium plus one RDA (recommended dietary allowance) of zinc, manganese, and copper. A thousand milligrams of calcium is a quart of milk. Even better is 1,500 mg—a quart and a half of milk, a quart of yoghurt, or a quarter of a pound of cheese. But, you say, you eat a lot of dark-green, leafy vegetables. Do you eat four and a half pounds a day? It's chemistry, folks. It's Dr. Ernie Swift's analytical chemistry revisited. Most women in America get 500 mg of calcium a day on average—half of what they need. Is it any wonder that 30 percent of postmenopausal American women have osteoporosis?

We need essential amino acids—I won't dwell on them. There are eight of them. We get them from the protein in our diets. Don't let people kid you that vegetarianism is God's own way. Maybe it is Her way, but if it is, you'd better be sure that you balance the grains and the legumes, because you're not going to get those eight essential aminos if you don't. Most people who are on strict vegetarian diets never get the amount of essential amino acids for proper growth.

Then come the 13 vitamins—4 fat soluble, 9 water soluble. We know the structure and function of all of them. Does it matter whether they're synthetic or natural? No. Are there any data that say that megadosing does anything? No. Here I'm saying it in Linus's own palace. I love Linus, but he was wrong about vitamin C.

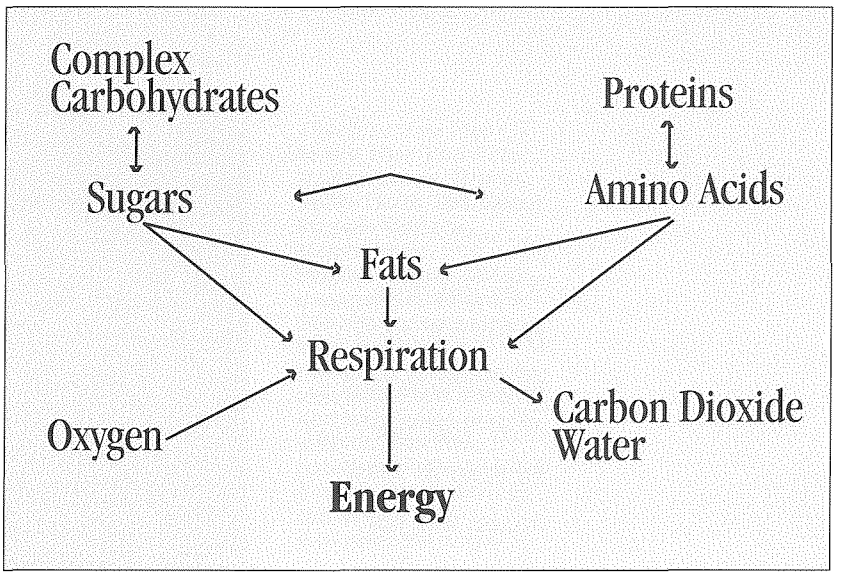


There are no data that support him on the claims that megadosing of any vitamin prevents or cures disease, antioxidants notwithstanding. (I work on antioxidants; I know about free radicals. In fact, I had to stop Angela Davis, then a student activist, from exploiting UCSD when I went there.) If you're having deficiency problems, that's something else. Or if you're pregnant. Birth defects and malnutrition among the poor are a big problem in this country. Too many young women give birth to premature babies because they don't have the vitamins and the minerals and the trace elements. Folic acid deficiency is directly linked to spina bifida, and any vitamin deficiency gives rise to malformations. It's damned tough to get 100 percent of the U.S. RDA if you're trying to do it in food off the shelf. Should you try to do it in food? Of course. But it makes no difference if you get what you need from vitamin supplements or fortified foods. It's in the bag. That's all that counts.

Last come my favorites: the trace elements, all 11 of them—including the iron, the copper, the zinc, the manganese, the fluoride, the iodine, the selenium. I got tenure on these elements. The biggest nutritional-deficiency disease in America is iron-deficiency anemia, and with it goes copper deficiency, and frequently manganese and zinc as well. In my classroom at UCSD I get very bright kids; the only kids brighter are the Caltech students. I ask these wonderful kids in my class, "How many women in this room eat meat four or five times a week?" No hands go up. "How many eat it twice a week?" One or two hands go

Left: *Still Life with Cooking Utensils*, Jean-Baptiste Simeon Chardin, French, 1699–1779; courtesy of the Norton Simon Foundation, Pasadena, California, estate of Robert Ellis Simon, 1969.
Red meat can be beautiful.

Right: In the body's biochemistry, complex carbohydrates are broken down into sugars and proteins into amino acids, which ultimately go into the respiration process or get stored as fat. Sugars and amino acids are interconvertible, but fat is a one-way street.



up. "How many don't eat meat?" All the rest of the hands go up. I say, "Where are you getting your iron?" "Oh, Dr. Saltman, don't worry about it," they say. "We love dark-green leafy vegetables." Do you know how much broccoli you have to eat to get one U.S. RDA of iron? Eight and a half pounds. You can get a lot of reading done on that kind of diet. Read my book; you'll get through it in one day.

Some of you will say, "Oh, not to worry, doc; I eat fish and chicken." Do you eat three times as much fish and chicken as you would if you ate red meat? That's the analytical chemistry of how much iron, how much copper, how much zinc is in fish and chicken compared to red meat. If you still insist that red meat ruins your karma, I suggest an iron supplement.

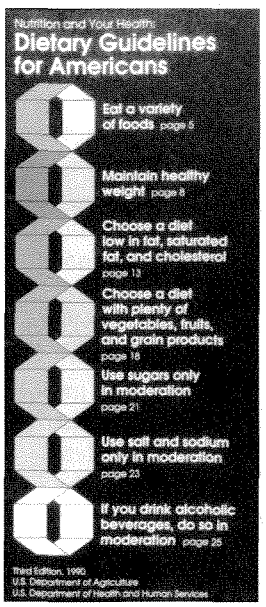
If you still insist that red meat ruins your karma, I suggest an iron supplement.

That's the bag—the 44 chemicals. Now, what happens to them when they get into your body? Let me review briefly the biochemistry that you have been studying lately as you get your children through their eighth-grade biology class (because if I don't take you through this, you're still going to believe that fats are different and all that other stuff). Complex carbohydrates (starches) are broken down in our intestine into sugars and then absorbed. Proteins are broken down to polypeptides and then to the amino acids. Sugars and amino acids are interrelated; they are interconvertible in our cells, and they can be built up or down depending upon how the body needs to store them. We store complex carbos as glycogen. You sometimes hear athletes talk about glycogen loading before a race. I'll tell you this: if you're not in the upper one half of one percent of world-class triathlon or marathon people, don't even think about it because it's trivial. Only about half of one percent of our dry body weight is complex carbohydrate as glycogen. Most of the carbos in your body circulate as glucose. Ultimately the sugars go into respiration in the Krebs cycle, and so do the amino acids. But fats, whether we eat the fat or make it by converting sugars or amino acids to fats, are our primary form of stored energy. Fats cannot be converted effectively to amino acids or sugars. And here's where we get into the first law: if you have excessive amounts of calories, which you eat but don't burn, whether it's from carbohydrates, amino acids, or fats, you store that excess as fat.

This is actually good news. Fat is a marvelous high-test aviation fuel that we can call up, break down, and burn. At optimal performance, great athletes can burn 70 percent fat and 30 percent carbos; that's the carburetion of a great athlete. If you're really in terrific shape, you've got the ability to metabolize the sugars to oxaloacetic acid, which is necessary to run the Krebs cycle and thus burn your fat, which is the best stored fuel that you can use, and be a champion. Thus fats metaphorically burn in the flame of sugars in all of our cells. The trained athlete is conditioned to have better oxygen delivery to muscle via better lung capacity, more red cells, and increased myoglobin. Further, athletes have more mitochondria, site of the Krebs cycle and the burning of the fat. The "couch potato" will rely primarily on carbohydrate for energy and thus be less efficient in burning the stored fat.

Remember how oxygen gets to your cells? It's

The greatest thing about a vegetarian diet is that you can't eat enough of it to make you fat.



transported in the blood's hemoglobin, which contains most of the body's iron. Then it dumps onto myoglobin, another iron protein, and then it goes on to the mitochondria. All the chemicals in the bag are part of this process—all of the coenzymes that are made from the vitamins, all the trace elements that are required as cofactors, all of the mineral salts that are required for electrolyte balance.

When the Dietary Guidelines for Americans —the McGovern Report (some of us are still Democrats despite Mr. McGovern)—came out in its first edition, it was considered government policy for a healthy America. They gave *that* up. Now, if the United States of America consulted with good scientists and physicians, and thought rationally about dietary matters, and then came up with this set of guidelines, is it any wonder that people go into the supermarkets wondering about the labels? Have you read the label on your favorite breakfast food lately? One of my students told me this one: she went into a supermarket and was going to buy a low-cal chocolate pudding. She compared it with the regular chocolate pudding of the same brand and discovered the low-cal was three times the price. But in reading the labels of the two packages she couldn't figure out how they were different. Then she discovered, in the directions for preparation, how the one becomes low-cal, low-fat chocolate pudding: you make the low-cal pudding with skim milk.

Let me go through our national guidelines one by one. "Eat a variety of foods." My grandmother knew that. But the variety my grandmother served, based on her childhood in her gabernya of Bessarabia, was a hell of a lot different from that in the supermarkets of America. If you talk to little children in this country, it's a question of which flavors of ice cream constitute the variety.

"Maintain a healthy weight." What's a healthy weight? Is the ideal weight that of a young woman who's anorexic? Ten percent of the women on my campus are anorexic or bulimic. Is it the weight in the Metropolitan Life Insurance tables? These height/weight tables tell you that if you're this age and this height and this sex, your chances of living one more year are enhanced if you're within this weight range. That's all. Another measure is body-mass index, which the National Institutes of Health advises using to assess health risks (you can read about it in my book). Assessing health risks is an important admonition, because obesity is a disease. Don't talk to me about fat in your diet; talk to me about fat on your body. Conditions correlated with obesity include coronary heart disease, stroke, late-onset diabetes, some forms of cancer, hypertension, and gall-bladder disease. About the only morbidity activities left are guns, drugs, and driving Ferraris into cement walls.

Getting back to our national guidelines, we come to: "Choose a diet low in fat, saturated fat, and cholesterol." Where did that come from? Why do you include cholesterol with fat? Well, it's a lipid, isn't it? And everyone knows that cholesterol is bad for you, don't they? Does Judith Taylor, the first person to derive all her nutrients from TPN, have cholesterol in her body? You bet. She has as much as you do; she makes it all herself. You make 85 percent of your cholesterol yourself; you can take or leave the other 15 percent. Some people make too much cholesterol because they've got lousy genes or are obese. And as for fat—is saturated fat different from unsaturated, monounsaturated, or polyunsaturated fat? Recent studies show them all coming out about the same. A calorie is a calorie is a calorie. A lipid is a lipid is a lipid. Polyunsaturated fatty acids are essential. That's what lecithin has in it. Why is the government telling us to avoid these things?

"Choose a diet with plenty of vegetables, fruits, and grain products." Why? An apple a day is supposed to keep the doctor away. But what's in the apple that's in the bag? Water, sugar, a little bit of potassium, sodium, 10 percent of the U.S. RDA of vitamin C. Where's the protein? Where's the calcium? Where's the iron? Where are the other vitamins? But it's got fiber! Did you see any fiber in the bag? Judith Taylor has no bowel. Judith Taylor has no bowel

***The Way You Hear It Is the Way You Sing It*, Jan Steen, Dutch, 1625–1679; The Royal Picture Gallery, Mauritshuis, The Hague. These three generations in one of Steen's many paintings of a "merry company" seem to be enjoying their wine and food quite merrily indeed. But the painting's title implies a warning not to lead the young into intemperate ways.**

Wine does reduce coronary heart disease, stroke, and stress. That's the good news. The bad news is that zinfandel has no calcium.

movements. But if you have a bowel, you'd better have bowel movements, and you'd better have fiber. The real good news about fiber is that you can't digest it; it fills you up so you don't eat so many calories and don't get fat. Do you want to know what's the most nutritious food in terms of its nutrient density that you can buy in a supermarket? Pizza. I'm serious. All the nutrients from the bag are in a well-made pizza. Of course everyone eats pizza because it's good for them, right? And as a matter of fact, it *is* good for you—if you don't take too many calories. So what is this "vegetables, fruits, and grains" stuff all about? The greatest thing about a vegetarian diet is that you can't eat enough of it to make you fat.

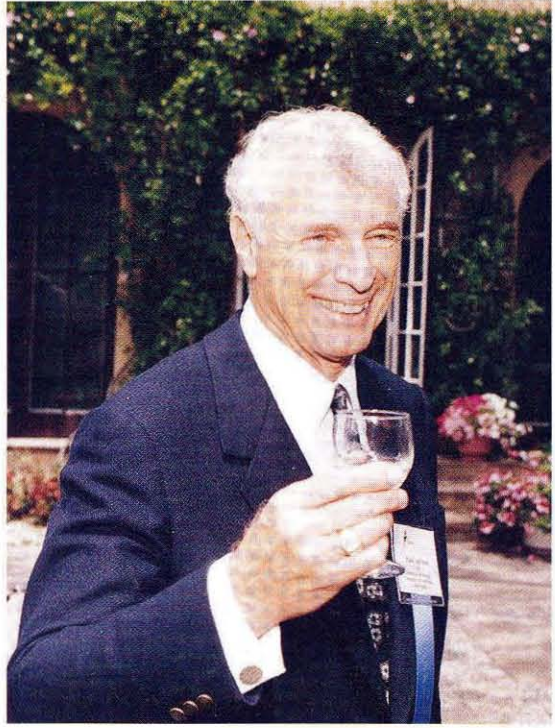
The next bit of policy tells us to use sugars moderately. Does that include polysaccharides and complex carbos? It doesn't say, but it implies that all sugars are bad. Do you know what food most promotes tooth decay? Dried fruits. They stick to your teeth and rot them. The next worst food is a "healthy" granola bar.

The next item—salt and sodium—I've already discussed, and that brings us to the last point: "If you drink alcoholic beverages, do so in moderation." Moderation in whose mind's eye? Actually, the statistics are pretty clear on this one, and I believe them and I practice them. I drink two glasses of wine a day—for medicinal reasons only, of course. Wine does reduce coronary heart disease, stroke, and stress. That's the good news. The bad news is that zinfandel has no calcium. I supplement calcium.

When I spoke to the Chinese, I told them: Don't follow the American principles. Listen to me instead. I believe that any national food policy must begin with an adequate food supply. In a day and age when we argue about school lunch programs and food stamps, just remember that although many of us are well fed and obese, there are a lot of people who are not well fed. And in China it's a hell of a lot worse. Any Chinese food policy, and any U.S. food policy, must ensure that there's adequate food to be supplied and distributed.

Second, we need to have adequate nutritional knowledge. Probably most of you didn't know about the bag, didn't fully appreciate the 44 chemical nutrients, and believed in the evils of fat and so on. But if you think *you're* ignorant, you should look at the middle school and high-school kids in America. The United States ranks 18th nation in the world in elementary- and secondary-school math and science education. I find that appalling. After the sixth grade, 70 percent of American children never take another math or science course. So we should get nutritional knowledge to the kids in elementary school, and they shouldn't be taught by some home economist running around with four basic food groups or pyramids. Teach them to understand chemistry and biology so they can make intelligent decisions about their lives based on that understanding.

Next we need to address the special needs of pregnant women, the special needs of children during growth, and the special needs of women as opposed to men, of young and old, and of people with diseases that need to be treated. Don't try



The author in 1949 (below) and in 1995.

to make one diet fit all. There is an infinite number of diets that can be tailored for each person.

We also need to exercise some personal responsibility. We've developed a doctor cult in America. Some of my best friends are physicians, but I think they've done a terrible thing for themselves. They have convinced the people of this country that when they lay on hands diseases go away, and thereby they absolve us of responsibility for our own health. We have come to believe that whatever dangerous excesses we indulge in, doctors and medical science will take care of us. Wrong. In the first place, doctors can't cure everything, and in the second place, with the HMO gatekeepers we'll never get near them in the future anyway.

And last: celebrate foods and culture. Here's where the *yin* comes in. We live in a world of fears and phobias—good foods, bad foods; health foods, junk foods. Can't we be good to ourselves? Before I went to China I saw a wonderful film called *Eat Drink Man Woman*. It's a celebration of food as life and love. And it was also very good nutrition—the best Cantonese you'll ever see, and if you don't salivate throughout the picture, you're insensitive. Food is love. The 1963 film *Tom Jones* contains three and a half minutes of the most erotic sex I've ever seen on film in my life. (I show the scene to my nutrition class, because they're too young to remember it.) The man and woman in the scene are fully clothed; they don't touch one another. The eroticism is all done through food. Food is life. The Catholics don't do wafers and wine for nutritional value. And if you think it's fun eating Pesach dinners, you're crazy.

When my book, *The University of California San Diego Nutrition Book*, first came out, I went on a book tour. I was in Cleveland, and there's this disc jockey, a real tough cookie, who was going to interview me. He'd read my book. I knew that because he'd underlined a lot of passages. (I get very nervous when I see that. It means the kid's been studying and I'm in trouble.) So he starts off by asking me what I think of some currently popular life-extension diet. I said, "My friend, the issue isn't extending life; as far as I'm concerned the issue is the quality of life." Then this rascal goes right for the jugular. He says, "Dr. Saltman, would you define the quality of life for me." So I blurted out the following definition, and I leave you with this:

I said that for me, personally, it's to be sound of mind and sound of body and free of pain. That's one quality. The second quality of life for me is to love and be loved. And the third quality is to share good wine and good food with people you love and who love you, and who are sound of mind, sound of body, and free of pain. May you be so blessed. □

On Caltech's 1945–46 basketball team, 6'5" freshman Paul ("The Goon") Saltman was the only civilian on an otherwise all-Navy squad. He played center for four years, and as team captain in his senior year was the league's third highest scorer. Playing basketball at Caltech taught him, he says, how to lose; "but I also learned that you play for the game (and the ones that you won were terrific), so I stayed in science." He received his BS in chemistry in 1949, and, after Paris, returned to Caltech to earn his PhD in biochemistry in 1953. After 14 years on the faculty of the USC School of Medicine, Saltman moved to UC San Diego in 1967, where he is professor of biology. Caltech's Distinguished Alumni Award of 1973 counts among his many awards. This article was adapted from his general-session speech at Seminar Day last May, which in turn was adapted from an address to the International Symposium on Nutrition and Fitness in Beijing in October 1994. His Seminar Day talk, which was extremely well received, precipitated an alumni run (on the way to lunch) on Saltman's book, The University of California San Diego Nutrition Book *(coauthors Joel Gurin and Ira Mothner; Little, Brown and Company, 1987, 1993). The Caltech Bookstore (Mail Code 1-51, Pasadena, CA 91125; phone: 800-514-BOOK) has since restocked, and is willing to fill orders. The book, which* Science *magazine called "accurate and authoritative . . . fun to read," costs $12.95; add $4.00 for handling and shipping.*

Recollections

Prompted by reading Judith Goodstein's history of Caltech, Millikan's School, *Jack Allen wrote to the Goodsteins with some historical anecdotes of his own. Like his old friend David Goodstein, Allen was in low-temperature physics. He came to Caltech in 1934, where attempts to liquefy helium were not successful, whereupon he went on to Cambridge University, where he co-discovered superfluidity in liquid helium. Before he retired, he was chairman of the physics department at St. Andrews University in Scotland. Along the way he encountered a number of the major figures in 20th century physics, including some of Caltech's best and brightest, whom he observed with a keen appreciation of the absurd. He has graciously allowed* E&S *to publish some of his recollections, presuming that none will invite legal objection.*

When R. A. Millikan was still in Chicago, he was working late one night and then walked home across the dark campus. On the way a chap bumped heavily into him. Millikan thought he was being mugged. He felt for his watch in his upper left waistcoat pocket and felt nothing. He grabbed the man, shook him till his teeth nearly fell out and shouted, "Give me that watch!" The chap, now terrified, gave him the watch and ran away. When Millikan got home, he found he had two watches.

Another story about Millikan concerns his attempt to find out the nature of cosmic rays. He had a nice waterproof, gold-leaf electroscope and wanted to test the absorption of the rays by water at different latitudes. The farthest north was to be James Bay, part of Hudson Bay. On the way he stopped in Toronto and hired a rowboat to do a test in the Toronto harbor. Unknown to him, J.C. McLennan of the University of Toronto (who was there when I got my PhD at Toronto), was doing something similar; the nature and origin of cosmic rays was a hot subject in the early twenties. McLennan also had a rowboat and an electroscope, and by chance they were both in their boats in the bay at the same time. They were both hot-headed and keen on priority. So, with neither telling the other what they were doing (although they knew perfectly well), they each proceeded to try to ram the other's boat. After one or two bumps they decided it was unrewarding to pursue, so they parted, still saying nothing.

* * *

Theodore von Kármán had a great sense of humor. He liked to show that the Kármán street of alternately right- and left-handed vortices is what makes flags wave in the breeze—among other things. He claimed to have the highest frequency of car collisions in California, and was of the opinion that the distance between successive collisions could be treated as a mean-free-path problem in kinetic theory.

* * *

Richard Tolman was chairman at a conference I once attended at Stanford. One speaker was of Chinese origin and had a name spelled something like Hyem Hsieh. Richard looked at the paper, hesitated a minute, and then introduced him: "We will now have a paper on . . . by, hmm, by Dr. YMCA."

* * *

I only got to know Werner Heisenberg after the war when I got him to come and give us some lectures. At a celebration dinner at the end, he gave a little farewell speech, telling us how he became a physicist. He had intended to study math, and, in those days, to enroll in the University of Munich, one had to go to the professor and ask to be admitted. He went to the math professor's office and sat across the desk from him. Unknown to Werner, the professor's dog came in each day and slept under the desk. Werner, changing position, moved his leg and caught the dog, who snarled and nipped his ankle. Werner jumped up in pain and ran from the room, chased by the dog. He sought refuge in the room of the professor of physics—that was his story. I liked him enormously and we kept up New Year's letters for years until he died.

* * *

Niels Bohr went to America in the early years of World War II. Once, when he was incognito, riding the elevator to his secret office in a New York building, Bram Pais also happened to be in the elevator. He said, "I'm pleased to see you, Professor Bohr." Bohr replied, "You must be mistaken; I am Mr. Black." Then he said, "You must be Dr. Pais," to which Bram replied, "You are mistaken; I am Mr. White." Then they chatted together. Another story about Bohr involves Rutherford's funeral. Bohr was an official mourner at the ceremony in Westminster Abbey and had to wear a top hat. He had a very large head, and it was only after a long search in London costumiers that a top hat big enough for him was found.

* * *

In about 1950 I attended a lecture given by Max Born in London. During the question period Maurice Pryce asked a rather impolite question (he was like that). He said something like, "If you had been born yesterday, I could have understood your statement about..." Max replied, "I *was* Born yesterday; I have always been Born."

* * *

Erwin Schrödinger gave the closing talk at the low-temperature conference in 1946 in Cambridge. He remarked that it was such a pleasure that everyone gave their papers in English. Why, even Walter Heitler and Fritz London (then both at DeValera's Dublin School of Advanced Studies, which aped Princeton's) had refrained from using their native Erse. It brought the house down.

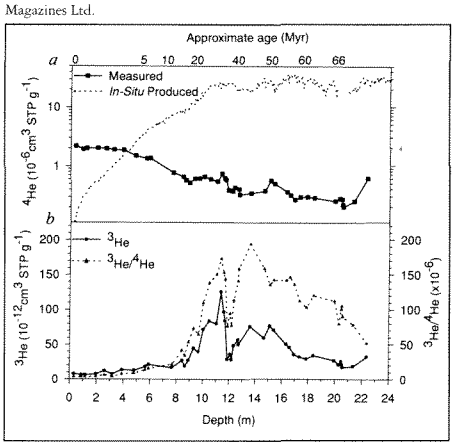
^{3}He Tells Death Knells from the Seafloor

If you can write your name in the dust on top of your piano, it's not your sloppy housekeeping that's to blame, but the fact that you're engaged in an unequal struggle with the universe. Every year, some 40,000 metric tons of interplanetary dust rains down on us—from the tails of Earth-crossing comets, from asteroids grinding against one another, from Heaven knows what. Not all of this goes straight to your living room, of course—most of it falls in the ocean and eventually settles to the bottom. Now Assistant Professor of Geochemistry Ken Farley has found a way to measure the amount of extraterrestrial dust in seafloor sediments, and has discovered that it has varied by a factor of 10 over the last 70 million years.

Furthermore, the highest dust concentrations correspond with epoch-ending extinctions. There's a dust spike 66 million years ago at the end of the Cretaceous period—the so-called K/T boundary—when most scientists agree that an object nearly the diameter of the city of San Francisco walloped Earth and nuked the dinosaurs. But the most dramatic leap occurs near the end of the Eocene. The dust flux nearly triples in the interval between 37.6 and 36.3 million years ago—a twinkling, in geologic time—and remains elevated for several million years thereafter. The Eocene ended with a major (the biggest since the death of the dinos), but gradual, extinction, notes Farley. "It's not like the K/T boundary, where everyone's happy one day and dead the next." The dust date coincides with the age of several layers of tektites—glassy blobs believed to be melted ejecta from meteorite impacts—found around the world. The lingering dust cloud and the multiple tektite layers suggest that Earth was hit by a flurry of dusty objects, possibly a comet shower, over an extended period. (This could happen if a comet whose orbit crosses Earth's began to disintegrate, leaving a thick trail of debris. As Earth swept along its orbit like a dust cloth, it could cross this trail millions of times, but it wouldn't collect a tektite layer until it had the bad fortune to run into one of the larger pieces.) The two million years leading up to the present are also very dusty, and—perhaps not coincidentally, Farley thinks—have been an era of extensive glaciation.

Farley's samples come from a core pulled from the seabed some 1,100

The Eocene ended with a major (the biggest since the death of the dinos), but gradual, extinction, notes Farley. "It's not like the K/T boundary, where everyone's happy one day and dead the next."



The graph's top panel shows the measured concentration of ^{4}He (solid line), in millionths of a cubic centimeter of gas at 25° C and one atmosphere of pressure per gram of sediment, compared with the amount expected to be produced (dotted line) based on the sediments' ages and their uranium and thorium contents.

The bottom panel shows the concentration of ^{3}He (solid line), in *trillionths* of a cubic centimeter of gas at 25° C and one atmosphere of pressure per gram of sediment, along the left vertical axis. The right vertical axis shows the number of ^{3}He atoms per million ^{4}He atoms (dotted line). In both plots, the analytical uncertainty is smaller than the symbols.

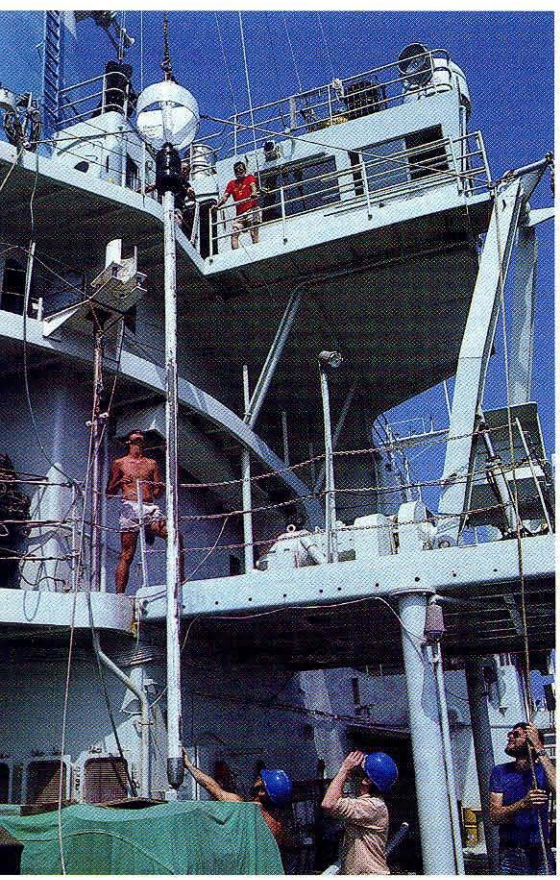
kilometers north of Honolulu—as far from the continents as you can get—in order to minimize the amount of terrestrial sediment. The core was taken by a Woods Hole Oceanographic Institution team with a piston corer—"it's like sticking a soda straw into pudding, then pulling the straw back up," Farley explains—and consists of very fine clay, reminiscent of talcum powder, laid down so painfully slowly that 20 meters' worth spans 70 million years. Even so, most of the material is homegrown. Farley estimates that only a few particles per million are outlanders.

You can't tell the space aliens from the locals by looking at them, but the spacefarers have been tattooed with exotic helium-3 nuclei. Helium comes in two varieties: ^{3}He comes primarily from the hydrogen-fusion reactions that power the sun; ^{4}He, which is heavier by one neutron, is created by the radioactive decay of uranium and thorium. Most of Earth's original stock of helium has been lost back to space over the last 4.5 billion years, and since the world isn't fusion-powered, what little helium we have now comes almost exclusively from decaying elements in the planet's crust. (There are a million atoms of ^{4}He for every atom of ^{3}He in the air.) But beyond our atmosphere, the ^{3}He-rich solar wind bombards interplanetary dust with such ferocity that ^{3}He nuclei lodge in the particles' skin. The dust also has trapped "primordial" ^{3}He—remnants of the gas from which the solar system formed. Thus, measuring the ^{3}He reveals the amount of space dust in the sample. And, assuming the sedimentation rate is known, you can deduce the rate at which Earth wiped up the stuff.

In principle, analyzing a core is a straightforward application of a standard lab technique. The extracted helium is ionized in a mass spectrometer, which sorts the ions by shooting them through a magnetic field. The lighter ^{3}He$^+$ nuclei get pulled farther off course and emerge from the field at a very different angle than their pudgier brethren. But extraction entails cooking the sample at 1100° C to melt the minerals that carry the helium, which also breaks down calcium carbonate—the vast bulk of many sediments—to calcium oxide and a huge exhalation of carbon dioxide. And if gas molecules and helium ions ricochet off one another willy-nilly in the mass spectrometer, the ions emerge from the magnetic field in random directions. So the system has two cold traps to freeze out the carbon dioxide, and arrays of filters and chemical scavengers to remove other gases, before the sample reaches the instrument. Then there's the mathematics. The terrestrial ^{3}He component has to be subtracted out—small amounts of it are produced as byproducts of some radioactive decay processes. And the sedimentation rate really *isn't* constant, because the core site has traveled thousands of miles in 70 million years—from the East Pacific Rise, some thousand kilometers south-southeast of Acapulco, to its current Hawaiian address. As the site passes under various ocean currents, and as its distance from land changes, the sedimentation rate varies. So Farley uses oceanographers' estimates of the changing sedimentation rates en route, to adjust the calculations.

Although this core was taken in the early 1970s and has since been "studied to death," Farley says, no one had ever tried to use ^{3}He as an alien-dust tracer. Helium is such an accomplished escape artist that it wasn't expected to have lingered long—it diffuses through almost everything, according to Farley. In fact, "you can't use ordinary Pyrex vacuum lines to analyze it, because it just blows right through the walls." So within 10 million years at most after the splashdown of an alien dust mote, all its ^{3}He should have snuck away and any helium found in the samples would be from the decay of radioactive elements in the sediment. In fact, Farley originally started these experiments to prove exactly that. He expected that the older samples from lower in the core would contain decreasing amounts of ^{3}He in a smoothly diminishing curve, while containing increasing amounts of ^{4}He as decay products accumulated. Instead, the ^{4}He content declined as the samples got older, and both the absolute abundance of ^{3}He and the ratio of ^{3}He to ^{4}He varied in sync with each other. "So these results are real," says Farley. "They can't be a loss phenomenon."

The cores don't preserve short-term



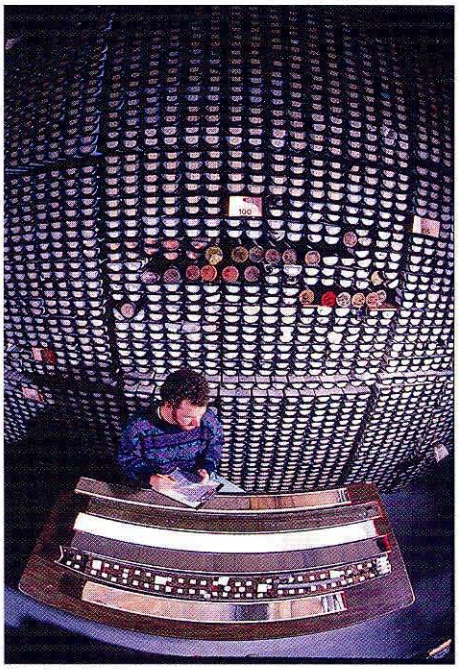


Photo by T. Kleindinst

Left: A piston-coring rig at sea. Right: The core library at Woods Hole. The core sections on the table in the foreground aren't really curved, but have been distorted by the camera lens. Photos courtesy of the Woods Hole Oceanographic Institution.

dribbles and spurts in the dust flux because marine worms, which have been around for longer than the cores are deep, constantly churn through the sediment's top 20 or so centimeters as it's deposited. In this case, 20 centimeters represents up to 900,000 years, so the Hawaiian core has a very low time resolution. But in locales where sedimentation is faster, 20 centimeters is a smaller slice of time. In principle, says Farley, such high-resolution cores might show details as fine as 900 years. But faster sedimentation means fewer foreign particles per unit volume, so getting enough dust to analyze requires larger samples, which means that much more gas to cope with. So the researchers are working on cleverer ways of extracting the helium.

Farley and postdoc Desmond Patterson are now looking at a core from the North Atlantic, where sediment accumulates 100–1,000 times faster. The preliminary results, just presented at the International Astronomical Union's Conference on Interplanetary Dust, are from samples spanning 240,000 to 440,000 years ago at 20,000-year intervals. The dust rate seems to fluctuate in correlation with a pronounced glacial cycle that recurs every 100,000 years. Most of the glacial cycles are known to derive from changes in Earth's orbit that modulate the amount of sunlight we receive, but the 100,000-year cycle cannot be so easily explained.

But before cosmic dust can be linked to climate change, cores from sites around the world need to be examined. (Fortunately, the international Ocean Drilling Program, which provided the North Atlantic core, has been circumnavigating the planet since 1968.) If all the cores display a similar pattern, then there's truly a global effect; if they don't, then the cores are recording the influence of winds, currents, or other factors on the dust's local accumulation rate.

Farley plans to run both the high- and low-resolution records further back in time. He hopes to survey the last million years at high resolution, because, in geologic terms, 200,000 years is nothing—the 100,000-year cycle, for instance, only appears twice in the current data, and who knows what slower cycles remain to be discovered? And there's no telling how far back the low-resolution technique can be pushed before the ^{3}He peters out. All the other known extraterrestrial tracers, such as iridium, record the impacts of large bodies—rare events with spectacular consequences. But this incessant drizzle of dust, while admittedly less dramatic, may be more important in the short term as a herald of climate change. Are we on the brink of another Ice Age? There may be a way to find out. □ —*DS*

It's the Dawn of a New Sunspot Cycle

The first sunspot in the new sunspot cycle was identified on Saturday, August 12, by Professor of Astrophysics Harold Zirin and colleagues at Caltech's Big Bear Solar Observatory. The new sunspot marks the beginning of the end of the sun's current quiescent period.

Sunspots are relatively dark spots on the sun's surface. They look dark because they're cooler than their surroundings—a balmy 4,000 K in the umbra, or darker central region, compared to the 6,000 K typical of the sun's visible surface, or photosphere. (The sunspot's penumbra, the not-quite-so-dark region surrounding the umbra, generally runs around 5,700 K.) But if you could see a typical midsized sunspot—one whose umbra is about the diameter of Earth—in isolation, it would appear about as big as Saturn currently does in the night sky, yet shine as brightly as 50 full moons.

The solar maximum for this new cycle should occur in the year 2000 or 2001.

Sunspots are associated with strong magnetic fields and with solar flares, and follow an approximately 11-year cycle of activity, as measured from maxium to maxium or minumum to minimum. Early in the cycle, sunspots appear rarely and at relatively high solar latitudes around 20 to 30 degrees. Thereafter, their points of origin drift toward the solar equator until the end of the cycle, although some spots may still appear at high latitudes. Simultaneously, sunspots increase in size and frequency until they reach "solar maximum." Solar flares and related phenomena also peak in intensity at this point. Then the number of sunspots (and the level of related activity) slowly declines until a relatively quiet phase called solar minimum is reached. The solar maximum for this new cycle should occur in the year 2000 or 2001.

There is typically some overlap between successive sunspot cycles. As the last sunspots of one cycle appear near the equator, at solar latitudes of 0 to 10 degrees, the next cycle starts again with sunspots near 30 degrees. The magnetic polarity of the new spots, however, is reversed—a discovery made by Caltech's George Ellery Hale at the solar telescopes he built atop Mount Wilson, overlooking Pasadena.

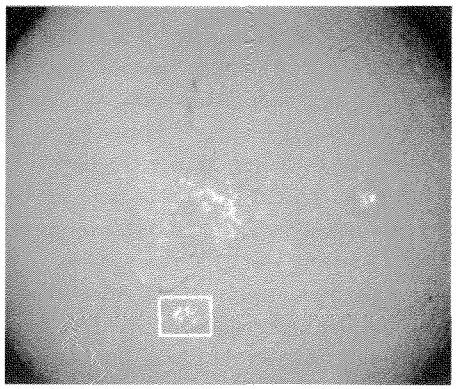
The sun has been at solar minimum through much of 1994 and this year, with a few spots showing up near the equator. The new-cycle sunspot group appeared at a solar latitude of 21 degrees, and its magnetic polarity is opposite to that seen over the last decade, thus identifying it as the start of a new cycle—the 23rd since astronomers began keeping track. There were as many as five sunspots in the group, which remained visible for five days. After the sunspots vanished, the magnetically active region, or plage, remained observable until carried from view by the sun's rotation, says chief observer William Marquette. "We watched it for a week and a half, until it disappeared over the sun's west limb as a decaying magnetic structure."

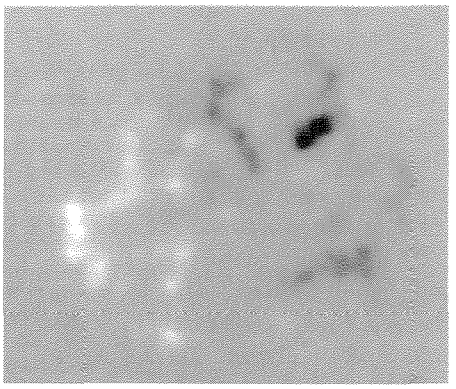
Sunspot polarity is a complex business. Sunspots generally appear in pairs or in larger groups. Each spot maintains its relative position within the pair or group as the sun rotates. The two sunspots in a pair have opposite polarity and polarities within a group are even more complex, so by convention, solar astronomers use the leading spot (called the p-spot, for preceding spot) to determine the group's polarity. And once you cross the sun's equator, the polarties reverse, so if the p-spots are negative in the northern hemisphere, as they are in the waning sunspot cycle, they'll be positive in the southern. The new-cycle sunspot region appeared in the south, and has a negative p-spot. (Negative, in this case, means a south magnetic pole.)

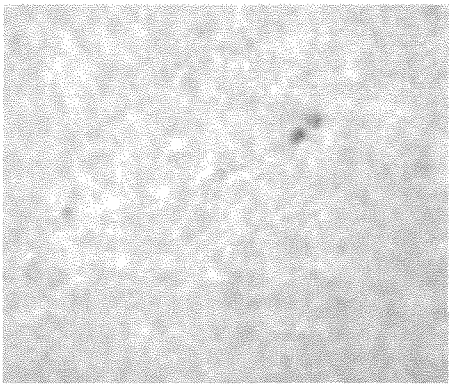
You can't tell a sunspot's polarity just by looking at it. (Kids, don't try this at home!) But when light waves pass through a magnetic field, that portion of the field that's oriented along the waves' direction of travel gives them a little twist—what's called circular polarization. Unpolarized light waves vibrate in all directions perpendicular to their direction of travel. Plane-polarized light waves (the kind that your polarized anti-

A magnetogram of the boxed area. The sun rotates from left to right in this image, so the leading sunspot is dark, indicating south, magnetic polarity—the opposite of the old cycle.

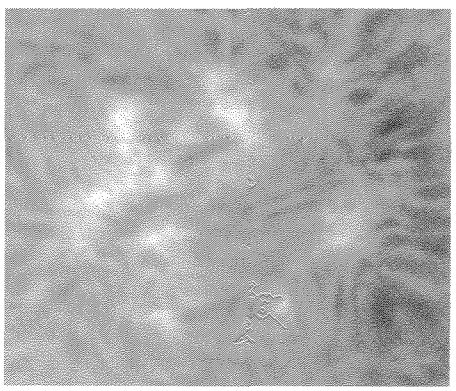
The same area as seen in visible light. The larger sunspot is approximately 4,000 kilometers in diameter—somewhat bigger than the moon.







Above: The first sunspot region of the new solar cycle is marked with a box in this full-disk image of the sun, taken at the hydrogen-α wavelength on August 16. There are two old-cycle regions along the equator. North is to the top. Below: A close-up of the boxed area, as seen in hydrogen-α light.



These images are available on the World Wide Web at http://sundog.caltech.edu under "First New Solar Cycle Spot." Images courtesy of Anders Johannesson and Bill Marquette, Big Bear Solar Observatory.

glare sunglasses filter out) all vibrate in the same direction—vertically, say. Circularly polarized light waves still vibrate in random directions, but the direction in which they vibrate rotates in unison—either clockwise or counterclockwise—as the wave travels. This effect is so small, however, that it's only observable in monochromatic light—light of a single wavelength. So the observer picks a wavelength of interest—which isn't necessarily one at which hydrogen or helium emits light—and photographs (or, in this day and age, videotapes) the sun through an appropriate filter. By setting the filter slightly to the blue, or shorter-wavelength, side of the observing wavelength, the counterclockwise-polarized component of the light shows up. (Counterclockwise polarization translates to negative polarity, or a south magnetic pole.) Repeating the process with the filter set a bit to the red, or longer-wavelength, side reveals the areas of clockwise polarization. And finally, subtracting the two images from each other gives a magnetogram—an image in which the positive areas appear bright and negative areas appear dark in proportion to the field strength.

This new sunspot appeared a bit earlier than astronomers expected. Typically, as a solar cycle comes to a close, late bursts of sunspot activity will appear near the equator before the new cycle starts. Scientists had seen such late pulses of sunspots in 1972 and 1984, but saw little late activity this time and therefore expected an early beginning to the new cycle, but not this early.

Sunspots have effects far beyond the sun itself, so while solar astronomers are excited by this news, people in many other fields are keenly interested as well. Solar flares often occur above sunspots, spewing high-energy electrons, x-rays, and other particles that slam into Earth's ionosphere, disrupting radio communications, painting the polar skies with the aurora's colorful lights, and sometimes even causing widespread power outages. These high-energy collisions also heat the upper atmosphere, expanding it farther out into space where it can grab hold of low-orbiting satellites and slowly drag them down, or tug on their outstretched solar panels and set them spinning like pinwheels. The sudden onset of the new cycle means that the operators of these satellites may have to use their boosters—if they have any—to loft them into higher orbits out of harm's way, while aging satellites whose fuel reserves are spent will wind up taking a fiery early retirement. And estimates of the useful lifetimes of satellites as yet unlaunched will need to be revised to account for the increased atmospheric drag. □

Random Walk

Galileo Update

Galileo, the JPL spacecraft currently en route to Jupiter, has been busy lately. On July 12, the spacecraft released a 339-kilogram probe, which is now traveling the remaining 82 million kilometers to Jupiter on its own. Upon arrival, the probe will parachute down through the brightly colored cloud layers that form the planet's visible surface, while sampling the atmosphere's composition and measuring its winds and lightning storms. As much as 75 minutes' worth of data will be relayed to the spacecraft for transmission to Earth. Meanwhile, on July 27, Galileo fired its main engine to maneuver onto its own approach path. Since then, it has been traveling through the most intense interplanetary dust storm on record, with peak counts of up to 20,000 particles per day compared to the norm of one particle every three days. Both probe and orbiter are slated to arrive at their destinations this December 7.

Watson Lectures Set for Autumn

The Fall 1995–Winter 1996 Earnest C. Watson Lecture Series will span 35 orders of magnitude, from the most distant quasars to the atom-sized world of nanotechnology. On the calendar: *Friday, September 22* (note the unusual day—all the other Watson lectures will be on Wednesdays, as per custom): "Science with the Keck Telescope"—S. George Djorgovski, associate professor of astronomy; *October 11*: "Heart Attack or Heartburn: New Chemical Diagnostics that Make the Call"—Thomas J. Meade, senior research fellow in biology; *November 15*: "The Caltech Electronic Nose Project"—Nathan S. Lewis (BS, MS '77), professor of chemistry; *January 10*: "Global Climate, Mass Extinctions, and the Fallout of Extraterrestrial Matter to the Earth"—Kenneth Farley, assistant professor of geochemistry; and *January 24*: "The Hopes (Amidst the Hype) of Nanotechnology"—Michael L. Roukes, associate professor of physics.

All lectures are at 8:00 p.m. in Beckman Auditorium; admission is free.

Simon Chairs Biology

On July 1, Mel Simon, the Biaggini Professor of Biological Sciences, became the chair of the biology division, succeeding John Abelson, the Beadle Professor of Biology, who is stepping down after six years of service.

Simon, who earned his BS in chemistry from the City College of New York and his PhD in biochemistry from Brandeis University, studies how organisms detect and respond to chemical changes in the environment—the mechanisms of sensory-cell function, and the biological circuits that process the resulting information.

A Summer's Harvest of Honors and Awards

The 1995 ASCIT (Associated Students of Caltech) Teaching Awards, given for excellence in teaching at the undergraduate level, went to Paul Dimotakis, Northrup Professor of Aeronautics and Professor of Applied Physics; Barbara Imperiali, associate professor of chemistry; Jeremy Kahn, assistant professor of mathematics; David Rutledge, professor of electrical engineering; and Jonas Zmuidzinas, assistant professor of physics. And this year for the first time, ASCIT also gave honorable mentions—to Jim McCarthy, assistant professor of astronomy; Moshe Sluhovsky, instructor in history; and Alan Weinstein, associate professor of physics.

The Graduate Student Council considered both classroom instruction and mentoring in presenting GSC Teaching Awards to Yaser Abu-Mostafa, professor of electrical engineering and computer science; Chris Brennen, professor and executive officer for mechanical engineering; George Rossman, professor of mineralogy; and Edward Zukoski, professor of jet propulsion and mechanical engineering, emeritus. Outstanding Teaching Assistant Awards went to Patrick Chuang of environmental engineering and Sanjoy Mahajan of physics.

Professor of Geophysics Tom Ahrens (MS '58) will recieve the 1995 Arthur L. Day Medal and be given a life fellowship in the Geological Society of America, in honor of his "outstanding contribution to geologic knowledge through the application of physics and chemistry to the solution of geologic problems."

Pamela Bjorkman, associate professor of biology, and associate investigator for Howard Hughes Medical Institute, has won the Paul Ehrlich Prize for her research into cancer and AIDS, an award she is sharing with two other scientists.

Thomas Caughey, Hayman Professor of Mechanical Engineering, has been named the 1995 recipient of the J. P. Den Hartog Award by the American Society of Mechanical Engineers for "lifetime contributions to the teaching and practice of vibration engineering."

Professor of Computer Science Mani Chandy has been chosen to receive the 1996 Koji Kobayashi Computers and Communications Award from the Institute of Electrical and Electronics Engineers.

William Johnson, Mettler Professor of Engineering and Applied Science, will receive the 1996 William Hume-Rothery Award from the Minerals, Metals & Materials Society, in recognition of his contributions to the science of alloys.

Professor of Physics Harvey Newman and an international team of physicists working with him on the MARK J experiment have been awarded a special prize by the European Physical Society "for establishing the existence of the gluon." Theirs was the first direct observation of gluons, the fundamental quanta responsible for binding together quarks (the basic building blocks of matter) within more complex particles such as pions, kaons, protons, and neutrons.

Dinakar Ramakrishnan, professor of mathematics, has been inducted into the Johns Hopkins Society of Scholars. Ramakrishnan specializes in algebraic number theory and algebraic geometry.

Assistant Professor of Biology Erin Schuman has been named a 1995 Pew Scholar by the Pew Scholars Program in the Biomedical Sciences. (See page 18 for a description of Schuman's research.)

Edward Stone, vice president, director of JPL, and Morrisroe Professor of Physics, has been awarded a NASA Outstanding Leadership Medal.

Professor of Electrical Engineering P. P. Vaidyanathan has been named the recipient of the 1995 Frederick Emmons Terman Award, sponsored by Hewlett-Packard and presented by the American Society for Engineering Education.

Ahmed Zewail, Pauling Professor of Chemical Physics and Professor of Physics, has received the Order of Merit, First Class, from Egyptian president M. Hosni Mubarak, an honor akin to knighthood in Britain. Zewail, born and educated in Egypt but now an American citizen, is the first nonresident of Egypt to be so honored. Zewail also won the Leonardo da Vinci Award of Excellence, for achievements of great international significance. An international jury selected him and two others for the award, which is sponsored by the Moët Hennessy–Louis Vuitton Foundation of France.

The Northridge earthquake revealed how vulnerable our steel-frame buildings are, but some other types of modern construction didn't perform as well as expected, either. Seven parking structures made of precast concrete, for example, suffered at least partial collapse. This three-story parking garage at the Northridge Fashion Center became a split-level. Photo courtesy of the Earthquake Engineering Research Institute.