ENGINEERING & SCIENCE

California Institute of Technology

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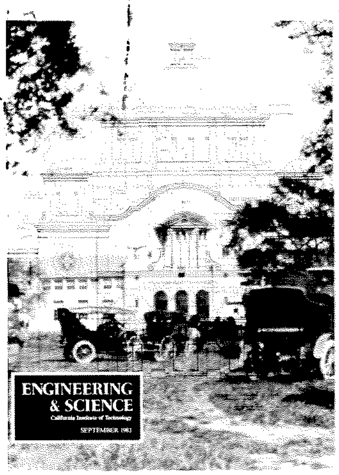
In This Issue



Looking Back

On the cover — a view of Caltech's first building on its present campus, both as it really looked and as its architects visualized it. Throop Hall, originally dedicated as Pasadena Hall on June 8, 1910, was paid for with money raised by the citizens of Pasadena, and it housed the entire institution until 1917. For more photos of the early look of Caltech, see "A Unified Vision," which begins on page 13.

Second Sight

While Charles Elachi doesn't claim second sight for himself, his research on the sensing of remote objects by radar has given him a remarkable glimpse of what lies beneath some surfaces. He has been leader of a group at JPL that built and employed the radar apparatus carried on the second flight of the space shuttle, and he has done considerable research on the theory of electromagnetism. Last spring Elachi gave a Watson Lecture on some of the surprising results of all that looking down not only at but into the earth. "Seeing under the Sahara: Spaceborne Imaging Radar," which begins on page 4, is adapted from that lecture.

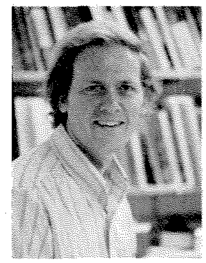
Elachi is a Caltech alumnus (MS '69, PhD '71), who is currently a senior research scientist at JPL and a lecturer in electrical engineering on the campus. A native of Lebanon, he originally came to Pasadena from Grenoble, France, where he had received a BSc in physics at the University and an engineer's diploma at the Polytechnic Institute.

Honorable Mention

John Miles, who is professor of applied mechanics and geophysics and vice chancellor for academic affairs at UC San Diego, may have one of the most spectacular degree-earning records in Caltech alumni history. Five of them were awarded to him in three consecutive commencements — a BS in 1942, two MS's in 1943, and an Engineer's degree and a PhD in 1944. From 1945 until 1961 he was on the faculty at UCLA. Then — after three years as professor of applied mathematics at the Institute of Advanced Studies of the Australian National University — he returned to the United States and UC San Diego.

Miles has had a distinguished career. He is a member of a number of professional and honorary organizations, including the National Academy of Sciences; and the American Society of Mechanical Engineers awarded him its prestigious Timoshenko Medal for 1982. "An Applied Mathematician's Apology," which begins on page 9, was Miles's speech on that occasion.

Thinking about Sight



David Van Essen, associate professor of biology, received his BS at Caltech in 1967 and then went away for nine years, returning as a faculty member in 1976. In the interim he got a PhD at Harvard in 1971 and then went abroad for further study at the University of Oslo in Norway and at University College in London.

Van Essen is interested in discovering the ways visual information, transmitted from the eyes, is processed in higher centers of the monkey's brain, and he has become an expert in the field. It is a field with great potential for useful application to human problems. Knowledge of the function of the many anatomically distinct visual areas located in the cerebral cortex can, for example, provide valuable insights about the capacities for visual perception and recognition shared by monkeys and humans. "Insight into Sight," which begins on page 16, is adapted from several lectures Van Essen has recently given on his specialty.

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ENGINEERING & SCIENCE

CALIFORNIA INSTITUTE OF TECHNOLOGY | SEPTEMBER 1983 — VOLUME XLVII, NUMBER 1

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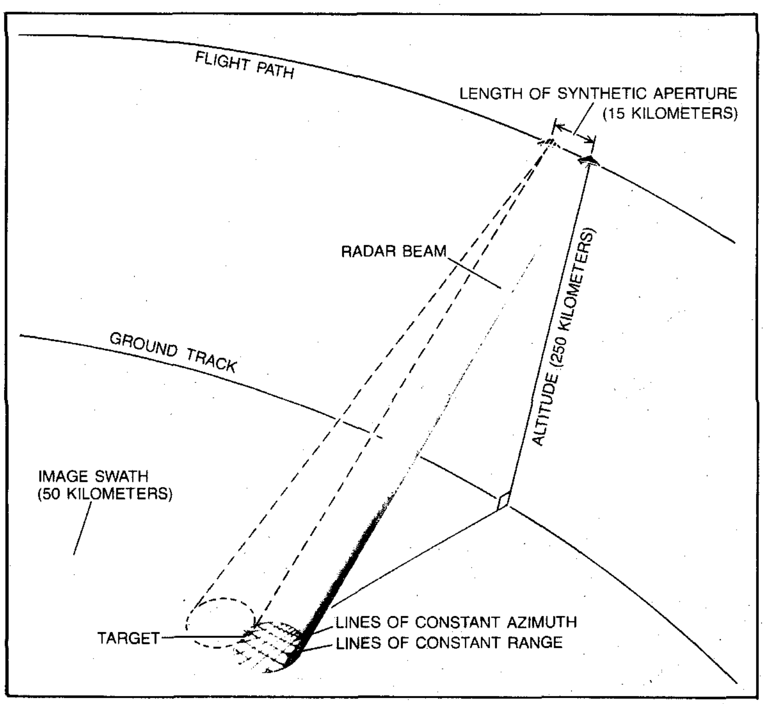
Seeing under the Sahara: Spaceborne Imaging Radar

by Charles Elachi

OUR EYES are sensitive to only a very narrow band of the electromagnetic spectrum. But in the last few years instruments launched into orbit around the earth have been viewing the earth at wavelengths beyond the visible and providing some richly detailed and often surprising images of the earth's surface, because the waves in different parts of the electromagnetic spectrum have different properties that determine what the instrument will "see." Landsat sensors operate in the visible and near infrared, while Seasat and the space shuttle Columbia have carried imaging radars, which "see" beyond the far infrared with the still longer microwaves. The Shuttle Imaging Radar (SIR-A) on Columbia sent back some particularly startling images of southern Egypt, revealing an unknown geomorphology buried beneath the eastern Sahara Desert — ancient river valleys and dry stream beds indicative of a much different past climate.



The Shuttle Imaging Radar (SIR-A) synthesized a 15-kilometer-long antenna by using the shuttle's motion along its flight path to put its 10-meter antenna in a series of locations and by then combining the signals coherently. The two-dimensional radar image is resolved by measuring its range (how long it takes the echo of the microwave pulse to return to the sensor) and its azimuth (determined by the Doppler shift, or change in frequency due to the relative motion of spacecraft and target).

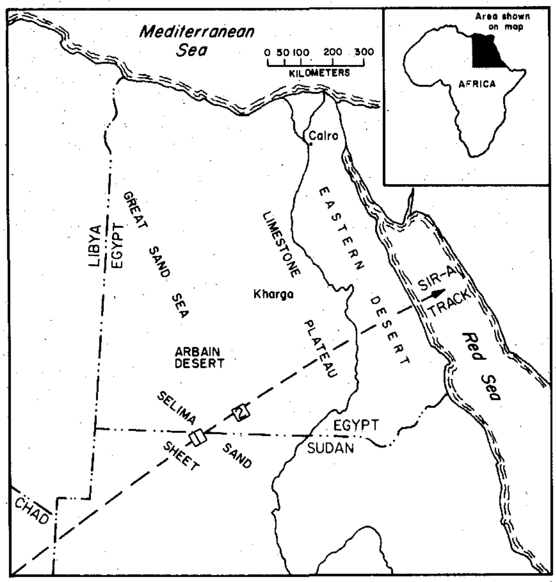
A radar instrument sends out microwave pulses that bounce off a target and echo back. In one dimension, the imaged scene can be resolved by measuring how long it takes the echo to return to the sensor. Doppler shifts of the echoes, the change to higher or lower frequencies, determine the resolution in the other dimension. So if we process and analyze all the information (time delay and spectral content) in the signals, we end up with a two-dimensional image. Differences in the radar backscatter are a function of the slope and roughness of the target and of its electrical properties. Radar waves are attenuated by the electrical properties of moist soil, but very dry sand would theoretically let the radar signal pass through a sand cover. In the eastern Sahara where it rains only about every 50 years, the sand is about as dry as soil can get, and the radar waves could probe through a sand layer a few meters thick.

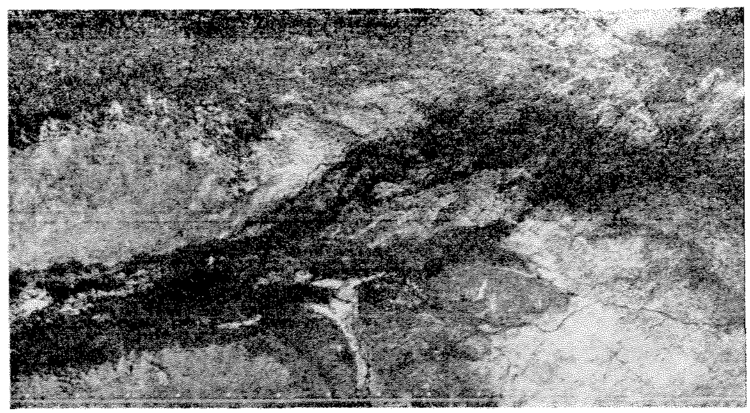
The resolution of an image depends on the ratio of the operating wavelength to the size of the sensor aperture or, in the case of radar, the length of the antenna. Since the wavelength of microwaves is several orders of magnitude greater than that of light (SIR-A's signal had a 24-centimeter wavelength), the antenna necessary for adequate resolution in imaging would have to be enormous. This problem has been solved in much the same way that radio astronomers with very long baseline interferometry (VLBI) create an antenna with a baseline of many thousand kilometers by combining the signals from an array of antennas in different locations around the world. In what is called synthetic aperture radar we don't actually use an array of antennas but rather take advantage of the fact that the antenna is moving, using the motion of the satellite to put the antenna in different locations and then combining the signals coherently, thus synthesizing a long aperture. The signal from the antenna in one position on the flight path is added to the signal from the next position on the flight path and so on a couple of thousand times. So even though our antenna for the first Shuttle Imaging Radar was only 10 meters long, we actually had an antenna effectively 15 *kilometers* long.

Because the shuttle could travel 15 kilometers in two seconds, we had to have stable clocks to be able to combine all the information precisely. We also needed a powerful computer to coherently add together the hundreds of millions of bits per second from the radar echoes to generate an image. Since the fastest computer available is still too slow to handle this rate of data processing in real time, we used optical holographic techniques in SIR-A to combine all the signals and generate the radar images.

SIR-A flew on the second shuttle flight in November 1981, the first one to carry a scientific payload. When we picked up the film after the landing and took it back to JPL, everyone on the project stayed up all night working — developing the original film, processing it on an optical correlator, and developing the resulting film to get the image. At 6 a.m., when the first one emerged successfully (it was over Australia), we had a big champagne celebration.

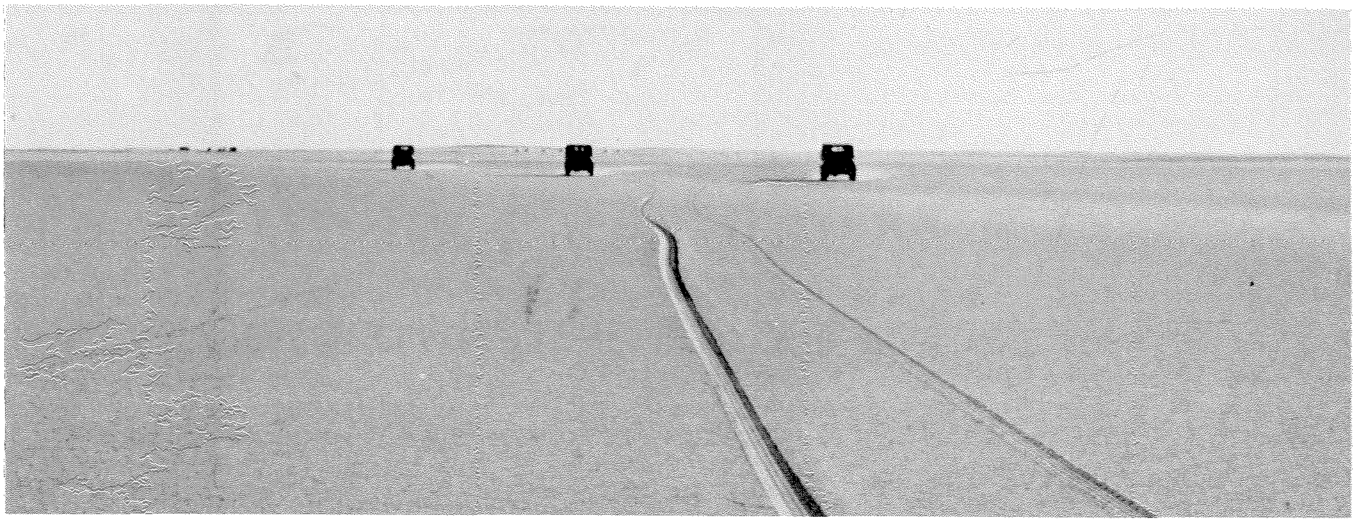
We had collected a large amount of data on the morphology of many regions around the earth; we imaged in 50-kilometer-wide swaths a





The shuttle's path across the eastern Sahara is indicated by the dotted line originating in the lower left corner of the map. The box marked 1 represents the location of the SIR-A image below, which is compared with a Landsat image of the same area (bottom). At lower right in the radar image, channels can be seen that are practically invisible in the corresponding Landsat view. The box marked 2 on the map is the location of the images on page 8.

total of about 10 million square kilometers around the world, about the area of the United States. So it took us several months to develop all the film, which was more than 1000 meters long and weighed 20 kilograms. We developed it in pieces, and the Egypt piece was somewhere in the middle. We finally got to it two months after the mission because we weren't expecting anything particularly exciting from it. Even



Although there are no roads in the Arabian Desert, trucks could drive easily across the sand "pavement."

though we knew that penetration through sand was theoretically possible, we weren't looking for it. This was a discovery purely by chance.

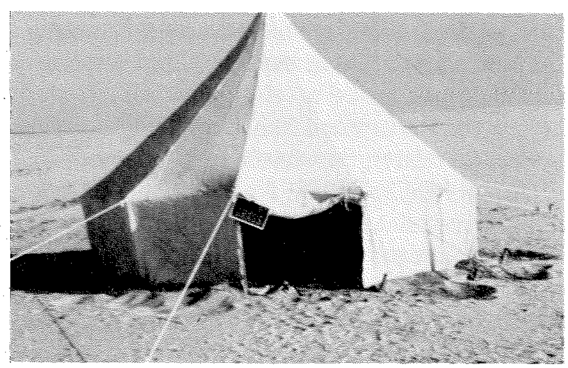
Our first reaction when we saw the drainage channels and valleys on the image was that we had the wrong track, that it was somewhere else, not the Egypt-Sudan border. One of the ten investigators on the team, Carol Breed, a geologist with the United States Geological Survey in Flagstaff, studies sand dunes and deserts all over the world. She had just returned from that area two months before the shuttle flight and swore there was no indication of such channels on the surface; she suggested that we might be penetrating the surface sand cover.

We rechecked our coverage and verified that the image was indeed over southern Egypt. It was kind of a slow process convincing ourselves that the radar had indeed penetrated the sand, but as soon as we realized it, we did some quick calculations and found that theoretically we really could be penetrating 2 to 6 meters. When we realized that we were seeing below the surface, we knew that it was a major discovery for the whole field of earth remote sensing. But the USGS co-investigators and I, as the principal investigator on the experiment, wanted to make sure it was really true. Not only were we curious from a geological standpoint, but our reputations were at stake. So we planned an expedition to Egypt to actually follow the same path as the shuttle to verify whether and how far we were seeing below the sand.

Seven scientists joined the expedition in September 1982: four geologists from USGS, an anthropologist from the University of Pennsylvania, and Ronald Blom and myself from JPL. The Egyptian Geological Survey organized the whole expedition — six jeeps, two trucks, tents, food, water, and everything we would need for two weeks in one of the most barren and desolate places on earth.

We flew from Cairo to Kharga, an oasis of about 10,000 people, which was the closest we could fly to the Selima Sand Sheet, part of the Arbain Desert (which, in turn, is part of the Eastern Sahara) straddling the border of Egypt and the Sudan. Then we had to drive, starting at 10 a.m. and arriving at midnight. There were no roads, but we could drive 60 mph on the sand because the surface is covered with a thin pavement of pebbles. This very fine, dry sand has accumulated over several thousand years, blown down by the prevailing winds from the Great Sand Sea to the north, and the top layer of pebbles formed a sort of pavement that

(Near right) The author, standing at right, poses for a desert portrait with some of the Egyptian workers. (Center) The sign on the camp tent warns people to keep off the grass. (Far right) Artifacts, such as this arrowhead, from 100,000 to 200,000 years old, were found lying on the desert surface.



doesn't blow into the air even in a high wind. The Arbain Desert is totally uninhabited. It's basically featureless, and the few rocky outcrops look much like the Viking Landers' close-up views of Mars. During the entire ride we didn't see a single piece of grass or anything green. Compared to this, the Mojave Desert is a lush garden. The aridity scale of this region is 200; that means that the capacity of the sun to evaporate moisture is 200 times greater than the amount of moisture coming from rain or condensation. In comparison, Death Valley has an aridity factor of 7.

Life in a scientific camp in the middle of such a desert was not as bad as you might think. Our Egyptian support crew put up all our tents and even made up our beds. It was almost as good as home. We also had a cook, but the food wasn't quite like home. The area was so dry that by the second day all the moisture had been sucked out of the pita bread, and for the next two weeks we ate pita crackers.

Our diet staple was duck; every night we had duck soup and then duck for dinner. The ducks stayed with our cook in the kitchen tent, where he also slept. We asked him how he picked a particular duck for that night's meal, and he told us that he chopped the head off the noisiest one that had kept him awake the previous night. After a couple of days the ducks got very quiet. We were really tired of duck by the time we got back to Kharga two weeks later at the end of the expedition and were eager for a steak or at least something different. But the only restaurant in town had only one item on the menu each night. I'm sure you can guess what it was *that* night.

In two weeks of ducks and digging we did find what we were looking for — evidence that the shuttle radar had indeed seen through the sand surface. A dozen Egyptian workers came with us to dig. For awhile they thought we had gone crazy from the sun, going out into the middle of nowhere and asking them to dig. After they dug these holes, they would see us all

Digging holes in the middle of nowhere (while the scientists photographed) made no sense to the Egyptians.

taking notes and photographs, and then we would go on to the next place and start all over again. Fortunately I know Arabic and could explain to them what we were doing.

It took us a while to accurately locate ourselves when all we could see was sand all over the place. We went to several places where we had seen interesting features on our radar images, and we must have dug about 40 holes. The sand depths in the holes ranged from 0.8 meters to 2.5 meters. In one area the thing we were looking for was the same white limestone that is exposed in a major plateau emerging from the sand to the east of this area, closer to the Nile Valley. In the radar image the exposed limestone looks very bright because it is a rough surface. The sand surface, which is perfectly smooth, should appear dark on the radar, but instead it looks just as bright as the exposed limestone. When our Egyptian workers dug through the sand, they did hit limestone. This convinced us that the radar was reflecting off the limestone bedrock beneath the sand.

We also found hundreds of human artifacts, such as arrowheads and hand axes, just lying on the surface. We weren't the first to make this discovery. Anthropologists have been interested in the area for the last 30 years, puzzled as to how such an inhospitable climate could have supported a population. They had even found cave drawings of domesticated animals. The artifacts we found are from the Acheulian period — 100,000 to 200,000 years old — but ostrich eggshells found by us and previous expeditions have yielded carbon-dated ages as young as 6,000 years. This is very recent even on a human time scale; the pyramids, for example, were built in northern Egypt about 5,000 years ago.

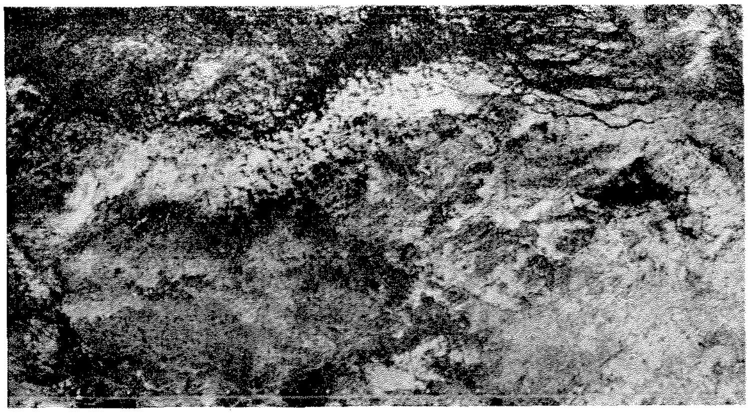
It is now generally thought that over the last

200,000 years the climate has been changing back and forth from very arid desert to a somewhat more savannah-like environment with vegetated areas. During the more hospitable periods, people and animals migrated from central eastern Africa up into the Sudan and Egypt. When it became arid again, all habitation ceased. Our discovery of the buried river valleys, some wider than the Nile, gives strong support to the hypothesis that the climate was indeed less arid in the past.

Another puzzle that our discovery helps solve is why the area is so flat. Usually such flatness is the result of fluvial activity. There *are* dry stream channels running down a large plateau to the west of the Arbain Desert but then disappearing under the sand. Our verification of the continuation of those rivers has helped explain some of the geologic history of the region.

By radar mapping the entire area, we hope to be able to explain much more of the geologic and hydrologic history of this desert region. A complete map could establish the locations of dry lakes and sites of likely ancient habitation, and uncover the evolution of the Nile and its tributaries and the drainage basins of northeast Africa. SIR-A was the first piece of scientific hardware to come back from space on the shuttle, and the same instrument, with a fair amount of modification and retitled SIR-B, will go up again on the shuttle in August 1984 to accomplish this task as well as investigate the radar penetration capability in other arid regions in China, South Africa, and Peru.

The SIR-A image (top) shows a region of drainages in the top right corner invisible to Landsat (bottom). These views are of the Arbain Desert at the site marked 2 on the map on page 5.



About 10 percent of the earth's surface is arid enough to get some radar penetration below the surface. A region doesn't have to be as dry as the Sahara, as we had originally thought. (Actually, radar can see four kilometers through Antarctic ice to the bedrock below and has discovered Mayan canal systems buried in the Guatemalan jungles, but that's another story.) We looked up some older radar images made by Seasat in 1978 of the Mojave Desert, which, as I mentioned before, is a garden spot compared to southern Egypt. And we saw some surprising features that didn't appear on photographs — dikes of harder rock extending beneath the alluvium. Recently a couple of team members went out to this particular site near Barstow and measured the depth of the alluvium at two meters, which is theoretically consistent with tests we had done with some of the drier sand from the Sahara (which, in theory, can be penetrated as far as six meters). Before SIR-B goes up we plan to bury reflectors, which will show up very bright on the radar image, at various depths to see how far below the surface we can see them.

A still more sophisticated instrument, SIR-C, has been proposed to fly in 1987. This one will send out signals at different frequencies, which will penetrate to different depths, and in a sense will be able to peel the different levels like an onion.

Radar is not just earth bound. In 1988 the Venus Radar Mapper mission will carry an instrument very similar to SIR-A to see through the total cloud cover of that planet and give us the first complete high-resolution map of its surface. Saturn's large moon Titan, as revealed in images sent back by Voyager, is also completely surrounded by clouds. Discussions are currently taking place about sending a radar mission to Titan by the end of this decade.

But it has been the technology of the past 20-30 years that has broadened our sight, allowing us to see beyond the small part of the electromagnetic spectrum that evolution allotted us, into the ultraviolet, the infrared, and the microwave, giving us a more complete picture of what's happening around us, a more in-depth understanding of the features of our own planet and, eventually, others. □

An Applied Mathematician's Apology

by John Miles

I EXPECT that many of you will recognize my title as derived from G. H. Hardy's *A Mathematician's Apology.* But, whereas Hardy felt no need to define *mathematician,* the position is otherwise for an *applied mathematician.* Some mathematicians, I fear, might choose to borrow von Kármán's definition of an aerodynamicist and define an applied mathematician as one who "assumes everything but the responsibility."

The applied mathematician, naturally, might prefer a more flattering description. To this task I am unequal, but I believe that the spirit of applied mathematics is admirably conveyed by Lord Rayleigh's statement [from the preface to the second edition of his *Theory of Sound*]:

> In the mathematical investigations I have usually employed such methods as present themselves naturally to a physicist. The pure mathematician will complain, and (it must be confessed) sometimes with justice, of deficient rigor. But to this question there are two sides. For, however important it may be to maintain a uniformly high standard in pure mathematics, the physicist may occasionally do well to rest content with arguments which are fairly satisfactory and conclusive from his point of view. To his mind, exercised in a different order of ideas, the more severe procedure of the pure mathematician may appear not more but less demonstrative.

Now it may be objected that Rayleigh was a physicist, not an applied mathematician. Such distinctions are difficult. I am told that a physicist and a mathematician once disagreed on whether the late John von Neumann was a physicist or a mathematician. The physicist suggested that they resolve their argument by putting the following problem to von Neumann: *Two locomotives are approaching one another on the same track at a relative speed of 10 miles per hour. A deer bot-fly begins to fly back and forth between the locomotives at a constant speed of 100 miles per hour at a time when the locomotives are 5 miles apart. How far does the deer bot-fly fly before he is crushed between the two locomotives?* Now the idea here, or at least the idea held by physicists, is that a mathematician naturally will calculate the general term for the fly's *n*'th passage and then sum the series — whence, after some considerable time, he will arrive at the answer. The physicist, on the other hand, supposedly remarks to himself that the elapsed time between start and finish is 5 miles divided by 10 miles per hour, or 1/2 hour, and hence comes up very quickly with the answer that the deer bot-fly must fly 50 miles.

Well, our physicist put the question to von Neumann, and von Neumann answered instantly, "50 miles." The physicist started to exclaim, "Oh, Professor von Neumann, I am so glad to learn. . . ." "Oh, it was nothing," interrupted von Neumann. "I only had to sum a series!"

At this point, lest I be placed in the position of disbursing entomologically unsound information to a general audience, I think that an aside on the deer bot-fly may be in order. I therefore would like to exhibit what is perhaps both my shortest and my most widely read publication, a letter written to the Sydney *Morning Herald* on 21 January 1963.

> Sir,
>
> I refer to a recent series of letters in these columns . . . commenting on the speed of the deer bot-fly. Claims that this insect, also known simply as the deer fly, could achieve speeds up to 818 miles per hour [mph] have been made repeatedly for over a quarter of a century. E.g., the *Illustrated London News,* 1 January 1938, credited the female deer fly with a speed of 614 mph and the male with 818 mph (this alleged advantage of the male, presumably in the interests of biological necessity, appears to have been overlooked in other sources). *Newsweek,* November 15, 1954, stated, "Some naturalists claim that the little deer bot-fly, the fastest thing alive outside of winged man, can hit 400 mph." It would appear that, by 1954, naturalists had become aware of the difficulties of supersonic flight.
>
> In fact, this question was dealt with decisively by Irving Langmuir, Nobel Laureate, in 1938 [*Science,* Vol. 87, pp. 233-234, March 11, 1938]. Langmuir identified the original source of such claims as Charles H. T. Townsend, who, writing in the *Journal of the New York Entomological Society,* stated that "on 12,000 foot summits in New Mexico I have seen pass me at an incredible velocity what were certainly males of Cephenomyia. I could barely distinguish that something had passed — only a brownish blur in the air of about the right size for these flies and without a sense of form. As closely as I can estimate, their speed must have approximated 400 yards per second." Dr. Townsend did not say how he identified the sex of the "brownish blur" and appears not to have realized that 400 yards per second is equivalent to 818 mph. . . .
>
> Langmuir, on the basis of reasonable assumptions, estimated that, to achieve a speed of 818 mph, a deer fly would have to consume 1.5 times his own weight of food each second; at 25 mph, the corresponding figure would be 5 percent of his weight per hour. Langmuir also estimated, on the basis of experiments, that a deer fly would appear merely as a blur at 13 mph, would be barely visible at 26 mph, and would be wholly invisible at 64 mph. And, referring to the statement that deer flies "strike one's bare skin with a very noticeable impact," he commented that if the speed were 818 mph "such a projectile would penetrate deeply into human flesh." He concluded that "a speed of 25 miles per hour is a reasonable one for the deer fly, while 800 miles per hour is utterly impossible."
>
> I remain, Sir,
>
> Yours faithfully,

To return to the problem of defining an applied mathematician: The lines were not always drawn so sharply, either between physics and mathematics or between pure and applied mathematics. Indeed, applied mechanics as we know it today was largely the creation of Euler and the Bernoullis, and the vibrating string was the field on which such as Euler, Daniel Bernoulli, D'Alembert, and Lagrange waged their celebrated battles on the nature of a solution to a partial differential equation.

Von Kármán, in his 1940 address to the ASME on "Mathematics from the Engineer's Viewpoint," called the 18th century the "heroic period" of mathematics and the 19th century the "era of codification." Mathematics in the 18th century was largely, if not mainly, motivated by an understanding of the real, physical world. All of this had changed by the middle of the 19th century, at least on the Continent — although we should not forget that Gauss, surely the greatest mathematician of that century, was not above applied mathematics.

In England, this transition was delayed, and, as late as 1874, Maxwell declared: "There may be some mathematicians who pursue their studies entirely for their own sake. Most men, however, think that the chief use of mathematics is found in the interpretation of nature." And, if this seems too extreme, we have only to read the papers of Sir George Gabriel Stokes, the Lucasian Professor of Mathematics in the University of Cambridge through the end of the 19th century. But then I suppose that most mathematicians would regard Stokes as a physicist. (As far as I know, no one ever asked him about the deer bot-fly and the locomotives.)

I have, perhaps, dwelt too long on a bootless attempt to define an applied mathematician and should turn to what I originally promised — an apology for being one. This theme — of explaining why one does what he does — has been dealt with by both Hardy and A. E. Housman. Hardy began his 1920 inaugural lecture as Professor of Mathematics at Oxford by saying:

> There is one method of meeting such a situation which is sometimes adopted with

> considerable success. The lecturer may set out to justify his existence by enlarging upon the overwhelming importance, both to his University and to the community in general, of the particular studies on which he is engaged. He may point out how ridiculously inadequate is the recognition at present afforded to them; how urgent it is in the national interest that they should be largely and immediately re-endowed; and how immensely all of us would benefit were we to entrust him and his colleagues with a predominant voice in all questions of educational administration.

All of which sounds familiar today.

Hardy returned to this theme some 20 years later, and, in *A Mathematician's Apology,* says:

> A man who sets out to justify his existence and his activities has to distinguish two different questions. The first is whether the work which he does is worth doing; and the second is why he does it, whatever its value may be. The first question is often very difficult, and the answer very discouraging, but most people will find the second easy enough even then [and] the only answer which we need consider seriously [is] I do what I do because it is the one and only thing that I can do at all well.

And, as for the first question, whether the work he does is worth doing, Hardy concludes his *Apology* by saying:

> The case for my life, then, . . . is this: that I have added something to knowledge, and helped others to add more; and that these somethings have a value which differs in degree only, and not in kind, from that of . . . other artists, great or small, who have left some kind of memorial behind them.

But, to Hardy at least, mathematical creation had a special "character of permanence" which led him to declare: "Archimedes will be remembered when Aeschylus is forgotten, because languages die and mathematical ideas do not."

C. P. Snow, referring to this eloquent statement, questioned whether mathematical fame was not a little too "anonymous" to be wholly satisfying and pointed out that the work of Aeschylus carries with it a much more coherent picture of the writer's personality than does that of Archimedes. Another friend of Hardy's, when they were passing the Nelson column in Trafalgar Square, asked him whether, if he had a statue on a column in London, he would "prefer the column to be so high that the statue was invisible, or low enough for the features to be recognizable?" Hardy answered, "I would choose the first alternative, Dr. Snow, presumably, the second."

A. E. Housman, in his 1892 *Introductory Lecture* to the united Faculties of University College, London, attacks the question on a broader front. As he points out,

> Everyone has his favorite study, and he is therefore disposed to lay down, as the aim of learning in general, the aim which his favorite study seems specifically fitted to achieve, and the recognition of which as the aim of learning in general would increase the popularity of that study and the importance of those who profess it. . . . And accordingly we find that the aim of acquiring knowledge is differently defined by different people. In how many different ways, I do not know, but it will be sufficient . . . to consider the answers given by two great parties: the advocates of those sciences which have now succeeded in arrogating to themselves the name of Science, and of those studies which call themselves by the title, perhaps equally arrogant, of Humane Letters.
>
> The partisans of Science define the aim of learning to be utility. I do not mean to say that any eminent man of science commits himself to this opinion; some of them have publicly and scornfully repudiated it, and all of them, I imagine, reject it in their hearts. But there is no denying that this is the view which makes Science popular. . . . And the popular view has the very distinguished countenance of Mr. Herbert Spencer. . . . The following, for instance, is the method by which he [Spencer] endeavors to terrorise us into studying geology. We may, any of us, some day, take shares in a joint-stock company, and that company may engage in mining operations; and those operations may be directed to the discovery of coal; and for want of geological information the joint-stock company may go mining for coal under the old red sandstone, where there is no coal; and then the mining operations will be fruitless, and the joint-stock company will come to grief, and where shall we be then? This is, indeed, to eat the bread of carefulness. After all, men have been known to complete their pilgrimage through this vale of tears without taking shares in a joint-stock company. But the true reply to Mr. Spencer's intimidations I imagine to be this: that the attempt to fortify man's estate against all contingencies by such precautions as these is in the first place interminable and in the second place hope-

less. As Sarpedon says to Glaucus in the *Iliad*, a hundred thousand fates stand close to us always, which none can flee and none avoid. The complexity of the universe is infinite, and the days of a man's life are threescore years and ten.

Turning to the humanists, Housman tells us that:

> While the partisans of Science define the end of education as the useful, the partisans of the Humanities define it, more sublimely, as the good and the beautiful. We study, they say, not that we may earn a livelihood, but that we may transform and beautify our inner nature by culture.

But he finds the partisans of the Humanities no more convincing than those of Science and concludes that:

> The two fancied aims of learning laid down by these two parties will not stand the test of examination. . . . And no wonder, for these are the fabrications of men anxious to impose their own favorite pursuits on others, or of men who are ill at ease in their conscience until they have invented some external justification for those pursuits. The acquisition of knowledge needs no such justification. . . . Curiosity, the desire to know things as they are, is a craving no less native to the being of man, no less universal through mankind, than the craving for food and drink.
>
> For knowledge . . . is not merely a means of procuring good, but is good in itself simply: it is not a coin which we pay down to purchase happiness, but has happiness indissolubly bound up with it.

Returning to my own apology, I want to make some general remarks on what an applied mathematician does and how he does it. It is customary, in the first place, to distinguish between the attitudes and activities of the applied mathematician, on the one hand, and, say, the theoretical physicist on the other hand. In fact, as I have already said, this distinction is not a very sharp one — not nearly as sharp, for example, as the distinction between the applied mathematician and the pure mathematician.

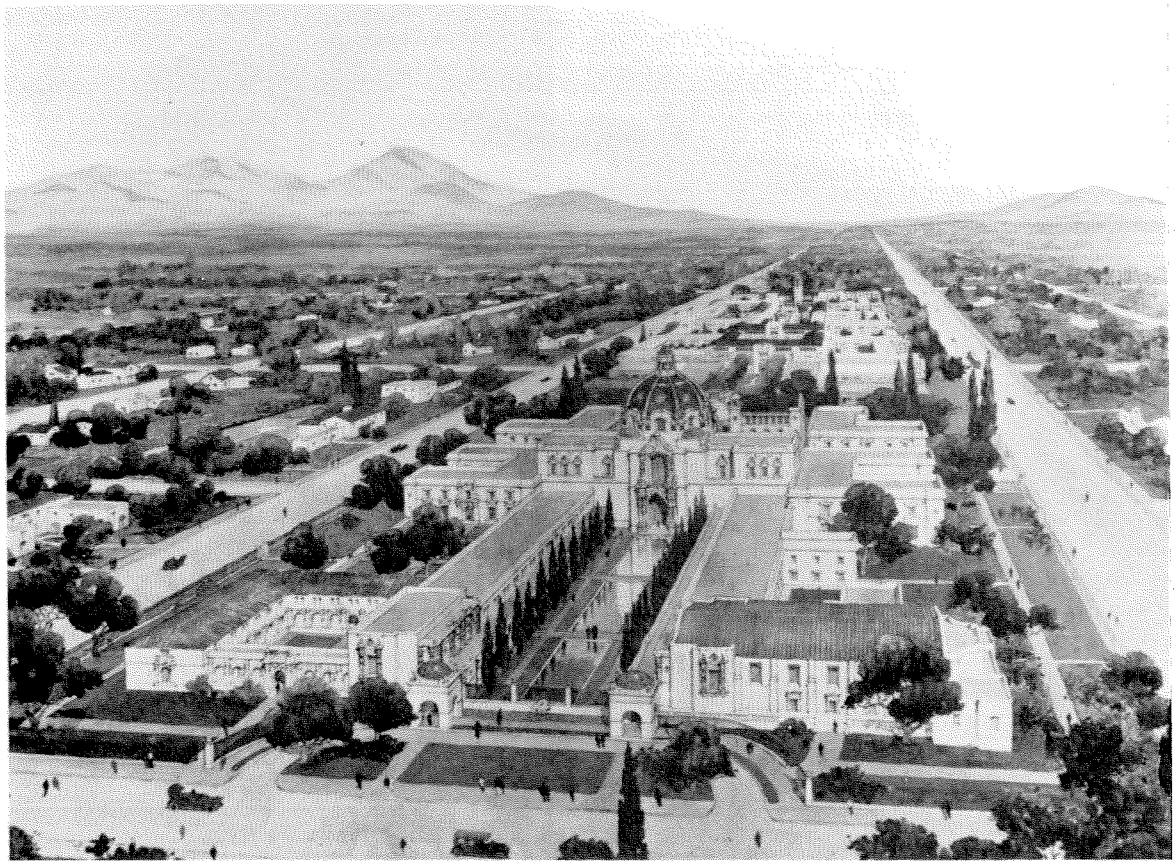
It is sometimes argued that the primary interest of the theoretical physicist is the discovery of *new* physical laws, whereas that of the applied mathematician is the description of physical phenomena in terms of *known* physical laws. Now, to some extent, this is true; the modern theoretical physicist works, for the most part, in areas where the so-called laws are less securely established, usually because they fail in certain critical predictions, whereas the applied mathematician typically works in an area such as mechanics, where the basic framework goes back at least to Euler and Cauchy, if not to Newton. On the other hand, very few theoretical physicists are so fortunate as actually to discover new laws, and the adequacy of the accepted laws of mechanics for the prediction of next winter's rainfall, let alone the next ice age, is still open to question. Nevertheless, the foundations of fluid mechanics are pretty firm, and — even in areas where one expects them to break down, as in describing shock waves of only a few mean-free paths in thickness — the Navier-Stokes equations have been spectacularly successful. So much so that David Gilbarg once remarked that "equations have often been successful beyond the limits of their original hypotheses, and indeed this type of success is one of the hallmarks of a great theory."

This brings me to a theme that has, I believe, always been appreciated by both theoretical physicists and applied mathematicians but that has been espoused with special vigor by James Lighthill — namely, that the real issue for the applied mathematician is the interaction between mathematical analysis and physical ideas; and that, in particular, the primary job of the applied mathematician is the generation of new physical *ideas* through mathematical investigations. As Truesdell and Toupin put it, in their *Principles of Classical Mechanics and Field Theory,*

> The developments must illumine the *physical aspects* of the theory, not necessarily in the narrower sense of prediction of numerical results for comparison with experimental measurement, but rather for the grasp and picture of the theory in relation to experience. In this spirit do we pursue our subject, *neither seeking nor avoiding* mathematical complexity.

I believe that the central idea which I have been trying to convey in these last remarks — that mathematical analysis of physical problems frequently leads to physical ideas that become evident only after the formal analysis has been carried through — can best be expressed by another of von Kármán's favorite aphorisms: "Mathematics is sometimes more intelligent than the people who use it!"

In fact, I do not wish either to overvalue, or to undervalue, the role of mathematics in the understanding of nature. But I do say, quite unequivocally, that it *is* with the understanding of nature that applied mathematics is primarily, if not wholly, concerned.□

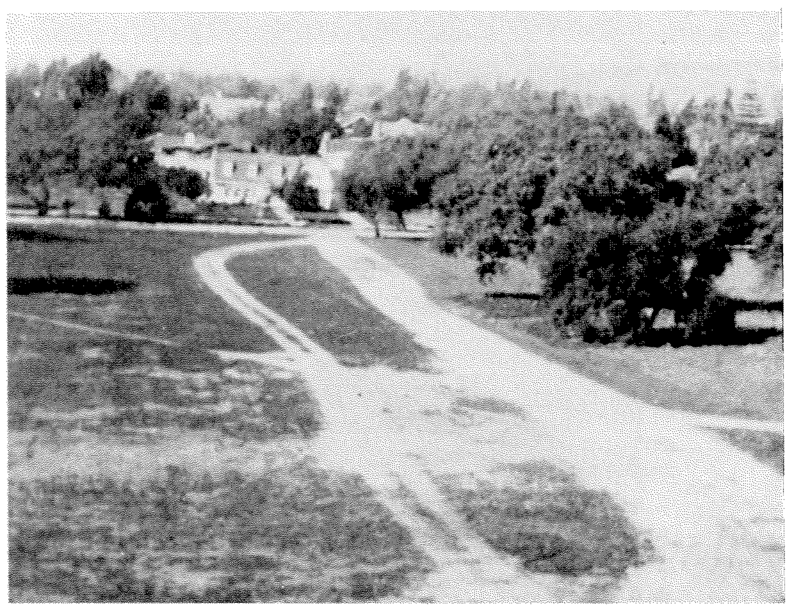


In 1923, Bertram Goodhue presented this aerial perspective of the proposed campus viewed from the west. The huge central building was to be a library. Today's Millikan Library is not in that style, but it is in that location.

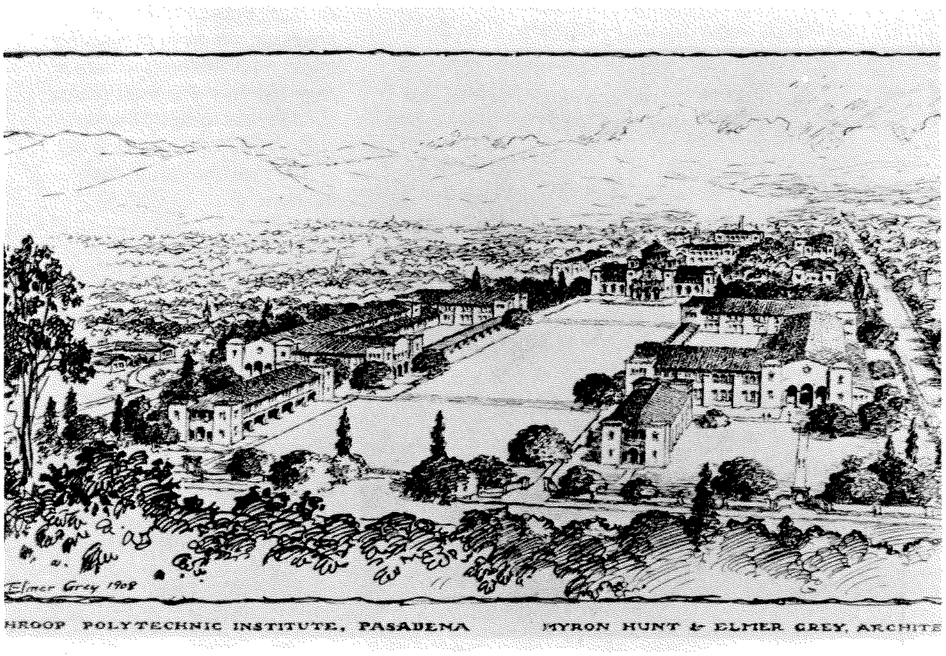
A Unified Vision

RESULTS OF RESEARCH that goes on in offices, labs, and libraries on the Caltech campus usually surface initially in articles in scientific and engineering professional journals. But some recent research appeared in rather different form from May through July as the Baxter Art Gallery show "Caltech 1910-1950: An Urban Architecture for Southern California." The show was made up of historical photographs and documents, blueprints, and original architectural drawings (many from the more than a thousand such drawings on file at Physical Plant), and it was accompanied by a 64-page illustrated catalog. In the preface to the catalog, Jay Belloli, director of the gallery, discussed the philosophy behind both the campus buildings and the exhibit:

> The most important truth that Caltech and the original Caltech campus teach is what can be accomplished by persons of vision. . . . And a campus of architectural excellence was considered a significant part



If you had stood on the site of the future library in the early days of Caltech and looked west, you would have seen this view. The house in the distance was located on Wilson Avenue, and it now serves as an annex to Page House, with living quarters for seven to nine undergraduates.



This 1908 aerial perspective of Hunt and Grey's proposed campus shows Throop Hall as a focal point. Culbertson Hall, whose interior is shown at the right, was completed in 1922 and torn down in 1972 to make room for a new geology building.

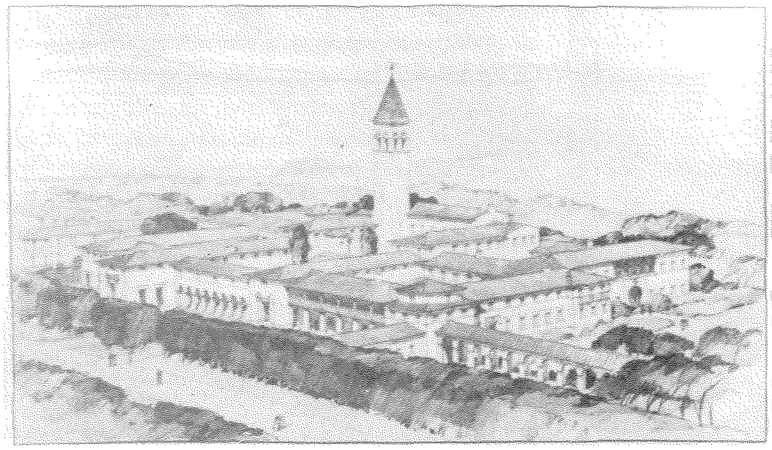
of the educational process, the quality of buildings and spaces intended to help students become aware of the importance of aesthetic appreciation.

More simply, Caltech, as in its academic disciplines, hired some of the finest architects available to create the spaces in which the new institution would grow. The intelligence, complexity, and subtlety of the original architecture in some ways complements the quality of research, education, and scientific achievement that Caltech so quickly achieved. The somewhat classical view of education, and the sensitivity to historical precedents shown by the architects, spoke of the transmission of cultural values and made it possible to conceive of a campus plan that took many years to realize.

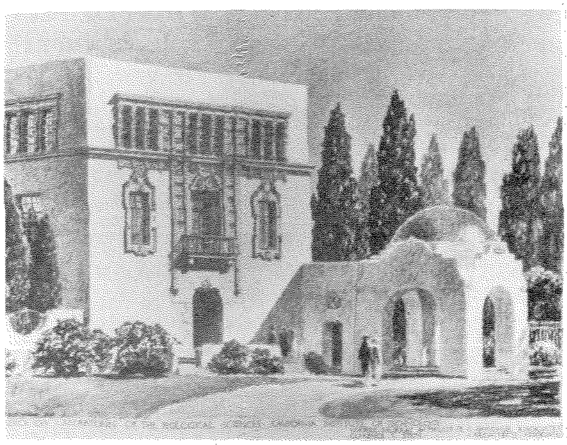
What is most encouraging about the development of Caltech and its architecture is the level of control the founders believed they possessed over their world and their destinies. The idea that a unified vision of exceptional achievement is possible, can be planned and executed over decades, and brought to fruition, is perhaps more difficult to accept now than it was then. But the period of Caltech in which the original campus was developed gives great hope that such a complex and extraordinary achievement is still within our grasp.

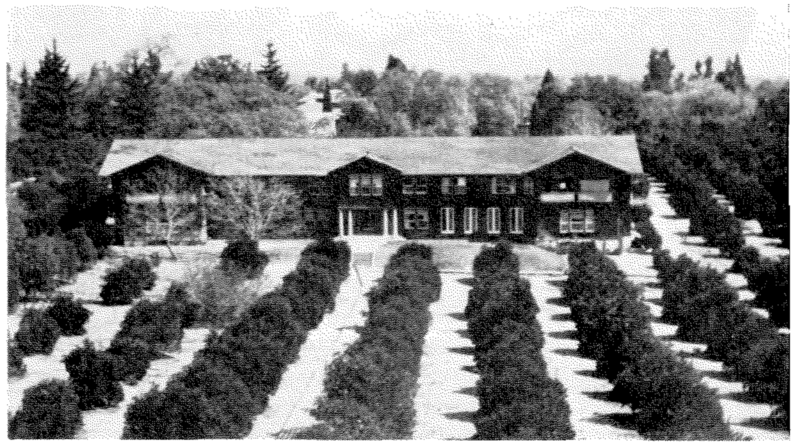
The six major articles in the catalog are by scholars whose basic reference material from Caltech consisted of some 300 pages of letters, documents, minutes, clippings, and the like assembled from the Archives files by Alice Stone, free-lance writer specializing in the history of Pasadena. The resulting articles discuss the work of the principal architects for the early campus, the history of the Institute in relation to them and the buildings they designed, and the relationship of Caltech's architecture to its educational commitments and to southern California and American architecture. In order of appearance, the articles and their authors are: "Windows Back of a Dream" by Alice Stone and Judith Goodstein, Institute archivist and faculty associate in history; "Bertram Goodhue" by Richard Oliver, architect and professor of architecture at Columbia University; "Gordon Kaufmann" by Joseph Giovannini, architectural and design writer for the *New York Times;* "Caltech and Southern California Architecture" by Alson Clark, head librarian for the Architecture and Fine Arts Library and instructor in the history of architecture at USC; "From Arcady to Anarchy: American College Architecture Between the Wars" by Helen Searing, Alice Pratt Brown Professor of Art at Smith College; and "The Caltech Campus in the Twentieth Century" by Stefanos Polyzoides and Peter de Bretteville, architects and professors of architecture at USC, who were also guest curators.

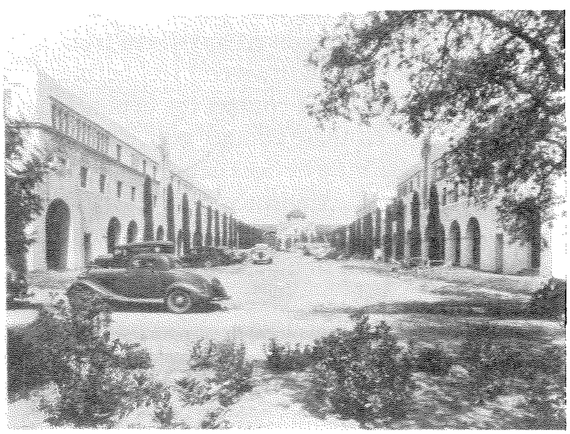
The show is over now and the photographs and original drawings are back in their files, but we have reproduced some of the pictures on these pages. A few copies of the catalog and a four-color poster of the 1917 Goodhue perspective of the campus are still for sale at Baxter Art Gallery on the campus.□ — *JB*



From top to bottom, left, still another aerial perspective of the proposed campus — this one was done by Gordon Kaufmann about 1929 and depicts his vision of the east campus. A 1928 drawing of the west end of Kerckhoff Laboratories, which anchored the buildings on the north side of the Wilson Avenue Mall, now known as the Bechtel Mall. In the center left, this mall as the buildings neared completion in 1938. At the bottom, an aerial view of the campus as it actually looked in 1938, the Wilson Mall in the foreground, Throop Hall in the center, and the Athenaeum at the far end of the long axis.



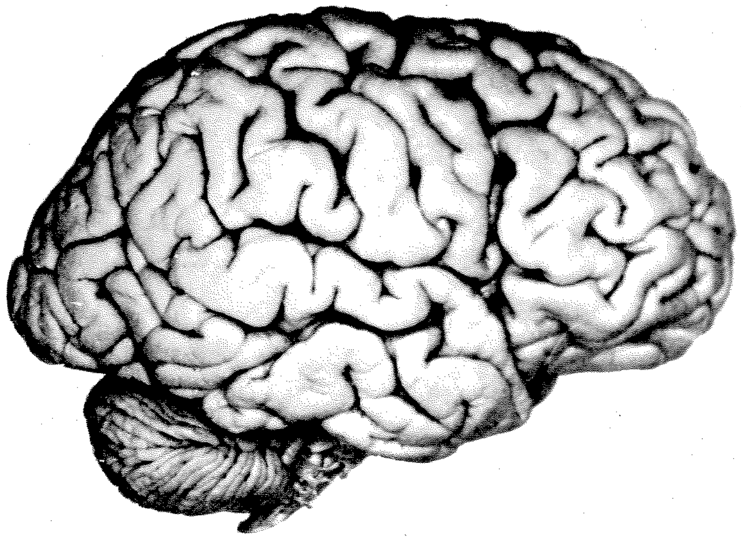




Caltech's "Old Dorm" (above) was removed from an earlier campus and relocated among the orange groves on the east side of Throop Hall. It served as a dormitory, coffee shop, and meeting place for Throop Club for nearly 50 years. Below, one of the many beautiful architectural details given the campus by Gordon Kaufmann. This is a door to one of the student houses.

Insight into Sight

by David C. Van Essen



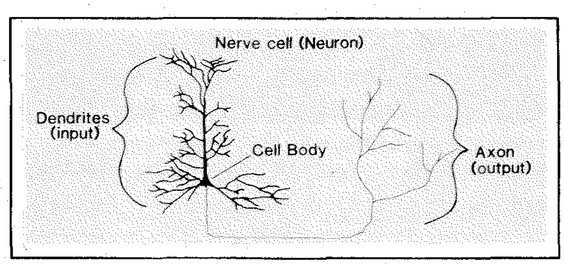
A view of the left hemisphere of the human brain as seen from the side. The cerebral cortex, with its numerous convolutions, is the dominant subdivision of the brain and is responsible for many of our higher mental functions.

WHAT HAPPENS within the brain as we look at the world around us? Is it possible to account for our visual perceptions in terms of the patterns of activity within the intricate living circuits of the brain? Scientists and philosophers alike have long been intrigued by such matters. In recent years research on the function of the visual system has clarified many basic issues and begun to provide coherent answers to these questions.

The impressive capacities of the human visual system are evident in many seemingly routine activities. For example, our ability to recognize a face in a photograph is based on the rapid and precise analysis of information about light intensity at many different points. The sequence of events in this analysis is of such bewildering complexity that it is profitable to begin with the consideration of much simpler examples. When we look at a single spot of light projected onto a screen, for instance, we can ask a number of basic but nonetheless useful questions: How is the light from the spot detected by the eye? How is the information encoded within the eye and sent back to the brain? To how many visual centers in the brain is it sent? How is it processed in each of those centers? Where does the actual percept of a spot arise? And how is the entire sequence different if the spot is projected onto a different part of the screen? By starting with relatively simple questions that build up in levels of complexity, we can make considerable progress toward fathoming many interesting aspects of brain function as it relates to vision.

It is useful at the outset to comment briefly on the raw materials used for processing information within the nervous system. The human brain weighs about five pounds and is made of rather soft and squishy biological materials. Superficially, it may not appear as imposing as one might expect for the most complicated device in the known universe. It is composed of an enormous number of fundamental subunits called nerve cells, or neurons. These are analogous to the transistors and other circuit elements that make up computers and other electronic devices. Each neuron has a cell body, which nourishes the cell and does various housekeeping chores, and it also has a collection of fine branches, which are used for making the connections that are essential for its role in processing information. One set of branches, called dendrites, are located close to the cell body and are used to receive input from other sources. Another branch, called the axon, provides the output of the cell. The axon starts as a single long fiber that travels anywhere from a fraction of an inch up to several feet before branching profusely to contact the dendrites at its target cells. At these contact points are exquisitely precise little devices called synapses, which allow for the transmission of information from the axon, or output side, of one cell to the dendrites, or input side, of the next cell.

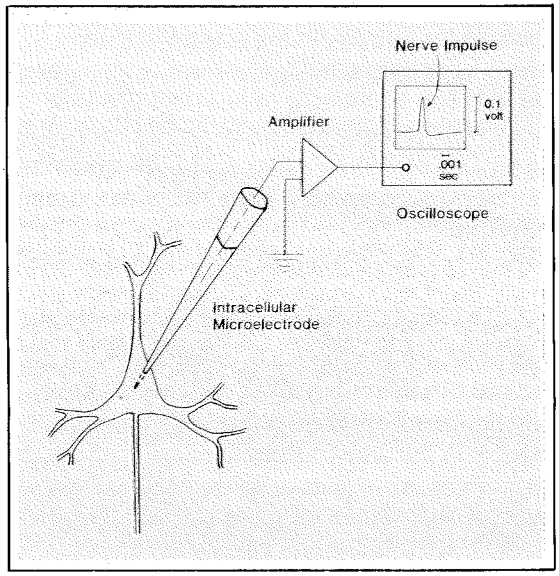
There are approximately 100 billion nerve cells within the human brain. These cells typically have thousands of synaptic inputs and thousands of synaptic outputs, so there are on the order of 100 trillion synapses in the brain — truly a staggering number in comparison with the number of electrical connections in even the most powerful computer. Although the signals used by the brain are electrical in nature, their



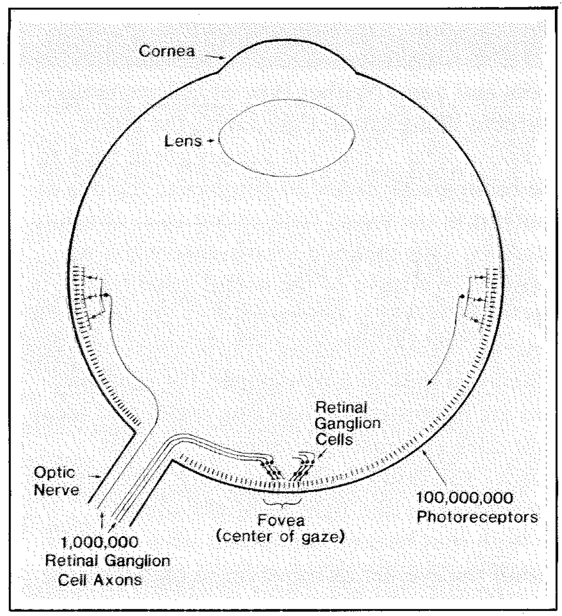
A typical nerve cell. The regions dealing with inputs and outputs are well separated from one another.

activity does not involve electrons flowing through wires. Rather, electrical potentials (voltages) are generated across an extremely thin sheet, the cell membrane, that separates the inside from the outside of the cell. We can record those signals with a microelectrode that is either inserted into the inside of the cell or placed just outside the cell membrane. The signals that are picked up by the microelectrode can be amplified and sent to an oscilloscope, a device that simply displays voltage as a function of time. A single nerve impulse is about 0.1 volt in amplitude and 0.001 second in duration. The size and shape of these impulses are constant; to transmit information, the cell changes the frequency at which the impulses are generated.

Visual signals enter the brain through the eye, which works very much like a camera, with an optical apparatus in front (the cornea and lens) and a sensory or receiving surface in back (the retina). An object in the external world is focused by means of the lens so that a sharp image is formed on the retina. In a microscope the retina reveals itself as a highly complicated sheet of tissue, only 0.01 inch thick but consisting of many layers of cells stacked together. When light reaches the retina, it is absorbed by specialized cells, called photoreceptors, which are densely packed together in a single layer. In each eye there are about 100 million photoreceptors of two basic types: rods, which are exquisitely sensitive to dim lights and are used for night vision, and cones, which are used for normal daytime vision. Cones come in three varieties that together provide the sense of color vision.



Technique for recording the electrical activity of nerve cells. In the diagram shown here, a glass tube drawn to an extremely fine tip and filled with a conducting solution is inserted into the cell. The amplifier strengthens the signal coming from the microelectrode and sends it to the oscilloscope, where it appears as a brief, stereotyped event.



A schematic cross section of the eye. The retina is a thin sheet containing several types of nerve cell. These include photoreceptors, which convert light energy into electrical signals, and retinal ganglion cells, which process the visual signals and transmit information to the brain via the optic nerve.

An individual photoreceptor detects light and generates an electrical signal that indicates the amount of light absorbed at that particular spot on the retina. Each photoreceptor is pretty much oblivious to what is happening to its neighbors. This situation changes dramatically, however, by the time signals reach the output stage of the retina, which is a collection of cells called retinal ganglion cells. Each retinal ganglion cell sends a single axon across the surface of the retina and out to the brain through a bundle called the optic nerve. Since there are only one million retinal ganglion cells to handle the information coming from the 100 million photoreceptors, there must be a considerable convergence of information. This is handled in a clever fashion, by distributing retinal ganglion cells in a highly nonuniform manner. At the very back of the retina is a region called the fovea, which corresponds to the center of gaze. In this small region each photoreceptor has a direct linkage to a single retinal ganglion cell, so that resolution of fine detail is preserved. Off to the side of the retina, the information from literally hundreds or thousands of photoreceptors impinges onto each retinal ganglion cell. These cells in the periphery can detect the presence of light quite well but cannot tell exactly which photoreceptor was illuminated. Visual acuity, therefore, is much lower in the region of peripheral vision.

Retinal ganglion cells have another property that is even more important for understanding the kinds of transformations in information content that take place within the visual pathway. This feature was first discovered some 30 years ago by Stephen Kuffler, one of the founders of modern neurobiology, who studied the effects of different patterns of illumination on the retina. Kuffler found that the activity of any given retinal ganglion cell could be influenced by illumination of a small region called the receptive field of the cell. The receptive field can be thought of as a region on the retina itself or, equivalently, as the corresponding region on the projection screen on which the eyes are focused and on which the visual stimuli are projected. The receptive field is not uniform in its organization, though, but rather is divided into concentric central and surround zones, which are antagonistic to one another. In one type of retinal ganglion cell, called an "on-center" cell, illumination of the center excites the cell and illumination of the surround inhibits its activity. In the other major type, the "off-center" cell, the arrangement is exactly the opposite, with light in the center inhibiting the cell and light in the surround exciting it. The most effective stimuli for on-center cells are spots and elongated slits of light, whereas the most effective stimuli for off-center cells are dark spots and bars. Neither type of cell responds to uniform illumination that covers the entire receptive field. Thus, the signals going back to the brain are arranged to emphasize regions of contrast in the visual field rather than absolute intensity. This makes a lot of sense when we consider that most of the useful information in our visual world is represented by contours that separate regions differing in brightness or color. When you look at a newspaper, for example, you are interested in analyzing regions of local light-dark contrast that represent printed words. You don't really care much whether you are reading in dim light or bright sunlight.

With that background about what goes on within the eye, let us move on to higher visual centers. The output from each retina goes by way of the two optic nerves to a juncture called the optic chiasm, right along the midline of the brain. At the optic chiasm an important redistribution of retinal ganglion cell axons takes place. Beyond the chiasm each hemisphere receives inputs from only the opposite half of the visual field, but it receives that information from both eyes. The retinal ganglion cell axons terminate in a relay structure named the lateral geniculate nucleus, which in turn sends its axons to the primary visual cortex. The primary visual cortex is the largest single subdivision of the cerebral cortex, which is itself the dominant structure of the brain.

The cerebral cortex is responsible in large part for a wide variety of different functions, including the senses of vision, hearing and touch, the control of voluntary movements, and the ability to reason, calculate, and use language and music. This rich diversity of functions is all the more impressive in view of the structural uniformity of the cortex. It is a sheet of gray matter about 0.1 inch thick that forms the outer wrapping of each hemisphere. Underneath the cortex is the white matter, composed of the axons of nerve cells whose cell bodies are in the gray matter of one region or another. The wrinkled appearance of the cortex is due to the numerous folds, or convolutions, that are characteristic of the brains of humans and other advanced mammals. These convolutions arise because the cortex is a sheet of limited thickness, which has increased rapidly in surface area during evolution and so has been crumpled or folded to get it to fit into a skull of limited dimensions.

An important principle of cortical organization is that it is divided into many functionally distinct subdivisions, or cortical areas. The total number of areas and their exact layout varies considerably in different species. In my own laboratory we have chosen to study the macaque monkey, a close relative of the common rhesus monkey, because of its superb visual system, very much like our own in many respects.

The task of identifying different cortical areas and determining their boundaries has been a major challenge to neuroscientists for more than a century. Fifteen years ago it was believed that there were only three or four cortical areas concerned with vision and even fewer areas concerned with other sensory modalities such as hearing and touch. This picture has now changed dramatically, thanks largely to the availability of new techniques for analyzing functional pathways within the brain. One especially important procedure involves the injection of special tracer substances into localized regions of the brain. One type of tracer is selectively transported from the cell bodies of neurons along their axons in the white matter to their synaptic terminations in various target areas. Another type of tracer is selectively transported in the reverse direction, from synaptic terminals back along the axons to the cell bodies, wherever they may be located. In either case, the final distribution of the tracers can be determined by appropriate treatment of histological sections cut through the brain.

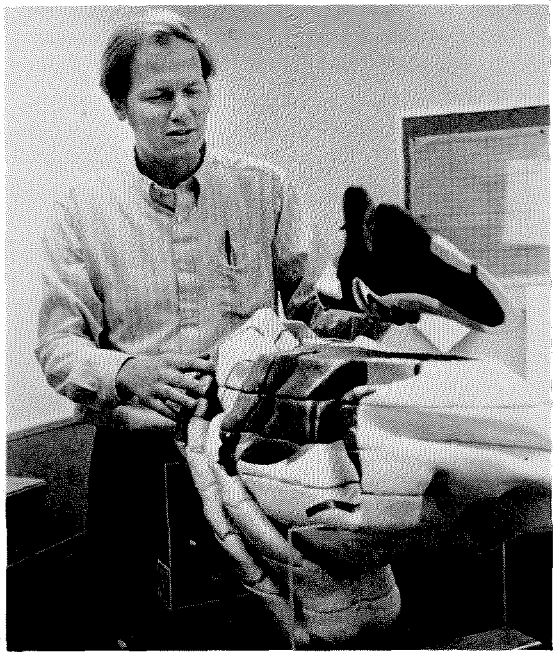
Using these techniques along with other complementary procedures, scientists have learned a great deal about cortical organization in recent years. In my own laboratory we have discovered the existence of four previously unidentified visual areas in the cortex of the macaque monkey. Related discoveries in other laboratories have added to the number of identified cortical areas in the macaque as well as in a number of other laboratory animals.

One way of documenting the location of different cortical areas is to paint them in different colors on a scale model of the brain (right). This has the advantage of conveying the relationships that exist among areas in the intact brain. There are, however, problems with this format, particularly because it is difficult to see some of the smaller areas that lie within one or another of the deep cortical folds. In order to get around this difficulty we have developed a procedure for constructing unfolded, two-dimensional maps that accurately represent the surface of the cortex (below). One can see in this figure that the entire posterior half of the cortex is visual in function, while much smaller regions are devoted to the senses of hearing and touch and to the control of body movements. About 30 cortical areas have been identified to date, of which a dozen are visual in function. There are still a number of relatively uncharted regions in which we can anticipate that additional areas will be discovered.

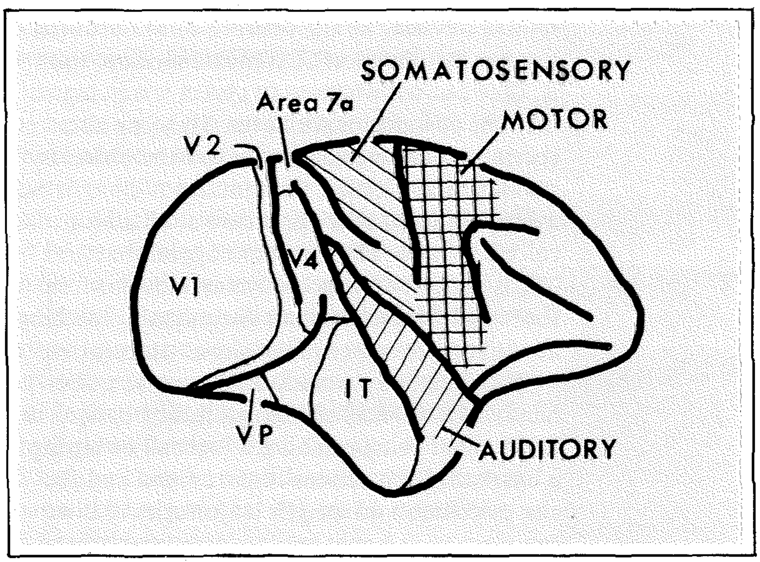
The primary visual cortex (visual area 1, or V1 on the map) is a large area covering about one-sixth of the entire cerebral cortex, and it is the direct recipient of information relayed from the retina up through the lateral geniculate nucleus. This large sheet of cortex that makes up V1 in one hemisphere must process information from the entire opposite half of the visual field. (Its counterpart in the other hemisphere takes care of the remaining half of the visual field.) Within this sheet there is an orderly representation of the visual field, with the center of gaze represented at one end and the periphery of the visual field at the other. Neighboring points in the visual field are represented as neighboring points on the cortical surface. At a more detailed level scientists have found that the cortex can be subdivided on anatomical and physiological grounds into a large number of distinct modules, about one millimeter on a side. Within each of these modules there are approximately 100,000 nerve cells, each of them looking out at one tiny region of visual space. Together, the cells in that module carry out a first-order analysis of what things of visual interest are in that region.

In order to ascertain the nature of this first-order analysis, we can study the responses of simple neurons to a variety of visual stimuli. This approach, pioneered for the visual cortex by Nobel laureates David Hubel and Torsten Wiesel, has revealed a number of intriguing properties of cortical neurons. Most important is the fact that these cells are orientation selective: They insist not only that a light/dark contour be present in a certain place in the visual field, but also that this contour be elongated in a particular orientation. Some cells detect the presence of vertical contours, others detect horizontal contours, and still others detect various oblique angles. Many of these cells are also able to signal information about other basic features, such as the color of a stimulus, its size and distance away, and its direction and speed of motion.

After all the cells in V1 have finished their analysis of the visual world, the partially processed information is distributed to the numerous higher visual areas for additional rounds of



The author with a scale model of a monkey's brain. The model is greatly enlarged from the original size of the brain, which is only a few inches long. Individual functional subdivisions of the cerebral cortex are indicated in various shades. The visual cortex is located at the rear of the brain, where the author's right hand is placed. In his left hand is a section through the top of the brain to show the white matter (painted black on the model).



An unfolded, flattened map of the monkey's cerebral cortex. The various visual areas in the cortex denoted by V1, V2, etc., are illustrated in a drawing of the intact hemisphere (upper left) and again on the cortical map. Visual areas occupy about half of the entire cerebral cortex, whereas considerably smaller regions are devoted to other functional modalities of hearing, touch, and motor control. The largest area, V1, is separated from neighboring cortex on the map by a cut, or artificial discontinuity, introduced to minimize distortions in the representation of surface area.

analysis. In order to understand what occurs at these higher levels, it is first necessary to know which visual areas receive direct input from V1 and which receive their input indirectly, relayed through intermediate areas. It turns out that the pathways among cortical areas are quite complex, as each area has multiple sources of inputs and multiple outputs. Despite this complexity, we have recently found that there is a high degree of order within the system. Specifically, it is possible to arrange all of the visual areas into an overall hierarchical scheme, in which each area occupies a well-defined position in relation to other areas with which it is connected. This hierarchy is analogous to various schemes that are used to portray organizational relationships in certain human institutions, such as judicial and executive branches of government. In the visual pathway V1, not surprisingly, is at the bottom of the cortical hierarchy, and the visual areas in the temporal and parietal lobes are at the highest levels.

In parallel with this progress in understanding the anatomical organization of the visual cortex, we have also begun to make headway in analyzing the functions of some of the higher visual areas. The emphasis in my laboratory has been on understanding the way in which information about form, color, and motion in the visual world is processed. We have found that there appear to be two distinct functional streams within the visual cortex, one concerned specifically with motion analysis and the other concerned with both form and color.

The specialization for motion analysis is illustrated most clearly by considering area MT. This is a small visual area buried deep within one of the cortical fields; it was originally discovered by John Allman, associate professor of biology at Caltech, in a different species of monkey. Nearly all the neurons in MT are selective for the direction of stimulus motion; that is, they can tell whether an object is moving to the left, upward, or whatever. They are also specialized to determine how fast the object is moving, and whether the stimulus is close or far away. But these cells don't care at all about color or shape. These results suggest that area MT is concerned with analyzing movement in the visual field and telling the animal something about complex three-dimensional trajectories.

This capability would, of course, be quite handy to a monkey catching a falling banana or to a human being catching a football or hitting a baseball. Such actions require rapid and precise calculation of specific trajectories that we can react to in a split second. It is very convenient to have a system that can handle this without worrying for the moment about exactly what size or shape of object is approaching. The system for analyzing motion appears to start way down in the retina, involving a subset of retinal ganglion cells that are particularly sensitive to moving stimuli. These cells connect up to particular layers within the lateral geniculate nucleus. From there the information is transmitted to specific layers within V1 and then to MT. We are now interested in finding out what happens to these signals after they leave MT and reach still higher targets within the cortex.

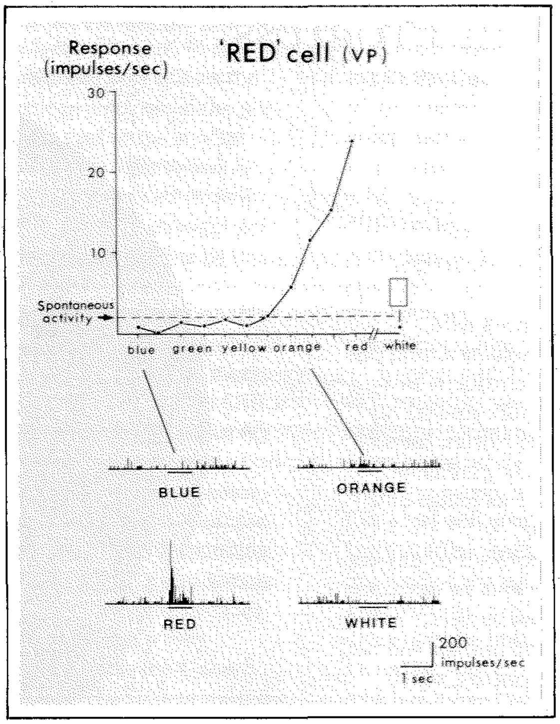
The cortex involved in analyzing form and color appears to be considerably more extensive than that for motion analysis. As was already pointed out, the output from V1 includes activity in a large number of cells that are responsive to local contours in the visual field, such as the margins of a face, or the eyes and nose within a face. We can imagine that the cells in area V1 look at these images in a piecemeal fashion, separately signaling a vertical contour here and a horizontal contour there, and so on. We know that subsequent stages take place in a number of areas, including areas V2, V4, VP, and the inferotemporal cortex (IT), whose locations are indicated on the cortical map. We do not yet know much about the nature of the higher level analysis that takes place in these areas; one attractive possibility, however, is that the piecemeal analysis carried out in V1 is reassembled in such a way that individual higher order neurons detect more complex patterns than just bars and edges. Neurons at intermediate levels, for example, might detect corners or contours with a particular curvature. Neurons at the highest levels might signal the presence of still more complex patterns, such as a nose, an entire face, or a tree. On the other hand, it may well be that complex features in the visual world can only be signaled by coordinated activity within an ensemble of neurons and not just by a single cell. Now that we know which visual areas to explore, it may be possible to resolve within the forseeable future which of these general schemes accounts for our ability to recognize an infinite variety of forms and patterns.

Our sense of color has always been a source of fascination to vision researchers. This is partly because color greatly enriches and enhances the beauty of our visual world, and partly because of the availability of optical methods that give the experimentalist precise control over the spectral composition of stimuli. It has been known since the 19th century that color is encoded within the eye by three types of photoreceptors. One type, the blue cone, absorbs light preferentially at short wavelengths; another, the green cone, is most sensitive at intermediate wavelengths; and the third, the red cone, is most sensitive at long wavelengths. Each type of cone absorbs light over a large portion of the spectrum, though, and our ability to distinguish subtle differences in hue is dependent on making comparisons among the degree of activation of each cone type. Such comparisons begin within the retina itself and are continued up at the level of the visual cortex. We have found that in the various areas concerned with form and pattern vision (specifically areas V2, V4, and VP), a majority of neurons are also selective for the color of visual stimuli (right). Thus, form and color appear to be processed together in the same visual areas and sometimes within the same neurons, whereas motion, as already discussed, is largely segregated into a separate functional stream.

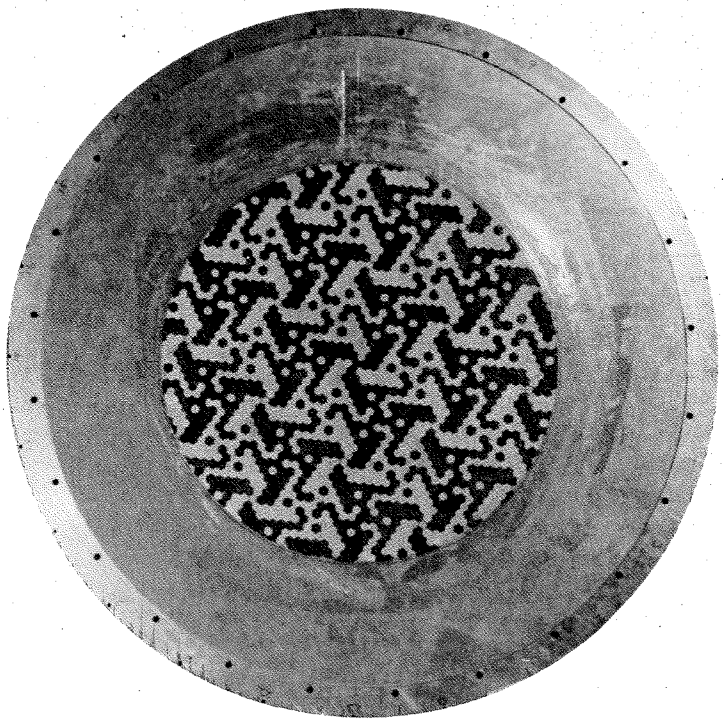
An interesting complexity in our sense of color vision has been pointed out by Edwin Land, inventor of the Polaroid Land camera. Last year in his Lauritsen lecture here at Caltech, Land demonstrated the remarkable ability of the human visual system to compensate for large changes in illumination and in the spectral content of the light coming to our eyes. Such compensatory interactions are important in our everyday ability to recognize the colors of natural objects despite the differences in illumination between, say, yellowish candlelight versus bluish fluorescent lights. The same phenomenon can be demonstrated by viewing a richly colored scene with and without color filters in front of the eyes. A yellow banana, for example, seen behind a red filter is still interpreted as yellow in its reddish surroundings, even though the light coming from it is distinctly orange when viewed in isolation. Although our ability to compensate for these changes in illumination is by no means perfect, it's still an impressive accomplishment. Preliminary studies from other laboratories suggest that this compensation may take place at high levels of the visual pathway. Further studies are needed to determine whether this actually does occur, and, if so, what happens in terms of the specific neural circuitry.

To summarize, we have seen that it is possible to take a particular sensory system within the brain and follow the kinds of transformations that occur as we go through many successive stages of processing. In the future it will be possible to delve even farther into the system and understand a great deal more about the basic principles of visual perception. Eventually these studies on animal models will help us to understand the operation of the cerebral cortex in the human brain. We are still not in a position to accurately determine the precise localizations of what may be a very large number of functional subdivisions in the human brain, as is now possible for the brains of other species. But we can expect that such discoveries will be aided by the recent development of powerful, noninvasive techniques for detecting activity in specific regions of the human brain.

Here at Caltech we have more than a dozen research groups studying various aspects of the structure, function, chemistry, and development of the brain. These studies are carried out at several levels, from that of the molecular constituents of the brain, to assemblies of cells, to the behavior of the entire organism. The rewards of these diverse and complementary approaches will be more than purely intellectual in nature. Much of what we have learned and will yet learn will also have direct relevance to the ability to diagnose, understand, and treat a variety of diseases and disorders of the nervous system. As basic scientists we cannot say with certainty exactly which disease will be cured at which particular time, or which therapeutic product will be developed. Sooner or later, though, we can be confident of great progress that will have practical impact on improving and enriching our own lives. □



Properties of a red-sensitive neuron in visual area VP. Below are histograms showing the response of the neuron to lights of different colors projected onto a screen facing the animal. The light was flashed on during the one-second period indicated by the horizontal bar. Only the red light provoked a large response from the cell, as indicated by the sharp peak in the histogram, which is a plot of instantaneous frequency of nerve impulses in the cell. Blue light and white light actually depressed the spontaneous background activity of the cell, and orange light produced only a weak response. The graph at the top shows the average response of the cell to these and other colored stimuli.



Hex Sign

THE REPEATED hexagonal design above would make a nice patchwork quilt. In fact, Tom Prince's wife, Charlene Reichert, *is* making a quilt out of it. But its primary function is as a mask for a coded aperture gamma ray camera. The hexagonal pattern forms the "code," which can be mathematically unfolded to derive an image of a source of gamma rays.

Prince, assistant professor of physics, designed the array for what he describes as a "very fancy pinhole camera." Normal telescope lenses and mirrors will not do for gamma ray astronomy, which operates in the very energetic region of the electromagnetic spectrum beyond x rays, between 30,000 and 10 million electron volts (photons of visible light have energies between 1.5 and 3.5 electron volts).

If scientists in this relatively new field can devise clever enough techniques to detect gamma rays, these high-energy photons will undoubtedly provide important information about a number of astrophysical phenomena such as supernovas, particle acceleration, neutron stars, dust grains, and processes at the galactic center, where electrons and positrons are annihilating each other and producing gamma rays. For example, gamma ray astronomers are interested in what gamma rays may reveal about nucleosynthesis — how heavier elements, whose newly formed nuclei would be radioactive and emit gamma rays, are generated from a supernova explosion.

Even a supernova explosion, however, does not dispatch gamma rays to the earth in sufficient numbers for them to be captured by a simple pinhole camera with a single hole. So Prince's "fancier" version has many holes. Because the numerous holes cast many overlapping images, they have to be arranged in a particular pattern, which allows the image to be unscrambled. Prince and co-workers have developed a whole family of geometric patterns for the mask, called "rotating hexagonal uniformly redundant arrays," based on mathematically complex arrangements of cells. These patterns are designed to cast maximally different shadow patterns from sources in different directions. In addition, while an image is being made, the entire mask is rotating to provide an additional time-dependent coding of the image besides the spatial coding of the mask pattern.

The shadow pattern from the mask is cast onto a detector — an Anger camera, which is widely used in medicine for detecting the presence of radioactive isotopes. When gamma rays pass through the holes in the mask, they strike the sodium iodide crystal of the Anger camera, producing light, which is then amplified by 19 photomultiplier tubes. A computer, which knows the code of the apertures, then unscrambles, analyzes, and produces the image.

Caltech's involvement in gamma ray astronomy has been fostered by Prince, together with cosmic ray scientists Rochus Vogt, provost of the Institute, and Edward Stone, chairman of the Division of Physics, Mathematics and Astronomy. The gamma ray astronomy group, which also includes grad students Mark Finger and Chris Starr, staff scientists Alan Cummings and Rick Cook, and technical manager Bill Althouse, has recently tested a somewhat smaller prototype of their instrument in the laboratory with low-energy (122 kev) gamma rays. In about a year they hope to launch a full-scale gamma ray telescope in a balloon to carry it to an altitude favorable for intercepting gamma rays. The telescope, weighing well over a ton, must be accurately pointed while suspended on a long tether from a spinning balloon. This requires a special pointing platform which uses computer-controlled motors to counteract the balloon rotation. In addition, the telescope must be shielded from the earth, because our own atmosphere is itself very bright in gamma rays caused by interacting cosmic rays.

The coded aperture camera has great promise for gamma ray astronomy because it promises particularly high angular resolution, more than ten times better than past instruments and better, in fact, than the instrument already scheduled to be launched in NASA's Gamma Ray Observatory satellite later in the decade. The Caltech group also hopes to have an opportunity to send its instrument into space eventually, since balloon flights provide only limited observation time. A telescope of this type carried on board the space shuttle or mounted on a future space platform would be a powerful instrument for detecting and locating weak cosmic gamma ray sources. □ — *JD*

Budget Politics

SQUABBLING over the federal budget is an annual rite in Congress and between Congress and the president. Conflicts over who gets what have been particularly noticeable lately because of strong partisan divisions in Washington. Rod Kiewiet, associate professor of political science, doesn't really care who gets what but is interested in discovering the factors that influence the federal budget appropriations process and in being able to predict for any given year how much a government agency will get to spend.

Earlier studies have already looked at this process, but they came up with what Kiewiet considers boring conclusions that really don't explain anything at all. Most of the studies have concluded that the final appropriation is merely a function of what the president asks for. They consider the federal budget a self-contained process that inches inexorably upward, immune to changes from outside factors. Kiewiet dismisses these notions as the result of inadequate statistical work and poor interpretation. Along with Matthew McCubbins, PhD '83, and now assistant professor of political science at the University of Texas at Austin, he set out to develop a statistical model of the appropriations process that would have some reasonable theoretic and predictive value.

For one thing, earlier studies didn't correct for inflation; McCubbins and Kiewiet's model deflates budgets into real dollars. Also, instead of looking at raw dollar amounts, they concerned themselves with the percentage change in an agency's budget compared to the previous year. Kiewiet sees this as the real budget battleground, since the percentage change in real terms is what determines whether an agency will be able to carry out new policies or will have to cut back. And the changes are what congressmen look at, line by line, when making their decisions.

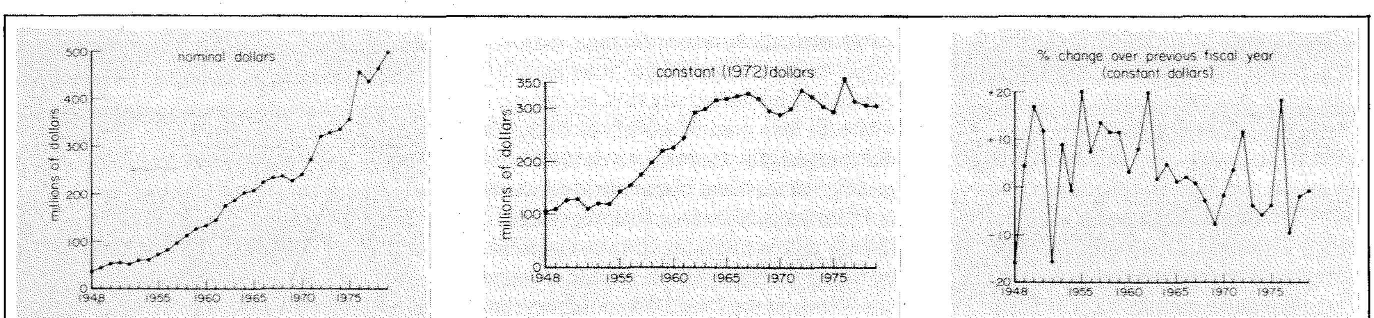
Kiewiet and McCubbins are analyzing time series data (from 1947 to 1979) on 37 government agencies — a diverse set ranging from the FBI and the Office of Education to the Geological Survey and the Soil Conservation Service. They are not dealing with defense agencies because the ups and downs of defense spending, as well as of social spending (the lion's share of which is entitlement programs) are the product of broader trends in budgetary fiscal policy.

Unlike earlier studies, the Caltech research, which was the first to examine factors external to the budgetary process in a multivariate model, shows that these factors do affect how much the government spends. For instance, the state of the economy (things like rates of inflation and unemployment) even influences different agencies in different ways. When the two political scientists divided the agencies into two groups — standard line agencies, such as the Bureau of the Mint and the National Bureau of Standards, and what they called constituency-oriented agencies, which deliver benefits to clearly identifiable groups of people — it turned out that unemployment, but not inflation, affected the two groups differently. Budgets of the constituency-oriented agencies, in particular the public works agencies — the Corps of Engineers, Bureau of Reclamation, and so on — grew at a much greater rate during periods of high unemployment. It appears, then, that Congress really does use public works to give people work.

Whether or not it's an election year also matters to agency budgets, according to the Caltech study. Congress is more generous in an election year — not much, but a little. The partisan makeup of Congress, on the other hand, matters a lot. Budgets are one area where party differences are undeniably important, according to Kiewiet. The more Democrats there are in Congress, the larger the agencies' growth rates. Democratic presidents submit bigger budgets too.

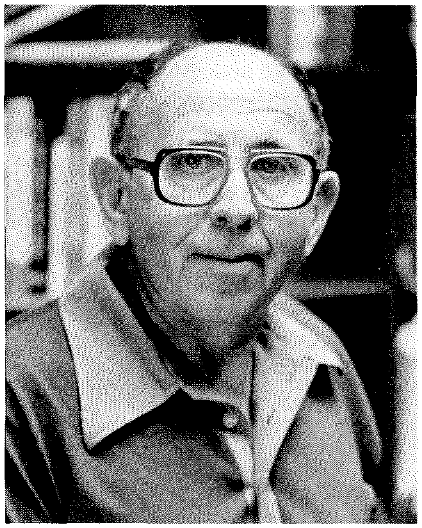
Kiewiet and McCubbins want their two-equation model, which uses the statistical technique of two-stage least squares, to predict simultaneously both what the president will ask for and what Congress will give him. And while some factors affect both, others influence only one side of the equation or the other. For example, preliminary testing indicates that the president's budget is affected by wartime. Korea and Vietnam, which occurred within the scope of the study, had similar effects of lowering presidential requests for agency funds. The effect of Vietnam can be seen most dramatically during the Johnson years, when all the factors should have favored government growth. Kiewiet's figures indicate that agencies would have grown at a 5-6 percent faster rate than they actually did, if the Vietnam war had not occurred.

Another variable they are currently testing is the internal structure of Congress, not the new budget procedures introduced in 1975, which are largely considered to be window dressing, but rather the growth in the number of subcommittees since World War II and the consequent diffusion of power. Kiewiet suspects that this institutional change could easily generate pressure to be more generous to everyone's pet agencies, with the end result that "it's a bigger log that gets rolled down the road." □ — *JD*



Federal budget appropriations over 30 years for the Soil Conservation Service look very different when viewed in nominal dollar amounts (left), corrected for inflation (center), and expressed as a percentage change in constant dollars over the previous fiscal year (right). The last graph gives the best picture of this agency's actual funding fate.

Retirements — 1983



Burton H. Klein

Professor of Economics, Emeritus

IN COLLEGE professors, the ability to concentrate on the matter at hand to the exclusion of all else sometimes leads to charges of absent-mindedness. In the case of Burt Klein, who became professor of economics emeritus at Caltech this year, it has also led to a reputation for a probing, original, and perceptive approach to whatever problem he is zeroing in on. "You don't always agree with his conclusions," says his colleague Alan Sweezy, "but you never fail to get a lot of new ideas about the possibilities."

One of Klein's conclusions is, for example, that industry needs to be more unstable, at least on the small-scale level of firms involved in all-out rivalry to dominate an active, technologically evolving field. That kind of instability, he says, produces a number of economic benefits, including large-scale stability in the economy as a whole. Klein is particularly interested in the economics of innovation and how it is related to organizational structure. He feels that many American organizations have become so stable that they have ossified. In explanation of his theories he has written a number of books, most recently *Dynamic Economics* and *The Slowdown in Productivity Advances: A Dynamic Explanation.*

Klein received both his AB and his PhD from Harvard, was a staff member of the President's Council of Economic Advisers from 1948 to 1952, and then joined RAND Corporation. He became head of RAND's economics department in 1961, and came to Caltech in 1967. In addition he has served as a consultant to the Council of Economic Advisers, the Bureau of Budget, the Disarmament Agency, the Brookings Institution, and the Swedish and Israeli governments. A project that interests him currently is making a study of the differences between American and Japanese industry and productivity.

Heinz Lowenstam

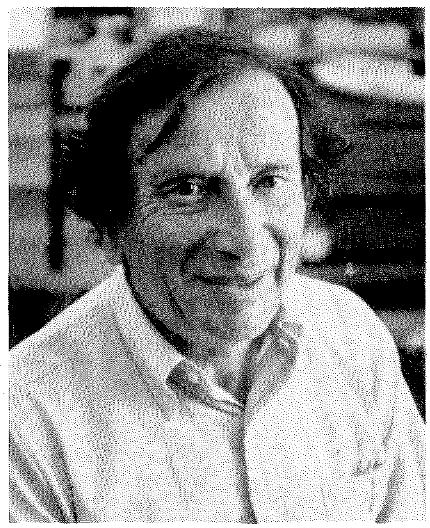
Professor of Paleoecology, Emeritus

ORDINARILY, "survivor" and "pearl diver" are not words used to describe academicians, but Leon Silver, the Keck Foundation Professor of Resource Geology, chose them to characterize Heinz Lowenstam, who recently became professor of paleoecology emeritus. Speaking at the May faculty dinner, Silver documented his usage with both biographical material and research evaluation. Lowenstam, he pointed out, who was born in Germany and attended the University of Munich, earned a PhD in paleontology in 1937. Under the influence of the Nazis, however, the degree was denied because Lowenstam is Jewish. (A happy footnote to this episode is that Munich did award him an honorary PhD in 1981 and created a symposium in his honor.)

Actual survival probably was possible only because Lowenstam left Germany in 1937 for the United States. His scholastic credentials, in the form of two letters from his professors, were accepted by the University of Chicago, where he was granted a PhD in 1939. He did research for that degree on the geology of the East Nazareth Mountains in Palestine and later worked on local Illinois paleontology, getting to the field by riding the streetcar to the end of the line — where he found 400-million-year-old fossils in some outcrops. Over the next several years he worked as state paleontologist at the Illinois State Museum, as a geologist for the Illinois State Geological Survey, and as research associate and then associate professor at the University of Chicago. In 1952 he came to Caltech as professor of paleoecology.

Lowenstam's research has been distinguished, and he has been elected to the National Academy of Sciences and the American Academy of Arts and Sciences because of it. He is recognized as the developer of the thesis that ancient reefs are important petroleum habitats and, with Nobel Laureate Harold Urey and Sam Epstein (now professor of geochemistry at Caltech), of the ability to determine by means of oxygen isotopes the temperatures of ancient seas. These seas have continued to interest him, but he has also done research on modern reefs and the ecology of living as well as fossil marine organisms, being particularly interested in the evolution of their skeletal mineralogy. Recently he has been studying geochemical methods for distinguishing minerals produced by living organisms from inorganically formed minerals.

Petroleum habitats, the thermal history of oceans, and unforeseen mineral diversity in invertebrates are a few of the "pearls" Lowenstam has dived for and found, but, said Silver, "taking the unexpected point of view and thus forcing scientists to readdress fundamental questions is the hallmark of all his thinking, and that is his greatest contribution."



James O. McCaldin

Professor of Applied Physics and Electrical Engineering, Emeritus

JAMES O. McCALDIN has decided, after 15 years of teaching and directing graduate students, to go more fully into some of his other interests — including music and an Arizona ranch. So, in September, he adds "professor emeritus" to his academic title. McCaldin is known for his carefully thought-through advice to both graduate and undergraduate students and for making the freshman Solid-State Electronics Laboratory course one of the more enjoyable academic possibilities of the freshman year. When his other interests permit, he will continue to spend time at the Institute, pursuing his life-long interest in materials and devices and informally educating students in their subtleties.

McCaldin completed his PhD degree in engineering at Caltech in 1954. After a couple of years devoted to physical metallurgy at General Motors, he focused his efforts on semiconductor materials at the Hughes Aircraft Company, becoming department head for that activity. This work continued at the North American Aviation Science Center, after its founding in 1961. He is one of the pioneers in some of the key technologies that have made possible the current semiconductor revolution. He did early work on the planar process, for example, which is used in all modern chip-based electronics. In some of the earliest papers on the subject, he established the use of ion implantation for doping semiconductor devices. In recent years, he has concentrated on the properties of interfaces and on developing methods for preparing semiconductor-grade crystals on dissimilar substrates. Says his colleague Thomas McGill, "His research has always been characterized by an adventuresome but scholarly development of a new concept that has frequently later become one of the keys to important technological developments."

Ray D. Owen

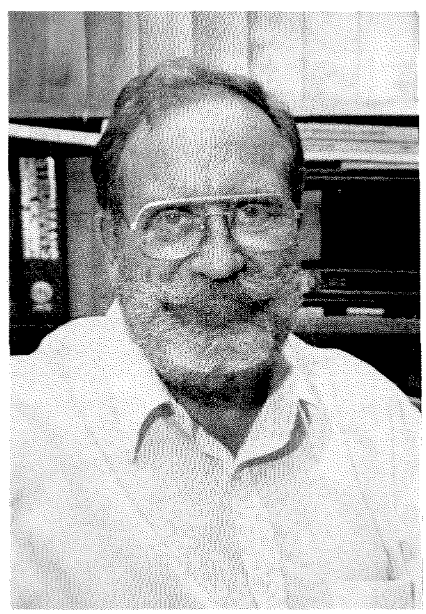
Professor of Biology, Emeritus

AT THE FACULTY dinner in May, Ray Owen was described by Kent Clark, professor of literature, as warmer than most people, "possibly because he was born in a cold climate and learned early to huddle"; a genius in immunogenetics, "National Academy and all that"; Welsh, "which means that he's a singer (and a star in the Caltech Stock Company) and inherently crafty even though he looks increasingly guileless"; and with the tragic flaw of being a baseball fan (of the California Angels), "a curse on a level somewhere between having scabies and wearing a hair shirt." All more or less true.

Wisconsin-born and of Welsh descent, Ray David Owen got his PhD at the University of Wisconsin in genetics in 1941. In 1947 he came to Caltech as associate professor of biology, became full professor in 1953, and professor emeritus in 1983. In the interim he has had an active and distinguished career. His research has been mainly in the fields of mammalian genetics and immunology and in such areas as tissue and organ transplantation and developmental studies. He is co-author with Adrian Srb and Robert Edgar of a widely used textbook, *General Genetics.*

In addition to membership in NAS, he belongs to a number of other learned and professional societies. He has served as officer or board member for many of them and as a member of many national and state committees. He was president of the Genetics Society of America, for example, on the board of directors of the American Society of Human Genetics, and chairman of various committees for the National Institutes of Health and the National Science Foundation. For three years he was the "scientist-member" of the President's Cancer Panel, acting in an advisory capacity to Presidents Nixon and Ford.

Somehow, Owen has also found time to be a conscientious and busy citizen of the Caltech community. He was chairman of the Division of Biology from 1961 to 1968 and vice president for student affairs and dean of students from 1975 to 1980. He has been a dedicated teacher throughout his career and is a recipient of an ASCIT award for teaching excellence. He found his chairmanship of the faculty committee on the freshman year at Caltech in the late 1960s particularly rewarding since its work led to the inauguration of pass-fail grading for freshmen, the introduction of electives into the freshman curriculum, and the admission of women to Caltech's freshman class. For some or all of the above reasons, Owen was elected to honorary membership in the Caltech Alumni Association in June.



The Optimum Shape

Researchers at the General Motors Research Laboratories have developed the first integrated system for computer design of mechanical parts with minimum mass. Optimal Shape Generation automatically optimizes the component shape in a single computer run.

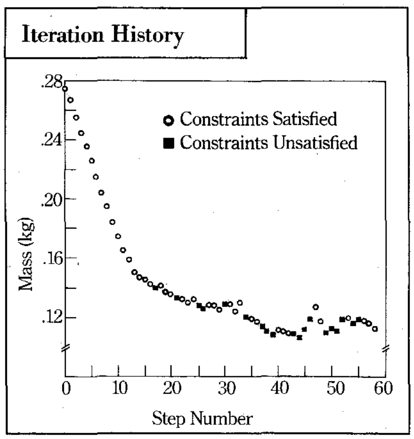
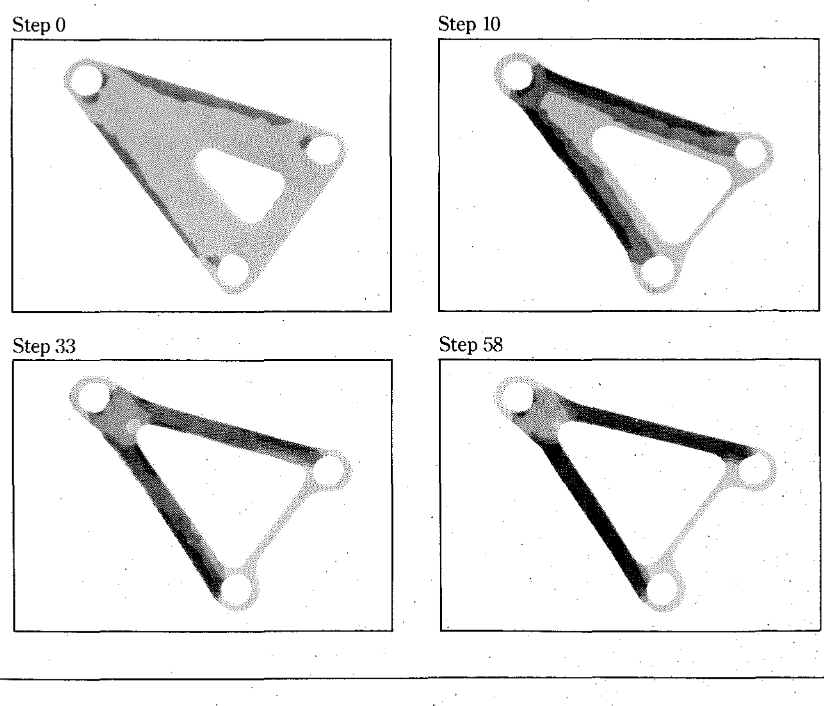


Figure 1: Decreasing mass plotted as a function of design iterations for the component shown in Figure 2.

Figure 2: Black-and-white photographs of shapes which appear in color on the CRT screen. Increasing darkness indicates increasing stress levels within the design limits.



COMPUTER-AIDED design systems automate the processes of generating geometric data and engineering drawings of parts, but they do not determine whether these parts meet structural performance requirements. In an ongoing research project at the General Motors Research Laboratories, a system has been developed that automatically ensures that the design meets structural performance constraints. More important, Optimal Shape Generation provides the component shape with the minimum mass capable of satisfying structural demands in a single computer run, without requiring human interaction with the machine.

In the last two decades, extensive research has been done in the area of computer design of structural components. Most of this work has focused on individual aspects of the process. Drs. Jim Bennett and Mark Botkin have succeeded in integrating the process from description of the model through convergence to the optimum solution.

Conventional systems continue distinctions characteristic of age-old "build and test" methods by separating the tasks of design generation and design analysis. Typically, a "designer" uses one computer system to produce engineering drawings of a given part. The task then shifts to an "evaluator" who creates a mathematical model with which to test the design on another computer system. The evaluator determines only whether or not the design meets the requirements. A lengthy interaction between the designer and the evaluator is required to optimize the design. Optimal Shape Generation integrates the process from design generation through design optimization. The system can generate the mathematical model from the design data as the shape changes without requiring additional input, thereby turning the process from a multiperson, multimachine operation into a one-person, one-machine operation.

Since there is no interaction beyond the initial input, a flexible description of the problem is crucial to effective use of the system. The researchers responded to this challenge by developing a geometric format based on a parametric description of the boundary. Defining the problem with geometric data is desirable because it describes the shape of the part in a form directly suitable for conceptual visualization.

Because the boundary geometric description must be transformed into an analysis model not once but several times, some type of automatic finite element mesh generation is required. The researchers adapted a mesh generation technique which divides a closed region into triangular elements based on a discrete description of the boundary. The sizes of the elements of the mesh are determined by a characteristic length selected for each problem and are related to the need for accurately describing the geometry. Automatic triangulation is used to create a set of connectivities for the discrete points placed uniformly throughout the part's interior with approximately the same density as the boundary points. The combination of boundary data description and automatic mesh generation permits the system to accommodate major changes in shape from the initial design.

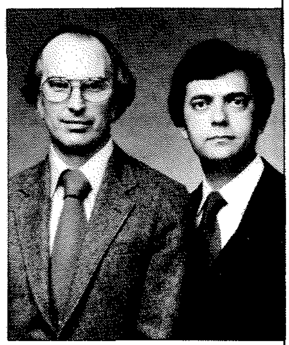
ADEQUACY of the triangular meshes to calculate accurate stress levels was next addressed by the development of an adaptive mesh refinement scheme. By evaluating the solution for the uniform mesh created by the choice of characteristic length and identifying areas where the strain energy density changes rapidly, the system selects the areas of the mesh that require mesh refinement. These refinements can take the form of either adding elements in the area to be refined or increasing the order of the finite element polynomial interpolation. The former approach has been taken, because it can be implemented automatically and does not require the formulation of new finite elements.

The culmination of the process introduces an optimization routine which directs the design toward a minimum mass configuration. A mathematical optimization technique is used to change the design to that shape giving minimum mass within the structural constraints. This optimization technique is based upon a sequential first-order Taylor series approximation of the constraints and a feasible directions solution of the problem. Periodic mesh refinements are performed throughout the optimization, since the design is continually changing, and the system must predict the stresses and the behavior of the constraints as the design changes.

"By taking an integrated approach," says Dr. Bennett, "we're able to combine the objectives of reducing the mass of the material and meeting structural performance requirements in a single automatic system."

"We expect," adds Dr. Botkin, "that in the future this technique will become the standard way of designing structural components."

THE MEN BEHIND THE WORK



Drs. Jim Bennett and Mark Botkin are members of the Engineering Mechanics Department at the General Motors Research Laboratories.

Dr. Bennett holds the title of Assistant Department Head. He attended the University of Michigan as an undergraduate and received his graduate degrees from the same institution in the field of aerospace engineering. His Ph.D. thesis concerned non-linear vibrations. Before coming to General Motors in 1973, he taught aeronautical and astronautical engineering at the University of Illinois.

Dr. Botkin is a Staff Research Engineer. He received his undergraduate and graduate degrees from the University of Missouri at Rolla. His graduate work was in the field of civil engineering, and his doctoral thesis concerned structural optimization. Prior to joining General Motors in 1978, he worked for four years as a consultant to computer applications engineers.

Random Walk

Ray Untereiner — 1898-1983

ROBERT ANDREWS MILLIKAN met Raymond Edward Untereiner between trains in Chicago in 1925 and hired him on the spot. Millikan wanted all Caltech students to do at least one-fifth of their academic work in the humanities, and he was building an outstanding teaching faculty to do the job.

Born on April 25, 1898, in Redlands, California, Ray Untereiner became an outstanding debator on an outstanding University of Redlands debate team. With his AB in hand he went to Harvard to study economics and law. He taught economics and had the best academic record in the department while earning his master's degree, but he really wanted to be a lawyer and was disappointed when eye trouble forced him to leave Harvard Law School in 1923.

He moved to Joliet, Illinois, where he taught high school and was able to resume his law studies at night at Mayo College where he received a Doctor of Jurisprudence degree in 1925, the same year he met Dr. Millikan — and married Lucile Whitlock, to whom he proposed the night they met.

Beginning in the fall of 1925, Ray coached the Caltech debate team and practiced law in downtown Los Angeles until 1931 when he returned to Chicago for one year to finish a Northwestern PhD in economics. During the depression years, he taught economics and law and, when Bill Munro was away, history. One law class particularly remembered him for his offhand remark, "A contract is binding even if it is written on cheese."

Ray was dean of freshmen from 1937 to 1943, during which time the Untereiners got to know the Millikans quite well. Every fall the Millikans had the freshmen (and the Untereiners) to dinner, 30 students at a time, for six consecutive Sunday evenings. In those days Caltech had fraternities, and Ray was also the faculty adviser to the Gnomes.

From 1941 to 1943, Ray was chairman of a Los Angeles County Citizens Committee on local tax reform. He was also chairman of the Free Enterprise Committee of the L.A. Chamber of Commerce. In 1943 he went to New York City where, for two years, he was economist for the National Association of Manufacturers, but he returned to Caltech as professor of history and economics rather than opting for a higher paying job in industry.

In 1951, Ray ran for the Pasadena School Board on a reform ticket, was elected president of the Board, and guided the schools through a difficult time. From 1954 to 1959, he was a member of the California Public Utilities Commission. He and Lucile lived in San Francisco and loved it. From 1959 to 1961, after he resumed his teaching at Caltech, Ray was an adviser to the Atomic Energy Commission.

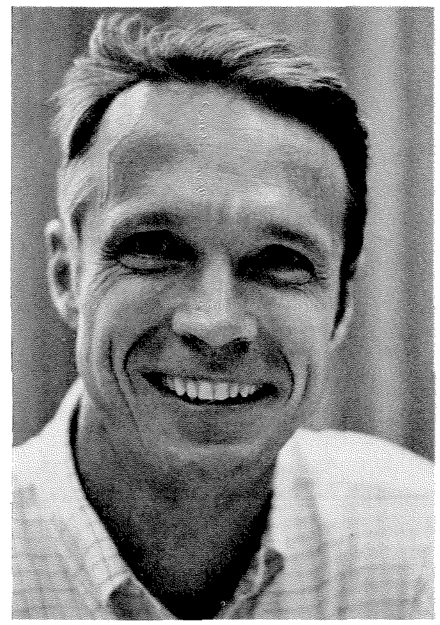
When I came to Caltech in 1959, I shared an office in the basement of Dabney Hall with Ray Untereiner. No one could have been more gracious than he. I much enjoyed his good humor, his stories, and his appreciation of good living. Ray and Lucile entertained the Olivers with grace and elegance in the lovely home they owned for the 34 years between 1932 and 1966. It was on the northeast corner of Wilson and San Pasqual, virtually on campus.

When I was a city director, Ray was a member of a Charter Study Committee considering, among other things, a charter amendment to permit district-only primary elections. It was a change I favored, and I was greatly pleased when he told me, in some confidence, that I was "on the side of the angels." He was a good friend and a thoughtful person whose wisdom was widely acknowledged.

Ray retired in 1968, after which he and Lucile traveled widely. Until recently, they spent summers at Lake Tahoe where they enjoyed their friends, their children, and their grandchildren. Ray suffered a stroke in 1981, but he allowed his disability to interfere only slightly with his social schedule. He came to Caltech faculty parties, he dined as well and played bridge as fiercely, and as well, as ever. He was 85 when he died on July 7, 1983. He had had a good life.

— *Robert Oliver, professor of economics*

People Power



THE LATE John D. MacArthur, an insurance and real estate magnate, liked to bet "on individual explorers, while everybody else is off on another track." So he set up the John D. and Catherine T. MacArthur Foundation of Chicago and made it clear that he wanted it to support exceptionally talented people, not projects. In July, John Hopfield, who is Dickinson Professor of Chemistry and Biology at Caltech, was recognized as one of those people. He received a MacArthur Foundation Prize Fellow Award — a no-strings-attached, tax-free grant of $244,000 to be paid out over a period of five years.

Hopfield will use his award to continue his current research — sans a lot of economic pressure. He is attempting to understand the relation between structure and function in biological systems by constructing models of collections of neurons in an effort to determine how the brain functions as a physical system. He believes it is possible that some of the unique mechanisms of the brain can be incorporated into computers to dramatically change and improve computer capabilities. (See "Brain, Computer, and Memory," by John Hopfield. *E&S*, September 1982.)

Originally a physicist, Hopfield came to Caltech from Princeton where he had been on the faculty for 16 years, and before that, at UC Berkeley. He got his AB from Swarthmore in 1954 and his PhD at Cornell in 1958 and then was a member of the technical staff of Bell Telephone Laboratories for two years. He is a member of the National Academy of Sciences and of the American Academy of Arts and Sciences. In 1969 he was recipient of the American Physics Society's Buckley Prize in Solid State Physics for his work on the interaction of light with solids.

Information Resource

Caltech's libraries acquired a new head man on July 1, one who is charged with developing and implementing a new approach to problems of a university library system in an era of rapidly expanding amounts of information and almost equally rapidly changing technology to deal with it. Glenn L. Brudvig has a title that is new in the history of libraries at Caltech as well — director of information resources. Brudvig comes to the Institute from the University of Minnesota where he was director of the Bio-Medical Library, a post in which he developed automated procedures that put that institution in the forefront of medical libraries in the country. He was also director of the Institute of Technology Libraries at the University and had been responsible for the direction and development of computer applications in the libraries system.

A native of Wisconsin, Brudvig attended the University of North Dakota, where he received a BS in education and an MA in history. He also has an MA in library science from the University of Minnesota. And he is the father of a Caltech alumnus, Gary, who received his PhD at the Institute in 1981.