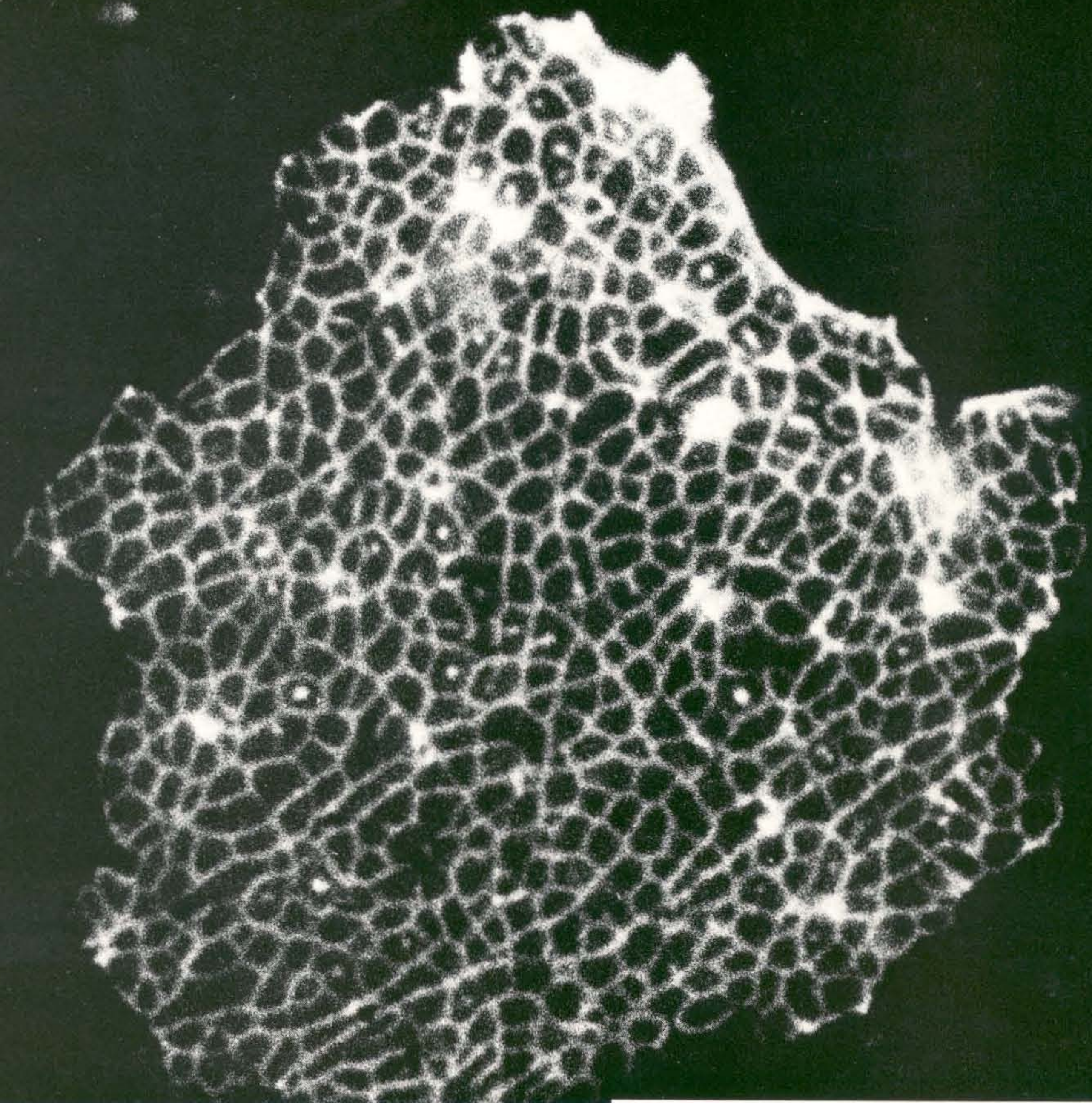
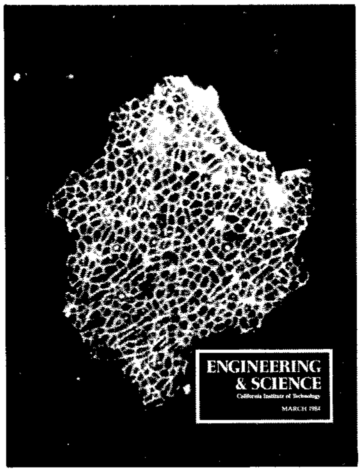


ENGINEERING & SCIENCE

California Institute of Technology

MARCH 1984

In This Issue

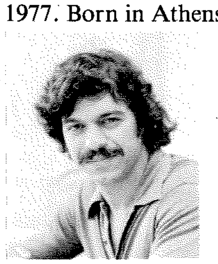


Cell Skeleton

On the cover — the scaffolding of a muscle cell under a fluorescent light microscope (1 micron equals 2.8 mm). This cross section is perpendicular to the long axis of the muscle fiber, showing the intermediate filaments, which surround and integrate the muscle cell's contractile units with each other and with the cell membrane. The techniques for getting inside the cell to illuminate its structure were developed by research fellow Bruce Granger, working in the laboratory of Elias Lazarides, associate professor of biology, and were part of his thesis, which won the Clauser Prize for the most original dissertation in 1982.

The structure is made of desmin, a protein discovered by Lazarides in his work on a small group of such proteins, which make up the "skeletons" of all cells. In his article, "Spaced-Out Cells," adapted from his Seminar Day talk, Lazarides explains the common principles he has found governing these proteins as cells differentiate into specialized cells with different functions. The article begins on page 12.

Lazarides came to Caltech in 1977. Born in Athens, Greece, he



came to the United States for a high school philosophy course and stayed on to earn his BA from Wesleyan University in 1971 and PhD in biochemistry and molecular biology from Harvard in 1975.

Planning Parenthood

Alan Sweezy has been listed as emeritus in the Catalog since 1977, but he's far from retired, even from academic pursuits. He has, for example, kept right on meeting with a class in economics each term. And that's a good thing. Recently David Grether, chairman of the Division of the Humanities and Social Sciences, pointed out, "He has one of the most remarkable records as a teacher of anyone I have ever heard of. If you were to look around today at such major universities as Chicago, Yale, Stanford, Minnesota, MIT, and Caltech, you would find on all their faculties professors of economics who first learned economics from Alan Sweezy. That's an amazing achievement considering that for most of the 34 years he's been at Caltech, there wasn't any graduate work in economics here. He was and continues to be one of the most popular and effective teachers at the Institute."

The Watson Lecture for which Grether was introducing Sweezy was not about economics but population control problems, a subject to which Sweezy has long contributed both scholarly papers and practical help. He has been associate director of Caltech's population program and is active in various off-campus organizations that deal with family planning and population growth. For three years he was chairman of the board of the Planned Parenthood Federation of America, and he has long been a member of the local chapter of Zero Population Growth. In "Is the Population Bomb Still Ticking?" which begins on page 21, he brings us up to date on current thinking about population control.

Medicine Man

When *Newsweek* described Lewis Thomas as "evolution's most accomplished prose stylist," it was complimenting the clarity of his writing about the interrelationships of living things. Dr. Thomas recently addressed the annual black tie dinner of The Associates, and they found him equally clear as a speaker. His talk on that occasion, "Science and Social Science," begins on page 5. Parts of the talk were adapted from material published elsewhere.

Dr. Thomas is now chancellor of The Memorial Sloan-Kettering Cancer Center and professor of pathology and medicine at Cornell University Medical College. He has also served as dean of New York University Bellevue Medical Center and Yale University School of Medicine. From 1968 to 1972 he was a member of the President's Scientific Advisory Committee.

Known as the father of modern immunology and experimental pathology because of his medical achievements, Thomas has also received numerous honorary degrees and awards in science, law and letters, and music. And he is an award-winning author, having received the National Book Award in 1974 for *Lives of a Cell* and the American Book Award in 1981 for *The Medusa and the Snail.* More recently he has published a memoir of his career, *The Youngest Science, Notes of a Medicine Watcher,* and *Late Night Thoughts on Listening to Mahler's Ninth Symphony.*

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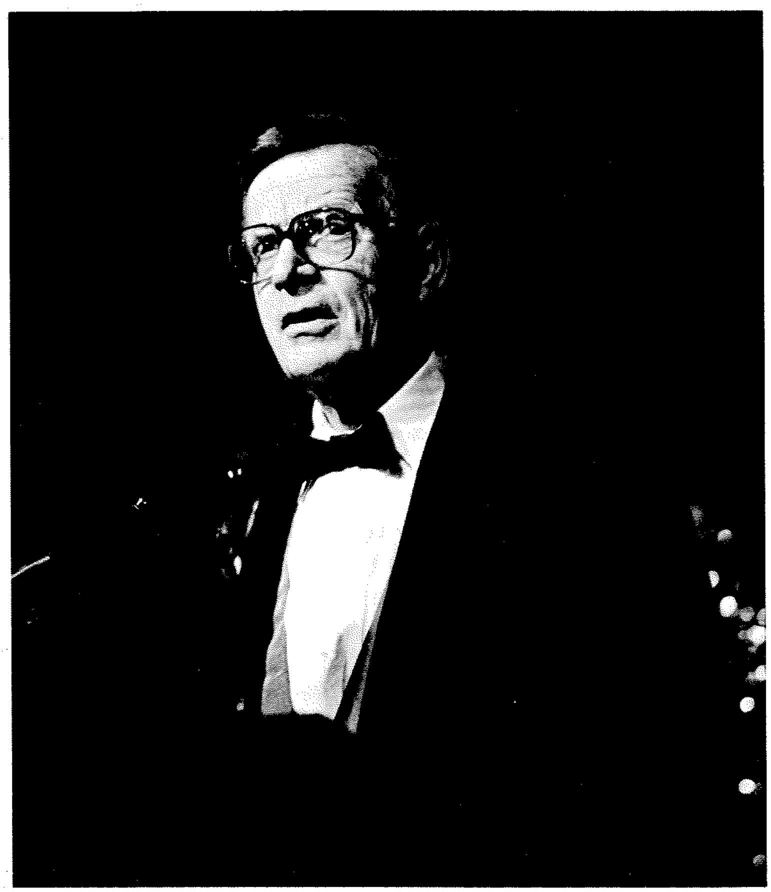
Science and Social Science

by Lewis Thomas

HUMAN BEINGS HAVE never before had such a bad press. By all reports we're unable to get anything straight or right these days, and there seems to be almost nothing good to say for ourselves. In just the past century we've doubled our population twice and will double it again before the next one has run out. We have swarmed over the open face of the earth, occupied every available acre of livable space, displaced numberless other creatures from their accustomed niches, caused one extinction after another with more to come, polluted all our waterways and even part of the oceans.

And now in our efforts to make energy and keep ourselves warm, we appear to be witlessly altering the earth's climate by inserting too much carbon dioxide into the atmosphere, and if we don't pull up short before long, we might be producing a new greenhouse effect around the planet, melting the Antarctic ice shelf and swamping all coastlines including this one and the one I worry the most about — Manhattan. Not to mention what we are doing to each other and what we are thinking seriously of doing in the years just ahead with the most remarkable toy ever made by man — the thermonuclear bomb.

Our capacity for folly has never been matched by any other species. The long record of evolution instructs us that the way other creatures get along in nature is to accommodate, to fit in, to give a little whenever they take a little. The rest of life does this all the time, setting up symbiotic arrangements whenever the possibility comes into view. Except for us the life of the planet conducts itself as though it were an immense coherent body of connected life, an intricate system and even, as I see it, an



organism, an embryo maybe, conceived as each one of us was first brought to life as a single successful cell.

I have no memory of ever having been a single cell myself, 70 years ago; but I was, and whenever I think of it, I tremble at the sheer luck. The thought that the whole biosphere, all that conjoined life — all million or 30 million or whatever the number is, it's still an incalculable number of what we call species of living

We are not a disease of the planet. We have the makings of exceedingly useful working parts. We are just new at the task, that's our trouble.

things — had their collective beginning as a single solitary cell 3½ billion years ago, sweeps me off my feet.

Our deepest folly is the notion that we are in charge of the place, that we own it and somehow can run it. We are beginning to treat the earth as a sort of domesticated household pet, living in an environment invented by us, part kitchen garden, part park, and part zoo. It is an idea we must rid ourselves of soon, for it is not so; it is the other way around. We are not separate beings; we are a living part of the earth's life, owned and operated by the earth, and probably specialized for functions on its behalf that we have not yet glimpsed. Conceivably, and this is the best thought I have about us, we might turn out to be sort of a sense organ for the whole creature, a set of eyes, even a storage place for some thought. Perhaps if we can continue our own embryologic development as a species, it might be our privilege to carry seeds of life to other parts of the galaxy.

But right now we have a lot to learn. One of our troubles may be that we are still so new and so young. In the way evolution clocks time, we arrived on the scene only a moment ago, down from the trees puzzling over our apposing thumbs and wondering what on earth we're supposed to do with the flabbergasting gift of language and metaphor. Our very juvenility could account for the ways in which we still fumble and drop things and get things wrong. I like this thought even though the historians might prefer to put it otherwise. They might say — some of them do say — that, "Look, we've been at it thousands of years, trying out one failed culture after another, folly after folly, and now we are about to run out our string." As a biologist, I cannot agree. I say that a few thousand years is hardly enough time for a brand new species to draw breath.

And now with that thought, for the moment anyway, I feel better about us. We are not a disease of the planet. We have the makings of exceedingly useful working parts. We are just new to the task, that's our trouble. Indeed we are not yet clear in our minds as to what the task is beyond the imperative to learn. We have all the habits of a social species, more compulsively social than any other, even the bees and the ants. Our nest, or hive, or equivalent, is language. We are held together by speech; we are at each other all day long. Our great advantage over all other social animals is that we possess the kind of brain that permits us to change our minds. We are not obliged as the ants are to follow genetic blueprints for every last detail of our behavior. Our genes are more cryptic and ambiguous in their instructions. "Get along," says our DNA. "Talk to each other; figure out the world; be useful; and above all, keep an eye out for affection."

One important thing we have already learned. We are a novel species, but we are constructed out of the living parts of very ancient organisms. We go back a long way. Sometime around a billion years ago, probably more, the bacterial cells that had been the sole occupants of the earth for the preceding 2½ billion years began joining up to form much larger cells with nuclei like ours. Certain lines of bacteria had learned earlier on to make use of oxygen for getting their energy, and somehow or other these swam into the new cells and turned into the mitochondria of what we call higher nucleated cells. These creatures are still with us, thank goodness, packed inside every cell in our bodies. If it were not for their presence and their hard work, we humans could never make a move or even create a song.

The chemical messages exchanged among all the cells in our bodies regulating us are also antique legacies. Sophisticated hormones like insulin, growth hormone, and the sex steroids, and a multitude of peptides — including the endorphins, which modulate functions in our brain — were invented long ago by the bacteria and their immediate progeny, the protozoans. And they still make them for reasons that are entirely obscure. We almost certainly inherited the genes needed for things like these from our ancestors in the mud. We may be the greatest and brainiest of all biological opportunists on the planet, but we owe debts of long standing to the beings that came before us and to those that now surround us and will, I hope, help us along into the future.

I used to think of the social sciences as all of a dreary piece, somehow fundamentally different from the kinds of science in which I'd been trained — softer and fuzzier, mainly underpinned by something like guesswork and unlikely, as I thought, to get anywhere in a lifetime. I believed that questionnaires, and surveys, and computers to handle very big numbers, and the uncontrolled use of imagination, and wishing (most of all wishing) were the only instruments available to researchers in these fields. And I thought that people doing social science were overanxious to quantify whatever they had in the way of information and ideas, and that they were all afflicted with what someone has called "physics envy."

I should note here that our colleagues in the physical sciences, I think, have had the same feeling for a great many years about my field — biomedical science — until some of them overheard that we had some neat little structures like nucleic acids, which we could measure by borrowing isotope technologies, and in they came to invade our territory and take over the parts of it they liked, which they named biophysics. But I still sense that the world of physics, where the only language spoken is pure, unaccented mathematics, regards itself as the very pinnacle of intellectual life. And from this austere perch, the physicists look down at us biologists with gentle amusement, murmuring things about fuzzy notions and soft data and incomplete guesses. Science is a hierarchy of snobberies, and right now the social sciences are climbing the ladder from the lowest rung.

This doesn't mean that I'm comfortable with my prejudice. I've known some people who assure me that economics, both micro and macro, is a genuine scientific enterprise with predictive accuracy and solid data, and I know a number of sociologists who strike me as being a lot smarter than I am. And the numberless subdivisions in psychology these days seem to be attracting any number of very bright young people.

Parenthetically I wish the social scientists, wherever they are, and especially the psychiatrists, were further along in their fields than they seem to be. We need in a hurry some professionals who can tell us what has gone wrong in the minds of statesmen of this generation. How is it possible for so many people with the outward appearance of steadiness and authority, intelligent and convincing enough to have reached the highest positions in the governments of the world, to have lost so completely their sense of responsibility to the human beings to whom they are accountable? Their obsession with stockpiling nuclear armaments and their urgency in laying out detailed plans for using them have at the core aspects of what we should be calling lunacy in other people under other circumstances. And just before they let fly everything at their disposal and this uniquely intelligent species begins to go down, it would be a small comfort to understand how it happened to happen. But I digress.

I used to think that people doing social science were overanxious to quantify, that they were all afflicted with what someone has called "physics envy."

I do have in mind one field in social science that is a stunning wonder, in which more has been accomplished for the illumination of the human mind and for the explanation of the most species-specific aspect of human behavior than any other endeavor I can think of. And the continuing and dazzling success of this field gives me sharp pause in my casual efforts to appraise other parts of social science. I refer, of course, to that queen of sciences, matching the best of physics and biology, namely, philology or — as it is now called in the academic world — comparative linguistics.

This is really a branch of biology, I like to think, certainly human biology. For I can think of no scientific endeavor located more centrally at the core of human existence than the study of language. Indeed, I doubt that we could have evolved from whatever we were at our earliest beginnings (small-headed creatures with a tendency to wander about in small clusters trying to make friends) to what we later became (the most compulsively social of all creatures on the planet) if we had not developed the gift of speech. It may be true that we could think without language, but it would not be human thought.

There are two ways of looking at the ancient roots of modern words. One is to dismiss them as fossils or artifacts, meaningless for the meaning of contemporary words, not something to be thought about while speaking or writing — hazardous in fact to try doing this, risking falling off the bicycle because of the concentrated effort. The other approach, which I do like, is to regard the old roots as hidden reminders, memories of old meanings that are really connected to today's meaning as built-in allusions — how a word "human," for instance, comes from an old Indo-European root, *dhghem*, which meant the earth or soil. And "humble" and "human" are sibling words from that same root, teaching a plain, "humiliating" lesson most of us never succeed in learning in a whole lifetime.

Language is the single human trait that marks us out as specifically human, the one property that enables our survival as the most social of all creatures on earth.

There are some nice words indicating human qualities — "good" itself, which is a word that by actual count by somebody or other is said to have occurred more frequently than any other word in Shakespeare's plays. "Good" came from an Indo-European root *ghedh*, which originally meant simply "to unite." And it moved into Old English as *togaedere* and then into English as "together," "gather," and then "good." And "bad," by the way, came from *bheidh*, meaning "to compel," and hence into German, *baidjan*, meaning to afflict, and then into English as "bad." "Worse" came from an Indo-European root (heaven knows how many thousands of words and years ago), *wers*, meaning "to confuse," which became *werra* in Germanic and then became "war" in English, as well as the worst of things.

Anything "marvelous" or "miraculous" causes the same human response, and the old Indo-European root for these words identifies the response. The root was *smei*, meaning simply "to smile." A marvel is something to smile in the presence of, in "admiration," which, by the way, is a cognate coming from the same root along with, of all telling words, "mirror."

The oddest of all things about language is that we do it with our genes. We are biologically coded to speak not just isolated words but whole strings of words in sentences, and we very likely have genes with instructions for grammar and syntax. Chomsky proposed about 30 years ago that language is indeed a biological trait, setting off a wrangling argument among the linguists, which continues to this day. But we do it collectively, never alone. It's the one aspect of human behavior that does identify us once and for all as the human species. Language, in a sense, is sociobiology at its most complex and puzzling.

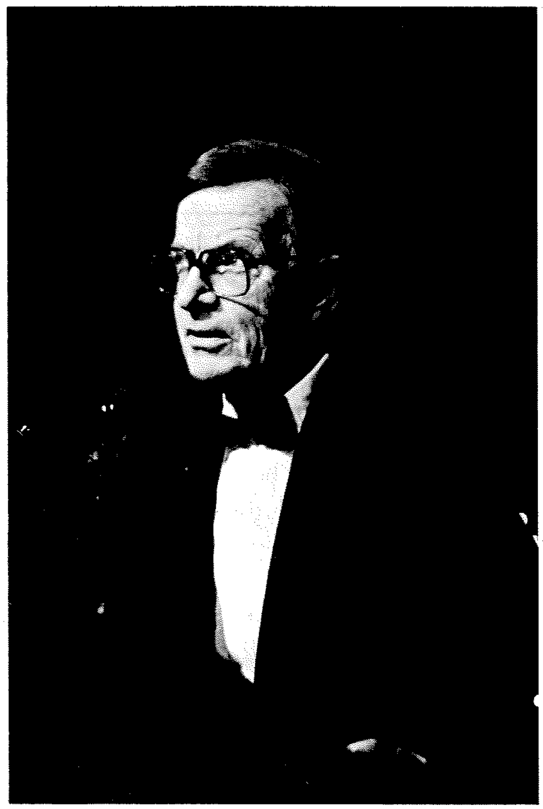
We don't have many models of social behavior to study at close hand, but the best and the nearest of them, and the easiest to analyze, involve our most humble cousins, the social insects. There's nothing at all wonderful about a single, solitary termite. Indeed, there really isn't any such creature, functionally speaking, as a lone termite, any more than you can imagine, if you try to do it, a genuinely solitary human being. There's no such thing. Two or three termites gathered together on a dish are not much better. They move about and touch each other nervously, but nothing happens.

But if you keep adding more termites until they reach a critical mass, the miracle then begins. As though they had suddenly received a piece of extraordinary news, they organize in platoons and begin stacking up pellets to precisely the right height, and then turning the arches to connect the columns, constructing the cathedral and its chambers in which the colony will live out its life for the decades ahead, air conditioned, humidity controlled, and all of this following chemical blueprints coded in their genes, flawlessly and stone blind. They are not the dense mass of individual insects they appear to be; they are an organism, a thoughtful, meditative brain, and a million legs. All we really know about this thing is that it does its architecture and engineering by a complicated system of chemical signals, and a single termite off by itself doesn't know its own name, much less the time of day. It is a real mystery, something to smile in the presence of.

I used to wonder about human childhood and the evolution of our species. It seemed to me unparsimonious for nature to keep expending all that energy on such a long period of vulnerability and defenselessness with nothing to show for it in biological terms beyond the sheer, irresponsible, feckless pleasure of childhood itself. After all, I used to think, it's one-sixth of a whole human lifespan; why didn't evolution take care of that, allowing us to jump, catlike, from our juvenile to our adult and, as I was then thinking, productive stage of life? I had forgotten about language, the single human trait that marks us out as specifically human, the one property that enables our survival as the most social of all creatures on earth — more interdependent and more interconnected than even the famous social insects. I had forgotten that, and I had forgotten that children do that in childhood. Language is what childhood is for.

What I hadn't known until recently is that children not only learn language, any old language you like, they *make* language — any new language *they* like. Derek Bickerton, who is professor of linguistics at the University of Hawaii, has, I think, come close to proving something like this. In 1880 the Hawaiian Islands were opened up for sugar production, and large numbers of Japanese, Koreans, Chinese, and Spanish-speaking Filipinos and Puerto Ricans came to the islands to work in plantations alongside Hawaiian-speaking natives, and all of them supervised by English-speaking Americans. Nobody could understand anyone else and, as happens in such situations, a crude sort of pidgin speech developed quite quickly, using words borrowed from the various languages, principally from the dominant English. Pidgin English, which is a mispronunciation of "business" English, was not really a language; it was more like a system for signaling, pointing, and naming. But it lacked sentence structure, and it was devoid, or almost devoid, of grammar.

And then sometime between 1880 and 1910 Hawaiian creole appeared as the common language of the worker population — a genuine complex speech with its own syntactical sentence structure, its own tight grammatical rules, containing words borrowed from all the other tongues. Bickerton analyzed this new creole and claims now that it closely resembles in the details of its grammar other creole tongues in other colonial settings elsewhere in the world. It is fundamentally different from the languages spoken in the homes of the different ethnic groups on the islands in 1880. It is therefore a new language. And when it appeared, it could not be understood or spoken by the adult generation who arrived in 1880, nor could the American overseers comprehend it. Bickerton's discovery is that this brand new language, never heard or spoken before, must have been made by the first generation of children — syntax, grammatical rules, sentence structure, metaphors, and all.



And there it is — children make language. Children are not only biologically equipped to learn speech; if necessary they can manufacture it out of their collective heads and in something like perfection, at that. It puts children in a new light, or I think it does. No wonder we need a long childhood; a pity it can't be longer. When human speech first appeared sometime perhaps within the last 100,000 years, maybe more recently (certainly no time at all as evolution goes), and turning then our species from whatever it was into our kind of creature — heads filled with metaphors and memories, awareness, fear of death, and all — maybe it was the children who started it off. Maybe, as in the termite model, language required for its beginning nothing more than the critical mass of children being raised together and at each other in close quarters for a long enough time. And maybe when it first started up in some newly stabilized agricultural or hunting and gathering community, the parents and the elders around the communal fire wondered wordlessly what those incessant sounds being made by the children were and wondered why the children seemed so pleased.

We named the place we lived in, or someone did, the "world" long ago from the Indo-European root, *wiros*, which meant "man." And we now live in the universe, that stupefying piece of expanding geometry. Our suburbs are the local solar systems into which sooner or later we will spread life and then perhaps further. And of all the celestial bodies within reach or view as far as we can see out to the edge, the most wonderful and marvelous and mysterious is turning out to be our own planet earth. There is nothing to match it anywhere, not yet anyway. And it is a living system, regulating itself, making its oxygen, maintaining its own temperature, keeping all its infinite living parts connected as interdependent, including us. It is the strangest of all places, and there is everything in the world to learn about it. It can keep us awake and jubilant with questions for millennia ahead, if we can learn not to meddle and not to destroy and how to ask the questions.

We can take it, I think, at the present time from what we can see of it that it is one single huge life, made up of innumerable discrete working parts, which interact with each other in continual complicated maneuvers so that the whole being maintains a kind of stability for itself over long stretches of time. On occasion over the 3½ or more billion years of life's existence on the planet, catastrophes of one sort or another have occurred. Continents have split and drifted away from each other on plates that comprise the earth's cracked shell, and volcanoes have clouded the atmosphere and shut off the sunlight, and meteorites have crashed into the surface, ice ages have come and gone, and countless species have emerged and then become extinct. But the life of the whole organism goes on. And now humanity is here — a recent development. It is not all that much human vanity to say that the human species is the most important thing in all those 3½ billion years, depending on what you mean by important. We have the power to become a new kind of endangerment to the earth's life, outmatching any of the natural catastrophes before our time. It is possible, but not necessarily probable. But we might, if we can use our brains and act together as a species, turn out to be useful. And it is up to us.

> We have the power to become a new kind of endangerment to the earth's life, outmatching any of the natural catastrophes before our time.

The first thing we have to do is to learn a lot more than we now know about how the whole organism works. Without knowledge we could kill off vast tissues of the earth's flesh without realizing what we were doing. Already there are evidences of the risks we pose. We are not only interfering with the balance of constituents in the atmosphere, risking an increase in the mean temperature of the whole planet, we are interfering with the cyclic exchange of nutrients between the land and the sea, endangering terrestrial life by deforestation, desertification, and threatening marine life by pollution. We are surely overpopulating the place with our own species and crowding out other forms of life and destroying their ecological niches. In the end, if we keep it up, we will surely do ourselves in. And if we hasten the process by engaging in nuclear warfare, we could do in much of the rest of the life at the same time.

But we do have excellent brains, and they're good enough to permit us to see what we're doing, and they're ideally constructed for looking ahead. I spend part of my time these days looking about for signs of hope for the future. One of the best ones is a social invention to the credit of this country, the National Aeronautics and Space Administration — not the NASA of the moon shot, or the tour of Mars, or the vehicles now threading their way through the orbits of the outer planets, although this side of NASA is all high marks for the agency. The NASA program that lifts my heart and gives me hope is one entitled Global Habitability. It is a low-key, modest-sounding proposal now awaiting approval and funding, indeed probably now just awaiting attention. The purpose of the project is nothing less than a close-up, detailed, deeply reductionist study of the anatomy, physiology, and pathology of the earth itself.

NASA, I am told, is having a hard time with its budget these days, partly due to the general shortage of money for science, but mostly because of the immense costs of the shuttle. I don't know where the Global Habitability project stands on the list of priorities, but I hope it is up somewhere near the top. Like everyone else, I am delighted and fascinated by the shuttle. It is surely the world's most exhilarating toy, and I have no quarrels with its expense. However, I do wish NASA could have just a little more money to do this other job, which no other agency on earth can do. Dipping into the petty cash box in the Department of Defense might get the thing nicely started, and nobody is likely to argue that the DOD shouldn't have the defense of the entire planet as much on its mind as the protection of our own borders. We need, for the long run, to be sure that the borders are always there and recognizable, which is one of the problems for which NASA can be exceedingly useful.

The Global Habitability program is no sort of quick fix, which of course means political trouble in getting it under way. It is research for the decades ahead, not just for the next couple of years. And it cannot be done on the cheap, which means wrangles over the budget in and out of Congress. It will require, as well, collaborated efforts by researchers from many different disciplines in science and engineering and from virtually every country on the face of the earth, which means international politics at its most difficult. But the case for beginning the project is as strong as that for any scientific enterprise ever envisioned by humanity.

Working scientists and their astonishing sensory instruments have already been able to look closely at the surfaces of other planets and make predictions about their chemical composition and atmospheric history. Man has walked on the moon, even played a sort of golf on the moon. The public is well aware of these matters, and there is already talk about the prospects for explorations to the edge of the solar system and beyond. What is not yet enough talked about is the golden opportunity now at hand to employ these same technologies for exploring what is by far the most puzzling and the strangest object in the solar system, or for that matter, any solar system that we can guess at.

The earth is a strange phenomenon. The interactions among the land masses, the oceans, and the air seem to be orderly cyclical events keeping the life going, but the life itself produces enormous effects on these natural components of the planet. Events that meddle with the runoff from the land into the sea, or change the exhalation of terrestrial vapor and its condensation over the ocean will alter the viability of life in both places, and this in turn will result in new changes in the climate everywhere. The cyclic exchanges of carbon and nitrogen and phosphorous and sulfur moving back and forth from the water to the land not only sustain life as a whole, but switch it on in one place and turn it off in another, depending on the climate. And the latter is in part dependent on the life.

Among the earth's numberless species, coordination and cooperating seem to be a more general rule than we used to think.

Among the earth's numberless species, coordination and cooperating seem to be a more general rule than we used to think. Living things tend to keep an eye on each other as well as on the sky. The tools possessed by NASA for scrutinizing the most intimate details of planetary life are wonderfully precise, revealing the acre-by-acre distribution of fields and forests and farms and wasteland and houses everywhere on the globe, the seasonal movement of icepacks at the poles, and the distribution and depth of the snowfall, the chemical elements in the outer and inner atmosphere, and the upwelling and downwelling of regions of the waters of the earth. It is possible now to begin monitoring this planet, spotting early on the evidences of trouble ahead for our species or for others, especially the kinds of trouble for which we humans are responsible. I cannot think of a better work for the international science community on the ground or out in space, and I hope we will get on with it. The military people are out there too, of course, competitors for their kind of scientific prize, but they are more interested in biological phenomena as targets rather than objects for affection.

Maybe this will change. Already I am told, their photographic equipment is so good that they can make pictures of individual people with upturned faces — even the tears on the faces — anywhere. Keep them at it, I say, and make them take a long, long look. And meanwhile, give NASA a piece of their budget.□

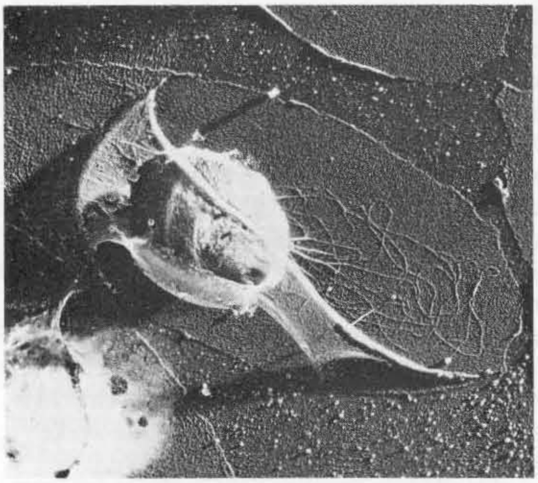
Spaced-Out Cells

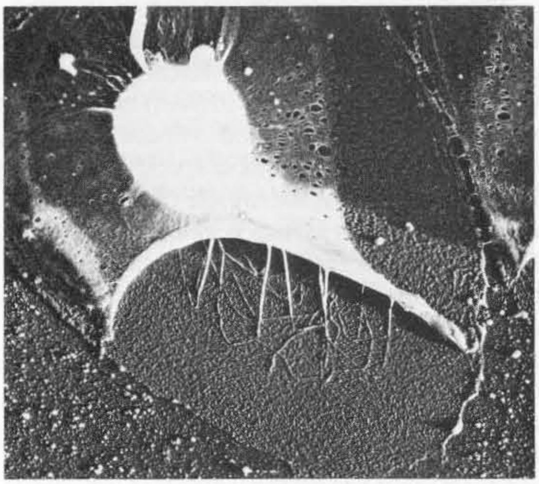
by Elias Lazarides

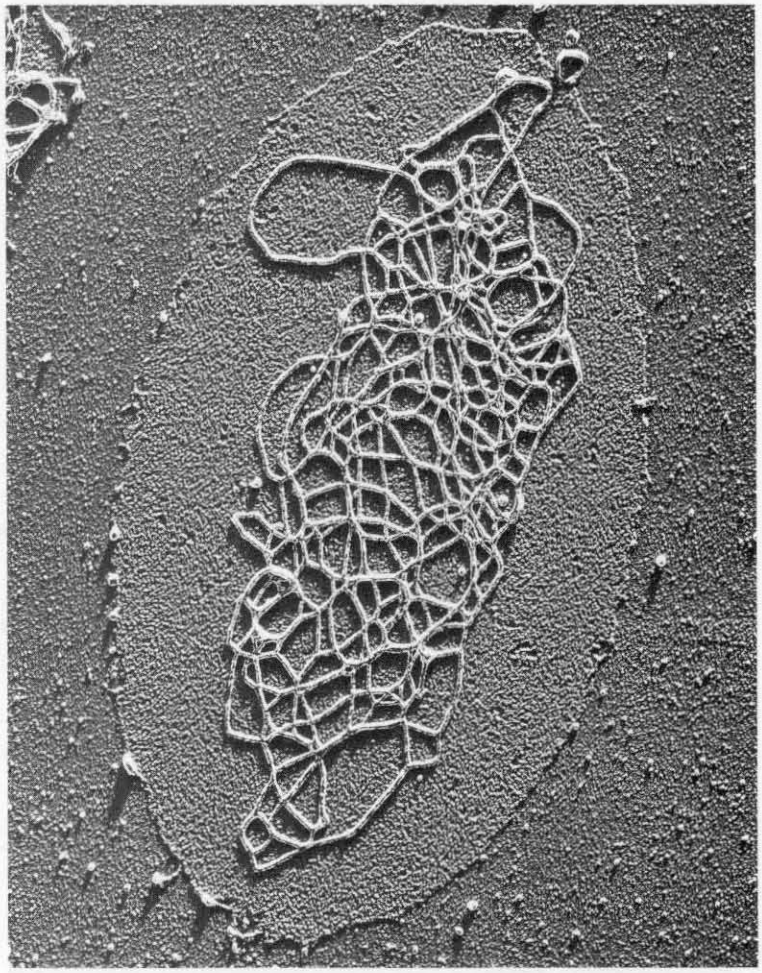
A BAG OF FLUID — that's the most common concept of a cell. But it doesn't look like that at all; a cell is a highly structured system, organized from one end to the other in three-dimensional space. The revolution in our concept of how a cell is put together has come about only in the past 10 years as the result of new technologies developed in our laboratory that have enabled us to look inside the cell and discover its complicated and integrated cytoskeleton. A small group of proteins makes up this scaffolding, which is universal among all types of cells, even though it has different functions in different cells. We have found that common principles govern what these proteins do as embryonic cells differentiate into specialized adult cells; studying these processes may bring significant insights into a number of human diseases, including muscular dystrophy and heart disease.

One way or another, every cell in our bodies is capable of being deformed. Red blood cells can serve as a simple example. There are about 5 million red blood cells per cubic millimeter in our blood, and they get squeezed thousands of times every hour through our blood vessels. Each time a red blood cell goes through a capillary, which is narrower than the normal width of the cell, the cell must be deformed from a round or oval shape to a long sausage-like structure. And after it has passed through the capillary, it resumes its former shape. The cell does this for a number of generations (about 120 days) before it peters out and is removed from circulation.

The human red blood cell has to pack millions of molecules of hemoglobin into a very small space (approximately seven microns in length and three microns in width). If the cell had nothing to keep its structure together, the osmotic pressure that the hemoglobin molecules impose on the cell would cause it to rupture eventually, especially when squeezing through a capillary. But it does have something to keep its structure together — a huge, dense (50-100 milligrams per milliliter) network of proteins, under the membrane of the red blood cell. This network is highly compacted — three to four times the viscosity of the blood — and consists of fibrous proteins (spectrin and actin) that are specifically bound under the cell membrane to control the shape of the cell and allow it to be elastic. Spectrin has been known for some time to be a component of red blood cells. We have determined its ubiquitous presence in all cells only recently, thus allowing us to envision that all cell membranes may be capable of deformability, an event that may have a common molec-







Rupturing the upper cell membrane with sonic waves exposes the system of protein intermediate filaments that are attached to the lower part of the membrane, seen in the electron micrograph of a red blood cell at right, above. At left, top and bottom, the network of intermediate filaments, which gives the cell structure in three-dimensional space, can be seen attaching the nucleus of the chicken red blood cell to the membrane.

ular principle. (Postdoctoral fellows Jim Nelson and Elizabeth Repasky were particularly involved in this work.)

Elegant techniques allow us to see the shapes of these protein molecules. We can isolate a single protein from this whole network, spray it on a carbon film, coat it with platinum, and make a platinum replica of it. They are very long molecules — about 200 nanometers — and they come together end to end under the plasma membrane of the red blood cell to form a highly flexible, elastic network.

This flexible network under the membrane is not the only form of cell structure. For some reason, the chicken's red blood cell is slightly more complicated than a human cell. Unlike human red blood cells, which are cup shaped, chicken red blood cells are ovoid, football-shaped cells filled with hemoglobin; the main difference is that the chicken cell has a nucleus. The invariant position of this nucleus in the cells demonstrates another form of cell structure. If we lower the ionic strength of the medium in which the cells are isolated, the membrane will open and all the hemoglobin will spill out. But even when the cell loses all its "filling," the nucleus still stays in the center, because in addition to the band of material at the periphery of the cell, which allows the cell to keep its ovoid shape, there is another structural system superimposed on the cell's space — a system of fibers called intermediate filaments.

Research fellow Bruce Granger has devised a rather elegant technique for getting inside the cell and looking at the three-dimensional disposition of this structure. The technique involves passing sonic waves through a cell stuck onto a glass cover slip. As you increase the frequency of the sonic waves, the membrane begins to rupture, and the upper part of the membrane, which is not attached to the glass, begins to peel back. Then we can see the whole system of intermediate filaments inside the cell, spanning from the upper to the lower part of the membrane.

The intermediate filament network links the parts of the membrane together and the membrane to the nucleus like a three-dimensional gluing system. This network, also made of spectrin and actin under the plasma membrane, takes up about half of the space inside the cell, but the cell still manages to pack everything else in there too. In the case of the red blood cell, it packs millions of molecules of hemoglobin in between the fibers.

Not only are nuclei and membranes integrated by these fibers but also the mitochondria — the structures in the cell that make ATP (adenosine triphosphate), which is necessary to cell metabolism. Mitochondria have to keep an invariant position and not slosh around in the cytoplasm as cells change their shape. Again, the intermediate filaments link the outer membranes of the mitochondria all the way to the upper and lower surfaces of the cell. Every point in the cell has its own fixed place in the cell's organization.

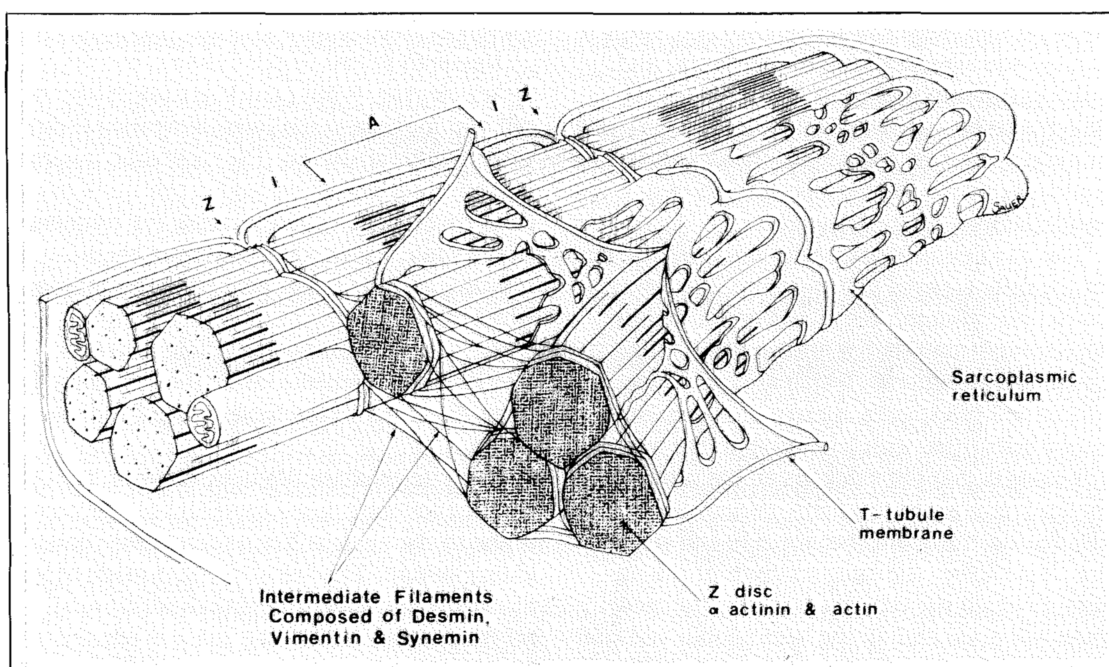
Other cells besides red blood cells have to be elastic. For example, the lens cell of the eye has to undergo many elastic changes as the lens accommodates light. We discovered that spectrin is the protein that provides flexibility in the lens also.

Of course, not all cells deform in the same way that red blood cells and lens cells do. Muscles do something very different, but spectrin is again on the scene here performing a different function. Our muscles contract extremely rapidly, go back and forth on the order of milliseconds. Muscles manage to contract and affect our movements because they're highly striated, that is, all the contractile units, called myofibrils, are arranged along the long axis. As they contract, a great amount of tension develops along that axis. If cells did not have a way of translating this tension to lateral tension, the cell membranes would balloon out. To avoid that, imposed on the long-axis system is a lateral-axis system which apparently integrates the membrane with everything else along the lateral axis in the muscle fiber, as shown in the figure below. Intermediate filaments, with gluing struts of spectrin, keep the system of vertical and transverse axes in register. When the muscle contracts, the membrane puckers at the specific points where the spectrin struts are not attached to it, while the areas where spectrin is attached remain invariant due to their association with intermediate filaments. So, as you develop tension in one direction, you also develop tension in the other direction to keep the whole system together.

By removing the cell membrane and using detergents and different salt concentrations, we can preferentially remove different structures in the cell (in this case the myofibrils) and leave the unifying scaffold behind. We can see that fibers surround myofibrils at specific points. Looking laterally at the muscle fibers we can see how the whole system is glued together from one end of the cell to the other; it's mechanically integrated, just like the red blood cell. These fibers glue themselves at the periphery of the myofibrils to integrate the whole space and provide tension in one direction as tension is developed in another direction. And the glue is, again, a combination of intermediate filaments and spectrin.

Protein fiber structures are found performing still other functions in different types of cells, often two or three structural systems imposed on one another. In the epithelium of the

In this diagram of a muscle fiber, spectrin struts (attached to the membrane at points marked Z along the top) glue the network of intermediate filaments (web-like structure peeled out at bottom, left) to the membrane, keeping the whole system in register during contraction.



human intestine little structures called microvilli move particles of mucus up and down as we digest food. The whole system has to contract and expand, applying a great amount of tension on the columnar epithelial cells. As this takes place, the cells have to have a way of translating and linking movement from place to place. A system of filaments in one place induces movement continuously along the microvilli to move down all the particles.

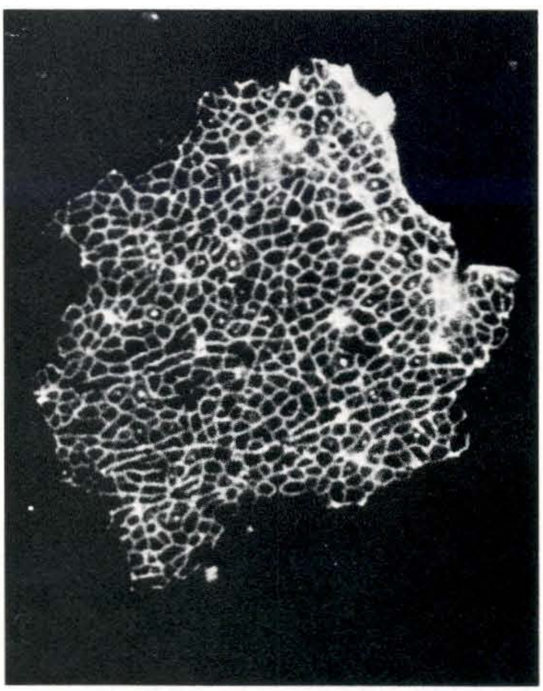
Cells also have to spend a lot of energy to keep themselves flat. When a cell is cooled, it presumably lowers its energy state by pulling all its membranes inside around the nuclear area. When it does so, it leaves behind structural material attached to specific sites of the substrate. If we revive the cell, it will expand all its membranes along tracks composed of actin filaments that provide tension to the cell.

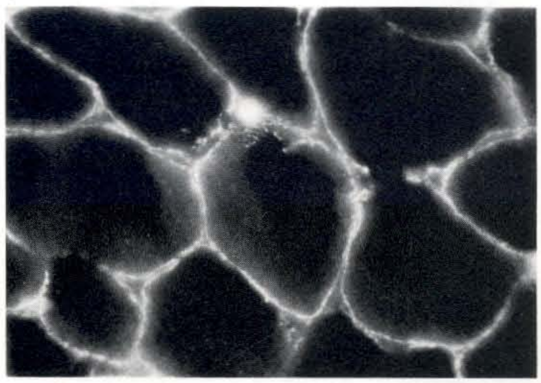
There are still other fibers of similar structure in the cell, whose function is to keep the cell in a three-dimensional shape. There's a system of geodesic (or "biodesic") structures surrounding the nuclear area and extending in a staircase-like fashion all the way to the edge of the cell.

A different protein associated with actin filaments does exactly the same job of cross-linking individual filaments. This second network is found in highly motile cells that have whip-like structures. This is the same system that links the nucleus to the membrane in the red blood cell — the intermediate filaments. But in the motile cells, there is an entirely different distribution of proteins than in the static red blood cells. The amount of cross linking of the fibers has been decreased during the cell's differentiation.

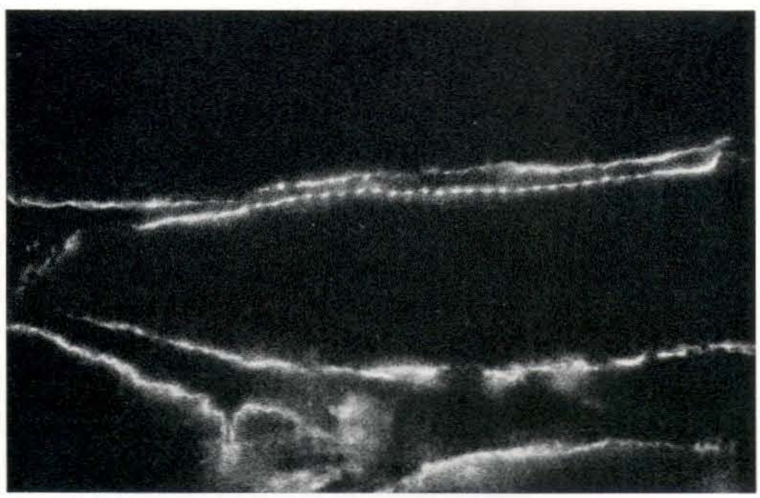
From DNA cloning technologies we know that the protein molecules that enable these cells to maintain their structure, to move, and to deform their shapes are universal — they're the same in unicellular organisms of yeast and in human beings. The system diversifies itself through a complicated set of accessory proteins, which allow these same molecules to assume different functions in different cell types to produce differentiated phenotypes — red blood cells, muscle cells, lens cells, nerve cells, and so on. Also, within the same cell type, nerve cells, for example, variations of a particular protein establish segregated domains, which perform different functions during cell differentiation.

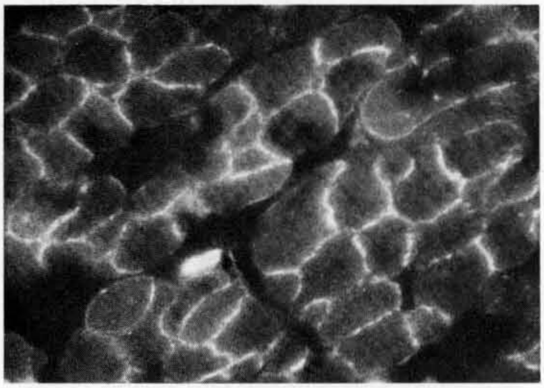
We know that each human cell contains approximately 10,000 different proteins, each of which increases in many thousand copies to bring the total of protein molecules within our cytoplasm to more than a million per cell. We have developed a technique for studying one protein at a time by making antibodies against it. We can give a protein from, say, a chicken cell, to a rabbit, and the rabbit's system will recognize it as foreign and produce antibodies





Fluorescent antibody techniques show up the intermediate filaments (far left) surrounding the myofibrils of the muscle fiber, and the spectrin under the membrane along the lateral axis (below) and in cross section (left).





In this cross section through the atrium of a chicken heart, fluorescent antibodies illuminate spectrin under the cell membranes, just as in the muscle cells on the previous page.

against it. (Sometimes we have to slightly change it chemically to trick the rabbit into recognizing the protein as foreign.) We can put a fluorescent tag (rhodamine, which is red, or fluoresceine, which is green) on this antibody, remove the membrane of the cell, put the antibodies inside, and observe with a fluorescent microscope to see where the antibodies bind. This technique has revealed that more than 50 percent of the mass of the cell is occupied by protein fibers.

We can study the biochemical composition of these fibers by making antibodies to other components, and, using different antibodies and different colors, show that different molecules co-exist in the same structure. With the fluorescent tags, we can choose a particular protein, localize it within the cell, and study its distribution during differentiation. In this way we can do molecular mapping of all the components in the cell at different stages of differentiation.

The distribution changes dramatically during cell differentiation. In the early differentiation stage of a muscle cell, as it begins to put together the contractile unit, it immediately changes the distribution of the proteins. They bind to specific structures in the cell to form the striated pattern characteristic of the adult muscle cell. We can use differentiation in tissue culture to delineate and analyze the molecular details of how the system assembles.

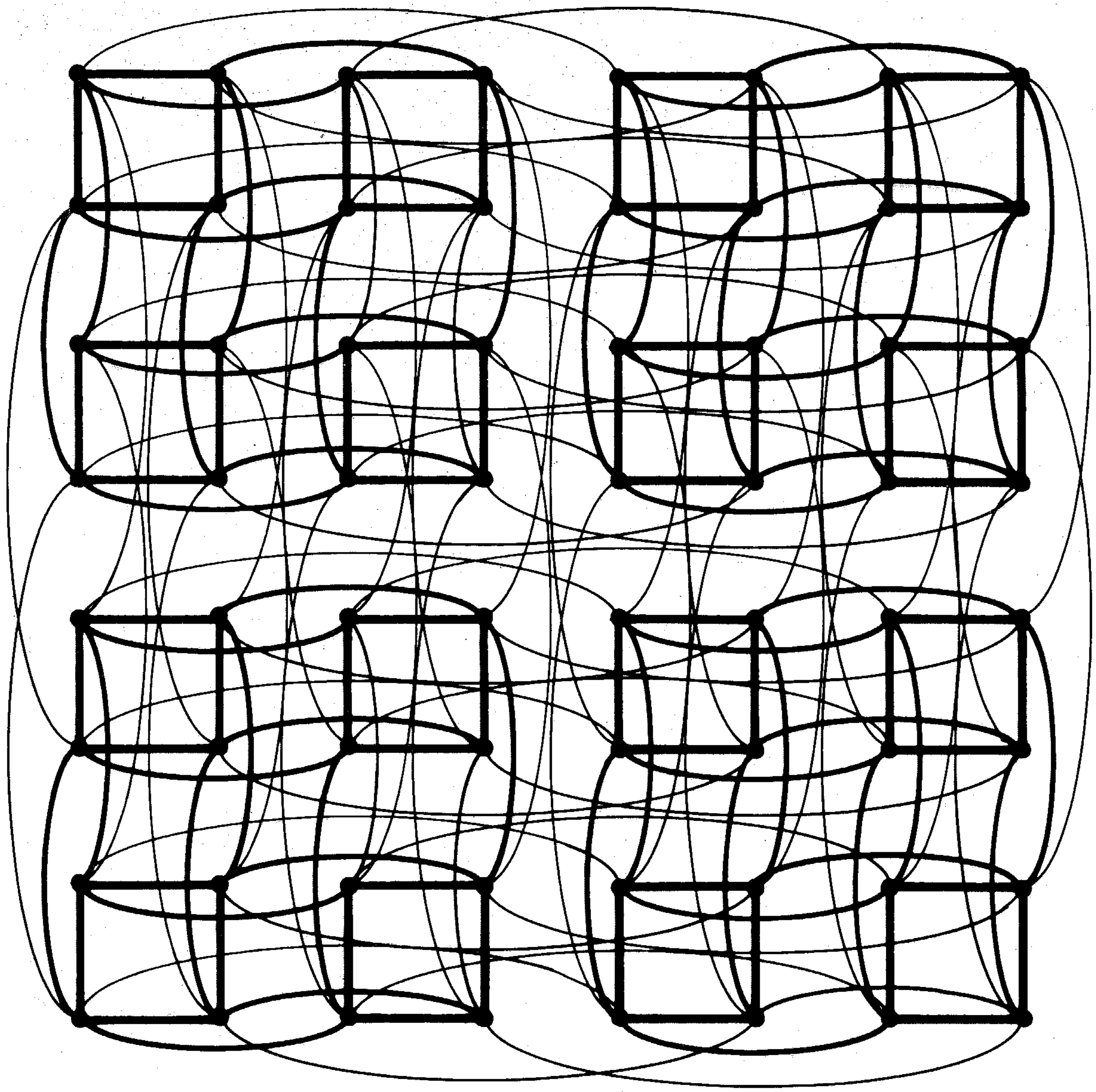
So far we've been looking at cells that are highly structured and specialized to do only one thing — either circulate like red blood cells, move up and down like muscle cells, or left and right like epithelial cells. There are many others — lymphocytes, macrophages, fibroblasts, which move around in our bodies during embryogenesis. Nerve cells, for example, have a very complicated system of fibers in their cytoplasm to mediate movement. They move by means of structures that look like potato chips (so we call them ruffles). Ruffles have the function of feeling the environment around the cell in three-dimensional space, allowing the cell to position itself on the substrate or onto other cells. It's interesting to watch nerve cells grow because they use these ruffles to feel other nerve cells around them — to avoid the trunks, or axons, of other nerve cells until they find the ends of the nerve cells and make contact.

With the fluorescent antibody technique we can show quite nicely what each of these structures contains. And we've discovered actin, the same molecule we found in muscles and red blood cells, doing here a very different job, which is to mediate the movement of this membrane's ruffle.

The ubiquitous spectrin is also present in nerve cells, and it appears to be the protein involved in the post-synaptic site. During differentiation we find it appearing at sites where synapses are being formed at the moment they're being formed. Actually two types of spectrin exist in the highly structured neuron, and the cell can segregate these forms of the protein in an anisotropic distribution, one form having the capacity to accumulate at specific sites on the membrane. This rearrangement of spectrin subunits into segregated domains occurs during differentiation, and we have been able to trace the stages of cell development at which one type diminishes in favor of the other or when it switches completely from one to the other.

The universal presence of such proteins as spectrin and actin have given rise to insights into how cells age, how changes in only a few proteins could affect so many parts of the human body. The changes in flexibility of skin cells, muscle cells, and so on as we age are due, at least in part, to an increase in intermediate filaments, which stiffen the cells and make them less elastic. Hypertrophy, or enlargement of the heart, is due to a vast accumulation of intermediate filaments produced to resist the tension often put on the heart muscle by athletes. The use of such drugs as steroids also increases the intermediate filaments.

We think that other forms of heart disease may also stem from anomalies in the distribution of specific proteins in heart muscle cells during cell differentiation in the embryo. And muscular dystrophic cells display a highly abnormal way of switching from one phenotype of a particular molecule to another during differentiation. We believe that this basic biomedical research into cell structure and function will inevitably result in better understanding of a large number of human afflictions and eventually lead to discoveries of new treatments. □



Caltech's concurrent computer is connected as a Boolean 6-cube, drawn schematically here. Each square is a 2-cube; with corresponding corners connected to a neighbor, it's a 3-cube; and with these two repeated and corners connected, you have a 4-cube. Repeating twice again and joining corresponding corners (lightest lines) you end up with a 6-cube.

Cosmic Cubism

CALTECH'S CONCURRENT COMPUTER, resembling a horizontal stack of microprocessor boards, sits unassumingly on a desk top in Jorgensen Laboratory's basement. Aside from its nickname, the "Cosmic Cube," which offers a hint of its vast potential, there's nothing about it to give you a clue that it's the fastest computer on campus. It's hardly a cube; the name refers to its wiring. About 5 feet long, 8 inches high, and 14 inches deep, and consuming only 700 watts, the Cosmic Cube is comparatively tiny for its computing power, which is about a tenth of that of the Cray-1, the largest and most powerful computer in use today.

The Cosmic Cube is just what it looks like — a bunch of microprocessors (64 to be exact) harnessed together. It's called a "homogeneous ensemble machine" because it's a computer built as a group of identical computers working together. Instead of working on a problem sequentially, one calculation after another, as conventional, Von Neumann computers do, each of the concurrent processor's 64 small computers (nodes) works on a piece of the problem at the same time as all the others. Its homogeneous, modular architecture makes possible open-ended expansion (a 128-node machine is under construction and a 1,024-node model is planned), and its creators are talking about building computers 1,000 times the power of the Cray-1 in just a few years — at a fraction of the cost and size.

This revolutionary computer is the result of a collaboration between Charles Seitz, associate professor of computer science, and Geoffrey Fox, professor of theoretical physics and dean for educational computing. Seitz and his students developed the architecture and design of the machine, while Fox has applied the computer to numerically intensive scientific and engineering computation on the campus and at JPL.

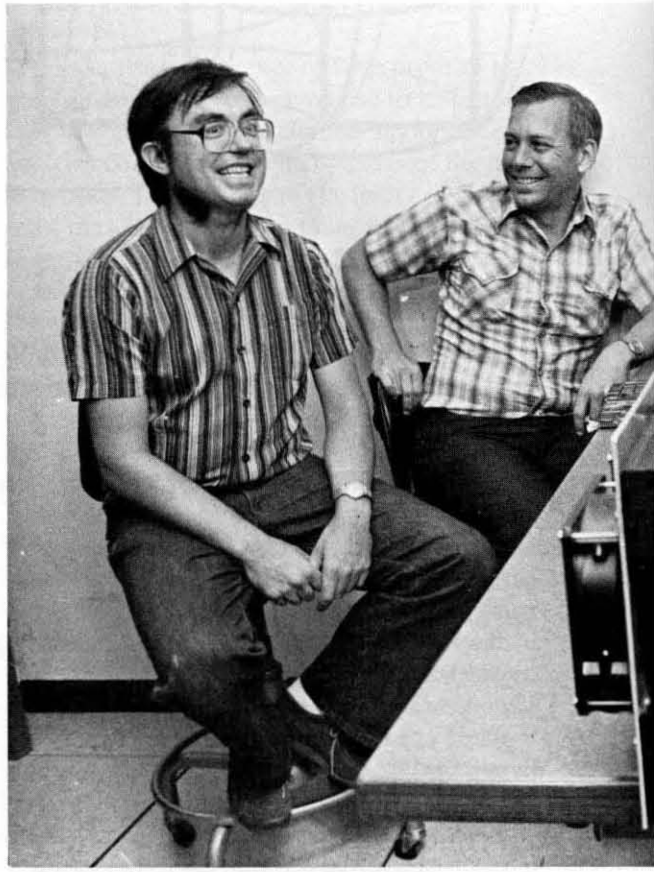
Exploiting microelectronic technology and concurrency to multiply the power and speed of computing while lowering the cost is not unique to Caltech. In fact, there is, according to Fox, a "staggering amount" of work being done in the field of concurrent, or parallel, processing around the country, staggering at least in comparison to the amount of progress made so far. (Although the terms "parallel" and "concurrent" are often used interchangeably, the Caltech group prefers "concurrent" as a truer description of how the parts of the Cosmic Cube operate — independently, rather than in lockstep with each other.) But Seitz and Fox's work is far ahead of the rest because "we have real hardware and real software solving a real problem." Caltech's size and interdisciplinary atmosphere encourages the sort of collaboration that can create a prototype like the Cosmic Cube and put it to work immediately on state-of-the-art problems.

Seitz has been working on high-performance architecture suitable for very large scale integration (VLSI) since 1978. It was not until 1982, after he and his graduate students (in particular Dick Lang, Bart Locanthi, Erik DeBenedictis, Chris Lutz, and Bill Athas) had developed their ideas about the programming and technology of this family of machines and had studied them extensively through computer simulations, that they built the 4-node predecessor of the Cosmic Cube. The machine proved so successful in running Fox's programs that Seitz and Fox got together to build the 64-node version.

Both the 4-node and 64-node models use Intel 8086-8087 processors, the same family of chips used in the IBM personal computer. The technology of microcomputers and video games has developed rapidly out of intense competition, and its enormous popularity in the marketplace (home computers are selling in the millions) brings economies of scale. Seitz considers that Pac Man technology, which is in many respects more advanced than that of the Cray-1, has subsidized development of the Cosmic Cube. Even though this amazing technology has gone into some frivolous applications, he says, it's still "an elegant, expressive, and beautiful medium for switching systems of extraordinary complexity." The cost-effective technology is not, however, a good fit for the Cray-1. While the Cosmic Cube offers a tenth of the Cray's power, its cost, at $80,000, is more like a hundredth.

The Cosmic Cube achieves its huge calculating capacity through the teamwork of its 64 computers wired together according to a fairly simple mathematical structure — a Boolean lattice, or six-dimensional hypercube. (Actually, the string of microprocessors could still solve a fair number of difficult problems even when randomly wired together, according to Seitz, and Fox has longed to get his hands on the rows of personal computers that sit alone and unused at night in, say, a bank, and team them up for some giant physics problem.) Each node communicates only with its six nearest-neighbor nodes in the hypercube topology; there is no shared memory with the rest of the computer.

Problems for the Cosmic Cube to solve must be capable of being decomposed into approximately equal segments for each node. The operation of the Cube is particularly simple when the variables at one site are affected only by the variables near it, and you only have to know local conditions to predict the next value. For example, says Fox, to predict the weather in



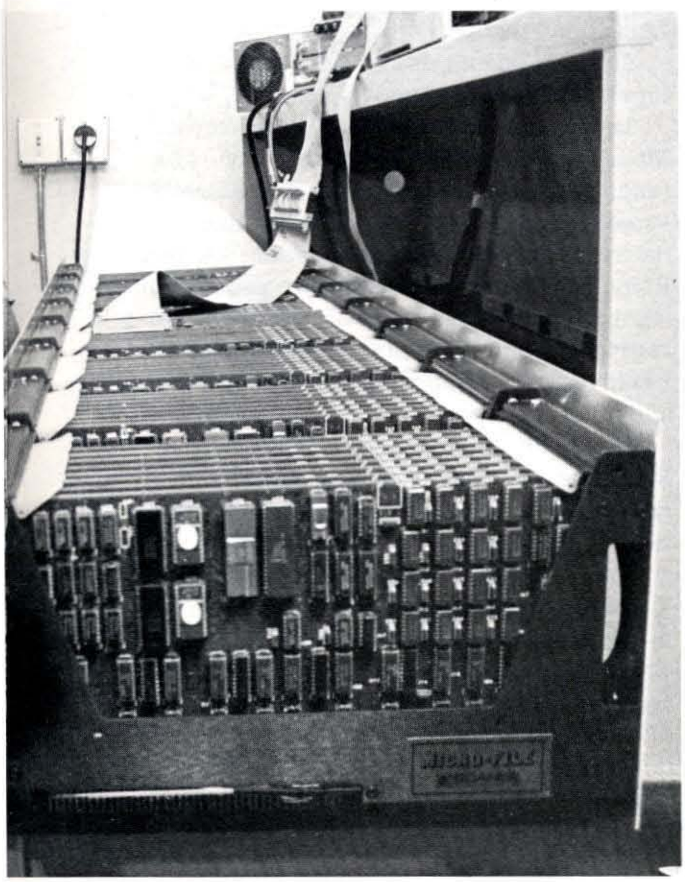
Geoffrey Fox (left) and Charles Seitz display their 64-node Cosmic Cube. One of the nodes, a complete microprocessor in itself, is visible at the front end of the concurrent computer.

Los Angeles in the immediate future, you don't need to know the weather in New York, even though they might be related over a long time.

Meteorology is, indeed, one of the fields with problems well suited to the concurrent processor's capacities — problems that depend on relatively simple algorithms, or equations, but in very large volume. Efficient algorithms for concurrent processing must be such that the time spent communicating is very low compared to the time spent calculating. It turns out that there's a wide range of scientific and engineering problems that fit this approach, as discovered by Fox and the Concurrent Computation Group, which surveyed the heavy computer users on the campus and at JPL for possible efficient application of concurrent processing to their problems.

A number of problems in high energy physics, astrophysics, geophysics, chemistry, and applied mechanics have been seriously hampered by lack of computing power for their vast calculations, since conventional computer technology has leveled off, and current large computers, although they are getting cheaper, are no faster than they were 10 years ago.

But some problems, for their sheer size, require speed; otherwise they would need years or even lifetimes of costly computer time to solve. Anything that has a basic unit (an event, grid point, star, matrix element, pixel) that is manipulated by a basic algorithm and is computationally intensive because the unit is repeated an enormous number of times, is well suited to concurrent processing. This includes all problems involving simulation, modeling, or image processing. Problems depending on partial differential equations, as does Fox's own work in high energy physics, or on matrix inversion, as do some problems in chemical physics, are good candidates for this approach. Applied areas such as oil exploration, aircraft design, and microcircuit design also stand to benefit significantly from the computing power promised by concurrent processing. Seitz, for example, plans to make use of the Cosmic Cube for circuit simulation in designing new generations of chips for its descendants. "Of course, you always wish you had the machine you're building to design its parts," says Seitz.



Fox's group in high energy physics (including research fellow Steve Otto and grad students Eugene Brooks and Mark Johnson) is the first to use the Cosmic Cube to work on a previously unsolvable problem — numerical calculation of the quantum field theory called Quantum Chromodynamics. To do a good job of calculating all the interactions in four dimensions, Fox figured he would need something like 100 to 1,000 times the power of a Cray (or 10,000 years on the VAX). The numerical techniques for solving the quantum field theory problem, which are identical to those in statistical mechanics, were pointed out several years ago. But trying to solve the problem in more than two dimensions was very difficult and inconclusive with current computers. "We believe we understand the fundamental physics; we know how to solve the basic equations; but we didn't have the computing power to calculate the consequences," says Fox.

Although the Cosmic Cube still isn't the answer to Fox's prayers, it will typically run about eight times faster than the VAX. It has already put in more than 1,500 hours toward solving Fox's problem as a three-dimensional grid, and with the potential of concurrent processing, he believes that all the fundamental questions describing elementary particles will be solved in the next few years. "It makes research much more meaningful," says Fox. He thinks there is every reason to believe that major scientific breakthroughs in a number of fields will result from the application of concurrent processing.

Several other projects (in astrophysics, chemical physics, geophysics, and, again, high energy physics) are being readied for the 64-node computer to tackle in the next six months, and Fox hopes to have perhaps a dozen working well within a year and a half. One of those coming up soon on the agenda is a study of the formation of galaxies, how they evolve from a system of stars and where the spiral arms come from. It's easy to see how the problem can be broken down into groups of stars, but on first thought, the problem of dealing with long-range gravitational forces might seem to spoil the minimal communication requirement of concurrent processing. But, says Fox, even though you do need to know the value of variables in the whole system rather than just the nearest neighbors, the Cosmic Cube actually should deal with long-range forces quite nicely. The essential criterion is not locality but rather the ratio of communication to calculation time, and although problems involving long-range forces do imply greater communication time, they also imply an even greater calculation time, and the ratio remains small.

Software is being developed at Caltech to implement the concurrent algorithms for numerous problems. Although critics have claimed that programming for concurrent computers will be virtually impossible, Seitz and Fox insist that it's not particularly difficult at all, and point to running application as evidence. Their programming tools make extensive use of software portability, and programs are written in the same languages used by conventional sequential computers, but with a library of procedures for dealing with communication between concurrent processes.

While Fox puts the Cosmic Cube to work, Seitz is designing future generations of machines. A 128-node Cosmic Cube Mark II is being built at JPL to provide additional cycles for scientific applications by next summer. It will have more than twice the performance and four times the storage capacity. Advanced technology nodes, with 10 times higher performance, are being designed using the latest single-chip instruction and floating point processors and will be in use in two to three years. Another machine with much smaller and faster node elements is already well under way, using the "Mosaic" chip Seitz's students have designed. Mosaic, a single, thumbnail-size chip, uses the same architecture, with the storage capacity scaled down, as the 78-chip Cosmic Cube node. It gains in processing what it sacrifices in storage. Many huge computational problems don't really need much storage.

The technology to manufacture Mosaic chips is at the state of the art of custom VLSI and allows a 1,000-node concurrent computer, which would outrun even the Cray-1 for many problems, to be packed into one cubic foot. The essential critical improvement is not in size but in performance for its cost. The Cray-1, which costs roughly $5 million, has a performance on typical problems of 50 million floating point operations per second, a performance/cost ratio of 10. One of the Cosmic Cube's 64 nodes, at a cost of $1,000 and performance of 50 thousand floating point operations per second, has a ratio of 50. And the Mosaic chip, which will cost about $50, will have a performance/cost ratio of more than 2,000.

Continued advances in microelectronics will make it possible within a few years to provide on a single chip the performance of Mosaic elements with increased storage, resulting in a machine similar to the Cosmic Cube with single-chip elements. This was in fact the original idea behind the Cosmic Cube; it's representative of a system whose mode elements could be integrated on a single chip using the technologies that are today in transition between the research laboratories and commercial use. In anticipation of this advanced microelectronic technology, the Cosmic Cube is a "hardware simulation" that allows experiments with the applications, algorithms, and programming of future concurrent supercomputers.

Seitz expects to complete a 1,000-element Mosaic machine by the summer of 1985, with funding from the Defense Advanced Research Projects Agency. The Department of Energy, the System Development Foundation, and the Ralph M. Parsons Foundation are also continuing to support development of concurrent processing, and Intel Corporation and Digital Equipment Corporation have contributed chips and other hardware.

Because the Cosmic Cube is open ended, Seitz believes he can keep using basically the same techniques to expand it until wiring limitations creep in at the 100,000-node range. His goal is to keep making open-ended computers "because these crazy guys have open-ended problems." There will always be problems big enough to be divided into 10^5 or 10^6 parts. Fox agrees that once scientists and engineers know one thing, they'll keep going on to even bigger things. After he solves his favorite problem of quantum field theories in four dimensions with a 1,000- or 10,000-node computer, some even larger problem will certainly turn up.□ — *JD*

Is the Population Bomb Still Ticking?

by Alan R. Sweezy

YES, IT IS still ticking. According to Ann and Paul Ehrlich, the authors of *The Population Bomb,* "In the 15 years since *The Population Bomb* was written, well over a billion people have been added to the human total." What's more, the world is continuing to grow at a rapid rate, though the growth is now very unevenly distributed. In Europe, North America, and Japan growth has slowed down; in parts of Europe it has even stopped. In large parts of the less developed countries, however — southern Asia, the Middle East, Africa, and Latin America — growth continues at a rate close to 2 percent a year. That means a doubling in about 35 years, and unless we can slow it down, we are faced with a pretty grim prospect.

Can the bomb be defused? The chief instrument so far for doing that — that is, for reducing the birth rate to slow population growth — is the promotion and strengthening of family planning programs. How effective these programs can be has been a subject of hot debate over the last decade or more. The view of the majority of the learned professions — sociologists, demographers, and economists — has until recently been that family planning programs can't do much. As you know, they operate by making the knowledge and the means of controlling births available to people. They have to go on the assumption that once this knowledge and these means have been made available, people will actually use them. The reason this won't work, according to the pundits in the field, is that people in poor countries have lots of children because they want to have lots of children. And they want to have lots of children because children are an economic asset. Children, it is said, are valuable for the work they do, which is particularly true in peasant agriculture. They're the only source of security in old age for most of the people in these societies. In addition, where infant mortality is still high, they provide an insurance against the great and unpredictable risks of children dying in infancy. These are powerful arguments, and they have had a great deal of influence on attitudes toward family planning.

At the World Population Conference in Bucharest in 1974, the view that family planning could not have an appreciable effect on population growth became the standard view. It was taken up from our scholarly colleagues by the representatives of the Third World countries and pushed with great enthusiasm. The *New Internationalist,* the organ of the Third World delegates at the conference, set the tone with a lead article headed "The Best Pill Is Development." The article presented the view that family planning programs won't work and that the only way to get birth rates down, and thus to slow population growth, is through economic development. That's a somewhat pessimistic view since one of the barriers to development is excessive population growth.

The development school buttressed their argument by an appeal to history. In the Western world — Europe and North America — birth rates were high in the late 18th and early 19th centuries. They were almost as high as they are in the less developed world today. But by the first quarter of the 20th century they had come down to something like their present low level. From an average of about six children, the rate fell to just a little over two in the course of 100 to 150 years.

In looking to the future it is important to learn from the past, and the question obviously is: What caused the decline in fertility in the West? (Fertility, incidentally, is used by demographers in a rather special sense. It means not the ability to bear children, but simply the number of children. We talk about high fertility in societies where six or eight children are the rule; low fertility where two or three.) The pro-development school argue that there are two possible explanations — family planning or development. Obviously, the decline was not brought about through the spread of family planning programs. There simply weren't any family planning programs, and the few voices raised in advocacy were scorned and suppressed. All the authoritative elements in society — the government, the church, the judiciary — were strongly against attempts of any kind to control reproduction.

Nor are modern contraceptives responsible. The pill is extremely recent and so is the IUD (intra-uterine device). What are now called the conventional contraceptives, the condom and diaphragm, were not developed until the late 19th century and didn't come into widespread use until the 20th century. So not only is there nothing to be said for family planning programs, but modern contraceptive technology also played no part in bringing about the decline. If the above are ruled out, what is left?

The usual answer is economic development. In the world today, we see that without exception the birth rates are low in the developed countries. This seems to provide strong evidence that economic and social development was responsible for the 19th century decline in fertility. Recently, however, some interesting work has been done in historical demography, work that furnishes the basis for an alternative view.

The key concept in this new view is what is called "natural fertility," which one of the leading authorities characterizes as "situations in which couples do not attempt to terminate childbearing before the end of the biologic reproductive span. In fact, the very idea of wanting any specific number of children may be quite foreign." In other words, instead of being determined by a calculation of advantage, as the sociologists, demographers, and economists have been telling us, children simply come. There is no thought as to what a desirable family size would be. This was no doubt the prevalent attitude up until maybe 100 years ago.

Though the concept of natural fertility stresses the absence of any attempt to limit family size, it doesn't mean that all societies in which natural fertility prevails will have the same size families. Fertility may be different because customs that have nothing to do with family size may intervene to affect the number of children born. The most important of these is breast feeding. In societies in which breast feeding is common and prolonged, the interval between births is longer. This is not a reliable contraceptive, of course, and any individual couple would be foolish to depend on it, but statistically it holds up very well. Factors that can influence the interval between births also include periods of separation due to the seasonal migration of one of the spouses, variations in the frequency of intercourse, and customs prohibiting resumption of intercourse for some period following birth. All of these are consistent with a regime of natural fertility, since they are not aimed at controlling family size.

How can we tell whether a particular society is a natural fertility society? Since reproduction will continue as long as biologically possible, the age of the mother at the birth of the last child gives us a clue. The table at right* shows the average age of wives at the birth of their last child in a number of presumably natural fertility societies. These figures are the result of painstaking family reconstitution studies, which have been a prominent feature of the work of historical demographers in recent years. You see the remarkable similarity in these villages — four of them are French, four German. The average age of the mother at the birth of the last child is very close to 40 in all of them. Where you see that, there is a strong presumption that no attempt is being made to control family size — that reproduction is being left to take care of itself.

Demographers have developed a more elaborate indicator, using the age pattern of childbearing. The table below shows how this pattern differs in two societies at the extremes of control over fertility. The first column presents the age-specific fertility rates for the Hutterites, who are a most remarkable people. Not only is theirs a natural fertility society, it is the most completely "natural" of any society you will find anywhere. They also have the highest fertility that has ever been reported by a society that keeps reliable records. The Hutterites are a religious group who left Germany and moved to the United States. Their first habitat was in North Dakota, but they have spread out. (If they keep on the way they are doing now, this is going to be a country of Hutterites and not many other people.) Their religion completely forbids any type of birth control, and the average number of children in the last 50 years has been from 10 to 12 per woman. They are hardworking people, with a reasonably high standard of living. They believe in using the advantages of modern health care, so they have low death rates, low infant mortality, so their high fertility leads directly to high population growth.

At the other extreme we have Great Britain around 1920, a typical modern society with low fertility norms and widespread use of birth control. The number of births per 1000 women in the first age group — 20 to 24 — is nearly the same in the two societies. But then it rises among the Hutterites and stays at a high level until biological limits begin to be reached, while in Britain it drops rapidly as couples reach the optimum size family, which at that time was typically two. Young people had most of their children in their 20s, and having reached the

WIFE'S AVERAGE AGE AT LAST BIRTH IN PRETRANSITION SOCIETIES

(Family reconstitution studies of French and German villages)

Location	Number of studies/ villages[a]	Wife's average age at last birth[b]
French couples married in the 17th and 18th centuries		
South and central France	4	39.3
Paris region and north France	4	40.4
Northwest France	7	40.4
Northeast France	3	39.8
German couples married before 1850		
Southwest Germany	5	39.9
Bavaria	3	40.6
Hesse	4	40.7
East Friesland	2	39.6

AGE-SPECIFIC MARITAL FERTILITY RATES

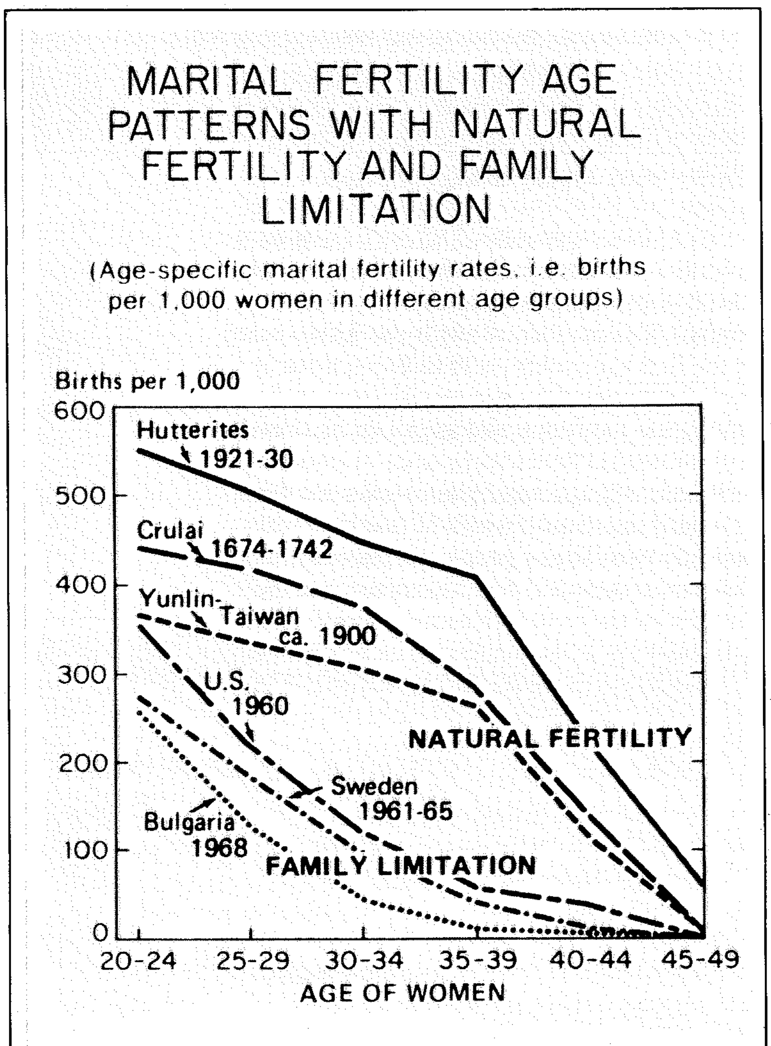
AGE	HUTTERITES (1946-50)	GREAT BRITAIN (1920)
20 - 24	386	320
25 - 29	498	165
30 - 34	443	90
35 - 39	370	50
40 - 44	215	20

*Etienne van de Walle and John Knodel, "Europe's Fertility Transition: New Evidence and Lessons for Today's Developing World," *Population Bulletin*, vol. 34, no. 6 (Population Reference Bureau, Inc., Washington, D. C., 1980) p. 11.

desired number, they began to limit severely, so there is virtually nothing in the higher age groups.

The chart below* shows the same phenomenon, in more elaborate form, based on the work of Ansley Coale, one of the leading demographers in the United States. The top lines show three natural fertility societies, the Hutterites, Crulai (a French village) in the 17th century, and Taiwan around 1900. They all have convex curves, with fertility remaining fairly high until the late 30s, when it drops for biological reasons rather than any conscious effort at control. The opposite, or concave, type of curve is given by the fertility pattern of the United States, Sweden, and Bulgaria in the 1960s, all countries in which birth control was widespread. Coale has used these curves to construct what he calls an index of family limitation. He has taken several typical natural fertility societies and combined their curves to use as a base. Then comparing the shape of the age-specific fertility curve for other societies with this natural fertility composite, he gets an index of family limitation. If the society's age-specific curve conforms closely to that of the natural fertility societies, his index shows zero family limitation. As you move to a more sophisticated society in terms of reproductive patterns, the index of family limitation goes up.

*Ibid. p. 14.



Parenthetically, I think Malthus's ideas are a perfect representation of those of a natural fertility society. Malthus wrote his famous book in 1798, at a time when natural fertility ideas were prevalent. In that book he said that "the checks to population which have been observed to prevail in the same and different countries seem to be resolvable into three elements. One is moral restraint. The second is vice. And the third is misery."

Moral restraint means postponing marriage. If you wait until you are fairly well along to get married, you won't have so many children. Misery is the famous positive check to population growth, chiefly through the limitation of the food supply, or the inability of the food supply to grow as fast as the population. That, of course, leads to starvation, which provides a check to population. Malthus does not go on to describe vice; he probably thinks that if his readers don't know about it already he's not going to tell them. But there is plenty of evidence that what he is talking about is contraception. That is so horrible to Malthus that it is perhaps worse than misery. It is too bad if we produce so many people that we fall into starvation and other types of disaster, but that may be better than to be guilty of immoral conduct.

Now come back to my main thesis: the relation of development to the decline of fertility in Europe. I suppose, even if you accept the idea that natural fertility prevailed before the transition of the 19th century, you could still argue that development caused the decline. The argument would run like this: It's true that people in a state of natural fertility don't make any attempt to limit the number of children, but that is because they want as many as they can possibly have. Why? Because children are economically valuable. If this argument is valid, perhaps it can still be said that development brought about the decline of fertility in Europe.

Now that argument has a fatal flaw. We are indebted again to recent historical demographic research for making clear what the flaw is. If development is the cause of fertility decline, then you will find in the various countries in which fertility has dropped that development preceded the decline. Until quite recently, what scholars did was to look around the world today and, seeing that in the developed countries fertility is low, concluded development must have been what brought it down. That, however, is not really the relevant point. The question is: What was the state of development in a particular country at the time the fertility decline began?

In the table at right, I have picked out a few countries to illustrate the point. First, we have the date at which marital fertility began to decline. (Incidentally, the research of the Ansley Coale group at Princeton has brought out the interesting point that once fertility started to decline it never reversed its trend. That suggests it was a pretty fundamental phenomenon.) Then we see the relation between fertility decline and two indicators of development: infant mortality and the percent of the male labor force in agriculture. It is clear that in this group of countries a wide range of conditions existed at the time the fertility decline began. Comparison of the figures for Hungary and those for England and Wales (combined) is especially striking. These two countries represented pretty much the opposite extremes of economic development in Europe in the 19th century. Hungary — with 73 percent of its labor force in agriculture, poor, with a high infant mortality rate — was a country which in every way defies the specifications of the development school. England was at the opposite end of the spectrum. England, in fact, was the prototype of an economically developed country. Nevertheless, the two experienced a decline in the marital fertility rate at almost the same time.

Now look at the first country on the list — France. Though we tend to take England as a model, actually France is just as important and was a lot bigger in the late 18th century and early 19th century. The table shows that the English pattern, the pattern of a strong relation between development and fertility decline, was not true of France. In France the decline began nearly a century earlier, and at a time when the labor force was predominantly in agriculture, infant mortality was still quite high, and the standard of living was modest compared to late 19th century England. This again illustrates the lack of correlation between the decline in fertility and the state of economic and social development.

What lessons can we draw from this for the world today? It doesn't prove, of course, that family planning programs are going to be successful. On the other hand, it does show, quite convincingly I think, that economic and social development is not a prerequisite for a decline in fertility. And that is an encouraging conclusion. At Bucharest the family planners took a beating. The argument of the development people at that time had not been challenged, the concept of natural fertility had not become widely known. The facts about the lack of correlation between development and fertility decline had not been pointed out. As a result, the family planners went away from Bucharest discouraged. They continued, fortunately, to go on with their work, and, in fact, their programs spread in spite of their discouragement. But it was a heavy burden. I knew some of them at that time, and I knew that they were fighting against the feeling that what they were doing was bound to fail. This recent research on demographic history has at least removed the burden of defeatism. It hasn't given us any proof that family planning programs will succeed, but it at least opens up the possibility that they will.

If development was not the cause of the fertility decline, what was the cause? The answer is pretty elusive. It has been suggested that some kind of cultural diffusion process was at work. But we don't know much about how the change in fertility spreads from one area to another or what gets it started in the first place. All we can say is that attitudes can change in a way which is favorable to a decline in birth rates without economic development.

Let's turn now to the less developed countries in the world today. We feel less pessimistic about the success of family planning and related programs than we did 10 years ago. But have we any actual experience yet as to the success of these programs? The time, of course, has been short. A real effort didn't begin until the early 1960s and in most of the less developed coun-

STARTING DATE OF FERTILITY TRANSITION AND INDICATORS OF CONCURRENT DEMOGRAPHIC AND SOCIOECONOMIC CONDITIONS

	DATE OF DECLINE IN MARITAL FERTILITY BY 10 PERCENT	INFANT DEATHS PER 1,000 LIVE BIRTHS	PERCENT OF MALE LABOR FORCE IN AGRICULTURE
EUROPEAN COUNTRIES			
FRANCE	ca. 1800	185	70
BELGIUM	1882	161	30
SWITZERLAND	1885	165	33
GERMANY	1890	221	38
HUNGARY	ca. 1890	250	73
ENGLAND AND WALES	1892	149	15

CHIANG MAI (NORTHERN THAILAND)	
POPULATION 1.03 MILLION	
RURAL 92% ENGAGED IN AGRICULTURE 77%	
PER CAPITA INCOME $85	
YEAR	TOTAL MARITAL FERTILITY
1968	4.42
69	4.00
70	3.37
71	3.03
72	2.76
73	2.93
74	2.65
75	2.49
76	2.29

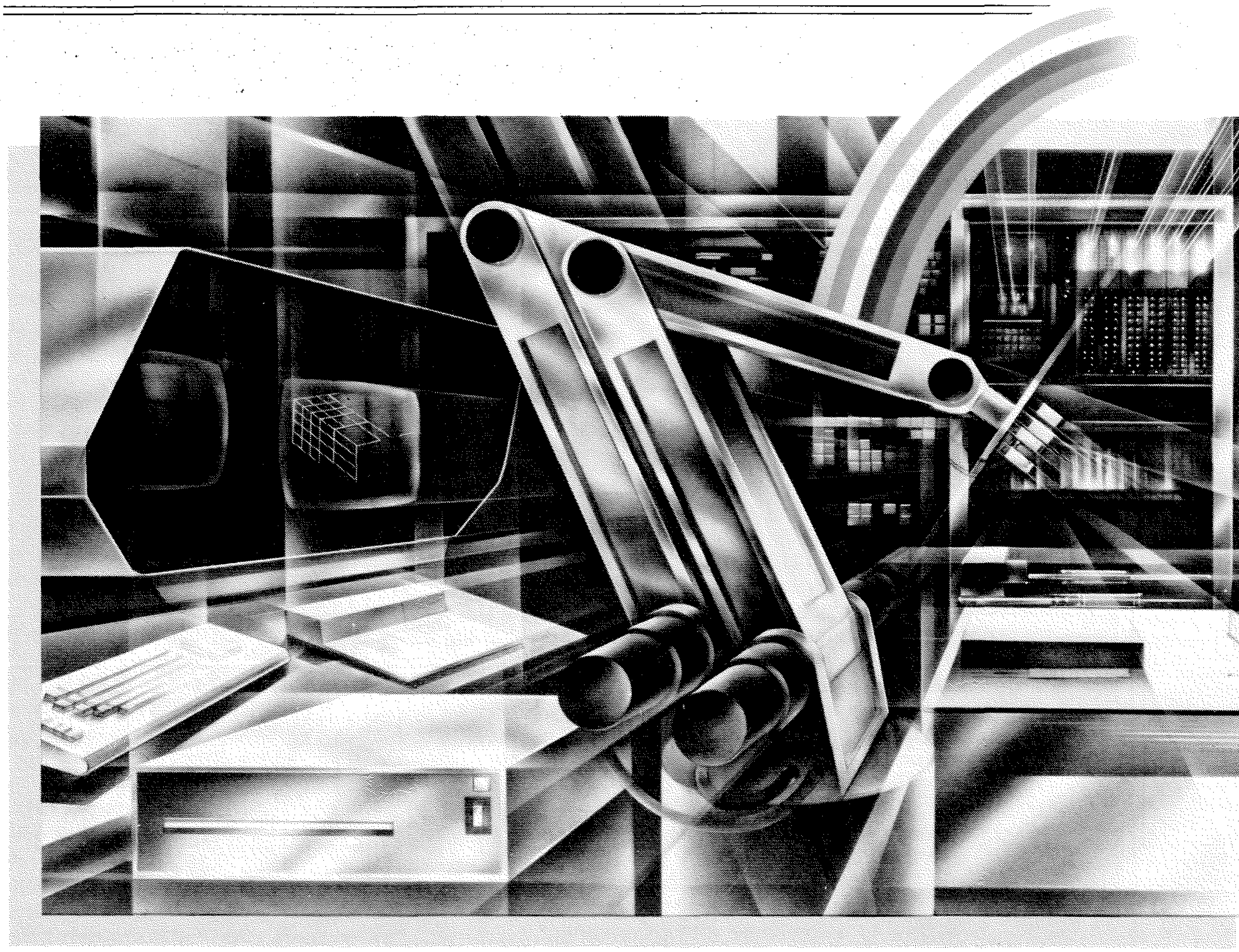
tries until the 1970s. There have been some encouraging developments. Many of you have heard, I'm sure, of the success stories that have been reported from Taiwan, Hong Kong, Singapore, and South Korea. In all of them birth rates have dropped to something like the Western level in the last 20 years. These are not pure cases, however, in terms of the argument we have been considering. Economic development has been rapid in all four of these areas. They have also had vigorous family planning programs. So we don't come out with a clear-cut answer on either side of the family-planning-versus-development argument. It is easy to conclude that both are important. As far as it goes, that is fine. If you can have both development and strong family planning programs, your chance of solving the population problem is greatly improved. But there are big areas of the world — southern Asia, the Middle East, Africa — in which the outlook for development is not very promising. Can development be by-passed? Are there policies — family planning or something else — that can speed up the process?

I am going to cite two encouraging examples — one very small and the other extremely big. The very small one is a province in northern Thailand called Chiang Mai. Its population is approximately a million, of which 92 percent is rural — 77 percent are engaged in agriculture. The per capita income is $85 in U.S. terms. It is a perfect example of a rural, poor, backward country. But in the table at left you can see that beginning in the late 1960s the marital fertility rate dropped very rapidly from a 4.4 level to a 2.3 level in the middle 1970s, which is virtually the same as the rate in Europe and the United States.

We don't really know why. They had a strong and effective family planning program, and it is tempting to say that was the cause. Demographers who have studied Chiang Mai, however, think it was a contributing rather than the sole cause because when the program began back in the early 1960s, the decline was already under way. Something had begun to change in the attitude of the people that led them to start taking measures to limit childbearing. When the family planning program came along in the late 1960s, they embraced it with enthusiasm. This remarkably rapid drop — a drop which took 40 years in the United States in the 19th century — was all done in Chiang Mai in less than one decade.

The other great example, of course, is mainland China. With a low economic level and a high rate of population growth, mainland China decided about a decade ago to do something about the problem. If they had followed the advice of the pundits at Bucharest, they would not have made that decision. They would have decided to leave the whole thing alone until they had succeeded in building up their economy. But the Chinese felt one of the great obstacles to building their economy was their excessive population size and their continuing population growth. So they did set out to do something about it.

There are many problems connected with the Chinese program, particularly now that they have set a goal that is so extraordinarily ambitious — the one-child family. But without trying to judge yet to what extent they will actually succeed in reaching this drastic goal, we can say that in the decade of the 1970s their program had considerable success. The birth rate at the beginning of that decade was about 35 per thousand, which is comparable to the European birth rates before the transition. By 1979, according to the official Chinese figures, it had dropped to 18. That is almost a 50 percent drop, and it was accomplished by a very vigorous program, a great deal of peer pressure. In fact, the Chinese threw in everything they could think of to contribute to the success of the program. The results are encouraging as to the possibilities for vigorous family planning programs in other parts of the world. □



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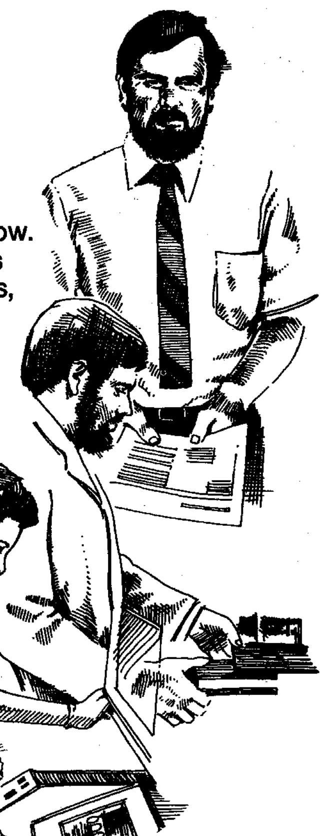

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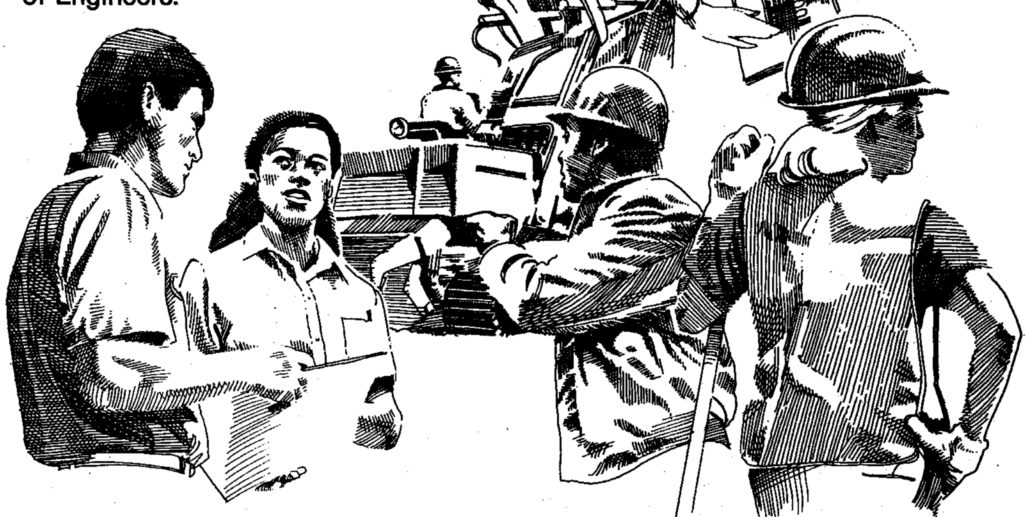

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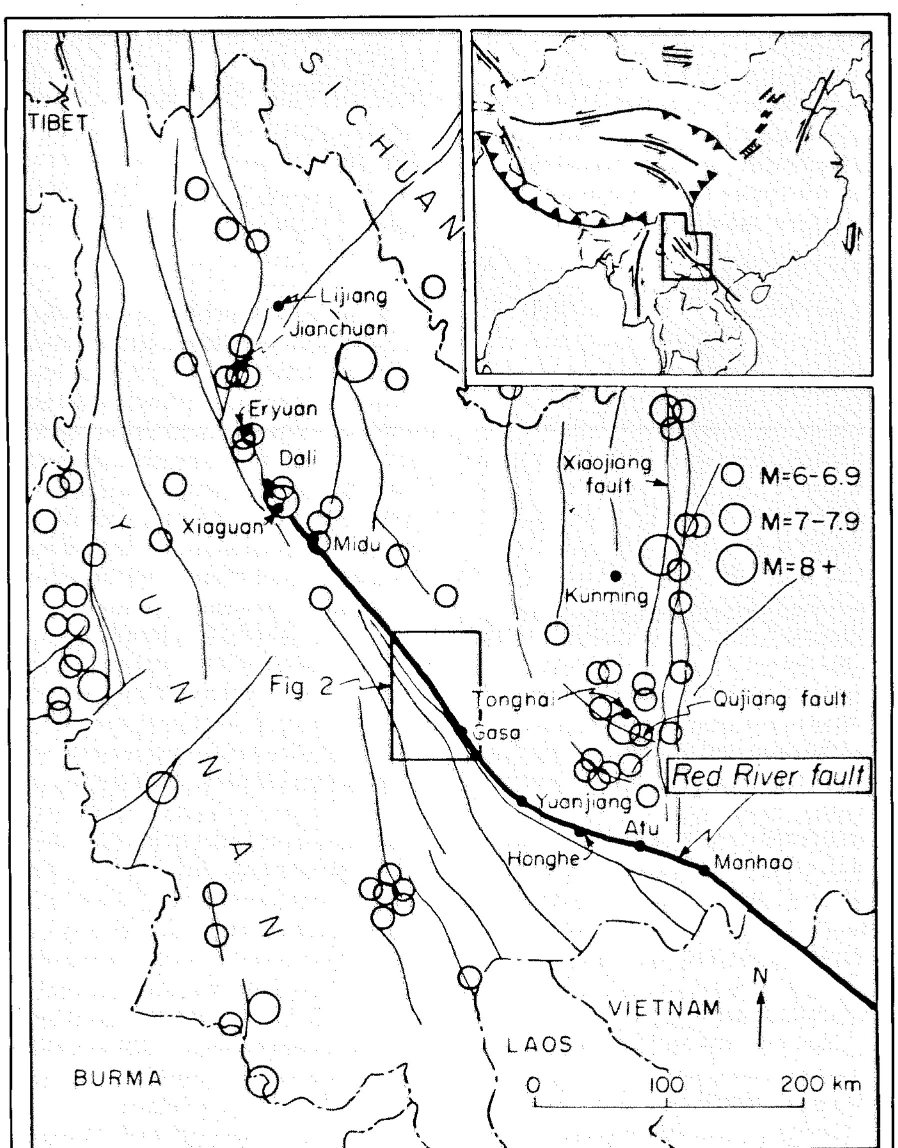
China's Fault

STUDYING EARTHQUAKE faults in rural China, with all the attendant logistical problems, may not be the most comfortable — or effective — way to pursue research, but it has its rewards. For one thing, it's socially useful, says Kerry Sieh, associate professor of geology, who spent three months there last spring with his family and graduate student Ray Weldon. Of all countries, China is most prone to large destructive earthquakes, and determining the probability of one's occurrence on a particular fault could help save hundreds of thousands of lives.

For another, China's geology is scientifically exciting. Ever since the Indian subcontinent began to collide with Asia 45 million years ago, China has been trying to get out of the way, squeezing, wrinkling, and faulting its way out to the east and south. One of the great faults activated during this process, the Red River fault, which runs for several hundred kilometers through China's Yunnan Province, was the object of Sieh's 1983 journey.

Several years ago most Chinese geologists had thought this ancient fault to be safely inactive. But, based on interpretation of satellite imagery, Clarence Allen, professor of geology and geophysics, suspected that it was an active fault capable of a great earthquake. With a group of Chinese geologists, Allen and Sieh visited the area in 1981 and confirmed up to six kilometers of geologically youthful, right-lateral offset along the fault. They speculate that this offset may have accumulated during the last 1 or 2 million years. They also found evidence of younger, even more recent fault activity.

But how recent? To be of any practical value to the Chinese, the likelihood of a large earthquake there would have to be quantified. So Sieh returned to Yunnan, a province that borders on Vietnam, Laos, Thailand, and Burma, for three months last spring to study evidence of the behavior of the Red River fault over the past few thousand years. He looked for offsets in young landforms and sediments and excavated for specific signs of earthquakes in particular layers of sediment, layers that can be radiocarbon dated. A sequence of such earthquake dates gives a good picture of the frequency at which earthquakes occur on a given fault and, consequently, a general idea of when to expect the next one. His work on the San Andreas fault, for example, has indicated that southern California, where the last big quake hit in 1857 and the repeat time for such quakes has been about 150 years, has about a 50 percent chance of experiencing a quake of



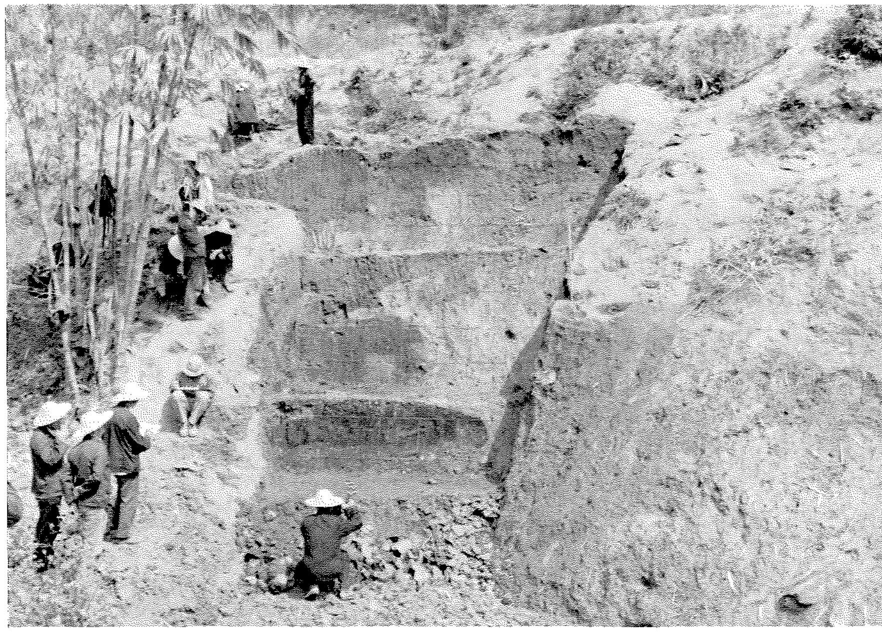
The Red River fault angles southeast from India's impact with Asia (inset). Circles indicate historical earthquakes of various magnitudes, none of them along the major section of the fault itself. Sieh's group excavated at Gasa (center) and Dali (to the northwest) in search of older earthquake clues.

magnitude 8 or larger in the next 50 years.

Local historical records, which are fairly complete for the past 500 years in Yunnan, mention no earthquake along the Red River fault. This says nothing more than that the average recurrence interval is probably more than 500 years, and if the last quake was, say, 600 years ago, another could be imminent. Sieh and his Chinese colleagues returned to one site (dubbed Butterfly Creek by Sieh for its abundance of butterflies when he and Allen visited it in 1981) and found it to be particularly interesting — especially since it was now the wrong time of year for butterflies and Sieh, who collects them, wasn't distracted. With the help of local Dai farmers using hoes, Sieh and his colleagues excavated the site, uncovering, as the cut became larger and larger, evidence of five large earthquakes in the sediment that had accumulated in the creek. Knowledge of those five events will help establish a reliable picture of the frequency of the Red River fault's movement.

Sieh took samples — for radiocarbon dating — from this and two other sites in southern and western Yunnan, but was shocked and frustrated on his arrival in China to learn that he would not be able to take them out of China for analysis. This apparent setback was resolved, however, when the radiocarbon samples mysteriously showed up on his doorstep in late October. Additional samples are expected to arrive with a team of Chinese geologists who will visit Caltech in the spring. These are paleomagnetic and soils samples, which the Chinese will participate in analyzing. Tests are not yet complete on any of the samples, but when the dates of the earthquakes and the average recurrence interval are determined, the Chinese will know whether they should prepare for an imminent event on the Red River fault or forget about it and aim their efforts at more dangerous faults. In addition, a better understanding of the activity of the Red River fault will help fill in the "big picture" of India's collision with Asia.

Sieh says that his family's experiences living in rural China were sufficiently rich and rewarding to outweigh the difficulties of working in an unfamiliar country and culture. He is hopeful about continued research in China because "the geology of China is alluringly active, and its awesome natural hazards challenge mitigation."□ — *JD*



At "Butterfly Creek" in Gasa, along the Red River fault, Chinese geologists and Caltech grad student Ray Weldon (sitting, left center) take notes on an early stage of the excavations. Evidence of five earthquakes was eventually found here.

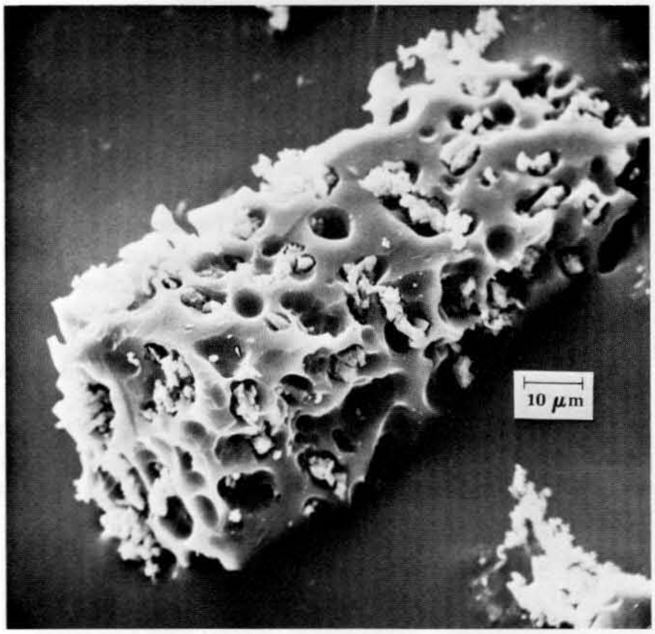
Fake Coal

About four years ago Richard Flagan was examining the structure of fine ash particles with an electron microscope at the Jet Propulsion Laboratory, when he noticed some pictures on the wall that looked strikingly familiar. The pictures were electron micrographs of silicon particles from a JPL project to produce silicon for photovoltaic cells, but to Flagan, associate professor of environmental engineering science at Caltech, they looked exactly like ash particles from coal combustion. He was intrigued enough to follow it up.

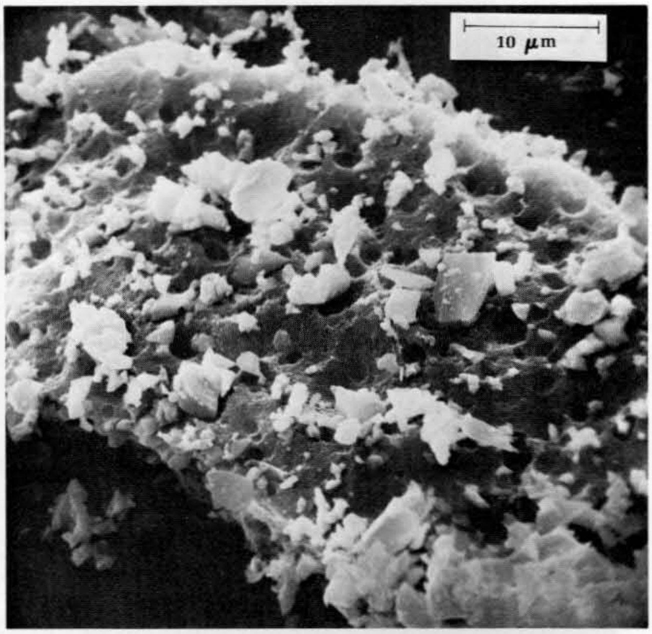
Combustion, not silicon production, is actually Flagan's area of expertise. His research has involved study of the formation of aerosols (suspended particles) produced from gases, in particular ash from burning coal. Ash is mineral matter that typically makes up about 10 percent of ordinary U.S. coal. Coal-fired utility plants burn coal as a powder, with particles reaching temperatures as high as 2000°C, high enough to vaporize a small fraction of the ash, even portions of those constituents not usually thought of as volatile.

Coal ash had previously been thought merely a nuisance by engineers, since control devices remove about 98-99 percent of it from the effluent. Control devices, however, remove the larger particles more efficiently than the smaller ones, letting escape some of the small ones, which don't settle out to collect visibly on windowsills but can invisibly find their way deep into human lungs. And research eight years ago showed that the smaller the particles of ash, the more heavily enriched they are with toxic heavy metals and other trace species.

The dynamics of coal ash evolution has been far from completely understood. Aerosol particles can condense directly out of the vapor to form very small (a few nanometers), new particles, which then grow by coagulation. Unfortunately it's difficult to build a predictive model for the vaporization of ash because coal is such complex stuff that its thermodynamic properties are not known. Its chemical mixture can differ from batch to batch, even from particle to particle, and it changes so much during the combustion process that it has been impossible to examine any general mechanisms of vaporization. As a way of simulating coal combustion while avoiding the complicated chemistry of coal, Flagan and former graduate student Connie Senior developed a synthetic coal — a glassy carbon, whose porosity could be controlled and whose ash is simply quartz (silica). They will also use different ash materials in subsequent experiments.



The electron micrograph, above, of partially burned, non-porous, synthetic coal shows depressions forming under the ash (whiter particles), since the oxygen can attack the carbon through cracks, which occur primarily around the ash, causing increased vaporization.



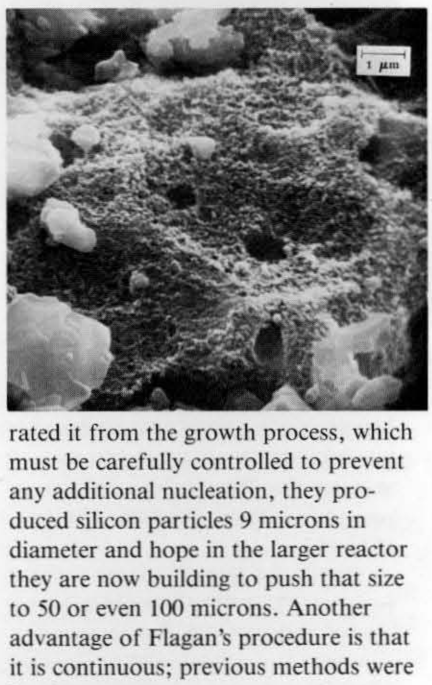
Partially burned, porous carbon, on the other hand (above), is pitted all over. This is caused by a similar mechanism--oxidation of the carbon in the particle's interior due to oxygen diffusion into the many small pores, visible in the greater enlargement below.

In the synthetic coal Flagan and Senior have a tool that allows them to study the role of pore structure in coal combustion and gasification. Burning this simple, known substance as a powder under carefully controlled conditions has enabled them to observe how vaporization occurs on the surface of the powder particles and in the pores, which, as they open up during burning, allow more vaporization. A major factor in vaporization is reduction of the ash oxides to more volatile forms; this occurs to a greater extent inside the particles where the oxygen content is much lower than on their surface. In their experiments only about one-fourth of a gram of coal is burned per hour, heated to a reactor wall temperature of 1300°C; the burning particles themselves are much hotter. Measurements of the temperature of individual burning particles are now being made in order to provide a complete enough description to be able to test detailed models of the process.

Scanning electron micrographs of the synthetic coal have provided enormous insight into these mechanisms. And it was also the electron microscope that led from Flagan's coal ash work directly, and unexpectedly, to a high-technology spinoff. The pictures on the wall at JPL were of silicon particles produced in a free-space reactor, an attempt as part of the Flat Plate Solar Array Project to develop a new technology for producing high-quality silicon. Conventional silicon production methods use so much power that the silicon currently available is very expensive for use in solar cells.

In the free-space reactor, silicon particles nucleated out of silane gas (SiH_4) then were collected and melted to make the single silicon crystal necessary for a photovoltaic cell. But the particles were smaller than a micron, so small that collecting and melting them was extremely difficult. Efforts to increase particle size in the free-space reactor had been unsuccessful. Since Flagan was already working with silica (silicon dioxide) particles vaporized out of his synthetic coal, he and grad student M. K. Alam undertook to figure out how to grow larger particles of silicon for the JPL project (funded by the Department of Energy).

Flagan and Alam discovered that conditions in the free-space reactor generated too many particles in the system. For so many particles to then grow to sufficient size in vapor deposition, an unfeasibly large amount of pressure would be required. Their solution was to limit the number of particles formed in the initial burst of nucleation. By designing a small two-stage reactor that quenched the nucleation and sepa-



rated it from the growth process, which must be carefully controlled to prevent any additional nucleation, they produced silicon particles 9 microns in diameter and hope in the larger reactor they are now building to push that size to 50 or even 100 microns. Another advantage of Flagan's procedure is that it is continuous; previous methods were batch processes.

Now that they have a chemical process that works, purity is the main concern, since silicon for photovoltaics must be much purer than that for electronics. But Flagan believes that his method has the potential for a very high degree of purity because the silicon never touches a solid surface. The process is also energy efficient, a necessary condition if solar cells are ever to become practical. And they are now quite close, he believes, to becoming practical. □ — *JD*

Random Walk

Like It Is

USING A RECOGNIZABLE symbol, mark, or name is one way to promote a distinct identity — as, for example, the big "M" that leads a subset of the hungry to McDonald's Family Restaurants for a hamburger, or the word "Kleenex" that has come to stand for all brands of paper handkerchiefs. Since 1968 the Caltech symbol — or logo — has been a hand or hands holding a torch, but times change and so do fashions in graphics, so that logo has recently been updated. The new version, also created by designer Doyald Young, appears on the back cover, and its use is being encouraged throughout the Institute. It will appear as a watermark on the official stationery and on many publications, and, no doubt, on car stickers, sweatshirts, and beer mugs. There were several variations on the original torch, which led to some confusion, so it is hoped that the new one will be used exclusively from now on.

And while we're on the subject of identities and correct usage, discrepancies also tend to creep into the spelling of the short form of the Institute's name. CalTech, Cal Tech, and Cal-Tech are some of the unauthorized versions. Caltech is the way it is supposed to be.

Millikan Museum

ROBERT A. MILLIKAN's roll-top desk, covered with letters, notes, and family photographs, looked as if he had just left for a minute. The apparatus for his classic oil drop experiment to measure the charge of the electron appeared exactly as it had when he performed it.

But it was only a stage set — for program 12 of "The Mechanical Universe," Caltech's TV physics course currently in production (*E&S*, November 1983). Based on the version of Physics 1 developed by David Goodstein, professor of physics and applied physics — with a little help from location shots, computer graphics, and drama from the past — the series is funded by the Annenberg/CPB Project, from whom it has recently received an additional grant of $2.85 million.

After a lot of heavy mathematical sledding in the initial programs, the one on Millikan's oil drop experiment is part of a respite designed to introduce a deeper dimension with some history and philosophy of science — and how physics is *really* done. Under the direction of associate producer Mark Rothschild, Millikan's office and lab were carefully and authentically recreated in the basement of West Bridge after photographs of the real thing (with the exception that office and lab were never in the same room). Pictures and documents came from the Archives, as did Millikan's desk, which archivist Judy Goodstein uses. Most of the scientific equipment was provided by Professor of Physics Eugene Cowan, who never throws anything out. ("When people left, they'd leave the stuff around, and I'd just squirrel it away.") As for the rest of the period items, according to art director Nelson Willis, "There are places in Hollywood that will rent *anything*."

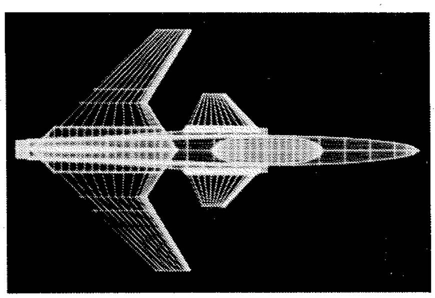
The set lasted only a few days. Then it was dismantled and everything returned — to the Archives, to Cowan's laboratory junkyard, and to Hollywood.

Watson Lectures

TO CELEBRATE the 21st year of Beckman Auditorium and what became known as the Earnest C. Watson Lecture Series, Victor Neher, professor of physics, emeritus, recreated Watson's famous "Liquid Air" lecture and demonstration on February 22. Watson had begun the series with that lecture in the fall of 1963.

Coming up during the remainder of this academic year are four more Watson Lectures: "Turbulent Flow," by Paul Dimotakis, associate professor of aeronautics and applied physics (March 14); "The Evolution of Computer Graphics," by Alan Barr, research fellow in computer science, and James Kajiya, assistant professor of computer science (April 4); "The Legends of Caltech," by alumni W. A. Dodge, Jr., R. B. Moulton, H. W. Sigworth, and A. C. Smith (May 2); and "Gravitational Wave Experiments — A New Challenge for Laser Techniques," by Ronald Drever, professor of physics.

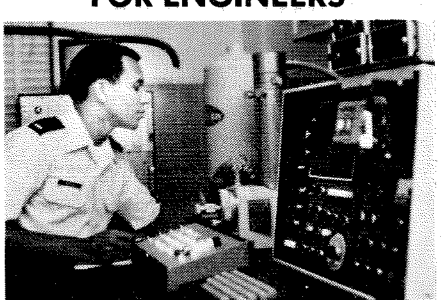
ENGINEERING TAKES ON EXCITING NEW DIMENSIONS IN THE AIR FORCE.



Computer-generated design for investigating structural strengths and weaknesses.

Developing and managing Air Force engineering projects could be the most important, exciting challenge of your life. The projects extend to virtually every engineering frontier.

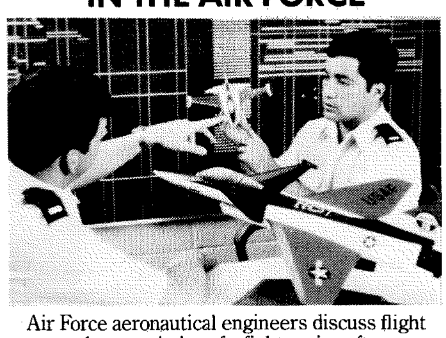
5 CAREER FIELDS FOR ENGINEERS



Air Force electrical engineer studying aircraft electrical power supply system.

Engineering opportunities in the Air Force include these five career areas: aeronautical, architectural, astronautical, electrical and nuclear. Hundreds of diverse specialties are included in a wide variety of work settings. For example, an electrical engineer may work in aircraft design, space systems, power production, communications or research. An aeronautical engineer might be included in wind tunnel testing, designing cockpit displays and flight testing.

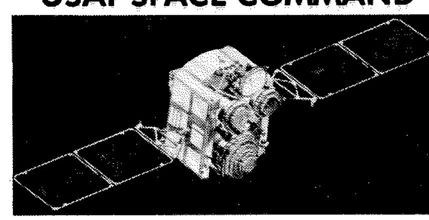
PROJECT RESPONSIBILITY COMES EARLY IN THE AIR FORCE



Air Force aeronautical engineers discuss flight characteristics of a fighter aircraft.

Most Air Force engineers have complete project responsibility early in their careers. For example, a first lieutenant directed work on a new airborne electronic system to pinpoint radiating targets. Another engineer tested the jet engines for advanced tanker and cargo aircraft.

OPPORTUNITIES IN THE NEW USAF SPACE COMMAND



Artist's concept of the DSCS III Defense Satellite Communications System satellite. (USAF photo.)

Recently, the Air Force formed a new Space Command. Its role is to pull together space operations and research and development efforts, focusing on the unique technological needs of space systems. You may have an opportunity to join the team that operates superior space systems as the Air Force moves into the twenty-first century.

To learn more about how you can be part of the team, as an officer, see your Air Force recruiter or call toll free 1-800-423-USAF (in California call 1-800-232-USAF). There's no obligation.

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