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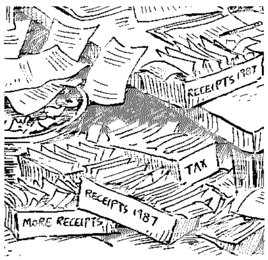

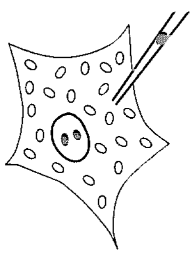

On the cover: Mount Tabor near Nazareth is geologically unique—a single block marked by fault lines on all sides. Heinz Lowenstam, while mapping the geology of the Nazareth Mountains in the 1930s, often climbed this winding road, where a Bavarian monk would invite him in for a beer at the monastery near the top. Lowenstam also met British, Bedouins, and Jewish settlers in the course of his work. The story begins on page 20.

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PLAY HERE
California Lottery
LOTTO
1989 California Short Tax Form And Instructions

The *Real* California Lottery: Your Income Tax

The odds of winning in this game are significantly better.

by Jeffrey A. Dubin

Dubin, looking for the best odds, ponders which lottery to play.

The California Lottery lets you pay a dollar and pick six numbers between 1 and 53. If you guess all six correctly, you win a jackpot of up to several million dollars. Your odds of winning are about one in 23 million—not very good.

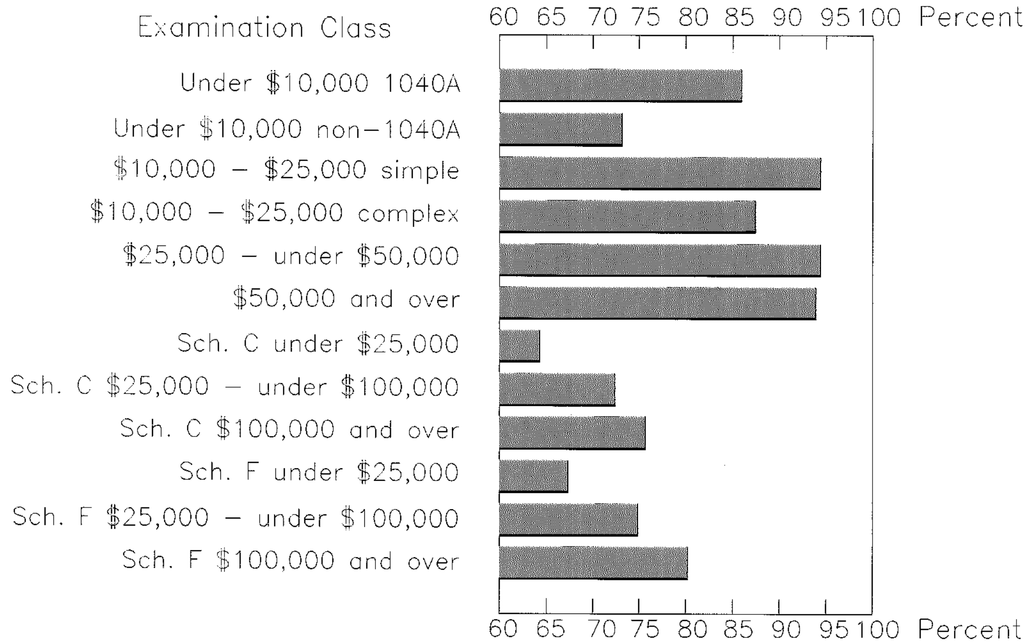
There is, however, another lottery that people in California play from time to time: cheating on their income taxes. The odds of winning in this game, the *real* California lottery, are significantly better. As demonstrated below, in order to "win" in the California tax lottery you must first not "lose" in the federal lottery. Today, the IRS audits roughly one percent of all individual tax returns filed. So the chances of getting away with a few omissions on a tax return—"winning"—are 99 out of 100. However, state income tax collection, including California's, is beginning to follow the federal model more closely. Since this includes adopting new enforcement strategies, the chances of "winning" may be changing.

We all react differently to our tax responsibilities, and the pattern of noncompliance is far from uniform. Unlike playing the California Lottery, which is a game, playing the Tax Lottery is a crime. As with any crime, the Tax Lottery has two components. One is the probability of getting caught, and the other is the punishment if found guilty. The probability of getting caught is much lower now than it was ten years ago. However, if you are caught cheating today, the consequences are much more severe.

What happens to your tax return once you mail it away? In California, state tax returns go to the main office of the Franchise Tax Board (FTB), in Sacramento, where they are delivered in large bins. The contents of each bin are weighed and then dumped into machines that snip the tops off the envelopes. The machines put the envelopes and tops in one basket, and the returns in another. Then the principle of conservation of mass is applied: the two baskets are weighed and that weight is compared to the total weight received to make sure that nothing has been lost in the process.

The baskets of returns then go to temporary clerks who enter information from the returns into a computer. If every item from every return had to be entered, the data-entry process would take a very long time. (As it is, tax-entry season lasts about six months, and the FTB is one of the biggest employers of seasonal labor in the state.) Instead, only a limited number of items are extracted. These items, marked by bullets on the tax form, include wages, tips, and salaries, alimony payments, Schedule A itemized deductions, and charitable contributions. These bullet items are the only pieces of information used in the initial screening of the returns for potential audits. Items not used include moving expenses, exemption credits, Schedule C (sole-proprietorship income), and even such facts as whether your return was handwritten, typed, or prepared by a paid preparer. The logic behind the choice of information retained is sometimes difficult to understand. For example, information is recorded about payments to IRA accounts, but not to Keogh accounts.

Once this information is entered, the FTB checks the returns for arithmetic consistency; if



The percent of true tax liability actually reported varies widely, depending on individual income levels and the tax forms filed, as shown in this voluntary compliance level data from 1982. Schedule C, "Profit or Loss From Business," is filed by the self-employed. Schedule F is "Farm Income and Expenses."

any mistakes that cannot be corrected easily are found, the return is sent back to the taxpayer. If that were the end of the story, you'd think you had a simple strategy to win this lottery—accurately report the wages, tips, and other bullet items that are entered in the initial screening and don't worry about the rest.

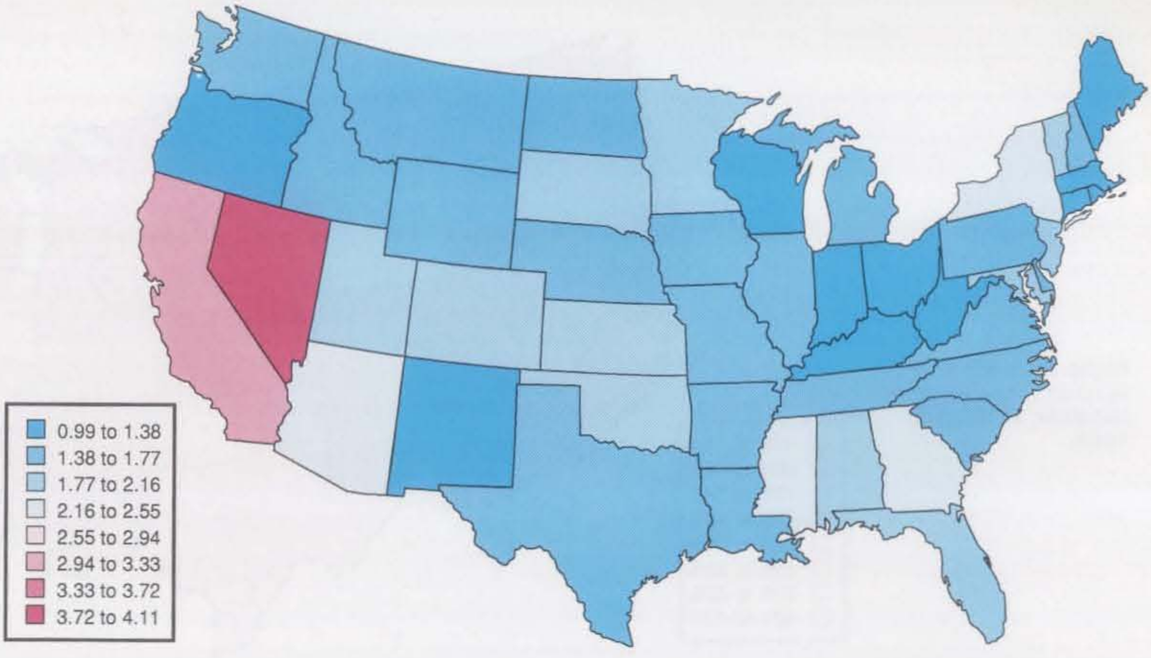
Unfortunately, this strategy is of limited utility, because all returns that meet some very broad criteria are earmarked for closer scrutiny. For example, all returns with wages, tips, and salary income that exceed a certain amount are put aside. This does not necessarily mean that these returns will be audited; rather that they will be looked at a little more carefully. After the year's worth of tax-return data is entered into the computer, it is put away for about three years. During this time the FTB awaits information from the IRS.

The United States Congress and the state legislatures have explicitly provided for the exchange of otherwise confidential tax-return and related information between the IRS and state tax agencies in order to avoid duplicate efforts and enforce tax compliance. The IRS and cooperating states now routinely synchronize certain audit decisions. Currently, nearly every state (and the District of Columbia) have agreed to coordinate tax information and audits with the IRS. There is, consequently, a direct linkage between the activities of state and federal tax agencies.

To better understand California's tax lottery, the federal audit process needs to be looked at in more detail. First of all, what is an audit? If the IRS (or FTB) discovers a discrepancy that can't easily be explained, the taxpayer is required to defend the information entered on the tax form. This is an audit. During an audit, which can take place by mail or in person, an auditor examines the return and supporting documents to determine the true tax liability. The burden is on the taxpayer to produce the evidence—receipts, canceled checks, and so forth—needed to support the information entered on the form.

One way the IRS selects returns for audit is based on the Taxpayer Compliance Measurement Program (TCMP). Every three years, the IRS audits some 50,000 lucky winners chosen at random from across the nation. These people have won the grand prize—a full-blown audit during which they must drag in all of their shoe boxes full of receipts. The IRS scrutinizes the tax return, line by line, and determines whether each item has been recorded accurately. The auditors then compare the amount that they believe is owed with the amount stated on the return. More often than not, the difference is in the IRS's favor.

Using the TCMP data from 1982, the IRS has calculated and made available statistics on the percentage of the true tax liability that was actually reported by taxpayers. In 1982, this level—the Voluntary Compliance Level—was estimated to be an average of 83.7 percent for all taxpayers. In other words, the average return underreported the taxpayer's true liability by 16.3 percent. Individuals filing Schedule Cs who reported less than $25,000 in gross receipts were relatively less compliant; but for those indi-



Percentage of tax returns audited by state, 1978. The maps accompanying this article were prepared with the assistance of Tom Boyce of the Campus Computing Organization.

viduals filing Form 1040 with under $10,000 of income, or Form 1040EZ (the simple, one-page tax form), the voluntary compliance level was significantly higher. This latter group, of course, has very few ways to cheat, since the employer withholds tax from each paycheck and reports the amounts directly to the IRS via W-2 forms.

The IRS also uses the TCMP to extrapolate individual noncompliance levels to the population as a whole. The most recent estimate is that approximately $90 billion in tax revenue due the government will go unpaid this year—up from $81 billion in 1981 and $29 billion in 1973. The IRS collected roughly a trillion dollars in individual income taxes last year; hence the "Tax Gap" is now about ten percent of total income-tax revenue.

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The TCMP estimate of the Tax Gap tends to fluctuate from year to year, depending to some extent on how it's put together. For example, the amount of tax cheating may actually have stayed constant from 1981 to 1986, but the examination protocols that uncover the true tax liability may have changed. And even when the IRS scrutinizes a return under the TCMP program, it's hard to sniff out some of the most effective dodges, such as the underreporting of income or the nonreporting of secondary income sources. The auditors can add up all the receipts and double-check the deductions, but if the income isn't in the records to begin with, it's very difficult to construct an audit trail.

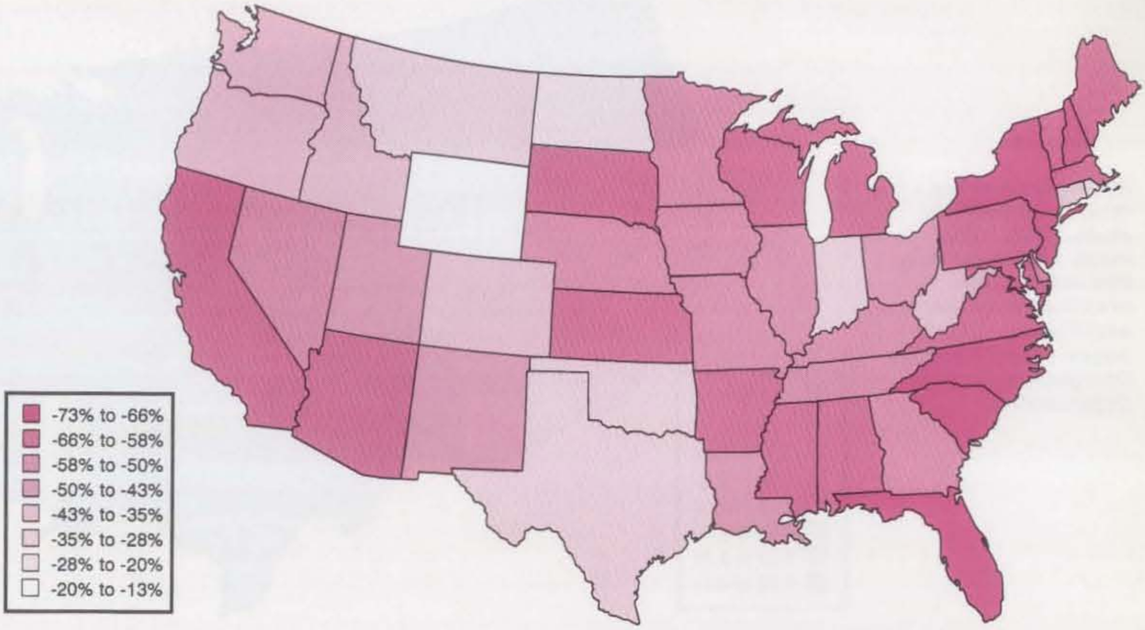
As I mentioned above, the IRS uses information from the TCMP to develop an audit strategy. The agency correlates the individual's compliance level, as measured by the TCMP audit, with such characteristics of the individual's tax return as the amount of income reported and the pattern of deductions. This process produces a scoring rule that is then applied to all returns: low scores indicate relatively compliant returns and high scores relatively noncompliant returns. Within each IRS district—usually a state—the IRS ranks the returns by their TCMP-derived scores and audits those returns with the greatest potential yield first. This is a sensible strategy; auditors don't want to invest their limited time on people who aren't likely to owe them a worthwhile amount of money.

The fundamental issues of tax compliance are of great interest to economists, and to social scientists in general. When Louis Wilde, a professor of economics here at Caltech; Michael Graetz, the Hotchkiss Professor of Law at the Yale Law School; and I began to study the Tax Lottery, we decided to focus not on the Tax Gap, which isn't collected, but on the effect that audits and penalties have on what is. Does an increased threat of an audit actually increase collections? Our answer is that it does.

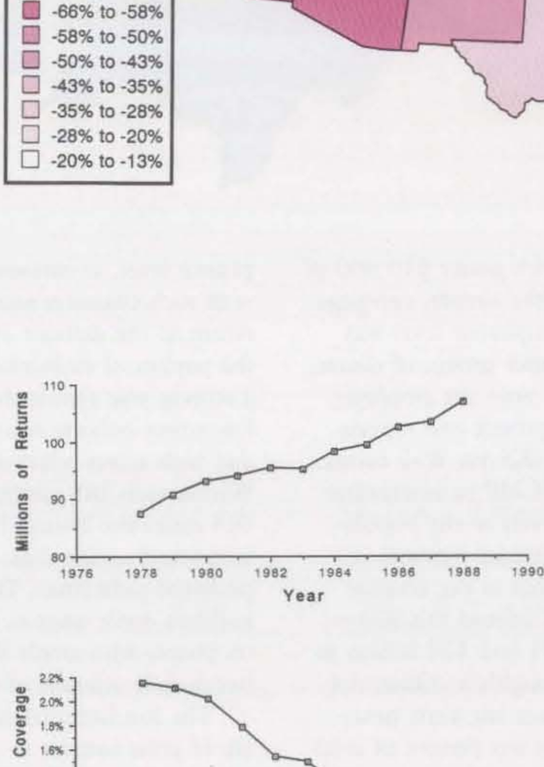
The above map shows the 1978 audit rate percentage by state. California and Nevada were being audited at a rate well above the national average. This makes sense for California because of the state's booming economy—the yields from these audits must have been fairly lucrative at the time. The reason why Nevada received so much attention is less evident.

There are relatively few people in Nevada, but there's a lot of gambling. In 1978, casinos

Right: Percent change in audit rates by state between 1978 and 1988.



Top: Number of returns filed. Middle: Percentage of returns audited. Bottom: Average penalty rate as a percentage of the tax owed. The IRS raised its penalty rate to compensate for the declining audit rate.



didn't report people's gambling winnings, so they were fairly easy to hide. One thing people like to do with their winnings is to purchase big-ticket items such as cars. Las Vegas, not surprisingly, has many car dealerships. People would just turn their cash into cars and drive away. However, these transactions are recorded at the dealerships and leave a perfect audit trail. The IRS caught on to this, and decided to watch Nevada more closely.

The nature of auditing has changed dramatically over time. The figures to the left are for the years 1978–1988. The number of returns filed grew rapidly—about 13 percent per year. The average population growth, however, was only about one percent per year; therefore, a large part of the increase in the number of returns filed can be attributed to changes in filing requirements. Although the number of returns filed has gone up, the percentage audited has fallen. In 1978, two out of every hundred returns were selected for examination. By 1988 the overall audit rate was half that, about one percent. The audit rate for the high-income population has fallen even faster. This rate was nearly 11 percent in 1979, but has decreased to just over two percent. (These audits, while based in part on the TCMP scoring rule, are not themselves the dreaded TCMP audits; unless the auditor discovers evidence of wider wrongdoing, these audits examine only those sections of the return that triggered the audit.)

In some states, the audit rate fell by as much as 70 percent, as the map above shows. California, Nevada, and the East Coast had the most

Unless the auditor discovers evidence of wider wrongdoing, these audits examine only those sections of the return that triggered the audit.

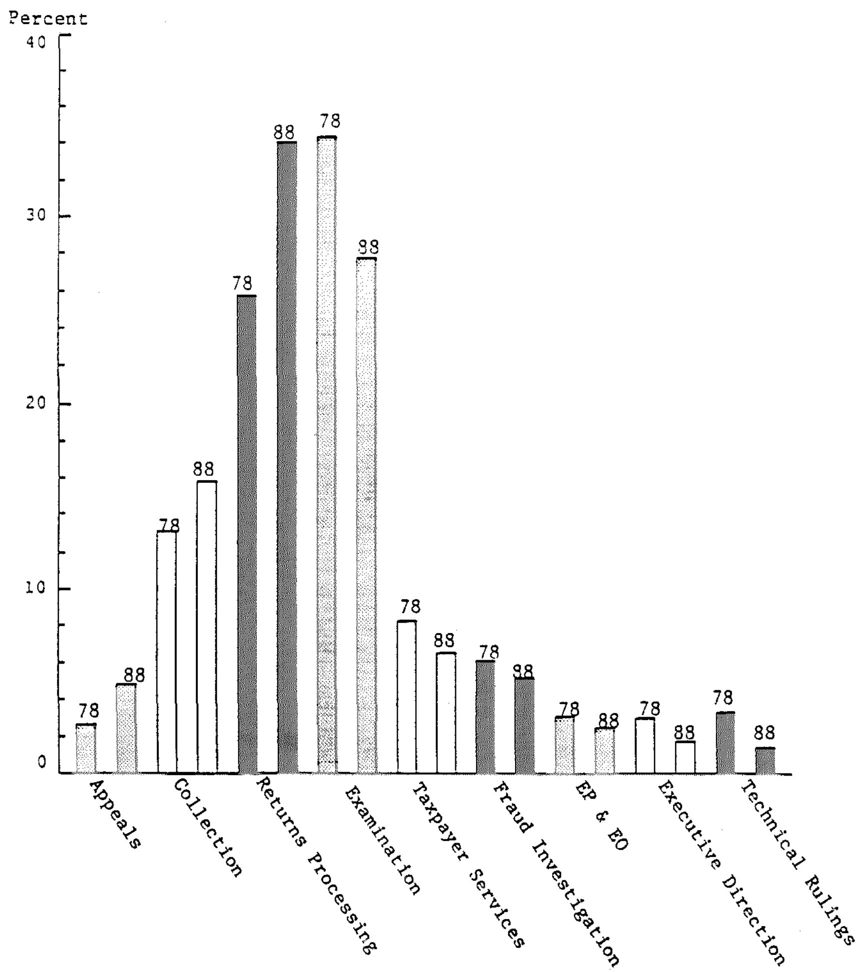
significant decreases in audits, while in some states, such as Texas and Colorado, the rate declined less than the national average. California, which historically had a higher than average state audit rate, reached a slightly below-average rate by the end of the period. California had one of the fastest-growing populations during this period, so the fall in the audit rate was somewhat predictable. The IRS simply couldn't keep up. In Nevada, the significant decline in the audit rate can be attributed to simple changes in the law. Those same gambling winnings mentioned earlier are now tracked by "informational returns" issued by the casinos. The paper trail thus created removes the necessity for IRS field audits while maintaining the same, if not a better, compliance level. Texas, on the other hand, received increased attention from the IRS in an effort to crack down on abusive tax shelters, most notably oil and gas partnerships.

If the IRS isn't auditing individuals at the same rate they were a decade ago, what is it doing instead? It's not shifting to corporate audits—the picture is nearly the same for Subchapter S corporations and partnerships as it is for individuals. Audit rates have fallen significantly for all except the very largest corporations. The IRS is, in fact, doing three things differently. First, it is extensively computerizing its operations. Second, it is hoping that a stiff increase in penalties will compensate for declining audit rates. Third, it is doing criminal investigations for other agencies.

We compared the IRS's 1978 and 1988 budgets, and found that more money was being spent on computer processing—money that had previously financed audits. The use of good, old-fashioned, face-to-face auditing has clearly fallen off, to be replaced in large part by the use of third-party reporting and computerized technology. This is an example of the classic labor–capital tradeoff—computers with green eyeshades have replaced their human counterparts.

This new emphasis on computing puts the IRS and the FTB in a better position to gather more information about you. More documents—informational returns—are being filed in conjunction with your return. In the past, an average of six documents, including W-2s, were filed on your behalf by third parties. By 1988, that number had increased to about eight. Computers are able to digest this information and detect possible discrepancies. As a result, the IRS can take the discretion out of your hands. For example, if you choose not to report

Below: Budget allocations as percentages of the IRS's total budget, 1978 and 1988.



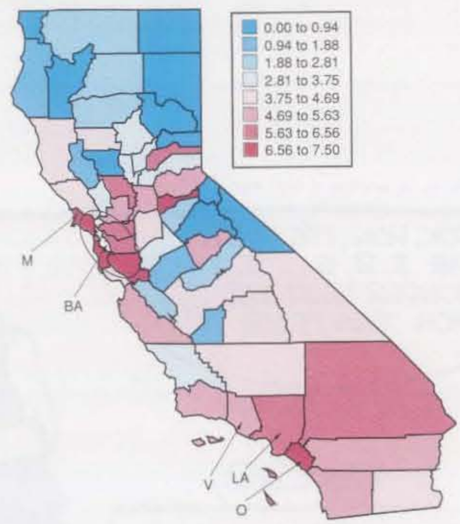
Computers with green eyeshades have replaced their human counterparts.

interest income from a smaller bank account one year, the authorities are now more likely to discover the omission. In fact, the IRS now processes almost 98 percent of the informational returns that are filed on your behalf.

The government apparently believes that there exists a trade-off between auditing and penalties. Alarmed by the growing Tax Gap, Congress feared that the United States was becoming a nation of tax cheaters. Starting in 1981, legislation was passed to make the penalties for tax evasion more severe. Formerly, a common tax-evasion strategy was to pay your taxes late. Since interest rates in the marketplace were higher than the IRS's statutory rates, an opportunity existed to pocket the difference until the IRS forced you to pay, without even assessing a penalty. Now there are strict penalties for late filing and that loophole is closed. There is no empirical evidence as yet, however, to support the notion that stricter penalties deter other forms of noncompliance.

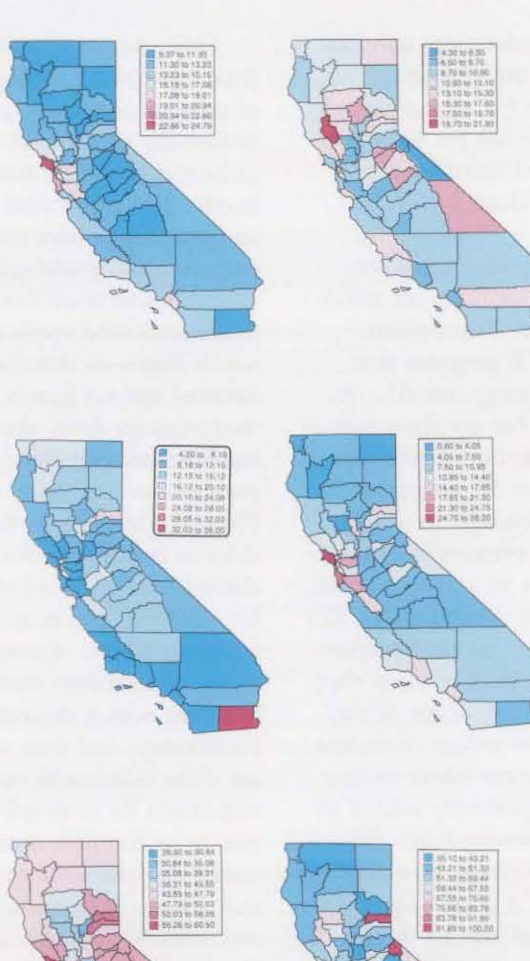
The IRS has always conducted criminal investigations. Historically, about 30 percent of these investigations started as a result of audits. This percentage has dramatically declined, as has the percentage of prosecutions resulting from these examinations. Nowadays, IRS resources are frequently borrowed by other agencies to aid in the prosecution of suspected criminals. When the Drug Enforcement Administration prosecutes a kingpin under RICO (the Racketeer-Influenced and Corrupt Organizations Act), it attempts to assemble as much evidence as possible. The IRS frequently provides both additional supporting evidence and "forensic" accounting expertise. As a result, the agency is often torn between noncompliance and other kinds of criminal investigations, and may be paying less attention to individual taxpayers.

Taken together, the picture that emerges is one of a more sophisticated and more efficient IRS, but also an IRS that has turned somewhat away from the traditional audit. The fall in federal audit rates coupled with the general reliance of states on information provided by the IRS might lead us to conclude that California has simply mirrored the federal pattern. On the other hand, California policy, while influenced by the federal model, may react differently to the underlying pattern of noncompliance within the state. The IRS is not very forthcoming about its audit policies. The federal audit-selection rule is probably among the government's most closely guarded secrets. Fortunately, the FTB has been more cooperative about providing information, making it possible to exam-



You could stare at these maps for a while and you might have some success discerning the pattern. You could just as easily go blind.

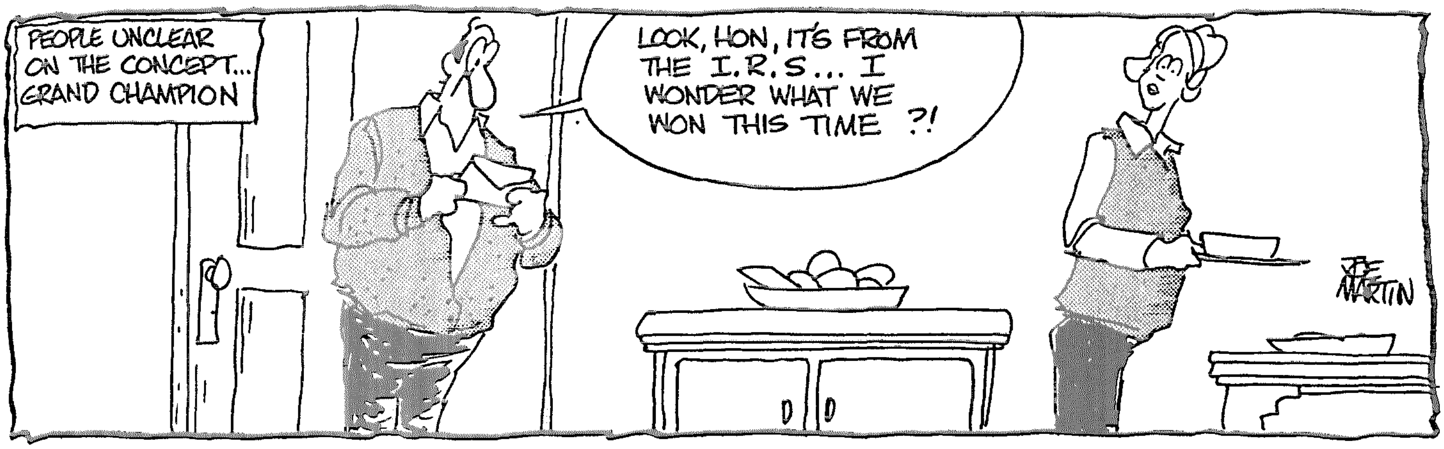
Above: Notice of Proposed Assessment rates (percent). M, BA, V, LA, and O stand for Marin County, the Bay Area, Ventura County, Los Angeles County, and Orange County, respectively.
Left-hand column, from the top down: personal income (thousands of dollars), unemployment rate (percent), and high-school education (percent).
Right-hand column: population over 65 (percent), offsetting losses (percent), and use of paid preparers (percent).
The two red counties on the paid preparers map are "outliers"—statistical artifacts caused by the small sample size.
All figures are per-county averages based on FTB data for 1984, except for high-school education, which is based on 1980 census data.



ine its tax policy a little more closely.

The larger map shows that the FTB gives Los Angeles County a lot of audit attention, but that the farm areas receive relatively little. The Bay Area receives significant audit coverage, as indicated by the dark red areas. Orange County also shows significant audit activity relative to the rest of the state. (This figure actually shows the percentage of returns that received a "Notice of Proposed Assessment." These notices are issued by the FTB as a result of its audit program, an IRS audit reported to the FTB, or a special FTB program to locate people who don't file their tax returns.)

We have found several correlations between taxpayer demographics, characteristics of individual returns, and the state audit rate. The small maps display some of these correlated factors. Areas in which personal income is higher tend to be audited more. Personal income is relatively high in Orange County, around the Bay Area, and in Marin county, and these regions have a correspondingly high audit rate. By contrast, unemployment rates have a negative effect on the audit rate. The yield from auditing in areas with high unemployment is generally not very good. High-school education is also negatively correlated with the audit rate. (Unfortunately, as few as one in four adults in the farm areas have high-school educations. Even in Marin County, the figure is only about 60 percent. As an educator, this map really gave me pause when I first drew it.) Why do people with higher levels of education receive fewer audits? One theory is that better-educated people are simply harder to



I'm not suggesting that you should cheat on your taxes, or rush out and buy a lottery ticket. If I had to gamble, I'd place my money on the FTB and the IRS.

catch—they can conceal their financial activities better. Another is that they understand the tax code better and can therefore file a more compliant return. (In this regard, it has yet to be determined whether the recent federal tax "simplification" has led individuals to file more compliant returns.)

Areas in which a larger percentage of the population is 65 years of age or older are associated with more audit activity. This pattern might be due to a special FTB program that monitors the exemption for being over 65. A 64-year-old filling out his or her tax form may think, "If I got into the movie on a senior discount last week, why not take the exemption?" This extra year may now be enough to trigger an audit. The use of a paid preparer is negatively associated with your chance of getting audited, at least in California. We are uncertain why this is so. Perhaps returns prepared by paid preparers are more compliant at the state level, in that the preparers have a detailed knowledge of the tax laws. And, finally, the percentage of returns showing offsetting losses—returns where income has been offset by losses—is positively related to county-level audit rates. Offsetting losses can occur if you file a partnership return in which this year's income is offset by a greater loss carried forward from the previous year, or if you file a sole-proprietorship return showing more expenses than receipts. It so happens that people in Marin show a lot of offsetting losses, as do Ventura and Orange Counties. These areas receive correspondingly greater audit attention from the FTB.

How did we combine these seemingly unrelated factors and conclude that the increased use of paid preparers is negatively associated with the probability of an audit while increased personal income is positively associated with this likelihood? You could stare at these maps for a while and you might have some success discerning the pattern. You could just as easily go blind.

Economic researchers today use econometric techniques—the application of statistics to economic data—to determine the relationship between various factors. Econometrics is a relatively nascent field, about 60 years old, but it has been successfully applied to many different problems and in many different disciplines. Physical scientists can frequently control the variables in their experiments, working with pure chemicals at standard temperature and pressure, for example. An economist's laboratory is necessarily the world. Econometrics tries to discern causal relationships among uncontrollable factors. We start with a theoretical model that predicts a relationship, and then test the observed data to see if the relationship holds. The statistical techniques can be as simple as linear-regression analysis, or as complex as simultaneous equation systems, nonparametric methods, or methods that seek to maximize the likelihood of the observed outcomes from within a specified class of alternative models.

In our study of the Tax Lottery, we examined the demographic characteristics of the filer as well as the information filed to explain county-level differences in the state audit rate. We also analyzed how the amount of tax col-

The average taxpayer spends from four to ten hours a year preparing tax forms.

lected changed over time in response to the audit rate, while controlling for a variety of other factors that had also changed. The tricky part is that, when the audit rate increases, collections should increase as people become more compliant. The IRS, however, is not an innocent bystander—it raises audit rates when collections fall because that's how the missing money is retrieved. Just looking at the data on collections and audits doesn't show which force is the driving one. Econometrics helped us to separate the effect of audits on individual behavior from the effect of IRS behavior on audits. This analysis enabled us to demonstrate that increased audit coverage caused increased compliance.

A back-of-the-envelope calculation shows that a dollar spent on the Tax Lottery is a pretty good bet. If you attempt to cheat California out of a dollar in taxes, you get to keep about 80 cents of that dollar on the average. The California Lottery works just the opposite—a dollar spent is, on average, 80 cents thrown away. (The California Lottery isn't even a fair bet, for several reasons: taxes are collected on gambling winnings, a fraction of every dollar spent on the lottery is appropriated to the school system, and the payout scheme doles out large winnings in annual installments rather than as a lump sum up front.) I'm not suggesting that you should cheat on your taxes, or rush out and buy a lottery ticket. If I had to gamble, I'd place my money on the FTB and the IRS. Every dollar they spend on enforcement results in a $14 gain. This statistic is fairly uniform across income classes and holds for both corporations and individuals.

In the future, there will likely be a decrease in the $90 billion of uncollected taxes. There's a wealth of information on taxpayers that the IRS and the FTB have not even attempted to use. But they're becoming more sophisticated and their computers are getting faster. Many paid preparers and national tax-preparation services now file tax returns magnetically. With the entire return in machine-readable form, tax agencies can easily examine a greater number of tax-return items, which should improve the audit-selection process. It's also likely that the tax authorities will be able to trace an individual's tax-return information over time. Incredibly, very little of that currently takes place. For example, I've not seen any evidence that your past audit history influences your current likelihood of an audit. The information simply is not retained. As for the guy who seems to get audited year after year, it could be that he just consistently files a return that produces a big TCMP score, and is therefore subject to an increased chance of being audited.

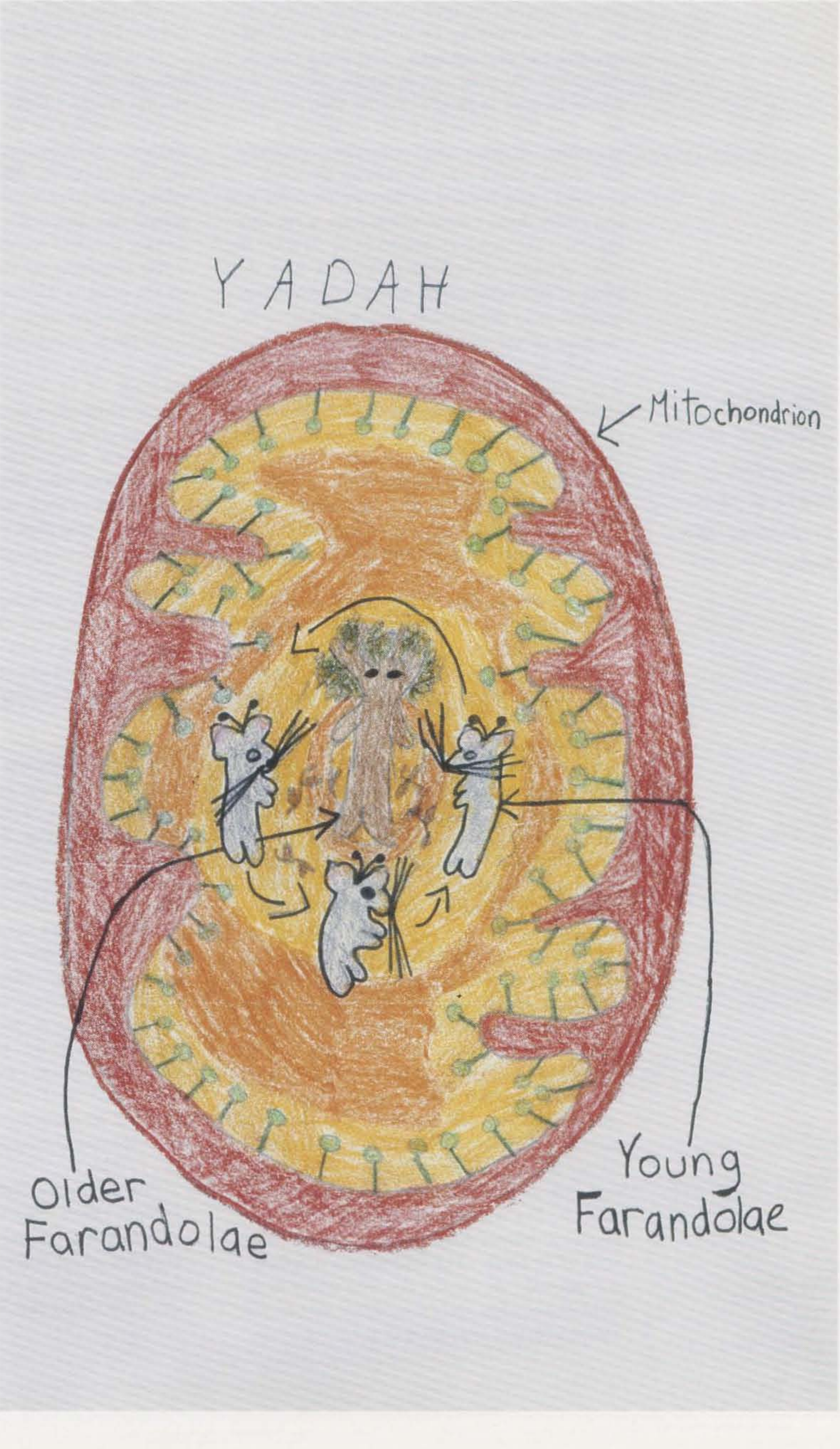
The California tax return has recently been brought into close correspondence with the federal tax return. There should, therefore, be fewer opportunities for tax evasion as the differential treatment of deductions, exemptions, credits, and the like disappear. More and more states are taking their income tax as a percentage of the federal one, and that's not a bad idea. The average taxpayer spends from four to ten hours a year preparing tax forms—a dead-weight loss on the order of $25 billion annually if those hours had been spent in gainful employment.

It seems that as long as we conduct our commerce in cash, there will be opportunities for tax cheating. If we switch to a debit society—do all of our transactions electronically—and get rid of cash altogether, I think we could eliminate noncompliance completely. Interestingly enough, no one seems to want that. People don't want a record kept of their activities. Cash is being used more now than ever before.

Although computer technology and information-matching have made the IRS and FTB more efficient, auditing remains their most powerful enforcement tool. As long as the Tax Lottery remains a game of chance, one thing is certain: let the audit rate fall, and more people are encouraged to play the Tax Lottery. □

Jeffrey Dubin came to Caltech as an assistant professor of economics in 1982 and became an associate professor in 1988. He received his AB from UC Berkeley in 1978, and his PhD from MIT in 1982. His research focuses on microeconomic modeling, particularly on discrete-choice econometrics, which is the study of how individuals choose from among a limited set of alternatives—deciding how to vote, for example, or what model car to buy. Besides tax compliance, he has published articles on such topics as risk assessment and nuclear energy, energy-demand forecasting, rate-structure design, the effects of welfare and entitlement programs on unemployment, and a book, Consumer Durable Choices and the Demand for Electricity. *This article, based on a Seminar Day talk, is Dubin's first contribution to* E&S.

The FTB gave Dubin special access to their computer system to gather many of the statistics needed for this research. While on the computer, he pulled up his own return for curiosity's sake, and discovered that he had been assessed a penalty. He swears that it had nothing to do with tax evasion.


YADAH
Mitochondrion
Older Farandolae
Young Farandolae

Mitochondrial DNA: The Second Genetic System

Prospects are promising that, with all the basic information now available on the human mitochondrial genome, its role in human disease and aging will soon be understood.

by Giuseppe Attardi

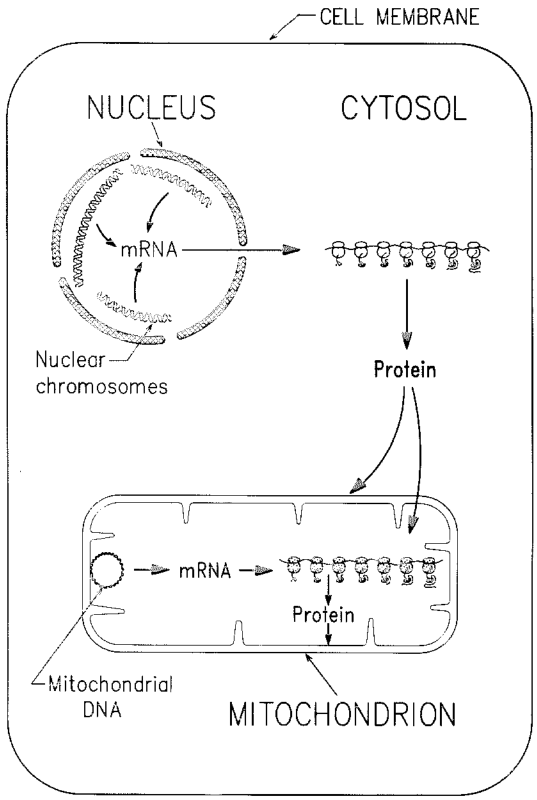
Mitochondria do not really contain microscopic, mouse-like creatures called farandolae, as imagined in Madeleine L'Engle's science fiction book for children, "A Wind in the Door." (Yadah is the name of a particular mitochondrion in the book.) Farandolae, the book explains, are "genetically independent of their mitochondria. . . . And if anything happens to the farandolae in the mitochondrion, the mitochondrion gets sick. And probably dies." A number of diseases recently identified are, in fact, the result of mutations in mitochondrial DNA. Drawing by Laura Attardi, age 10.

All animal and plant cells and other nucleated cells contain, besides the main genetic system localized in the nucleus, a second genetic system sequestered within the mitochondria. These are the powerhouses of the cell, specialized for the production of energy from respiration. The evolutionary origin of mitochondria merges with the origin of the present-day nucleated cells. It is generally accepted that mitochondria are, in fact, descendants of primitive aerobic bacteria, which were engulfed by the progenitors of contemporary nucleated cells about 1.5 billion years ago. These early progenitors were not capable of aerobic metabolism, but acquired the capacity to utilize atmospheric oxygen for energy production by incorporating organisms that could. During the long evolution that followed their acquisition by the nucleated cells, the primitive bacteria lost the capacity of autonomous multiplication and became dependent to an increasing extent on the host cell for all their functions. This loss of autonomy by the intracellular bacteria was the consequence of the transfer to the nucleus of the major part of the genes of the primitive bacterial chromosome.

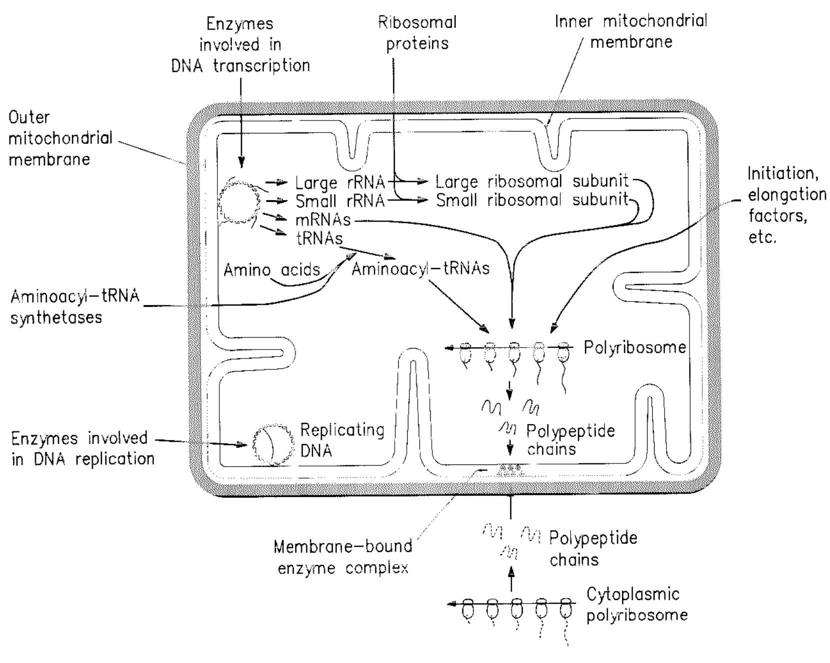
The DNA sequestered in mitochondria is the residue of those bacteria's genetic material. The dimensions of the DNA are very small—equivalent to about one three-thousandth of the smallest human chromosome. The mitochondria themselves have maintained some similarities in size and shape to the primitive bacteria. Of the two mitochondrial membranes, the external one derives from the membrane of the nucleated cell that engulfed the bacterium, whereas the internal one derives from the bacterial membrane and maintains some of its chemical characteristics.

Every present-day nucleated cell contains a large number of mitochondria, varying in man between a few such organelles and several hundred, depending upon the type of cell. Each mitochondrion contains several identical or near-identical copies of mitochondrial DNA, and, accordingly, each cell contains from a few dozen to a few thousand molecules of mitochondrial DNA. This variability in the number of mitochondria reflects the energy needs of the various cell types. Thus, in brown fat, which is a tissue whose mitochondria are specialized for heat production from respiration, each cell's cytoplasm is literally packed with mitochondria. Adult humans have very little brown fat; it is, however, abundant in children, and heat production by brown fat mitochondria is essential for newborn infants' survival. In some cell types mitochondria are uniformly distributed in the cytoplasm, while in others they are located in close proximity to other structures or organelles that require a high level of energy to perform their function. Thus, in heart muscle, mitochondria are tightly packed in linear arrays in the narrow spaces separating myofibrils—the structures specialized for muscular contraction, which depend for their activity on adenosine triphosphate (ATP), the product of chemical energy generated in mitochondria. Another striking example of the close association of mitochondria with structures requiring a high supply of energy is provided by spermatozoa. In these cells the long tail contains longitudinal contractile fibrils, which ensure the

Right: The formation of functional mitochondria within a nucleated cell requires the participation of a large number of proteins encoded in nuclear genes, synthesized in the cytosol, and then imported into the mitochondria. But also necessary are a few proteins that are encoded in the mitochondrial DNA itself and synthesized in the mitochondria.



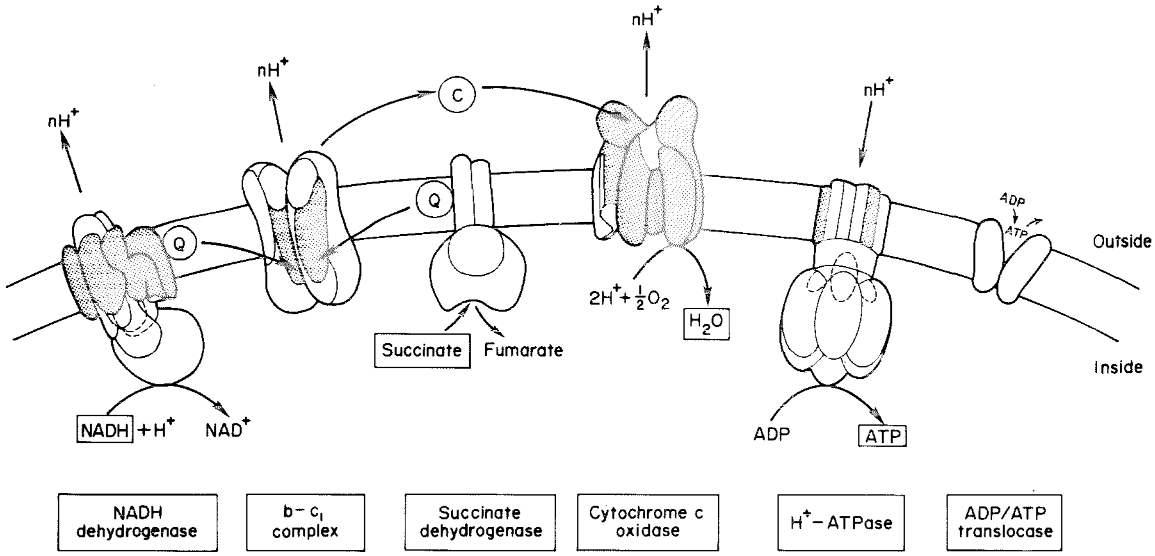
Below: This diagram of a mitochondrion shows the route by which the information in mitochondrial DNA is translated into the proteins that, along with the proteins imported from the cell's cytosol, form the enzyme complexes of the inner mitochondrial membrane.



sperm motility and which are surrounded by tightly packed mitochondria aligned to form a spiral.

In the course of their evolution from primitive bacteria, mitochondria became completely dependent on nuclear genes for their growth and function. Most mitochondrial proteins, including those necessary for the replication and expression of mitochondrial DNA, are encoded in nuclear genes, as shown in the illustration above. The genes are transcribed into RNA copies carrying genetic messages. These messenger RNAs (mRNAs) are transported into the soluble fraction of the cytoplasm, or cytosol, where they are translated into proteins by the protein-synthesizing apparatus; these proteins are subsequently imported into the mitochondria. The small number of genes of the primitive bacterial chromosome that constitute the mitochondrial DNA encode proteins that play an essential role in the mitochondrion's energy-producing functions. These genes are also transcribed into mRNAs, which are then translated into proteins by a mitochondria-specific protein-synthesizing apparatus. The RNA components of this protein-synthesizing machinery are also encoded in mitochondrial DNA.

The diagram at left describes what is known about the role of animal mitochondrial DNA in the formation of mitochondria. Mitochondrial DNA is replicated through the activity of enzymes encoded in nuclear genes and synthesized in the cytosol. Other enzymes encoded in the nucleus transcribe the DNA into RNA copies. Mitochondrial DNA codes for two ribo-



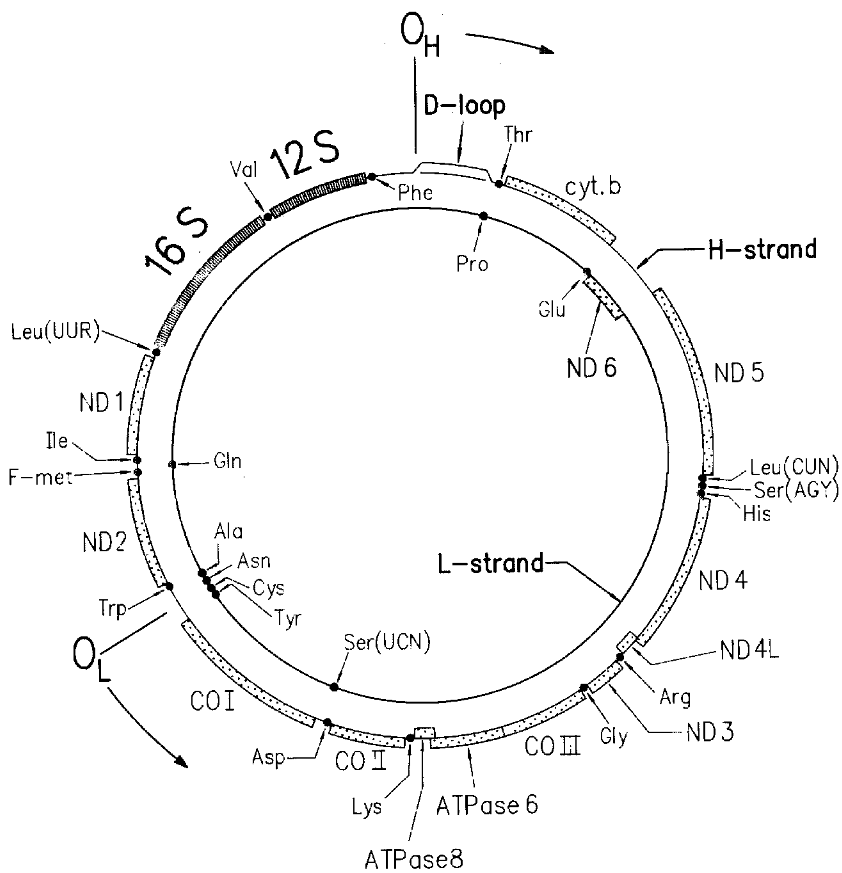
The genetic origins of important components of the mitochondrion can be seen in this drawing of the enzymes of the inner mitochondrial membrane, which preside over the production of energy. These include four respiratory enzymes, along with H^+-ATPase and ADP/ATP translocase. The enzyme subunits that are encoded in mitochondrial DNA are represented by shading, while those encoded in the cell nucleus are unshaded.

somal RNA species, or rRNAs, which are specific structural components of mitochondrial ribosomes, that is, the machines specialized for protein synthesis within the mitochondria. The two rRNA species become associated with a large set of proteins encoded in the nucleus, and synthesized in the cytosol, to form the large and small subunits of the mitochondrial ribosomes. Mitochondrial DNA also codes for 13 mRNAs, which specify an equivalent number of proteins. Finally, mitochondrial DNA encodes 22 different transfer RNAs, or tRNAs. These are small RNA molecules specific for different amino acids, which have the function of translating the genetic messages contained in the DNA sequence into the amino acid sequence of proteins. Each species of tRNA becomes linked to its corresponding amino acid through the activity of specific enzymes that are encoded in the nucleus (aminoacyl-tRNA synthetases). The mRNAs bind to the ribosomal subunits to form structures called polyribosomes that look like strings of beads. These, with the help of aminoacyl-tRNAs and of specific initiation and elongation factors, decipher the messages contained in the mRNAs and synthesize the corresponding proteins. These proteins then become associated with proteins that have been imported from the cytosol into the mitochondria and form the large enzymatic complexes of the inner mitochondrial membrane.

That enzymatic apparatus of the inner mitochondrial membrane is shown in close-up in schematic form above. This apparatus presides over the production of energy and includes four respiratory enzymes, which transfer in series the electrons derived from the oxidation of respiratory substrates to oxygen, with concomitant production of water. The energy producing apparatus also includes the ATP synthetase, also called mitochondrial proton-ATPase, which synthesizes ATP by utilizing the energy produced by respiration. And finally, it includes a protein that regulates the traffic of ATP and of its precursor ADP (adenosine diphosphate) across the inner mitochondrial membrane. In the diagram the subunits of the enzyme complexes of this membrane that are encoded in the nucleus are not shaded to distinguish them from those that are encoded in mitochondrial DNA, which are shaded. You can see that three respiratory enzymes and the ATP synthetase claim their genetic origin from both genomes.

The genetic map of human mitochondrial DNA on the following page shows the genes transcribed from the two strands of DNA. This information has emerged from studies that we started at Caltech about 20 years ago. This work culminated 10 years later in the determination of the complete sequence of human mitochondrial DNA in Frederick Sanger's laboratory in Cambridge University in England, and four years ago in the complete functional identification of the proteins encoded in mitochondrial DNA, carried out in our laboratory, in collaboration with Russell Doolittle at UC San Diego.

The arrangement of the genes in human mitochondrial DNA, and probably in mitochondrial DNA from all vertebrate cells, exhibits characteristics of compactness and economy that



Representing work begun at Caltech 20 years ago, this complete map of human mitochondrial DNA shows the positions of all the genes. Most of the genes are transcribed from the H-strand (outside), including those coding for the 2 rRNAs (hatched bars), 12 proteins (dotted bars), and 14 tRNAs (black dots). The L (inside) strand includes 8 genes for tRNAs (black dots) and 1 gene for a protein (dotted bar). The map illustrates the compactness of mitochondrial DNA, as opposed to nuclear DNA, in which long stretches of noncoding sequences separate the genes. Here the genes lie right next to each other, and a nontranscribed segment in one strand corresponds to a transcribed segment in the other.

have no parallel in the living world, except in viruses. In fact, the genes transcribed from one or the other of the two strands saturate the length of mitochondrial DNA almost completely. The majority of the genes are transcribed from one of the two strands, which is designated as the heavy (H) strand because of its relative density in a solution of cesium chloride. These genes include those for the 2 rRNA species, 12 genes coding for proteins, and 14 genes coding for tRNAs. The genes transcribed from the other strand, designated as the light (L) strand, include 8 genes for tRNA and 1 gene encoding a protein. Note that a nontranscribed segment in one of the two strands corresponds to a transcribed segment in the other strand. In the nuclear chromosomes the genes are separated by long noncoding segments, and many genes are discontinuous, with intervening sequences interrupting the coding sequences. By contrast, in mitochondrial DNA, the genes, all continuous, are immediately adjacent to each other and in some cases even overlapping, and there is an almost complete absence of noncoding stretches. Mitochondrial DNA of vertebrate cells, in the course of the evolution of these cells from the more primitive nucleated cells, has undergone an extreme reduction of its dimensions by elimination of intergenic spacers. This contraction in size has also been accompanied by a reduction and structural simplification of the individual genes themselves. Note that the arrangement of the genes in the genetic map is very characteristic: the genes coding for the rRNA species and those coding for proteins are separated with an almost absolute regularity by tRNA genes.

It is not surprising that a unique mode of DNA transcription into RNA has evolved to match the extremely compact and economical gene organization of the mammalian mitochondrial DNA. In fact, in contrast to the nuclear genes, which are copied into RNA molecules individually, mitochondrial genes are transcribed from each strand in the form of giant molecules corresponding to the entire length of the DNA, with each comprising many genes. These giant transcripts must then be cut by specific enzymes to produce the various species of rRNAs, tRNAs, and mRNAs.

A characteristic property of the human—and of mammalian in general—mitochondrial DNA is its great tendency to mutate, thus changing its nucleotide sequence. This tendency to mutate is about 10-fold higher than in nuclear genes. Apart from mutations occurring as a result of replication mistakes, there are those produced by direct action of chemical agents on DNA. Cellu-

Between two individuals randomly chosen, mitochondrial DNA differs on average in about 50 of its 16,560 nucleotide pairs.

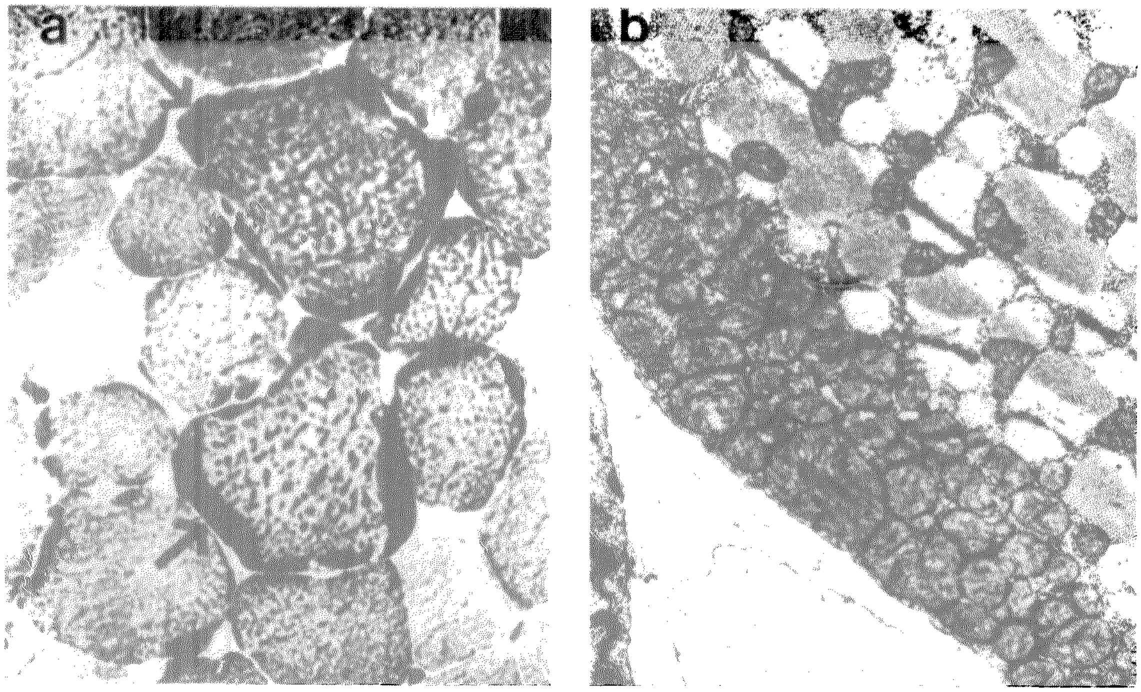
lar DNA, in general, is known to suffer oxidative damage from oxygen derivatives produced by aerobic metabolism. Bruce Ames at UC Berkeley has shown that this damage is about 15 times greater in mitochondrial DNA than in nuclear DNA, and damage by alkylation (the addition of a hydrocarbon chain) is also much more frequent in mitochondrial DNA. DNA repair systems are very inefficient in mitochondria, and, in addition, mitochondrial DNA is not protected by histones or similar proteins, as nuclear DNA is. The sequence variation that is continuously produced in mitochondrial DNA, when it affects the DNA of the germ cell line, may be transmitted to the progeny. This transmission occurs exclusively through the maternal lineage—only the egg contributes its mitochondrial DNA to the zygote at the time of fertilization. Therefore, every individual inherits his or her mitochondrial DNA exclusively from the mother, and the mother in turn from her mother, and so on. Today, a powerful technology is available to investigate the sequence variation of mitochondrial DNA among individuals. Thus, it has been established that, between two individuals randomly chosen, mitochondrial DNA differs on average in about 50 of its 16,560 nucleotide pairs, that is, in approximately 0.3 percent of its nucleotides.

The large variation existing between mitochondrial DNA sequences of different individuals has provided a powerful tool for studying the genetic relatedness of human populations and thus for investigating the evolution of man. Furthermore, the exclusive maternal inheritance of mitochondrial DNA allows the tracing of the genetic differences between individuals through maternal lineages in populations. By comparing the mitochondrial DNA sequences of a large number of individuals from different geographic populations, an evolutionary tree has been constructed (by Alan Wilson and his collaborators at UC Berkeley) that relates the different mitochondrial DNA types to one another and to an ancestral mitochondrial DNA type. This ancestral type is postulated to have belonged to a woman who lived in Africa about 200,000 years ago. By a similar analysis of mitochondrial DNA variation in Amerindian populations from North, Central, and South America, Douglas Wallace at Emory University has recently shown that the mitochondrial DNAs of American Indians must have derived from at least four primary maternal lineages of Asian origin.

About one-fifth of the nucleotide differences existing between mitochondrial DNAs of different individuals produces corresponding differences in the amino acid sequence of the proteins encoded in mitochondrial DNA. It is very likely that at least a part of this variation affects the properties of these proteins and has functional consequences. There is already good evidence from pathological situations that the sequence variation of mitochondrial genes plays a significant role in determining differences in the capacity to produce energy, especially in the tissues that have high energy requirements, such as the brain, the skeletal muscles, the heart, the retina, the kidney, and the liver.

Superimposed upon the mitochondrial DNA sequence variation between individuals that we inherit from our mothers is a mitochondrial DNA heterogeneity that is continuously produced in our tissues during our lives as a consequence of mutations. It is, in fact, to be expected that mitochondrial DNA mutations resulting from replication errors, and possibly from damage by oxidation or alkylation, accumulate progressively during the life of an individual. There is already clear evidence that mutations resulting from deletions or insertions of short DNA segments in mitochondrial DNA are much more abundant in senescent mice than in young mice. So it's a plausible idea that the progressive damage in mitochondrial DNA that occurs during aging contributes to the decrease in respiratory capacity of an individual's tissues. Researchers in Australia have demonstrated that such a decrease occurs in skeletal muscles as humans age; it presumably also takes place in other tissues.

Besides this aging-related, general deterioration of mitochondrial DNA, some specific mutations occurring in mitochondrial DNA, either inherited or produced during the life of an individual, can cause clear damage to the organism, thereby producing specific diseases. A heterogeneous group of diseases, called mitochondrial diseases and characterized by mitochondrial dysfunction, affects either singly or in combination the nervous system, the skeletal muscles, the heart, the retina, the kidney, and the liver—all organs that have high energetic needs and so depend heavily on the respiratory functions of mitochondria. For several of these diseases, an association with specific mitochondrial DNA mutations has been clearly demonstrated. One of them, designated MERRF (myoclonic epilepsy and ragged red fiber syndrome), is characterized by epilepsy, dementia, cerebellar disturbances, and defects of the skeletal and heart muscle. In this syndrome, as well as in other mitochondrial muscular diseases, muscle fibers of affected individuals exhibit a characteristic accumulation



The photograph at right (a) shows a cross section of muscle fibers from a patient with a muscular mitochondrial disease. Accumulations of mitochondria (stained darker) are apparent at the periphery of the ragged red fibers (arrows). In the higher magnification of an electron microscope (b) the large accumulation of mitochondria can be seen more clearly at the edge of a cross section of a single fiber. (Courtesy of Salvatore DiMauro, Columbia University.)

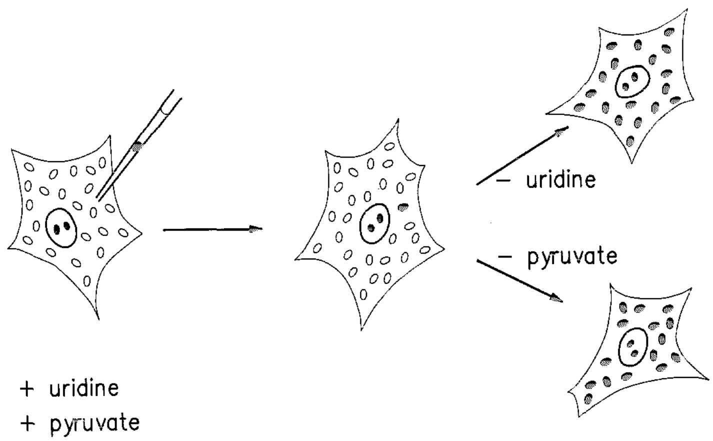
Some specific mutations occurring in mitochondrial DNA, either inherited or produced during the lifetime of an individual, can cause clear damage to the organism.

of mitochondria at the periphery, under the cell membrane. The left-hand photograph (a) above shows a cross section of muscle fibers from an individual affected by a mitochondrial muscular disease. The black material (stained red in the original preparation) at the periphery of the ragged red fibers represents accumulations of mitochondria. These are more easily recognizable in the view at higher magnification on the right (b)—an electron-microscope picture of a portion of a transverse section of a muscle fiber. You can see the enormous accumulation of mitochondria at the periphery of the fibers, which has resulted from a proliferation of defective mitochondria. This proliferation is an attempt on the part of the sick fibers to compensate for the functional defect of the mitochondria by producing more of them. Wallace and his collaborators have recently identified the mutation of mitochondrial DNA that produces the MERRF syndrome as a single nucleotide change in the tRNA specific for lysine, one of the amino acids.

Another mutation of mitochondrial DNA, which produces a well-characterized disease, had previously been identified. Leber's hereditary optic neuropathy, which is transmitted through the maternal lineage, affects mostly males and produces a rapid bilateral loss of central vision due to optic nerve atrophy. In most, if not all, of the families affected by this disease, the mutation, which changes a single amino acid, occurs at a specific site in a mitochondrial gene encoding a subunit of NADH dehydrogenase, the first respiratory enzyme.

Another type of disease-causing mutation that affects mitochondrial DNA is not inherited, but appears sporadically. These mutations consist of deletions that have removed a portion (between 8 and 75 percent) of the mitochondrial DNA. These deletions, first discovered by investigators at the University of London, do not involve the two origins of replication of the mitochondrial genome, therefore preserving the replicating capacity of the shortened molecules. Such deletions have been found in patients affected by a variety of mitochondrial diseases, such as Kearns-Sayre syndrome, characterized by paralysis of external eye muscles, retina degeneration, and cerebellar symptoms, and Pearson's disease, characterized by bone-marrow and pancreas alterations. The identification of patients affected by mitochondrial diseases clearly associated with mitochondrial DNA mutations has increased rapidly in the two years since the first molecular description of such diseases. With the increasing availability of molecular assays for such diseases and the growing awareness on the part of physicians of the possible mitochondrial genetic origin of syndromes affecting the nervous, muscular, and other systems, we expect the number of pathological forms associated with mitochondrial DNA mutations to continue to increase in the coming years.

Prospects are promising that genetic manipulations of the human mitochondrial genome can find applications in mitochondrial diseases. In our laboratory, we are developing new technologies aimed at transferring mitochondria from one cell to another, at replacing completely the mito-



In recent developments in the Caltech lab, human cell lines have been isolated whose mitochondria have been depleted of mitochondrial DNA. Such cells are deficient in respiratory function and dependent on uridine and pyruvate for growth, but injecting the cells with a single mitochondrion with functional DNA repopulates all the mitochondria with DNA and "cures" their deficiencies.

chondrial DNA complement of a cell with foreign mitochondrial DNA, and at introducing DNA directly into the mitochondria of a living cell. We are following two main approaches. First, graduate student Michael King has isolated human cell lines whose mitochondria have been completely depleted of mitochondrial DNA by long-term exposure to ethidium bromide, an inhibitor of mitochondrial DNA replication. These cell lines are, as expected, respiratory deficient, and derive their energy exclusively from fermentation of glucose. Furthermore, these cells have developed metabolic defects due to the lack of a respiratory chain. In particular, two metabolites, uridine and pyruvate, must be added to the nutritive medium for the cells to grow.

The drawing above shows how these cells lacking mitochondrial DNA (designated ρ^0) can be injected with single mitochondria containing functional mitochondrial DNA, and how this DNA can then repopulate the entire complement of mitochondria. As a result, the injected cell reacquires respiratory competence and the capacity to grow in the absence of uridine and/or pyruvate. Another approach more frequently applied for introducing mitochondria into the ρ^0 human cells involves removing the nuclei of the chosen mitochondrial donor cells, and then fusing the enucleated cells with the ρ^0 cells. Many "transmitochondrial" cell lines containing nuclei from ρ^0 cells and mitochondria derived from human cells from other sources have already been constructed in our laboratory by King and others. This type of experimental strategy will be very useful for introducing into ρ^0 cells mitochondria derived from patients affected by mitochondrial diseases. This approach has already allowed Anne Chomyn, senior research associate, to determine that the defect associated with a mitochondrial myopathy could be transferred with the injected mitochondria, and thus to establish that the mutation underlying the defect was of mitochondrial origin and to determine its nature.

We are also working on another type of genetic manipulation aimed at the direct introduction of intact mitochondrial DNA molecules or fragments of them into the mitochondria of human cells, by means of a so-called "biological gun." With this instrument, developed by John Sanford at Cornell, metallic microcarriers—bullets less than a micron in size and coated with the desired DNA—are fired directly into the cells by the force of gun powder. This gun has already been applied successfully to the transformation of chloroplasts in the unicellular alga *Chlamydomonas*, and of mitochondria in yeast. On the basis of others' experience with these organisms, we hope that DNA introduced with the biological gun into human cells will repopulate the entire mitochondrial complement of the cells and confer new properties on them. Such an experimental strategy, if successful, would open the way to the correction of mitochondrial DNA mutations by the introduction of functional genes into the defective cells.

In view of this recent work, I believe it is reasonable to expect that the new approaches for the genetic manipulation of human cells will be very useful for the diagnosis, the genetic and molecular analysis, and, eventually, the therapeutic treatment of mitochondrial diseases. □

In 1989 Giuseppe Attardi received the $70,000 Antonio Feltrinelli International Prize for Medicine, presented every five years by the Accademia Nazionale dei Lincei, founded in 1603 in Rome. This article was adapted from his acceptance speech at the ceremonies in Rome.

Attardi is the Grace C. Steele Professor of Molecular Biology. He earned his MD degree from the University of Padua in 1947 and joined the Caltech faculty in 1963, becoming full professor in 1967. In 1984 he was elected to the National Academy of Sciences.

His daughter's drawing on page 12 was suggested by Attardi as an illustration even though it was inspired by science fiction. He considers the book, written in 1973, quite prescient in its discussion of mitochondrial diseases, of which little was known before the past couple of years.

Oral History Heinz Lowenstam Paleontologist in Palestine 1935-36

"Don't worry. I have friends in New York. They will take care of it."

Heinz Lowenstam in Jerusalem, 1936.

Heinz Lowenstam, professor of paleoecology, emeritus, was born in 1912 in Upper Silesia, in what was then southeastern Germany and is now south-central Poland—a region of coal, lead, and zinc mines, smelters, and steel mills. As a boy playing on the mine dumps, Lowenstam developed an interest in collecting minerals, and in high school switched to collecting fossils instead (which he also found on the mine dumps), which set him on a course to study paleontology. In high school he also heard a talk by Alfred Wegener, who first proposed the continental drift theory. Although the theory was not generally accepted for several more decades, the talk made a believer of Lowenstam and inspired his interest in geology.

In 1933, the year Hitler became chancellor, Lowenstam enrolled at the University of Munich, famous for its school of paleontology. He studied with Professors Broili and Dacqué and simmered under the growing antisemitism as the Nazis gained influence in the university. When Kölbl, a Nazi functionary and unknown professor from an Austrian agricultural school, became head of the geology department at Munich (and aghast to discover the presence of a Jew), Lowenstam finally boiled over and determined on a dramatic departure.

The following article was excerpted from a series of interviews with Lowenstam, who became known for his startling discovery, in the early sixties, of magnetite biomineralization, which was initially greeted with about the same skepticism accorded continental drift. Heidi Aspaturian conducted the interviews in 1988 for the Caltech Archives' Oral History Project.

Heidi Aspaturian: Wasn't it unusual for a Jew in Nazi Germany to write a PhD thesis on Palestine?

Heinz Lowenstam: Well, during one field trip with Kölbl in '35, there was a big discussion among the students, and he was pounding the table and saying, "German things must be done by Germans." A few minutes later, without even remembering what he had said, he said to me, "Don't you think it's time to think about the subject for your doctor's dissertation?" I was just boiling, and I said, "Yes, I want to go to Palestine and write a doctor's thesis on the subject of Palestine." He was ready to pounce on me. And then he smiled and said, "Okay." I remember coming home that night to the apartment in Schwabing, and my landlord, an American friend who published medieval manuscripts, asked me what I had done that day. Lately I had shot my mouth off at the university. So he would question me every evening about what I had said that day. Half of the time we would move at night; he was sure the Gestapo would come and pick me up. I could never keep my mouth shut. So, when he said, "What did you say today?" I told him, "I shot my mouth off, but I can't produce. I don't have the money to go to Palestine." He said, "Don't worry. I have friends in New York. They will take care of it."

So I went to Palestine for a year and a half. Earlier, when Edgar Dacqué and I had talked about possible thesis topics, he had said, "You want to do your dissertation on a paleontologic subject, don't you?" I said yes. He said, "No.

I could use the fossil content and see how it correlated with other areas in Egypt and in the Balkans.

Right: the eastern Nazareth Mountains on the southern border of Galilee; Lowenstam mapped their geology for his doctoral dissertation. Below: one of his Bedouin hosts.

You take an area and map the geology of it, including some volcanic and igneous rocks, if they are there. Then, when you have done all of that and integrated the geology and structure and history of the territory, then you do your paleontology." I don't know why I listened to him, but it was the best thing that ever happened to me. I learned the significance of field information, which today is widely abandoned in favor of the computer, which runs the same old data in new forms instead of giving new information.

HA: How long did it take you to make arrangements to go to Palestine?

HL: You know, I have no recollection. It was apparently fairly simple. I went on an Italian ship from Trieste to Haifa. The food was terrible. The rumor was that the ship might turn around any time and go back because the Italians had taken over Ethiopia, and there was the possibility that the British would react and there might be war. So there was a rather curious atmosphere.

HA: What was the topic of your thesis?

HL: The geology of the eastern Nazareth Mountains of Palestine. That is the southern border of Galilee, quite a bit below the Golan Heights. Actually, Prof. Picard of Hebrew University had mapped the western Nazareth Mountains. I thought it would be interesting to see the continuation toward the Dead Sea rift valley. That was the pivotal area, where the Emek region, which was on the valley border,

came up against the big rift that came from East Africa. It was very interesting to date some of the movements that took place.

HA: From a paleontological standpoint, were you looking at the fossils in the area as a means of dating?

HL: Yes. I used the fossils for correlation and age assignment. I could use the fossil content and see how it correlated with other areas in Egypt and in the Balkans. Some fossils would even correlate with Bohemia, in central Europe.

HA: Where did you live during this period?

HL: I started off in the Emek in Kibbutz Ginnegar, which had just been founded. We lived in tents, in deep mud—it was the rainy season. It was miserable. I used that as a base. I did everything by foot, initially, later by horse and donkey. And from there I moved up to Kafr Kana, to the Greek Orthodox monastery. If you paid a little bit, they took you in. The Roman Catholics, across the alley, wouldn't take me, but the Greek Orthodox did. Their main interest was that one of the flock, one of their people, would be my guide. I would pay him for that.

I learned Bedouin Arabic in a hurry. I'm very poor in languages, but I learned very fast because there was no other way to communicate.

HA: Did you speak Hebrew or Arabic?

HL: No. I learned Arabic in the end, when I lived among the Bedouins. From Kafr Kana, I moved to a settlement that was founded by Baron Hirsch for old Jews who came from Europe to die in Palestine. It was a very weird place. From there I moved to the Bedouin camp behind Mount Tabor for about two months.

HA: What prompted you to move to the Bedouin camp?

HL: Well, I was always advised by the British district commissioner—this was the period of the British mandate. He was an exceptional person. He was interested in the people he administered, and he spoke Arabic. He was a friend of the Bedouin sheik. And when I told him I was going to map that area, he said, "Well, you have two choices. You either need to have police protection—the Bedouins are very good shots—or, since I'm a friend of the Number One sheik, you can live with them. You are my friend and he is my friend, and you will become his friend." I decided it was much more romantic to live with the Bedouins, and that's where I learned Bedouin Arabic in a hurry. I'm very poor in languages, but I learned very fast because there was no other way to communicate.

HA: What was life with the Bedouins like?

HL: At the beginning it was very difficult. I almost left because I was literally covered by fleas and I didn't sleep for four nights. By the time I decided I couldn't take it, they suddenly decreased. I got some kind of an immunity perhaps. No medical people believe it, but I know it from experience. My flea-population density went way down. So I stayed, and I learned Bedouin Arabic.

It was a very tight society of people living in subgroups. We lived in tents. When I arrived there, an Arab police officer took me over. All the way, riding to the tents, he

"I take him to the tels, the ancient ruin hills, and he picks up something, and when he thinks I don't see him, he throws it away. Then he goes out into the deserts here and breaks up rocks with his hammer. . . . But he's harmless."

tried to talk me out of going. He said, "They are pigs; they are dirty. You can't live with such people; they aren't even people; they're animals." The peasants were all against the Bedouins, because Bedouins would drive their herds any place, and the townspeople, like this officer, looked down on them. So we arrived. The sheik came out and had a rusty can of camel's milk, and he rolled this cigarette and licked it and handed it to me. Apparently I tried to step back involuntarily. The officer stuck his thumb into my back and whispered in my ear, "If you want to get killed, you asked for it. I don't want to; you take it." So there was always this real division. The Bedouins actually lived a very natural life—I thought they were doing very well. They had little huts. Once at the beginning I asked if they would sleep in them when it rained, and they thought it was very funny. They would suffocate, they said. The huts were for the goat cheese, which was their currency.

In time I learned Bedouin Arabic and even wrote some petitions for them to the district commissioner. They asked me to; they could not read or write. The sheik's oldest son was my guide. When I was out in the field, we always stopped at ruins—"tels"—because the British insisted that I was looking for antique stones—I wasn't doing geology.

HA: Why did they insist that?

HL: They were worried because oil had been found in Palestine in one spot. It later turned out not to be much, but they kept it to themselves. Everybody anticipated that the coming war would affect Palestine in a major way, and they were afraid if it was now known there was oil in the area, things would be even worse. They wanted nothing to do with it. So usually, while I worked in the mountains, the peasants would bring me amulets and coins and give them to me. I had a fantastic collection of coins going back to Maccabean times. Every time I came to Jerusalem, E. L. Sukenik, the first director of the Palestine Museum, which later became the Israeli Museum, would go through my collection and say, "Oh, we don't have this coin," or "We don't have this amulet." And I would give them to him.

The nice thing about it was that all I brought back to Germany were the dregs of the collection. When the Nazis confiscated what was left of the collection when I left the country, I almost laughed because they only got the things not wanted in Palestine.

That reminds me of a funny story. One day when the sheik's son took me out, we crossed the caravan route and a caravan came; and the son of the sheik knew the guide of the caravan. They greeted each other for about half an hour, asking about everything except your family—that comes as just barely a trace at the end. They didn't realize I could understand by then. So the other fellow said, "What are you doing with this character? What's he doing?" "Well," the son said, "You know, he's a nut, but he's harmless. He comes to us; he tells us he is looking for antique stones. So what do I do? I take him to the tels, the ancient ruin hills, and he picks up something, and when he thinks I don't

Far left: An Arab peasant with a camel hitched to his plow. Such peasants supplied Lowenstam with a "fantastic collection" of ancient coins. Center: A Bedouin tent. Left: During the disturbances, a British army detachment "rescued" Lowenstam from the Bedouins.

see him, he throws it away. Then he goes out into the deserts here and breaks up rocks with his hammer." The other one shook his head, and the son said, "But he's harmless, you see."

HA: Was there anyone among the Bedouins who was interested in what you were really doing?

HL: There could have been, but since I lived with the Number One sheik I had no way of finding out. I was with the top level. It was very interesting. The father of the sheik, a very old man, realized I had trouble, couldn't communicate—so he took me by the hand at the beginning. He would take me out and show me how to find things, something to eat and drink. I still had a few oranges with me, but when they ran out, I had nothing to drink. He taught me to pick up certain tiny plants that one could hardly see. You chewed them and went all day without being thirsty. Occasionally we would hit a waterhole. When we hit the waterhole the horses, the camels, everything would go in. I drank the water through a handkerchief.

One thing the district commissioner insisted on was, to the Bedouins I was a German. As a matter of fact, one day while we were in the camp, somebody behind me started to speak in Schwabian. I turned around and looked, and all I saw was an Arab. They had brought in one from the German Templar colony, in the Haifa area, to check if I really was German. They didn't suspect that I was a Jew, but to them I was a foreigner.

HA: Did it excite you to be in Palestine because of what it was historically?

HL: Yes, certainly it was exciting. Later I was in Jordan and unofficially in Saudi Arabia. It was unofficial because the British had officially confined me to Jerusalem. That happened because when I lived with the Bedouins, disturbances between the Arabs and Jews broke out. I didn't know about the disturbances because it was perfectly peaceful where I was. But one day a British army detachment appeared at the camp looking for me, dead or alive, because I was supposed to have been killed by the Bedouins.

HA: How did this rumor get started?

HL: My letters didn't go through. The runner who was supposed to take them somewhere apparently just threw them away after a while and then went home. I don't know why the British were interested in me—through the Iraq Petrol Company, probably. At any rate, the detachment grabbed me, and they did the craziest thing. Below the escarpment in the valley, there was the Khaduri school, an agricultural Jewish school that had been evacuated. They dumped me there, where there was one British officer. And he was scared to death. He taught me how to handle rifles. We were standing guard day and night. This was to save me. I'll never forget that one night, I heard something coming, and I shouted, and it kept coming, and I shot it, and it stopped. The next morning, we found a dead ass.

HA: Were most of your relationships with the

Above: Lowenstam with his friends in Jerusalem.
Far right: Camels and steam engines were both popular means of transportation in Palestine in the thirties.

sabras, or with British officials, or did you pretty much associate with both groups?

HL: All across. Some of my old friends, from childhood way back, were living in the Moshavims, privately owned Jewish settlements in the Emek, and I was in contact with the kibbutz residents and the Arabs.

Once while I was mapping the Nazareth Mountains farther west, I came upon a huge Persian carpet spread out and people sitting on it and people fanning people, and food all over. They were the Arab landowners, who had come home from Monaco and Nice because they had run out of money. They were waiting for the peasants to bring in the harvest so they could take three-quarters of it to finance going back. They thought I was a big joke. They said, "You mean to say you are here voluntarily?" I said, "Well, in a way I am." And they said, "It doesn't make sense." They often invited me to their places. So I even got to know the old Arab gentry who had sold land to the Jewish National Fund.

I knew I was in danger because now the Bedouins were thinking I was a British spy.

HA: How were your relations with the British officials? What were your impressions of them?

HL: Most of them were narrow-minded. It often turned out, as I got to know them better, that they were either the third sons or they were people who had done some minor thing that wasn't quite on the level, and the family wanted to have them disappear. So they went into the colonial army. That was the bulk of those people—the lowest possible excuse to go. They were not interested in the country and the people at all, with rare exceptions, like that district commissioner I knew. He had an interest in people in general, so he enjoyed what he was doing and he helped me a great deal.

While I was at the Khaduri school with the terrified officer, my notebooks and the collections I had made in that area were still in the Bedouin camp. The army detachment that had picked me up was like the harbor dregs of some British city, the worst people. I couldn't get across to them that I had to get my collections back and take them with me. I knew I was in danger because now the Bedouins were thinking I was a British spy, so I tried to get the officer to ride up and pick up my things in the camp. But he wouldn't go. One day I noticed that the Bedouins had all moved north to what I knew was a central meeting ground. As I found out later, they were having a gathering of the sheiks to decide whether or not to join the disturbances. When I saw that, I said to the officer, "I know how you can get up in the ravine and come right to the tent of the sheik I lived with, which was at the edge of the cliff. I know where my things are, if they are still there." I finally convinced him. We came up on two horses, and the Bedouin guard didn't know what to do because he had no instructions. So I had time to see that nothing had been touched. I could identify the most critical collections from the bags' markings, and Arab horse saddles are very wide. I stuffed the material in, got my notebooks, and rode out.

Then came another British detachment that had orders to take me to Jerusalem. So I came back to Jerusalem. I was not supposed to leave the city. They caught me a couple of times down at the Dead Sea and other places. In the meantime I had joined the Hagana—the Jewish underground army. I lived in Talpiot, which was in those days a peninsula most likely to be attacked. My closest friend lived there, and his brother, a telephone lineman, was killed by the Arabs. There were other things going on. At night I was in the Hagana. That was a tricky business, because after dark the British had imposed curfews. So we had all our guns taken apart and carried the pieces and slipped into our posts and assembled our weapons.

HA: What do you remember about the Jewish settlers at that time?

HL: I was most interested in the ones around the southern end of Lake Tiberias—the Sea of Galilee. They had lived there for almost a generation and a half. I met many of the leading people then, and they were quite interesting.

They were proud of what they had achieved—all the orchards and the agricultural development—but they said their children were like big cows.

They were unhappy about one thing. They were proud of what they had achieved—all the orchards and the agricultural development—but they said their children were like big cows. They had no interest in literature, in music, in culture; they were just peasants. This intrigued me very much.

HA: How did you communicate with these people?

HL: Mostly in German—I didn't know much Hebrew—and French, and some English, but not very well.

HA: Was there a general lack of contact between the Jews and the Arabs?

HL: Yes and no. Yes, in the sense that it was real, but no in that it wasn't the Jews who tried to keep apart from the Arabs. They initially had Arab guards, but they killed and did other things. So then the kibbutzim and the moshavs started having their own guards.

When I mapped the highest part of the Nazareth Mountains, there was a little Arab village. I knew the mayor of that town. I don't know how we communicated, but we communicated very well. One day he said to me, "I want to go down to the Emek, the Esdralon Valley to the central town of Afula there and get something at the post office." So we came down on two donkeys, riding side by side. He had never been there. It was the first time he had ever needed the post office. The mountains were very austere—like the desert—and his eyes got bigger and bigger when he saw all the green, lush fields in the valley. He said, "Who owns that?" "Kibbutzim." "Who are they?" I said, "Well, those Jewish people." He said, "Think what we lost." I said, "Now wait a minute. You see over there—that's an Arab cemetery. There were very few Arabs living here and they died from malaria. And then the first generation of the Jewish settlers who drained the swamps died from malaria." That didn't impress him at all. He said, "But look what's here!" In his mind, what was there had nothing to do with what it was before. His attitude was, "We don't have it; we live in the mountains." He could only see what was there now, and that's what counted.

Also, when I lived among the Bedouins, the British high commissioner made a speech after the disturbances had broken out. A runner came and reported on it, and it sounded to me like a great speech. He tried to say, "Look, we are thrown together here—Jews, Arabs, British. Let's make the best that we can make of it, instead of fighting and killing each other and making it difficult. Maybe we can help everybody in some way." And those sheiks were just rolling on the floor, holding their sides, laughing. I said, "What's so funny about it? That's a very sensible thing."

They looked at me like I was loco, and one of them said, "I'll tell you a little story"—that's how they would always answer. "The Turks occupied this country. One day a Turkish soldier was killed during my father's reign. What did the Turks do? Nothing. In half a year a Turkish regiment came. The chief officer was quartered with my father, and so on down the

Bedouins herd their sheep by Lake Tiberias (the Sea of Galilee).
Far right: Aqaba, Jordan's only port on the Red Sea.

line, down the social ladder of the Bedouins. They had a wonderful time slaughtering sheep, having big parties. And suddenly we realized, 'If this goes on, they will destroy our livelihood. We will starve to death.' So my father and his buddies got quietly together and decided to turn over the man who had killed the Turkish soldier. You know, the Turks had an awful time finding a tree, but they found one. They strung that guy up and marched off." He said, "You see, Britain is weak. Britain is talking." And that's the whole story today, ever since. Only power and might are important. That's the sad part of it.

HA: Do you recall how the Jewish settlers felt about the British mandate?

HL: It was of no concern. Life was so hard, to just survive. They had very little to eat. The top-level Zionists in the Ginnegar kibbutz were just complaining and talking. It was the others who came from Eastern European countries, Germany, and Austria, who were really doing the tough work. At that time the Zionists were really looked down on—Zionism was all right for the salon but not for the daily life of existence. It was really interesting, because many of the younger people were not Zionists at all. They came there; they took it for what it was and tried to survive.

HA: Do you recall any discussion about the situation in Europe?

HL: No. The concern was more that there might be war in the Mideast, because, you see, Haile Selassie, the Ethiopian emperor, was in Jerusalem. As a matter of fact, when I was confined to Jerusalem, I lived a block away from Haile Selassie and his court, and I went with him and his prime minister and several other ministers every day on the bus to town. He never saw anybody. He looked through people. The situation was very volatile. It looked like a British-Italian war, initially, in that part of the world. It looked like it could be any time, so we were more concerned about the local situation.

HA: What did Jerusalem look like in those days?

HL: There was the old city, and then there was the new adjacent part of Jewish Jerusalem. Living was very simple. I tried several times last year when I was there—I go every other year to the Weizmann Institute in Jerusalem—to locate where I lived in Talpiot. I was finally told by somebody who knew the area that all of that had been razed, and there are modern apartment buildings and more expensive villas substituted for the simple buildings. We had a very small, simple house, where I stayed with my friends.

HA: Did you meet any of the other faculty or intellectual leaders of the area?

HL: I met some in connection with a petition that the president of Hebrew University wrote, calling for Jews and Arabs to live together in peace. There were problems at that time, not only with the Arabs, but with the people in Tal-

Suddenly he got all excited and he had a vision. He said, "This is the end. This land will be taken over by the Jews." That was in '36. They thought he was out of his head.

piot who were "Jabotinsky boys"—members of the Irgun. I was one of several hundred people who signed that petition.

HA: Did you have any associations with people in archaeology or anthropology?

HL: Yes. The French consul was an anthropologist from the Sorbonne. Whenever I came to Jerusalem from the country, he would always have me over and discuss things because I knew Sukenik—the Jewish archaeologist who got all my collections. He asked me to keep an eye out for any likely places where there might have been human habitation. So, when I mapped the cave area at Jabal Kafsi, near Nazareth, I often had lunch in the cave entrance because there were no trees. That was the only place in the heat to get some shade, and to rest for a short time. I would pick up stone implements in some areas, scrapers in others. When I told the consul, he wanted to see them and then to keep them. That was the last I heard of him until after the war, when I got a monograph from the Sorbonne describing how he had excavated the Kafsi cave and found a Neanderthal woman skeleton with a stillborn baby skeleton next to it.

Also, when I lived with the Bedouins, there was a cliff facing the east. That region was all lava fields from the outpouring of the rift valley. The cliff was 50 percent limestone and 50 percent flint, and the whole slope was literally strewn with human artifacts. So in the evenings, when I rode back to camp, I would usually stop before it got dark for 15 or 20 minutes and pick up some of the implements. One time I brought one back to Sukenik that wasn't complete. He took one look at it and said, "You see, these kinds of markings are Paleolithic; these were done by a Mesolithic apprentice; and these were done by a Neolithic apprentice. They would use the broken pieces to practice the technique of making implements." I had a fantastic collection of them.

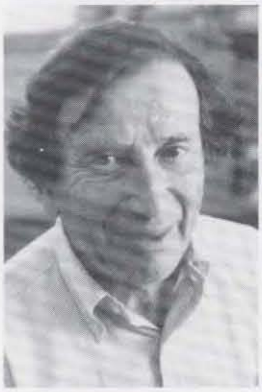
HA: Did you ever meet Ben Gurion, or Weizmann, or any of those people?

HL: I met Ben Gurion in a group at Bet Alpha, at Lake Tiberias, one of those famous kibbutzim where they talked about their children being like cows. He came in and he shook hands with everybody. Then they had something to discuss. But there were so many of the famous old-timers there. I forget the names. They were really interesting people. We talked about philosophy and other things, but not about the political situation.

I remember one other thing that was really intriguing. When I worked at the highest, very scenic, tiny Arab village at the top of the mountains, at lunch we would sit down. The men and my guide would sit down with me. The peasants who were plowing would sit down. But the women had to go on plowing; they didn't count. One day an old blind man came down, guided by some kid. He heard me talk. In the mountains I wasn't supposed to talk—a foreigner. And they didn't know I was Jewish. Suddenly he got all excited and he had a vision. He said, "This is the end. This land will be taken over by the Jews." That was in '36. They thought he was out of his head.

[*Lowenstam returned to Munich, where his dissertation was accepted and a date set for his doctoral examination. A week before the exam, a law was passed prohibiting Jews from earning doctoral degrees. In 1937 Lowenstam left for the University of Chicago, where he earned his PhD in 1939—and made a surprising discovery.*]

HL: While I was at Chicago, every so often oil companies would send people over to inquire about students who were interested in jobs. I was never interested. But the department chairman took my thesis to the company geologist of Socony Vacuum, and later told me what happened. The geologist took one look at the title and said, "Oh, that's old stuff. I don't want to see it." "Is anything wrong, sir?" The geologist said, "Oh, no. But we already have not only his notes from Palestine; we have the notes he made in Jordan and in Saudi Arabia. He never knew that he was a leg man for us; we financed his



Lowenstam with a tankful of chitons in his Caltech lab in 1963 (right) and in 1983 (left).

work." So my landlord in Munich—the one who published books of the Middle Ages—somehow had connections with the oil companies. Socony Vacuum was a subsidiary of Iraq Petroleum Company. And that's how he financed my trip to Palestine. Up to that time I had never realized why I kept running into geophysicists and geophysical crews the whole time I was in the Middle East. They obviously knew where I was, too, which amazed me, and they were always so nice.

Oil companies continued to follow Lowenstam around (and to fund his research), especially after he discovered that Silurian coral reefs were associated with deposits of oil. He worked for the Illinois State Museum and the Illinois State Geological Survey before returning in 1948 to the University of Chicago to work with Nobelist Harold Urey and Sam Epstein, now the Leonhard Professor of Geology, Emeritus, using isotope chemistry to determine the temperatures of ancient oceans. Geochemist Harrison Brown recruited Lowenstam and Epstein to Caltech in 1952, part of a raid that resulted in a group in geology known as the Chicago Mafia.

At Chicago Lowenstam was called a biogeochemist, but he came to Caltech as a professor of paleoecology, which he described as: "When you want to do anything you want without having to justify it, you call it paleoecology." Lowenstam did what he wanted, which was not always in the mainstream. Sometimes he also referred to himself as a "professional beachcomber," and liked to claim that his most interesting discoveries were the result of serendipity rather than the "scientific method."

His long-time interest in carbonate marine fossils found him in 1961 on a calcium carbonate (limestone) reef in Bermuda, where he was studying algae, whose skeletons he suspected as the source of some crystalline needle sediments. As he rested by a tidepool, he noticed a slug-like beast called a chiton carving chevron-shaped markings on the smooth pool bottom with its teeth. "And I saw that they were clearly indented into the limestone, which meant that the teeth of these beasts had to be harder than limestone." X-ray diffraction proved it to be magnetite. His colleagues joked that the chitons must be eating magnetite, but Lowenstam dissected the animal's tongue plate and observed where the teeth were mounted. "You could see the whole development—how it was being mineralized. I was quite sure on the basis of that that it came from inside the animal and couldn't be extraneous material." Although Lowenstam published his findings—that chitons had "iron teeth"—in 1962, the discovery that animals can actually manufacture such minerals wasn't accepted until 1975, when evidence of magnetic bacteria confirmed it. Since then creatures from tuna to pigeons to bees have been studied for their magnetite-making capability and use of the earth's magnetic field.

Although he has traveled widely, mostly to islands and reefs, the "father of biomineralization" did not return to Germany until 1981, when he was awarded an honorary degree from the University of Munich. And last spring he finally revisited his hometown in Upper Silesia. □

Lab Notes

The image-processing algorithms developed for the Voyager missions to the outer solar system are now being used to explore inner-space territories such as blood samples and cell cultures.

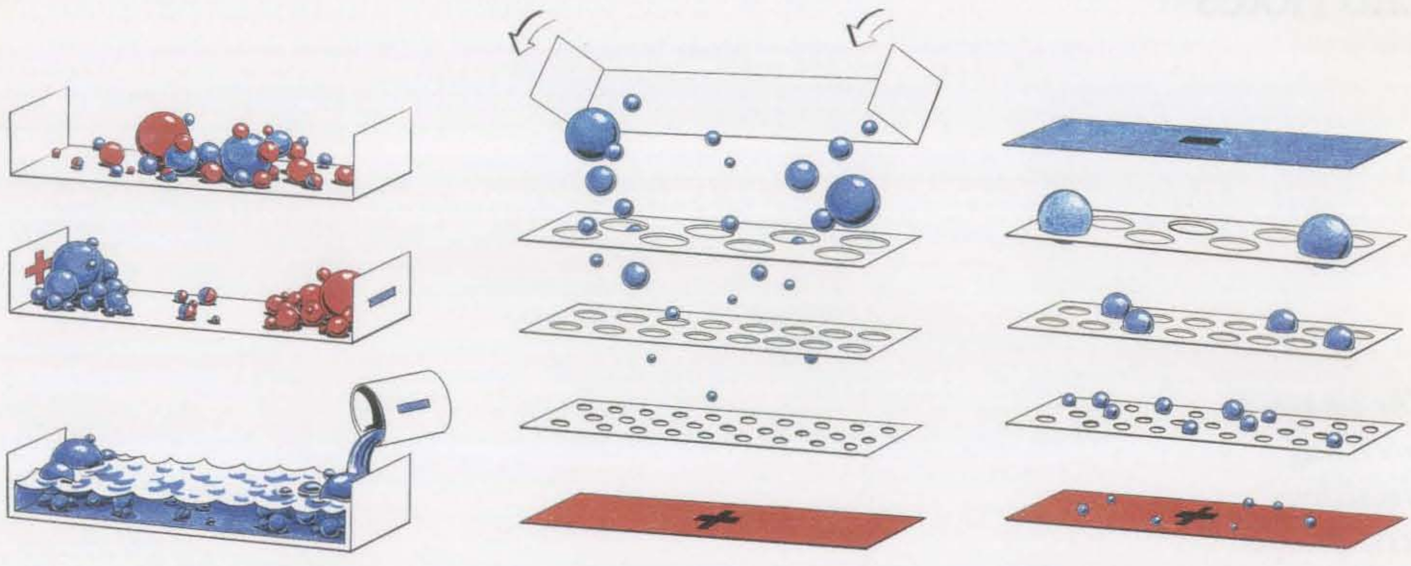
From the Great Red Spot to Protein Blots

Searching for volcanism on Triton and watching a cell develop are more closely related than you might think. The image-processing algorithms developed for the Voyager missions to the outer solar system are now being used to explore inner-space territories such as blood samples and cell cultures. But Jerry Solomon, a senior member of the technical staff at JPL, and biologist Michael Harrington, a member of the Beckman Institute at Caltech, aren't touching up mug shots of microbes—they're using the algorithms to read spots off a two-dimensional electrophoresis gel.

Two-dimensional gel electrophoresis is a powerful but underused technique for separating a complex mixture of very similar proteins such as plasma or cellular innards. The sample is applied to one end of a gel-filled capillary tube, and an electric field draws the proteins through it in proportion to their charges. Then the gel is extruded along the edge of a slab of a different gel, like toothpaste onto the bristles of a toothbrush, and treated with a mild detergent solution to give all the proteins a uniform charge. Another electric field, perpendicular to the previous one, draws the proteins onto the slab at migration rates inversely proportional to their sizes. The proteins are rendered visible either directly, by various stains, or indirectly, by radioactive labels. A one-microliter droplet of plasma will speckle a standard 20-centimeter-square gel with several thousand spots, each a different protein that can, if the sample is large enough, be analyzed and identified.

The technique has tremendous promise for basic biology and for medical diagnostics. A researcher studying cellular development could track the proteins involved at each stage by following the shifting patterns of spots on a series of gels. A disease caused by a missing or aberrant protein would reveal itself as a mismatched spot when gels from diseased and normal cell cultures are compared. Other deviations from the norm would be equally revealing—detecting brain-specific proteins in a cerebrospinal-fluid sample could indicate a brain injury, or some degenerative process like Alzheimer's disease.

The catch is that it's very hard to keep your eye on one spot in the crowd from gel to gel, even if nothing else is changing. Unfortunately, lots of things



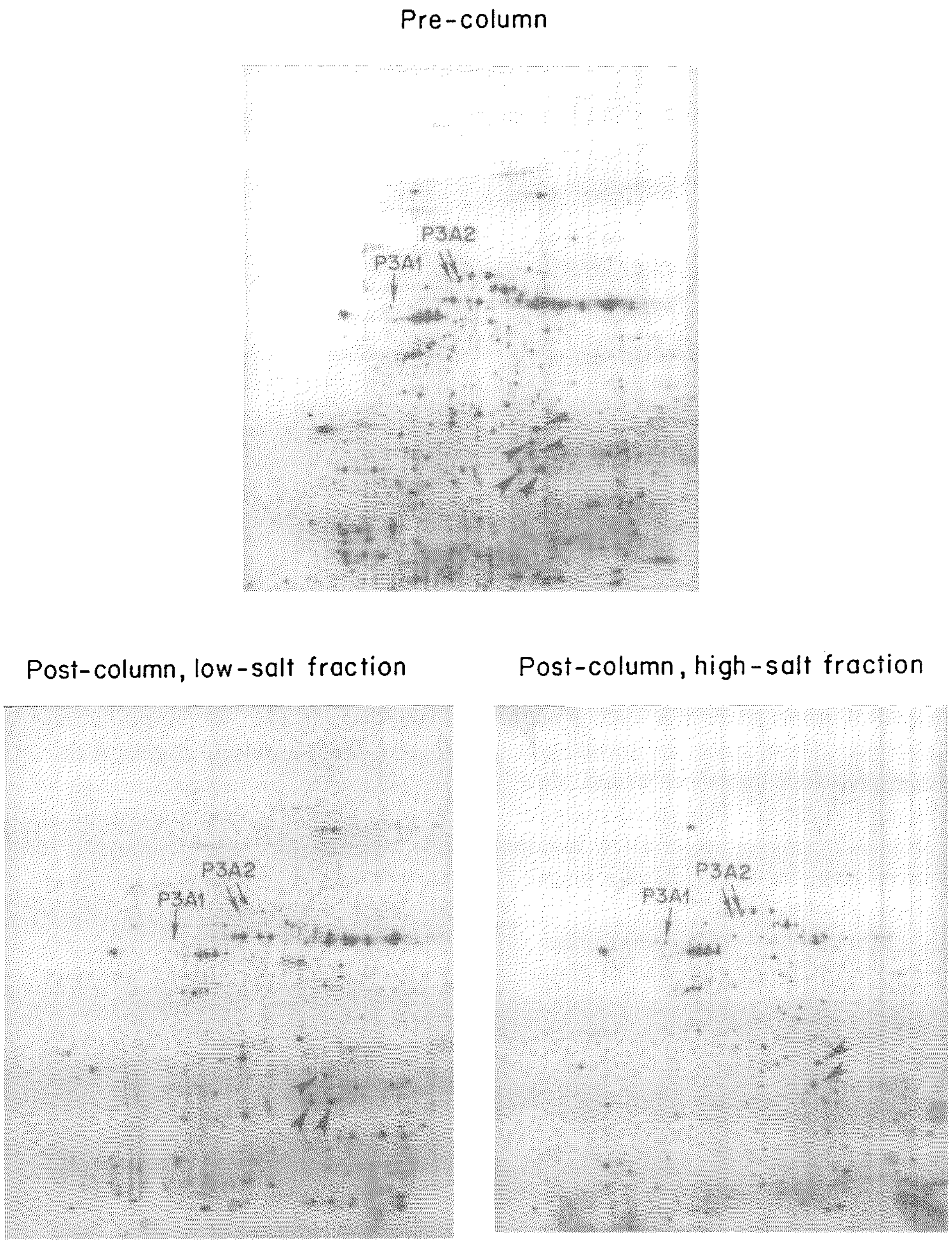
Two-dimensional gel electrophoresis in cartoon form. The spheres are protein molecules of various sizes; each sphere's color symbolizes the protein's charge—red is positive, blue is negative. Neutral proteins are shown as half red and half blue. The top left-hand drawing shows the initial sample. Applying an electric field (middle) separates the proteins by their charge. Adding a detergent solution (bottom) gives the separated proteins a uniform charge. The proteins can now be sorted by size (center drawing) by applying a second electric field in a direction perpendicular to the first field. The right-hand drawing shows the result—the proteins are sorted by charge along one dimension and by size along the other, allowing very similar proteins to be separated from one another.

are. The extrusion step allows all sorts of positioning errors to creep in. (Harrington is working on hybrid gels that would eliminate this transfer, and is trying to automate the whole process.) Subtle variations in the gels or in the electrical fields can make spots wander from run to run, even when the gels are perfectly aligned. And to cap it all off, a spot can change its appearance by developing a tail, metamorphosing from an oval to a kidney shape or even to a seeming paw-print, or fading from a sharply defined blot to a fuzzy smudge that blurs into its surroundings.

Harrington's and Solomon's close collaboration was essential to understanding and coping with all these variations. Some were separation artifacts, curable with a little judicious tinkering—the tails, for example, turned out to be due to interactions between the protein and the gel matrix. Others proved to be biologically significant and had to be handled through image processing. The kidneys and paw-prints—"concavities"—were actually two or more oval spots overlapping. And spots grew fuzzy when the proteins that made them had been converted to glycoproteins (by reactions with sugar molecules) in the normal course of metabolism. "Jerry wrote some code to arbitrarily give the 'fuzzies' clean edges," says Harrington. "No other system has done that. And he can pull the concavities apart into their component ellipses, so that we can match a concavity on one gel to an ellipse on another. These are the kinds of issues that can't be addressed by a biologist and a programmer working in isolation. Jerry wouldn't know which features were important, like the fuzzies, and which were irrelevant, like the tails. And I wouldn't know how to impart my gel-reading experience to a computer. I don't know of anywhere else where one could tackle all the mutually dependent aspects of developing this technology."

The pair has been working on the problem since the autumn of 1988, when Lee Hood, Bowles Professor of Biology and Director of the Center for Molecular Biotechnology, brought them together. They have gotten the system to the point where a gel can be scanned, its spots registered, and their pattern compared to previously scanned ones. But the biggest problem from the medical point of view is still ahead—building the data base of "normal" samples. For proteins as for people, "normal" encompasses many variations. In order to be of any diagnostic value, therefore, a "consensus normal" pattern must be assembled for each tissue type.

Doing basic biology doesn't have to wait, however. Eric Davidson, Chandler Professor of Cell Biology, studies the



Two-dimensional electrophoresis gels of proteins extracted from sea-urchin embryo nuclei, before and after passing through the affinity-binding column. P3A1 and P3A2 are known DNA-binding proteins. The "post-column, low-salt fraction" contains the proteins that weren't trapped by the column, while the "post-column, high-salt fraction" contains the ones that were. The five bold arrowheads show how effective the separation is.

process of gene activation—"expression"—that controls embryonic development, using sea-urchin embryos. An embryo begins as a single cell, which divides repeatedly to form a ball of identical cells, which differentiates to become the various parts of the complete organism. But differentiation starts long before any outward transformation becomes visible, as different sets of genes begin to be expressed in cells in specific regions of the embryo. Davidson's group is particularly interested in the onset of this process, known as "molecular differentiation," which occurs when the embryo's cell population approaches 100. At this early stage, the sea-urchin embryo consists of five invisible territories, each of which will construct a different portion of the larva. Davidson's and Hood's laboratories are collaborating to analyze the regulatory molecules that control gene expression in each territory. Davidson had guessed that 50 to 100 DNA-binding proteins would be needed to control the process, and the new system provides a way to identify them amid the thousand or so proteins present in the cell nucleus at that stage. Using methods developed by James Coffman, a postdoc in Davidson's lab, and Frank Calzone, now an assistant professor of biology at UC Irvine, the team adsorbs an extract of these proteins onto an affinity-binding column that traps all proteins with a predisposition to bind to DNA. Rinsing all the unbound proteins off the column and desorbing what remains yields an extract that two-dimensional gel analysis shows to contain roughly 50 proteins, including the DNA-binding proteins conclusively identified to date. The group will now tackle the problem of identifying the rest of the proteins. "This is tremendously exciting work that we couldn't have done without this image-processing system," says Harrington. "And the same general strategy can be applied to any kind of cell—neural precursors or immune-system components, for instance. We can also do double comparisons, using activated and quiescent cells, to determine which DNA-binding proteins are involved in a particular activation step." □—*DS*

It takes six laser beams, pressing in from above and below, left and right, and fore and aft, to hold the atoms in place.

Light Beams Trap Heavy Atoms

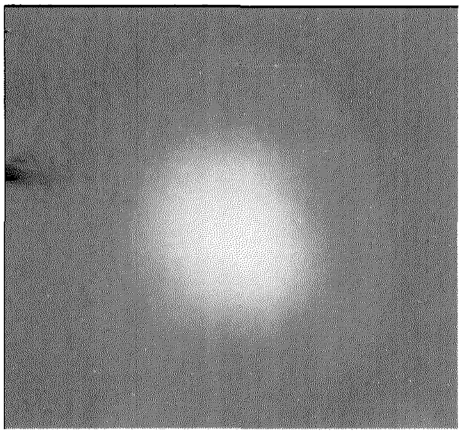
Just as Ping-Pong balls can hover in a jet of compressed air, atoms can float in a beam of light. And if keeping the balls in midair is tricky, the atomic equivalent is more so. It takes six laser beams, pressing in from above and below, left and right, and fore and aft, to hold the atoms in place.

Many laser-based atomic traps have been built over the last four or five years—elaborate, expensive contraptions that require a small army of graduate students and postdocs to run them, because of the ancillary apparatus needed to coax the atoms into the one-cubic-millimeter region where the lasers intersect. Atoms in a vapor at room temperature rip along at average velocities of hundreds of meters per second. Short of slamming the atoms into a brick wall (impractical), there's really no way to bring them to a dead halt within the span of a few millimeters. Instead, the atoms must be slowed—"cooled"—over a distance of a meter or so by head-on collisions with another laser beam to eventually yield "molasses"—a cloud of atoms stuck in a viscous sea of photons. These atoms are traveling at a leisurely half-meter per second, slow enough to catch. This speed is equivalent to a temperature of a few hundred microkelvin, or millionths of a degree above absolute zero.

But the "hot" room-temperature vapor really doesn't have to be elaborately cooled to yield a low-temperature cloud of atoms. The laws of statistics permit some atoms in the vapor to be much cooler than average to begin with. Trapping the few already-cold atoms cuts the tail off the distribution curve, as it were. Allowing the remaining atoms to rerandomize their motions regenerates the curve's tail, which can be cut off again ad infinitum, quickly filling the trap with cold atoms. A handful of traps have recently been built using this scheme, developed by Carl Weiman of the University of Colorado, and others.

And now Professor of Physics H. Jeff Kimble's group has got one, built this past summer by SURF (Summer Undergraduate Research Fellowship) student Robert Lee, a junior in applied physics, grad student Guangqing Chen, and postdoc José Tabosa. Kimble, who spent July lecturing at a summer session on quantum optics at Les Houches, France, offered what guidance he could via transatlantic telephone as Lee, Chen, and Tabosa built the vacuum system—"They did a superb job, basically unassisted," says Kimble. Cesium, their atomic quarry, burns spontaneously in air and is thus shipped in glass ampules filled with argon. The quartz-glass sample cell had to be mated to an intact ampule, which then had to be broken open from within the vacuum system without cracking the rest of the glassware—a problem eventually solved by using a small magnet, sealed into the system, as a drop hammer. The resulting vacuum system achieves a base pressure of less than 10^{-9} Torr, or one-trillionth of atmospheric pressure.

The trap uses a titanium-sapphire laser whose near-infrared beam passes through a maze of mirrors, beam splitters, and other optical components mounted on stalks so closely spaced that the entire setup resembles an unkempt asparagus patch growing on a four-by-ten-foot optical table. As the laser beam wends its way along, it is subdivided sixfold and its components refocused head-to-head to create the trap. The laser is tuned to a frequency slightly below one that cesium absorbs, so that an atom moving toward the beam will see the frequency shifted up, by the Doppler effect, to the absorbed one. Successively absorbed photons transfer their momentum to the atom, canceling out its forward motion, cooling it, and confining it within the trap. (Cesium,



A cloud of a million cesium atoms, formed into a one-millimeter-diameter sphere by the pressure of laser light.

The tiny ball of trapped atoms takes a visible hit, recoiling along the direction of the probe beam like a prizefighter who has just taken one on the chin.

despite its drawbacks as a chemical, has a comparatively simple absorption spectrum that makes it easy to trap.) Coils of wire above and below the trap carry current in opposite directions to create a strong "spherical quadrupole" magnetic field, whose influence on the cesium atoms' electrons is akin to the role of gravity in binding the planets in their orbits. That is, the magnetic field and the photons in concert create a "potential well" that holds the cold atoms.

The trap has been up and running since August 18. It holds about a million atoms in its current configuration. Any given atom stays in the trap for about a second before slithering out, but another atom immediately takes its place, making the trap stable for as long as the laser is on. At about 300 microkelvin, the atoms are so cold that the mechanical effect of absorbing or emitting photons is obvious. When atoms absorb photons, from a second (probe) laser for example, the tiny ball of trapped atoms takes a visible hit, recoiling along the direction of the probe beam like a prizefighter who has just taken one on the chin.

Kimble's group is pursuing nonlinear spectroscopic studies of the trapped atoms. Spectroscopy measures the interaction between atoms and photons. The interaction is generally linear—varying in proportion to the number of photons bombarding the atoms. But under certain circumstances—when the atoms are trapped in strong electromagnetic fields, for instance—the interaction is no longer linear, and the complex way that the interaction varies provides information about the status of the atoms and their coupling to the external field. "It's similar to the difference between observing a free-swinging pendulum and a system of two pendulums connected by a spring," says Kimble. Once the trap was running, Lee spent the second half of the summer firing a very weak (less than one microwatt) probe laser into the trapped atoms and observing their absorption spectrum. (If the beam is any stronger, it just drills a tunnel through the cloud of atoms.) He has already discovered one odd peak not visible in usual linear spectroscopy, and he, Chen, and Tabosa are trying to interpret it theoretically.

The trap has many potential uses beyond spectroscopy. Kimble and Associate Professor of Astrophysics Kenneth Libbrecht (a recent convert to optical physics) plan to build an atomic-beam source based on the trap. Once the atoms have been cooled, they can be collectively laser-accelerated to higher velocities and still remain "cold"—that is, they will have a small velocity dispersion even though they're moving in bulk at a large velocity. This beam of cold atoms will be used for experiments in "cavity quantum electrodynamics," which investigates the fundamental coupling of atoms in an optical resonator—from the atomic point of view, not unlike being trapped in a funhouse's hall of mirrors—to the electromagnetic field.

Stranger uses are also possible. Matter can behave as a wave under some conditions, just as light sometimes acts like a wave and sometimes like a particle. An atom's deBroglie wavelength is inversely proportional to its momentum. At normal temperatures, an atom's wavelength is infinitesimal compared to its diameter, but an atom cooled to a few microkelvin would have a wavelength of about one millionth of a meter—large enough to give the atom a wavelike character that can be diffracted by millimeter-scale obstacles. This leads to the possibility of atomic interferometry. A single atom, traveling as a wave, could be split into two waves by a slit. The waves could travel independently for quite a distance before being recombined to make an interference pattern. In effect, the atom "splits" and follows both spatially separated paths at once. Although this experiment won't help a harried mother who needs to be in two places at once, it will allow physicists access to an entirely new range of phenomena. □—*DS*

Books

Oxford University Press, 1990
432 pages, 27 illustrations

This contribution to the recent rush of biographies of eminent Victorians and Edwardians explores the life and art of the woman who was the most celebrated and prolific novelist of her time. She was photographed by Lewis Carroll, befriended by Henry James, reviewed by Gladstone, praised by Tolstoy, paid court to by President Theodore Roosevelt—and then forgotten. Now Mrs. Humphry Ward is at last recalled and brilliantly interpreted by John Sutherland, professor of literature at Caltech. His biography takes us step by step from her agonizing childhood—born Mary Augusta Arnold in 1851 in Tasmania—through her phenomenal career as a best-selling author and pioneering social reformer to her death in 1920, by which time reviewers were dismissing her last novels as "beneath notice." This detailed portrait depicts the political and personal context from which Mrs. Ward's novels emerged and describes those people who influenced her intellectually and assisted (or hindered) her at different periods of her life.

Mary was a child to whom the great poet and critic Matthew Arnold was "Uncle Matt," the renowned Thomas Arnold of Rugby was "Grand-dada," and Tom Arnold was "Papa." "That she was an Arnold was the most important single fact in Mary's life," Sutherland states. Yet, for the first 16 years of her life, she had little contact with her immediate family and seems to have spent far too much of her unruly childhood in solitary confinement. Her father writes of punishing her as a toddler by locking her up. When her family returned to England and then moved to Dublin, the unwanted Mary was given over to the care of her grandmother and aunt, who handled her great rages by having a strong footman carry her to a room where she "screamed herself out" behind bolted doors. At school she was locked into a cloakroom for punishment. A lonely child, she was made even lonelier by isolation. It is not surprising that Mary's first surviving story (written when she was 13) is an escapist romance wherein her heroine is imprisoned in the recesses of a dungeon.

According to Sutherland's account of Mary's early years, the wild, willful, clever child emerges as a Maggie Tulliver who breaks her expensive wax doll into bits and melts the pieces in little saucepans. In describing Mary's experiences at Rock Terrace Boarding School, Sutherland so graphically conveys the cold and punitive atmosphere that we feel Jane Eyre's years at Lowood were pleasant by comparison. Biographical narrative and novelistic realism merge in such passages to give us the sense that Mary's life imitated art, as though she had lived a Victorian novel before she ever wrote one.

Out of her oxymoronic beginnings —an orphan whose father and mother were very much alive—comes a whole series of further contradictions defining Mary Ward. She was both passive and dominant, poorly educated and learned, old-fashioned and modern, selfish and generous. She was a living paradox—"a woman called Humphry." She helped found Oxford's first institution for the higher education of women, but did not send either of her daughters to college. Afflicted all her life with debilitating illnesses (including writer's cramp), she nevertheless remained dynamically hard-working. Although she claimed that her right hand was too weak to produce critical or historical studies, it was strong enough to write more than two dozen lengthy novels. She was made enormously rich by her huge earnings, yet she was eventually drained dry financially by a reckless husband and a feckless son. Their compulsive gambling forced Mrs. Ward to become "a money-generating fiction machine."

One might think it would be difficult to write a highly readable biography about someone who wrote a good many not-very-readable (at least by current standards) novels. But Sutherland overcomes this difficulty with his superb prose style. Parts of this book are deeply moving, such as the description of the sudden death of Mary's sister Lucy. Other sections are dryly funny because Sutherland is a devastating master of meiosis, combined with a sardonic deadpan tone:

> The Edwardian [railroad] passenger was assisted at every station by an army of porters who—unlike their misnamed descendants—were actually prepared to carry luggage.

> It was . . . the Wards' first visit to the South of France and not what everyone would have considered a restful itinerary: Paris, Cannes, Monte Carlo, San Remo, Genoa, Spezia, Florence, Pisa—then back by sleeper, all in a fortnight.

Sutherland is as good at hyperbole as at understatement. He indicates Mary's vainglorious hopes for her only son: "This future Prime Minister of England went up to his college in October 1895." He characterizes a letter from Mary to her husband as one that "would have raised the spirits of Job." His prose is enlivened by similes: Mary wrote and rewrote her novels "until the manuscripts looked like battlefields." When one of her typescripts seems a trifle *large* ("around three-quarters of a million words"), Sutherland describes Mary as hoping that the publisher, "like a clever corsetière," can hide "what increasingly she saw as an ominous corpulence in her brain-child."

I should warn other American readers that I spent more than a few confusing moments puzzling over various Britishisms. Eventually it dawned on me that "mod cons" are "modern conveniences," but I'm still not exactly sure what it means to "cock a snook" at Oxford or just what Mary Ward's son *did* when he "made the College wall side in 1894." You also may find yourself a bit baffled by some military slang—do you know what "scrimshanking" is, for instance? But these bouts of bewilderment are not so much hindrances as chances for wonder (or research in the Oxford English Dictionary).

One of the facets of Mary Ward's character most difficult to understand is her opposition to female emancipation. She was actively antagonistic and in 1889 published an "Appeal" against women's suffrage that helped hold back for years the extension of the franchise to women. By 1908 she was head of the Women's National Anti-Suffrage League and argued her case vigorously throughout England and Scotland. "No one, least of all herself," Sutherland writes, "has convincingly explained why Mary Ward was so hostile to the cause of women's rights." But Sutherland goes on to suggest Mrs. Ward's "horror of 'militancy,'" her belief that it was "somehow unseemly" for women to want the vote, and, most important, her inability "to resist wanting to please and serve father figures." Much of her life was shaped by her need for approval from powerful and patriarchal males. Support for the suffragette movement would all too clearly have been for Mary a revolt against those masculine presences, both social and psychic, she longed to serve. Further speculation about her unwavering antisuffragism might turn profitably to her reactions to her father's religious crises. Thomas Arnold converted twice to Roman Catholicism. The first change of heart, in 1856, almost destroyed his marriage and forced his resignation as Education Secretary at Hobart. He returned to Anglicanism in 1865, but eleven years later reconverted to Catholicism, thereby ruining his chances for a chair at Oxford. Such destructive irresolution may have caused an unconscious counter-response in Mary, an unwillingness to change her mind once she took a position. Thus she locked herself into an intellectual prison, in spite of her earlier horror at confinement.

Some of Sutherland's more intriguing, but also discomfiting, chapters describe the altering attitudes toward Mrs. Ward as the 19th century drew to an end. By this point in the biography, the reader (at least this reader) is so sympathetic to Mary and so impressed with her literary output and her social and philanthropic work that it is painful to read about some of the bitter attacks on her. As she moved from being, in the late 1880s, "a famous novelist and thinker" to, in the late nineties, "an institution, an embodiment of middle-class, late-Victorian values," she became a target of scorn for the younger generation. Lytton Strachey hated her, calling her "old and sordid and insignificant." Max Beerbohm found her dull. Virginia Woolf claimed that "reading Mrs Ward was like catching flu." Even her own beloved nephew Aldous Huxley—his first name taken from the hero of one of Mary Ward's novels—cruelly satirized her in his first published work of fiction. Sutherland's book, however, overcomes these opinions, giving Mrs. Ward a kind of majesty earned through productive labor in the face of suffering. Perhaps we can now begin to agree with Sir Arthur Conan Doyle: "If we wish to give an idea of the later Victorian era with its transition period, its mental unrest, its groping after new truths, its sharp contrasts between old conditions and new problems, where could the student of 2000 find it more clearly set forth, with great dignity of language and thought, than in Mrs Ward." Sutherland gives us a 10-year head start.

At one time in the United States a free copy of Mrs. Ward's far-famed novel *Robert Elsmere* was given with every purchase of a bar of a certain new soap. Nowadays it is not quite so easy or so cheap to get our hands on her books. Still, an excellent series called Virago Modern Classics, issued by Penguin and "dedicated to the celebration of women writers and to the rediscovery and reprinting of their works," published Mrs. Ward's *Marcella* in 1984; and we can hope that the interest generated by Sutherland's new biography will encourage other presses to reissue more of her good, and once vastly popular, novels. In the meantime, and with the illumination provided by Sutherland, I am going to begin a rereading of *Marcella*:

> "The mists—and the sun—and the first streaks of yellow in the beeches—beautiful!—*beautiful!*"
>
> And with a long breath of delight Marcella Boyce threw herself on her knees by the window she had just opened . . .

Jenijoy La Belle
Professor of Literature

Books continued

Origami Zoo
An Amazing Collection of Folded Paper Animals

by Robert J. Lang and Stephen Weiss

St. Martin's Press, 1990
155 pages

Robert Lang (BS '82, PhD '86) and his coauthor, both considered among the world's finest paper folders, present a menagerie of 37 original designs for paper beasts—from woolly mammoths to horseflies and black widow spiders, from pandas and skunks to eagles and praying mantises—with detailed diagrams and step-by-step instructions on how to make them yourself. It helps to have a lot of patience and excellent small-muscle control, but anyone who mastered the origami beaver that Lang designed for *E&S* readers in the Winter 1989 issue should have no trouble—well, perhaps a little trouble with the praying mantis. Lang works in the Photonics Group at JPL and is a lecturer in applied physics at Caltech.

The Curious Cook
More Kitchen Science and Lore

by Harold McGee

North Point Press, 1990
339 pages

McGee (BS '73) earned his PhD in English literature from Yale and went on to write *On Food and Cooking: The Science and Lore of the Kitchen* (1984), of which the *New York Times Book Review* said: "Good books of food scholarship are rare; this one is to be treasured." Now comes the sequel, proving wrong anyone who thought the first encyclopedic volume covered everything there was to cover. Here McGee goes beyond the scholarship of the first book and describes his own experiments—"the fun I've had playing with foods." Learn, for example, how spattered oil from a frying pan ends up on the *inside* of the cook's glasses (not exactly Millikan's oil-drop experiment); why mushrooms don't get soggy if you soak them; why oil wilts lettuce leaves but why cutting them with a knife does *not* turn them brown; why searing meat does not seal in juices; and why cooking in an aluminum pan won't give you Alzheimer's disease. You don't have to be a cook to find this fun to read; any scientist who eats will find it fascinating.

Raising Money
Venture Funding & How to Get It

by Ronald E. Merrill and Gaylord E. Nichols

AMACOM, American Management Association, 1990
283 pages

The authors offer a wealth of tips for getting over the first major hurdle of starting your own business—finding capital. They tell how other new entrepreneurs have done it, what investors look for, how to avoid the legal pitfalls, and how to write a successful business plan; most important, they describe how to establish an enduring relationship with investors. Most of the case studies in the book originated in the Caltech/MIT Enterprise Forum, a unique organization that advises new companies and critiques business plans. As director of Caltech's Industrial Relations Center, "Nick" Nichols played a leading role in founding the Enterprise Forum, and Merrill has been a key participant for many years. The book's foreword is contributed by Caltech Trustee (and venture capitalist) Benjamin Rosen (BS '54), who starts off: "When I was at Caltech some thirty-odd years ago, and we were assigned, say, a physics problem, there more often than not was a unique answer to that problem. Well, the answer to a business problem may not be unique. In fact, in many cases, there is no answer." But even if there are no unique answers, there are strategies, and this book tells how to develop and follow them.

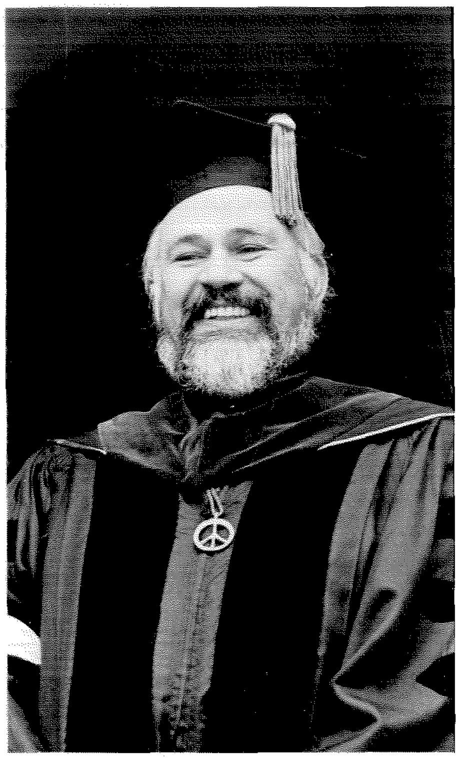
The Right Place at the Right Time

by John D. Roberts

ACS Books
American Chemical Society, 1990
299 pages

In this book, part of the series *Profiles, Pathways, and Dreams: Autobiographies of Eminent Chemists*, Jack Roberts, faculty member since 1952, former division chairman, former provost, and currently Institute Professor of Chemistry, Emeritus, chronicles his career, which he sums up as having been "unbelievably fortunate" for reasons of always being where the title suggests. The book contains a lot of chemistry for those interested in the development of nuclear magnetic resonance, but nonchemists need not by deterred by the drawings of chemical structures that decorate most of the pages. In between is the personal story, told with the characteristic Roberts warmth, of his "lucky" life. Many photographs.

David R. Smith
1923-1990



Professor of Literature David R. Smith, a Caltech faculty member for more than three decades and a scholar of Joseph Conrad's works, died of cancer August 31, 1990. Born May 21, 1923, in Langdon, North Dakota, Smith earned his BA (1944) from Pomona College and MA (1950) and PhD (1960) from Claremont Graduate School.

A man of great physical vitality and appetite for life, Smith was an enthusiastic surfer and sailor. He served as a popular and irreverent master of student houses from 1969 to 1975, and founded Caltech's Baxter Art Gallery in 1970, nationally known for its "daring" exhibits of contemporary art. He directed the gallery for the first five years, and from 1980 until the gallery's demise in 1985 was chairman of its board of governors. In addition to scholarly works in his own field, notably his book *Preface to a Career: Conrad's Manifesto* (he was also editor of the journal *Joseph Conrad Today*), Smith contributed a number of essays to Baxter Art Gallery catalogs, and collaborated with his wife, Professor of French Annette Smith, on a published translation of *Mademoiselle Irnois and Other Stories* by Arthur de Gobineau.

Among the friends and colleagues who spoke at a memorial service in Dabney Lounge October 11, was Martin Webster (BS '37), cofounder of the Caltech literary group, an informal group of alumni and their spouses that has been meeting to read and discuss books for 37 years. David and Annette Smith acted as the group's mentors for 23 of those years. Diane Wakoski, University Distinguished Professor of English at Michigan State University (and lecturer in English and poet in residence at Caltech in 1972), read her poem "For David." Smith was the author of a book on Wakoski's poetry, not yet published when he died.

Jack Miles, book editor of the *Los Angeles Times*, read from several documents Smith was reading, or writing, during his last months of life. Among them was the Cabeza de Vaca's 16th-century memoir of an "inward journey that took place during a harrowing outward journey," which found resonance in Smith's own situation, and which he and his wife were reading together. Annette Smith wrote about their last months: "Because David inscribed his death in a larger picture, with total compliance with the transience of the mortal world, it was a truly transcendent adventure, a terrific opening. We thought of it as an adventure—our last joint venture."

Miles also read from a letter Smith had written to a fellow ex-Marine, who was organizing a reunion of the men in his unit. Smith had served as a lieutenant, later captain, in the Marine Corps from 1942 to 1946, and saw action on Iwo Jima. His letter (with reference to Lt. George Todd, who, like Smith, was from Glendale) described the desperate nighttime attempt of 46 marines (of whom only 7 survived) to take a hill from the Japanese, part of an engagement known as Cushman's Pocket. They gained the hill but couldn't hold it.

"Because of the extreme pitch of the land, protection from the rear and the flanks was the hardest. And we paid the price, particularly as they were mostly behind us, and one son of a bitch among them was a first-rate

sharpshooter. Within minutes of the first light he killed my favorite among the men, a kid of 18; my sergeant; George—bullet between the eyes. It was instantaneous. And he got me in the solar plexus. The ironies abound, for if my rifleman was a kid of 18, George and I were kids of 22, though acting like men, and the sergeant a kid of 25. The bullet that hit me turned out not to have gone through, though I didn't know it at the time, as there was an exit wound on the rear quarter of my left side. It hit a button on my jacket, which broke it up and caused the core to go around my chest cage outside the ribs but inside the skin. Then came the mortars, which chewed up what was left of us. . . . We finally made it out, after several disastrous attempts, at night as we had come. . . . We had all been wounded for nearly 24 hours, had lost a great deal of blood. We were tired and getting slow. I was able to crawl on my back (couldn't crawl on my gut) along those deep tracks the tanks left in the volcanic sand. . . . I should like to add that being an officer in the Marine Corps, serving under Col. Robert L. Cushman, and, for that matter, serving in Cushman's Pocket have all been elements in a central core of pride that has governed my life these past 45 years."

Miles remarked on Smith's "considerable self-confidence, to which his identity as a marine officer contributed much," and added, "David Smith knew how to have a good time, as if we didn't know, and to show you a good time. And what's so special about that? How do we get from Iwo Jima to that? Just by way of the observation that a worried man doesn't either have or give much pleasure. David may often enough have been irritated but he was never finally afraid. I take it that this was the gift of the bullet that entered his solar plexus, traveled the circumference of his rib cage, outside the bones but under the skin, and exited at the rear . . . —a survivor's unshakable sense of being among the lucky ones."

Mac Pigman, associate professor of literature, spoke of his friendship with Smith, which had begun even before Pigman arrived at Caltech as a young faculty member. He also noted his courage, although not on the battlefield. "The memory that stays with me the most is one of my last ones—of David when he was in the hospital. It was his first stay in the hospital, and so I was nervous visiting him because he was very ill. I knew that he was dying and he knew that he was dying, and I was anxious about what might or might not happen when we talked. I was impressed with the serenity and the courage with which he faced his death. He had the courage to feel the pain of losing his life at a time that he was flourishing as a scholar to a degree that he had perhaps not been until very recent years. He was losing his life at a time at which he was very much involved in so many activities, and yet he had the courage to talk about his feelings of loss." Pigman has taken over production of Smith's last work—a collection of essays Smith had edited, *Joseph Conrad's "Under Western Eyes": Beginnings, Revisions, Final Forms*, from a Conrad conference that Smith had held at Caltech last year.

David Smith's leadership and scholarship were also evoked by Eleanor Searle, the Edie and Lew Wasserman Professor of History and executive officer for the humanities. In referring to Smith's own contribution to the forthcoming collection of essays, "that brilliant article about the 'K' in Conrad," she remarked that, "it was almost as if David talked to Conrad; it was almost as if he knew him. He went to the manuscript and found Conrad marking passages with the initial of his Polish surname. David could point out that it was there for a reason, that it was Conrad talking to Conrad. And David in doing this article was himself talking to Conrad. He had that wonderful scholarly ability of getting to the marrow of his subject. And as a colleague he got to the marrow of us all."

Another colleague, Professor of Literature Jenijoy La Belle, read several selections of poetry and ended with the final sentences of Conrad's *The Secret Sharer*:

> Already the ship was drawing ahead. Nothing! no one in the world should stand now between us, throwing a shadow in the way of silent knowledge and mute affection.
>
> Walking to the taffrail, I was in time to make out, on the very edge of a darkness thrown by a towering black mass like the very gateway of Erebus—yes, I was in time to catch an evanescent glimpse of my white hat left behind to mark the spot where the secret sharer of my cabin and of my thoughts, as though he were my second self, had lowered himself into the water to take his punishment: a free man, a proud swimmer striking out for a new destiny.

Donations to the David R. Smith Memorial Fund may be sent to Charlene Chindlund, Caltech 105-40, Pasadena, California 91125. □

Random Walk

Already aluminized, several segments of the W. M. Keck Telescope's 10-meter mirror await installation at the Mauna Kea, Hawaii, site. With 9 of its 36 mirror segments installed (making it as large as Palomar's 200-inch Hale Telescope), the Keck instrument will see first light this month. The telescope is a joint project of Caltech and the University of California.

Honors and Awards

Allan Acosta has been named the second Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering.

Professor of Chemistry Jacqueline Barton has been given the 1990 Medal of Distinction by Barnard College, her alma mater.

Harry Gray, Beckman Professor of Chemistry and director of the Beckman Institute, has been named the 1991 winner of the American Chemical Society's Priestley Medal, the nation's highest honor in chemistry.

George Housner, Braun Professor of Engineering, Emeritus, has been elected to honorary membership in the American Society of Civil Engineers.

Associate Professor of Astronomy Shrinivas Kulkarni has been awarded a 1990 Packard Fellowship in Science and Engineering by the David and Lucile Packard Foundation, one of 20 young scientists nationwide to be so honored. The fellowship provides funding of $100,000 per year for five years for research expenses.

Nathan Lewis, associate professor of chemistry, will receive the 1991 American Chemical Society Award in Pure Chemistry next April at the ACS annual meeting.

Hans Liepmann, Von Kármán Professor of Aeronautics, Emeritus, has received this year's Lord Foundation Award for Systems and Functional Analysis.

Bruce Murray, professor of planetary science and director of Caltech's Jet Propulsion Laboratory from 1976 to 1982, has won two awards for his book, *Journey into Space: The First Thirty Years of Space Exploration*—the American Institute of Physics Science-Writing Award in Physics and Astronomy and the Eugene M. Emme Astronautical Literature Award, presented by the American Astronautical Society. The chapter describing Voyager's birth was excerpted in the Summer 1989 *E&S*.

Institute Professor of Chemistry, Emeritus, John Roberts has been awarded the National Medal of Science in recognition of contributions made in a long and outstanding scientific career. The award was presented in a White House ceremony November 12.

Barry Simon, IBM Professor of Mathematics and Theoretical Physics, has been elected a foreign corresponding member of the Austrian Academy of Sciences.

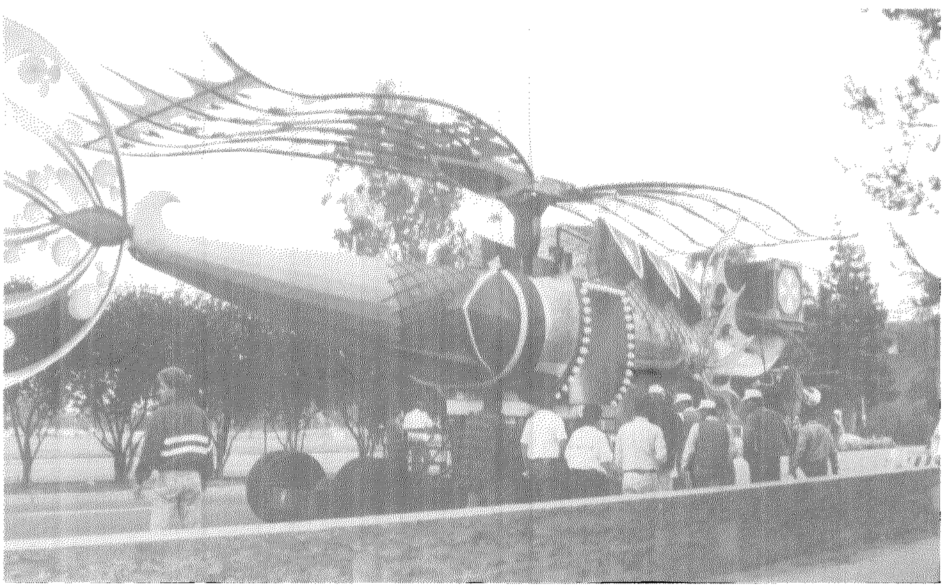
Roger Sperry, Nobel laureate and Board of Trustees Professor of Psychobiology, Emeritus, has been honored by his alma mater, Oberlin College, which dedicated a new neuroscience research center to him—the Sperry Wing of the Kettering Hall of Science.

In other Voyager news, Project Scientist Edward Stone, professor of physics and JPL director-designate, has received the Association for Unmanned Vehicle Systems Operations Award for 1990 and *Discover* magazine's 1990 Discover Award for Technological Innovation in Aviation/Aerospace.

Professor of Literature John Sutherland has been elected a Fellow of the Royal Society of Literature of the United Kingdom. The honor is conferred upon writers who have published books of a high literary standard. (Note book review on page 36.)

The Indian National Science Academy has elected Professor of Geology Peter Wyllie a Foreign Fellow.

The Associated Students of Caltech (ASCIT) 1990 awards for teaching excellence went to Joel Burdick, assistant professor of mechanical engineering; Peter Fay, professor of history; John Feiler, graduate student in physics; Valentina Lindholm, lecturer in Russian; Robert McEliece, professor of electrical engineering; Jane Raymond, member of the professional staff in chemistry; Robert Ripperdan, PhD '90 in geology; and Kerry Vahala, associate professor of applied physics.



Caltech will kick off its Centennial celebration with a float in the Tournament of Roses parade on New Year's Day 1991. Entitled "For Every Action . . . A Reaction," the Time Traveler float features a complicated chain reaction that ends by dropping an apple on Isaac Newton's head. It's the first time that a Rube Goldberg device of this magnitude has ever been attempted in a Rose Parade float. Accompanied by a contingent of beavers, the float will appear sixth (the third float) in the line of march. The float is shown here on its first trial run, sans beavers, animation, and flowers.

Research Directors Conference

The Office for Industrial Associates is sponsoring its annual Research Directors Conference January 29–30, 1991 under the theme "Caltech: The Next 100 Years." A number of faculty members will discuss their research, and the keynote address will be given by Paul MacCready (MS '48, PhD '52), president of AeroVironment, Inc., and creator of the muscle-powered *Gossamer Condor*, the solar-powered *Sunraycer*, and other imaginative alternative vehicles. The registration fee of $450 is waived for Industrial Associates companies, the Caltech-JPL community, Caltech alumni, and faculty and staff of other universities. For more information call (818) 356-6599.

Sayonara, Japan; Hello, Caltech

Introductory Japanese was offered at Caltech for the first time this fall, attracting more than 80 prospective students. Two classes were formed, but many students will have to wait until next quarter.

The classes are being taught by Kayoko Hirata, lecturer in Japanese and an expert in computer-assisted language instruction. A native of Japan, Hirata earned her master's at the University of Oregon and her PhD at the University of Arizona, and taught Japanese at both places. She will be using a word-processing program from Japan to produce lessons on her Macintosh.

"The curriculum will be very intensive," says Hirata. "The classes meet five hours a week. Japanese is so different from English that it takes this much effort to become proficient."

The classes are being funded by The Japan Foundation in a three-year pilot program that will also include intermediate and technical Japanese as student fluency rises. Caltech will continue funding the program if student interest remains strong. The Japan Foundation was established by Japan's Ministry of Foreign Affairs in 1972 to promote cultural exchange.

Watson Lectures

The Earnest C. Watson Lecture Series for this fall includes: *November 14:* A New Era of Superconductivity—Nai-Chang Yeh, assistant professor of physics; *November 28:* Destructive Earthquakes in California: October 17, 1989 and Beyond—George Housner, Braun Professor of Engineering, Emeritus; and *December 5:* Exploring the Structure of Proteins—Douglas Rees, professor of chemistry. All lectures are at 8:00 pm in the Beckman Auditorium. Admission is free.

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Rotation Program Interest: Yes ______ No ______

DEGREES NOW HELD OR EXPECTED:

Bachelor's: Field ______ Grad. Date ______ School ______ CUM. GPA ______

Master's: Field ______ Grad. Date ______ School ______ CUM. GPA ______

Other: Field ______ Grad. Date ______ School ______ CUM. GPA ______

Minimum GPA-3.0/4.0.

HUGHES