RLE currents

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The Research Laboratory of Electronics at the Massachusetts Institute of Technology

IMAGE PROCESSING AT RLE:
Focusing on the Future

Powerful radio and optical telescopes receive cosmic signals beamed from light years away; using image processing techniques, radio astronomers can determine their source. High-resolution, multidimensional pictures of the human body are produced by imaging equipment, and then examined by medical personnel to assist in diagnosis. In a hotly contested technological and political race, Japan and the United States propose new television broadcast systems which promise 35mm quality on home television screens. Beneath the layers of paint on da Vinci's *Mona Lisa*, art preservationists can detect previously hidden features with the aid of digital image processing. These diverse examples offer merely a glance at the issues and applications associated with the scanning, storing, retrieval, transmission, processing, and display of high-quality images.

The broad field of image processing involves the manipulation and analysis of visual data. Fundamental mathematical procedures (known as algorithms) are applied to the data, enabling it to be processed in real time by digital computer systems or analog video hardware designed for this purpose. New algorithms are constantly being developed for image coding and compression,

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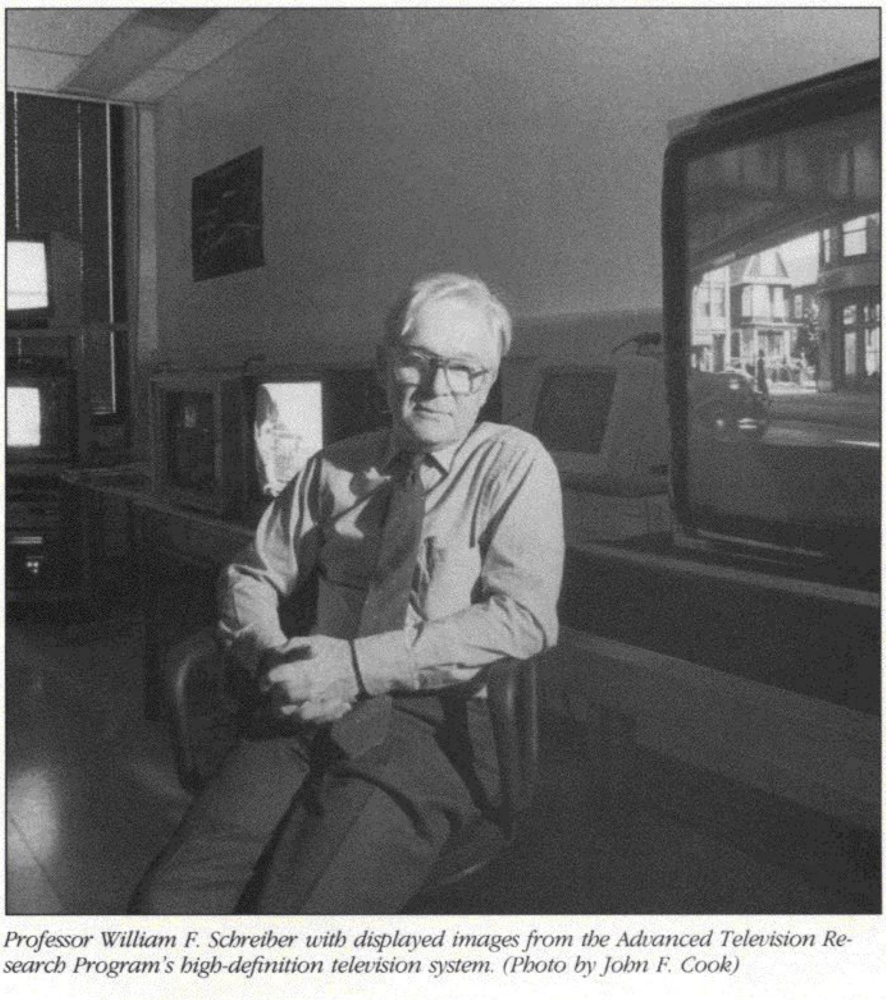
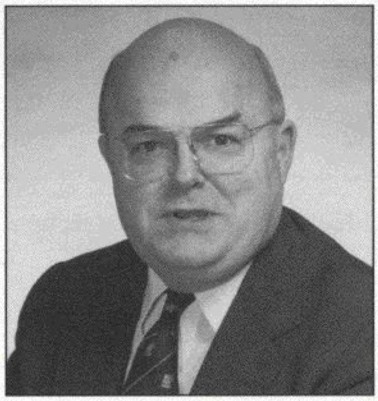


Professor William F. Schreiber with displayed images from the Advanced Television Research Program's high-definition television system. (Photo by John F. Cook)

Director's Message

Building on a long tradition of RLE research in information theory, coding, and human cognitive information processing, research in image processing and its exploitation in a wide variety of applications is a major part of RLE's interdisciplinary program. Basic techniques for source and channel modeling, algorithms for coding, compression, enhancement, and object identification, together with the constraining effects of human visual behavior and international system standards, all combine to provide new solutions to a large range of application needs. Many RLE researchers find image processing techniques central to their research, and much of the recent innovation in signal processing is directed at two-dimensional problems, rather than a single dimension where much of the research effort was previously focused. VLSI technology, both analog and digital, is making many sophisticated image processing tasks practical, in systems with broad commercial appeal (television and multimedia computing), as well as diverse instrumentation applications. Indeed, the blend of increasingly complex and effective algorithms with compact and efficient implementations makes image processing a thriving research area in RLE.



Professor Jonathan Allen, Director Research Laboratory of Electronics

IMAGE PROCESSING
(continued)

feature extraction, and spatial filtering.

Scientific advances in algorithm development, coupled with technological advances in devices and systems, have resulted in a wide range of imaging applications for science, industry, and government. Other uses for image processing include remote sensing, robot vision, industrial inspection, automation systems, electronic publishing, and optical character recognition.

Image Processing Activities

Major research activities within the image processing field include image coding, compression, restoration, and enhancement.

Compression of coded visual data is used in order to remove redundant information, and to represent the image in a minimal number of code bits. This permits more efficient and economic use of storage space and channel capacity or bandwidth. Image compression techniques are based on fundamental information theory, and most exploit the spatial relationship among the neighboring (or adjacent) *pixels* (picture elements) of an image. Basic research in the modelling of human vision processes (also known as visual psychophysics) contributes to the understanding of image coding and recognition. Many design parameters for *high-definition television* (HDTV) systems are based on the results from experiments in human visual psychophysics which investigate temporal and spatial processing, motion sensing, and color analysis. Researchers involved in image coding and compression address issues such as image quality versus bit rate and sampling densities; hardware/software implementation, complexity, and speed; and the susceptibility to transmission errors.

Image restoration uses mathematical models to characterize the source of an image's *degradation* (for example, noise, blur, defocus, ghosting, or distortion caused by the image's sensor, transmission channel, or display). Quantitative approaches are then used to measure and remove the degradation. Consequently, image restoration focuses on the selective emphasis and suppression of various elements within a picture. The image in question can also be improved or enhanced to a more useable or subjectively pleasing form.

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RLE ***currents***

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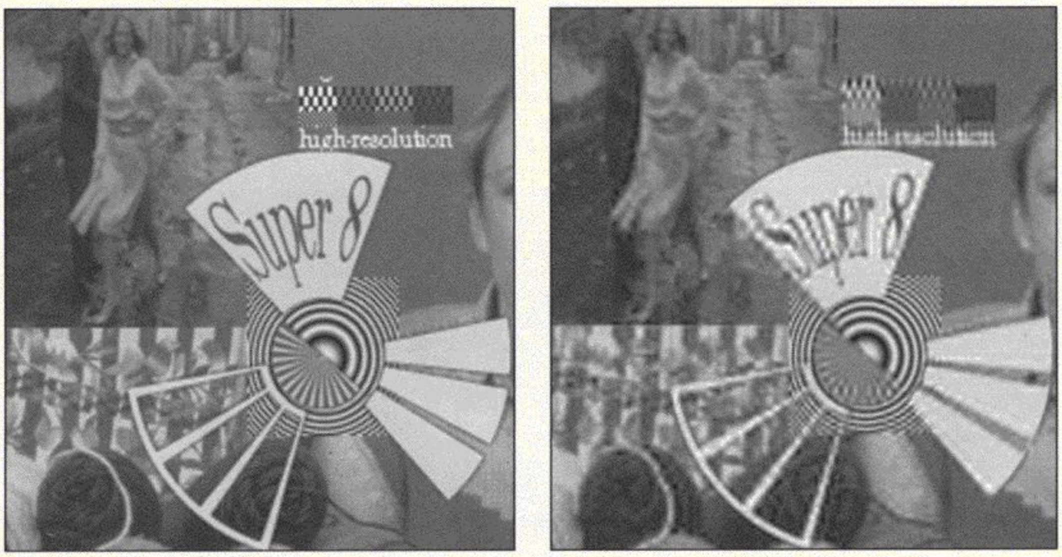

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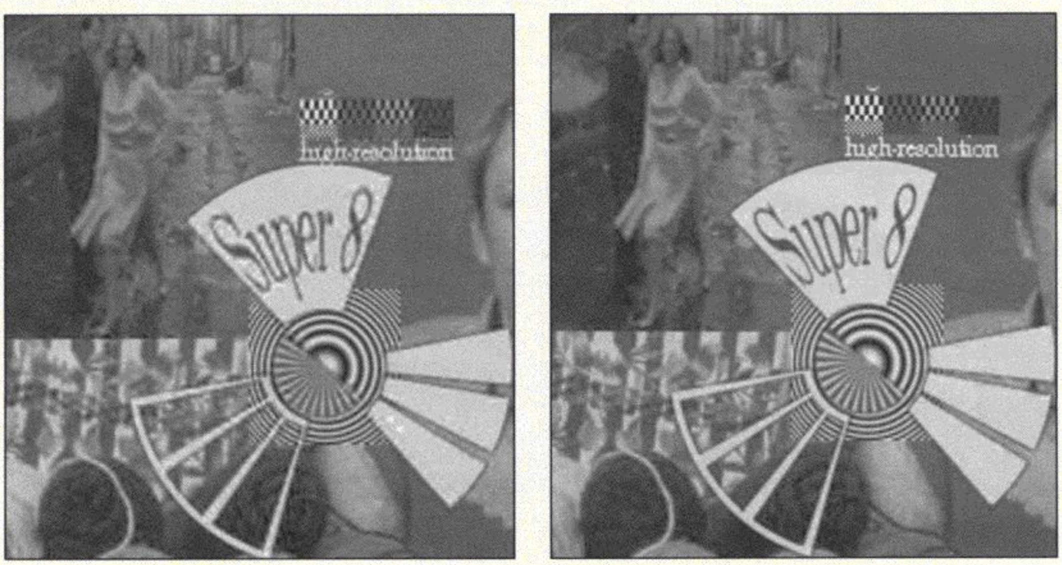

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Above: *These images show the effectiveness of adaptive modulation in subband coding. The original image (a), with the result of normal transmission in a noisy channel (b), and the result through the same noisy channel at the same transmission power (c).*

Left: *When a signal's spectrum is divided in a large number of subband components, the result should look like a real moving image, not like a noise pattern. This requirement places important statistical limits on a signal. The result is that most subbands are empty most of the time, thus their elimination does not result in a loss of image quality. These four images are a single frame taken from a 90-frame test sequence that features very rapid motion. The original (a), with a fixed selection of just 25% of the subbands (b), and an adaptive selection of 25% (c). The best result achieved to date is (d), where only 1/8 of the original subbands are used. Some additional digital information is needed so the receiver can reconstruct the image.*

Image Processing for Broadcast Communications

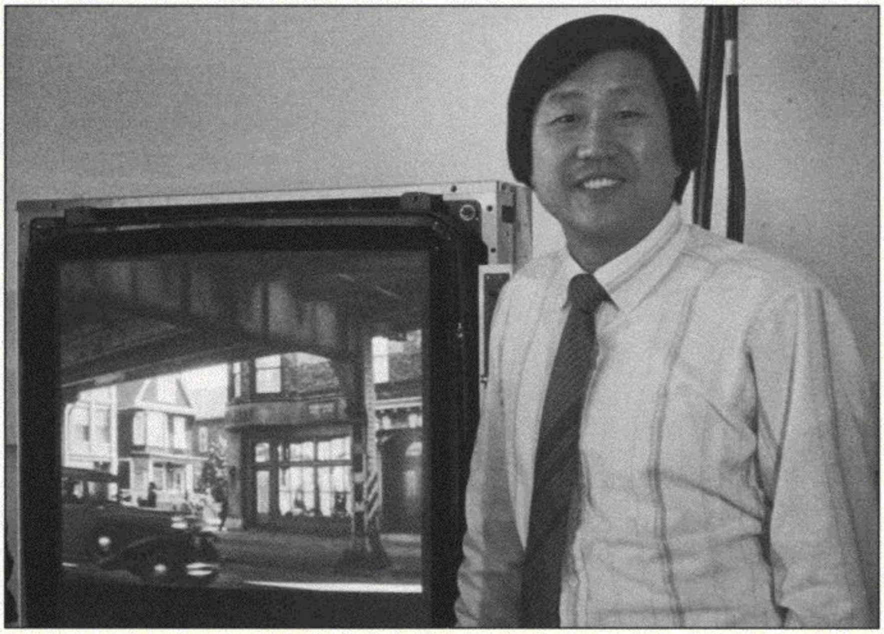
Since the establishment of television broadcast standards in 1941, television signals have been interlaced. That is, the 525-line image on our television screens is generated by the display of the odd-numbered lines, and then 1/60th of a second later, the display of the even-numbered lines. Thus, a television's electron tube generates a half-resolution picture 60 times per second. These alternating scan fields produce an interline flicker visible to the human eye which results in a degraded signal.

Professor William F. Schreiber has experimented with *deinterlacing*, or *progressive scan*, where all the lines of a television image are transmitted in numerical order at twice the speed. This produces a higher quality image with twice the resolution. But, an intelligent or smart receiver that has "frame memory" is needed in order to simultaneously process the data received in the transmission while displaying the processed picture.

The development of innovative video transmission techniques, such as progressive scan, has raised the issue of updated standards for television signals. The newly evolving industry of high-definition television (HDTV) is anticipated as the next wave in the high-tech consumer electronics revolution, and is expected to generate tens of billions of dollars in annual revenues. These developments will not only affect consumer products such as television, VCRs and other video equipment, but also direct satellite systems and the semiconductor industry.

Advanced Television Research Program

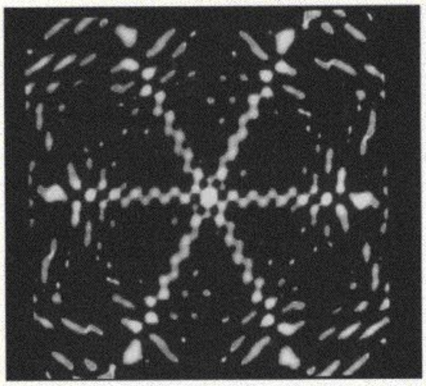
The Advanced Television Research Program (ATRP) at RLE was established in 1983 to develop the science and technology essential to advanced television systems. The program is supported by the Center for Advanced Television Studies, a group of ten companies which broadly represent the American television broadcast industry. Under the direction of Professor Jae S. Lim, ATRP seeks to design advanced television systems, encourage MIT students to work in the television industry, and provide a common place for its sponsors to investigate issues of mutual interest without violating antitrust laws.



Professor Jae S. Lim demonstrates a television monitor displaying the result of source-adaptive video processing research. In this method, developed at ATRP, the receiver is able to adapt to the characteristics of different video sources. For example, film is normally viewed at 24 frames per second. In this new method, a 3:2 pull-down method is used to convert the film to the National Television Standard Committee source. This information can be used to significantly improve video quality. (Photo by John F. Cook)

Segment of a movie frame displayed on a National Television Standards Committee monitor, today's current U.S. broadcast standard.

Segment of the same movie frame displayed on an advanced television monitor that was obtained using ATRP's source-adaptive method. This method does not require any modification to the transmitter, thus it is receiver-compatible.



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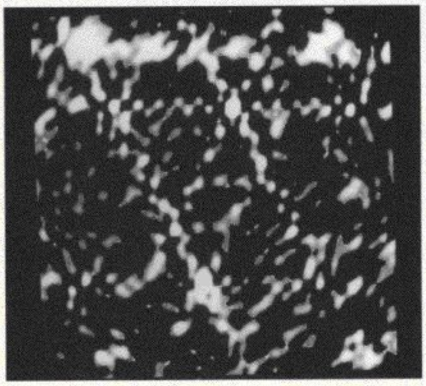

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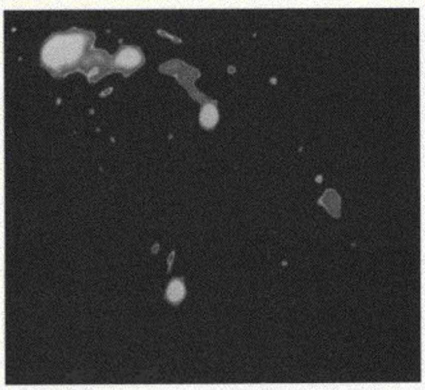

C

This photographic sequence demonstrates how radio signal maps from the Very Large Array undergo signal processing to enhance important features:

(a) The "beam pattern" illustrates how a star-like quasar image would appear in an initial map.

(b) The appearance of the quasar 0957+561 in the initial map is processed by a cleaning procedure using the beam pattern of the map in (a).

(c) The final clean map shows the two brightest quasar images clearly. The signal from the quasar image (which is accompanied by a pair of jets on either side), is the first visible image, travelling approximately 10 billion years. The signal from the corner quasar (which is lacking jets) travels a more curved route through space. Professor Burke's group has determined that its travel time is 14 months longer than the first appearing quasar.

Audience research studies conducted by ATRP have shown the main limitation to television picture quality is transmission impairments in over-the-air television channels. By designing an entirely new system, ATRP research has found it possible to overcome major signal impairments (ghosts, noise, and interference). This is achieved by modifying the transmitted signal in anticipation of channel degradation, and then decoding the received signal and accounting for channel degradation. With this system, it is possible to increase the signal's robustness, while providing greater picture and sound quality in the same 6-MHz channel bandwidth. In addition, more stations can be accommodated within a given spectral band, since there is greater spectrum efficiency. Similar techniques have also been devised for cable, satellite, and optical fiber transmissions.

One problem inherent with this entirely new HDTV system design is that the signals it generates cannot be accepted by today's receivers. In order to serve today's receivers, ATRP has proposed simultaneous transmission (*simulcasting*) of the same program in both the old and new formats via separate channels. The channels currently not used due to interference can be used to accommodate the channels needed for the transmission of new formats. The Federal Communications Commission has recently decided that a completely new HDTV system design based on a simulcasting approach will be the basis for the new United States high-definition television standard.

Simultaneous transmission of the same program in both old and new formats via separate channels has met with resistance in the broadcast industry, where a receiver-compatible signal format is preferred. ATRP has demonstrated a receiver-compatible version of its proposed new system, which provides improved picture quality within one of today's channels, but does not have the improved resistance to channel impairments or the higher spectrum frequency. The same smart receiver used in the compatible system will be phased out after a transition period.

In related research, Professor Lim and his students have proposed a method to improve the quality of the current National Television Standards Committee (NTSC) television picture. The approach addresses the problem of

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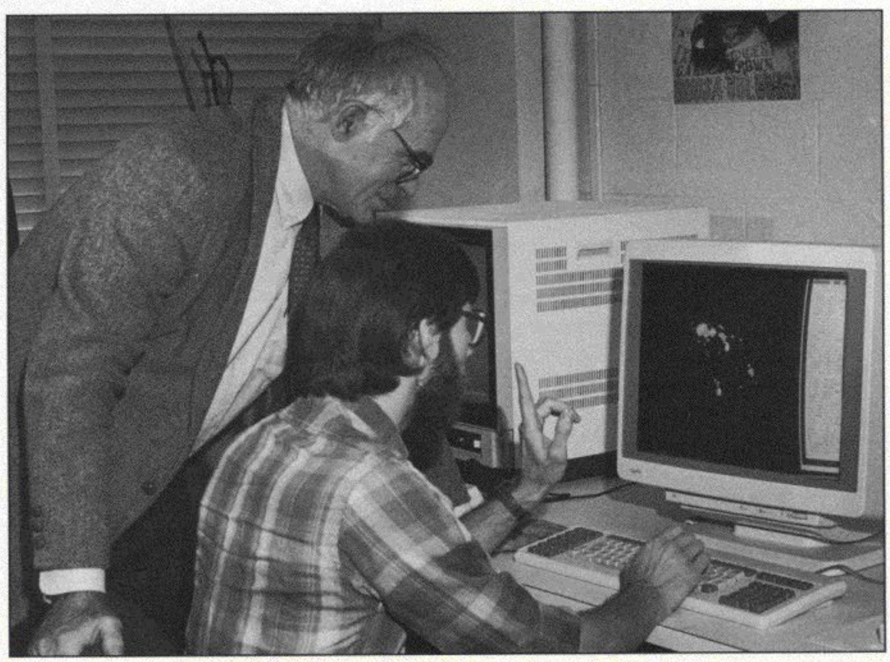
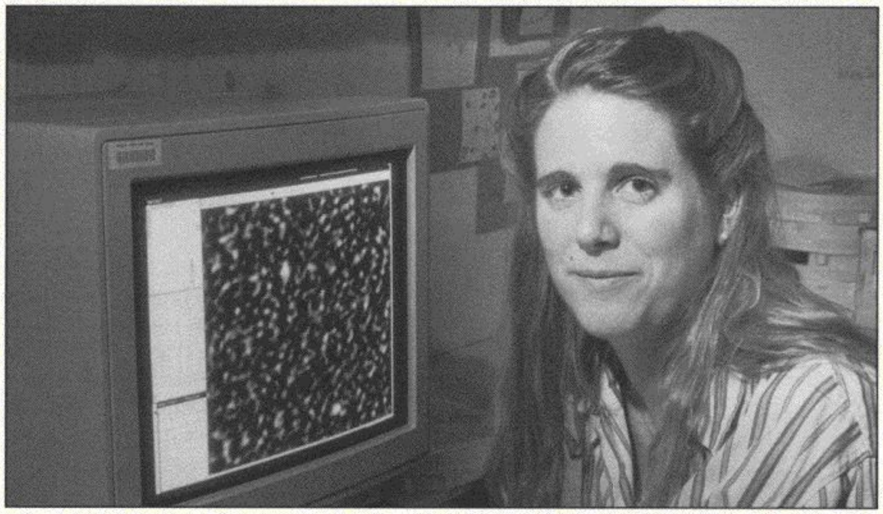


Graduate student Samuel R. Conner (seated) shows Professor Bernard F. Burke one of the ten-year series of radio "snapshots" taken with the Very Large Array used to determine the large-scale geometric properties of the universe. The image on the screen is the gravitationally lensed quasar 0957+561. (Photo by John F. Cook) channel noise and degradations (snow, echo, and channel crosstalk), as opposed to other methods which increase the spatial or temporal resolution of the television picture. Professor Lim's research aims to reduce the effects of channel imperfections on the received television picture by making more efficient use of the currently underused bandwidth and dynamic range of the NTSC signal. By using the technique of receiver-compatible adaptive modulation, more power is concentrated in higher spatial frequencies, and digital modulation is used to send additional information in the image's vertical and horizontal blanking periods. As a result, the existing television signal can be changed so that it is more robust in the presence of high-frequency disturbances. It is also possible to modify this approach so that the modulated signal can be received by a standard receiver, but an improved receiver will be needed to realize the benefits of adaptive modulation. Current research will attempt to determine the degree to which channel degradations are removed when the signal is displayed on an improved receiver, and how much the signal is distorted when displayed on a standard receiver.

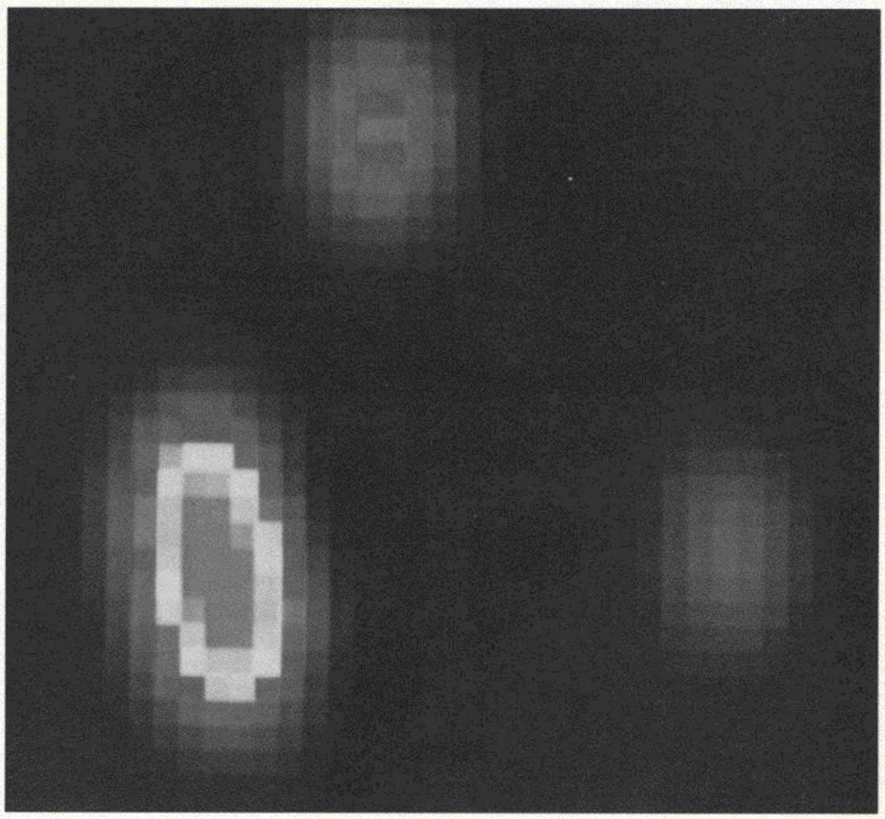
Professor Lim also conducts research on motion estimation for motion compensation in image coding. Motion estimation can be used to improve image sequence restoration, and interpolating between two adjacent image frames. Another project attempts to devise improved analysis and design tools for multirate filter banks for transform/subband image coding. To achieve this, a design algorithm has been developed with improved convergence behavior over existing methods for the special case of a two-channel perfect reconstruction filter bank. Additional research applies image processing techniques to speech spectrograms. In this project, information from both wide- and narrowband spectrograms will be incorporated into a single display. Other image processing projects include the design of a digital advanced television system, the development of methods to convert one television standard to another (*transcoding*), and the design of source-adaptive advanced television systems.

Image Processing for Radio Astronomy

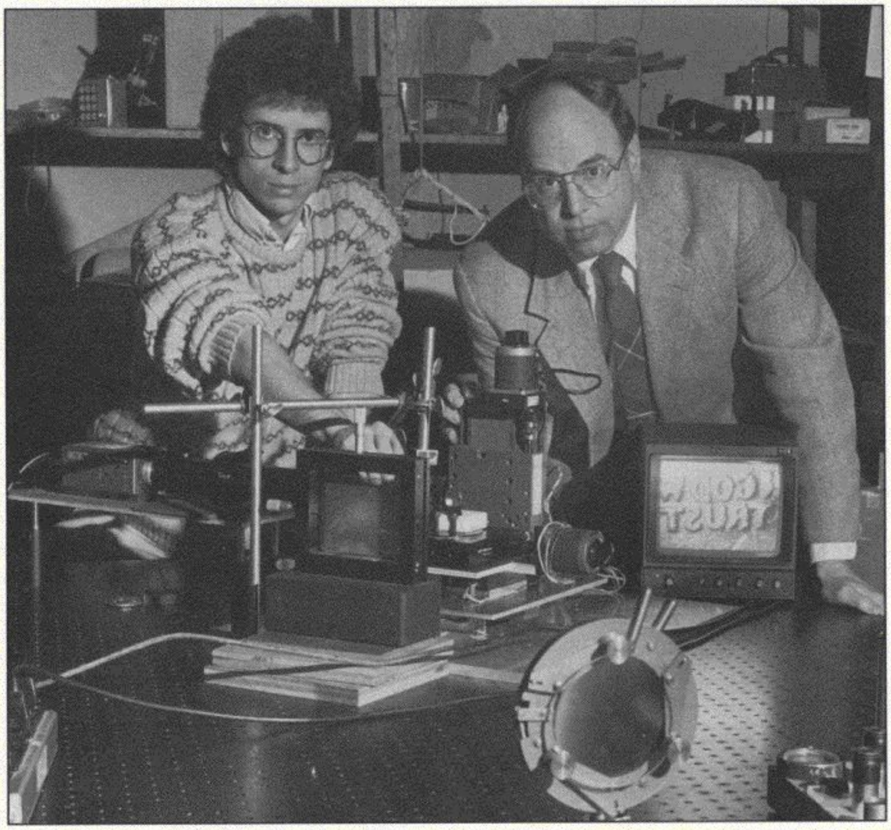
One activity of RLE's Radio Astronomy



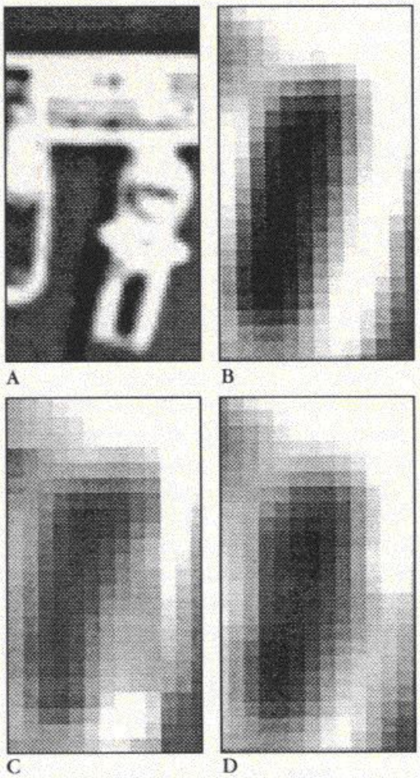
Professor Jacqueline N. Hewitt displays a radio image of a nearby star (YY Gem). The focus of her work, in collaboration with researchers at the MIT Haystack Observatory in Westford, Massachusetts, is aimed at measuring radio emissions using Very Long Baseline Interferometry (VLBI). VLBI can give extremely precise position measurements, and researchers would like to use this technique to determine if nearby stars have planetary companions. The data for this image was taken with the Very Large Array (VLA) in New Mexico. Professor Hewitt examines how a star's radio emission varies with time, so it is necessary to exclude other sources of emission and interference from the data. Once these effects are removed, a series of "snapshots" are produced, from which it can be determined more precisely how the star's radio emission varies with time. (Photo by John F. Cook)



One example of using image processing to address problems in astrophysics is the analysis of the gravitational lens MG0414+0534, shown here. Under the direction of Professor Jacqueline N. Hewitt, student James Brody has calculated theoretical images of the object and has developed an automatic technique to compare theoretical images with the data. In this way, the parameters of a mass distribution consistent with the observed properties of MG0414+0534 can be determined.



Professor David H. Staelin (right) and graduate student Howard R. Stuart adjust a positioning and imaging device designed to explore the limits to precision and speed when measuring or "reading" the detailed shapes of small mechanical objects. Because desired accuracies are on the order of microns, problems arise in the micro-optical behavior of surfaces, precision micro-distance measuring algorithms, and computational efficiency. Similar apparatus is being developed to address the issues of duplicating or "writing" the objects which have been "read." The monitor in the photograph displays the reversed image of a quarter's imprint "In God We Trust." (Photo by John F. Cook)



In earlier video image processing research, Professor David H. Staelin and his students studied adaptive block transform coding techniques on full-motion video sequences, with and without motion compensation. In comparing the use of the discrete cosine transform (DCT) and a new class of transforms called lapped orthogonal transforms (LOT), these photographs show how discontinuities at the block boundaries of an image coded with LOT in (d) are reduced by 1.2 dB, relative to the DCT in (c). The original uncoded image (a) is a side view of a 16mm motion picture camera, and (b) is a magnified segment of it.

Group is the exploration of matter and energy in the universe associated with the *gravitational lens* effect. Working to study this phenomenon are Professors Bernard F. Burke and Jacqueline N. Hewitt. This effect uses radio and lightwave deflections created by the gravitational fields associated with large bodies of matter. The effect occurs when two or more objects at different distances from the earth lie along the same line of sight, thus, they seem to appear at the same location in the sky. Radiation from the more distant object, usually a quasar, is bent by the gravitational field of the foreground objects. This results in what can be called a "cosmic mirage," with distorted or multiple images of the background object.

Spread over a 25-mile diameter in the New Mexico desert are 28 dish antennas that make up the Very Large Array (VLA) radio telescope. The VLA is used by the Radio Astronomy Group to study cosmic phenomena, including very distant radio signals too faint to be observed optically. Radio signal maps taken from the VLA are enhanced by image processing techniques to reveal important features. One of the major objectives is to discover new examples of multiple quasar imaging by the gravitational lens effect caused by intervening galaxies or clusters of galaxies. The most dramatic cases are examples of the "Einstein ring" effect, where the radio object is imaged into a ring around the intervening massive object. Two cases of this phenomenon have been discovered, which indicate that this may not be an uncommon occurrence.

Image Processing for Manufacturing Technologies

Professor David H. Staelin of RLE's Radio Astronomy Group is investigating the development of image processing methods and equipment to measure the shape of three-dimensional objects with sub-mil (below 0.001 inch) accuracy. The result of this work would be the ability to quickly fabricate these objects in metal, ceramic, or plastic with sub-mil precision. Holographically generated illumination patterns provide the signal, and permit the shape of an object to be measured at high data rates. Research on this project continues on the development of methods for adaptive experiment design and materials.

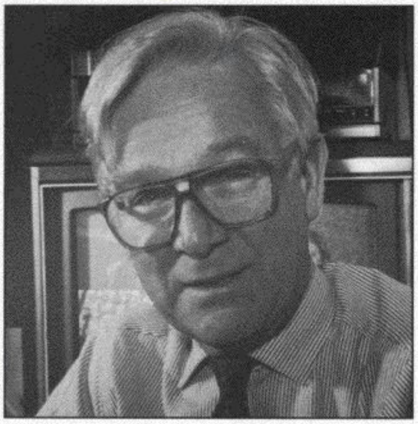
by Dorothy A. Fleischer

FACULTY PROFILE: William F. Schreiber

Over nearly four decades, Professor William F. Schreiber has pioneered developments in the field of image processing and transmission coding. As a native New Yorker, Professor Schreiber received the BS ('45) and MS ('47) in electrical engineering from Columbia University, and a PhD ('53) in applied physics from Harvard University, where he was a Gordon McKay and a Charles Coffin fellow. He was a Junior Engineer at Sylvania Electric Products in Bayside, New York, from 1947 to 1949. From 1953 to 1959, he directed electronics research at Technicolor Corporation in Hollywood.

Professor Schreiber came to MIT in 1959 as an Associate Professor and joined RLE's Cognitive Information Processing Group. From 1964-1966, he served as Visiting Professor at the Indian Institute of Technology in Kanpur, India, as part of a USAID project. In 1968, he became full Professor of Electrical Engineering and, from 1979 to 1982, was Bernard Gordon Professor of Electrical Engineering. In 1983, he was appointed Director of the newly established Advanced Television Research Program at RLE.

In 1989, Professor Schreiber was honored with two distinguished awards. For a third time, he received the Journal Award from the Society of Motion Picture and Television Engineers for his article with Professor E. DuBois of INRS in Montreal titled "Improvements to NTSC by Multidimensional Filtering." He previously received the Journal Award in 1960 and again in 1984. Professor Schreiber also received the Albert Rose Electronic Imager of the Year Award from the Institute for Graphic Communication, which cited his contribution to the advancement of the technical state of the art in electronic imaging. Professor Schreiber spoke with **currents** *shortly before leaving in January 1990 for a sabbatical in Lausanne, Switzerland.*



Professor William F. Schreiber (Photo by John F. Cook)

• What attracted you to the field of image processing and transmission?

I could always see better than I could hear, so I was always more interested in pictures than sound. As a recent engineering graduate, I was fascinated by Claude Shannon's 1948 paper, "A Mathematical Theory of Communication." Then, at Sylvania, I tried to apply information theory to image transmission. But, since I wasn't mathematically prepared to deal with these problems, I went to Harvard for a PhD. For my thesis, and several years after that, I was convinced that entropy was the key to bandwidth reduction. So, I got involved in measuring the statistics of image signals. After several more years of measuring probability distributions, I became convinced that the scope of entropy coding for signal compression was very limited.

• Was there someone who greatly influenced you early in your career?

No, not really, but I was fortunate to have met Norbert Wiener. When he was asked by what factor television bandwidth could be reduced, he answered, "100 to 1." And, in a way, he was right.

• Before coming to MIT, you worked at the Technicolor Corporation in Hollywood during the '50s as a research scientist. What was the nature of your work there?

This was the period when many groups tried to develop a video tape recorder. The problem was the very wide channel capacity needed, as compared with an audio recorder—perhaps 1000 times as much. Some thought video bandwidth reduction could make the problem of expanding the recording capacity less difficult. The people at Technicolor were in this group, so that was my main task. It turned out that the problem was solved entirely by improving the tape recorders, without using any bandwidth reduction at all. Our work was not completely wasted because we laid the foundation for later work in which bandwidth reduction eventually became an acceptable idea.

Personally, the Technicolor period was very instructive. I learned something about the extremely high standards that imaging professionals use in evaluating their results. It dawned on me that traditional manual methods which depended on the skill of the operator could produce excellent results, and that computer-based methods were of no unique value in themselves, but they would only be adopted if they offered some advantage in cost, speed, quality, or convenience.

• What brought you to MIT's academic environment?

Peter Elias, who was on my doctoral committee at Harvard, went to MIT at about the same time that I went to Hollywood. I stayed in contact with him through frequent visits and found out that he really liked it here. Eventually, he suggested that I come to MIT. I hadn't thought seriously about teaching, partly because I enjoyed the industrial environment. But, I decided to give it a try, and I've been here ever since.

• After joining RLE, you collaborated with Sam Mason and Murray Eden in the Cognitive Information Processing Group (CIPG). What was the focus of your research?

In CIPG, we attempted to deal with several aspects of semantically significant information, such as sensory aids for the handicapped. One of the more promising projects in RLE at that time was the reading machine for the blind. Although we never produced a practical machine for that purpose, we learned a lot about character recognition and speech generation. I was able to develop a deeper insight into the way humans absorb visual information, and I eventually applied these ideas to practical imaging systems. After several years spent on biological image processing, I decided to abandon the field, because I felt that the main result of our work, considering the approaches we used at that time, would increase the cost but not the quality of medical care.

• During your career, you've participated in two outside business ventures (Electronic Image Systems and ECRM). Were these businesses successful vehicles for developing and applying your ideas?

I cannot emphasize enough how important those experiences were in teaching me what I now think are the most significant aspects of engineering. The application of science and technology to real-world problems is as important, difficult, and should be as intellectually respectable as pure science. There is no way to learn the value of what one does in engineering without trying to apply it. During most of my years at MIT, many of my colleagues did not agree with this opinion. However, with the decline of American technological competitiveness, more people are coming around to this view. If we can't compete in the world market with high-tech products and processes, then we will gradually become too poor to support work in pure science.

The best schools in the country, including MIT, must find a way to motivate more of their best graduates to get into the economic front lines. One of the secrets of the Japanese economic miracle is that their best graduates from their best schools (which are not, in fact, very good) are designing products at big companies. Many students are highly motivated toward design when they come to MIT, but are diverted by the curriculum's and faculty's emphasis on theory. My efforts to make the curriculum more practical, while preserving its scientific basis, came to naught during my period as Bernard Gordon Professor. The faculty was simply not interested. That is one of my deepest regrets about my long career at MIT. It's not difficult to motivate students towards careers in design, and an easy way to do that is to have industrially sponsored graduate research projects.

• In 1970, you developed a new digital system for the Associated Press Wirephoto Service that used laser technology. How far has the idea of the Laserphoto come?

The laser facsimile machines that we developed for the Associated Press were by far the cheapest ones ever made. All AP fax machines are now of this type, and our machine was the forerunner of today's laser printers. After the Laserphoto system was announced, I visited many Japanese companies, with the intention of getting them to use our ideas in their other products. They did, but without our participation or any compensation. It was an interesting experience in the international exchange of technology, and it has prepared me somewhat for today's high-definition television controversy.

• What was your two-year sabbatical like at the Indian Institute of Technology in Kanpur (1964-1966)?

Those two years at IIT Kanpur were a marvelous experience for me. It was the largest overseas American educational project sponsored by USAID. Lou Smullin organized it when MIT got involved, and quite a few people from MIT went, although Louie was the only MIT person there during the time I was there. About thirty American educators and their families at a time participated in the program. Each of us was asked to bring our research. Actually, there was more teaching than research going on, because we were essentially creating the curriculum for a world-class educational institution, the "MIT of India," so to speak.

While I was there, we installed an entire television system on the Kanpur campus and had a student station operating on cable transmission. We must have put in three miles of cable! The students created the programs, and the other students watched. It was great. One day, the then president of India, Dr. Radhakrishnan, a well-known Hindu scholar, came to visit, and we put him on TV. We placed TV sets all over the campus, so many people saw television for the first time, and they saw the president of India on television for the first time. Many of my Indian students persisted in the image processing field. Some of the students who were in my image processing laboratory subsequently started the first television factory in India. Others came to this country and became quite well known. Image processing research was something that really took hold in India.

Almost everyone at IIT lived on campus—the faculty, students, staff, and workers. All the faculty lived next door to each other, and our kids were the same age. (Of course, all their kids have become doctors and lawyers, and ours haven't.) I've kept in contact with many of the Indian faculty, and many of them have come to this country. Indians never stay in hotels; they stay with friends. As a result, we have had many Indian friends and their children come to stay us many times. I've also gone back several times, the last time in 1974.

I loved India, and I made a big effort to learn Hindi. Although I didn't become proficient, I could read road signs, write short letters, make simple conversation, and ask directions. Being able to read the road signs turned out to be immensely valuable because, in many parts of India, you just don't find any signs in the Roman alphabet.

• What was the impetus behind the Advanced Television Research Program (ATRP)?

The United States has pretty much bowed out of consumer electronics. Today, it's a $40 billion a year industry almost entirely in foreign hands. In fact, there are some foreign-owned factories in the United States. Most of the American laboratories closed because of devastating competition from Japanese TV manufacturers. Broadcasters were using mostly imported equipment. In 1982, many people in the American television industry became concerned and decided to set up a new jointly sponsored laboratory. They formed an organization called the Center for Advanced Television Studies (CATS), and went around to universities, looking for a place to invest their money. We submitted a proposal, which they funded. In 1983, we started our program with a three-year contract, and it was recently renewed for a second time.

We didn't work on broadcast television until 1983. But, we previously worked on some TV coding problems, and we were able to apply everything we had ever learned about image processing to this TV work. It all came together in ATRP. Of course, we learned a few new things in those six years. For example, the adaptive modulation that we use to overcome noise in blank areas was something we actually developed ten years ago. Now, there are special problems we have to attack, such as transcoding from one system to another and overcoming image degradation due to channel impairments.

One thing that sets our effort apart from everybody else's is that MIT is not a company. We try to develop things that are good for the whole country, not just for one company. A lot of broadcasters, for example, wish high-definition television (HDTV) would go away. They see it as a threat to their audience share, rather than an opportunity. For the country, it's an immense opportunity, because if HDTV is successful, between $100 and $200 billion will be spent in the first ten or fifteen years. It will make a big difference where HDTV equipment comes from. If it's mostly made in the United States, it will be very beneficial. If it's mostly imported, it'll just make us poorer. There's no way we can buy $100 billion of HDTV overseas and get rich from doing it.

ATRP has been a great project. We've had no shortage of students, and if we had twice the money, we would have twice as many students. We have good students; as good as I've ever had in the time I've been at MIT. With good students, good equipment, and a good problem to work on—you do good work. It's as simple as that!

• *I understand that an HDTV system developed in your laboratory is being considered as a possible American broadcast standard by the FCC.*

The television system we developed by computer simulation is one of eight possible systems that the FCC will test for the American HDTV broadcasting standard. Of these eight systems, five are compatible with today's television system, and three are not—ours, Zenith's (one of our sponsors), and the Japanese system. The Japanese have actually proposed two systems; one is compatible and the other is not. All the systems will be tested within an eighteen-month period starting in early 1990. Our system will be the last tested because we asked for last place. The FCC might make a decision by 1992, and we might be on the air shortly after that.

The people who don't want HDTV have made all sorts of proposals that would postpone it. In my view, postponing HDTV will just invite the Japanese in. Thus far, the Japanese haven't attacked the problem of over-the-air transmission impairments, at least they haven't talked about it. But, they are certainly as smart as we are, and they have many more people working on it. If we give them five years or so, they will develop very good systems. I think we should press ahead as fast as possible. Whether we will, remains to be seen. We are trying to solicit money from industry in addition to the money we have from DARPA in order to maximize the possibility that our system will be the best one tested.

• *What about the issue of compatibility between old and new systems?*

When we started thinking seriously about a new HDTV system for the United States, the knee-jerk reaction from almost everybody in this country was that it had to be compatible with our present system. The first National Television Standards Committee (NTSC) in 1941 set the black-and-white standards, and the color standards were set in 1953 by the second NTSC. When color was introduced in 1953, it was compatible with the previous black-and-white system. So, if you had a black-and-white receiver, you could receive the new color programs in black and white, and the new receivers could receive the old black-and-white programs also in black and white.

At that time, almost everybody wanted a compatible system for color. It was the proverbial chicken-and-egg problem: the industry would not spend money on color programs unless people had color receivers, and people would not buy color receivers unless there were color programs to watch. With a compatible system, the color programs could be received by everyone. In 1953, there were ten million receivers in the United States. Today, there are between 160 and 180 million. For the sake of those ten million receivers in 1953, all of them long since gone, we seriously prejudiced the new system. Furthermore, color television grew very slowly. It took ten years to reach the 1% penetration level. If it hadn't been for David Sarnoff, who invested $3 billion of RCA money at today's prices, color television may well have failed in the United States because of a lack of interest. But, Sarnoff pushed it until NBC was broadcasting enough color programs, then people bought color receivers, and it finally took off.

The difference between color and black and white is *much* greater than the difference between medium definition and high definition. If you decide on a totally new system that is not compatible with the old one, you can make a *much* better system. We can overcome channel impairments and make better quality pictures in the home. Previously, we determined from our audience studies that we wouldn't get better quality pictures in the home at all, unless we overcame channel impairments. No system compatible with NTSC can overcome channel impairments. So, six of the new systems proposed to the FCC are not going to work. Only three will work—maybe. Actually, the Japanese system doesn't do such a good job of overcoming channel impairments because it wasn't designed for that. It was designed for satellite broadcasting, as were the European systems, and satellite channels are much cleaner. But, Zenith and MIT designed systems for real channels. Now, it's beginning to dawn on everyone that we were right, and we're faced with an interesting situation.

• *Where should funding for HDTV come from in this country? In Japan, the Japan Broadcasting Company (NHK) has been a mechanism for much of HDTV's funding and development in that country.*

NHK is similar to the BBC, and is actually supported by license fees from television and radio. It's not officially a branch of the government—it's a nonprofit organization. However, in Japan, they organize things differently, and although they have antitrust laws too, they don't inhibit this kind of work. NHK has orchestrated the development of HDTV. They did the principal systems work themselves, and parceled out the development of various products to the big Japanese companies. NHK is the largest customer of professional equipment made by all the Japanese television companies. When NHK speaks, the others listen. When NHK

Graduate students of the Advanced Television Research Program and Professor William F. Schreiber discuss the fruits of their labor, an advanced television image on the monitor display. From left: students David Kuo and Adam S. Tom, Professor Schreiber, and student Peter A. Monta. The advanced television monitor image is courtesy of Eastman Kodak Company. (Photo by John F. Cook)

asks the other companies to spend money, the companies do it. Sony, alone, has spent more than $100 million on HDTV development—probably more than any other company.

People have tried to estimate how much the Japanese have spent on HDTV—some say $500 million, others say $1 billion. That may seem like a lot of money, but General Motors spent $3 billion to introduce the Saturn automobile. Any new model car from Detroit costs $1 billion to introduce. A Boeing 747 costs $150 million. Each TV network is a $4 billion operation, and all the networks together are smaller than NYNEX. So, in those terms, a billion dollars isn't much money.

Our research sponsors include the networks (ABC, NBC, and PBS), as well as Ampex, General Instruments, Kodak, Motorola, Tektronix, and Zenith. One would think the support would come from the entire TV industry, except that industry in this country has gotten out of the habit of investing long-term money. If David Sarnoff was here today, he wouldn't be free to spend money the way he did on color television. The result is that we are losing out in one industry after another. Companies are not making investments and are no longer as competitive as before. There are many reasons for this; they're reacting to the circumstances they work under.

A year ago, DARPA decided to spend $30 million on HDTV on the grounds of national security. But, recently, a determined effort was made to kill not only the DARPA program, but every government program in aid of industry. That attempt failed because those people went too far. The fact is that government has always aided industry in this country. We wouldn't have a computer industry today without government aid. Time-sharing was developed with DARPA money. The aircraft industry wouldn't exist without government money, and the semiconductor industry has grown mostly from government money. There you have three separate industries, all of which are or have been successful, and all depended largely on government money to get started. So, it's not an un-American thing to do.

• *What has been the most challenging aspect of your research?*

My laboratory has been 100% industrially sponsored for twenty years, and it is one of the few MIT laboratories like that. There has never been any real shortage of money, when you take the time to look at it. The plus side of industrial sponsorship is that the money is there. Such projects often provide excellent thesis topics and can motivate students to take jobs that are important for society. The minus side is that many industrial sponsors have a narrow view of what they're getting for their money. Especially when companies have been divided into profit centers, where the managers are responsible for profit and loss, and where the benefits from university research are compared with those derived from hiring a few more salesmen.

The right kind of money furthers a goal that we can adopt as our own (like a better television system), and at the same time, give us enough freedom to pursue that goal in ways we believe are the best—free from the industry's views and a single company's economic welfare. At the moment, we don't have enough money because we know what we want to do and, because of the dynamics of the HDTV race, we don't have much time in which to do it. In terms of the HDTV system, the FCC will only test the hardware, not the computer programs, so we have to spend money to put our system into hardware. To get the money that people are willing to spend, and at the same time give us enough scope to do research in an intellectually responsible way; in a fundamental way; in a way that is useful to the education of students—is a problem. The two best things about my thirty years at MIT are that I've had the privilege of working with the best students in the world, and that I was allowed to do pretty much whatever I wanted to do, as long as I could find the money.

On another level, the basic visual communications problem is learning how to transmit better pictures in a very poor-quality channel with restricted capacity. Getting good results has certainly been a major challenge, but it is also a major attraction. Why would we want to work on it if it wasn't difficult? That's the whole idea. It should be a difficult problem, and it should be one that we can attack with fundamental ideas.

• *What do you consider to be your most significant achievement to date?*

If our television system works out the way I hope, it will certainly be the most significant achievement. Before that, the project in which I took the most satisfaction was the development of the electronic laser camera. That was an opportunity to apply myself to an important practical problem—the printing of pictures on paper. Everything I knew about image processing up to that point went into that product. I have always found product design to be attractive—how to make a terrific machine at the lowest price, easiest to use, highest quality output, most reliable, and easy to repair. I get a lot of satisfaction from that.

• *How do you see your research as a direct benefit to society?*

In *Four Reasons for the Abolition of Television*, the book's author argues that television is bad for us, and we would be better off without it. It's possible that he's right, that it does encourage habits of thought that are bad for the community. If we look at television's influence on the election process, for example, we may think it's true. On the other hand, I suspect our children are much better educated because of television. Certainly, they are more *broadly* educated because of television than they would otherwise be.

Technologically, television's impact is enormous. The technology in television is the same technology that exists in the rest of the electronics industry. Within a few years, the electronics industry will be the largest industry in every developed country. The head of Mercedes-Benz has said that electronics is now 5% of the cost of producing a Mercedes-Benz, and he expects it will be 25%. We don't think of a car as an electronic device, but a Cadillac Allante has twenty-two microprocessors, and the average number of microprocessors is currently three per car. If you were to count all the microprocessors in your house, you'd be amazed. I used to tell people to count the number of *motors* they had in their home to realize that it was truly an electrical society. But, now, it's an *electronic* society. Every product's got a micro in it—microwave ovens, dishwashers, washing machines, stoves.

Electronics *is* industry, so you can't pick and choose. If you're going to be in the electronics industry, you have to be in the *whole* electronics industry. You can't say, "I'm going to stay out of consumer electronics because there's no profit there, I'm just going to make radar," or "I'm just going to make computers." The whole electronics industry is at risk if American industry doesn't get a big piece of HDTV. It's the next big thing that's coming, and it's coming without a doubt. It will be delayed if we have a recession, but we will recover from it eventually, and we'll still have the same problem. If we fail to get part of the HDTV market, it will be an economic disaster for the United States, and it won't be confined to television. It will involve the whole electronics industry.

In terms of economic impact, television is a very important industry. Of course, graphic arts and printing is also an important industry, but there are many aspects of that industry other than images. In television, the picture is the whole thing, and television exists to transport pictures to the home. Whatever you think of television's social value, there's no question that it's a strong economic and social force in this country. It's the principal means of communication—and I suspect, principal means of education—and people spend a lot of money on it. So, those are all good reasons to work on it.

• *As a scientist who deals with images, I suspect you also have an artistic side. What are your thoughts on the colorization of motion pictures?*

I'm involved in so many controversial aspects of television that I try to stay out of the ones I don't have to get involved in! Most colorization is technically very poor, and I don't think it improves the picture at all. No one knows how to make an original picture look like it was taken in color. Current colorization techniques are not good because they're primitive.

The writer, director, producer and all those involved, make a product appropriate to the medium they use. When black-and-white movies were made, they were made for black-and-white purposes. They were *not* made with the expectation of being in color. If they were, they would have been made in a different way, just as the programs made for today's television will not look much better on high-definition television, because present-day television is low definition. Therefore, they feature close-in shots and try to fill the screen with a face. They don't show two hundred dancing girls on the screen where they would vanish into the noise. Programs made for high-definition television would not only look very good on high-definition television, they would look very poor on today's television. So, the problem is trying to take the work produced for one medium and use it in another medium.

The problem is obvious when a movie made for the wide screen is shown on television. A perfect example is the glorious opening scene in *Bridge on the River Kwai.* It's a total failure on television! It's like taking Elizabeth Taylor's scene in *Cleopatra* when she comes into Rome, and showing it on a small black-and-white television. Her image was made to fill a screen fifty feet wide! So, colorization in an artistic sense, is a failure, because those movies were made to be seen in black and white. But, apparently, at least on television, the old black-and-white movies that are colorized seem to have more audience appeal than the original black-and-white versions.

• *How would you like to be remembered?*

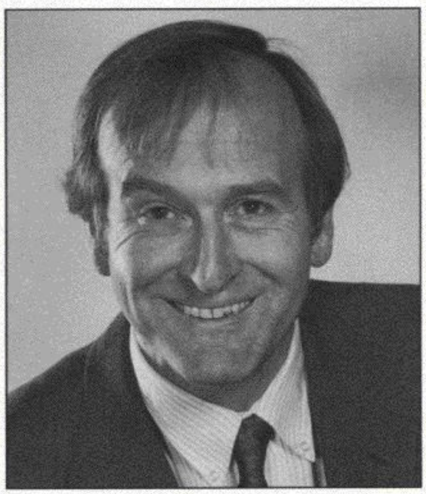
In principle, I don't care whether I am remembered or not. (That isn't exactly true, of course, but I would like it to be.) What I do care about is whether the various issues that I have been working on, both scientific and social, develop along the lines that I have been urging. As a teacher, I have had the opportunity to influence many students. Whether my views on the proper education of engineers take hold, depends primarily on them. They will also be responsible for the spread, if any, of my views on the most fruitful approaches to image processing.

The HDTV project, in which we have been engaged these last seven years, has made use of virtually every aspect of image processing on which I have ever worked. Its technical success has validated many of the approaches that I have advocated for many years. If it is adopted, or if it heavily influences the standards that will be used, I would be immensely gratified. However, the HDTV issue also shows, in microcosm, how the United States is losing its ability to compete in high technology. If we fail to reverse course, we will become poorer, and many social gains that we have made in the last decades will be lost. I have tried as hard as I can to influence public policy in this area. If it turns out that I was instrumental in a renaissance of American technological competitiveness, that will please me as much as the adoption of my ideas about image processing.

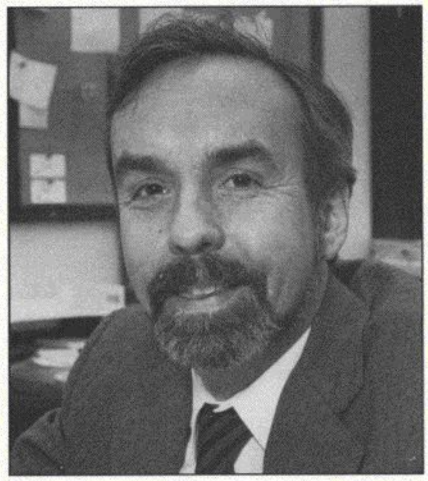
circuit breakers

The MIT School of Engineering has announced the establishment of the Amar Bose Teaching Award. The award is named in honor of ***Dr. Amar G. Bose*** (SB/SM '52, ScD '56), Professor of Electrical Engineering and Computer Science. It will be presented for the first time this spring to a faculty member whose undergraduate teaching contributions are characterized by dedication, care, creativity, and inspiration to students and colleagues. Professor Bose has been a member of the MIT faculty since 1956, and is recognized as one of MIT's finest teachers. He is also the founder and chairman of the board of the Bose Corporation of Framingham, Massachusetts. Professor Bose has been affiliated with RLE since 1953 in the area of acoustics and nonlinear systems. *(Photo courtesy of Bose Corporation)*

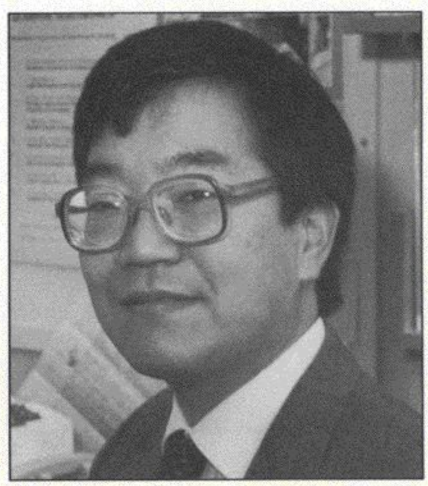
Dr. Sylvia T. Ceyer, Class of 1943 Career Development Associate Professor of Chemistry, was promoted to full Professor. Professor Ceyer joined the MIT faculty in 1981, and was previously a postdoctoral fellow at the National Bureau of Standards. As a member of RLE's Materials and Fabrication Group, her research has included molecular beam surface scattering experiments to analyze the chemistry that occurs during the plasma etching of silicon and gallium arsenide. She has received numerous awards, including the 1981 Dreyfus Award, the 1987 Harold E. Edgerton Award, the 1988 Baker Award, and the 1988 Young Scholar Award from the American Association of University Women. Professor Ceyer has also held an Arthur P. Sloan Foundation Fellowship and a Camille and Henry Dreyfus Teacher-Scholar grant. *(Photo by John F. Cook)*



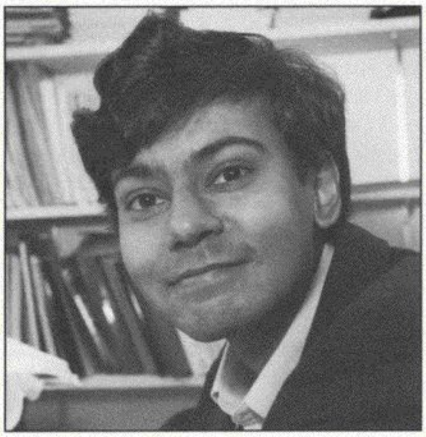
Dr. Henry I. Smith was appointed to the newly established Joseph F. and Nancy P. Keithley Professorship in the Department of Electrical Engineering and Computer Science for a five-year term. Professor Smith joined the MIT faculty in 1980, after twelve years on the staff at Lincoln Laboratory. He established the RLE Submicron Structures Laboratory in 1978, where he is director. As a member of RLE's Materials and Fabrication Group, Professor Smith is widely acknowledged for his contributions to submicron structure technology and research, and his leadership in teaching and promoting submicron structures. *(Photo by John F. Cook)*



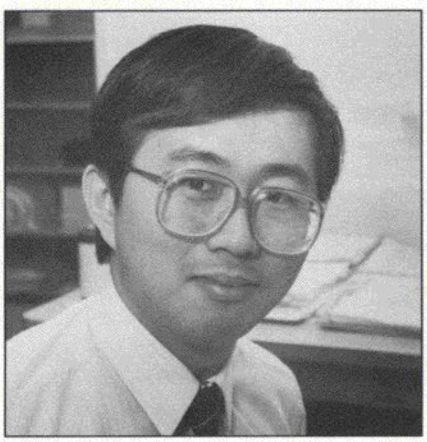
Dr. John L. Wyatt, Jr. (SB '68), Associate Professor of Electrical Engineering and Computer Science, was promoted to full Professor. Professor Wyatt has been a member of the MIT faculty since 1985, and his research interests in RLE's Circuits and Systems have focused on the dynamics of nonlinear circuits and systems, analog VLSI for machine vision, delay estimation in digital integrated circuits, and neural networks. He received his MS from Princeton University ('70), and his PhD from the University of California at Berkeley ('79). Professor Wyatt is a member of the IEEE and the International Neural Networks Society. *(Photo by John F. Cook)*



Dr. James G. Fujimoto (SB '79, SM '81, PhD '84), Associate Professor of Electrical Engineering and Computer Science, is corecipient of the 1990 National Academy of Sciences Award for Initiatives in Research. The annual award was established in 1981 by AT&T Bell Laboratories to recognize innovative young scientists, and to encourage research that will lead to new capabilities for human benefit. Professor Fujimoto, a member of RLE's Optics and Devices Group, was cited for his work on femtosecond optics and its applications in quantum electronics and laser medicine. He and his students have produced laser pulses as short as a few wavelengths of light, and have used them to uncover fundamental information about ultrafast dynamics in optoelectronic materials and devices. Dr. Fujimoto, and corecipient Dr. Wayne Knox of AT&T Bell Laboratories, will receive the award in April at the Academy's annual meeting in Washington, D.C. *(Photo by John F. Cook)*



Dr. Srinivas Devadas, *Assistant Professor of Electrical Engineering and Computer Science*

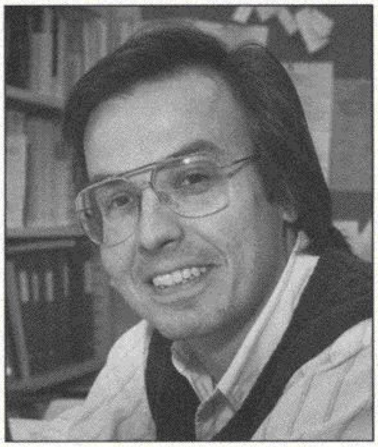


Dr. Ying-Ching Eric Yang, *Research Scientist*

("circuit breakers" text continues on page 20)

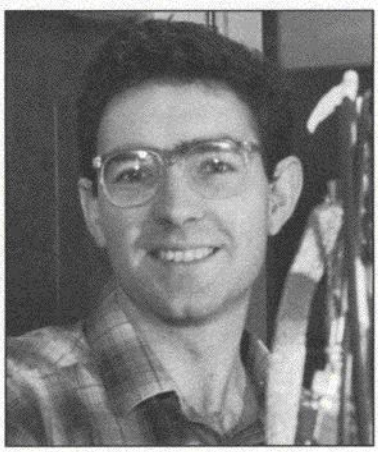
SLOAN FOUNDATION FELLOWS

Congratulations to three RLE faculty members who recently received Alfred P. Sloan Foundation Research Fellowships in Physics. The two-year Sloan fellowships were established in 1955 to provide support and recognition to young scientists in physics, chemistry, mathematics, neuroscience, and economics.



Dr. John M. Graybeal, Assistant Professor of Physics. Professor Graybeal's research in RLE's Surfaces and Interfaces Group focuses on superconductivity, including high-temperature superconductivity and novel low-temperature superconducting devices. He also carries out fundamental studies of phase transitions in metallic spin glasses. *(Photo by John F. Cook)*

Dr. Jacqueline N. Hewitt (PhD '86), Assistant Professor of Physics. A member of RLE's Radio Astronomy Group, Professor Hewitt was also awarded the annual Annie Jump Cannon Award in Astronomy from the American Association of University Women. She was cited for her research in the application of radio astronomy and interferometry techniques to problems in astrophysics. *(Photo by John F. Cook)*



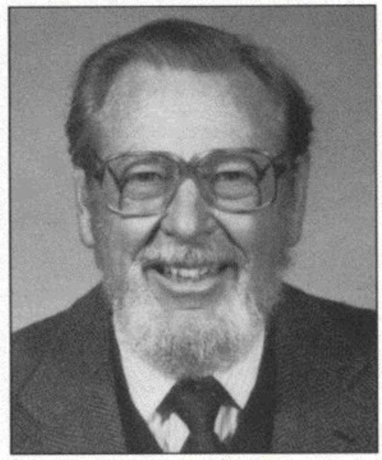
Dr. Simon G. J. Mochrie (PhD '84), Assistant Professor of Physics. Professor Mochrie's research involves the stability of metal and semiconductor surfaces at RLE's Surfaces and Interfaces Group. Most recently, he has studied the Pt(001) surface to model the behavior of an incommensurate overlayer on a substrate. This will contribute to the better understanding of thin film orientation on a substrate. *(Photo by John F. Cook)*

IN MEMORIAM

Professor Emeritus Yuk Wing Lee, 85, died November 8, 1989, in California. He had suffered from leukemia. Born in Macao, China, Professor Lee (SB '27, SM '28, ScD '30) held professorships at three universities in China—the National Tsing Hua University, St. John's University, and Ta Tung University. In his MIT doctoral thesis, "Synthesis of Electrical Networks by Means of Fourier Transforms of Laugerre's Functions," Professor Lee was recognized as the first person to coin the term "synthesis" in that particular context. He joined the MIT faculty in 1946, and the following year, taught the first graduate course in statistical communication theory. Professors Lee and Amar G. Bose persuaded Professor Norbert Wiener to present a series of lectures on nonlinear problems in random theory. Professor Lee tape recorded the lectures, and photographed hundreds of complex equations diagramed on the blackboard by Wiener. This material became the first book on the subject in English, *Nonlinear Problems in Random Theory,* published in 1958. In addition to many papers and articles on statistical communication theory, Professor Lee was the author of *Statistical Theory of Communication,* published in 1960. He also held an honorary doctorate of applied sciences from Katholiecke Universitie in Leuven, Belgium. *(Photo courtesy MIT Museum)*

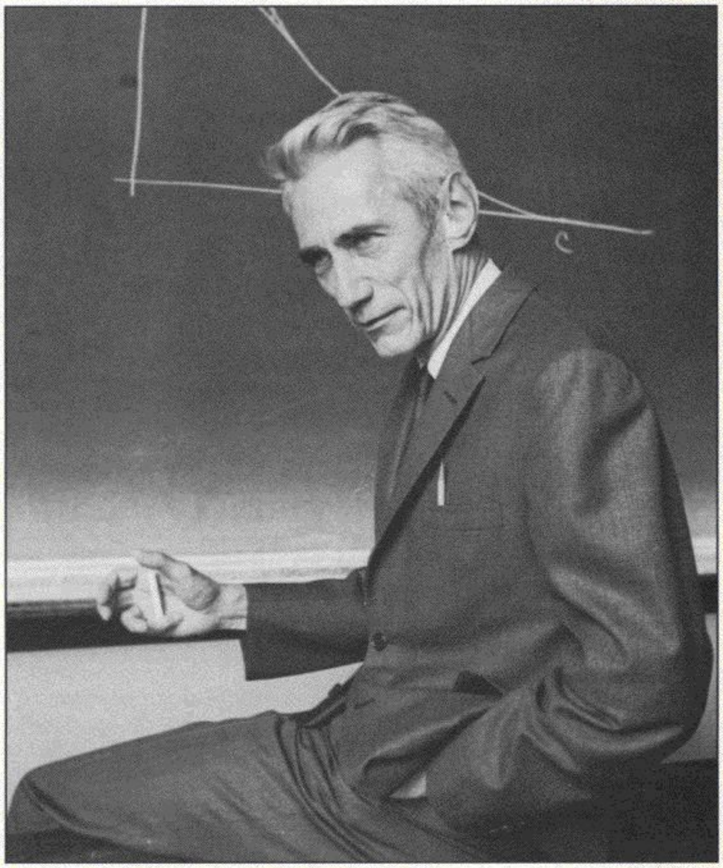
In a 1957 photograph, Doc Edgerton (left) helps RLE glass shop staffers Anthony Velluto and Lawrence Ryan fill the time capsule that was buried at the dedication of MIT's Karl Taylor Compton Laboratories (Building 26). In 1983, MIT dedicated the EG&G Education Center (Building 34) to Professor Edgerton and his collaborators, Kenneth Germeshausen and Herbert Grier.

Professor Emeritus Harold E. "Doc" Edgerton, 86, died January 4, 1990, after suffering a heart attack at MIT. Born in Fremont, Nebraska, he graduated from the University of Nebraska in 1925 with a degree in electrical engineering. He came to MIT to complete his graduate work (SM '27, ScD '31) and joined the faculty in 1932. Professor Edgerton had been affiliated with RLE since its inception in 1946. His initial interest in stroboscopic photography stemmed from his doctoral research, and paved the way for many industrial applications, including night-time aerial and underwater photography. Collaboration with two of his students, Kenneth J. Germeshausen and Herbert E. Grier, resulted in formation of the company EG&G, which helped to develop the instrumentation and applications for high-speed strobe photography. Professor Edgerton also participated in the archaeological "photo excavation" of many historic underwater wrecks and lost cities. His work in this area led to the development of side-scan sonar technology. Professor Edgerton was the recipient of many distinguished honors and awards, the most recent being the National Geographic Society Centennial Award and the National Medal of Technology in 1988. In addition, he was a member of many organizations and professional societies. *(Photo courtesy MIT Museum)*



Professor Richard B. Adler, 67, died February 5, 1990, from injuries suffered when he was struck by a car while jogging near his home in Concord, Massachusetts. A native New Yorker, Professor Adler attended Harvard, and then transferred to MIT, where he received his SB ('43) and ScD ('49). After serving in the U.S. Navy as an instructor at MIT's Radar School, he joined the faculty in 1950 in the Department of Electrical Engineering and Computer Science. From 1978-1989, he was Associate Department Head, and was appointed Distinguished Professor in 1985. Professor Adler had served as Co-Director of MIT's Microsystems Technology Laboratory since last September. He had been affiliated with RLE since 1973. In an effort to bring transistor-based solid-state electronics to undergraduate education, he established the international university-industry Semiconductor Electronics Education Committee in 1960, and served as its Technical Director. His collaboration with Robert Fano and Lan Jen Chu led to the publication of *Electromagnetic Fields, Energy and Forces,* and *Electrical Energy Transmission and Radiation.* In 1986, he received the IEEE Medal in Engineering Education for his role as the co-author of these textbooks which revolutionized the teaching of traditional electrical engineering in the late 1950s. *(Photo courtesy MIT Communications Office)*

History of Image Processing and Transmission at RLE



ca. 1948

Professor Claude E. Shannon, who joined RLE's Processing and Transmission of Information Group in 1956, laid the foundation for research in information theory. He theorized that a message could be encoded and sent in "bits," with groups of bits representing a sequence of letters rather than a single letter. Once these bits were converted into electrical impulses, the signal could be compressed and channel capacity increased. These ideas also suggested the use of error correcting methods to eliminate the effects of noise in a transmission. (Photo courtesy MIT Museum)

1950

Dr. Norbert Wiener conducted studies to convert speech into a sequence of tactilely perceptible patterns that a totally deaf person might learn to interpret. In the original experimental device, called Felix, several bandpass filters were used to subdivide the voice range. To fix successive band limits, each band represented approximately an equal amount of energy when averaged over speech. Five channels were used initially, with the outputs arranged to control the amplitude of five small vibrators on which the fingers of one hand rested. (Photo by Alfred Eisenstaedt)

1955

Research staff members Lamar Washington, Jr. (left) and Dr. Clifford M. Witcher collaborated on RLE's Sensory Aids Project and developed the experimental Vocatac. The device was based on the work by Dr. Norbert Wiener to convert speech signals into tactile form. (Photo by Ben Diver)

1958

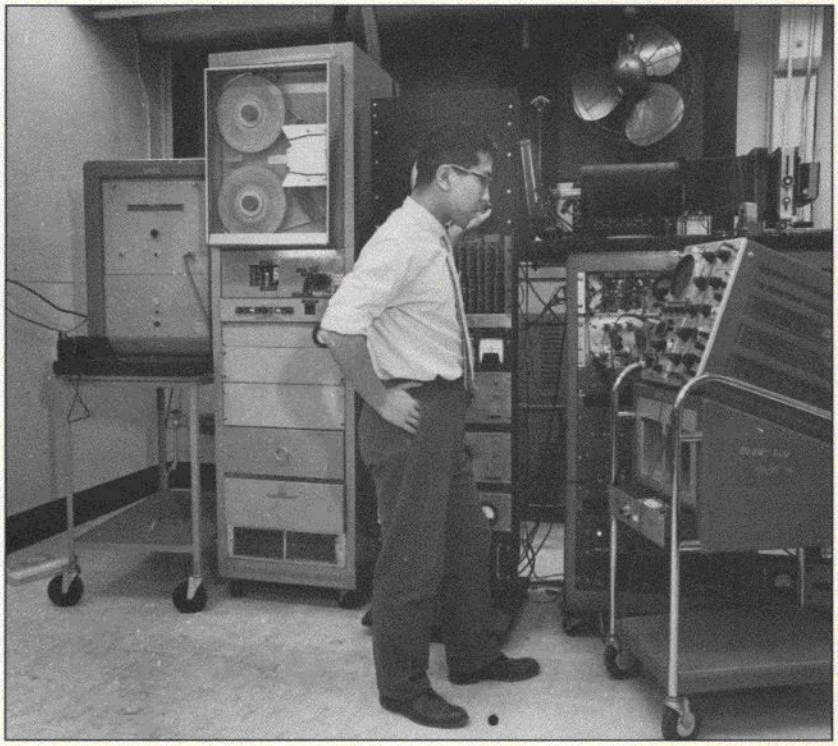
RLE's Processing and Transmission of Information Group. The statistical investigation of information sources is the subject of discussion among Professor Robert M. Fano (standing) and (seated from left) Professors Peter Elias, David A. Huffman, and Wilbur B. Davenport, Jr. (Photo by Ben Diver)

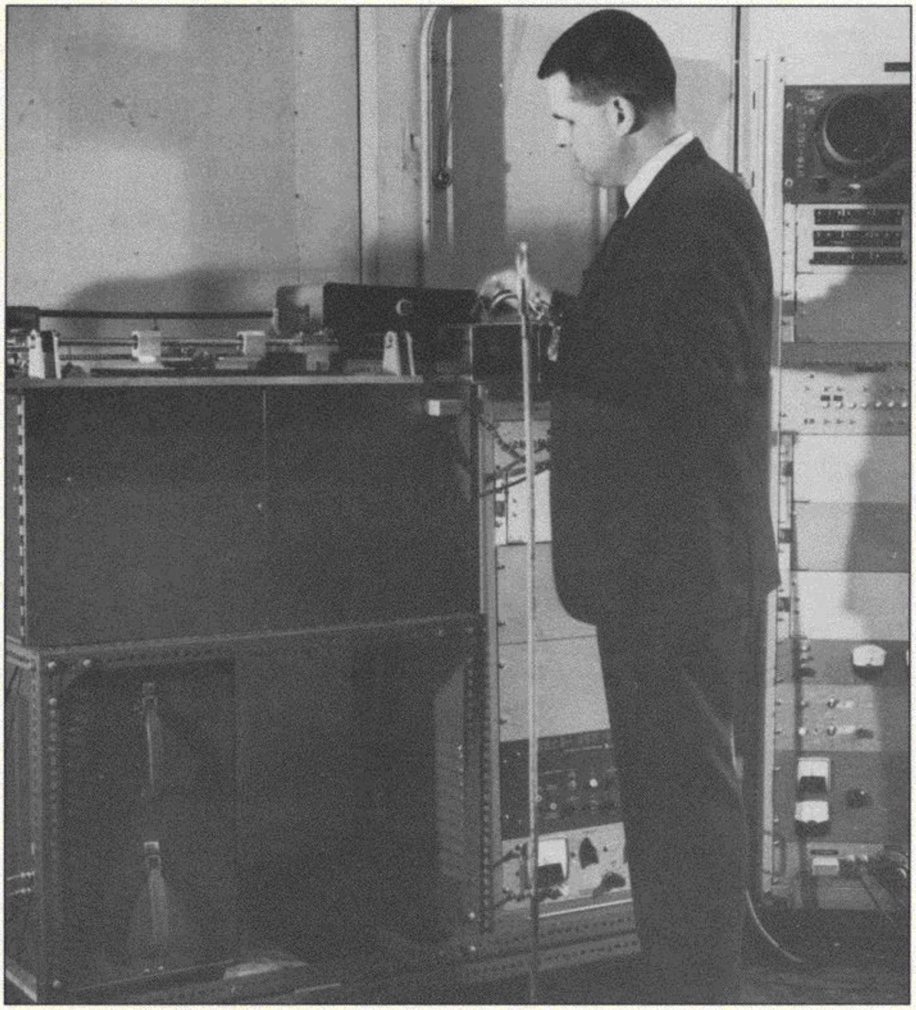
1961

RLE Director Henry J. Zimmermann (left) confers with Professor Samuel J. Mason. RLE's Cognitive Information Processing Group was initially led by Professors Mason and Murray Eden. Professor Eden used feature techniques to characterize handwritten script, while Professor Mason developed character recognition techniques for a variety of fonts in his quest to develop a reading machine for the blind. Later, Professor Donald E. Troxel built on this work by demonstrating computer input scanning for the machine. (Photo by Phokion Karas)

1963

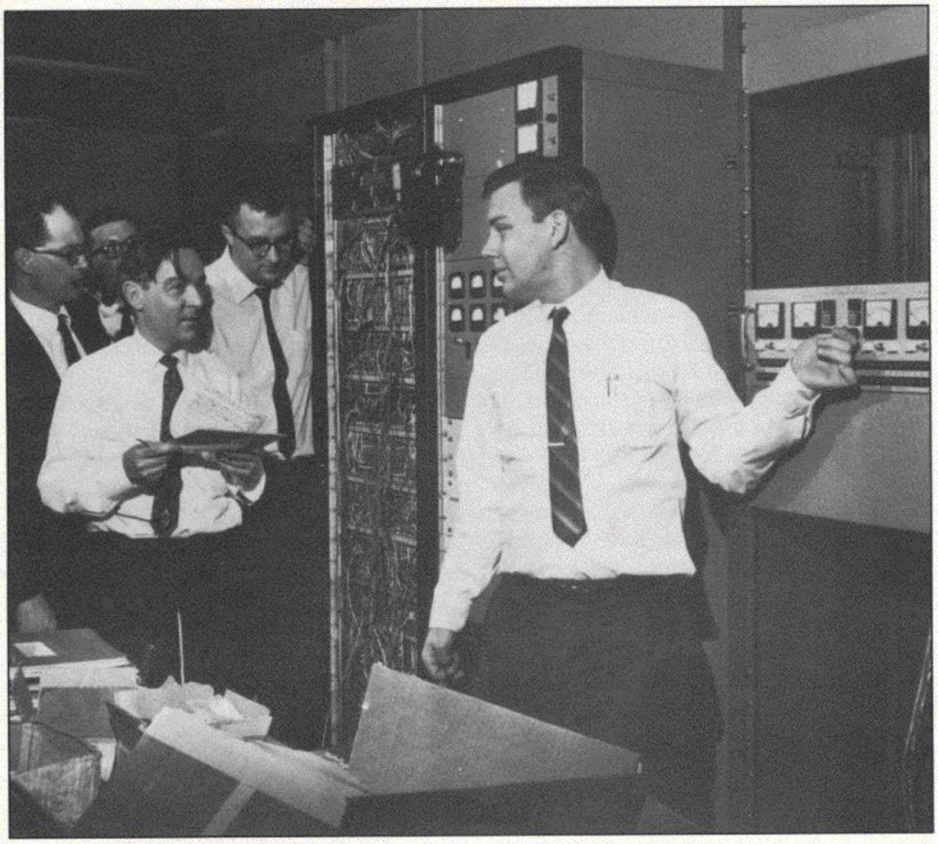
Professor Thomas S. Huang with the flying-spot or optical scanner. The scanner uses a small point of light to rapidly scan an image in a rectangular pattern. Light reflected or transmitted by the image is received by a phototube that generates electric signals. In 1968, Professor Huang and his students used this equipment to perform Fourier transform coding, and originated the concept of coding in blocks smaller than the original image. (Photo by Phokion Karas)





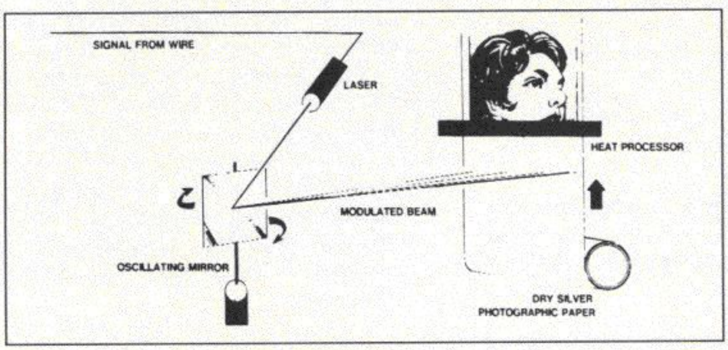
1967

Research Associate Dr. Kenneth R. Ingham works with RLE's first reading machine for the blind. It was the first affordable optical character reader and, in combination with the PDP-1 computer, it comprised the first computer system that could scan text and read it aloud. The system was also capable of outputting spelled speech and braille. (Photo by Richard Geraigery)



1971

Professors William F. Schreiber, Donald E. Troxel, and Charles L. Seitz (in foreground) demonstrate equipment used for the digital wirephoto standards converter project to two Associated Press representatives (in background). The standards converter translated wirephotos simultaneously between the United States and Europe, since U.S. images contained more lines than European images. In 1968, the converter was installed at the Associated Press in New York City, with greatly improved picture quality and time savings over previous procedures. (Photo courtesy of Associated Press)



1975

Professors William F. Schreiber and Donald E. Troxel continued their collaboration on another imaging project for the Associated Press—the Laserphoto system. The flatbed scanner used a laser beam light source, and pictures were heat-processed on specially developed dry silver paper. In the mid-'70s, it replaced all existing AP wirephoto machines in the United States.

Professor Donald E. Troxel has made significant contributions to RLE's Image Processing Group. In the '60s, Professor Troxel was involved in the group's research on tactile communication and optical character recognition and was a major contributor to the development of RLE's reading machine for the blind. During the '70s, another facet of his work was the development of the "Electronic Darkroom," an interactive multiprocessing computer system for wirephoto reception, storage, editing, and transmission. In combination with the Laserphoto system, it gave picture editors the freedom to manipulate wirephotos entirely by computer. This method was adopted by the Associated Press in the late '70s. Professor Troxel's primary focus is now in the area of computer-aided fabrication of integrated circuits. (Photo by John F. Cook)

circuit breakers

(continued)

Dr. Srinivas Devadas was appointed to the Analog Devices Career Development Professorship in the Department of Electrical Engineering and Computer Science for a two-year term. In 1988, Professor Devadas joined RLE from the University of California at Berkeley, where he completed his PhD in high-level computer-aided design synthesis and testing. Professor Devadas is known for his significant contributions to data path synthesis and logic synthesis and verification. In RLE's Circuits and Systems Group, his research focuses on the computer-aided design of integrated circuits and systems, particularly in the areas of test generation and logic synthesis. *(Photo by John F. Cook)*

Dr. Ying-Ching Eric Yang (PhD '89) was appointed Research Scientist in RLE's Center for Electromagnetic Theory Applications. Dr. Yang's research involves electromagnetic propagation, coupling in microelectronic integrated circuits, and electromagnetic interference as it affects the communications and control of airport precision landing systems. Dr. Yang received his BS in Electrical Engineering from the National Taiwan University in Taipei ('81). *(Photo by John F. Cook)*

UPDATE: Collegium

RLE is pleased to announce the newest member of the Collegium. The Electronics and Telecommunications Research Institute (ETRI) of Daejeon, Korea, joined the RLE Collegium. ETRI is the first Korean company to establish a collegium relationship with MIT.

The RLE Collegium was established in 1987 to promote innovative relationships between the Laboratory and business organizations. The goal of RLE's Collegium is to increase communication between RLE researchers and industrial professionals in electronics and related fields.

Collegium members have the opportunity to develop close affiliations with the Laboratory's research staff and can quickly access emerging results and scientific directions. Collegium benefits include access to a wide range of publications, educational video programs, RLE patent disclosures, seminars, and laboratory visits.

The RLE Collegium membership fee is $20,000 annually. Members of MIT's Industrial Liaison Program can elect to transfer 25% of their ILP membership fee to the RLE Collegium. Membership benefits are supported by the Collegium fee. In addition, these funds will encourage new research initiatives and build new laboratory facilities within RLE.

For more information on the RLE Collegium, please contact RLE Headquarters or the Industrial Liaison Program at MIT.

Publications

RLE has recently published the following technical reports:

Acoustic Evidence for the Development of Speech, by Corine Anna Bickley. RLE TR No. 548. October 1989. 146 pp. $14.00.

An Algorithm Design Environment for Signal Processing, by Michele Mae Covell. RLE TR No. 549. December 1989. 256 pp. $17.00.

Detection Statistics for Multichannel Data, by Tae Hong Joo. RLE TR No. 550. December 1989. 113 pp. $11.00.

A Novel QMF Design Algorithm, by Kambiz Casey Zangi. RLE TR No. 551. March 1990. 60 pp. $10.00.

The annual ***RLE Progress Report*** will be available in June 1990. ***Progress Report No. 132***, covering the period January through December 1989, contains a statement of research objectives and a summary of research efforts for each RLE research group. Faculty, staff, and students who participated in these projects, and sources of funding are identified at the beginning of each chapter. The ***Progress Report*** also lists current RLE personnel.

The RLE Communications Group welcomes inquiries regarding our research and publications. Please contact:

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