RLE

currents

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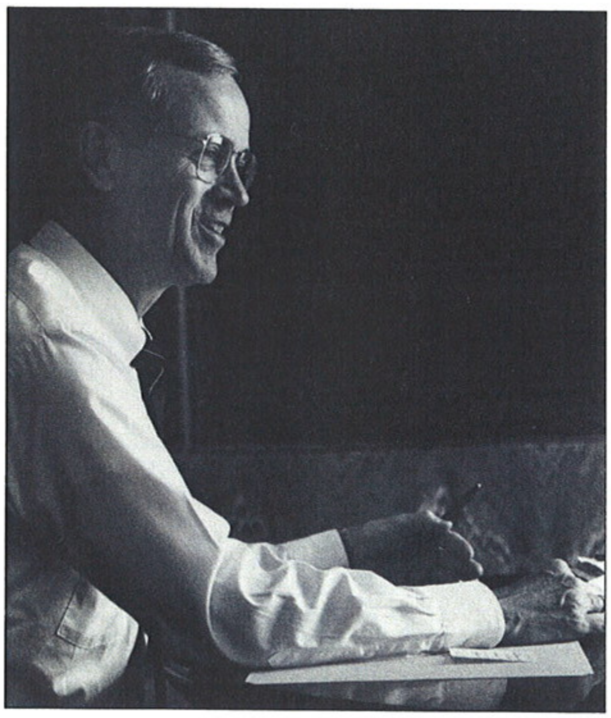
The Research Laboratory of Electronics at the Massachusetts Institute of Technology

MEASURING THE RETURN ON INVESTMENT IN UNIVERSITY-BASED RESEARCH



Charles M. Vest, MIT President *(Photo by Donna Coveney)*

This issue of ***RLE currents*** is a celebration and a demonstration of the broad social return derived from investing in advanced education and research—a return in the form of new knowledge, technologies, jobs, and a better quality of life.

Research in science and technology has generated profound advances in virtually every facet of modern life: communications, health care, the manufacturing industries and financial services, military security, housing, transportation, energy generation, environmental protection, agriculture, entertainment, and the management of government and industry. It will be even more critical in the future, where we can already picture the benefits of gene therapy, artificial organs, microscopic machinery, intelligent software, wireless networks, sustainable agriculture, and more.

The profiles of the RLE alumni in these pages are testimony to the wisdom of making such an investment. In a sense, each is a case study of how bringing together faculty and students from many disciplines creates an intellectual ferment that sparks both innovation and entrepreneurship.

Jerry Wiesner once referred to RLE as a "unique scientific incubator . . . which . . . has provided an almost ideal research environment and has been a model for the structure of other research centers." From its well-focused origin as the MIT Radiation Laboratory, RLE has moved with the times, or, more accurately, it has moved ahead of the times.

What has made it so special? The laboratory itself puts it this way: "The constant tension between individual focus and intergroup collaborations leads to highly specialized strengths and collective efforts that arise from the mutual interest of many investigators . . . The focus is on basic understanding, and the development of intellectual means to model increasingly complex phenomena. In this way, a foundation is established for building new high-performance technologies while constantly exploiting these technologies to further research progress."

Today, this broad mission and operating philosophy is expressed in work performed by sixteen distinct

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research groups in RLE, ranging from such fields as materials and fabrication and quantum-effect and optical devices to speech, sensory, and optical communication; and from advanced television and signal processing to radio astronomy.

This practice of bringing together people from many fields to work on problems of common interest, and of combining advanced education and research, is something uniquely American. It defines the research university as we know it. RLE has been a prime example of this for the past fifty years. It is a vital learning community in which senior scholars advance our understanding and introduce fresh, innovative young minds into the creation of knowledge—thereby educating the next generation of scientists and engineers. This system has made higher education in this country the primary wellspring of the ideas and people that are the source of innovation in a growing array of industries.

Indeed, several econometric studies conducted over the past few years have concluded that at least half the economic growth in this country since World War II has been due to technological innovation, and that the lion's share of that innovation has come from research universities. Of course, universities have not done this alone. Universities are part of a national innovation system that includes industry and government as well. Working in at least a loosely coupled manner, these institutions have created a system that produces new scientific and technological knowledge, recognizes its relevance to public and commercial good, translates some of it into industrial practice, and prepares people to develop, implement, and market it.

One could argue that the return on investment in research is even higher than 50 percent.

Take Project Whirlwind, for example, which led to the development of the magnetic core memory. The federal government sponsored this research at MIT as part of an effort to strengthen the national air defense system. Not only did it succeed in meeting its original goals, but this work also stimulated the rapid growth of this country's computer industry. This was accomplished by licensing MIT's patents on magnetic core memories to existing companies, which thrived on this new technology; by forming new companies based on the Whirlwind technology, such as the Digital Equipment Corporation; and by demonstrating the effectiveness of related technologies such as computer-aided design and numerically controlled tools, which have become big businesses in their own right.

To cite a more general case, it has been estimated that, over the last three decades, the Department of Defense alone has funded university research in information technology to the tune of $5 billion. These university programs have produced one-third to one-half of the major breakthroughs in computer and communications companies. Today, these businesses account for $500 billion of this country's gross domestic product. By any measure, that is an extraordinary return on the investment in higher education and research.

Another measure of the return on investment in university-based research is jobs. A 1989 study by the Bank of Boston found that MIT graduates and faculty had established more than 600 companies in Massachusetts. These companies, with annual sales of $40 billion, created jobs for more than 300,000 people in the state. Similarly, the Chase Manhattan Bank identified 225 companies in Silicon Valley that were founded by MIT students, alumni, and faculty. These companies recorded revenues of more than $22 billion, accounting for more than 150,000 jobs. The Bank of Boston is currently updating its study, and I am confident that when it is released this fall, the record of our contributions to the economy will be even stronger. And this is just MIT. Similar stories can be told by public and private universities across the country.

How did this stimulus to the economy come about? Through people. When we talk about technology transfer, we are talking about people: the faculty, researchers, and students who conduct research and carry their skills and knowledge to other universities, to positions in government, and to industry. As John Armstrong, IBM's former vice president for research, has said, "The best vehicle for technology transfer is the moving van." These are the stories that you will read about in the pages that follow.

While people are the key to generating and transferring scientific and technical knowledge, we need to remember that none of this can happen without the proper setting and support. I would suggest that the following conditions come quite close to what faculty members believe enables them to do their best work:

- Support based on the quality of ideas and performance.
- Continuity of support.
- A good understanding by sponsors of how science and technology work.
- Minimal bureaucratic responsibility and paper work.
- Full coverage of the real and appropriate cost of research.
- Recognition of the dual role of research and education.
- A sense of accountability on the part of the investigator.
- Flexibility to "change course" when appropriate.

The Research Laboratory of Electronics has been fortunate that the sponsor of its core research program—the Joint

RLE currents

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Services Electronics Program—has provided this kind of support over the past fifty years. The continuity, flexibility, and understanding demonstrated by this support has made JSEP one of the longest-running research programs in the world. Its substantial achievements are directly attributable to the generosity and perception of its sponsors.

RLE's philosophy and the environment that continuous federal funding has created have paid enormous societal benefits. One measure of this has been the establishment of more than 75 companies by MIT students and staff associated with RLE, including those mentioned in this issue. Others include Bose, Teknekron, EG&G, ThermoElectron, Qualcomm, International Data Group, Meditech, and Lotus Development. An examination of these and other RLE-associated companies shows that not only has federal investment in university research and advanced education launched numerous companies, but it also has launched new industries, and has created ranges of new technologies for both defense and civilian applications.

Despite the demonstrated value of maintaining a strong, certain, and consistent investment in science and technology, however, there has been a major change in the role of the federal government in research and development. This has been driven in large measure by shifting priorities brought about by the end of the Cold War, the challenges of international economic competition, and the decision to balance the federal budget. Federal support of university research has remained rather strong this year, and there is considerable goodwill in Congress. Indeed, the budget process during the last cycle sustained the government's support for science. Nonetheless, the long-term prospects for civilian research and development do not bode well. Under both congressional and administration budget proposals, reductions of approximately 20 percent for civilian research and development are predicted by 2002.

To put this in context, the federal government currently devotes only 2 or 3 percent of its outlays to real scientific and engineering research and development. What worries me is that just as our national investment in research and development appears to be decreasing, other countries, particularly in Asia, are increasing their investments in R&D.

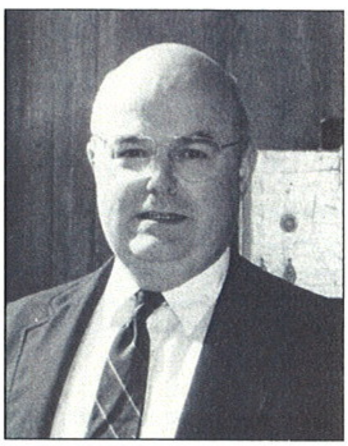
Now, I recognize that the federal government faces daunting budgetary pressures, and their proper resolution concerns us all as citizens, but we need to ask ourselves: Is the excellence of our human and intellectual capital growing rapidly enough? What will be the source of innovation for our industries if the wellspring runs dry?

Despite the pressures to reduce such funding, it is my firm belief that the federal government will need to remain the primary sponsor of research and graduate education in science and engineering in this country. Clearly, the times are changing and we must be open-minded about the changes in the system that need to occur. We in the universities must improve our own educational and cost effectiveness, and we need to establish new and better connections with industry as well.

Indeed, I believe that new kinds of partnerships hold the key to renewing our national investment in research and education. To ensure that our investment in science and technology, and in people, remains strong and productive, we must work together to identify new directions for research and create new settings and styles of education. In establishing such partnerships, we would do well to talk with and learn from the many RLE alumni who know what it means to start new ventures and make them grow.

by Charles M. Vest, MIT President

Director's Message



Jonathan Allen, Director, Research Laboratory of Electronics

In this issue of ***currents***, we continue to profile RLE alumni who have formed significant companies that have introduced new technologies and products while bolstering the economy.

For one alumnus, we have departed from our usual format. Robert Noyce (PhD'53), who went on to co-invent the integrated circuit and to cofound Intel, died suddenly in June 1990. Since he was such a prominent contributor to the electronics industry, we present a summary of his life and two interviews with those close to him. Pendred Noyce, one of Bob's four children, provides a deeply personal account of her father; while Gordon Moore, chairman of Intel, recounts the evolution of their joint careers. I hope you find this to be a fitting tribute.

On another note, as we look ahead to our 50th anniversary celebration on November 1 and 2, all of us at RLE are working hard to bring together a banner occasion.

Waiting for you on Friday afternoon will be a well-organized set of lab tours and a poster session. A gala evening reception will herald the opening of a special RLE exhibit in MIT's Compton Gallery.

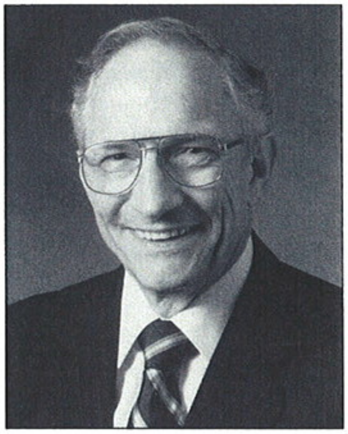
On Saturday, a reunion breakfast at the MIT Faculty Club will be followed by six talks presented by RLE's faculty at MIT's new Tang Center. These talks will be geared for general audiences, and will demonstrate some of RLE's cutting-edge research. Two plenary talks will follow lunch, one by MIT President Charles Vest, and the second by science author and television series host James Burke. All of this will be capped by a lively dinner party on Saturday evening.

For more details on each event, please turn to page 30. It promises to be a great time; fifty years is a very special milestone, and we're giving it our all! Please join us—we'll be delighted to see you.

ROBERT N. NOYCE

Fresh from Grinnell College in Iowa, Bob Noyce enrolled in MIT in the fall of 1949. He anticipated continuing his studies on the transistor, a newly discovered device that he had been fortunate enough to work with while an undergraduate at Grinnell. His physics professor at Grinnell, Grant O. Gale, had acquired two of the first transistors from a colleague at AT&T, co-inventor John Bardeen.

To Bob Noyce's disappointment, studies on the transistor had not yet begun by the time he arrived at MIT. Instead, he worked with Professor Wayne B. Nottingham's Physical Electronics Group in RLE on cathodes and electronic circuits. His doctoral dissertation was titled Photoelectronic Study of Surface States on Insulators, *and he received his PhD in 1953.*



Robert N. Noyce (Photo courtesy Intel)

His professional career began at Philco Corporation as a research engineer. He then joined Shockley Semiconductor Laboratory. As a member of the "Fairchild Eight," he left Shockley to cofound Fairchild Semiconductor, where he served as research director. In 1959, he became vice president and general manager, and then group vice president of Fairchild Camera & Instrument from 1965 to 1968.

Along with Texas Instruments' Jack Kilby, he was named co-inventor of the integrated circuit in 1959. Coincidentally, the two scientists had been working independently to find answers to similar problems with transistors and diodes. Bob's solution, based on colleague Jean Hoerni's planar transistor device, enabled microchips to be easily mass produced. Ultimately, Bob became the holder of sixteen patents for semiconductor devices, methods, and structures.

In 1968, he and colleague Gordon E. Moore cofounded N.M. Electronics, which later was renamed Intel Corporation. Bob served as Intel's president and chairman from 1968 to 1975. In order to focus his efforts on issues in the semiconductor industry, Bob stepped down as Intel's president. He continued to serve as vice chairman until 1979.

With four other colleagues, Bob established the Semiconductor Industry Association in 1979. He left Intel in 1988 to become CEO of SEMATECH, a consortium of fourteen American electronics companies working with DARPA to maintain competitiveness in global semiconductor markets.

During the 1970s and 1980s, he renewed his ties with MIT by serving as a member of the San Francisco Area Council, and on the visiting committee of the Department of Electrical Engineering and Computer Science. He was also a life member of the Sustaining Fellows Program and a regional chairman for MIT's Campaign for the Future.

On June 3, 1990, Bob Noyce suffered a fatal heart attack. Earlier that year, with the conviction that his goals at SEMATECH had been accomplished, he had announced plans to step down from his CEO position by year's end. His daughter Penny Noyce said, "My father told me that he planned to live past ninety. I only wish that he had. I think he crammed ninety years worth of living into sixty-two."

***RLE currents** presents these interviews with Dr. Gordon Moore and Dr. Penny Noyce as a tribute to the late Dr. Robert N. Noyce (PhD'53), a dedicated entrepreneur and scientist whose innovative companies and inventions have touched all our lives.*

PENDRED E. NOYCE

Pendred E. Noyce is the second of Robert N. Noyce's and Elizabeth Bottomley Noyce's four children. Born in Abington, Pennsylvania, in 1955, while her father was starting his career at Philco, she went on to graduate from the Stanford School of Medicine. Currently, Dr. Noyce is a staff internist at the Boston Neighborhood Health Center.

An advocate for improved mathematics and science education, Dr. Noyce works with Ann Bowers, her late father's second wife, to oversee the Robert N. Noyce Foundation. Among other programs, the foundation supports Project 2061, a long-term initiative of the American Association for the Advancement of Science that seeks to reform K-12 education in science, mathematics, and technology. She is also active in Partnerships Advancing Learning of Mathematics and Science, a statewide program of the Massachusetts Department of Education and the National Science Foundation. Dr. Noyce also works with her mother, philanthropist Elizabeth Bottomley Noyce, in her efforts to fund charitable organizations in Maine.

Dr. Noyce serves on the board of overseers at Boston's Museum of Science, on the editorial board of the Journal of Science Education and Technology, *and on the advisory board of Summerbridge Cambridge.*

MEMORIES . . . My most vivid memories are family vacations. I remember my father spending so much time preparing us kids to ski with those double-layered leather boots. When we fell off the ski lift, he'd pick us up and dust us off every time. On one vacation, when we took ice skating lessons, he'd watch us kids and then do leaps around the rink. He'd fall occasionally, but he made great progress because of his gutsiness. He'd say that you can do 90 percent of a task in 50 percent of the time; it's the last 10 percent that takes time. In those activities where he was willing to be an amateur, he'd go ahead to get to that 90-percent level.

He played hard and plunged into everything he did. Whenever he saw a musical instrument he hadn't seen before, he would try to play it. One time, he hit a home run in a father-son softball game and everybody got on him, telling him that fathers weren't supposed to hit home runs.

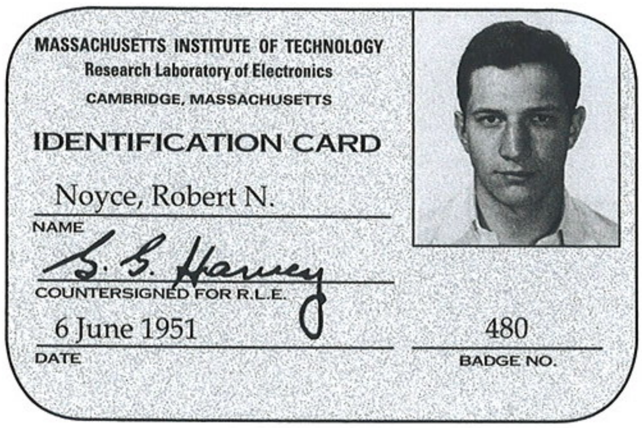
When we moved to California, there were mustard fields behind our house with apricot orchards all around. Of course, that changed during the time we lived there. By the time I was an adolescent, I remarked on this change and was told that it was my father's fault. I didn't understand what that meant then. Certainly, though, being in a place that was undergoing rapid economic growth is part of what I remember.

At home, my father spent lots of time in our basement fiddling with stuff. When we lived in Los Altos, he led a small madrigal group. Whenever they met at our house, we'd go to sleep with songs and music coming from the living room.

He had badge number eight at Fairchild, and I knew that meant he was important and one of the bosses. The story was that he was the last one who broke off from Shockley, and that's why his badge number was eight. I don't know if it's true, but that's what I understood.

Roger Boravoy, a patent attorney at Fairchild, and his family were our friends. Once, they came over to our house, and he asked his two-year-old daughter, "What did Bob Noyce invent?" She said, "An integrated circuit." I was seven or eight at the time, and I didn't know that until she piped up and said it. My father was modest and he didn't talk much about it at home.

As Fairchild grew, many people whom my father had started it with went off to start their own companies. In his words, they were the "Fairchildren," and he was one of the last to go. Eventually, my father became discontented with the fact that Fairchild Semiconductor was doing better than any other division, and it was asked to carry the rest of the company.



By the time he started Intel, I was thirteen and I understood more. At home, when he talked about starting Intel, he said that he was going to hire only perfect people. We teased him and said, "Don't you already have only perfect people at Fairchild?"

LESSONS . . . We would complain about our wages for chores and he'd say that we had to work hard to make money. He also made it clear that education was important and that we were expected to do our best. He made bets with us about our report cards before he opened them. Once, he gave me a hard time for getting an A- or B+. I said, "I bet you didn't get all A's." He pulled out all his report cards going back to second grade, and he did get all A's. Other than that, he wanted us to do whatever interested us. There was no push to do a particular thing. Initiative and adventure were important.

MENTORS . . . My father talked about many intellectual areas, and he was interested in what people had to say, but he didn't talk much about himself or the influences on his life. He did have a lot of respect for his father. Part of that respect had to do with his father being an intellectual and a leader in a small community. He was also very close to Gordon Moore, since they were partners for such a long time; and Grant Gale, his professor at Grinnell College.

The wife of my father's PhD advisor at MIT recently sent me a note that my father had written while he was at Fairchild. The note told his former advisor that he was still a mentor because of the integrity of the work that had been done in the advisor's lab. What especially struck me was my father's reference to integrity as the thing he took away.

MIT . . . I get the impression he wasn't terribly proud of his doctoral work. He didn't think it was his best work and it probably wasn't the area he was most interested in. When I visited Grant Gale after my father's death, he showed me a letter from one of my father's MIT advisors. Grant had written to MIT asking how his old student Bob Noyce was doing, and if he had been adequately prepared. There was a sense that my father had gone off to the big city and Grant, his old professor, wanted to know if he was doing all right. The MIT professor responded that my father was doing well, but it must be disappointing to him because they didn't have transistors, which they had in Iowa.

CONTRIBUTIONS . . . Clearly, the impact of integrated circuits on what we do every day is huge. I think my father felt lucky to be in the right place at the right time and to also be studying the right thing. Someone else probably would have come along and it would have happened anyway, but he was there at a pivotal time. The time was right and Jack Kilby's invention was 85 percent of the way there. I met Jack at my father's memorial service in Texas. I think they respected each other. There was a dispute at one time because Jack was named as the inventor of the integrated circuit. Sometimes my father would talk about it, but there was never any animosity. It was just something the lawyers were doing and something he was strongly invested in personally.

I think more about my father's contributions in terms of building an environment and an attitude for people and the company. My father contributed to the idea that business is a meritocracy, and everybody is free to contribute as much as they can. Nobody had a reserved parking place or a huge corporate office with a mahogany desk bigger than anyone else's. It wasn't about the power of position; it was about the power of ideas.

MOTIVATION . . . I've spent much time trying to figure out what made him a leader, besides his talents. He didn't mind working on a team as long as he could have his freedom of movement, but I can't think of any group he belonged to where he wasn't the leader. It wasn't that he was domineering or dominating, it was simply that he was dominant and people paid attention to what he said. He had great intellectual power, but he never made other people feel that they didn't have it. It was never one-upsmanship. People liked to be around him because of his optimism and openness. He believed in competition without animosity or suspicion.

He always liked starting something new. One thing he said when he started Intel was that Fairchild had gotten too big. I think after a while Intel got too big for him too. He didn't really want it to stay small, but that's when it was most exciting.

He also liked risk and things that were on the edge. Just look at the sports he liked—skiing, flying, scuba diving, and hang gliding. He could have been a pioneer at any time in history. He would have been somebody who went to the frontier because he liked to live at the edge where innovation and individual effort are required.

He liked to look at something formulated into a problem and then figure out an approach. Within that, there were the elements of play and of building things. I think he felt more comfortable solving technical problems than human problems. Although he liked people and being a leader, he didn't like interpersonal conflict. He was graceful about nurturing the strengths of those who worked with him. Someone once told me that when they first started at Intel, they submitted a report and it came back with a handwritten note from my father saying it was good work. This person didn't expect someone on my father's level to respond personally. It was about empowering other people. There was something essentially nonenvious about my father that enabled him to do that.

He had a profound impact on many people. Usually, it was something he said to them along the lines of, "You can do it." One of his friends became interested in a harpsichord that my father had built. He encouraged his friend, and that man has been building harpsichords ever since! My father had an authority when he told someone "You can do this," and they would believe him.

EDUCATION . . . Shortly before he died, my father spoke at a Junior Achievement national convention. He talked about the values he grew up with—work hard, save your money, and get an education. He was impatient with middle-class families who said they didn't have enough money to send their kids to college. He thought it was irresponsible and poor planning. He said when he was growing up during the Depression, they didn't always have shoes, but his parents were always putting aside money for college. Well, college at that time didn't cost as much as it does now, and he did get scholarships at Grinnell, which he was always grateful for. He believed education was the most important thing because it provided people with the opportunity to take initiative in their lives.

All of his activities were at the higher education level, until he heard Bruce Albert of the National Academy of Sciences talk about the K-12 system. This was a couple of years before he died, and he became concerned about it. He talked to his wife Ann Bowers about what he could do after he left SEMATECH, which he had planned to do the spring before his death.

Today, the Noyce Foundation, which was set up in his will, is focused on K-12. Ann is trying to make sure things are being done the way he would have liked them. It's been interesting trying to make the foundation reflect his values when it wasn't something we actually talked about.

ETC. . . . I think my father would like to be remembered as somebody who had much joy in life; who made a contribution and inspired others. He didn't talk a lot about MIT. I know more about Grinnell, and he was more closely linked there than to MIT. However, he did endow a nontenured professorship at MIT, and a while ago I spent a day talking to various people there. My reflections from having been at MIT are that all the buildings are like a huge basement inside, and my father was always very happy experimenting with his stuff in the basement.

GORDON E. MOORE

Chairman, Intel Corporation

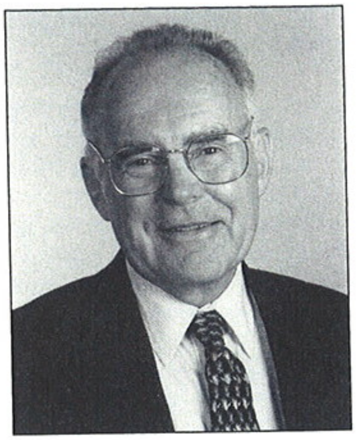
Gordon E. Moore, a graduate of the University of California at Berkeley (BS '50) and Caltech (PhD '54), conducted basic research in chemical physics at Johns Hopkins' Applied Physics Laboratory before joining Shockley Semiconductor Laboratory in Palo Alto, in 1956. Subsequently, he became part of the notorious "Fairchild Eight," a group of Shockley employees who left to establish Fairchild Semiconductor in 1957. He served as Fairchild's manager of engineering and then director of R&D, as it became the first company to commercially produce integrated circuits.

In 1965, Dr. Moore wrote an article for Electronics, *in which he predicted the power of integrated circuits would double every year with proportionate reductions in cost. The prediction became known as Moore's Law, and today it is an axiom in the electronics industry.*

Intel was cofounded in 1968 by Dr. Moore and Robert N. Noyce (PhD '53). Their goal was to develop semiconductor computer memory, a new technology that would replace magnetic core memory. By 1971, Intel had introduced the world's first microprocessor. Today, 75 percent of all personal computers are based on Intel's microprocessor architecture.

FIRST IMPRESSIONS . . . I was a physical chemist at Johns Hopkins University when Bill Shockley phoned me. I had wanted to return to California, where I grew up, and to do something more practical. So, this was a great opportunity. I met Bob Noyce in April of 1956. He came to work for Shockley on a Friday, and I came on the following Monday. We were staff members, and Bob became the *de facto* leader of our group. He met people easier than anyone I've known, and everyone liked him when they first met him. He could easily walk into any situation and be at home.

BEGINNINGS . . . Shockley had peculiar ideas about motivating people, and there were bizarre incidents, so we tried to insulate him from any management role. We even asked Arnold Beckman, who had financed the organization, to get Shockley appointed at Stanford or involved in consulting. We were making great progress until someone told Beckman it would ruin Shockley's career, so he changed his mind. He said Shockley was the boss, take it or leave it. We decided that we had burned our bridges so badly that we all had to look for new jobs.



Gordon E. Moore (Photo courtesy Intel)

Initially, there were seven of us. Someone in our group wrote to his father's friend at an investment banking firm, asking if he knew of a company that would hire the whole gang. When one of the firm's senior partners and Arthur Rock visited us, someone in our group talked Bob into coming along. The investment bankers told us that we should set up our own company, and they would find us the financial support. We contacted about thirty-five companies on the New York Stock Exchange that might have wanted a semiconductor operation. They all turned us down without even talking to us. Then, the bankers accidentally ran into Sherman Fairchild, and the management at Fairchild Camera and Instrument were willing to take a shot at it. That was the founding of Fairchild Semiconductor.

None of us had any business experience, so the first thing we did was hire Ed Baldwin as our boss. He had been engineering manager at Hughes Semiconductor. About a year later, he spun off another company with some of the people he brought with him. We discussed whether or not we should look for someone else because we didn't want this to happen again. So, we elected Bob as the general manager of Fairchild Semiconductor. That's when he officially became my boss.

NEW DIRECTIONS . . . Fairchild wanted to run the company with a three-man committee and a board of directors who didn't know anything about our business. They also wanted to bring in someone from the outside, even though Bob was the logical internal candidate. Bob knew he was going to be passed over, so he decided it was time to do something else. I was director of the laboratory then, and I was frustrated too. It was becoming difficult to move new ideas from the laboratory into production. So, I thought it was a good time to go. When Bob and I decided to start a company, Andy Grove, the lab's assistant director, wanted to come along too.

Raising money for Intel was interesting. It was the heyday of venture capital, and we had our successful track record from Fairchild. Art Rock, now a San Francisco-based venture capitalist, called some friends and raised the money in an afternoon. When we started Intel, Bob was president and I was executive vice president. Bob had more of an outside focus since he had been away from the technical aspects of the business for some time. I had more of an inside focus since I was still running a laboratory. We had worked together long enough and we trusted one another.

GOALS . . . With Intel, we saw an opportunity to change the leverage in the semiconductor business. It was difficult to define a complex product that could be made in large volume since everything tended to become unique above the individual gate level. The industry was at a point where low-cost assembly in southeast Asia was a competitive advantage.

We saw an opportunity to develop new technologies oriented to making semiconductor memories; specifically a product that could be made in complex blocks and sold for various applications. By doing that, we thought we could compete with established companies by putting cleverness back into processing silicon.

HALLMARKS . . . We made some fortunate choices, such as the metallic oxide semiconductor (MOS) technology we chose to develop. We started with what I call, in looking back, our "Goldilocks strategy." We decided to develop three areas—bipolar technology, silicon gate MOS, and multichip assembly technologies, where we put several memory chips into one package. The bipolar technology worked so well that our competitors copied it right away. The multichip technology was just too hard, and we still can't do it cost effectively. But, the silicon gate MOS technology was just right.

When we focused on it, we got by a few technical problems without major difficulty, but the larger established companies got hung up on them. As a result, we had the technology to ourselves for about seven years, and we had a good chance to become established. It wasn't until 1975 that we had competition in silicon gate from the established companies. If it had been easier, we would have had competition sooner. If it had been harder, we might have run out of money before we even had our first client. But, we didn't know that when we started out.

CONTRIBUTIONS . . . Bob's technical contributions were extremely important up through the integrated circuit invention. They were key to the growth of the industry. Another one of his contributions happened in the beginning when we had trouble selling them. Our point of contact to the customer typically had been the circuit designer. When we told the designers that we had the circuit already designed, it didn't hit a responsive chord. They had all kinds of reasons why it wouldn't be reliable. Bob told them, "We'll sell you the circuit for less than you can buy the individual components to build it yourself." That was a major step in getting integrated circuits broadly accepted, and it gave the industry a big boost. Suddenly, it was the cheapest way to do things.

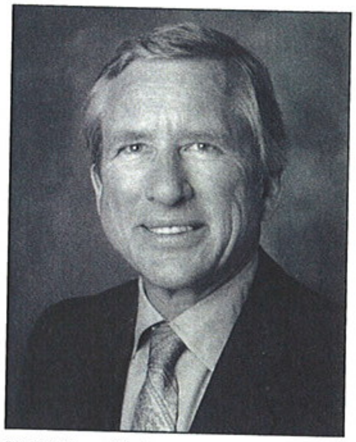
Later, Bob was one of the first people to realize the impact of the Japanese push towards quality. When he returned from a trip to Japan, he gave us a fix on how their quality was much better than ours. It took a while for that to sink in, but he certainly started us thinking about it. Partly as the result of that, he was instrumental in forming the Semiconductor Industry Association, which has had a significant impact on trade-related issues. In turn, that led to his position on competitiveness, which resulted in the formation of SEMATECH. Bob was one of the driving forces in this whole competitiveness issue. He finally took on the job of

(continued on page 25)

H. RICHARD JOHNSON

Vice Chairman, Watkins-Johnson Company

H. Richard Johnson (PhD '52) came to MIT in 1947 after completing his bachelor's degree at Cornell University (BEE '46). He received a four-year physics fellowship at RLE and worked in the laboratory during its formative years, from 1947 to 1952. After graduation from MIT, Dr. Johnson headed the microwave tube department at Hughes Research Laboratories, where he met Dean A. Watkins. In 1957, they established Watkins-Johnson Company (WJ) of Palo Alto, California. Originally founded as a defense electronics firm, WJ later diversified its business to semiconductor manufacturing equipment, telecommunications, electronic products, and environmental consulting services. Its product line expanded to include receiver and digital processors for intelligence collection, solid-state microwave devices and subsystems, and chemical-vapor-deposition machines for semiconductor manufacturing. Today, WJ's semiconductor equipment is used by a majority of the world's producers of microprocessor, logic, and computer memory chips. A holder of three patents and a former Stanford University lecturer, Dr. Johnson served as WJ's president and CEO until 1988.



H. Richard Johnson
(Photo courtesy Watkins-Johnson)

MEMORIES . . . When I got to MIT in 1947, I was told to look around RLE and see what I might be interested in. RLE had everything—state-of-the-art equipment, brain power, and lots of room. I became interested in Lou Smullin's group, which was working on traveling-wave tubes. After one project with him, Professor Stratton suggested it would be better for me to do something more in line with physics. I found Woody Strandberg, and he became my thesis advisor for my work on microwave spectroscopy.

BEGINNINGS . . . Dean Watkins and I were on the technical staff at Hughes Aircraft in Culver City, California, where they were working on traveling-wave tubes. I didn't know much about them, and I became acquainted with Watkins by picking his brain on the subject. Watkins left Hughes after a year to join the faculty at Stanford, but five years later he became restless. In 1957, he asked if I would like to start a company with him. As a middle manager at Hughes, I was also restless and I thought it would be fun. We raised some money (now called venture capital) from a company in San Francisco with help from a couple of MIT graduates—Bill Hewlett ('36) and Fred Terman ('24). In the beginning, Dean Watkins was president, I was vice president, and we had about three employees. When we went public ten years later, I became CEO and Watkins became chairman of the board. We've always worked closely together and our offices have always been side by side. Today, Watkins is the chairman of the board, I'm vice chairman, and we have about 2,200 employees worldwide.

GOALS . . . Traveling-wave tubes were the only things Watkins and I knew anything about. A lot of big companies like GE, Sylvania, and RCA were working on them then. We thought we could make a tube with better electrical specifications and better reliability, and we did. We wanted R&D contracts from the government so we could develop products that we could also manufacture. We also wanted to make a profit so we wouldn't disappear.

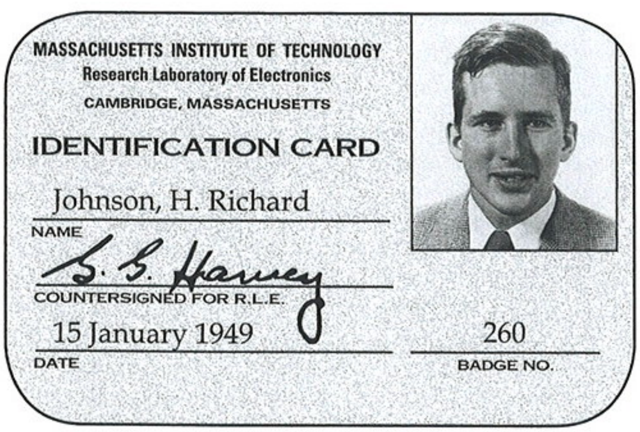
HALLMARKS . . . Watkins-Johnson made state-of-the-art traveling-wave tubes that enabled spacecraft to radio signals back to Earth. Pioneer X, which flew out of our solar system some time ago, contained traveling-wave tubes that we made for its voice. So do the Voyagers I and II, and Galileo spacecrafts. These spacecraft transmit at different frequencies. Some are S-band, others are X-band, and others have both frequencies. They can measure the atmospheres in moons and other planets as the two frequencies are occluded. We also made low-noise traveling-wave tube amplifiers that are now obsolete, but when we made them, they had the world's best noise figures and the longest life. We also sold intelligence-gathering radio receiving equipment.

We now make solid-state amplifiers with state-of-the art properties, low-noise amplifiers, and mixers with high dynamic range. In addition to being the sole supplier for several parts of the Hughes and Raytheon Advanced Medium-Range Air-to-Air Missile, we make solid-state microwave components, microwave subsystems, radio receiving equipment for the intelligence community, and processing tools for the semiconductor industry. Our machines work at atmospheric pressure and can make the doped silicon dioxide dielectric coating on wafers. These machines have greater throughput than our competition's. One of our machines deposits the oxide from silane. The newer ones use tetraethyl orthosilicate, which is a low-temperature process that does a better job of coating deep grooves in small geometries. Our semiconductor processing equipment accounts for about 40 percent of our sales, and it's practically 80 percent of our profits.

In the defense business, we're one of the suppliers that still makes microwave equipment. Many of our competitors have disappeared or are not very strong. In the business of semiconductor processing equipment, our throughput is what sets us apart. Our products enable the contact dielectric to be applied to more wafers per hour than any other method.

GROWTH . . . When I was CEO, we perceived solid state as the wave of the future. We started working on silicon, but decided that too many people knew so much about it that we would never catch up. So, we tried a new material—gallium arsenide. A tremendous amount was accomplished by Keith Kennedy when he became our CEO in 1988. We were making chemical-vapor-deposition machines when he took over, but it wasn't a major part of our business. In his first year, the company got a little bigger and made a little more profit. Then world peace broke out and defense took a nosedive. It didn't look good for a couple of years, but then Keith got our semiconductor business fired up. Also, many of our competitors disappeared. Now, our semiconductor business is quite successful.

ISSUES . . . We're a defense company and the world is now a more peaceful place than it was before, so defense budgets aren't as large as they used to be. It's also difficult to be able to do something new quickly, and then have a product that works and is quickly accepted. For example, in broadening our semiconductor equipment line, we would like to make a high-density plasma coating system. With this system, we might be able to make lower dielectric and intermetallic dielectric layers, which cannot be done with our current equipment. This will be a new venture for us, and we're trying to do it fast so that when the need arises for these machines, we'll have a working piece of equipment that we can manufacture. It's a frantic process; making sure something works the way we want it to, and doing it with the people we already have so that we can afford to finish it on time. Your tool may be the greatest in the world, but if it's six months late, customers won't use it.



CORPORATE CULTURE . . . It's our policy to obtain technical staff at the beginning of their careers, when they start out from school. The top universities have the best, brightest, and most motivated young people. So, when you find a person who has graduated from one of the top schools with good grades, you have a smart person. We have quite a few MIT graduates on staff, and we're getting more all the time. When you hire an engineer who has just graduated from a top school with good grades and good references, you have someone who has an excellent chance of being productive. If you hire an experienced engineer who has had many jobs, you have an excellent chance of winding up as the top line on their resume before that person does anything useful. We do hire senior engineers when we have problems that we don't know anything about and when we don't want to reinvent the wheel. In addition, we're so small that we don't do fundamental science unless it relates to something that we can sell fairly soon. So, in that area, the new graduates bring us modern knowledge.

We don't bet the company on wild schemes. We simply move ahead slowly. We've produced mostly monotonic growth that hasn't been spectacular, but it's comfortable. We do take some risks, but not colossal ones, if we can avoid them. We have three main manufacturing sites where we also do engineering. In Palo Alto, we do defense component and subsystem production. In Scotts Valley, California, we do semiconductor R&D and production. In Gaithersburg, Maryland, we do wireless communications equipment. We've also been trying to start demonstration laboratories in Japan, South Korea, Singapore, and Belgium.

REWARDS . . . It's good to see the company doing all right. It's fun to be the old man who gets credit for a lot of the good things that have happened in the company. I also enjoy my association with our employees. We have many loyal employees who appreciate working here. I don't own a large part of the company and we have a lot of employee ownership. It's a good place to work and we've helped a lot of people.

ETC. . . . I used to see Bob Noyce (PhD'53) and Gordon Moore when they started Fairchild Semiconductor in Palo Alto, in 1957. We didn't have any direct business connections because they made silicon transistors and we were in the microwave business. However, Bob and I both knew William Shockley, and he was one thing we could always talk about.

Before I graduated from MIT, Shockley invited me to visit Bell Labs, where he was working at the time. He wanted me to talk about what I was doing, so I gave a talk about ketene. It wasn't my doctoral thesis, but I knew more about it than anyone.

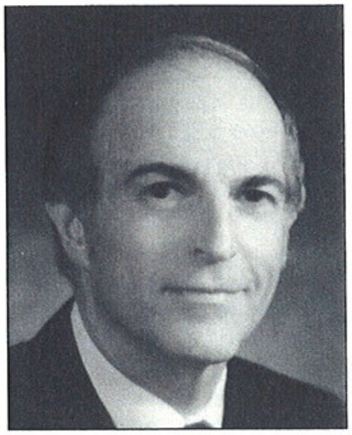
At my talk, it was like a murderer's row with Anderson and Shockley in attendance. When I finished, no one had a question, except for Shockley. He said, "In that one microwave absorption line, you said the statistical weight was three." He drew a picture on the blackboard and said it was possible that the weight was one. I had copied the statistic from a Herzberg book, so I knew it was right. I didn't know what to say, but I told Shockley that I would think about it and write him a letter. When I returned to MIT, I got out the book, and he was right! I wrote a letter telling him I was sorry. In my paper on ketene, I even gave him credit for helping me.

Two years later, I met Shockley again at a conference in California. We were on a long line waiting for food. Shockley went to the front of the line and got a plate of food. He came through the line offering it to people; trying to proselytize them.

When he got to me, he said, "I know you. What's the connection?" When I reminded him, he said "Oh, yeah. You're the guy who didn't know a damn thing about quantum mechanics." One of my specialties at MIT had been quantum mechanics, so it was an awkward moment. Then I said, "Does your wife like it here in California?" He replied, "She didn't like it, so I had to get a new wife." I couldn't think of anything else to say. After another awkward silence, he continued down the line with his tray of food. He was smart, but he certainly was a character.

DAVID I. KOSOWSKY

Chairman Emeritus, Damon Corporation



David I. Kosowsky
(Photo courtesy David I. Kosowsky)

David I. Kosowsky (SM '52, ScD '55) worked in RLE as a research assistant and staff member from 1951 to 1955. In 1961, Dr. Kosowsky co-founded Damon Corporation of Needham Heights, Massachusetts, with Carl E. Hurtig, a former RLE staff member. Damon quickly diversified its original electronics business by developing new services and products in health care, medical science and instrumentation, and educational and leisure-time activities. Dr. Kosowsky served as Damon's chairman and CEO until 1989. He continues to devote much of his time to serving on the boards of many nonprofit and civic organizations in the Boston area.

MEMORIES . . . In 1951, I came to MIT with several other City College graduates. When I applied for a research assistantship, I ended up at RLE. City College had been a good place to learn, but it didn't have the opportunities that we had at RLE. RLE was a place where innovation could flourish. There were many stimulating people and lots of exciting interaction. I was able to do what I enjoyed, just as long as it was reasonable and contributive. It didn't matter if it had a direct relationship to any current project. What was important was that it was innovative or interesting to the people around me.

MENTORS . . . Jerry Wiesner was responsible for many things that have happened in my life. He was one of the most wonderful people I have ever met. In 1955, Jerry and Jerrold Zacharias formed a company called Hycon Eastern, which later changed its name to Hermes Electronics. At the time of my graduation, Jerry asked me to join Hycon. I had been offered a job at Hughes Aircraft, largely because of my thesis work in crystal filters, but I decided to join Hycon, where I started a division based on my thesis research. My business career, up to and including the formation of my own company, was based on crystal filters.

MOTIVATION . . . Hermes went public in 1958 and merged with Itek Corporation in 1960. Itek's primary interest in Hermes was its communications work. After the merger, a division called Itek Electro-Products was created to house the Hermes Crystal Filter Division. This new operation did not fit either Itek's business interest or its corporate culture, and it did not thrive. In 1961, I formed a company called Damon Engineering with a few of my coworkers. Damon was formed to continue the work on the piezoelectric crystal products that we had started at MIT.

BEGINNINGS . . . Damon was a small electronics company when it was formed. In 1965, we entered the education business. This business was based on Jerrold Zacharias' idea of teaching science to kids in the post-Sputnik era. We developed inexpensive apparatus that turned the classroom into a laboratory, since most elementary and secondary schools didn't have laboratories. Basically, we followed the development of new curriculum programs, working with the development groups on apparatus for their programs. Then, we approached the publishers of the new course textbooks and entered into exclusive marketing arrangements with them. At the time when Damon had its first public offering in 1967, it had about $3 million in sales from electronic and educational products.

Damon also entered the hobby business in order to provide science-oriented students with a means to purchase the apparatus that was only available to them in school. We acquired companies that marketed to school-age children, such as Estes Corporation, which manufactured model rockets. Estes was a well-known company with a very large catalog business. We did not acquire them for their model rockets, but rather to use their catalog distribution system for our scientific apparatus. Children of all ages liked the rockets, but they just weren't turned on by the science apparatus. Over time, our education business became dwarfed by the hobby business, which took off on its own.

GROWTH . . . In 1969, in the midst of strong growth, we began an acquisition program in medicine to further diversify our business. We acquired IEC (International Equipment Company), a laboratory centrifuge company, and used it as a vehicle to enter the clinical laboratory business. The Clinical Laboratory Act of 1967 made it possible for non-physicians to own clinical laboratories. In 1969, there were thousands of small independent clinical laboratories serving physicians and hospitals. We were the first company to acquire and consolidate clinical laboratories, taking advantage of new instrumentation that automated blood chemistry and other laboratory tests. The new automated machines required large volumes of tests in order to achieve the desired economy of scale. The consolidation and centralization of small independent laboratories made this possible. By the early 1970s, Damon laboratories had combined revenues of about $100 million, resulting from acquisitions and internal growth.

We began as an electronics company and became primarily a medical company, so it's hard to predict where you're going to go. We also formed Damon Biotech, based on a technology called microencapsulation. However, we were acquired before that technology could be fully developed.

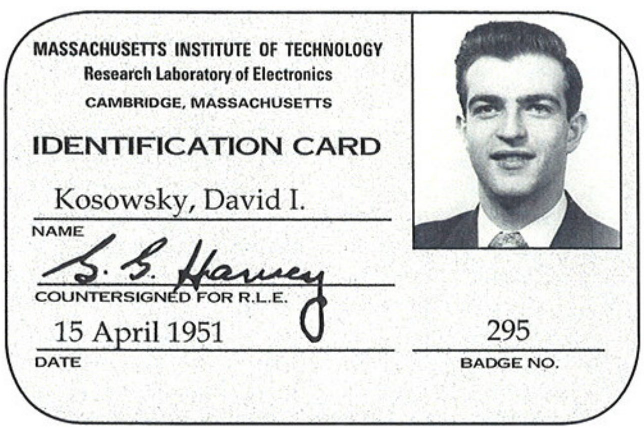
FIRSTS . . . Damon formed the first, and for a while the largest, network of central laboratory facilities. Before Damon, a few central facilities served physicians by mail order. In addition, we were the first independent network to work extensively with hospitals. Damon's clinical laboratory network became its fastest growing business segment.

PARTING WAYS . . . Damon's aggressive acquisition program had its dangers, and we had some difficult years in the mid-1970s. We recovered in the late 1970s, with strong growth continuing into the 1980s.

In 1988, Damon was attacked by a private group supported by Drexel-Burnham-Lambert. It was the 1980s; the days of Michael Milken and junk bonds. Damon had a lot of cash and diverse shareholders, but we didn't think we would be attacked since we weren't that big. We had about $250 million in sales. We were also technology-based, and in an industry without many large players.

This was one of the toughest times of my life. Damon was a company I had founded and enjoyed running. However, there were few choices when put into play by raiders. We could have arranged a leveraged buyout, but Damon always had a lot of cash and flexibility, and I didn't want to run a leveraged company, spending my most of my time dealing with large amounts of debt. Damon could also have been bought by someone else, which is what happened a few years later when Corning acquired the Damon laboratories. In the end, we made a friendly buy-out arrangement with the raiders.

CHALLENGES . . . The biggest challenge was dealing with a public company and all the pressures that being public creates. Stock performance is not always related to corporate performance, particularly on a short-term basis. Putting acquisitions together, making them work, and providing opportunities for former owners of acquired companies was also challenging and, at times, very rewarding.



OBSTACLES . . . There was some conflict between wanting to spend much of my time in science and research, and yet knowing that I couldn't or shouldn't. In the days of Damon Biotech, I often visited the laboratories at MIT's Biology Department and at local teaching hospitals. I was also interested in management, and although science was generally more interesting to me, management usually won out because that was my primary responsibility.

SUCCESS . . . For the first five years of its life, the odds are very much against the success of a new business. The primary reason for this is usually insufficient capital. Most entrepreneurs underestimate the true capital needs of a new enterprise. Another significant problem, particularly in businesses that experience rapid growth, may be the inability of the founding entrepreneur to develop the management skills needed to lead a growing business, or to recruit people to perform those functions.

As a company grows and becomes successful, management often finds it difficult to continue to do innovative or entrepreneurial things. The entrepreneurial spirit may have to be directed in different ways. While it may be impractical to continually form new companies, it is possible to enter new areas in innovative and entrepreneurial ways. Damon, for example, was heavily involved in four distinct businesses: electronics, education and hobby products, laboratory medicine, and biotechnology. To make this possible, Damon had to attract people with technical, entrepreneurial, financial, and management skills. I was gratified that we could do this, and particularly that we could meet the challenge of getting entrepreneurs to work as part of our team. By definition, entrepreneurs want to do their own thing.

TECHNOLOGY TRANSFER . . . Damon was involved in technology transfer on many levels, particularly in the biotech area, where Damon funded research at universities and hospitals, and made arrangements to sponsor the development of the results of such research. This was an interesting area because there are conflicts between the roles of industry and universities that need to be addressed and resolved.

ISSUES . . . Some time ago, the United States government legislated a number of entitlement programs in medicine, and now it's difficult to change them. It's clear that we are either not able or willing to continue funding these entitlements at the anticipated growth levels. In laboratory medicine, there will likely be a negative effect in terms of cuts in funding for programs like Medicaid and Medicare. All third-party payers would like to pay less. The only balance to that is economy of scale, and the question is when does that reach the point of diminishing returns?

Today, there are so many issues in medicine: aging, technology, growth without cohesiveness, third-party payments, patients not involved in their own decision making, and physicians working in all types of financial arrangements. It's such a patchwork that it's difficult to predict outcomes, but the financial constraints will certainly always be there. Healthcare financing is an enormous problem, and there are no simple solutions.

REWARDS . . . My work with hospitals has been rewarding. Hospital boards can attract people from many different disciplines. One of my biggest rewards was to bring some knowledge of both health care and business to a complex activity that involved working with both physicians and laymen. On the business side, it was, of course, most rewarding to watch Damon grow.

SIGNIFICANT ACHIEVEMENT . . . Building a successful business from scratch was fun, and to the outside world it might have been my principal achievement. On the other hand, some of the technical things I did were personally more rewarding at times.

MIT has been responsible for so much in my life. It's an institution without peer. The success and contributions of its alumni, even in fields removed from their areas of specialization and training, is testimony to the fact that in the MIT environment, one learns that engineering and science has a significant responsibility to society as a whole.

Ronald A. Howard

Director, Strategic Decisions Group

Ronald A. Howard (SBEE/SBEcon.'55, SM'56, EE'57, ScD'58) cofounded Strategic Decisions Group (SDG) of Menlo Park, California. After serving as an assistant professor in RLE from 1958 to 1962, and as a member of the MIT faculty until 1965, Dr. Howard joined Stanford as professor of engineering-economic systems. As one of the founders of the decision analysis discipline, he has published many articles on probabilistic modeling and decision analysis. His three books on dynamic programming and Markov processes serve as major textbooks and references for research in these fields. Dr. Howard has used decision analysis techniques in a variety of applications—from investment planning to research strategy, and from hurricane seeding to nuclear waste isolation. Today, SDG is an international consulting firm dedicated to helping business executives, planners, and engineers improve their analysis and decision-making skills. As director of Stanford's Decision and Ethics Center, Dr. Howard also leads a program in social analysis.

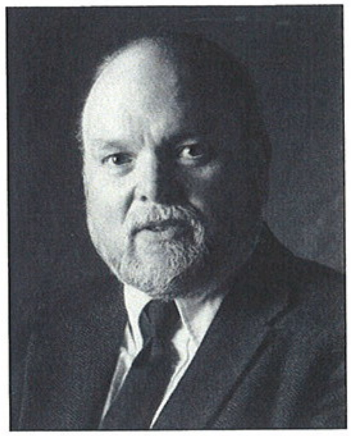
MEMORIES . . . I came to MIT as an undergraduate because of its reputation in science and engineering. This was in the early days of integrated circuits. Later, as a young assistant professor, my interests moved from electrical engineering to using technical ideas in a broader range of problems.

From 1958 to 1964, the hot topics included information theory and magnetohydrodynamics. This was before the integration of computer science and electrical engineering, and we were beginning to see the impact of computers. I was heavily involved in that research and its applications. My interest was in applying technology more broadly to systems and organizations. MIT's Operations Research Center had a connection with RLE, and I worked on system analysis there. I also taught for six years and started a probability course in electrical engineering. I wanted to make sure that people in electrical engineering studied probability and economics. Before leaving MIT, I became associate director at the Operations Research Center.

BEGINNINGS . . . I was one of the five founders of Charles River Associates (CRA). CRA was the successor of another company that I founded with my colleagues called Systems Analysis and Research Corporation. That was an off-shoot of another company called United Research. We had left United Research to start Systems Analysis and Research. After six months, we discovered that we had differences with some of our colleagues. That's when we started CRA. In all these companies, we combined technical and economic ideas. CRA's goal was to bring high-quality economic analysis to business problems with a focus on transportation.

SDG
STRATEGIC DECISIONS GROUP

NEW DIRECTIONS . . . When Bill Linvill (SB'43, SM'45, ScD'49) and I came to the West Coast from MIT, we asked, "Where's Arthur D. Little?" I had always used them as my clinical laboratory, but they weren't here, except for a small office. So, we started a joint engineering-economic systems program at



Ronald A. Howard
(Photo courtesy SDG)

Stanford Research Institute and Stanford University. Students went there on internships and had access to the latest thinking. After a few years, that became the decision analysis group. It was the first such group in industry and it served companies like Exxon, Xerox, and Morgan Guaranty. Two groups of my former doctoral students split off from that. One formed Applied Decision Analysis, and the other formed Decision Focus. Both are still going today. In 1980, three colleagues and I started Strategic Decisions Group (SDG), and today we have over 200 employees.

GOALS . . . SDG's goal is to improve business decision quality for Fortune 100 companies in the United States and internationally. Most of our work involves business problems. We look into what makes a high-quality decision and how you can tell when you have made one. We're not talking about feeling good about a decision. We're talking about leaving a person with a clarity of action about what to do. That doesn't mean clarity of result, and it doesn't mean the situation will necessarily get better. It's knowing you're doing the right thing.

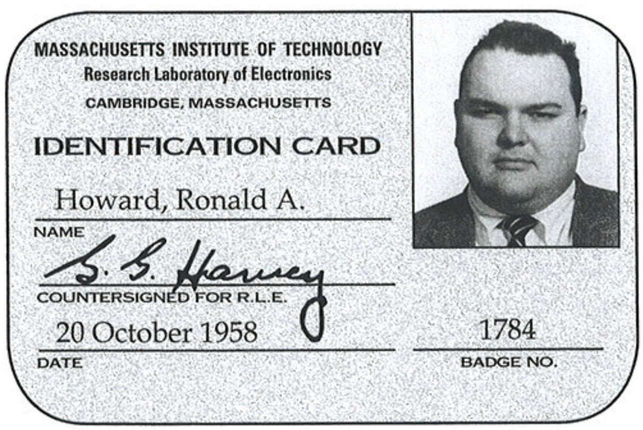
Conversation is what leads people to clarity of action. For example, someone who has spent a lot of money on an investment that's not working out may be tempted to throw more money at it in a futile try to save it. A brief conversation will reveal the initial investment as a sunk cost that should play no role in decisions about the future. Such conversations alone can resolve many issues.

Beyond that, the conversation may involve calculation. Ultimately, the process may also involve equations and computers. One example would be deciding which annuity to choose, but the process itself isn't about calculation. It's about conversation, which may then involve calculation. We must deal with alternatives, information, and preferences. We also must realize that we don't know the future and we must deal with uncertainty. The major factor that confuses people about what to do is uncertainty.

We also have a *pro bono* activity with a local organization, the Community Breast Health Project. We provide expertise to individuals who are faced with a breast cancer diagnosis and many real-life decision-making issues—psychological, family, social, economic, and technical. Stanford's Department of Psychiatry is also involved in the project. Their preliminary studies show that the difference in patients' attitude is a factor of two in results. Think about that. The scientific community wants to keep putting things in your body to see the effects. Here's something with a bigger effect that you can't write a prescription for, even though it's the best thing you can do for a patient.

FIRSTS . . . SDG is the first company to bring the latest, most powerful thoughts and procedures for decision making into the boardroom. There are many excellent consulting companies, and they may be able to help you just by helping you think through issues. SDG's philosophy is more fundamental. We want to leave people not just with clarity of action on a decision, but also empowered with new ways to help themselves. It may take a while to do that, and it may involve a change process, but ultimately we want them to be able to provide their own clarity of action.

Consulting companies are like universities for companies. They transfer technology because they bring in something companies don't have. Yet, they're so expensive that you don't want them around all the time. At SDG, we want to train clients to do things effectively themselves. Occasionally, they might need "brain surgery," and then they'll call us back. We're also working to extend the kind of decisions that we can help our clients with; from strategy to operations. We'd like to be able to say, "Here are the people who can make sure something happens." We can then serve them more broadly, instead of saying that they should do this, but we really can't help them with it. We always want to focus on decision making and not get diffuse.



CORPORATE CULTURE . . . We think about walking our talk and about the home in which we want to live. We think about the essence of our professional life, not just our business. Over the years, we've constructed something we call the value wheel. It's not for our clients; it's to remind ourselves what we're about. The idea is to have fun and to learn in our world of improving decision quality. We also want to treat people with dignity and respect. There's no deception, we tell the truth and we respect everybody—employees, clients, and each other. Then, we also have to be a business. We have to provide valuable services so we can hire the people we want and give them financial security.

At Stanford, I teach a course called The Ethical Analyst. We discuss a scenario in class where you're a sales rep and your company has told you not to talk about a new product that's coming out next week. Then, you meet with a customer who says, "You want me to buy your product, but I don't want it to become obsolete." What do you tell that customer? Think about it as if you were talking to a family member. If that customer was a family member, you'd tell them to wait a week. It's a problem when we have different standards for everyone.

CHALLENGES . . . We're world class in what one might call the hard thinking about decision making. If a person or a group wants to know what's best for them, we can help them in a way that few companies could. I call that knowing the right thing to do, but the challenge is in getting things done. For example, it's easy to get people to do something that's wrong; you could get a consensus on going over a cliff. Our challenge is to get the right thing done. We're world class at knowing the right thing, and we're becoming world class at getting it done. That's our challenge, on both the human and logical sides.

LIMITATIONS . . . We use specialized software and we have to develop some of our own tools to make our work efficient. We're like a pianist who wishes Steinway could make a better piano. We can't find the right piano, so we build one in our back room. These tools bridge the gap between the soft, fuzzy world of executive thought and the hard world of a computer. When you hit the wrong key, a computer doesn't understand what you mean. We have developed powerful ways to bridge that gap better. We use representational devices called influence diagrams, but right now there's no powerful computer software to help us design them. We could develop software, but it's not a good decision for us to spend money on it because it's so specialized. We only wish we could buy the computing engine from somebody.

FUTURE . . . At MIT's Media Lab, I saw possibilities for three-dimensional representations of what we do. Imagine flying around a three-dimensional spreadsheet where if you saw a speck, you could enter it, and the speck becomes the next level. It's like a virtual environment of a conceptual space. Three-dimensional influence diagrams are the next level. Suppose we had world-class computer representations of decisions and world-class commitment of people actually doing those things to support it. We're talking about a transformation, and that's exciting.

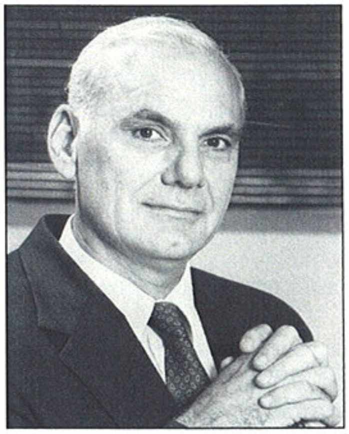
TECHNOLOGY TRANSFER . . . One of my recent doctoral students won a major prize in management science and operations research for his thesis on sensitivity to relevance. It has to do with how big a mistake could you make if you didn't consider the interdependence of certain factors when making a decision. He presented it to SDG as part of our professional development activities. This research had been judged outstanding by the professional community, and it was going right to the people who could introduce it to their next client. It goes both ways because he was also an intern when he did this research and he saw the issues involved. It's like a teaching hospital. SDG has a strong academic program because we have strong applications for it. That's what makes it work.

ETC. . . . This isn't an ivory tower, and we know we can help people. When I teach, I want to be able to warranty that what I teach are at least twenty-year ideas. I want them to last a lifetime. Most of what I learned at MIT met that criterion. I want my students to help people make decisions about everything from investments to medicine, and not just to have a theory on how to help people. That's what I'm committed to—helping people.

Lawrence G. Roberts

President, ATM Systems

Lawrence G. Roberts (SB '59, SM '60, PhD '63) is president of ATM Systems of Foster City, California, a division of AMP's Connectware subsidiary. Between 1958 and 1963, he was a student technician, research assistant, and thesis student in RLE. Since graduation, Dr. Roberts has been involved in the development of the data communications industry, and is an architect of today's packet switching technology. At ARPA from 1967 to 1973, Dr. Roberts promoted the idea of networking computers with different hardware and software in order to share resources. He was responsible for the development of the ARPANET, the first major packet network. In 1973, Dr. Roberts founded Telenet, the first packet data communications carrier. He went on to become president and CEO of DHL Corporation, where he created NetExpress, Inc., and served as its chairman and CEO from 1983 to 1993.



Lawrence G. Roberts
(Photo courtesy ATM Systems)

MEMORIES . . . I came to MIT in 1955 as an undergraduate. While staying on for my doctorate, I became involved in electronics and various research activities at RLE. I worked on the compression of photographs with Bill Schreiber, which was a hot topic. My thesis on the first hidden-line graphics developed the math for three-dimensional graphics, but I switched to communications after a few years. I also worked on the TX-2 with Tom Stockham (SB '55, SM '56, ScD '59), doing an analysis of the wave function needed to do a transform for the speakers that Amar Bose (SB/SM '52, ScD '56) was designing.

In 1962, I had a conversation with Lick [J.C.R. Licklider] and Corby [Fernando J. Corbatò]. Lick said a galactic network was needed where everyone could communicate and all the world's resources would be available, just like the Web. Lately, everyone is writing about the Internet and trying to reconstruct its past. It would be interesting to find Lick's memos, which were written in the early 1960s. Those memos are critical because Lick had the original idea, and he convinced me that it was important. After MIT, I went to the Advanced Research Projects Agency (ARPA) and started the ARPANET.

BEGINNINGS . . . In 1973, I started Telenet, the first packet service for data. It went public in 1978 and was sold to GTE in 1979. Now it's Sprint Data Service and probably the world's largest data service. I went on to DHL for a year to get them out of start-up mode. In 1982, DHL started NetExpress, which built the technology to carry facsimile on data networks. They also had a data communications operation that ran a facsimile service, where we built one of the first asynchronous transfer mode (ATM) switches. In 1993, NetExpress was sold in pieces to AMP, CMC, and KDD. I was interested in the ATM part, which AMP had bought. Their Connectware subsidiary was created for AMP's communications activities, and ATM Systems is a division of Connectware, which is where I am today.

ISSUES . . . From my discussions with Lick, it was clear that there was a gap between computerized communication technologies and communications for computers. The question was how to combine them effectively and intelligently. As packet switching developed for computer communications, things changed dramatically. While we were developing that market for government, I also saw a commercial market. No one pursued it because they thought it was totally incompatible since it involved packets, not circuits. Now, everything is packets, and ATM is simply little packets that handle everything. We're now building the second generation of ATM switches.

There was a period when everyone's ATMs moved data, but they didn't think about solving several critical problems. It wasn't desirable to do what everyone else was doing because when we built a switch, we had to make it work. So, we had to solve some key problems, and I knew what those were because I had been in this field for thirty years. Once, after speaking to Dave Clark at MIT's Laboratory for Computer Science, I concluded that we needed weighted fair queuing to ensure quality of service, so I designed chips to do that. It meant that we could guarantee both delay and bandwidth. No other ATM switches can do that. Now, we're years ahead of everyone in developing a switch that will work and manage quality of service.

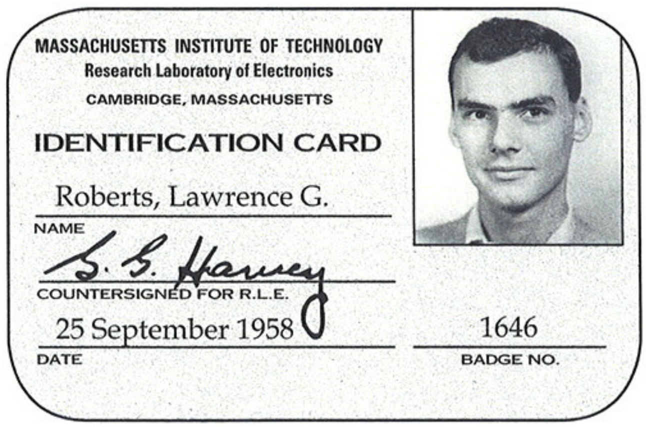
We also had a big hole in the technology that wasn't there for low-speed packet switching. With earlier packet technologies, like X.25, we had flow control, but with ATM, we didn't. So, either we added flow control to ATM or we had to depend on TCP (transmission control protocol), which is much too slow for ATM speeds. I started by designing a new, very low delay flow control for ATM called explicit rate, and submitted it to The ATM Forum. After two years it was accepted as the standard. At the same time, I've been adding it into our chips; laying out the chip design and the detailed code. The company is structured so that I don't have to spend all my time in administration. I can worry about the technology and make sure that it's right.

Our primary concern is getting our products out on time because custom chips always take longer than you think. In terms of switching, 90 percent of the logic is in the chip. Maybe half the work is software, but almost all the functionality is in the chip. For example, in weighted correct queuing, a single chip that does 256 cues must do 190 million additions per second. It's a large number of megaflops that do the computations, and it's all done inside the chip. We use VHDL code for greater design speed. When things are essentially operating at a cell per microsecond (700 nanoseconds for each cell), you must do a lot of computation in that time.

Some other companies won't even touch a chip. But we're at a point now where, if you're not doing chips and you don't have proprietary technology, you won't have a product. All the technology is in doing the chips. It's expensive and they take a long time, but that's an advantage. If it was easy, everybody would be doing it.

OBSTACLES . . . There's always a debate about whether people can do technical work and manage at the same time. Venture capitalists don't like it. They're afraid that if you're a technical person, you won't manage properly. It's a strong attitude that hurts industry. But, it turns out, if you know what you're doing, you can manage better than anybody.

FOREIGN COMPETITION . . . The United States will be ahead in ATM for a while, but the others will overwhelm us if we're not careful. We understand the market, the technology, and the language better. The Japanese had a tough time in the early stages, and they've been struggling to keep up with us. When they see that our first products are working consistently, that's when the United States gets into a serious disadvantage. We need to handle that differently by having one product for the entire world. At GTE, our mistake was developing different products for different countries. You should build one product for the whole world, and it must take advantage of whole-world economics to increase the volume. Then, you need to keep costs down and manage the product for high quality. The biggest factor is to continuously reengineer the product, rather than squeezing the last penny out of manufacturing. By reengineering, we can take advantage of the semiconductor cost reduction trend of 1.5 a year. If we don't get that, then we're losing it. So, it's better to put more money into engineering and redo the chips every year.



LIMITATIONS . . . I'd like a compiler that turns C code into a chip because it takes our engineers nine months to do that. The biggest problem is the time it takes to make a chip; twelve to eighteen months from conception to chip. And, if you're trying to design a product and turn it around, then you need another six months to test it. So, we need one to two years to get a product out when we'd like to have it in six to nine months.

Another problem is that we need supercomputers to do simulation. We have several Sun multiprocessors doing as much as they can, but we don't have a supercomputer. We're simulating one cell per minute, but they're supposed to operate at a microsecond.

Government regulation has also been a hindrance, particularly in the encryption area. In a speech to the National Academy of Sciences, Ivan Sutherland (PhD'63) of Sun said that government should decide when encryption is more important to commercial industry than it is to the government. If that's true, then they should make it available to commercial industry. When I was in the facsimile business, the government got in my way, because if I wanted to put encryption into a product, I couldn't ship it overseas. Encryption isn't critical in ATM yet, but it will be in a few years and we'll have to do something.

FUTURE . . . We're building a device to put ATM over Ethernet called Cells in Frames (CIF). It will drastically lower the cost of ATM to the desktop and the home. By using the current PC-Ethernet interface and by putting the ATM function into software, we benefit from ATM's quality of service and flow control at the cost of the Ethernet. We're planning a line of products for the office, Internet, and the home, using CIF that will support mixed voice, data, and video with quality. We'll have to make several chips to reduce the cost, but it will support ATM functionality in our homes. Basically, everything will be sent in little blocks through local networks to your stereo, television, and other appliances because you'll be able to multiplex everything together. The chips will be available for it, so you'll be able to interface it and connect it economically to all places and switch it.

In terms of connections to wireless, the whole communications network will connect fairly smoothly with wireless. At the moment, we don't have much bandwidth allocated to wireless communication, and it's limited. I'd like to see a broadband spread-spectrum wireless in each building so we can have 100 megabits from your device. Nothing like that is available today with very small bandwidths in the one-megabit range. When people go to ATM, they'll need higher bandwidths for video, and they'll want it in their wireless. We also have many people sharing one band, and that's an even tougher problem. We'd like to have more bandwidth, but that's a problem for the FCC.

SIGNIFICANT ACHIEVEMENT . . . It's either developing the ARPANET or the ATM's new flow-control technology. The development of the ARPANET (the initial Internet) was primarily a management and vision achievement. The explicit rate flow-control design is a more technically significant achievement due to its extreme complexity and it's critical importance.

REWARDS . . . Speaking, publishing, and talking with customers is all rewarding. I publish technical documents through email and send them to the community working in my field. It's rewarding because I can put my thoughts out there and see how the customers like what we're doing.

CHALLENGES . . . Working on details is most challenging because it gets more difficult as I get older. Five years ago, I began doing research on aging issues. I also started taking supplements, which help my brain work like it used to. Few people my age can do detailed programming and design, although they might be good at providing their intelligence and historical knowledge to people. I find it extremely powerful to be able to do both: supervising people who design a product, knowing what that product should do and how to design and simulate it, and running the company. It's a tremendously interesting combination.

J. William Poduska, Sr.

Chairman, Advanced Visual Systems, Inc.

J. William Poduska, Sr. (SB '59, SM '60, ScD '62) worked in RLE's Plasma Dynamics Group from 1960 to 1964 as a research assistant, thesis student, and assistant professor. Dr. Poduska's entrepreneurial career is accentuated by the establishment and cofounding of five companies—Prime Computer, Apollo Computer, Stellar Computer, Stardent Computer, and Advanced Visual Systems (AVS). Headquartered in Waltham, Massachusetts, AVS is the worldwide leader in developing interactive visualization software that transforms complex data into two- and three-dimensional applications. AVS products are used in a broad range of applications, including engineering analysis, medical imaging, financial modeling, telecommunication, and environmental studies.

J. William Poduska, Sr.
(Photo courtesy AVS)

MEMORIES . . . Coming from the South and a military family, I started college at West Point. I was there a short time when I decided I should go to a place like MIT. What brought me to RLE was my association with the Dynamic Analysis and Control Laboratory (DACL), which was an analog computer lab. DACL eventually toned down its activities, but RLE was right there in Building 20 with the same set of activities. I became associated with Professors Woodson, Jackson, and White in the Energy Conversion Laboratory (ECL), and then RLE's Joint Army-Navy Sponsored Programs.

For a person interested in computation, flight, and entrepreneurial things, I couldn't have been born at a better time. Computers were just coming to MIT, and the first one I used was an IBM 650 drum machine. Paul Chana's courses in continuum theory, coupled with the ECL, got me interested in magnetofluiddynamics. It was very deep mathematics, which I enjoyed. At ECL, my studies on turbulence, especially magnetofluiddynamic turbulence, led me to use computers to solve problems. It was like the Peter Rabbit story. I wrapped my arms around the tar baby, and it wouldn't let loose. That, in turn, got me coupled with Fernando Corbató, Bob Dally, Marge Merwin, and Mike Esposito, who were starting the Compatible Time-Sharing System (CTSS). It got me in on the ground floor of those activities and struck the firing pin that got me moving in my career. So, I tell people that I'm a physicist turned bad because I got into the computation business.

What strikes me most about MIT at that time is its loose-fitting environment, and what a platform RLE was! I was an electrical engineer who became interested in fundamental physics problems and then in computation; all in one environment with people who had the flexibility of thought to support that kind of activity. The organizational structures at RLE, DACL, ESL, CTSS, and later Project MAC, gave me flexibility to wiggle around. One can talk about academic freedom in the abstract, but it's one thing to be theoretically capable and another to support people who are at the edges of the envelope. That's what RLE provided for me, and I cherish that.

BEGINNINGS . . . For four years after graduation, I was a Ford postdoctoral fellow and on the faculty at MIT. In the middle of that period, I was also on active duty for eighteen months at Fort Monmouth during the Cuban missile crisis.

After MIT, I worked at NASA's electronics research center in back of the old Tech Square. NASA was in its heyday, and the computational efforts required for future manned missions were extremely important. I ran the Manned Computer Systems Branch of NASA's Computer Research Laboratories, and supervised research for projects like the manned Mars mission, the lunar bay station, and the predecessor to the Earth orbiting laboratory. NASA closed the center at the end of 1969, but I was there for the first Apollo mission. That name Apollo has many connections. It was the name of my second company, and it's also the name of a faculty chair in MIT's Aero Department that we sponsor. Following NASA, I worked for Honeywell's research laboratory in Tech Square. In 1972, I went off with the founders of Prime Computer to begin my entrepreneurial career. There were seven of us, and I was badge number six.

HALLMARKS . . . We called Prime's machines, maybe a little arrogantly, Multics in a matchbox. It was the early 1970s, and we wanted to bring virtual memory and time-sharing to the minicomputer market. We sold machines that could support six to twelve users in a CTSS or Multics environment for $50,000 to $100,000. They weren't as robust as Multics, but they were on the level of a well-performing commercial-grade CTSS environment. They were successful not only in engineering environments, where we knew they'd be, but they were even more successful in commercial environments. We sold machines to businesses, corporate information operations, banks, and Wall Street. Ultimately, Prime sold ten times as many machines in the commercial market as it did in the private market. Frankly, it surprised me. In fact, they had to drag me into the commercial marketplace, but it worked out well. Prime was first to bring virtual memory to small-scale computers.

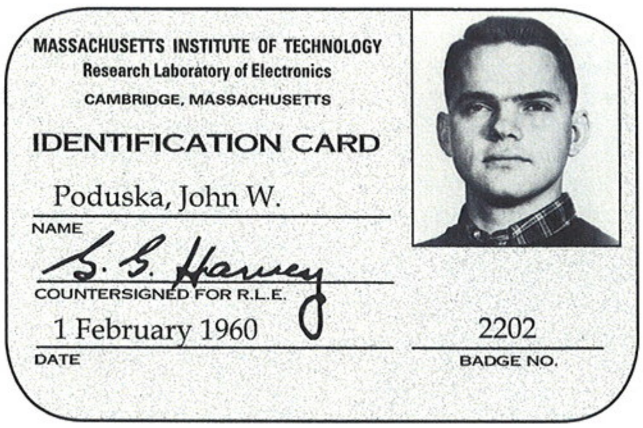
ADVANCED VISUAL SYSTEMS INC.

NEW DIRECTIONS . . . In 1979, I read two reports on the notion of workstations. One was by Steve Ward at MIT, and the other was from Carnegie-Mellon on SPICE (scientific programming interactive computer environment). I talked to several people about it, and we decided to form Apollo Computer. As the first commercially successful company to put workstations in the marketplace with a complement of display management and networking activities, Apollo just grew and grew. Now it's part of Hewlett-Packard, and their workstation business is arguably the world's largest in terms of revenues. Sun has more units, but Hewlett-Packard has the highest revenue content.

I left Apollo in 1985, and founded Stellar Computer. Of the four companies I've founded in the computer business (Prime, Apollo, Stellar, and Advanced Visual Systems), three were successes and one didn't go. Stellar was beaten out by Silicon Graphics. In 1989, Stellar merged with Ardent to form Stardent; merging our names as well. In about 1993, we sold off Stardent's hardware side to several companies and spun out its software side to AVS.

AVS's scientific visualization software is used mostly in applications like medical imaging for tomography or for reconstructing images from other kinds of data. We're also involved in imaging for underground seismic applications and aboveground cartography. We also make computer-aided design products that render images from constructed objects. The idea is to provide scientists with a set of tools to look at things they can't see, like airflow over a wing, where they have to construct something to be able to look at it.

ISSUES . . . It's easy to say that the computer business has grown by so many orders of magnitude as we'd like to think. Who hasn't heard the comparison between the IBM 650 with a 2,000-cell memory and my watch, which has more computing power than the entire MIT campus had when I was there. It's true, yet analysts miss certain points about the technology rise. One study had shown a 26 percent increase in technology annually. I forget if it was computer power or memory. Well, first you have to marvel at the precise number. Second, there's that straight line—on semilog paper, if you please. But technology doesn't grow in straight lines! It grows in big steps! We don't go from 1- to 1.2-megabyte DRAM. We go from 1- to 4-megabyte DRAM. The best time to start a company, based on technology, is on those steps; when you see the step and others don't, or when you get people together who understand it and then commercialize it.



FOREIGN COMPETITION . . . You hear a lot of bluster about foreign competition, especially in the tone of unfairness directed towards the Japanese, but I don't buy it. We're in a mode where communication and transportation bring us so close to being a single-world entity in commerce. To talk about international competition is to miss the point. The question is how can we collaborate and make things better. It's also an opportunity to sell. In the Far East, there's enormous opportunity to deal not only with ordinary products like wheat and cloth, but there's a hunger for intellectual products there as well. Fear is the entrepreneur's worst enemy, and it's senseless to run from opportunities like that. What we ponder now is how long will it be before South America and Africa get into the game.

FUTURE . . . Most of my work now is in the venture world. I see lots of software products, especially in graphics. The products I don't see in start-up companies are hardware products. Whether it's a Kendall Square Research or a Thinking Machines, all those companies had the same fate. They were on the wrong side of the curve. For many reasons, I'd stay out of hardware in the start-up mode. Some hardware products do work, particularly ones that do special things with vision and voice. But the numbers are against hardware start-ups because the return on invested capital compared with the return on assets is better in software. If you're going to be in the game, you must be in both hardware and software, unless you rely on somebody else's processor. That's why Intel does such a good job. Several start-ups are also exploring the prospect of business on the Internet. Turning that into a business will be difficult, but it'll be interesting to see how it shakes out. The commercial success won't be the new rocket science that comes out of it. It'll be the old block and tackling. For example, setting up services that people need and making those convenient.

OBSTACLES . . . When you start a venture company, no one is certain what's happening. People sit around a table and determine that they don't know where the money is coming from, or they don't know if an idea will work commercially. It's not for timid people. After a couple of years, suddenly something can turn bad. Then, there will be a few dark nights when you ask yourself all those existential questions on why you're doing this. So, overcoming fear is the biggest obstacle any entrepreneur faces.

DANGER IN SUCCESS . . . Bob Townsend, in *Up the Organization,* says that no CEO should be in that job more than five years. One can argue if it's five or ten years, but there's certainly an appropriate time to take off the chevrons and hand them to someone else. In each of the four companies I've been involved in forming, I got out reasonably fast, although I probably could have gotten out faster without hurting anything. I believe in management succession for the company's benefit. If I build an organization that can't survive without me, I've built a monument to myself and nothing else. If I build an organization that survives successfully without me, I've built something that has lasting value to itself and to the people around me. It's the latter that I prefer to do, and to the extent I've done that, it's given me the opportunity to do something else.

REWARDS . . . The most rewarding aspect of my work is seeing people from Prime and Apollo, like Paul Severino, go out and do it themselves. Paul started with Interland and now he's chairman of Bay Networks. It's rewarding to see Bill Warner go out and form Avid; to see Bill Kaiser (SB'61) as a general partner in Greylock; and to see Ed Zander from Apollo running a group at Sun. I get a kick out of that because you get the sense that we did something right, and it continues on.

Richard N. Spann

President, PreFund Associates

Richard N. Spann (SB '61, SM '62, PhD '66) was a member of RLE's Information Transmission Group, and served on the MIT faculty from 1963 to 1969. Along with Harry B. Lee (SB '57, SM '59, PhD '62), Dr. Spann and two other colleagues cofounded Applicon, Inc. in 1969. Applicon was one of the first companies to market computer-aided design and manufacturing systems. In 1976, Dr. Spann joined Adage, Inc., a manufacturer of computer graphic display systems. He served initially as Adage's vice president of R&D, and then as its president.

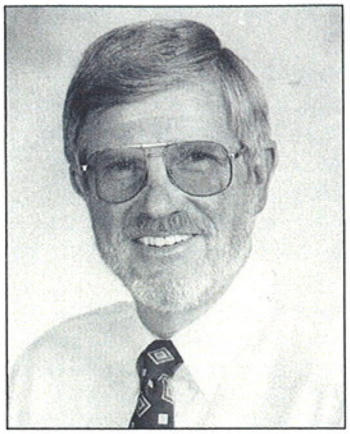
To pursue his own interests in the entrepreneurial process, Dr. Spann left Adage to start his own investment business, PreFund Associates of Carlisle, Massachusetts. Today, he successfully manages an investment portfolio of more than a dozen Massachusetts companies.

MEMORIES . . . As a high school senior, I was interested in math and engineering, but I was encouraged to seek a broad-based undergraduate education. Carleton College in Minnesota had a combined program with MIT. You first spent three years as a liberal arts student at Carleton and satisfied the graduation requirements by taking senior comprehensive exams at the end of your junior year. You then transferred to MIT and repeated your junior year in the major of your choice. After five years, you'd receive bachelor's degrees from both schools. The program appealed to me, but it wasn't overly popular because you could get a master's degree in the same amount of time.

After three great years at Carleton as a math major, I came to MIT. Although Carleton was a hard school, I was unprepared for the intensity and competitiveness of MIT. I was dumped into my junior year in Course VI with students who had been at MIT for two years. My first semester was a nightmare, but things slowly got better. I finished the program and went on for my master's and doctoral degrees.

My experience as a teaching assistant stirred my interest in the classroom. I became an instructor working primarily with Dave Huffman (ScD '53) and Fred Hennie (SB '55, SM '58, ScD '61). A course in switching theory and logic design was responsible for focusing my graduate field. Most of my graduate work was on the mathematical side of computer representations, which at that time was called automata theory. We studied abstract representations of computing that involved recursive function theory and the capabilities of idealized computer models. One goal was to formally characterize the computing capability of mathematical models that were derived from physical computer architectures.

The sixties was a time of much change and turmoil. In a short time, I went from feeding punched paper tape into the TX-0 to doing interactive graphics on the TX-2. The impact of computers on education was becoming significant. Since MIT didn't have a computer science department, questions were being raised about how to teach computer science within Course VI. Mike Athans, Mike Dertouzos, Sam Mason and I wrote a two-volume textbook that combined classic introductory Course VI material with a systems and a logic design approach. It was an arduous but satisfying process.



Richard N. Spann
(Photo by Photo Images, Inc.)

My most vivid memories of MIT and RLE are of its people. I remember listening to Sam Mason and Henry Zimmermann and thinking, "There's a lot of brain power here." My memories can still be triggered today. When a *New York Times* crossword puzzle clue reads "______ Chomsky," my mind flashes back to beating on the same coffee vending machine with Noam. The courses taught by Ernst Guillemin, Sam Caldwell, and Lan Jen Chu were more than science; they were history.

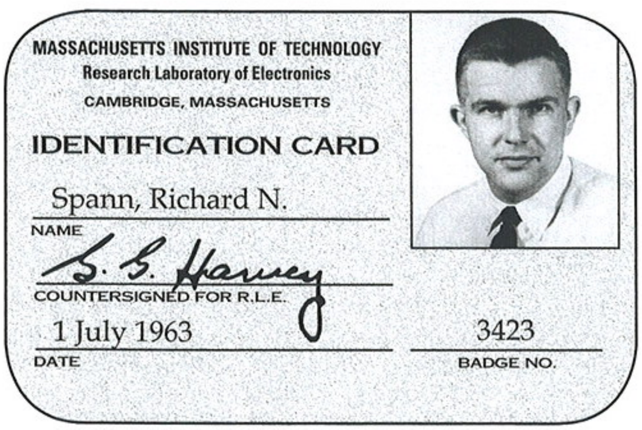
MOTIVATION . . . From 1966 to 1969, I taught at MIT and spent one day a week at Lincoln Lab in Jack Raffel's digital computer group. This was the group with the TX-2 computer, and was the one in which Ivan Sutherland (PhD '63) had worked. As a result, we had Sketchpad on the TX-2 with vector displays. The system was used interactively to design some small integrated circuits. In 1969, I took a leave of absence from the MIT faculty to spend full time at Lincoln. The ideas for Applicon germinated at Lincoln Lab. Its other founders were also associated with our group, and we were stimulated by its working environment. We sensed that there were opportunities that would be seized by someone else if we didn't pursue them.

BEGINNINGS . . . Four of us left Lincoln without a source of funding. We wrote a business plan that required $800,000 of capital and that assigned various responsibilities to ourselves. Mine was sales and marketing. After a nearly fruitless search, we ultimately raised $400,000 from a somewhat unlikely source—J. Peter Grace of W.R. Grace. Now, you can imagine what four young PhDs did with an $800,000 business plan and $400,000 in cash. We executed the $800,000 business plan and almost ran out of money! Fortunately, we attracted enough attention to raise additional capital from General Electric's venture capital subsidiary.

Applicon's first CAD system used an IBM 1130 computer, a Computek data tablet, and a Tektronix storage tube display. The system could only draw horizontal and vertical lines, so its applications were limited. However, it was of interest to integrated circuit designers. At the time, integrated circuit masks were created by cutting and peeling 400x rubylith masters. This was becoming increasingly difficult as the geometries became smaller. With our system, we could drive rubylith cutters. But what was more important, we could also drive the relatively new D.W. Mann 10x reticle generator. This eliminated the rubylith cutting step. We took our primitive line-drawing program, wrote an algorithm to generate the rectangular exposures that the reticle generator required, and marketed Applicon's system as a computer-aided integrated circuit design system.

For three years, I lived in California and made the rounds in what was a then-embryonic Silicon Valley. I had a small sales office with an Applicon system, one briefcase full of sales literature, and another full of tools. I'd sell a system, install it, train the users, and fix it. It was interesting to have gone from a prestigious MIT faculty position to being kept waiting in the lobby of Intel. Applicon's early sales were difficult and usually involved benchmark after benchmark before any decision was reached. I discovered quickly that you couldn't sell by teaching alone, yet you also couldn't sell without educating the customer. At the same time, we added features to our system to attack the mechanical design market. This resulted in an expanded prospect base that became the foundation for Applicon's long-term growth.

ISSUES . . . We had more ideas than money, so we had to be more focused or else we'd fail. This focus eliminated some of Applicon's products and probably played a role in one cofounder's departure in 1973. We had the expected friction among the four of us; each of whom were convinced they could run the company. I eventually came back East and directed Applicon's engineering activities for three years. I left the company in 1976, and the two remaining principals stayed for a while after that. Applicon went public in 1980, and was acquired by Schlumberger in 1982. In 1995, Applicon's alumni organized a 25th anniversary reunion that was attended by more than 250 former employees. Many of them were from the company's early years. That's certainly a testimony to the bonding power of start-ups.



NEW DIRECTIONS . . . In 1976, I joined Adage as vice president of R&D and was named president in 1978. The company was formed in 1957, and was an early investment of American Research and Development, which was recognized as the first organized venture capital fund. When I joined Adage, it was a $5.5-million company that produced high-end vector display systems that included a computer. We took that technology and transformed Adage into a graphics display terminal company that was focused on the IBM-compatible mainframe-attached marketplace. Our primary market was users of Lockheed's CADAM software. Adage grew rapidly, and it did an initial public offering in 1981. By 1984, the company had reached $50 million in sales. During this period, Adage embarked on a diversification strategy involving acquisitions, partnerships, and investments that produced two interesting adventures.

Adage became the exclusive reseller of a stand-alone CAD system in 1984. It was developed by an independent company and was targeted at our mainframe customers who used CADAM software. The product was called the CADstation, and it fit well in the market. Within its first year, it reached $10 million in annualized sales. When CADAM decided to fight the marketing battle in the courtroom, Adage was caught in one of the first (although little-known) look-and-feel software suits. The suit caused havoc in the marketplace and revenues for the product nose-dived. It was a long, vicious battle that was finally settled out of court, but it cost Adage a lot of revenue and a chunk of future opportunity.

Then, in 1985, I met a Russian mathematician who had an idea that promised a dramatically new level of CAD software performance. He was frustrated by the inability of venture investors to appreciate his revolutionary ideas. Adage and another investor provided seed funding and mentoring for his proposed endeavor. This was the beginning of the Parametric Technology Corporation (PTC), which is one of the better performing recent start-ups. PTC's products set the second-generation gold standard for CAD software. Today, Adage's small six-figure investment in PTC would be worth about $200 million.

CHANGING COURSE . . . In 1988, after more than ten years with Adage, it was time for a change, both for the company and for me. I always had an interest in the entrepreneurial process, and I thought of joining a venture capital firm. But, most of them were too large to invest in the seed-level activities that were of interest to me. I decided instead to found and capitalize PreFund Associates, my own venture investment activity. My goal is to make investments in early-stage companies where I can bring more than just money to the table. I have ten active investments, good deal flow, and continuing enthusiasm. I'm still at it today and having a good time.

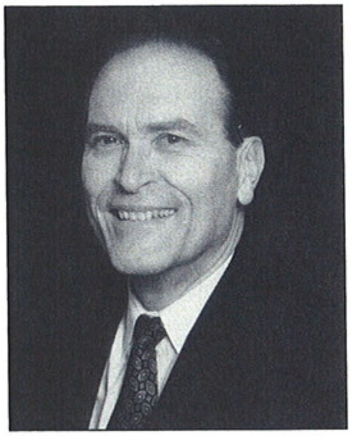
PRODUCTIVITY . . . Productivity and progress are hard to measure quantitatively in early-stage companies. It's unusual for a start-up not to substantially change its business plan during the first year. I invest in people, ideas, and markets. I don't invest in the one path of operation described in the business plan. I'm a fan of measurable and demonstrable checkpoints. Software is particularly difficult because it can be 90 percent complete yet half finished. I like companies to physically demonstrate their product development status on a regular basis. It's only when I see it that I know it's happening.

SIGNIFICANT ACHIEVEMENT . . . It's satisfying to have been on the curl of the CAD wave for quite a few years. It's hard to claim that any one company was the first CAD company, but I'm proud to have taken part in Applicon's pioneering efforts. It's also satisfying that the paradigm established by Adage's CADstation survived and has proven successful for its parent company. Later, it was exhilarating to watch Parametric Technology repeat the pioneering process and extend the frontier once again. I believe there's plenty of opportunity left for yet another revolution, and I'm out looking for the next big wave.

Norman E. Gaut

Chairman, CEO, and President, PictureTel Corporation

Norman E. Gaut (SM '64, PhD '67) was a member of RLE's Radio Astronomy Group from 1963 to 1967. After graduation, he cofounded Environmental Research and Technology (ERT), which provided a variety of environmental services including hazardous waste engineering and air quality monitoring. Following ERT's sale to Comsat Corporation in 1979, Dr. Gaut stayed with the company until 1985, and then joined PictureTel Corporation as its CEO. Founded in 1984 by a team of MIT and RLE alumni, today PictureTel is the leader in the global videoconferencing industry. Based in Danvers, Massachusetts, it is ranked as one of the fastest growing companies in the United States.



Norman E. Gaut
(Photo courtesy PictureTel Corporation)

MEMORIES . . . While I was an undergraduate at UCLA, the ROTC decided that I should be a meteorologist. Because of that education, I became intrigued by geophysics, particularly related to planetary work. At UCLA, I was told the place to go was MIT's meteorology department. I left the service in 1962, and enrolled at MIT. Since I also liked the planetary aspects of geophysics and fluid dynamics, I went into Course XXV, interdisciplinary science. I got my master's in meteorology under Victor Starr, focusing on the origins of the solar system. My PhD advisor, Alan Barrett, said a lot of techniques used by his radio astronomy group could also be used to probe planetary atmospheres. I was intrigued by that because it combined meteorological and planetary sciences, so I began working with microwave emissions from gaseous envelopes or planets. That brought me to RLE, where I met Dave Staelin (SB'60, SM'61, ScD'65). He loaned me his five-channel radiometer, which I used for one year to collect data at Lincoln Lab. My most vivid memory is RLE's energy and diversity. It was an exciting potpourri of intellectual ferment. You could try almost anything, and there was always someone who could help you.

BEGINNINGS . . . I always wanted to create a great company that included doing good science and engineering. As we finished our PhDs, my friend Jim Mahoney and I were interested in turning theory into practical solutions for some of the major problems facing society. Although we had no business experience, we thought starting a company would be a very interesting challenge. My thesis work on microwave propagation through the atmosphere had gotten me interested in the environment, and Jim was a professor teaching meteorology at Harvard's School of Public Health. At our company, Environmental Research and Technology (ERT), we first did theoretical work in planetary atmospheric measurements using passive microwaves. Our first job was to extend the theoretical basis of my thesis for NASA. They were looking at microwave probing of the Earth's atmosphere. Just doing extensions of my thesis kept us alive for a year.

There was little science in the commercial environmental game when we started ERT in 1968. We wanted to bring rigorous science to folks who had environmental problems. We built the business the hard way by knocking on doors and having people boot us out many times. Eventually, environmental laws were passed. Those created markets in which we, having been bruised and battered, understood the needs and solutions. After two tough years, we were suddenly in a position that no one else was in. We had computer algorithms and programs to analyze many forms of environmental data. ERT began to grow at greater than 100 percent a year.

PictureTel was started many years later by Dave Staelin and two students who developed the original video compression algorithms. When we first talked to people about digital communications, they said they didn't need it. We were a new technology and a new market—the worst combination. It was another tough start-up for me. However, this time I was more experienced and made fewer mistakes.

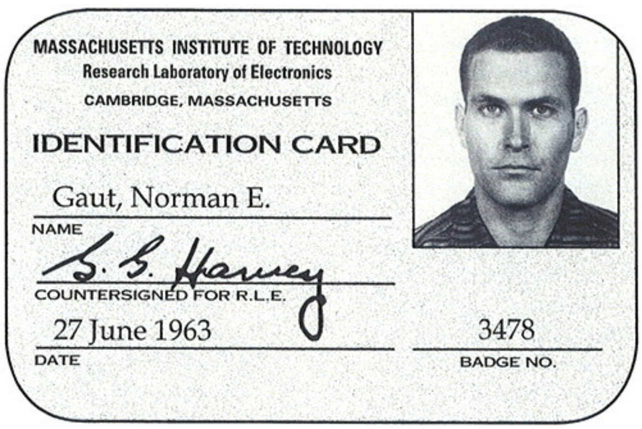
FIRSTS . . . ERT was the world's leading company in air quality measurement and analysis. In those days, there was no such thing as automatic data collection. People needed this information so they could make decisions and talk intelligently to the Environmental Protection Agency when they were told that they were polluting. We developed a service called AIRMAP (Air Monitoring Analysis and Prediction). We owned the equipment and provided data to our customers. Our first crazy idea for a highly sophisticated data collection system had someone reading the data hourly and calling us. When we asked folks at MIT how to do this more efficiently, they said we needed minicomputers. At that time, minicomputers were just beginning to come on the market, so we bought them and put together a 1,500-site monitoring system across the United States. We knew more than anyone about air quality, meteorological conditions, their combinations, and what they did. This included the effects of roads, power and chemical plants, and even the ozone produced by trees.

After we got AIRMAP going, we applied it to water. We built the world's first automated watershed information system using solar transmitters. From hundreds of measurement sites, this system transmitted 300 bits per second on a random basis to a satellite. We built a real-time watershed information system for the Arkansas River that allowed us to forecast floods hours in advance. The system could also tell us when and how to use water.

We also did a prodigious amount of research on atmospheric microwave radiation. In microwave probing of the Earth's atmosphere, we produced a set of theoretical calculations that included most of the effects of absorption, radiation, and scattering for a complex atmosphere. Today, much of that is standard analysis technique when they use microwave information from satellites equipped with passive microwave radiometers. We also pioneered analysis techniques using fluid mechanics to trace fluid flows in the atmosphere and bodies of water. That enabled us to predict, for instance, what would happen if there was an oil spill or something similar. At ERT, we were pioneers pushing back the envelope of knowledge across this whole spectrum.

EDUCATION . . . PictureTel University is an amalgam of internal programs that teach fundamental skills; for instance, how to use a PC or how to run Lotus Notes. It also has many courses on management skills. At every level, we try to keep everyone moving ahead educationally. We're interested in becoming a preeminent industrial, educational institution. In fact, several local companies send folks to our programs. We spend between one and two percent of our gross revenues on education. We try to persuade people and managers that no one is safe if they're not learning. We must be out there every year with something new, and we must be able think about how we're going to get there well in advance. If we want to play the game on a level with the world-class players, it requires a super educational effort. As an aside, training in industry is moving with alacrity to distance education through video communications, which is good for us. In fact, it drives a large part of our sales.

I'm also personally interested in making a dent in certain social problems. Somehow we have to break through what are basically educational ghettoes. Video communications could be the tool to do that. It can link people to the rest of the world and can open the eyes of those who would otherwise never see. A few years ago, a person at Boston University began using our equipment and developed an enormously successful distance learning program to teach graduate-level courses to employees at United Technologies in Hartford. BU is extending this program to collaborate with Fraunhofer Lab in Achen, Germany, using video to link the two institutions.



LIMITATIONS . . . Complexity doesn't just dog the user; it also dogs the developer. If you look at how PictureTel develops software today, which is 80 percent of what the company spends its money on, it's still crude. Even though we have good people and methodologies that allow us to look at defect ratios, it still gets down to someone writing a line of code and figuring out if it works. There must be more efficient and better ways. We need other breakthroughs as well. We believe they're coming for video and signal processing chips that operate at 10 to 20 billion operations per second. Give me that speed, and I'll give you wonderfully compressed video and audio at very low bandwidths. We're also stuck with sixty-year-old display technologies. We put a 300-pound piece of glass in front of you so that you can see images. There's still the question of how to display what's being pushed across the information superhighway.

FUNDAMENTAL SCIENCE VS. ENGINEERING APPLICATIONS . . . MIT's strength is its enormous depth of theoretical skills that are related directly to the real world. MIT is rooted thoroughly in theory and reality. The true genius of the institution is that marriage. That's probably why you see so many folks from MIT producing new companies. From PictureTel's standpoint, it's a continuum of activities from theory to the things we develop to make life simpler. That mix should be in constant ferment. If any link between our fundamental research and the products we produce are broken, then a basic part of our company's most important strength is broken. We need the stimulation of theory and thinking that envisions the world in ten years.

CONTRIBUTIONS . . . One of the most important things I do at PictureTel is take the plunge and say something can be done. I need to create a vision for folks to rally around. It doesn't have to be detailed, but it has to excite the imagination. It must involve having something the company wants to do, and then creating conditions under which they can produce good work.

FUTURE . . . The PC will be *the* communications device in the office. It will take a major effort to clean up all the issues, including the network issues, but the products we produce now are whittling away at these barriers. We're also solving issues on how to connect calls between your phone, PC, laptop, and videoconferencing system. It will be a seamless world of algorithms, data rates, networks, and platforms in which anyone can connect to anyone else.

ISSUES . . . One of the major issues is the speed with which technology is changing. A great product today is a mediocre product tomorrow and a dead product two years from now. Another example is that the world of networks is changing so fast, and no one can predict how they're going to be used one year from now. The idea of work is changing too. Today, folks can be classified as independent contractors as much as they can be called employees. They continuously need to renew their skill base. The old paradigms for how to treat people and the flexibility with which they can work are without merit. Now, you have to think about finding solutions that fit the worker as well as the corporation. We're putting video in employees' homes, which allows them to stay home or share work. We now have the technology to create an efficient work force that can be relatively dispersed, but one that can still act as a team to solve problems. We're still trying to understand that phenomenon. There will be some enabling technology that will involve PictureTel, the networks, the Internet, and PCs that's going to shake out a whole new set of working conditions from the old paradigms. It's going to be an interesting change and we want to drive it.

Robert J. Shillman

Chairman, CEO, and President, Cognex Corporation

Robert J. Shillman (SM '72, PhD '74) is founder, president, CEO, and chairman of Cognex Corporation of Natick, Massachusetts. From 1969 to 1980, he was a member of RLE's Neurophysiology Group and Center for Information Processing Group. A graduate of Northeastern University (BSEE '68), Dr. Shillman founded Cognex in 1981. "Dr. Bob," as he is called by his employees ("Cognoids"), is known for his fanciful managerial style, which is reflected in Cognex's unusual corporate culture.

Robert J. Shillman (Photo by David Schaer for The Middlesex News*)*

As the world's leading supplier of industrial machine vision systems, Cognex's products are used to automate alignment, gauging, and inspection in industries ranging from semiconductors and electronics to healthcare and consumer products. Cognex is one of Massachusetts' fastest growing high-tech companies, and has been named as a top company by several national business publications.

MEMORIES . . . After a year in Cornell's high-energy physics doctoral program, I realized that opportunities in physics were limited, and I would be a mediocre physicist at best. So, I returned to Boston to go to MIT. My interest was plasma physics, but I didn't know what to concentrate in. One area that interested me was cognitive processing. I experimented with teaching a machine to determine the difference between a cat and a dog. It was this interest in human perception that brought me to RLE.

While working on an acoustics project with Nelson Kiang, I concluded that we could poke probes in animals' brains for a long time before we understood how the brain or the mind works. There's a distinction here. The brain is a series of chemical synapses and electrical connections that become increasingly complex as we move toward the central part of the system. I was more interested in how the mind works. The human mind is a complex device that's best understood by doing psychological or psychophysical experiments. We need to understand the transformation of a signal to its output, and we shouldn't do it mechanistically by inserting probes.

COGNEX
Vision for Industry

That led me to Murray Eden's Cognitive Information Processing Group in RLE, where I explored character recognition. I studied how humans can determine other people's hand printing, and it became my doctoral thesis under Barry Blesser (SB '64, SM '65, PhD '69). That work ultimately led to Cognex's first machine in 1981—the Dataman. It had the world's most powerful algorithms for industrial optical character recognition (OCR), and it could read what humans couldn't.

MOTIVATION . . . In the early 1980s, I was a postdoc at MIT and a professor of electrical engineering at Tufts. After a couple of years, I thought there was more to do than teach, so I tried business. While I was working as an independent OCR consultant on a project for Battelle at Kurzweil Computer Products, this fellow would come in to the office. When they told me it was the president, Ray Kurzweil (SB'70), I asked myself why I was jumping on planes to make $1,000 a day as a consultant, while he owned his own company. So, I gave up my position at Tufts, took my life savings, and started my own company. I wanted to create an environment in which I would be happy to live. My goal was to be surrounded by like-minded people who wanted to have that feeling good work gives you at the end of the day.

BEGINNINGS . . . Cognex opened doors with a technology based on my doctoral thesis. Since then, it's been improved on by others at Cognex, including the company's cofounders—Marilyn Matz (SM'80), Bill Silver (SB '75, SM'80), and Bob Piankian (SM '72). Our first product used OCR technology to read highly degraded characters on tires, soda cans, nuclear fuel rods, and semiconductor wafers. Before long, Westinghouse came by to look at fuel rods and Bridgestone came by to look at tires.

IBM wanted us to read numbers on wafers, and they were our first sale. They also wanted us to inspect characters for their Quietwriter printer. The printer's entire assembly was automated, except for the quality control test where inspectors checked the baseline, kerning, and spacing. They also checked if any characters were tipped or broken. IBM sent us fifty sheets from a printer that needed readjusting and another fifty from a printer ready to be shipped. They mixed up the sheets and wanted our machine to sort them into two piles.

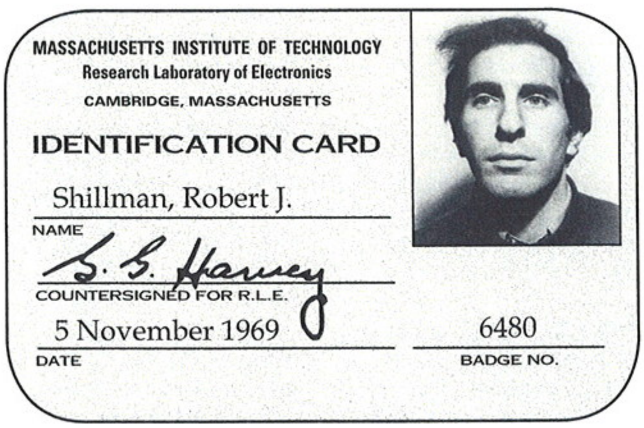
Unfortunately, inspecting or verifying numbers isn't the same as reading them, and our software was inappropriate for character inspection. So, we spent a lot of time studying what it meant for characters to be of good quality. Bill and Marilyn wrote the code, and our machine sorted the sheets without error. IBM also funded some of the product's development, which was called Checkpoint.

We also worked with drug companies. Every drug bottle or box has a high-quality preprinted label affixed to it. After the container is filled, on-demand printing is used to stamp the label with date and lot codes, but they're usually smudgy because it's done at high speed. These numbers are important because the FDA requires drug companies to verify date and lot codes if there's a recall. So, we became involved in character verification, which isn't the same as character inspection or reading. When the drug companies also wanted to check if the label was on straight or if the cap fit correctly, we put in a camera and developed software for it. So, from reading characters, we went to inspecting and verifying them, then locating labels, and measuring cap skew. We did this in an application-independent way by developing a broad set of engineering tools that could find, measure, and inspect things. We would then develop an application package from those tools.

HALLMARKS . . . In the early 1980s, we had over one hundred competitors in the United States. Factory automation was hot, and every venture capitalist had at least one investment in machine vision. However, there was a shortage of technology, marketing knowledge, and customers. Everyone had a piece of the technology, and everyone thought they had *the* solution. However, in business, and certainly in machine vision, there is no one solution. Many tools are needed and different tasks require application-specific knowledge.

Inspecting the paint on cars is different from inspecting the surface of semiconductor wafers. We're not just looking for scratches, it's what the scratch means to the process that's important. Other companies chased multimillion-dollar contracts to produce vision systems for car inspection. That wasn't for us. However, if you wanted to see if a cap was on a jar, we could do that. We were less grandiose in our goals, and it was the management skills of the people at Cognex that led to our success. It wasn't because our technology was better.

FIRSTS . . . In 1981, we had the first industrial character reader. Then, in 1986, we had Search—the first normalized correlation pattern finder. This was followed by the first single-board OEM (original equipment manufacturer) vision engine and the first patent for a dedicated vision chip, called the VC-1. In 1991, the Cognex 4000 was the first fully capable machine vision system for the VME bus. The Cognex 5000 was the first advanced vision system for the PC-AT. We also had Checkpoint, the first easy-to-use third-generation machine vision system. Now, you don't have to know about machine vision or formal programming language. All you do is point and click.



GOALS . . . Our first mission is to maintain ourselves, to grow, and to be the best—having the largest market share and being the most profitable machine vision company in the world. We are that already, but we must continuously work at maintaining that distinction. Our second mission is to be known worldwide as a company with the highest ethics when dealing with our customers, employees, vendors, and shareholders. I've always been firm on that because my father was my mentor in terms of running an ethical business. He wasn't economically successful, but he produced high-quality products and never cheated anyone. I want to show that it's possible to be highly ethical in everything we do and still make money.

ISSUES . . . We can't hire enough quality people as fast as the opportunities present themselves. Other high-tech companies have this trouble too. The problem is the lack of engineers in America. That stems from a misunderstanding on the part of educators, the people who control funding, and the people who motivate others to go into certain professions. Most high-tech companies are run by engineers, not by lawyers or MBAs. A misperception is that bankers and lawyers are paid more; that they're more prestigious than engineers. The reality is that engineers create things, bankers apportion them, and lawyers apportion them after taking a third. When we wonder how to compete with Japan, it has nothing to do with trade barriers. It's that Japan produces more engineers per capita than we do. Their engineers equal our lawyers per capita.

FUNDAMENTAL SCIENCE VS. ENGINEERING APPLICATIONS . . . We don't do fundamental science because of our set-up and because we need to be profitable. At Cognex, we believe it's important for someone else to do fundamental science, and we're happy to pay for it. It's not that we take everything from the public domain and apply it. We do develop products based on a customer's need for certain kinds of machine vision, but we're market focused. Typically, we're not doing that job for a particular customer; it's for that customer's marketplace.

CHALLENGES . . . Our success has been partly due to the small-company environment we've built. However, as we crack certain barriers, such as the $100-million barrier, I see people leaving who were strong players. Others join us because we're a $100-million company and they want to make us into a $250-million company. One solution would be to buy small companies and create uniquely different parts of Cognex.

We're being pulled by our customers to do more things, which means we'll have to grow in order to do them, but growth has its problems and we're seeing those for the first time. Every time Cognex changes for the benefit of its future, its personality changes too, mainly for the people who have been with us for many years. My biggest worry is not to lose those people in our rush for success. They may not be comfortable, unless they've grown in the company and understand that need to grow.

When I walk around Cognex, I'm truly interested in what people are doing, and my enthusiasm can be infectious. What frustrates me is that it's almost time for me to give up managing by walking around. We have eight offices worldwide, and I can hardly walk around this building anymore because it takes time to have conversations.

REWARDS . . . It's rewarding when employees thank me after returning from a five- or ten-year award trip, or when someone says, "Your company made me money and put my kids through college." It's rewarding when I see employees, who I hired in their twenties and now they're in their thirties, and they're company vice presidents with substantial responsibilities. It's also rewarding to see individuals grow and to see how the growth of Cognex's stock affects people's lives and gives happiness to others.

Lutz P. Henckels
CEO, LeCroy Corporation

Lutz P. Henckels
(Photo courtesy LeCroy Corporation)

Lutz P. Henckels (SB '67, SM '68, ScD '71), a native of Berlin, Germany, was a member of RLE's Radio Astronomy Group and Center for Information Processing Group from 1966 to 1972. After graduating from MIT, Dr. Henckels was a principal engineer at GenRad, Inc., and then director of software at Instrumentation Engineering.

In 1977, he founded HHB Softron, an engineering consulting firm, and HHB Systems, Inc., a supplier of electronic design automation tools. He served as president for twelve years, until HHB was sold to Racal-Redac in 1989. Dr. Henckels was president of Racal-Redac's United States operations before joining LeCroy Corporation as president and CEO in 1993.

LeCroy, based in Chestnut Ridge, New York, and Geneva, Switzerland, designs and manufactures high-performance test and measurement instrumentation for electronics applications and research in physical sciences. Their products include digital storage oscilloscopes, programmable signal sources, and nuclear research instrumentation.

Memories . . . After a year at the Technical University in Berlin, I came to the United States as part of an engineering co-op program. I did my co-op work at EG&G Laboratories in Boston. During that time, I applied to MIT and was accepted.

I liked the approach to studying here, which was more application-focused than in Germany. I also liked the professors' attitudes towards their students. Karl Wildes, my first electrical engineering professor at MIT, introduced me to the American way of life. No professor in Germany would take such a personal interest in a student, and I will be forever thankful for the critical, early guidance he provided.

My eight years at MIT gave me a foundation and a new outlook on life. Most importantly, MIT taught me how to approach fundamental issues, how to do research and analyze problems, and how to come up with creative solutions. That was the real value of my MIT education.

Motivation . . . After MIT, I went to GenRad. There, I was given the opportunity to pursue the development of a fault simulator on the DEC PDP-8 minicomputer. In today's world, that seems like an impossible task. Even then, it was considered impractical to put such a mainframe tool on a minicomputer. However, with the help of two other MIT graduates, Rene Haas (SB/SM'74) and Ken Brown (SB'72, SM'73), we mastered that challenge, and created a six-fault parallel simulator called CAPS on the PDP-8 computer. This made a mainframe tool available to the average test engineer. As a result, we became well known in the test industry, and GenRad became the leader in functional testing.

Our entrepreneurial desires eventually took over, and the three of us decided to leave GenRad and form our own company. However, we felt that we should first learn more about business before we started out on our own. So, we moved to New Jersey, took an offer from a small test and measurement company called Instrumentation Engineering, and stayed there for two years.

Beginnings . . . We were modest when we started HHB in the basement of my house. We planned to have a small consulting outfit with at most twelve people. Within five years, we had a $5-million business and 150 employees.

During that time, I attended Harvard Business School's Smaller Company Management Program, which influenced me greatly. It showed me that we should build a product business, rather than managing a "feast or famine" consulting business, where the employees rarely see the results of their success. So, we restructured HHB to become a product company. First, we took on a simulator development contract from Siemens in Germany, which gave Siemens a needed tool and HHB its first product called CADAT. We then raised venture capital to market CADAT and further grow the business. The restructured company grew 85 percent a year, made an operating profit of 22 percent, and went public on the NASDAQ stock market in 1987, just days before the market crash. In fact, we got the cash from the public offering on the day the market crashed.

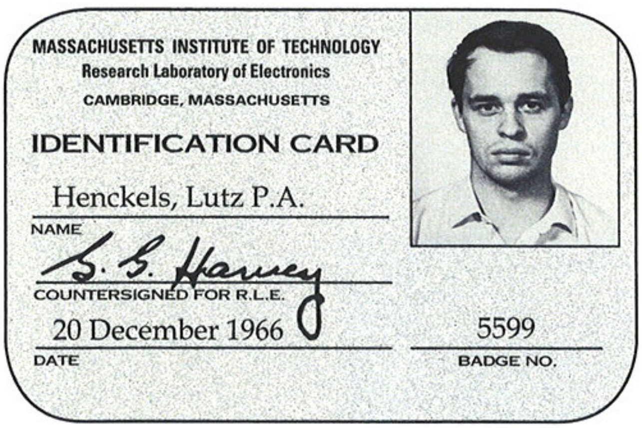
A key to our joint success was the fact that all three of us had studied at MIT. HHB's expertise in digital circuit simulation came from work that we had carried out as graduate students at MIT. Our large development contract with Siemens was obtained, in part, because of our MIT background. MIT is a respected institution that helps not only in terms of the research you can do, but also through its world-class recognition that it bestows on its students.

Parting Ways . . . HHB was bought out in the late 1980s by Cadnetix, a firm that was focused on printed circuit board layouts. They offered us a market value equal to four times our annual sales. They also offered us the opportunity to provide a complete electronic design automation solution, rather than a piece of a design solution. Unfortunately, shortly thereafter, Cadnetix got into a hostile tender offer fight with another company called Daisy Systems. They succeeded, and Cadnetix/HHB was bought out by Daisy, which in turn sold most of the HHB assets to Racal-Redac. Although the HHB shareholders made out well, the Daisy/Cadnetix employees lost out because Daisy went bankrupt a year-and-a-half later since they were not able to overcome the debt created by the hostile bid. The value in a technology enterprise is its people, and the total disregard of them is a sure way to failure.

New Directions . . . The sale of HHB's assets offered me a chance for a new beginning, and to apply my experience to a different setting. In 1993, I came in contact with Walter LeCroy, who asked me to join LeCroy as their CEO. LeCroy is in the test measurement business. It is best known for it contributions to high-energy physics, where the company has been the leader for three decades, providing measurement equipment for particle accelerators. Today, LeCroy's principal business is digital oscilloscopes, which accounts for over 85 percent of the company's sales. When I joined LeCroy, it was a privately held, $60-million company that had not grown in several years. On the positive side, it had a strong technology focus with clear technology leadership in signal acquisition and analysis.

By focusing the company on its strength in signal acquisition and analysis, LeCroy has been growing at 26 percent a year for the last two years. We completed our last fiscal year with about $101 million in sales.

HALLMARKS . . . LeCroy's technology leadership originated from its work in high-energy physics. Over time, the company developed a unique digital acquisition system that can make 4 billion precision measurements a second on an electronic waveform; storing up to 8 million such sample measurements in memory for further analysis. Clearly, this type of analog design technology is an art. It requires custom technology, custom chips, and superb technologists (who I call artists). Only three companies have this technology leadership in digital



oscilloscopes—Tektronix, Hewlett-Packard, and LeCroy. We are different from our competition because we are able to capture vastly more complex (8 million points) and very fast (1-gigahertz) signals, and then diagnose the problems in those signals. As a result, electronics engineers can more quickly get to the answer they are looking for from the digital oscilloscope.

SIGNIFICANT ACHIEVEMENT . . . I am a mountain climber, and whenever I reach a peak, I see a bigger peak in front of me. I don't ever look down because the next peak ahead is so big and difficult to climb that it overshadows the enjoyment of looking down. The next peak for LeCroy is to become number one in the high-end digital oscilloscope market, to broaden our technology leadership in signal acquisition into network analysis, and to continuously improve our operations to achieve more than 25 percent annual growth in net earnings for many years to come. That's a tough peak to climb, but I believe that LeCroy has the technology, and what is more important, the artists and people to get to the top.

GORDON E. MOORE *(continued from page 7)*

running SEMATECH himself because he couldn't find anyone else suited to do it. He went from detailed technical problems, such as space-charge recombination models, to looking globally at the industry and its impact on the United States.

MANAGEMENT STYLE . . . Bob wasn't a manager, he was a leader. He always set a direction and a tone. He thought that if you suggested good ideas to people, they would naturally do the right thing. He didn't like to manage because there was always the follow up involved.

CHALLENGES . . . Bob would never come at a problem from a conventional direction. He always had a different approach, and often it was an important one. He would come up with ideas completely out of left field. Everyone knew they wouldn't work, but you had to try them, and often the conventional wisdom was wrong. Sometimes you'd be receptive to them. Other times, things would be going so well that you didn't want to be distracted by too many wild ideas.

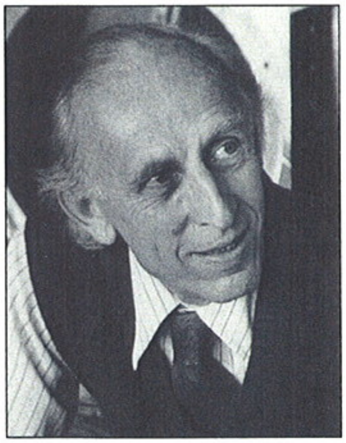
Once, we were trying to make contacts to our first transistors at Fairchild. I had the job of coming up with a single metal system to make contacts to both the base and the emitter. Bob asked why I didn't try aluminum. We both knew aluminum didn't make ohmic contacts to n-type silicon. Anyone who should have known that would have been Bob, with his background in device physics. But, the aluminum was easy, it worked perfectly, and it made a beautiful ohmic contact. It took five years before we actually understood why.

Another time, we had problems making diodes that had junctions with good, sharp breakdown characteristics. Occasionally we got good ones, but there was a huge variation. Someone at Bell Labs had just published an article about using nickel to increase the lifetime of silicon. Bob suggested nickel-plating the backs of the wafers before putting them in the diffusion furnace. I don't know why, but we tried it, and the junctions were as sharp as could be. Again, it took a while before we fully understood what was going on, but Bob had good intuition. He tried things that, for those of us who thought we knew something, we never would have tried ourselves.

He had clever new ideas about almost any subject. It got to a point where he spent less time at Intel and more time on outside activities. He was such an interesting guy with broad interests. He was always down to earth about everything. He became interested in dealing with Washington and was excited to be out there with the politicians. I think Bob would have liked to have been remembered as a Renaissance man, and successful in the wide variety of different ventures that he put his energy into.

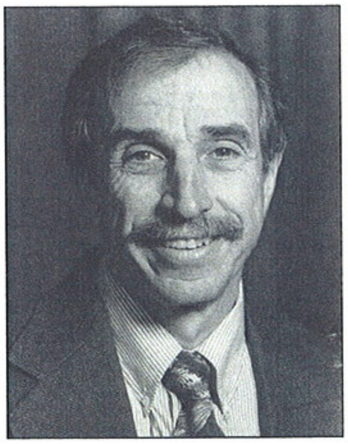
SIGNIFICANT ACHIEVEMENT . . . Bob and I grew up with the integrated circuit. He came up with the idea when we were at Fairchild. Then, he was promoted and I had the job of making them. Getting out the first integrated circuits was exciting. What we've accomplished at Intel is also exciting; building the company and its products. The basic technology that we developed at Fairchild became the foundation for the industry. Certainly, it was nice to be in the right place at the right time.

Dr. Jacqueline N. Hewitt (PhD'86), Associate Professor of Physics, was awarded tenure, effective July 1, 1996. Professor Hewitt is a principal investigator in RLE's Radio Astronomy Group, and previously held the Class of 1948 Career Development chair from 1992 to 1995. Since joining the MIT faculty in 1989, she and her colleagues have pioneered research in the detection of gravitational lenses. Her work in this area uses gravitational lenses to probe dark matter and other cosmological parameters. She was the discoverer of the first "Einstein ring," an image that is produced when a lens is highly symmetric and almost perfectly aligned with its source. A graduate of Bryn Mawr College (AB'76) Professor Hewitt has received the 1993 Henry G. Booker Prize from the International Union of Radio Science and the American Physical Society's 1995 Maria Goeppert-Mayer Award. *(Photo by John F. Cook)*



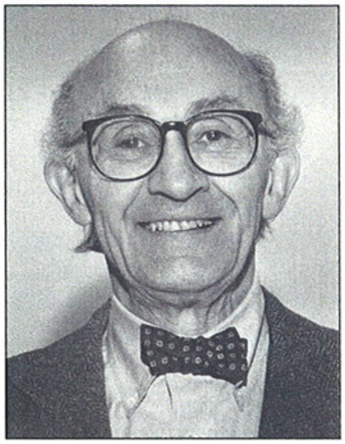
Dr. Uri Shaked, Professor of Electrical Engineering and Dean of the Faculty of Engineering at Tel Aviv University, has announced the establishment of the Bekefi Memorial Library. Following the generous donation of the late ***Professor Emeritus George Bekefi's*** scientific library to the Faculty of Engineering at Tel Aviv University, Professor Shaked said the it will "be an active memory for a great scientist and a generous person." The library will be housed in the Department of Electrical Engineering-Physical Electronics' Student Microwave Laboratory. All books will be catalogued by Tel Aviv University's Library of Exact Sciences and Engineering, and will be listed in its public computer network. Professor Bekefi, a plasma physicist in RLE and a member of the MIT physics faculty for thirty-four years, died August 17, 1995, following a battle with leukemia. *(Photo by John F. Cook)*

Dr. Gregory W. Wornell (SM'87, PhD'91) was appointed to the Cecil and Ida Green Career Development Professorship in the Department of Electrical Engineering and Computer Science, effective July 1, 1996. In addition, Professor Wornell was also selected as the first recipient of the newly established Junior Bose Award for Excellence in Teaching. The award, presented by the MIT School of Engineering, complements the original Bose Award (see Dr. Alan V. Oppenheim, below), and recognizes the excellent contributions of junior faculty members. Professor Wornell, who joined the MIT faculty in 1991, was also recently named as an Office of Naval Research Young Investigator. The ONR program selects young scientists and engineers who show exceptional promise for doing creative research and teaching. A principal investigator in RLE's Digital Signal Processing Group, Professor Wornell's research includes signal processing, multi-user broadband and wireless communications, and the application of fractal geometry and nonlinear dynamics to these studies. *(Photo by John F. Cook)*



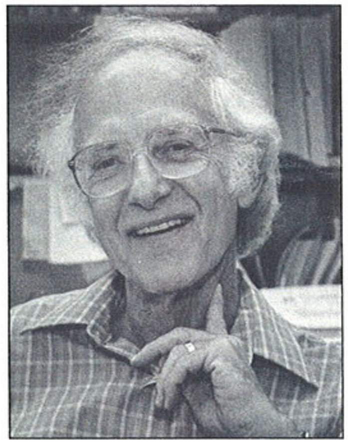
Dr. Alan V. Oppenheim (SB/SM'61, ScD'64), Distinguished Professor of Electrical Engineering, received the Bose Award for Excellence in Teaching on May 13, 1996. The annual award was established in 1989 by MIT's School of Engineering to recognize outstanding contributions by the faculty to undergraduate education. Professor Oppenheim has received many citations for his outstanding achievements in education, including the 1988 IEEE Education Medal and the 1984 IEEE Centennial Award. As a principal investigator in RLE's Digital Signal Processing Group, Professor Oppenheim's research focuses on speech, image, and geophysical signal processing. He is the coauthor of several widely used signal processing textbooks and the editor of several advanced books in the field. *(Photo by John F. Cook)*

1996 RLE Faculty Retirees



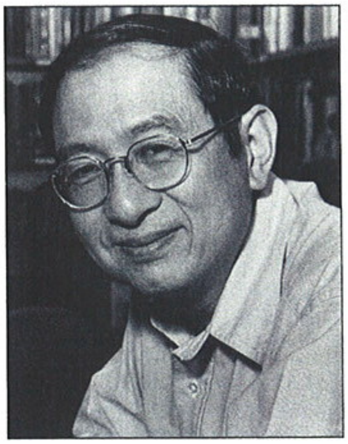
Dr. Abraham Bers (SM'55, ScD'59), Professor of Electrical Engineering and Computer Science, joined RLE in 1953 as a research assistant. He continued his work in the field of microwave electronics as a member of RLE's research staff, and was appointed to the MIT faculty in 1959. Professor Bers' recent research in RLE's Plasma Physics Group involves fundamental studies aimed at understanding transport in radiofrequency heating, current generation in toroidal plasmas, and related studies of induced stochasticity and chaos. He has served as president of the University Fusion Association and vice chairman of the American Physical Society's Division of Plasma Physics. He is a member of the American Association for the Advancement of Science and a fellow of the American Physical Society. *(Photo by John F. Cook)*

Dr. Shaoul Ezekiel (SM'64, ScD'68), Professor in the departments of Aeronautics and Astronautics as well as Electrical Engineering and Computer Science, came to RLE as a research assistant in 1965 to investigate gravitation research. Professor Ezekiel was appointed to the MIT faculty in the Department of Aeronautics and Astronautics in 1968, and the Department of Electrical Engineering and Computer Science in 1976. An authority on laser physics and engineering, Professor Ezekiel has made contributions to high-resolution laser spectroscopy and optical clocks. His research in the fields of lasers and optics include their application to atom-field interactions, laser spectroscopy, optical frequency-wavelength standards, and fiber-optic sensors. He also served as director of MIT's Center for Advanced Engineering Study from 1986 to 1995. *(Photo by John F. Cook)*

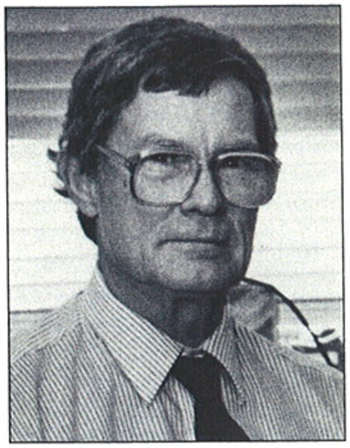


Dr. Lawrence S. Frishkopf (PhD'56), Professor of Electrical Engineering and Computer Science, has been affiliated with RLE's research in communications biophysics and auditory physiology starting in 1953. Professor Frishkopf was a research assistant and a research staff member in the Communications Biophysics Group, applying correlation techniques to the study of brain potentials. From 1957 to 1968, he was first a research fellow at the Rockefeller Institute, and then a member of the technical staff at Bell Telephone Laboratories. He returned to MIT in 1968 as a member of the faculty and a principal investigator in RLE's Auditory Physiology Group. His recent investigations have involved measuring hair cell stereociliary tuft motions in relation to frequency selectivity in alligator lizard cochlea. These studies have contributed to the understanding of acoustic analysis in more complex mammalian cochlea. *(Photo by John F. Cook)*

Dr. Hermann A. Haus (ScD'54), Institute Professor and principal investigator in RLE's Optics and Devices Group, has made prolific contributions to many emerging technologies in the field of optics. After coming to RLE as a research assistant in 1951, and joining the MIT faculty in 1954, his work focused on microwave tube and noise studies. In collaboration with the late Dr. Richard B. Adler (SB'43, ScD'49), he developed the circuit theory of linear noisy networks. His recent research includes quantum noise theory, waveguide devices, all-optical switching, soliton systems, squeezed state generation, and ultrashort pulse lasers. Professor Haus has received numerous awards and honors, including the 1984 Award of the IEEE Quantum Electronics and Applications Society, the Optical Society of America's 1987 Charles Hard Townes Award, the 1991 IEEE Education Medal, and the Optical Society of America's 1994 Frederic Ives Medal. *(Photo by John F. Cook)*



Dr. Nelson Yuan-sheng Kiang, Eaton-Peabody Professor in the Harvard-MIT Division of Health Science and Technology. After graduating from the University of Chicago (PhB'47, PhD'55), Professor Kiang joined RLE's research staff in its Communications Biophysics Group. In 1956, he was the first appointment to the newly established Eaton-Peabody Laboratory at the Massachusetts Eye and Ear Infirmary, where he has also served as director since 1962. He was appointed to the MIT faculty in 1983, and has also held a faculty appointment in the Department of Otology and Laryngology at the Harvard Medical School. In addition, Professor Kiang has held research appointments at Massachusetts General Hospital and the Massachusetts Eye and Ear Infirmary. His research interests have centered on how the ear and the brain work together to produce auditory information. The basic knowledge found in this research is applicable to the diagnoses of hearing disorders and the treatment of otologic and neurologic diseases. *(Photo by John F. Cook)*



Dr. John G. King (SB'50, PhD'53), Francis L. Friedman Professor of Physics, came to RLE as a thesis student in 1950. Later, he worked with Dr. Jerrold R. Zacharias on studies that led to the development of the first commercial atomic frequency standard. Appointed to the MIT faculty in 1953, Professor King served as RLE's associate director from 1973 to 1976. He was also a lecturer in the Department of Physiology at Boston University's School of Medicine from 1976 to 1985. A leading proponent of educational innovation and reform, Professor King has introduced several new teaching methods, including project lab, corridor labs, courses with take-home experiments, and concentrated study. His recent research interests have focused on fundamental null experiments and surface studies in biology. *(Photo by John F. Cook)*

RLE's New Research Staff

Dr. Narayana R. Aluru was appointed as a research scientist in RLE's Circuits and Systems Group, effective August 1, 1996. Dr. Aluru had joined RLE as a postdoctoral associate in 1995. He is a graduate of the Birla Institute of Technology and Science (BE'89), the Rennsalaer Polytechnic Institute (MS'91), and Stanford University (PhD'95). Working with Professor Jacob K. White's group, Dr. Aluru will design and implement new serial and parallel simulation algorithms for micro-electro-mechanical systems.

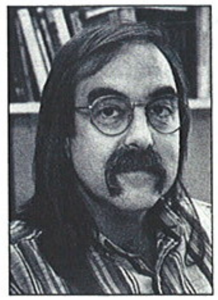
Jay H. Damask (SB'90, SM'93, PhD'96) was appointed as a research engineer in RLE's Quantum-Effect Devices Group, effective May 10, 1996. Since 1991, Dr. Damask had previously been a graduate student and research assistant in RLE's Optics and Devices Group. In his new position, he will work with Professor Henry I. Smith's group on the design, materials development, lithographic fabrication, and component testing for all-optical networks.

Dr. Gerhard de Lange was appointed as a research scientist in RLE's Optics and Devices Group, effective July 1, 1996. A graduate of the Technical University of Eindhoven (BA'83) and the University of Groningen (MS'88, PhD'94), Dr. de Lange had previously been a postdoctoral associate in RLE since 1994. Dr. de Lange will work with Professor Qing Hu's group in the area of superconducting receivers to develop micromachined cryogenic and room-temperature millimeter-wave imaging arrays.

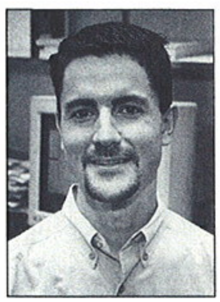
Dr. Kung-Hau Ding was appointed as a research scientist in RLE's Electromagnetics Group, effective June 1, 1996. Since 1993, he had been a postdoctoral associate in RLE. A graduate of National Tsing-Hua University (BS'78) and the University of Washington (MS'84, MS'85, PhD'89), Dr. Ding will conduct research in the field of microwave and millimeter-wave remote sensing of geophysical terrains.

Dr. Paul Duchnowski (SB'87, SM'89, PhD'93) was appointed as a research associate in RLE's Sensory Communications Group, effective January 1, 1996. Affiliated with RLE in various student and staff research positions since 1987, Dr. Duchnowski investigates phonetic speech recognition systems and the algorithms used to produce automatic speech cues in cued speech. His research is related to the group's development of aids for the hearing impaired and the deaf.

Dr. Steven H. Isabelle (PhD'95) was appointed as a research associate in RLE's Digital Signal Processing Group, effective July 1, 1996. Dr. Isabelle, a graduate of the Georgia Institute of Technology (BS'85, MS'86), has been affiliated with RLE as a graduate student and postdoctoral associate since 1987. His continued research will involve the development of advanced signal processing algorithms for wireless and wireline communications.



Dr. F. Thomas Korsmeyer (PhD'88) was appointed as a research engineer in RLE's Circuits and Systems Group, effective July 1, 1996. Previously, Dr. Korsmeyer had been affiliated with MIT's Department of Ocean Engineering since 1988, and had collaborated on research with Professor Jacob K. White's group in RLE on fast algorithms to solve complicated three-dimensional potential problems. A graduate of the University of Michigan (BA'73, BSE'79, MSE'80), his work will continue to support the group's research on adaptive gridding, with possible future work on order N methods applied to ocean engineering.



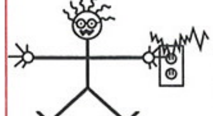
Dr. Pierre R. Villeneuve was appointed as a research scientist in RLE's Surfaces and Interfaces Group, effective June 1, 1996. Dr. Villeneuve, a graduate of the University of Ottawa (BS'88) and Laval University (PhD'93), had been a postdoctoral associate in RLE since 1994. In collaboration with Professor John J. Joannopoulos' group, he will investigate photonic bandgap materials and their application to the design of integrated photonic devices and semiconductor lasers.

Jennell C. Vick was appointed as a research specialist in RLE's Speech Communication Group, effective August 5, 1996. A graduate of Ohio University (BS'94) and Case Western Reserve University (MA'96), Ms. Vick will work with Senior Research Scientist Dr. Joseph S. Perkell to conduct research on speech motor control, which will also take into account the role of hearing.

Dr. Thomas E. Wiegand was appointed as a research scientist in RLE's Sensory Communication Group, effective July 15, 1996. A graduate of Franklin and Marshall College (AB'85) and Columbia University (BS'87, MA'90, MPhil'91, PhD'93), Dr. Wiegand joined RLE as a postdoctoral associate in 1993. His research on human-machine interfaces for virtual environments and teleoperator systems includes the development of a virtual workbench interface, as well as investigations into spatial knowledge acquisition and the effects of alterations in sensorimotor loops.

(Photos by John F. Cook)

SHORT CIRCUITS



The staff of ***RLE currents*** would like to note that the photo caption depicting Dr. Jerome B. Wiesner's inauguration on page 31 of the spring 1996 issue mistakenly identified Dr. Vannevar Bush ('16) as an MIT president emeritus. The late Dr. Bush had served as MIT's vice president and dean of engineering, as well as chairman and honorary chairman of the MIT Corporation. Thanks to Kathryn A. Willmore of the MIT President's Office for checking the error.

RLE 50th Anniversary Celebration

RLE's 50th anniversary celebration will take place at the MIT campus on Friday and Saturday, November 1 and 2, 1996. This special event, marking RLE's "50 Years of Impact and Innovation," will highlight not only the laboratory's contributions to science and technology, but also its impact on society. For more information, please contact RLE at 617-253-4653, or send email to rle50th@rle.mit.edu. Web browsers can view RLE's 50th anniversary web page at http://rleweb.mit.edu/rle50th.htm, which also contains an on-line registration form.

Friday, November 1

Poster Session

1:00-5:00 p.m.
The Grier Room (MIT Room 34-401)

RLE's students will present the latest in the laboratory's broad range of research. We hope you can join us for this kick-off event of RLE's 50th anniversary celebration.

Laboratory Tours

1:00-5:00 p.m.
Tours start from the Grier Room (MIT Room 34-401)

In connection with the poster session, RLE invites you to tour its unique scientific facilities. You will have the opportunity to meet with faculty, students, and staff, and discuss their latest research results.

Compton Gallery Exhibit and Opening Reception

5:30-8:00 p.m.
Lobby of MIT Building 13 and MIT Compton Gallery (MIT Building 10)

A gala reception will accompany the opening of RLE's exhibit in MIT's Compton Gallery. This new exhibit will not only feature artifacts and photographs from RLE's first 50 years, but it will also highlight some of the exciting research currently being undertaken in the lab. On Saturday, November 2, the Gallery will be open from 9:00 a.m. to 5:00 p.m.

On-site registration will take place on:

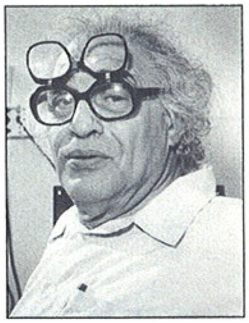
- Friday, November 1, from 1:00-5:00 p.m. in the lobby of MIT Building 36 (50 Vassar Street).
- Saturday, November 2, from 9:00-10:00 a.m. in the Tang Center lobby (MIT Building E51).

Saturday, November 2

Reunion Breakfast

8:00-9:30 a.m.
MIT Faculty Club (MIT Building E52, sixth floor)

All students, faculty, and staff who have been part of RLE since the laboratory's founding in 1946 are invited to attend RLE's reunion breakfast at the MIT Faculty Club. Professor Emeritus Jerome Y. Lettvin will be this morning's speaker. Tickets are limited, so register today.



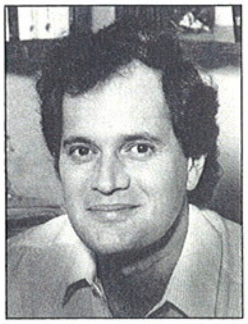
Professor Emeritus Jerome Y. Lettvin has been affiliated with RLE since 1951. Since that time, he has conducted research on the bioelectrical processes involved in cognition and sensory perception in living systems. He is widely recognized for his work on vision and pattern recognition published in the 1959 landmark paper, "What the Frog's Eye Tells the Frog's Brain."

Symposium—Technical Talks

Tang Center (MIT Building E51). Registration from 9:00-10:00 a.m. Presentations from 10:00 a.m.-1:00 p.m.
Lunch will be provided for all symposium registrants from 1:00-2:30 p.m.

Professor Dennis M. Freeman will present an overview of his investigations into the physiology of the inner ear, which seek to characterize the signal processing properties of the peripheral auditory system. He and his colleagues have introduced novel microscopic photodetection methods and high-resolution imaging techniques to measure the motions and physical properties of inner-ear structures. Professor Freeman will demonstrate a video system that has been developed in his group to measure the mechanical properties of these structures. The system includes a computer that records and analyzes video images, so that both three-dimensional structures and motions can be visualized.

Professor James G. Fujimoto will describe his group's work on optical coherence tomography (OCT), a new imaging technology that can obtain higher resolution biomedical images. Professor Fujimoto and his colleagues have helped to develop this new medical technology, which can perform noninvasive imaging of structures within the eye, retinal tumors, arterial plaque, and other biological structures. Applications for OCT include the diagnosis of several retinal diseases, including macular degeneration, and may hold promise for glaucoma treatment as well. Professor Fujimoto's group also develops new femtosecond laser generation and measurement techniques and investigates ultrafast phenomena in electronic and optoelectronic materials.



Professor John D. Joannopoulos will describe his theoretical studies in condensed matter physics that have provided many of the first calculations for the electronic and geometric structures of solids. He and his colleagues have predicted semiconductor surfaces, including the atomic configuration of several surface reconstructions, the sites and mechanisms for molecular chemisorption and diffusion, and the nature of surface phase transitions as a function of temperature. By developing techniques that predict atomic-level surface structure and use minimum energy calculations, this research not only reveals new surface states, it also provides increased understanding of the semiconductor growth process at a detailed atomic level, thus exploiting the best performance modern supercomputers can offer.

Professor Marc D. Kastner and his colleagues in RLE's Quantum-Effect Devices Group have pioneered a single-electron transistor device that turns on and off once for every electron that is added to it. In addition to their technological potential, such devices provide new insight into the behavior of electrons that are confined to regions with small dimensions. Professor Kastner will provide an overview of the single-electron transistor's technological applications, and how the transistor will further understanding of very small semiconductor devices. He will also address the possible role of self-assembled nanostructures in devices of the future.

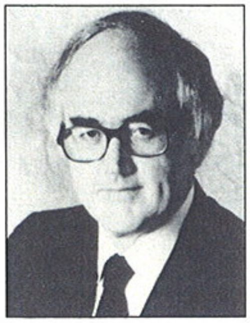
Professor Wolfgang Ketterle will discuss his research in basic atomic physics, where phenomena involving collisions, light scattering, and quantum statistics are studied. Professor Ketterle has been recognized for his emerging leadership in developing several new techniques used to extract energy from ultracold neutral atoms. His group's recent observation of the mysterious Bose-Einstein condensate (BEC) has permitted the study of ultracold matter in an entirely new regime. In the BEC state, matter is coherent and exhibits "laser-like" properties. While Professor Ketterle seeks to understand BEC properties, his longer range plans are to use coherent atoms for vast improvements in precision measurements and atom optics.

Professor Gregory W. Wornell will provide an insight into the increasingly important role the field of signal processing is playing in the development of future wireless communication systems. Professor Wornell and his group in RLE explore multiuser wireless and broadband communications, and have developed a variety of new signal processing techniques for next-generation systems. Future applications for this research include code-division multiple-access and packet-switched mobile radio networks, indoor spread-spectrum personal wireless systems, and digital audio and television broadcast systems.

Symposium–Plenary Talks

Wong Auditorium in Tang Center (MIT Building E51)
Tickets to the plenary talks are limited, so register today.

2:30–3:30 p.m.
MIT President Charles M. Vest will speak on science policy in America, the role of research universities in society, and how RLE can contribute to the solution of important societal needs. Dr. Vest's article, "Measuring the Return on Investment in University-Based Research," appears in this issue of ***RLE currents.***

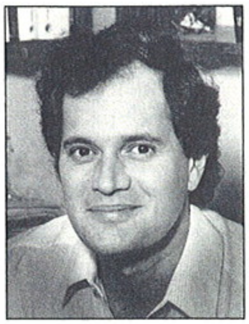


4:00–5:00 p.m.
Award-winning television host and author ***James Burke*** will detail the history of communication and describe the role that RLE has played. Mr. Burke's television series and books include: *Connections, The Day the Universe Changed, After the Warming, Masters of Illusion, Connections², and The Axemaker's Gift.*

Jubilee Dinner Party

6:30–10:00 p.m. Morss Hall, Walker Memorial (MIT Building 50)

To cap off the two-day celebration, we invite you to join us for this final, spectacular event of RLE's 50th anniversary, which will include cocktails, dinner, and dancing. Tickets are limited, so register today.



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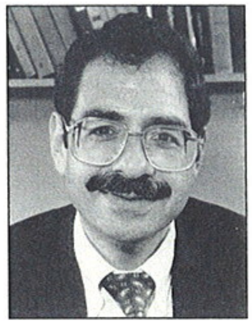

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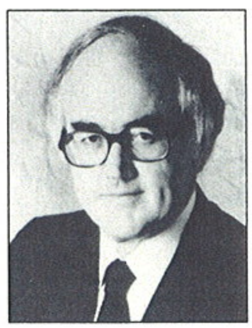

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RLE 50th Anniversary Celebration

November 1-2, 1996

PRELIMINARY SUMMARY OF EVENTS

(See pages 30 and 31 for details)

Friday, November 1, 1996

1:00-5:00 p.m.	Registration	Building 36, Lobby
1:00-5:00 p.m.	Poster Session and Open House	Building 34, Grier Room (34-401)
1:00-5:00 p.m.	RLE Lab Tours	Tours start from Grier Room (34-401)
5:30-8:00 p.m.	Gala Reception and Compton Gallery Exhibit Opening	Building 13, Lobby Building 10, Compton Gallery, First Floor

Saturday, November 2, 1996

8:00-9:30 a.m.	Reunion Breakfast	Building E52, MIT Faculty Club, Sixth Floor
9:00-10:00 a.m.	Registration	Building E51, Lobby (Tang Center)
10:00 a.m.-1:00 p.m.	Symposium—Technical Talks	Building E51 (Tang Center)
1:00-2:30 p.m.	Symposium Luncheon	Building E51 (Tang Center)
2:30-3:30 p.m.	Symposium—Plenary Talk: *MIT President Charles M. Vest*	Building E51, Wong Auditorium (Tang Center)
3:30-4:00 p.m.	Intermission	
4:00-5:00 p.m.	Symposium—Plenary Talk: *James Burke*	Wong Auditorium (Tang Center)
6:30-7:00 p.m.	Cocktails	Building 50, Walker Memorial, Morss Hall
7:00-10:00 p.m.	Jubilee Dinner Party	Building 50, Walker Memorial, Morss Hall

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