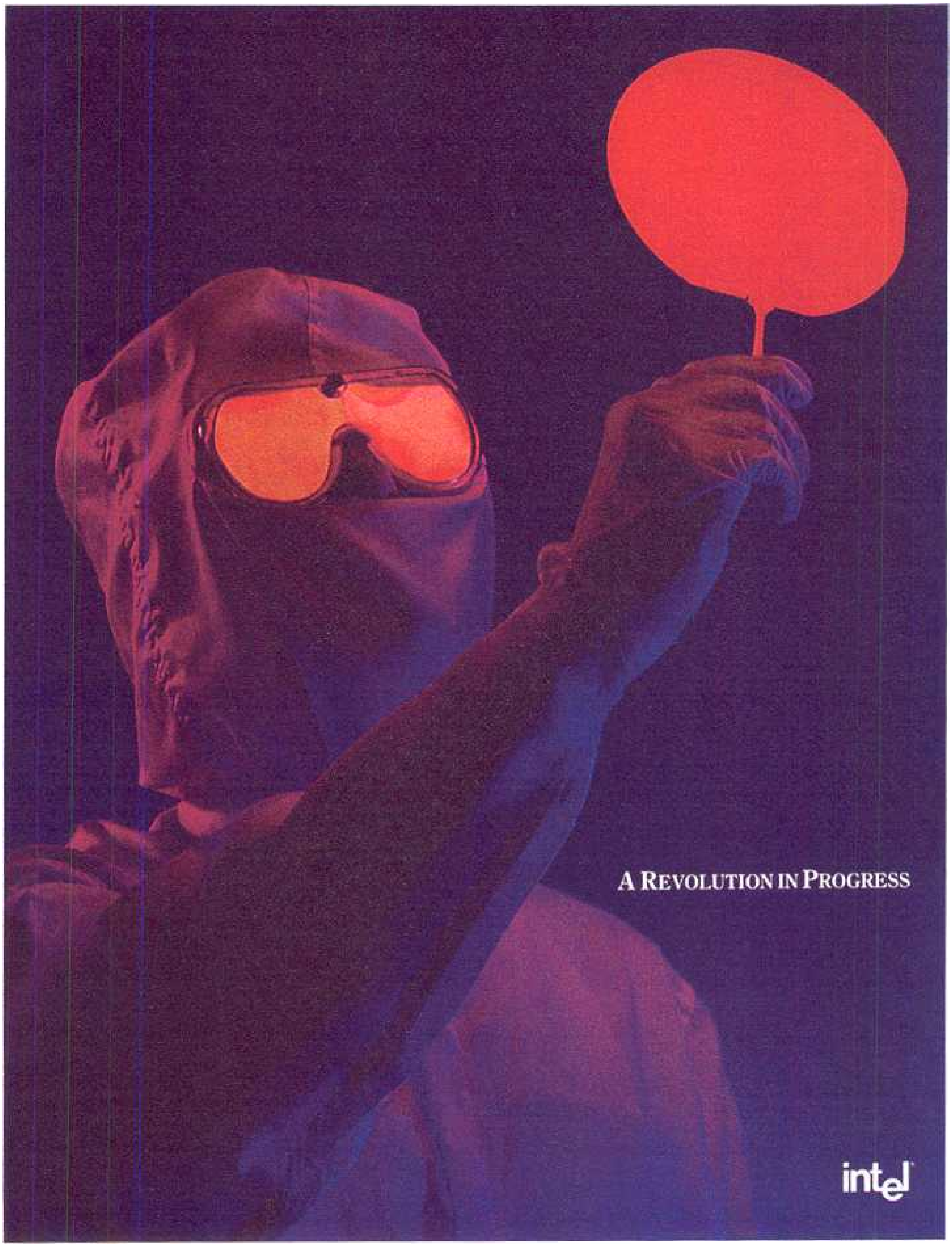
A REVOLUTION IN PROGRESS

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... A History of Intel to Date

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Edited by Glynnis Thompson Kaye

Researched and written by Mimi Real,
Oral History Associates
Assisted by Robert Warren

Designed by Hall Kelley Organization

Typography by Frank's Type Inc.

Printed by ColorGraphics, Inc.

A publication of Intel's Corporate Communications Department

Cover photo: R.J. Muna

FOREWORD

Producing the history of a company only 16 years old would ordinarily be a modest and perhaps premature task. Neither is true in Intel's case. So much of significance has happened here that we found the job both formidable and fascinating.

We have been rummaging around for over a year now digging into archives, conducting over 30 lengthy interviews with employees, checking facts and begging for early photos and memorabilia of the company. Many people—more than we have space to mention—have helped, and we thank them for their generous support of the project. Special thanks to Jean Jones who, as one of the company's original employees and as chairperson of Intel's Museum Committee, has coordinated the collection and preservation of much of the company's heritage. She has been an invaluable source of information.

Our goal has been to capture not just the facts but the spirit that pervades this company responsible for innovations like LSI memory and the microprocessor—innovations that are transforming much of society. To call this transformation a revolution is not an overstatement. And it is a revolution in progress—one that is underway but by no means finished.

INTEL: INNOVATOR OF THE INFORMATION REVOLUTION

The Industrial Revolution, which transformed the world like no other force before it, achieved much of its impact in about 100 years. The Information Revolution, sparked by the introduction of the computer, is making an impact of similar magnitude in a much shorter time. The advent of computers has allowed the amplification and distribution of machine intelligence in a manner similar to the way the Industrial Revolution unleashed and distributed machine power.

Of the companies providing the technology to fuel the Information Revolution, Intel has clearly been one of the leaders. Intel is responsible for two of the major post-war innovations in microelectronics that have made today's electronic age possible—large-scale integrated (LSI) memory and the microprocessor. These breakthroughs, combined with strong management and a unique company culture, have led to explosive growth for Intel. Starting with 12 employees and revenues of $2,672 in 1968, Intel now has more than 25,000 employees in locations around the world, and revenues exceeding $1 billion.

During this period, through recessions and booms, Intel has maintained pretax profit margins and return on equity far above its competitors, a performance unique for the semiconductor industry.

One of the keys to Intel's success was its founding team of Robert N. Noyce, Gordon E. Moore and Andrew S. Grove, three men who earned distinction as scientific pioneers early in their careers. Noyce, with a Ph.D. from M.I.T., holds many key patents in semiconductor technology and was co-inventor of the integrated circuit. Moore, a chemist with a Ph.D. from Caltech, made some of the basic discoveries that led to the integrated circuit and subsequent LSI developments. Grove, with a Ph.D. from the University of California, Berkeley, played a critical role in developing and implementing Metal Oxide Semiconductor (MOS) LSI technology.

Noyce and Moore had worked together at Shockley Semiconductor Laboratory and had later been among the founders of Fairchild Semiconductor in 1957. They hoped to develop advanced silicon-based semiconductor products. By 1968 Noyce was general manager and Moore was director of research and development. Grove, who had joined Fairchild in 1963, was assistant director of research and development.

When the directors of Fairchild began looking outside for a third chief executive officer within less than a year, Noyce told Sherman Fairchild that he was leaving. Moore's increasing frustration with transferring technology from the laboratory to production within Fairchild, combined with concern over the instability at the top of the organization, led him to resign. At the same time, Noyce and Moore saw a potential market in semiconductor memory and a chance to develop new technology oriented toward that opportunity.

Noyce and Moore incorporated on July 18, 1968. Almost immediately, Grove joined them to form the triumvirate that would lead Intel into the development of an exciting new electronics technology.

The new company set out with a precise focus: to exploit the emerging LSI technology—the placement of thousands of microminiature electronic devices on a tiny silicon chip. The first target was computer memory. At that time nearly all computer memories utilized magnetic cores, which were ten times cheaper than the equivalent semiconductor devices. Since integrated circuit costs had been declining and were expected to drop even more, Intel's founders felt the day was at hand when large-scale integration could push semiconductor memories across the cost threshold and into the growing computer market.

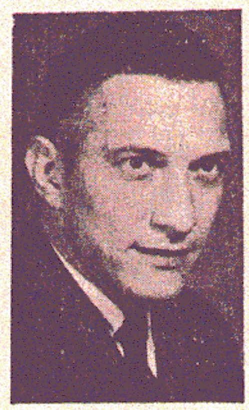
They were right. And, through the combined contributions of thousands of people, Intel has grown from their original idea into the leader it is today.

6—PALO ALTO TIMES, FRIDAY, AUG. 2, 1968

2 of founders leave

By MARGE SCANDLING

Two pioneers in the Midpeninsula integrated circuits industry, Dr. Robert Noyce and Dr. Gordon E. Moore, have resigned from Fairchild Semiconductor to start their own business.



ROBERT NOYCE

Their new company, to be called Intel Corp., will be in the general area of integrated electronics, according to Moore.

Both men were among the original eight founders of Fairchild Semiconductor in September, 1957. Fairchild is now one of the biggest of the many firms making up the highly competitive integrated circuits industry.

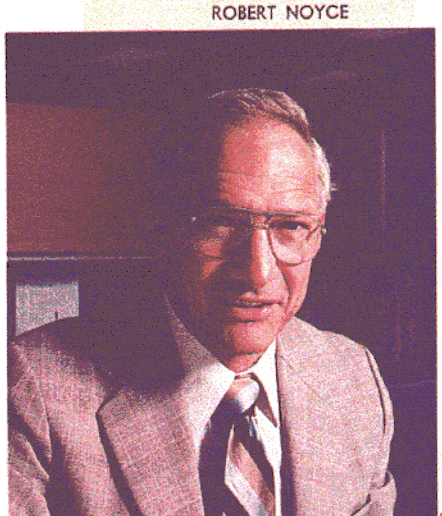
Noyce most recently has served as one of four group vice presidents guiding the operations of the parent Fairchild Camera & Instrument. He has been in charge of both Fairchild Semiconductor and
child Instrumentation, an
ated company.

Moore has been directo
Fairchild Semiconductor's
Alto Research Laboratory.

Moore, interviewed at
offices at 365 Middlefield
in Mountain View, said the
company will get under
with a fairly extensive dev
ment period that is to
"many months, probably."

DEVELOPMENT PLA

"Our strategy is to do
extended technological
before coming out with
ucts," he said. "We particu
are interested in product
that none of the manufact
are supplying."



Howard High

[...]e Fairchild, form own electronics firm

Business News

What turns both the founders on most is "the idea of getting back in the laboratory." Moore noted that they have found themselves increasingly absorbed in administrative rather than development work.

They didn't leave Fairchild, however, with the idea of starting a company together. Each made plans to leave separately, and then found their interests were so similar that it would be logical to get together.

A lucky break came when they were able to lease some of the space partly vacated by Union Carbide Corp. when it transferred more than 150 of its Mountain View force to a San Diego plant.

"It's larger than we need at first," Moore explained, "but it's equipped with the installations we need for specialty gas and water supplies."

HIRING PLANS

Moore and Noyce expect to hire a staff of about 50 during Intel's development phase, including about a dozen engineers. A few persons are already on the payroll, and Noyce was interviewing others this week while on a trip to the East Coast.

Financing is being arranged privately by Art Rock, San Francisco, who has specialized in finding capital for a number of well - established companies. Among them are Scientific Data Systems and Teledyne Inc.

Moore said he has to be vague about what areas of technology Intel will specialize in, because it hasn't been decided. In general, the company will avoid direct government business and product areas that others are already active in.

It plans to keep to the industrial rather than the consumer part of the industry.

Moore, 39, lives at 23965 Jabil Lane, Los Altos Hills.

He obtained his Ph.D. degree in chemistry and physics in 1954 from California Institute of Technology.

Before joining Fairchild, he was at Shockley Semiconductor Laboratory in Palo Alto with Noyce.

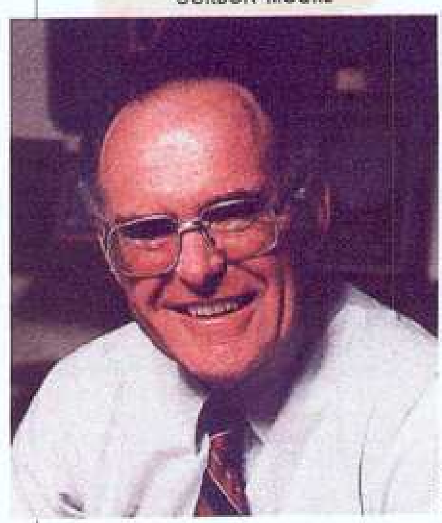
Noyce, 40, holds a Ph.D. degree in physical electronics and solid state physics from Massachusetts Institute of Technology.

His positions after co - founding Fairchild Semiconductor included research and development director, vice president and general manager, and group vice president.

His home is at 11420 Loyola Drive, Los Altos.

GORDON MOORE

Andy Grove



THE AGONY AND THE ECSTASY

William C. Eymann

In 1969 Intel's work force of 106 employees assembled in front of the company's first home in Mountain View, California.

THE TRIALS OF START-UP

The atmosphere at Intel during its start-up years could best be described as intense. A handful of bright, energetic engineers were gambling that they could set the standard in the memory industry with two virtually untried integrated circuit technologies, Schottky bipolar and silicon gate MOS. The results ranged from agonizing months of experimentation to the jubilation of producing a chip that worked.

Success was sometimes slow in coming. Although the 3101 bipolar device, introduced in the summer of 1969, soon developed a market, the MOS project—which promised greater density and performance at a lower price—did not reach production until late 1969, a full year after start-up. Even then, the first product, the 1101, did not work well. The anxiety level was high.

Having been through a similar start-up at Fairchild, Intel founders Bob Noyce and Gordon Moore did not feel the tension as much as others. "There was anxiety, sure," Noyce recalled. "We weren't certain that we could accomplish our objective, that is, get the price of memory down by a factor of one hundred. But most of us had been in the semiconductor business for all our careers and there was no one else who knew the business as well as we did."

For the rest, the tension was palpable. "It was intense," said Gene Greenwood, who joined Intel in 1970 and is now a product engineering manager. "Your whole life was intense. We'd work 12 to 18-hour days and it got so that I'd resent having to sleep."

Tempers often flared. Paul Metrovich, who came to Intel in 1969 as a senior technician, recalled, "Everyone would holler and scream at each other, letting off steam. I don't know how many times I went into Les Vadasz's office and called him everything I could think of, and he'd just laugh." Metrovich remembered Vadasz, who headed the MOS project, chasing an engineer through the plant while throwing pencils at him because of a late report.

Most of the anxiety came from the MOS project, which encountered formidable obstacles. For example, the technique for putting silicon on top of the oxide had yet to be perfected. "We'd put it down with evaporation," recalled Gene Flath, then manager, wafer fabrication, "and it would look nice, but pretty soon the surface would roll up like the top of a sardine can." The problem wasn't licked until a totally different polysilicon technique was developed.

The tribulations of the MOS team inspired Intel's first bet and simultaneously established a company tradition of betting as a management motivational tool. Andy Grove was then director of operations and was reminded daily of the MOS frustrations. "I was absolutely petrified we would fail," he recalled. In September 1968 he made a bet with Gordon Moore, Les Vadasz, Tom Rowe and Gene Flath, challenging them to produce a stable MOS capacitor by Thanksgiving. The stake was a bottle of Napoleon Cognac.

Tom Rowe, Intel's first process engineer, explained that building a stable MOS capacitor meant that its threshold voltage wouldn't vary more than a tenth of a volt, so it had to be uncontaminated. "We didn't even have distilled water in the plant!" he exclaimed.

Rowe got lots of exercise lugging bottled water into the plant, holding it up and pouring it over the diffusion equipment to clean it. But it still wasn't clean enough. "So eventually what we did—it was Les Vadasz's idea—was to use our phosphorous furnace," he recalled. "We lightly added a little bit of phosphorous to the MOS capacitor. On the last night we finally got one that didn't drift, although by using phosphorous we didn't do it exactly the way it was intended."

Nonetheless, the bet was won. "To this day Andy claims that because of the phosphorous we should have lost, but actually we won," said Flath.

MOUNTAIN VIEW REMEMBERED

The site of this intense activity and anxiety was Intel's first home, a small building in Mountain View, formerly occupied by Union Carbide Electronics. One of Flath's early memories is of the facility in which electronics history was to be made.

"It was a disaster. Carbide was still moving out, and there was equipment all over, wires and pipes hanging down, and the floor tile torn up. We picked a small section of the building and decided that's where we would put the fab area. Then we started to plan how we would equip it."

By coincidence, the Western Electronics Conference (Wescon) show had just opened in Los Angeles. Flath attended and literally ordered equipment right off the floor: "I'll have one of those, a couple of those, and three of those," he said. "We bought our Heavy-Duty Lindberg furnace bank there. It was a demonstration unit, and was in use until 1981 when the Mountain View fab was closed." Meanwhile, Andy Grove purchased bonders and Gordon Moore bought the evaporators.

Intel's first Christmas Eve in the building proved memorable. After most of the 20-odd employees had adjourned to the Wagon Wheel Restaurant in Mountain View for pre-holiday cheer, Bob Noyce noticed water on the floor near the evaporator room. A water line in the back of the vacuum system had burst, and gallons of water were quietly pouring out onto the floor. Noyce and the few employees still in the building—including Flath, Moore, and Jerry Larson—grabbed mops, squeegies, and giant quantities of paper towels, rolled up their pants, and in their bare feet spent the next two hours mopping up the floor. "If we hadn't caught it," recalled Flath, "the entire building would have been afloat after the holidays."

Manufacturing continued at the original Fab 1 in the Mountain View building until 1981 when production and employees were transferred to newer facilities in Santa Clara.

EASY MONEY

When Noyce and Moore decided to start Intel, they knew that one of the dangers for a young company was "running out of money on schedule but not getting the product out on schedule." So after incorporating, they appealed to Arthur Rock, a successful venture capitalist who had helped start Fairchild Semiconductor, Teledyne and Scientific Data Systems.

"Going to Art was a pretty casual thing," recalled Noyce. "We simply said that we were thinking of starting over again, and asked if he thought it was possible to raise the money. Rock replied that if we put up some of our own money, he wouldn't have any trouble." Noyce and Moore each kicked in $245,000 and Rock added $10,000. Rock soon raised an additional $2.5 million by

Art Rock, 1968

arranging for the sale of convertible debentures, mostly to individual investors. "Art simply got on the phone and called a number of friends, and they said, 'sure,' " Noyce remembered.

The business plan consisted of a single typewritten page which stated simply that the company was going into large-scale integrated circuits. Nothing specific. "Frankly, we didn't want people to know what we were doing," said Noyce. "We didn't want to attract competitors too soon."

Noyce's alma mater, Grinnell College in Iowa, was one of the early investors, acquiring $300,000 of debentures. This initial investment later proved so valuable that at one time it constituted 40 percent of the college's investment portfolio.

In the next two years, Intel realized another $2.16 million in private placements. The company went public in 1971 at $23.50 per share, raising $6.8 million.

RJ Muna

In March 1973, Intel scored its first $3-million month. Ed Gelbach, then director of marketing, ordered custom-labeled bottles of champagne for employees to celebrate the milestone.

INTEL DELIVERS

From its earliest days, Intel did not want to be perceived simply as an R&D house that could brilliantly invent a single component but not be able to deliver in quantities. "We felt it was important for us to go out of our way to deliver the products we were committed to, and to communicate this capability in the marketplace," explained Gordon Moore. "So we adopted the 'Intel Delivers' slogan and pushed it."

Bob Noyce added, "At the time everyone was talking about LSI, but nobody else was really doing anything. We were, and we felt we had to get across the message that LSI was here and not just pie in the sky."

Another aspect of "Intel Delivers" was assuring visiting customers that Intel was a reliable and substantial supplier, despite its small size. To do so, the company resorted to some ingenious solutions.

Andy Grove remembered being warned that one particular visiting customer needed reassurance that Intel was indeed a production house. A tour of the facility was arranged. Recalled Grove, "As the tour progressed, I ran around moving our people from one place in the building to another, so it would look busier." A number of employees wore several hats that day to give the customer a somewhat exaggerated picture of the workforce.

"As the tour progressed, I ran around moving our people from one place in the building to another, so it would look busier.
—Andy Grove"

Another attempt to impress customers was short-lived. At the time many of the staff members were Ph.D.s: Bob Noyce, Gordon Moore, Andy Grove, Ted Hoff and Dov Frohman. Someone decided it would be a good idea, when customers came to call, to page the Ph.D.s as "Doctor." The Ph.D.s soon put a stop to it themselves. "It sounded like a hospital: 'Dr. Moore to surgery,' " recalled Dov Frohman, "and we were all unhappy with it."

THE CHAMPAGNE TRADITION

Early successes established the champagne celebration tradition at Intel. When a circuit finally worked or a product was shipped for the first time, the news was announced over the paging system. Then someone would break out the bubbly.

Intel's first success was the 3101 bipolar project and the champagne flowed. The beleaguered MOS team, struggling at the other end of the lab to produce anything that functioned, was "pretty quiet" as the corks popped, recalled bipolar team member Ted Jenkins.

In the early days, when a circuit finally worked or a product was shipped for the first time, employees would gather in the cafeteria for a champagne celebration. After one such celebration, so many corks popped against the acoustical ceiling tile that it had to be replaced.

When the MOS team finally produced something workable, the joy was explosive. Remembered Metrovich, "It was about three o'clock in the afternoon, and we had a little party in the cafeteria. So many corks popped against the acoustical tile ceiling that it had to be replaced."

When Intel scored its first $3 million month in March 1973, Ed Gelbach commemorated the milestone by ordering a supply of small champagne bottles labeled "Domaine d'Intel" for employees. The tradition of custom-labeled wine or champagne bottles to celebrate achievements lives on.

ONE BIG FAMILY

In Intel's start-up years it was easy to communicate and socialize because the staff was small.

Employees would occasionally troop to Washington Park in Sunnyvale or Mitchell Park in Palo Alto for impromptu picnics. "These would usually celebrate some landmark event, and were organized by the employees," recalled Jean Jones, who joined Intel on day one as Bob Noyce and Gordon Moore's secretary.

Lunch was sometimes a family affair in the plant too. Every Thursday noon Bob Noyce and Gordon Moore would invite seven or eight employees to an informal meal, which would feature an open discussion in question-answer format. For a time this was a vital means of communication at Intel, but as the company grew, the lunches became fewer and they were finally dropped.

FIVE YEARS LATER

Intel celebrated its first five years with a summer party on San Francisco Bay. The festivities started in the afternoon, and included a Bay cruise, dancing to a live band and plenty to eat and drink. Intel staged an elaborate fireworks display as a grand finale.

By its fifth year, Intel was firmly established as an industry leader. The agonies and ecstasies of the "good old days," fast becoming the stuff of company legend, were giving way to the dramatic growth spurts of the mid-1970s, which would catapult Intel into the billion-dollar class by its fifteenth birthday.

> *There was anxiety, sure... We weren't certain that we could accomplish our objective, that is, get the price of memory down by a factor of one hundred. But most of us had been in the semiconductor business for all our careers and there was no one else who knew the business as well as we did.*
> *—Bob Noyce*

William C. Eymann

Betty Heiple and Joel Karp review one of the composite drawings that led to the 1103, a 1K dynamic RAM which went into production in 1970. The 1103 became an industry standard and by 1972 was the largest selling semiconductor memory in the world.

WHAT'S IN A NAME?

On July 18, 1968 Bob Noyce and Gordon Moore incorporated their new venture as N M Electronics. Not very creative, but at the time a company name was low on the priority list. Someone suggested Moore, Noyce Electronics, but it looked better than it sounded (More Noise).

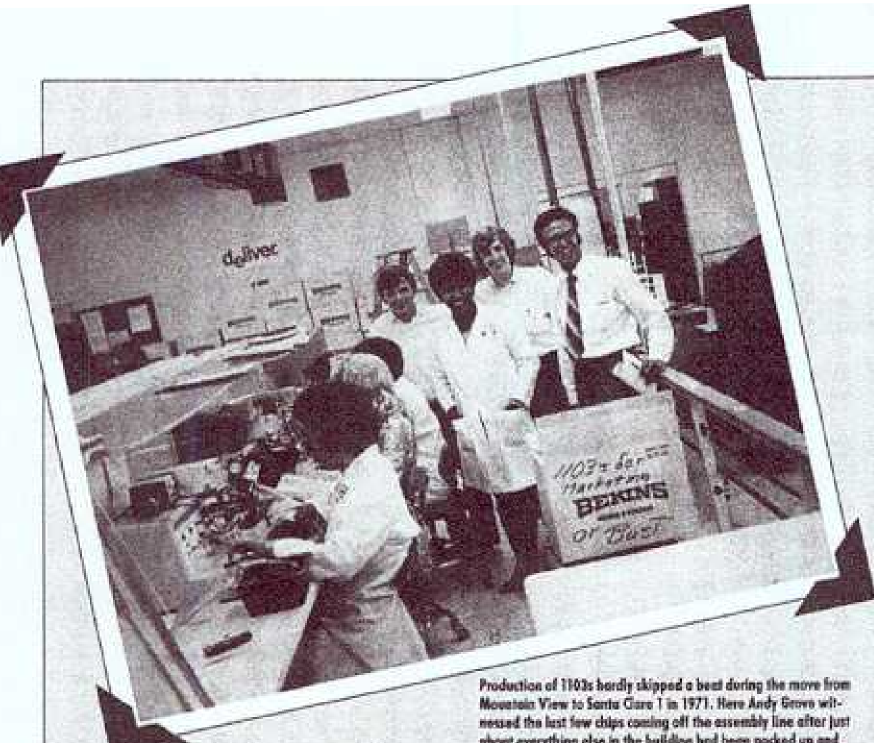
A long search followed for a more suitable company name. Integrated Electronics—the first choice, since it described the field the new venture was to tackle—had been taken, and the company ran another eight or ten selections past the State Corporations Commission without any luck. "Then we started using first syllables of various names we'd tried before, and came up with Intel, which sounded sort of sexy," recalled Noyce. There were potential conflicts here and abroad with other companies of the same or a similar name. Intel solved that problem by purchasing the rights to use the name from a company that used Intelco. "We thought that paying the $15,000 was easier than thinking up another alternative," said Moore.

The familiar logo with a dropped "e" was adopted soon thereafter. A public relations consultant, Jon Hall, suggested the design as a way of indicating where the syllable break should come, and hence the word each syllable stood for. The logo was approved promptly and enthusiastically.

OLD PEAR ORCHARD

By 1970 it was apparent that the original Mountain View facility would not accommodate Intel's growth, so the company purchased 26 acres in nearby Santa Clara. The property, located at the corner of the Central Expressway and Coffin Road, was a pear orchard. After construction of the first building, SC 1, employees could pick pears on the undeveloped land until SC 2 was built.

The association of a fledgling high-tech company with a Coffin Road address did not, many thought, project the best image, so Intel petitioned the city council to change the name of the street. The city council agreed, and the street was renamed Bowers after a prominent family in the area.



Production of 1103s hardly skipped a beat during the move from Mountain View to Santa Clara 1 in 1971. Here Andy Grove witnessed the last few chips coming off the assembly line after just about everything else in the building had been packed up and moved. Note the inscription on the packing box.

GETTING STARTED: THE 3101 AND 1103

Intel's charter was to design, manufacture and market semiconductor memory components incorporating large scale integration (LSI) technology. The company saw an untapped market in the replacement of computer core memories (then the industry standard) by producing low-cost, standardized circuits in high volume. Initial efforts were directed at bipolar and MOS memories.

The company's first successful product was the 3101 Schottky bipolar memory, a 64-bit high-speed static random access memory (RAM), introduced in 1969, just nine months after start-up. Bipolar memories were not new, but Intel adopted an innovation, Schottky bipolar technology (named for the German physicist, Walter Schottky). Not only did it work like a charm, but the company beat its competitors to the market.

Dick Bohn headed the project team which included Tom Innes, Ted Jenkins and H.T. Chua. Honeywell, which had established the industry standard for bipolar memories, had called for a new generation high-speed bipolar memory, and Intel jumped at the chance. Although Honeywell chose not to engage the new and unproved Mountain View company, Intel went ahead on its own anyway. "We delivered a brand new technology, we delivered ahead of anybody on that product, and it was an absolutely fantastic success story," said Les Vadasz. Added Andy Grove, "That project just purred."

The bipolar success generated much-needed revenue that helped establish the fledgling company in the semiconductor marketplace while it struggled to perfect its other technological breakthrough: the silicon gate MOS chip.

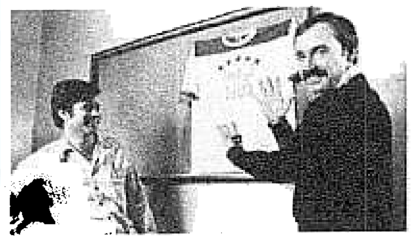
The 1103 dynamic RAM was phased out in 1979 and its "jersey" retired after eight years of prominence. Pictured are Bob Abbott (left), 1103 designer, and Ron Whittier, then Memory Components Division vice president and general manager. Whittier is indicating that more than 35 million 1103s were shipped.

ON THE MAP WITH THE 1103

In 1969, after a year of agony and frustration, Intel introduced the 1101, a 256-bit static RAM. This was the world's first high-

Robert Isaacs

1973 photograph of Bill Regitz who, as a Honeywell engineer and later as an Intel engineer, contributed to the design of Intel's early dynamic RAMs. He later became general manager of Intel's Memory Systems Operation.



SOOPER DIP

Intel's first MOS product, the 1101, made electronics history, proving the viability of the silicon gate process. Those who labored mightily to bring it to life remember the secret ingredient that made it possible.

"Les Vadasz led the design effort," recalled Tom Rowe, Intel's first process engineer. "We couldn't get the silicon gate process to work; it was a mess. We ran them on 2-inch wafers, and Intel thought that if we could run 20 working-die-per-wafer the company would be massively successful. It was a little bit like peeling an onion: every time we'd fix a problem, we'd uncover another one. I was afraid the last layer was going to be nothing. For all we knew the silicon gate process was no good. We'd make process change after process change and many design changes, but it was still yielding only about 2 die per wafer, which meant it was a commercial disaster.

"Then one morning we changed the acid dip formula, one step before aluminum evaporation, and when the first wafers came out they yielded 25 die per wafer, no exaggeration. By changing that one last process step, we went from 2 die per wafer to 25 die per wafer.

"George Staudacher, who was in charge of Sort, was so excited he started yelling, 'Holy hell, look what's going on here!' and pretty soon people came pouring out of their offices: Andy Grove, Gordon Moore and Les Vadasz were there, and I don't remember who else.

"The run was a split run; in other words, half was the old process and half was the new process. They'd say, 'Find another good wafer and put it on.' Staudacher would get it sorted, and sure enough there would be 20 to 30 die per wafer. Finally Grove came over to me and said, 'What did you do, Rowe; what did you change?' I told him we changed the acid dip.

"Well, Les was so excited he started jumping up and down and yelling, 'It's a *sooper* dip,' with his Hungarian accent, 'It's a *sooper* dip, it's a *sooper* dip,' over and over again. Someone heard him and went back and marked the container of acid, 'Super Dip.' So even though it wasn't a precise chemical formula, for over a year that container just sat there with that label 'Super Dip' on it.

"That was the real turning point for MOS; we proved that MOS silicon gate could make it that day."

Tom Vano

Les Vadasz, 1969

volume MOS semiconductor memory, and the first use of MOS silicon gate technology. Through constant innovation, it would lead to denser, higher performance memories at continually lower prices.

Although the 1101 was too complex and too small to achieve broad market acceptance and not capable of penetrating the core market, its basic MOS process was applied to shift registers (a simple form of serial memory). The market for shift registers was already established and Intel produced them profitably for a number of years. The resulting infusion of cash proved vital to Intel during the recession period of 1970-71.

During the same time frame, Intel was working on the 1102 and 1103, two designs for a 1K dynamic RAM using three transistors per memory cell. Intel and Honeywell were partners in the development of the 1102. Its design was led by Joel Karp, an Intel engineer, and Bill Regitz, who worked for Honeywell at the time but joined Intel in 1971. Intel's Bob Abbott, working under Vadasz, designed the 1103. Abbott explained, "As it turned out, the 1102 never made it to the market. And, although you couldn't say the 1103 was easy to use or produce, it was a little easier than the 1102 and it was smaller. In late 1970, Intel made the decision to put the 1103 into production, and to stop development of the 1102 altogether."

Honeywell provided invaluable assistance, testing early versions of the 1103 to rid it of hidden bugs, and perfecting package configurations and pin counts. "Honeywell was our biggest and best customer at one point, and they really encouraged us," recalled Gerry Parker, who was hired out of graduate school in 1969.

The introduction of the 1103, the world's first 1K dynamic RAM, was a turning point in the history of the integrated circuit: for the first time significant amounts of information could be stored on a single chip. It began to replace core memories and became an industry standard. By 1972 it was the largest selling semiconductor memory in the world. "It is now found in the products of 14 out of 18 mainframe computer manufacturers in the U.S., Europe and Japan," said Intel's 1972 annual report. That year, under the leadership of Albert Yu, Intel converted the Mountain View fab from 2-inch to 3-inch wafers, which doubled MOS die production capacity.

The 1103, by today's standards, was a primitive device. It was slow, difficult to make and test, and touchy to operate. But it proved that semiconductor memories were not only viable, but were a vast improvement over core memories, and it greatly increased the power of computers as they then existed. It also furthered the credibility of Intel as a new company, and produced revenues that were plowed back into development of subsequent products.

THE ROCKY ROAD TO A RAM

In developing the world's first 1K dynamic RAM, the 1103, Intel's young MOS team had to overcome a number of difficulties. For example, the product had a host of reliability problems. "I can remember in 1970 going out on the line twice a day and physically counting 1103s as the introduction date drew near," said Keith Thomson, who headed production control. "We almost knew each good unit by name."

"It was a bitch to test," said Les Vadasz. He remembered times of near euphoria when it appeared the product was working, only to have further testing reveal yet another problem. "The 1103 probably had more impact on the tester industry than it did as a memory," he laughed. Bill Regitz recalled actually shutting down testing of the part for a full week at one point because 30-40 percent of the parts were failing electrical test at final QA. "We worked around the clock with the people from Teradyne who made the testers, and finally located and solved a design problem in the tester. When it was fixed, our electrical final QA failure rate dropped to 15 percent."

Gerry Parker remembered efforts to overcome voltage, packaging and other shortcomings. "Once a customer returned a shipment of devices which were 'raining' inside because the glass used to seal them gave off moisture, acting like a pressure cooker," he recalled.

One of the later problems that beset the 1103 was loose bits of wire in the package. If the device was shaken, the bits would cause a short and the part would fail. The problem finally got so serious that Intel installed a machine to shake the devices and listen for rattles inside through a microphone. Dozens of inspectors were hired to examine each 1103 before it was sealed. "But it was a situation where 1 in 10,000 wires would be a serious problem," explained Parker, "so it was an incredibly difficult thing to inspect."

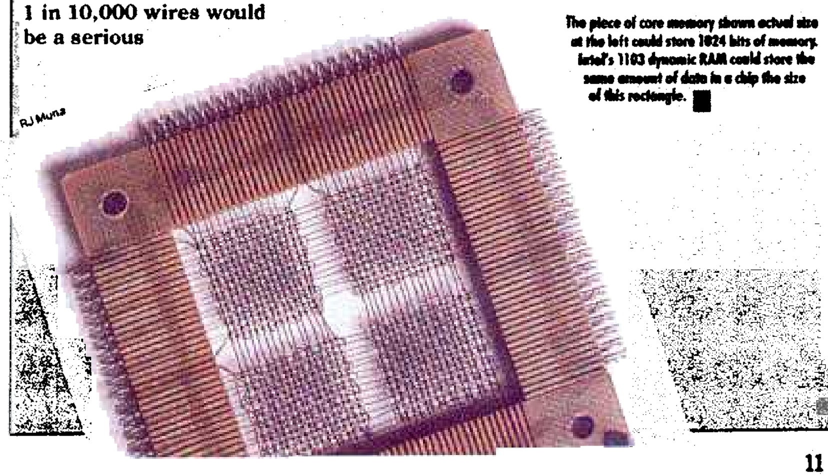
Although Intel management's commitment to the silicon gate approach never wavered, the problems and failures threatened the very life of the company. "We didn't have a product that was a major success until the 1103 in 1971," explained Andy Grove. "My worst nightmare was that the MOS memory would start drifting." (Drift on an MOS device, a phenomenon caused by even the tiniest bit of contamination, meant that the chip's electrical threshold did not hold constant. The changing voltage values would have rendered the chip worthless.)

Marketing the 1103 was a further challenge. Customers had difficulty using the chip, which led to numerous redesign projects, and Intel secretly harbored doubts about its early applications. Recalled Ed Gelbach, hired as vice president and marketing director in 1971, "We could never find a customer that used them and we were shipping literally hundreds of thousands of them. They were all testing the product and putting it in boards—they wanted to be in the forefront of technology—but it seemed like none of the customers ever shipped machines with the part. My recurring nightmare was that all those chips were going to be returned over a single weekend."

His concern was understandable. By 1972 almost all of the company's revenue resulted from 1103 sales. Commented Gelbach, "There was a general feeling that if the 1103 failed, Intel would not make it, and might not get another chance." As it turned out, thanks to the success of the 1103, Intel didn't need that other chance.

The piece of core memory shown actual size at the left could store 1024 bits of memory. Intel's 1103 dynamic RAM could store the same amount of data in a chip the size of this rectangle. ■

RJ Muna



STARTING ANOTHER REVOLUTION

The Intel ad in the November 15, 1971 issue of *Electronic News* was arresting: "Announcing A New Era of Integrated Electronics," it claimed. The statement, suggested by Gordon Moore, proved prophetic: Intel was introducing the world's first microprocessor, and would launch a revolution in the electronics industry.

Just four years later, in 1975, *Fortune* magazine would say, "The microprocessor is one of those rare innovations that simultaneously cuts manufacturing costs and adds to the value and capabilities of the product. As a result, the microprocessor has invaded a host of existing products and created new products never before possible."

This single invention revolutionized the way computers are designed and applied. It put intelligence into "dumb" machines and distributed processing capability into previously undreamed of applications.

The advent of intelligent machines based on microprocessors changed how we gather information, how we communicate, and how and where we work.

ENTER BUSICOM

In mid-1969 Busicom, a now-defunct Japanese calculator manufacturer, asked Intel to design a set of chips for a family of high-performance programmable calculators. Marcian E. "Ted" Hoff, an engineer who had joined Intel the previous year, was assigned to the project.

In Busicom's original design, the calculator required at least five chips, which Hoff considered too complex to be cost-effective. Furthermore, Intel's small MOS staff was fully occupied with the 1101, so the design resources were not available. Hoff came up with a novel alternative: by reducing the complexity of the instructions and providing a supporting memory device, he could create a general-purpose information processor. The processor, he reasoned, could find a wide array of uses for which it could be modified by programs stored in memory. "Instead of making their device act like a calculator," he recalled, "I wanted to make it function as a general purpose computer programmed to be a calculator."

To this end, Hoff and fellow engineers Federico Faggin and Stan Mazor came up with a design that involved four chips: a central processing unit (CPU) chip, a read-only memory (ROM) chip for the custom application programs, a random access memory (RAM) chip for processing data, and a shift register chip for input/output (I/O) port. The CPU chip, though it then had no name, would eventually be called a microprocessor.

Measuring one-eighth of an inch wide by one-sixth of an inch long and made up of 2300 MOS transistors, Intel's first microprocessor was equal in computing power to the first electronic computer, ENIAC, which

The first advertisement for a microprocessor ran in *Electronic News*, November 15, 1971. It announced the 4004 microprocessor, which launched revolutionary changes in how information is gathered, processed and communicated.

Robert Isaacs

1973 photograph of Marcian E. "Ted" Hoff, inventor of the microprocessor.

filled 3000 cubic feet with 18,000 vacuum tubes. The 4004, as it was to be called, could execute 60,000 operations a second, which by today's standards is primitive.

Initially the people at Busicom were not convinced that Intel was on the right track. It was not until early 1970 that they agreed to the concept and a contract whereby Intel would develop the chips for $60,000. The project proceeded, with Federico Faggin working furiously for nine months to complete the design. Masatoshi Shima, who represented Busicom and later joined Intel, designed the 4004 logic.

Intel delivered the chips, and Busicom eventually sold some 100,000 calculators.

Meanwhile, however, debate raged within Intel about what future this new chip had, and whether the company should negotiate for a return of the rights to it, which had gone to Busicom in the original contract. There were some who had no concept of what the new product was. Recalled Ed Gelbach, then director of marketing, "Originally, I think we saw it as a way to sell more memories and we were willing to make the investment on that basis."

But later, on a trip to Japan, he and Bob Noyce discussed the issue of the rights to the design. "We weren't sure where Busicom was headed or if it would succeed," remembered Gelbach. "But we did agree that we could do a lot more with this set of parts than sell it for calculators. So I made a commitment to Bob then and there that I would set up a separate group to pursue this."

Others—including Mazor and Hoff–were even more strongly convinced that the chips had a general purpose product potential. They had lists of possible product applications: cash registers, coin changers, traffic light controllers, and the like. They lobbied loudly that the company should return the $60,000 for the design rights.

Intel finally made the critical decision: it offered Busicom a lower price for the chips in return for securing the rights to the microprocessor design and the rights to market it for non-calculator applications. Busicom, by then in financial trouble, agreed. "The negotiations with Busicom were pretty unsophisticated from a legal standpoint," remembered Noyce, but that simple agreement would prove to be historic.

The Busicom deal hardly set off fireworks at Intel or in the industry. But Intel's man-

RJ Muna

Chuck O'Rear

1983 photograph of Masatoshi Shima, who now heads Intel's design center in Japan. As an employee of Busicom, a calculator manufacturer, Shima designed the logic for the 4004 microprocessor, which was developed by Intel for Busicom in 1971.

agement ultimately decided that the microprocessor represented a whole new type of computer with real commercial potential. It also offered the company an opportunity to extend its commitment in memories. Moore explained, "As soon as the microprocessor was a reality, we recognized that this was the next thing we wanted to do after semiconductor memory—a new direction in LSI. By programming, we could make a standard LSI circuit perform in a wide variety of applications. We seized it as another step in the direction we wanted to go."

> *"Originally, I think we saw it [the microprocessor] as a way to sell more memories and we were willing to make the investment on that basis."*
> *—Ed Gelbach*

MARKETING THE 4004

In 1971 Gelbach and his assistant, Hank Smith, took on the task of marketing the 4004. Their challenge was to convince logic designers to use the new technology.

The 4004 did not have very high performance but it was ideal for a variety of unsophisticated control applications. Initial market research was quite informal. Potential customers were asked why they didn't program their logic functions. The answer inevitably was "too expensive," to which Noyce would respond, "What if it cost $5; would you do it?" And the answer was always, "Sure."

"All we had to do was get the cost of the 4004 kit down from $30 or $40, and the customer could write his own program," said Noyce. "We had to create the need and get the price right." Gordon Moore remembered going to an industry conference in 1972 and saying, essentially, "Hey, we've got this thing; here's what it'll do. Now how can we in the industry figure out a need for 100,000 of them a month?"

It became apparent that potential users of the microprocessor needed help to use it. This prompted Gelbach and his group to produce the first generation of development aids, which were elementary programming tools. These made it easier for engineers to use Intel's first microprocessors. In just a couple of years, design aids, as they were called, actually became larger revenue producers than the microprocessors.

Intel's marketing strategy was to sell a $5000 development aid which in a year or two could produce orders for $50,000 worth of components. This plan would eventually pay off, but initially it appeared to generate more curiosity than cash: at one point Intel found that it was spending more on printing and mailing operating manuals than it generated in actual microprocessor sales.

A TURNING POINT: THE 8080

The 8-bit 8008 microprocessor had been developed in tandem with the 4004 and was introduced in April 1972. It was originally intended to be a custom chip for Computer Terminals Corp. of Texas, later to be known as Datapoint. Project designers were Hoff, Faggin, Mazor and a newcomer, Hal Feeney. As it developed, CTC rejected the 8008 because it was too slow for the company's purpose and required too many supporting chips. However, Intel offered the 8008 on the open market, where its orientation to data/character manipulation versus the 4004's arithmetic orientation caught the eye of a new group of users.

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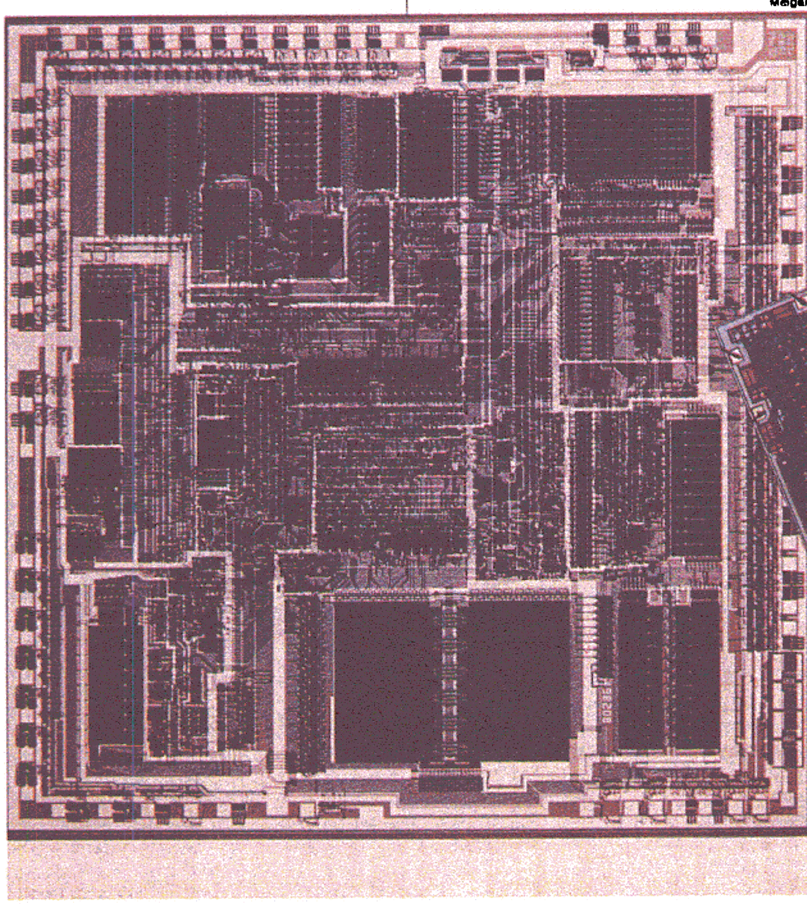
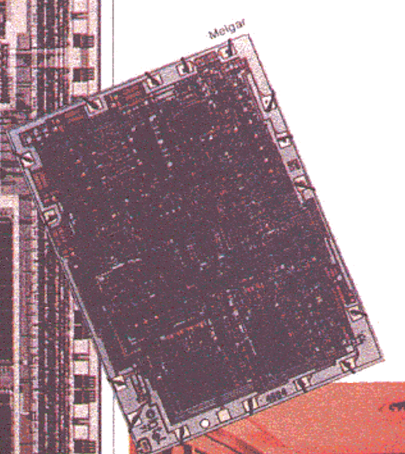


Relative sizes of the 80286 (left) and 4004 microprocessors are shown. The 4004, introduced in 1971, measures 117 X 159 mils (thousandths of an inch) and incorporates about 2300 transistors. The 80286, introduced in 1982, measures 347 X 347 mils and incorporates 130,000 transistors. Microprocessors have far more computing power than ENIAC (below), the first electronic computer, which was built in 1946.

Melgar



It soon became obvious to Intel and its competitors that there was an almost limitless number of applications for microprocessors. A big advance came in 1974 with Intel's 8080 chip, the first true general-purpose microprocessor.

The 8080 was a much more highly integrated chip than its predecessors, with about 10 times the performance. It could execute about 290,000 operations a second and could address 64K bytes of memory. Both the 4004 and 8008 utilized P-channel MOS technology, whereas the 8080 used the innovative N-channel MOS process, yielding vast gains in speed, power, capacity and density. What's more, the 8080 required only six support chips for operation, as opposed to 20 with the 8008.

The 8080 got its start as a project to speed up the 8008, with Mazor, Faggin and Shima as the engineering team. The idea, as Mazor explained it, was to use the 8008 masks with the process used for the N-channel 2102 RAM at the time. "After a bit of study, we realized we couldn't use the same masks with the new process," recalled Mazor, "so we ran a new mask set. I came up with the instructions in about two weeks, and we proceeded on the N-channel revision."

Shima implemented the 8080 in about a year and the new device was introduced in April 1974 at $360 apiece. "That figure had a nice ring to it," said Dave House, who joined Intel in 1974 and is now vice president and general manager of the Microcomputer Group. "Besides, it was a computer, and they usually cost thousands of dollars, so we felt it was a reasonable price." He added, with a smile: "I think we paid for the R&D in the first five months of shipments." "Those," laughed Gelbach, "were the good old days!"

The market response was enormous and the 8080 soon became an industry standard, creating a vast number of new uses and spawning whole new industries. It quickly erased any doubts about the revolutionary significance of the microprocessor.

Motorola introduced its 6800 about a year later, and its architecture was more familiar to programmers. "But we were ahead of Motorola and faster to produce and deliver," recalled House. "Furthermore, we did a more effective job of selling, using the 'solutions' approach to our customers: 'we've got the support systems and the peripherals to make your product more effective.'" This strategy paid off when Digital Equipment Corporation (DEC) went with the 8080, soon to be followed by other OEMs. "It was the domino effect after that," noted House. "Within six months Intel walked away with the 8-bit market."

FAR-REACHING DECISIONS—THE 8085 AND 8086

In late 1974 Intel management made a major commitment to advance the state-of-the-art in the computer business by designing a unique 16-bit architecture. It was hoped the product, the 432, would yield vast improvements in productivity through a complex multiprocessing architecture.

Meanwhile, competitors such as Motorola and Zilog were applying pressure in the 8-bit market, and it was clear that Intel would have to respond quickly. It did so with the highly successful 8085 microprocessor, a vast improvement over the 8080 because it operated on a single 5-volt power supply, was faster, and integrated more functions.

Although the 8085 was a success and remains so today, Intel soon recognized that delays in the 432 program posed a threat to the company's entry into the 16-bit market. It desperately needed a 16-bit device to fill the gap until the 432 was ready. At the same time, Intel wanted to build on the success of the 8080 solutions concept, and position itself as a company with complete solutions, not just components. So, in early 1976 the company decided to embark on a second 16-bit project. The resulting product was the 8086, a 16-bit device with 10 times the performance of the 8080. It was built as an extension of the 8080's architectural concepts, making it easier for customers to use and for Intel to market. The 8086 established a new 16-bit software architecture, and software compatibility became an extremely important strategy in developing and marketing the 80186 and 80286 microprocessors that would follow.

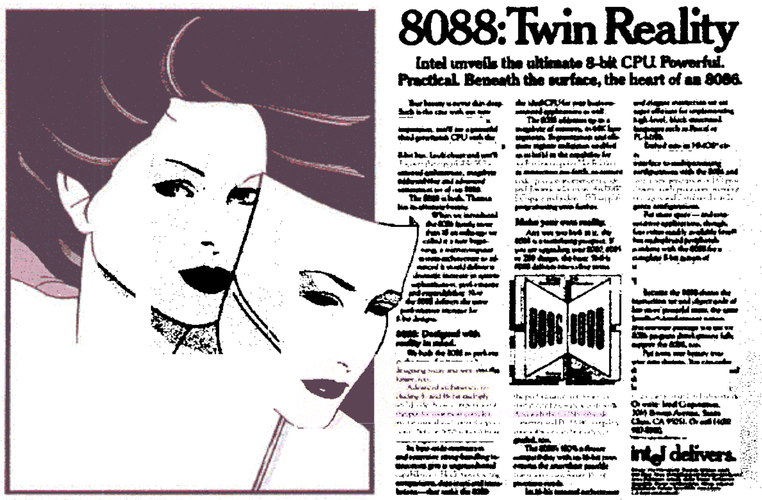
Jean Claude Cornet, who at the time was engineering director for microprocessors, was assigned to manage the 8086 program. In task force fashion, he assembled a close-knit team of specialists recruited from throughout the company. They were led by Bill Pohlman, and included Bob Koehler, John Bayliss, Jim McKevitt, Chuck Wildman and Steve Morse. Because of the time and competitive pressures involved, the team soon grew to 20 or so, which, according to Cornet, was unusual at the time. "What is remarkable is that many of these people had no more than a year's experience, and yet they brought to market a very complex product in less than two years," he said.

Cornet felt that careful definition of the process methodology was the key to the success of the 8086 project. "We did not have the benefit of computer-aided design tools," he said. "Everything had to be checked manually, so we tried to minimize the number of steps through precise planning." He recalled that seven rolls of paper were used to produce a complete drawing simultaneously. The fresco-like piece measured some 25 x 25 feet. The arduous hand process was later coded into computers to speed design work on subsequent devices.

The 8086 hit the market in June 1978 with a multi-page ad featuring a sunrise followed by the "first" 16-bit microcomputer—"the dawn of a new era." "A few minor competitors already had 16-bit products on the market," explained House, "but none of them had support and they weren't considered viable machines."

Although the new processor was introduced with support systems and board level products, it took nearly two years before it

> *"What is remarkable is that many of these people had no more than a year's experience, and yet they brought to market a very complex product [the 8086] in less than 2 years."*
> *—Jean Claude Cornet*



caught hold in the market. Justifiably, Intel people were concerned. "We were afraid," said House, "that it was a dud. It was too high end, and there wouldn't be enough volume for that kind of product." House recalled being "beaten up" regularly by Andy Grove because forecasts were not met. "But I said at the start it would be a slow ramp because it required new software and nobody had an operating system yet," House explained. And he was right. It was a long development cycle, with customers buying prototype quantities and working in their labs on software programs. But during this period, the 8086 won a lot of designs that did not show up in volume. Then in early 1980 the orders started to climb. "We had been promoting it with seminars and everything, and suddenly the orders rolled in like crazy," recalled House. It appeared that the 8086 was going to lock up the 16-bit market.

OPERATION CRUSH

The 8086 finally took hold, but competition wasn't asleep. Motorola's 68000, introduced about a year after the 8086, had initially proved to be a paper tiger. But by late 1979, the 68000, which many designers thought was a superior product, had developed a growing market. Intel was starting to lose design wins. "We could feel Motorola's momentum in the field," recalled Ken Aupperle, sales engineer at Intel's Atlantic Region office in Hauppauge, N.Y. "But the message wasn't getting through to management on the West Coast." Don Buckhout, Atlantic Region manager, was so alarmed he fired off an 8-page TWX to headquarters detailing the problems and recommending immediate action. By coincidence, Bert Hill, a field applications engineer in Denver, Colorado sent a long memo with the same conclusions postmarked the same day, November 2.

This sparked concern that if Intel didn't establish the 8086 as the standard in the 16-bit market, it could also be blocked out of the next generation microprocessor market. So management mobilized an all-out attack to make the 8086 and its 8-bit version, the 8088, industry standards.

The code name for the attack plan was Operation Crush, and it was headed by Bill Davidow. Crush team members determined two important factors that would serve as the program's platform: first, what was really important to customers was time-to-market, and that meant having not just a product, but complete solutions with software, peripherals and field support. Intel pushed this concept aggressively by coining the "Intel Delivers Solutions" slogan and promoting it aggressively through advertising, seminars and other promotions. Second, customers looked to Intel for the future. Intel responded by publishing a handbook which described products and systems of the future. Those interested in obtaining a copy had to attend one of the company's many seminars that were held worldwide.

"We set out to generate 100,000 sales leads," recalled Davidow, "and get that down to 10,000 qualified leads resulting in 2,000 design wins during 1980." But by the end of the first quarter only a couple hundred wins had been achieved and there was concern that the sales force would get discouraged. "We developed all kinds of incentives, including a trip to Tahiti, and the enthusiasm and momentum began to build," Davidow said. "The peer pressure in the field was tremendous—you just had to do it—and this was backed by some 50 seminars and advertising."

Bob Brannon, planning and marketing manager on the 432 program at the time, remembered Operation Crush as "all-out combat," complete with war room and a map of the world with pins identifying design wins. SWAT teams of engineering, applications and marketing people were supposed to be combat ready whenever a design win was threatened. "I was called in the middle of the night and told to be on a plane for Brussels in 24 hours," Brannon recalled in amazement. "SWAT team leaders would tell you where to go, who the customer was, and what part of the presentation you had to deliver. The presentations were already tailored to specific customer needs."

Operation Crush was enormously successful. It produced some 2500 design wins within a year, including IBM's selection of the 8088 for its personal computer. By 1984 the 8086 was outselling the 68000 by 9 to 1. More important, the Crush program reaffirmed Intel as the architectural leader.

THE NEXT GENERATION

By 1982 Intel's processor market share had started to decline again. But the company got back on top in a hurry with the 80186 and 80286, two products compatible with the 8086 and 8088. The 80186, designed by a team under the leadership of Dave Stamm, integrated onto the CPU a number of functions previously implemented in peripheral chips, producing higher reliability and faster operating speeds at less cost. It was suit-

Glynnis Kaye

1982 photograph of Gene Hill, project leader for Intel's 80286 microprocessor which, at the time of its 1982 introduction, offered about three times the performance of any other 16-bit processor on the market.

able for high volume applications such as computer workstations, word processors and personal computers.

Gene Hill was the project leader for the 80286, which offered about three times the performance of any 16-bit processor on the market. Aimed at the high end of the 16-bit market, the 80286 featured on-chip memory management, which meant it could support users performing several different tasks at the same time. It also incorporated a built-in security system to protect levels of data from alterations or misuse. It was designed for multitasking operations such as business systems, and office and industrial automation.

At first the 80186 and 80286 teams engaged in some friendly competition. "We had some intense rivalries as to whose chip was best," laughed Hill. "The 80186 people would joke that the best use of the 80286 was as an anchor for an ocean liner." But both chips, as it turned out, would be wildly successful.

Intel introduced the new processors with a market blitz similar to Operation Crush: marshaling talent, developing a plan, and executing. "Performance" was the battle cry. Recalled House, "Motorola was pushing performance because a trade publication had done a benchmarking report showing its 68000 had higher performance than the 8086. So we rolled the dice and asked an independent expert to benchmark the 80286. His report showed that the 80286 outperformed the 68000 and just about everything else on the market."

This information was used in advertising, seminars, and SWAT team presentations about the two new processors with outstanding results. "The 80186 went through the roof," House exclaimed. "The acceptance has been incredible." In its first year, Intel produced 30 times as many 80186s as it had 8086s in that processor's first year. Demand also required Intel to ramp up 80286 production quickly after its introduction.

There is scarcely an industry today that isn't affected by this technology. Yet the surface has just been scratched. Ever more powerful processors will evolve that will boost productivity dramatically and lower costs.

Who in 1971 would have imagined an invention as small as the 4004 would have such an impact in so short a time?

THE IBM PC DESIGN WIN

Perhaps the most significant of the more than 2,000 design wins credited to Operation Crush was the one that put Intel's 8088 in the IBM Personal Computer.

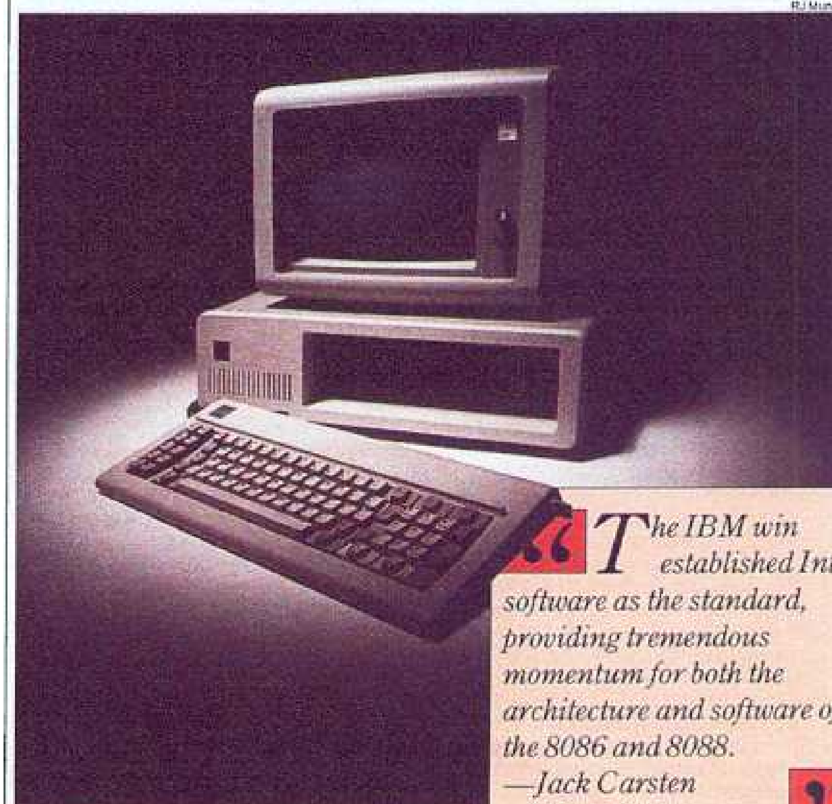
Early in the 1980s, IBM was developing its personal computer in rented space in a shopping center in Boca Raton, Florida. The company's strategy was to produce an open system using an industry-standard microprocessor. "We had the 8086 and the 8-bit version 8088 in the market," noted Dave House, then general manager of the Microprocessor and Peripheral Operation, "and, of course, the Z8000 and 68000 were just becoming available."

House recalled that it became apparent that IBM had chosen the 8088 when the Intel salesman in Boca Raton began filling orders for development systems and ICE™-88s. Of course, this was great news within Intel, but it was also frustrating. "It was proprietary information and we couldn't announce anything for four or five months," House said. "We knew Apple was going with the 68000, so we kept the Crush program going and toughed it out, all the time wanting to tell the world about the IBM win."

IBM brought its PC into production in just 14 months, a remarkable accomplishment which did not go unnoticed in the engineering community. "This should help us because customers know they have to be quick to market, which means complete solutions that we offer with our parts," House commented. Jack Carsten, then vice president and general manager of the Microcomputer Division agreed, "The IBM win established Intel software as the standard, providing tremendous momentum for both the architecture and software of the 8086 and 8088."

According to Infocorp. of Cupertino, California, microprocessors based on the 8086/88 architecture are now used in about 45 percent of the personal computers and small business systems on the market. Worldwide, that total market will equal about 6.2 million units in 1984, Infocorp. claims. And microprocessors are just the beginning. In keeping with its "total solution" approach, Intel is now a major supplier of the peripherals, microcontrollers, and memory devices also used in personal computers.

RJ Muna



"The IBM win established Intel software as the standard, providing tremendous momentum for both the architecture and software of the 8086 and 8088.
—Jack Carsten"

> "... *It may be that the nature of such high-risk research is that you may not find what you were looking for, but you find something else equally important.*
> *—Bob Noyce*"

THE 432—A NEW ARCHITECTURE

In February 1981, amid much fanfare, Intel introduced its 432 microprocessor. It provided for fault tolerance, nonstop performance, and it offered transparent multiprocessing, a feature which meant that processors could be added to the system for more power and versatility without rewriting software programs. The 432 gave promise of a great leap forward in productivity and a technology that might change the way computers were built.

But within 18 months, it was apparent that the 432 was too advanced for the marketplace. It was slow and too complex for many customers to understand or use. "We introduced it as a set of components rather than a system," explained Bill Lattin, who headed the project. "This was a mistake because it was much too complicated." It was recognized as an achievement in computer architecture, but without the software support, it was not ready to achieve anything commercially.

The 432 aroused considerable controversy within the company; to some it was a huge mistake and a failure, to others it was "courageous" and represented the "technology of the future." No one would deny that the 432 was innovative and ambitious.

The 432 got its start after the 8080 became established in the marketplace. Intel recognized that a more advanced processor would be needed and that the technology would be available for its development. "At that time, we thought we had one more chance to establish a new architecture before the massive software committed us unerringly to an evolutionary approach," recalled Gordon Moore. "The charter given to the 432 group was 'unfettered by compatibility' to go off, taking our new knowledge of the microcomputer market requirements, and develop an architecture that would endure for many years."

It appeared that the answer was to build a computer system that had real computer capabilities—not a controller, or "toy," as one manager put it—but a full-blown computer. Additionally, it would address many traditional computer problems: expandability, reliability and software costs. This would demand solving many computer science problems. Justin Rattner would lead several other bright young computer scientists on the 432 architecture. With innovative ideas, they convinced Intel management that the new architecture was the coming wave and that the opportunity to build an advanced computer on silicon was there.

The program started in mid-1975 in Santa Clara. In 1977 the group, which then numbered 17, moved to Oregon. The company was not experienced in operating locations outside California then, and Lattin had some difficulty getting the support equipment he needed to get the project rolling.

"We had ordered a $100,000 plotter, but nobody knew when it was arriving," he recalled. "When the trucker pulled in with it, he said we had a half-hour to unload it, or he was heading south!" Lattin quickly rented a forklift, and with four colleagues hanging on the back of the lift for balance he lowered the two-ton plotter gently to the ground. "It kind of shook me up there for a minute," Lattin said with a grin, "but there was no way I was going to let that equipment go back to California." By chance, his wife passed through the plant during the delicate operation and asked, "Is that what you really do here?"

The 432 program was technologically aggressive, but suffered a series of gut-wrenching delays. In early 1976 Intel made a decision to proceed with a second 16-bit machine, one that would be compatible with the 8080 market. In hindsight, this decision proved to be one of the most critical in Intel's history. The resulting product, the 8086, debuted in 1978 and, after a slow start, became a huge success.

Meanwhile, the 432 continued along in a stimulating but pressure-packed environment. Rattner commented, "The 432 was pushing the state of the art in almost every area—what could be more exciting? The engineers I know still recall the special environment we created."

Although the 432 has not become a commercial success, it has generated substantial interest among researchers at more than 35 colleges and universities in the U.S., Canada and Europe. By 1984 there were some 40 campus projects involving the 432, and Intel encouraged this academic research by donating equipment and counsel.

The 432, in retrospect, has been a classic example of Intel's willingness to take risks to maintain its leadership. "I'm proud of Intel," asserted Lattin. "One has to have the courage to fail if one is to make major contributions." But there has been a very substantial silver lining. "One of the most important results of the 432 program is the large chip methodology we developed which involved an entirely new set of tools and techniques," Rattner noted. "At the time, Intel had not built a chip with more than 30,000 or 40,000 transistors, so the techniques just weren't available. We were forced to develop a new approach to large-scale chip design. Today, many of the chip designs at Intel embrace that methodology. We take great pride in that."

Concluded Bob Noyce, "The technology and concepts learned from the 432 project have had enormous applicability to some other things we are doing and doing well. So it may be that the nature of such high-risk research is that you may not find what you were looking for, but you find something else equally important."

THE COMPUTER ON A CHIP

In 1976 Intel introduced the 8748, an 8-bit, single-chip computer or "microcontroller." It contained its own central processor, EPROM, data memory, on-chip peripherals and I/O to provide a highly integrated controller for systems.

A microcontroller controls real-time events, as opposed to microprocessors which are used to manipulate large amounts of data. A microcontroller takes information about what is happening and causes a system to respond appropriately. This ability has caused demand for microcontrollers to rise rapidly because high-volume applications tend to rely on real-time control functions. For example, the numbers of autos, video cassette recorders and printers produced each year are high, and each of these products might incorporate one or more microcontrollers.

The 8748 enabled users to prototype their products quickly and modify EPROM program storage as required, thus avoiding the long mask generation process. This proved to be a major innovation, and the MCS®-48 family, of which the 8748 was the first, soon became the most widely applied 8-bit microcontroller architecture in the world. Technologically, it was innovative as well, tying EPROM technology with microprocessors. As a result, the 8748 and the 8048, its smaller ROM version, were among Intel's hottest products in the late 1970s.

"It was one of those products we just couldn't make enough of," recalled Hank Blume, who headed up the design team for the 8748 and 8048, built about a year later. "Our goals were to design a superior microcontroller architecture and to exploit 5-volt EPROM with on-board logic," Blume said. "This would enable the customer to work with a single power supply and prototype a product faster and at less cost." The project team included Dave Stamm and Dave Budde, two recent college grads, and Howard Raphael. They coordinated closely with the 2716 EPROM technology team.

Gene Hill joined the MCS-48 team to help get the 8748 into production. Other members included Mark Holler, Mike Melloch and Bob Wickersheim. The pace was hectic. "The atmosphere was very much like a start-up," Hill recalled. One of his earliest memories of Intel was running into Allen Goodman, a coworker, in the lobby early one morning. "His wife was there and gave him some clean clothes," Hill said. "He ducked into the restroom, changed clothes, gave her the dirty ones, then went back upstairs to continue taping out the 8048. He'd obviously worked through the night."

The 8748 went into production in early 1977 but, blunted by brisk competition, reported design wins failed to live up to expectations.

The situation improved dramatically within months, thanks to three factors: the company's swift introduction of the low-cost PROMPT™-48 and ICE™-48 support systems to simplify customer design, aggressive pricing, and a burst of wins from customers who had been designing the device into their products unbeknown to Intel. By year's end, sales were soaring.

The exciting 8748 and 8048 opened the high-volume, low-end of the controller market for Intel. They were followed in 1980 by the more powerful 8051 family, which was developed under Hill's leadership. Bob Wickersheim was the 8051 project manager. In mid-1979, about halfway through the design phase, Wickersheim moved with the project to Chandler, Arizona, along with the Microcontroller Operation. At that point, Shep Hume took over as engineering manager. By the end of 1983, the 8051 had become one of the chips in greatest demand in the industry.

A third generation microcontroller, the 16-bit 8096, was introduced in 1982. It integrates over 120,000 transistors, the highest integration achieved in a single-chip controller. The 8096 promises to be the 16-bit world standard, according to John Ekiss, vice president and general manager, Special

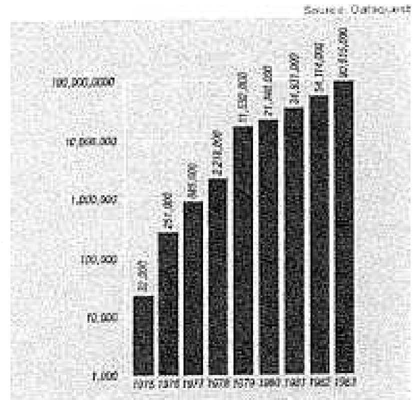
1982 photograph of Hank Blume, who headed up the design team for the 8748 and 8048 microcontrollers.

Components Division, which includes the Microcontroller Operation.

In 1983 Intel introduced the 80C51 and 80C49 controllers, its first microcontrollers built on the CHMOS process. CHMOS technology provides high performance with far less power consumption than HMOS, a critical factor in designing increasingly dense circuits.

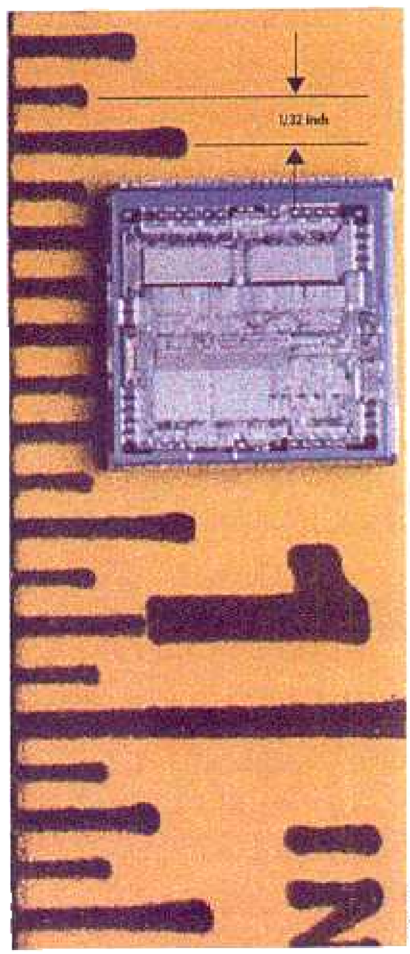
Ekiss is bullish on the future of the controller business. He notes, for example, that the $250 worth of electronics in a car today is projected to grow to $1400 in the next seven to ten years. "If you figure $100 worth of semiconductors per car and nine or ten million cars produced in the U.S. alone each year, you have a tremendous market. The potential is enormous."

Today the average home has about sixty electric motors running clocks, furnace fans and a host of other household appliances. Microcontrollers are finding their way into these appliances and being used in many other applications. The day will come when all of us will be surrounded by these dedicated devices and not even know they are there.



8-bit Microcontroller Unit Shipments

Actual size of Intel's 80C51 microcontroller, which is manufactured using Intel's high-performance, low-power CHMOS process.



SHOULD WE OR SHOULDN'T WE?

Ford calls it the "world's most advanced automotive computer," regulating a host of engine operations for more responsive performance and improved fuel efficiency for the consumer. It's the EEC-IV (Electronic Engine Control), built with the world's first 16-bit microcontroller, the Intel-designed 8061, and the 8361 RAM/ROM, and is an important component of every 1984 Ford automobile and truck. With the success of the EEC-IV it appears that Intel will enjoy a substantial position in the automotive market for years to come. But getting there was an agonizing experience that started in the mid-1970s.

"It took an enormous investment in the early going," recalled Bob Noyce. "We asked ourselves over and over whether we should be in the automotive business or not. Then we'd say that we had to be in the business regardless of cost."

The ambivalence was an understandable reaction from semiconductor engineers, who had seldom ventured that close to consumer products, and who viewed with alarm the escalating expenditures.

But once the decision was made in 1976 to pursue the automotive market, Intel did so with its customary fierce determination. "The shortest corporate objective ever in the history of the company was written that year," recalled Gordon Moore: "'Book Ford.'" Added Dick Boucher, who in 1978 assumed direction of the program, "All we needed were those two words. They needed no explanation; it was very crisp, clean, and short. We've never had an objective that could be clarified so easily with so few words." Continued Boucher, "Our major concern was whether we could handle the demands of a Ford or GM; would they overwhelm our resources? They didn't understand the semiconductor business, and we had a lot to learn about the exacting needs of auto production."

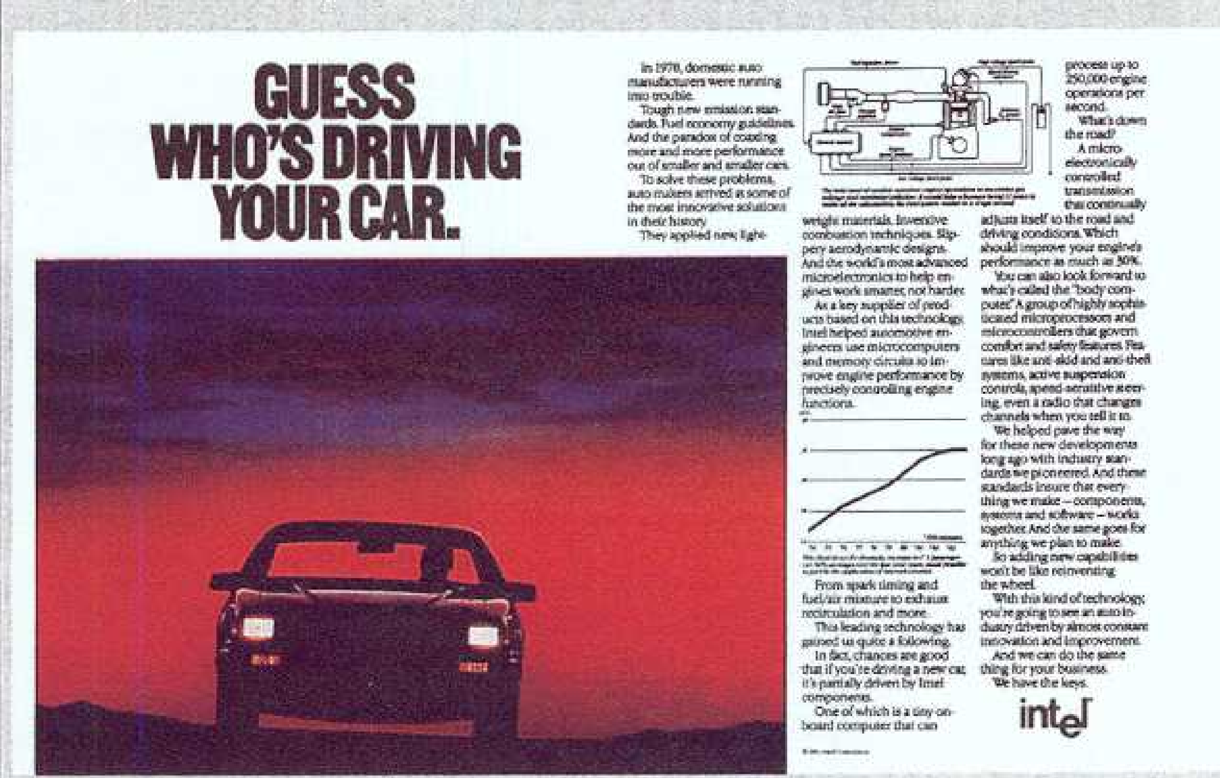
Boucher defined Intel's role as that of a technology resource to develop devices for total engine control. He and his group set up their own quarters and did their homework, working with a number of companies.

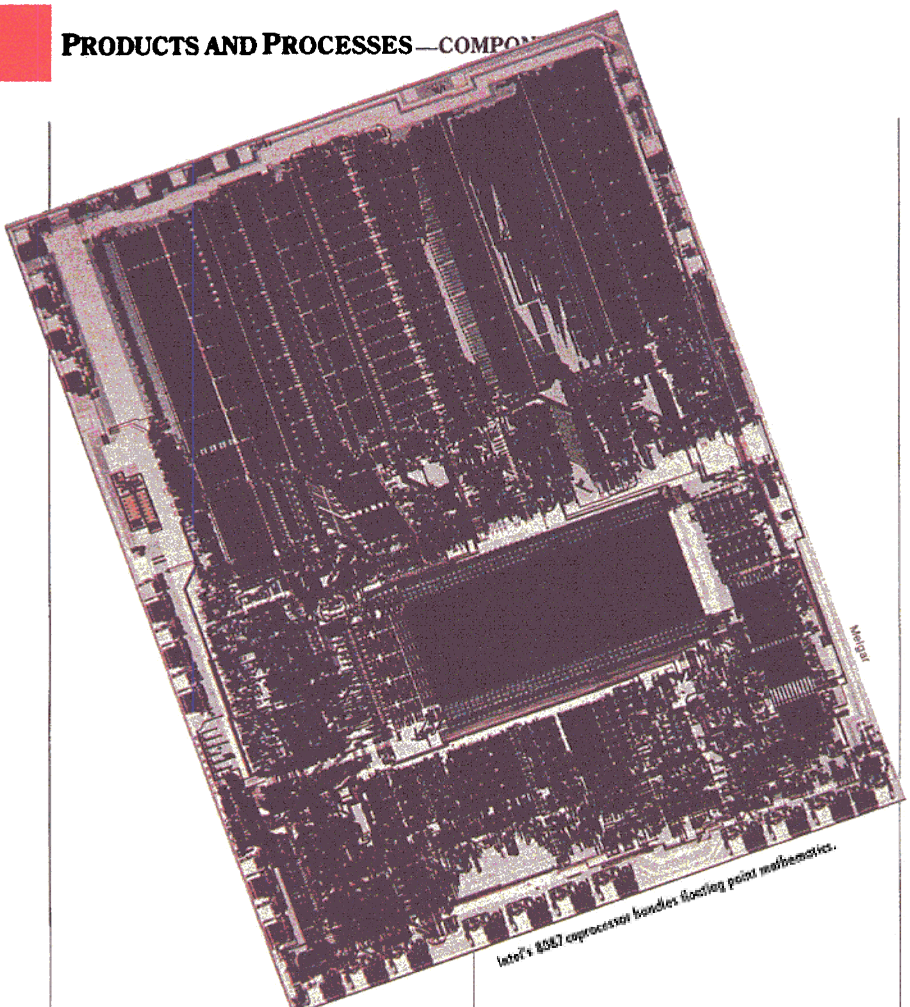
In 1981 Intel's first design, the EEC-III microcontroller, was used on a limited number of Fords. But Ford wanted a more sophisticated system, and Intel negotiated with Ford for a lead position in the EEC-IV program. The Automotive Engineering Operation developed the 8061, and a contract was signed whereby Intel became the primary supplier to Ford.

Looking back, Boucher remembered tough years. "You can imagine the pressure on the auto manufacturer; the production line has to keep moving," he said. "That pressure is passed along to the supplier, believe me!"

"I can remember," added Ed Gelbach, "in 1983 something like 150,000 automobiles a month were being produced by Ford Motor Company, and if for some reason we couldn't produce those microcontrollers, they would have had to shut down their assembly line and lay off about 40,000 people. I'm proud to say that Intel came through; the line never went down."

The demanding pace and the investment over a period of some eight years is now paying off. Intel now supplies powerful microcontrollers, microprocessors, and memories to a veritable Who's Who of automotive companies. These increasingly elaborate, sophisticated systems—controlling powertrain, instrumentation, and auto body functions—will vastly improve the comfort, convenience, operating cost, and safety of cars of the future.





Intel's 8087 coprocessor handles floating point mathematics.

Melgar

PERIPHERALS FOR THE TOTAL SOLUTION

As applications for Intel microprocessors increased steadily in the mid-1970s, it became necessary to integrate more functions onto the devices to lower costs and improve performance. The company answered this need by designing and building peripheral controller chips that interfaced with the CPU to perform various functions.

Among the early devices introduced beginning in 1975 were the 8255, 8253 and 8251 programmable chips. Other significant early products included the 8275 CRT controller and the 8271 floppy disk controller.

Peripherals have become a major revenue producer for Intel. The company's growing array of peripheral chips has expanded significantly the range of functions made possible with Intel microprocessors and increased their performance. By integrating more and more functions, these devices cut software costs and enable customers to bring their products to market faster.

An important impetus to the growth of Intel's peripheral business was the introduction of the coprocessor in 1980. A coprocessor is specialized hardware that acts as an extension of the host CPU to handle specific high-performance functions. This has the effect of offloading from the CPU specialized tasks more effectively handled by the coprocessor. The 8087 coprocessor, for example, makes it possible to solve difficult mathematical problems on the iAPX 86/88 system that formerly had to be solved on large higher-cost minicomputers or mainframes. It does the computation about 100 times faster than equivalent numeric software running directly on the microprocessor.

Intel now offers a number of coprocessors so that customers can economically select combinations to match their performance requirements. These include the 8089 I/O channel processor for data movement, the 82586 for data communications, and the 82730 text processor. The latter device was introduced in 1983 and was aimed at applications in word processing terminals, personal and small business computers, non-impact printers and typesetting systems.

The coprocessor was a remarkable engineering achievement, and many people played important roles during its development. The concept grew out of the 8086 program directed by Jean Claude Cornet beginning in 1976. Bill Pohlman, 8086 project manager, defined a floating-point extension to the 8086. His work resulted in the 8087 systems interface architecture. John Bayliss and Bob Koehler share a patent for the "functional partitiofing" that the iAPX 86/88 uses to distribute computing capacity among a number of processors.

John Palmer and Bruce Ravenel were responsible for the 8087's initial architectural design and software technology. In 1978, the 8087 project was sent to Intel Israel for implementation. "The design and architecture documentation on the 8087 were solid," recalled Cornet, "and we felt this would be a good opportunity for the Israel team to run with a project."

Under Rafi Nave, now general manager of Intel Israel Design Engineering, the logic and circuit designs were completed. Palmer, Ravenel and Nave share a patent for the invention of the 8087 math coprocessor.

The 8087 returned to the Microprocessor Operation in Santa Clara for production and test. The 8087 was the first implementation in silicon of the IEEE standard for floating-point mathematics. It was so innovative that three years after its introduction, competition still hadn't come out with a similar product.

Noted Cornet: "There is no question that the 8087 hastened the success of the 8086 family of microprocessors. Coprocessor performance was identified early on as one of the 8086's major selling features."

The 8087 was improved and now is also compatible with Intel's 8088 and 80186 microprocessors. It also established the technology for the coprocessors that would follow to provide even greater software integration—the 82720, 82730 and 82586.

Said Ted Jenkins, general manager of Intel's Peripheral Components Operation, "The coprocessor is an important step in performing specific functions. It eliminates the need for extensive software routines, and thus reduces software costs. As microcomputers become more powerful and applications more complex, the development of specialized peripherals and coprocessors will have to keep pace."

Intel's selection of more than 60 peripherals and coprocessors is the largest of any semiconductor manufacturer. This broad line of products is integral to Intel's philosophy of providing the "total solution" for its customers.

> *"It [the 8087] was so innovative that three years after its introduction, competition still hadn't come out with a similar product."*

THE EPROM: A BIT OF ELECTRONIC MAGIC

From its startup days, Intel has been responsible for many breakthroughs in integrated circuits. Few were more significant—and more unexpected—than the EPROM, the acronym for a mouthful of a chip name: the erasable programmable read-only-memory.

Intel introduced the world's first EPROM in January 1971. It is a read-only-memory (ROM) with a special difference: its program can be erased by ultraviolet light. ROMs are permanently programmed by the semiconductor manufacturer during the fabrication process. Thus, every ROM program change requires a new mask. EPROMs give designers greater flexibility because they are programmed electrically and can be erased by exposure to ultraviolet light and reprogrammed again and again.

At the time, no one imagined the role the EPROM would play in electronics history. Soon, this device would become a key to the microprocessor revolution.

Glynnis Kaye

1982 photograph of Dov Frohman, who invented the world's first EPROM, the 1701, which was introduced in 1971.

SERENDIPITY

When physicist Dov Frohman joined Intel from Fairchild in 1969, he worked on the MNOS concept—metal-nitride oxide—with which he was familiar. This was an MOS device project, yet it was significantly different in terms of process technology, requiring a source of silicon nitride. Many frustrations were encountered in processing the MNOS runs, however, so the company began to focus more on the silicon gate MOS process. Frohman turned his attention specifically to reliability problems the company was having with that process. He concluded that disconnected or floating gates could be the cause of some of the device failures. As he worked to solve the problem, Frohman had the inspiration that the floating gate phenomenon might be the basis for a memory, and, as he thought more about it, a memory that could be programmable and erasable. "Call it serendipity if you want," commented Les Vadasz, who was Frohman's supervisor at the time, "but we really backed into the EPROM. The origin of the whole thing was an attempt to explain a process problem, and Dov deserves all the credit for recognizing what we had and utilizing it to create a new memory concept."

The novel device—a floating gate memory—stored a charge permanently, which was a major breakthrough. Previously, devices required a constant power supply to maintain the memory function, and if power was lost, the devices had to be reprogrammed.

Frohman arranged for a demonstration of the new device in Gordon Moore's office. "We put together a 16-bit array with primitive transistor packages sticking out of the 16 sockets, an oscilloscope and pulse generator," he recounted, "and we carted all this into Gordon's office. There were red bulbs to indicate the bits. This was all new to us, and we were thrashing around. We showed Gordon that by pushing the button you could program the device, and we demonstrated that it would hold a charge."

Moore must have sensed a potential for the product because he made the commitment to proceed with development of the 1601, a 2K-bit programmed memory. Soon after Intel engineers understood the mechanism of the process, it was determined that the memory in the device could be erased by applying UV rays. This was a major innovation because the same memory device could then be reprogrammed. A glass window was added to the 1601 to allow the erasure, and another new product resulted—the 1701 EPROM.

> *"...Frohman had the inspiration that the floating gate phenomenon might be the basis for a memory, and, as he thought more about it, a memory that could be programmable and erasable."*

EARLY TESTING

Tom Rowe, Gene Greenwood and Greg Pasco were among those who worked to develop a product from the original concept. Frohman remembered that one of the problems they encountered was the size of the product. "It was 50 percent bigger than any chip Intel had made, and we had problems with our work table—it wasn't big enough to hold the mask layout photographic reductions for checkout," he recalled. "We had to piece four pieces together for each mask layer and that was crazy. Then it all had to be aligned, but finally we managed to improvise and get the masks prepared."

In September 1970 the team finally produced some devices and began testing. "In the second week we saw life and it was clear that we had a functional device," Frohman recalled. "We put the device on display and people were in disbelief. It dawned on them that this was for real."

But would the new device with a transparent lid retain memory for an extended period of time? That was the concern of both Intel and potential customers. Gerry Parker, who was involved in the reliability testing of the product, remembered, "Our biggest concern was that there was no way to prove that the product would not fail ten years out, because we didn't understand what might cause such failure." Despite numerous accelerated life tests, that was one question that could only be answered with time.

Then someone had an inspiration: where was there an environment severe enough to prove that this device would not lose its memory just sitting around in room light? The answer: "We charged the memories and put them on the roof in the bright sunlight. We measured them week after week, and they passed the test," said Vadasz.

A DRAMATIC DEMONSTRATION

Intel introduced the EPROM technology with a dramatic presentation at the February 1971 International Solid State Circuits Conference in Philadelphia. To demonstrate the EPROM's erasable feature as vividly as possible, the company produced a film. Gordon Moore remembered it and the audience reaction well:

"The movie showed a pattern of bits being erased—bit by bit, this sea of dots would disappear until only an Intel logo remained. With continued UV the last bits gradually faded until one single, persistent bit was left. Finally, it too disappeared, and the audience burst into applause. It was spectacular!"

WHAT DO WE DO WITH IT?

Although the film demonstration was a smash hit, Intel still wasn't sure what it had with the 1701. "It was just another kind of memory at the time," recalled Moore, "and people saw it as an R&D device." It was not until the advent of the microprocessor that the real significance of the EPROM was realized. The microprocessor created a demand for memory, and the fact that engineers could test and reprogram memories with the EPROM accelerated the development of the microprocessor. There was a synergistic relationship between the two.

"In retrospect," explained Moore, "the EPROM is probably as important in the development of the microcomputer industry as the microprocessor itself. But at the time, that certainly wasn't our idea. They were different but happily concurrent developments."

Ed Gelbach remembered that when he joined the company in mid-1971 the EPROM was a rather mundane product and that nobody knew what to do with it. He increased the price and advertised it as a prototype device, and it started to become profitable. But it was not until the EPROM tied in with the microprocessor that it really took off. Recalled Gelbach, "It made sense to be able to reprogram the microprocessor instead of buying fixed ROMs for it. You could change your system overnight or every five minutes with an EPROM."

THE NAKED RUNNER

With each new generation of ROMs cramming more and more memory onto a single chip, Intel introduced denser EPROMs. In 1975 the company introduced the 8K 2708, the first N-Channel EPROM. But it was the 2716 with its 5-volt power supply that was to become an industry standard. Introduced in 1977, the 2716 was compatible with any microprocessor system, greatly broadening its application potential.

Scanning Electron Microscopic view of a common table salt crystal resting on Intel's high-density 27128 EPROM. Each of the 27128's 131,072 cells measures approximately 7 microns (7 millionths of a meter) across, in contrast to the average salt crystal's 300 microns.

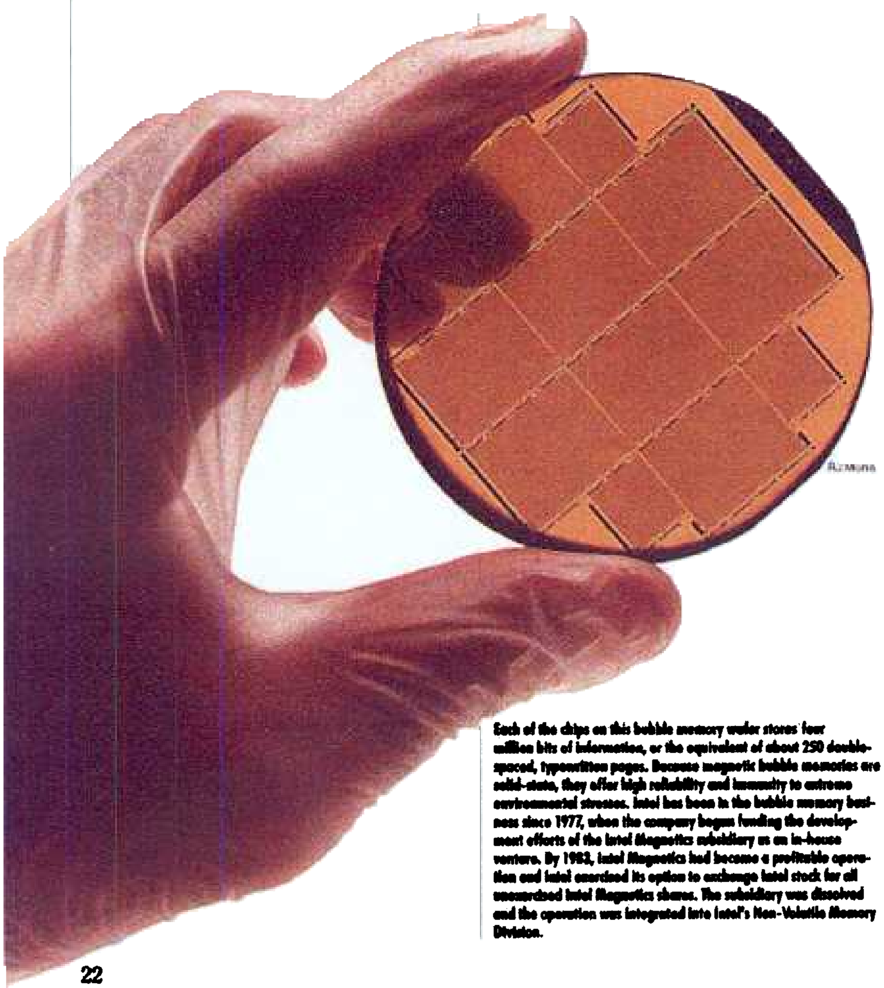
Almost overnight the 2716 gained wide acceptance in production, and the market ignited. "It was a huge success for a couple of years," recalled George Schneer, now vice president and general manager of the Non-Volatile Memory Division. "What's more, we had a lock on the market because competitors had trouble executing the floating gate technology." But the 2716 was also a "naked runner"; it was all alone in front of the pack, and if not improved, would soon get trampled by the competition. Intel tried to keep ahead with a new process design for a 32K and 64K EPROM, but the early yields on these devices were poor and competition arrived on the 16K scene with a vengeance. As competition increased and prices dropped, Intel soon found itself "wallowing in the pricing mud with the others, trying to protect market share," as Schneer put it.

By late 1980 Intel's EPROM business was in trouble. Prices had fallen by as much as 75 percent. What was more, the company faced a severe economic downturn with a newly completed plant with capacity to burn—Fab 6 at Chandler, Arizona.

GAMBATI!

The first step out of this grim situation was the formation of a 2764 task force with members from the Programmable Memory Operation and Technology Development as well as Harry Hollack and Ed Boleky of Fab 6.

From a product standpoint, the key to the aggressive program the task force launched was the use of new wafer stepper technology. The Technology Development group in Santa Clara had used the 2764 in its development work with the stepper process, reducing die size and producing dramatically



Each of the chips on this bubble memory wafer stores four million bits of information, or the equivalent of about 250 double-spaced, typewritten pages. Because magnetic bubble memories are solid-state, they offer high reliability and immunity to extreme environmental stresses. Intel has been in the bubble memory business since 1977, when the company began funding the development efforts of the Intel Magnetics subsidiary as an in-house venture. By 1982, Intel Magnetics had become a profitable operation and Intel exercised its option to exchange Intel stock for all unexercised Intel Magnetics shares. The subsidiary was dissolved and the operation was integrated into Intel's Non-Volatile Memory Division.

higher yields at substantially lower costs than with projection aligners. So the decision was made to install stepper equipment in Fab 6. "They were vibrating down there," Schneer said excitedly. " 'Give us something to do,' they cried. So we gave them something to do: come up on wafer steppers!" The new fab ramped up production of the 2764 rapidly, meeting extremely aggressive yield and reliability goals.

A new process, new product, new plant and new people. "It was high risk, bet your company, bet your division!" exclaimed Bob Derby, then the operation's director of marketing.

The marketing plan was equally innovative: introduce the 2764 in Japan. "Our backs were against the wall, so it was time to stand and fight," said Derby. "The Japanese have a word for it—'Gambati.' " Derby, who had been sales manager in Japan in 1979-'80 and understood their culture, explained the strategy: "We had a hot new product; why not introduce it right in our strongest competitor's backyard? This would have great shock value, particularly if we could show them that we had superior cost advantage."

Howard High

1980 photograph of Harry Hollack, who led the 1980 start-up of Fab 6 in Chandler, Arizona. Fab 6 contributed significantly to Intel's leadership in the EPROM marketplace by ramping up production of Intel's 2764 EPROM, and meeting extremely aggressive yield and reliability goals almost immediately after start-up.

With "Gambati" as their rallying cry, the 2764 task force members galvanized into action for their all-out assault. Recalled Derby, "We were first with the wafer steppers, we had a great product, and the marketing penetration plan was right on. Everyone had something to win with—design, test, fab, sales—and it caught their imagination."

By mid-1981 Fab 6 had turned out hundreds of thousands of the new EPROMs and output was doubling every quarter.

NEWER GENERATIONS

The success of the 2764 program in 1981-82 reinforced Intel's leadership in EPROMs. Technologies applied to shrink the 2764 and make it a more cost-effective part were used to revitalize the 2732 and build the next-generation 27128. Even newer technologies were used to develop the 256K 27256, introduced in 1983, and a 512K family in 1984.

"In the past," commented Jack Carsten, senior vice president and general manager, Components Group, "we were often the first to market with a product, then withdrew when competitors caught up. Now we redesign older products using newer technologies, while simultaneously developing high-complexity new parts. This strategy has the additional advantage of helping the fabs fine-tune newer processes and maximize use of available capacity.

Summarized Schneer, "With our new technologies we've broken out of the naked runner syndrome. Now Intel competes with a number of EPROM densities—upgraded older parts and newer ones—and we do it cost-effectively."

PRODUCTION EPROMS

By late 1983 Intel's 64K EPROM had become the highest demand EPROM on the market. Because of its flexibility, the EPROM had actually become the preferred read-only memory for system production, not just for system development.

To be able to build more production EPROMs, Intel introduced the 64K EPROM in a windowless plastic package. In the same amount of time, up to 10 times more dice can be assembled in plastic over traditional windowed packages. However, the "windows" which allow programs to be erased cannot easily be put in plastic packages.

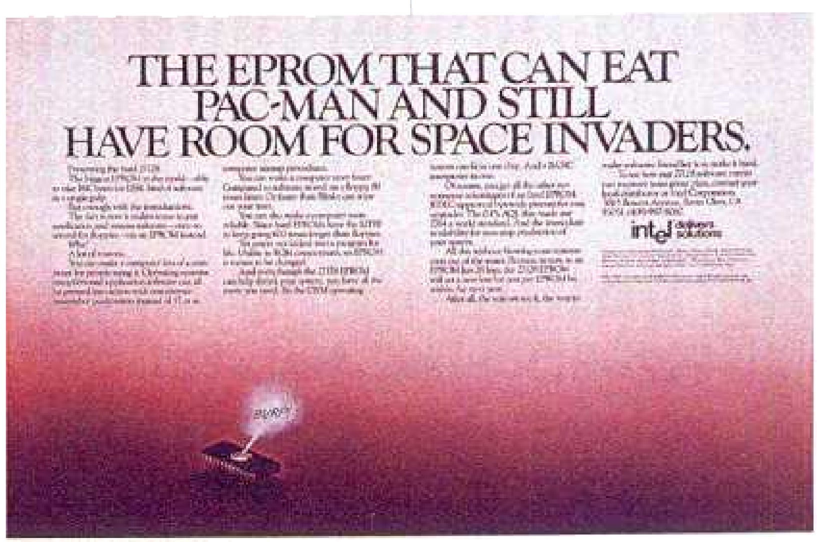
"This lack of erasability does not cause problems for the 80 percent or more EPROMs that are used in system production," explained Larry Palley, marketing manager for EPROMs. "By the time a manufacturer goes into production there really isn't any need to erase an EPROM. Most of an EPROM's flexibility is its ability to be programmed by the user. Once in production, the user can buy the unprogrammed production EPROMs in plastic and program in the fully tested code. The plastic parts are less expensive and more durable than standard EPROMs and provide inventory flexibility impossible with masked ROMs."

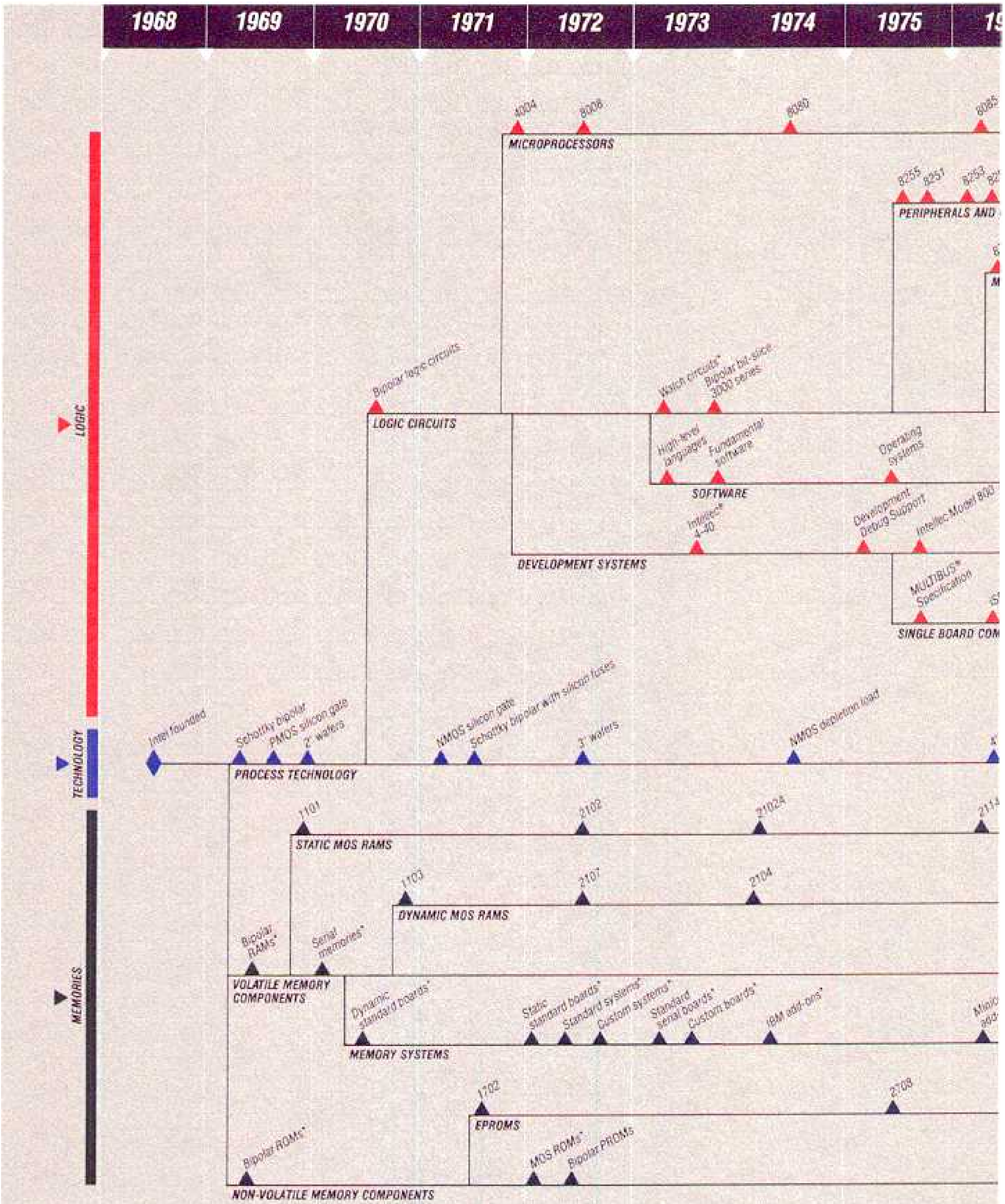
A NEW KIND OF EPROM

In 1980, after years of development work, Intel introduced the 2816 E²PROM, an electrically erasable read-only memory, another industry "first." The 2816 can be electrically reprogrammed in the field without removal from the host equipment and can even be reprogrammed remotely via a radio or telephone link. This flexibility permits OEM or end-user engineers to realize applications that were either impossible or prohibitively expensive with previous devices.

"Many of our customers can't afford the time or expense of removing and reprogramming an EPROM and putting it back in their equipment," explained Schneer. The military, for example, needs to be able to change programs in the field under difficult conditions, but they don't want their sensitive, high-tech gear taken apart to reprogram parts. Industrial operations such as a lathe or drill press often change programs several times a day. "With the 2816, any technician can plug in a cable, erase an old program and electrically punch in a new one right on the job," said Schneer.

With innovations such as the E²PROM, Intel continues to dominate the reprogrammable memory market. And to think it all started with the failure of the nitride-oxide project.

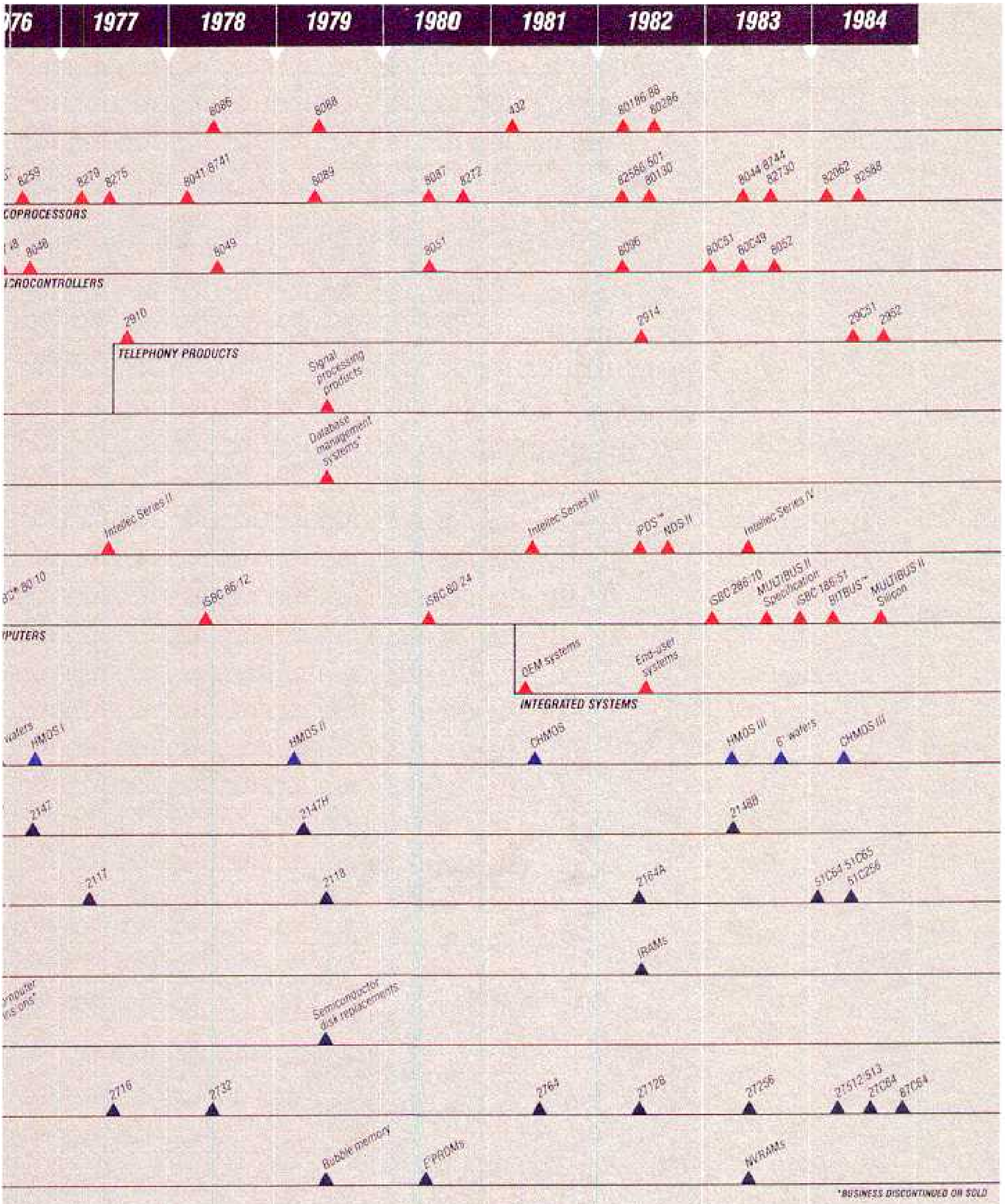




INTEL PRODUCT FAMILY TREE

Intel's Product Family Tree diagrams the evolution of Intel's product groups and technologies.

Major product families (e.g. microprocessors, single board computers, and EPROMs) are shown on branches in the logic and memory sections. Smaller product families and a few important



products are called out on the branches at their appropriate chronological points of introduction. Discontinued product lines are marked with asterisks.

The table at the right provides more complete detail in all product families. In the interest of space, complete product lines could not be included in every category in the table. Similarly, industrial or military grade products are not specifically designated, and all generations of every product are not listed.

LOGIC CIRCUITS

Bipolar Logic Circuits
1970—3205 1-of-8 decoder
1970—3404 6-bit latch
1971—3207 driver for 1103
1971—3405 3-bit CTL register
1971—3406 4-bit CTL register
1973—8224 oscillator
1974—8/3212 multi-mode latch buffer
1974—8/3214 interrupt control unit
1974—8/3216 parallel bus driver
1974—8/3226 parallel bus driver
1978—8284A oscillator
1978—8288 bus controller
1978—8202 DRAM controller
1978—8282 latch buffer
1978—8286 octal buffer
1978—8287 octal buffer
1978—8283 latch buffer
1979—8289 bus arbiter
1981—8203 DRAM controller
1982—82284 clock chip for 80286

Microprocessors
1971—4004 first microprocessor, 4-bit
1972—8008 first 8-bit
1974—8080 industry standard 8-bit
1976—8085 8-bit
1978—8086 industry standard, 16-bit
1979—8088 industry standard, 8-bit
1981—432 32-bit operands
1982—80188 high-integration 16-bit, 8-bit bus
1982—80186 high-integration 16-bit, 16-bit bus
1982—80286 high-performance 16-bit

Watch Circuits
1973—5801 timer/oscillator
1973—5201 LCD driver
1975—5203 LCD driver
1975—5810 first single-chip
1975—5814 4-digit LCD
1976—5816 6-digit LCD
1976—5830 6-digit LCD + chronograph
Business sold, 1978

Bipolar Bit-Slice 3000 Series
1973—3001 microprogram control unit
1973—3002 central processing element
1973—3003 look-ahead carry generator

Peripherals and Coprocessors
1975—8255 programmable peripheral interface
1975—8251 programmable communication interface
1976—8253 programmable interval timer
1976—8257 DMA controller
1976—8259 programmable interrupt controller
1977—8279 keyboard/display interface
1977—8271 floppy disk controller
1977—8275 programmable CRT controller
1977—8273 programmable protocol controller
1978—8041/8741 universal peripheral interface, 8-bit
1979—8089 8/16-bit I/O processor
1980—8087 first numeric coprocessor
1980—8272 floppy disk controller
1981—8274 multi protocol serial controller
1981—8206 error correction
1981—8207 DRAM controller
1982—82586 first LAN coprocessor
1982—82501 bipolar ethernet serial interface
1982—82285 clock chip for 82586 and 82730
1982—82288 bus controller for 80286
1982—80130 iRMX™ 86 kernel in silicon
1982—80150 CP/M* in silicon
1982—80287 numeric coprocessor
1983—82720 graphics display controller
1983—8044/8744 RUPI™
1983—82730 display coprocessor
1983—82731 bipolar video interface controller
1984—8256AH MUART
1984—8208 DRAM controller
1984—82258 ADMA controller
1984—82289 bus arbiter
1984—82062 Winchester disk drive controller
1984—82588 single-chip LAN controller
*CP/M is a trademark of Digital Research, Inc.

Microcontrollers
1976—8748 single-chip microcomputer with EPROM, 8-bit
1976—8048 8-bit
1977—8021 low-cost 8-bit
1978—8049 8048 with twice as much RAM/ROM
1978—8022 on-chip 8-bit A/D converter
1980—8051 advanced 8-bit
1980—8751 8051 with EPROM
1981—8749 high-performance 8-bit with EPROM
1982—8096 16-bit microcontroller
1982—8061/8361 16-bit kit for Ford
1983—80C51 CHMOS version of 8051
1983—80C49 CHMOS version of 8049
1983—8052 8051 with twice as much RAM/ROM

Telephony Products
1977—2910 first single-chip codec
1977—2911 single-chip codec
1978—2912 first single-chip filter
1982—2914 combination codec/filter
1984—29C51 CHMOS advanced telecommunications controller
1984—2952 integrated I/O controller
1984—2970 single-chip modem

Signal Processing Products
1979—2920 first signal processor
1982—2921 ROM signal processor

SOFTWARE

High-Level Languages
1973—PL/M first language for microprocessor
1976—microprocessor resident PL/M 80
1978—FORTRAN 80
1978—PL/M 86
1981—PASCAL 86
1982—PL/M 286
1981—FORTRAN 86
1982—PL/M 51
1983—C 86
1983—PASCAL 286
1984—PL/M 96

Fundamental Software
1973—8080 assembler and linkage tools
1975—EDIT
1977—8048 assembler
1978—8086/88 assembler and linkage tools
1979—8089 assembler
1979—CREDIT™
1980—8051 assembler and linkage tools
1982—program management tools
1982—80286/287 assembler and linkage tools
1983—AEDIT
1983—8096 assembler and linkage tools

Operating Systems
1975—ISIS operating system
1982—iNDX operating system
1982—XENIX* 86 operating system
1978—iRMX™ 80 real-time multitasking operating system
1980—iRMX 86 real-time multitasking operating system
1981—iRMX 88 real-time multitasking operating system
1983—XENIX 286 operating system
1984—iRMX 51 operating system
1984—iRMX 86 operating system, release 6
*XENIX is a trademark of Microsoft Corp.

Database Management Systems
1979—SYSTEM 2000*
Business discontinued, 1984

SYSTEMS

Development Systems
1972—SIM 4, SIM 8
1973—Intellec* 4-40
1973—Intellec 8-80
1975—Intellec Model 800
1975—UPP 103 prom programmer
1977—Intellec Series II
1980—NDS I network development system
1981—Intellec Series III
1981—iUP 200/201 prom programmer
1982—iPDS™ personal development system
1982—NDS II network development system
1983—ISIS cluster
1983—Intellec Series IV

Development Debug Support
1975—ICE™-80 in-circuit emulator
1977—ICE-48
1977—ICE-85
1979—ICE-86
1980—ICE-88
1981—PSCOPE
1981—ICE-51
1982—EMV-51
1983—I²ICE™
1984—SBE 96
1984—PSCOPE/iRMX 86

Single Board Computers (iSBCs)
1975—MULTIBUS* specification
1976—SBC* 80/10 single board computer
1977—iSBC 544 intelligent communication controller
1978—iSBC 80/30 8085-based single board computer
1978—iSBC 86/12 8086-based single board computer
1979—iSBC 576 digital I/O board
1979—iCS family (industrial control family)
1980—iSBC 80/24 SBC with iSBX™ connectors
1980—iSBX expansion specification
1981—iSBC 88/25 8088-based single board computer
1981—iSBC 550 Ethernet communication controller
1982—iSBC 570/576/577 speech transaction family
1983—iSBC 286/10 80286-based single board computer
1983—MULTIBUS II specification
1983—iSBC 186/51 COMMputer™
1984—BITBUS™ distributed control modules
1984—MULTIBUS II silicon

OEM Systems
1981—System 86/3XX
1983—System 286/3XX

End-User Systems
1982—iTPS transaction processing system
1982—iDIS™ database information system
1982—iDBP™ database processor

VOLATILE MEMORY COMPONENTS

Bipolar RAMs
1969—3101 first Intel product, 64-bit
1970—3102 partially decoded, 256-bit
1970—3104 content addressable, 16-bit
1973—3106/7 fully decoded, 256-bit
Discontinued, 1979

Static MOS RAMs
1969—1101 MOS LSI, 256-bit
1972—2102 5V, 1K
1974—2102A depletion load, 5V, 1K
1974—5101 CMOS, 1K
1976—2114 industry standard, 4K
1976—2115 HMOS I, 5V high speed 1K
1976—2147 HMOS I, 55ns, 4K
1979—2147H HMOS II, 35ns, 4K
1983—2148B HMOS III, 35 ns, 4K

Dynamic MOS RAMs
1970—1103 1K
1971—2105 1K
1972—2107 4K
1974—2106 4K
1974—2104 4K
1975—2116 16K
1977—2117 16K
1979—2118 first 5V HMOS, 16K
1982—2164A 16-pin, 5V, 64K
1984—51C64/51C65 CHMOS, 64K
1984—51C256 CHMOS, 256K

Serial Memories
1970—1401 shift register, 1K
1970—1402/3/4 shift register, 1K
1970—1407 dynamic shift register, 200-bit (Dual 100)
1972—2401/2/3/4 5V shift registers, 2K
1975—2416 charged couple device, 16K
Discontinued, 1977

Integrated RAMs (iRAMs)
1982—2186/87 64K
1984—51C86/87 64K CHMOS

NON-VOLATILE MEMORY COMPONENTS

Bipolar ROMs
1969—3301 1K-bit
Discontinued, 1976

EPROMs
1971—1702 first EPROM, 2K
1975—2708 8K
1977—2716 16K
1978—2732 32K
1981—2764 64K
1982—27128 128K
1983—27256 256K
1983—production EPROM (plastic pkg.)
1984—27512/513 512K
1984—27C64 CHMOS, 64K
1984—87C64 latched version CHMOS, 64K

MOS ROMs
1972—1302 2K
1974—2316 16K
Discontinued, 1980

Bipolar PROMs
1972—3601 1K
1974—3604/24 4K
1976—3608/28 8K
1979—3616/36 16K
1981—3632 32K

Bubble Memory Subsystems
1979—BPK 70 1 MBit
1980—iSBC 250 1 MBit board
1981—iSBC 254 1-4 MBit MULTIBUS board
1982—iSBC 251 1 MBit MULTIMODULE™ board
1982—BPK 74 4 MBit
1983—BPK 70-5 1 Mbit
1984—BCK 10-1/-4 bubble cassette kit

E²PROMs (Electrically Erasable PROMs)
1980—2816 E²PROM, 16K
1982—2817 16K
1983—2817A 5V, 16K

NVRAMs (Non-Volatile RAMs)
1983—2004 5V, 4K
1984—2001 5V, multiplexed 1K

MEMORY SYSTEMS

Dynamic Board-Level Standard Memory Systems
1970—MU-10 (1103)
1973—MU-40 (2107)
1977—MU-1600 (2116/2117)
1979—MU-91 (2117)
1980—CM-90 (2117)
1980—MU-91 (2164)
1982—CM-90 (2164)
(MU—Memory Unit, CM—Control and Memory)
Business sold to Zitel, 1983

Static Board-Level Standard Memory Systems
1972—CM-50 (1101A)
1977—CM-7060 (2114)
1980—CM-92 (2147)
Business sold to Zitel, 1983

System-Level Standard Memory Systems
1972—IN-10 (1103)
1975—IN-40 (2107)
1975—IN-1010 (1103)
1977—SY-1600 (2116)
1980—SY-90 (2117)
1980—SY-91 (2117)
1980—SY-92 (2147)
1982—SY-90 (2164)
1982—SY-91 (2164)
Business sold to Zitel, 1983

System-Level Custom Memory Systems
1972—IN-11 (1103) Univac
1974—IN-10 (1103) Univac
1975—IN-4029 (2107) Univac
1977—SY-1629 (2116/2117) Univac
1978—IN-508 (2109) Burroughs
1979—IN-780 (2147) Burroughs
1980—5400 (2118) G.E.
1982—SY-91-100 (2164) CSC
Business sold to Zitel, 1983

Serial Board-Level Standard Memory Systems
1973—IN-60 (2405)
1973—IN-62 (2405)
1975—IN-64 (2405)
1975—IN-65 (2416)
Discontinued, 1976

Custom Board-Level Memory Systems
1973—IN-25 (2102) DRS
1974—IN-261 (2114) Singer
1975—IN-501 (2104) Kodak
1975—IN-760/761 (2114/2147) ISS
1976—IN-406 (8080) Bizerba
1976—IN-505 (2104) Teradyne
1977—IN-502 (2117) Pfizer
1977—IN-510 (2104) Honeywell
1978—IN-500 (2117) Raytheon
1979—IN-706 (2147) Telettra
1980—IN-522 (2117) ICL
1981—IN-767 (2167) Singer
1982—IN-535 (2164) Siemens
Business sold to Zitel, 1983

IBM Add On Memories
1974—IN-7135 (2105) add-on memory for IBM 370-135
1975—IN-7145 (2105) add-on memory for IBM 370-145
1976—IN-7158 (2106) add-on memory for IBM 370-158
1976—IN-7125 (2117) add-on memory for IBM 370-125
1977—IN-7158 (2107) add-on memory for IBM 370-158
1978—IN-77XX (2147) universal memory system to support spectrum of IBM 370 computers (135-3033)
Business evolved to semiconductor disk replacement business

Minicomputer Add In/Add on
1976—SY-1670/1671 (2117/2109) DEC
1977—CM-5034 (2107) DEC
1978—IN-5004 (2116/2117) DEC
1979—CM-5160 (2164) DG
1980—CM-5150 (2164) DG
1981—SBC-890 (2117) DEC
1981—MU-5750 (2121) DEC
1981—MU-5780 (2121) DEC
Discontinued, 1983

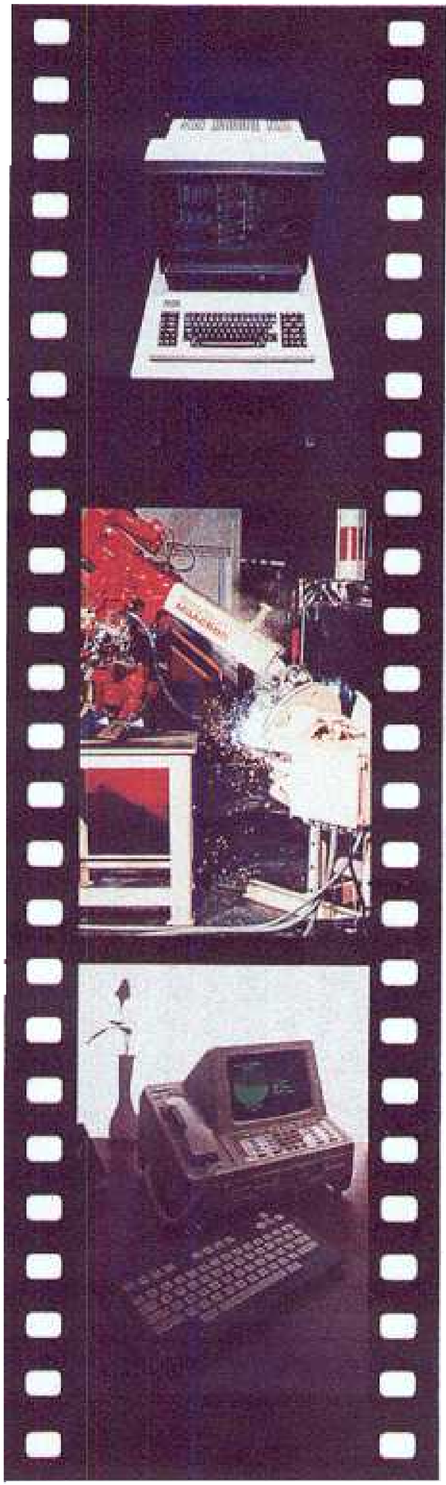
Semiconductor Disk Replacements
1979—Fast 3805 (16K)
1981—Fast 3815 (16K)
1982—Fast 3825 (64K)

Products and Processes

Intel's innovations have created scores of new products and enhanced many existing ones. Here is just a small sampling of the many markets Intel products have touched:

PERSONAL COMPUTERS
RJ Muna

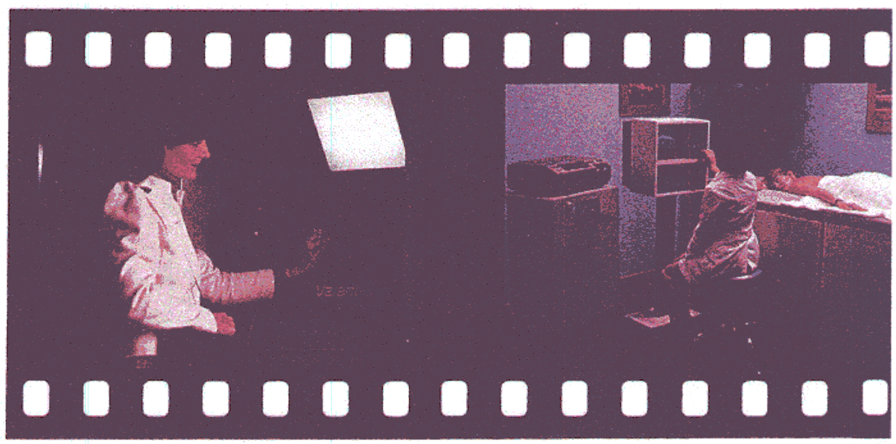
DIGITAL GASOLINE PUMPS
Richard Steinheimer



COMPUTER-AIDED ENGINEERING SYSTEMS
Photo courtesy of Daisy Systems

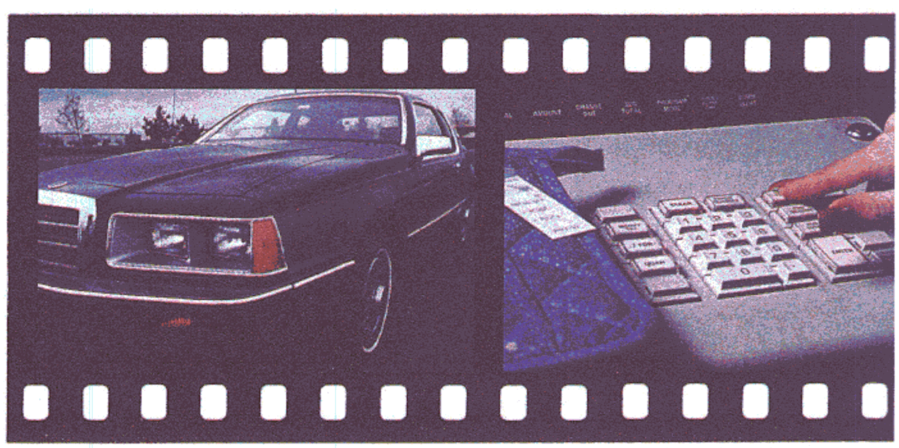
FACTORY AUTOMATION
Photo courtesy of Cincinnati Milacron

TELECOMMUNICATIONS
RJ Muna Photo courtesy of Rolm



AUTOMATIC TELLER MACHINES
Richard Steinheimer

MEDICAL INSTRUMENTATION
Photo courtesy of Technicare Ultrasound

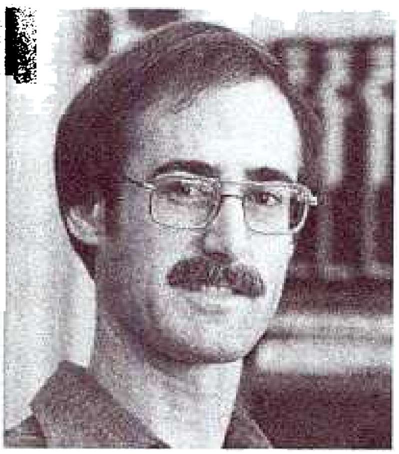


AUTOMOBILES
Howard High

POINT-OF-SALE TERMINALS
Howard High

PROCESS PRECEDES PRODUCTS

Intel was launched to tackle the computer memory market with an as-yet-untried laboratory curiosity: large-scale integrated (LSI) semiconductor memories. A key step in making integrated circuit (IC) memories practical was achieving a breakthrough in process technology. Wanting to try something new, Intel chose to develop two relatively new technological approaches that previously had been used only to make laboratory devices. These new technologies seemed to offer advantages for LSI circuits and were especially appropriate for memories. One was the silicon gate MOS process, which substituted a film of poly-crystalline silicon for the aluminum used previously; the other was a variation of the bipolar IC technology known as the Schottky TTL process.



1974 photograph of Dick Pashley, whose work led to Intel's HMOS (High-performance MOS) technology.

"Both were gambles," conceded Gordon Moore, "since they had never been used in manufacturing, but they allowed us to make a clean break with the past and undertake the development of processes especially suited for semiconductor memory." Added Les Vadasz, "There was a collective intuitive feeling about the features of silicon gate technology versus the metal gate process. It was a gut feeling that all of us on the team shared."

Surprisingly, the Schottky bipolar process developed quickly and without a hitch. It proved to be one of those rare technological advances where everything worked the first time. The silicon gate process, however, was not nearly so forgiving, and required many months of intense effort to solve technical problems. But focusing on these problems had the advantage of allowing Intel engineers to develop techniques that would make possible the production of the new silicon gate devices long before competition could get established.

> *"Remarkably, the part proved functional on its first run... It went right into production. Three years later we still hadn't changed the mask set!"*
> *—Dick Pashley*

Intel engineers doggedly worked with the MOS process, and in 1969, a year after the company's start-up, they introduced the 1101 static random access memory (RAM) chip. This was followed in 1970 by another MOS product, the 1103, the first dynamic RAM. The 1103 held 1024 (1K) bits of data and proved to be the first serious challenge to the dominance of core memories in computers. The 1103, in fact, marked the beginning of the LSI electronics industry.

Although innovative, Intel's early MOS memory products were difficult to use and test. In an effort to improve their marketability, Intel engineers, led by Vadasz, developed an N-channel, 5-volt power system that made it possible for MOS devices to operate with standard bipolar power voltages. This was a big step forward because it helped standardize the MOS process. Intel's first product to use 5 volts was the 2102 1K static RAM, introduced in 1972. It generated substantial sales and set the pattern for future technology.

HIGHER PERFORMANCE

The next major advance in MOS technology occurred in the mid-'70s, when Intel engineers began shrinking or scaling down the devices. An extension of the silicon gate process, this shrink technology made possible MOS chips comparable in speed to earlier bipolar devices at much lower power consumption and cost.

Dick Pashley, director of California Technology Development, remembered how the technology developed: "It actually started in 1973 with a crash program to speed up the 2102. When I was hired, we were losing business in static RAMs because our parts were too slow." Working with designers Frederico Faggin and Ben Warren, and process engineer Tom Rowe, Pashley redesigned the 2102 and added depletion loads which speeded up the process. This involved an ion implant, a new manufacturing challenge for Intel at the time. Remarkably, the part proved functional on its first run. Three days later Intel gambled and started 800 wafers for the 2102A, as the new part was called. Said Pashley, "It went right into production. Three years later we still hadn't changed the mask set!"

Almost overnight the 2102A returned Intel to leadership in the static RAM market. Then in 1975 Pashley's group hit on the technique of on-chip substrated back-biasing, which allowed MOS transistors to be scaled down in size even further. This led to the 2115, which met its speed goals and reached market quickly.

No sooner had the 2115 hit the field than Pashley's group was assigned the task of getting Intel into the high-performance MOS business. They experimented with a number of approaches, "some very elegant but for the most part difficult to build," explained Pashley. Finally they zeroed in on what was later called HMOS (high-performance MOS), which involved scaling the transistors and using positive photoresist and projection printing. In just six months the team characterized the process and used it to shrink the 2115 die to about half its previous size. This was the start of the shrink technology concept, which led to the design and manufacture of the 2147 static RAM, Intel's first HMOS product.

While the 2147 proved enormously successful, its real importance was realized later when the HMOS process was applied to microprocessors, DRAMs and other devices to improve their performance dramatically.

Since then the HMOS process has evolved to the point where Intel produces ever denser, smaller and higher performing devices. In 1983 Intel introduced the third generation of this technology, which produces devices up to 40 percent smaller than previously possible. "It has become an increasingly successful technology," commented Gerry Parker, vice president and director of Technology Development. "We have now reached a performance level which years ago we thought only the bipolar process could achieve."

CHMOS—TECHNOLOGY OF THE FUTURE

MOS circuits come in a variety of "flavors": N-channel (negatively charged), P-channel (positively charged), and CMOS ("C" for complementary, meaning that it contains both N- and P-type transistors).

Intel's earliest MOS technology was P-channel, but it proved to be limited in speed. With the 2102 in 1974, the company

Howard High

1981 photograph of Gerry Parker, Intel's vice president and director of Technology Development.

turned to N-channel MOS, which offered vast improvements in speed and allowed use of standard 5-volt power supplies.

While continuing to improve its N-channel devices, the company also began in the late 1970s to invest in CMOS processes. The idea was not new, having been published in 1963. Intel in the early 1970s had built CMOS chips for its Microma watches. But CMOS applications at that time were confined to a narrow range of low-power uses. The process was considered too complicated and expensive for LSI applications.

The major advantages of CMOS chips were that they used far less energy and generated far less heat than comparable NMOS devices. Furthermore, on a per function basis, CMOS circuits were easier to design than NMOS, and had wider operating margins.

Since managing power is a critical issue in the application of electronic devices, there is no doubt that CMOS is the technology of the future. Commented John Ekiss, vice president and general manager, Special Components Division, "It has broad application across the total spectrum of Intel's very large-scale integrated (VLSI) components, and the day will come when we will make everything with CMOS technology."

Intel's CHMOS development program was launched in Oregon in early 1979. (The H is Intel's addition to the acronym to indicate high performance.) Under the direction of Ken Yu, project manager for the development group, first generation CHMOS static RAMs were designed with the process. "Typically, Intel brings up new technologies on memory products," explained Sunlin Chou, director of Portland Technology Development. "It is easier to design and manufacture a memory, and easier to understand how the process works." Although the first CHMOS static RAMs weren't marketed—"our NMOS static RAMs were doing well," said Chou—the process was used to build the 80C49 and 80C51 microcontrollers, which have been successfully marketed.

In 1980 the development of CHMOS logic technologies was consolidated in California while Oregon focused on dynamic RAMs. Chou headed a team whose mission was to develop CHMOS DRAMs in 64K and 256K densities. This group produced a 64K CHMOS chip, the 51C64—the world's first DRAM in CHMOS—which was released in 1983 in test quantities to potential users. It was greeted enthusiastically, and Intel began to market the product in 1984. They also produced the world's first 256K CHMOS DRAM—the 51C256, which went into production a few months later.

Les Vadasz cautioned that Intel was not yet in the CHMOS market in the volumes that many competitors were. "But we'll be there," he said, "because there's no doubt that by the end of the decade this will be the technology for an overwhelming number of VLSI products."

FROM RUBIES TO CAD

In Intel's early days, the entire process of creating an integrated circuit, from the original design to fabrication, was a manually done and painstaking operation. Engineers drew the circuit on paper by hand, checking it by eye. Each layer of the design was then manually transferred onto rubylith. Operators worked at light tables with the design underneath the glass cutting each vector onto the red cellophane-like sheets. The rubylith was then photostepped to the correct size, a mask made, and the circuit finally fabricated in silicon. At each stage, checking and testing were also done by hand, which was not only time-consuming, but also allowed generous room for error.

In the early 1970s, Intel took the first step toward computer aided design (CAD) when it introduced digitizers which translated the hand-drawn design into digital format on a computer. This not only allowed some computer checking of the design, but also meant that the digitized information could be transferred to an optical pattern generation machine which would actually make the masks, thereby rendering the painstaking rubylith step obsolete.

By 1980 Intel was well on its way to computerizing circuit design and fabrication completely. All that remains today of the original manual method is the engineer's "napkin sketch" of a new circuit design. Computer aided workstations—sophisticated computer systems with color display screens—are used to enter schematic drawings. On the basis of the schematics, a mask designer draws the layout of the chip on the screen, with each layer shown in a different color.

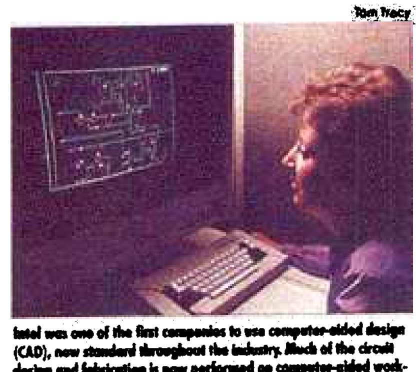
"Intel was one of the first companies to go totally to on-line entry, on-line schematics, and on-line layout," noted Steve Nachtsheim, who heads Intel's Corporate CAD group.

With the design in the workstation's memory, the circuit is tested and checked for design rule errors and other problems. "Intel was also one of the first companies to introduce an automated system that can compare the logic of what the chip is supposed to do—represented by the schematics—with the layout, which is the actual physical manifestation of the chip," explained Nachtsheim.

Today, CAD has virtually replaced manual labor in the creation of new integrated circuits. With the accelerating complexity of circuit design, it would take a workroom the size of a football field to hold all the rubylith operators that would be necessary to trace by hand the tens of millions of vectors in a current-generation chip. (The 4004, by contrast, had about 100,000 vectors.) It would be impossible to handle the complexity of today's chip designs if they had to be done by hand. Intel was one of the first companies to use CAD, but it is now standard throughout the industry.

In Intel's early days, each layer of an integrated circuit design was drawn by hand, then transferred onto rubylith. Operators such as the two women pictured here worked at light tables cutting each vector onto the red cellophane-like sheets. The rubylith was then photostepped to the correct size and a mask was made.

Tom Tracy



Intel was one of the first companies to use computer-aided design (CAD), now standard throughout the industry. Much of the circuit design and fabrication is now performed on computer-aided work-stations—sophisticated computer systems with color display screens. CAD has replaced the painstaking manual operations performed in early circuit design, enabling the development of extremely complex circuits that would be impossible otherwise.

EVER LARGER WAFERS

Intel started production at Fab 1 in Mountain View using 2-inch silicon wafers, the industry standard at the time. Gene Greenwood, hired by Intel in 1970, remembered that there was little promise of larger-sized wafers then: "We'd have discussions, and everyone was saying that you couldn't grow silicon accurately enough to make 3-inch wafers."

As with many other predictions in the fast-paced semiconductor industry, this one soon proved to be completely off base.

Improvements in silicon growing technology and fab equipment made it possible for Intel to convert the Mountain View Fab 1 to 3-inch wafers in late 1972, and the company brought up Fab 3 in Livermore on the same size in 1973. Three years later, Fab 3 was used to develop 4-inch wafers. ("We had three people: one engineer, one technician, and myself at Livermore for the whole 4-inch wafer development," laughed Ken Moyle.) In 1979 Fab 5 in Aloha, Oregon started up under Moyle's direction, the first plant to run solely on the larger size.

Intel soon converted its other fabs to the 4-inch size. Fab 6, built in 1980 at Chandler, Arizona, came up on 4-inch wafers, and introduced a host of process technologies including wafer steppers.

In late 1983 Intel became the first semiconductor producer in the world to try 6-inch wafers when Fab 7 at Rio Rancho, New Mexico, produced its first functional die on the 6-inch wafer size. Construction of Fab 7 had started in April 1980, but a recession delayed the plant startup, giving Intel an opportunity to jump to 6 inches. When the plant was finally completed in early 1983, trial runs were made with 5-inch wafers. These were so successful that the company committed to 6 inches.

In explaining the advantage of larger wafers, Gene Flath said, "It's a matter of economy of scale. Most operations process a single piece of silicon, so it can be 4-inch or 6-inch. But when you go from 4-inch to 6-inch, you more than double the number of circuits available from the wafer." The larger wafers, therefore, will significantly increase Intel's fab capacity without the addition of expensive new plants.

The move to 6 inches involved an extensive learning period. Virtually every step of the wafer fabrication process had to be changed, meaning that both Intel and the equipment manufacturers broke new ground with previously untried machines. "It was scary," commented Flath, "but our people said, 'Yes, we can do it.' "

Bringing up the new technology and machinery to produce die on 6-inch wafers was a nerveracking experience, somewhat reminiscent of Intel's early days with the MOS process: no one was quite sure when, or even if, the first functional die would come off the line. ("The stress level around here was very high," commented Mike Van Hoy, Fab 7 plant manager, in a laconic understatement.)

"I call December 1, 1983 our longest day," Van Hoy continued, referring to the target day for the first die production. "We got the first material out early, but the first round of testing didn't turn up any good die, so by 7 o'clock that evening we made the announcement that we were going to continue testing the wafers."

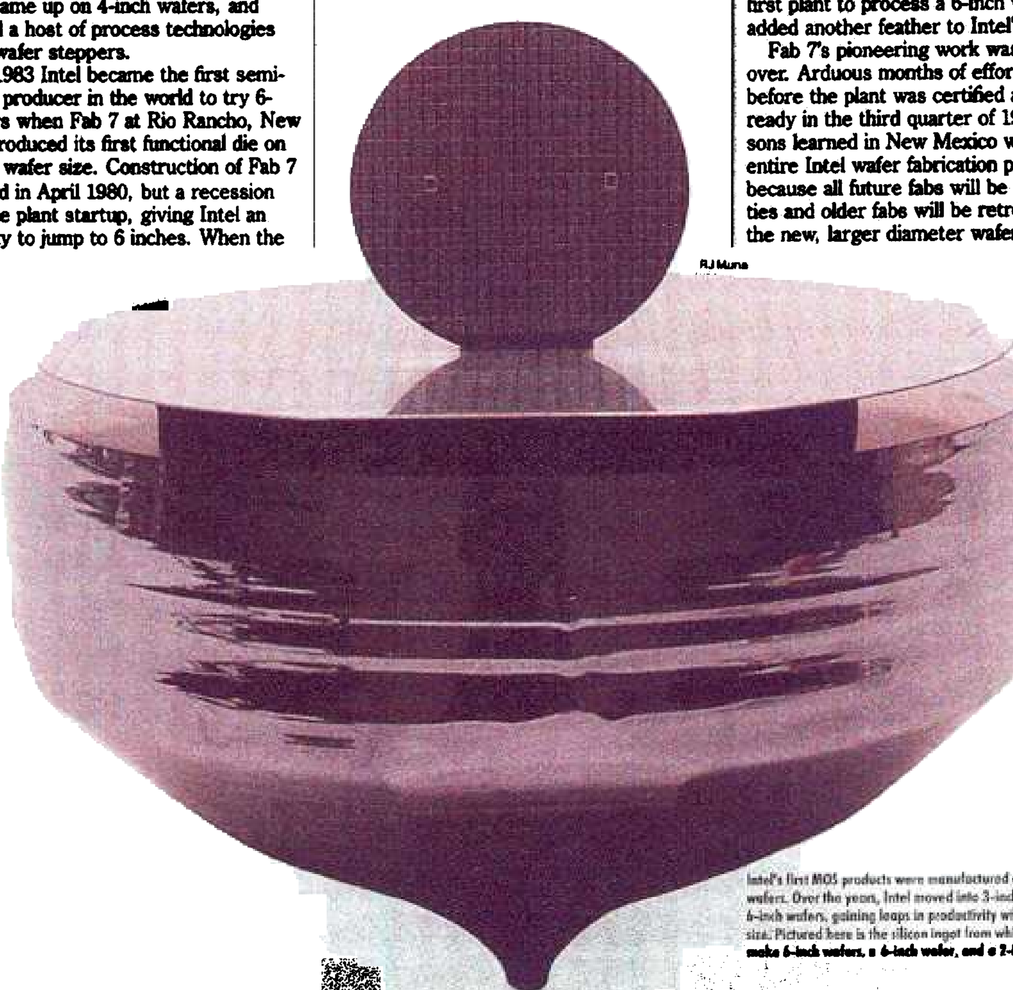
At last, at about 11:00 p.m., jubilant engineers reported to the engineering manager that they had found a good die. He immediately phoned Van Hoy, and the two put into motion one of the wilder celebrations Intel had ever seen. It had been a spur-of-the-moment inspiration from Van Hoy. "Our people were really ready for a release," he explained.

The following evening Fab 7 employees witnessed an unprecedented fireworks display in the fab parking lot, after which they all adjourned to a celebration at the Rio Rancho Inn, wiping out the Inn's beer supply.

Fab 7 was off to an explosive start: it had pushed the state-of-the-art as the world's first plant to process a 6-inch wafer, and added another feather to Intel's cap of firsts.

Fab 7's pioneering work was by no means over. Arduous months of effort would follow before the plant was certified as production-ready in the third quarter of 1984. The lessons learned in New Mexico will benefit the entire Intel wafer fabrication process because all future fabs will be 6-inch facilities and older fabs will be retrofitted with the new, larger diameter wafers.

RJ Muna



Intel's first MOS products were manufactured on 2-inch silicon wafers. Over the years, Intel moved into 3-inch, 4-inch, and finally 6-inch wafers, gaining leaps in productivity with each increase in size. Pictured here is the silicon ingot from which slices are cut to **make 6-inch wafers, a 6-inch wafer, and a 2-inch wafer.**

CLEAN ROOMS AND BUNNY SUITS

When Intel's first wafer fabrication facility opened in Mountain View in 1968, it followed what was then standard clean room operating practice in the industry: reasonable cleanliness, but no exotic clothes or procedures to ensure a sterile environment. "At that point," explained Gene Flath, "there were a few government-sponsored laboratories that were building dust-free 'white rooms,' but we didn't believe we needed them, and, in actual fact, we probably didn't." Intel did, however, insist on certain minimum standards. "A couple of people in Fab 1 got read the riot act," recalled Paul Metrovich, then a senior technician, "for bringing pizzas in and setting them on top of the diffusion furnaces to keep them warm."

With the opening of Fab 2 in 1971, clean room standards began to improve. Operators were told to wear full smocks (at first they were brown), but their hair still hung loose and nothing covered their shoes.

Smocks, as it turned out, were not the answer. "Operators took their smocks home with them," remembered Flath, "and washed them along with their linty socks and wool sweaters. It was also the rage to modify them with little embroidered flowers and patterns, or to shorten them into mini-smocks and cut the sleeves off." Moreover, as Intel's technology improved and chips shrank, maintaining a dust-free environment became critical.

Intel used the opening of Fab 3 in Livermore as the opportunity to introduce stricter clean room standards and bunny suits. Flath explained, "We built a laundry into Fab 3, and that committed us to the laundry business." Gradually, starting with longer smocks, the new dress standards were introduced at the other fabs, until they became uniform throughout the company.

The change brought a predictable response. "The bunny suits and the whole routine were a huge joke around the company for years," laughed Flath. "In fact, people used to find excuses to visit Fab 3 just so they could put a bunny suit on." Bunny suits were required at all subsequent fabs, and by 1980 they had become routine.

In May of that year, near disaster struck Fabs 4 and 5 in Oregon when nearby Mount St. Helens volcano erupted, shooting mounds of fine gray ash into the air. Under the leadership of Ken Moyle and Frank Alvarez, contingency measures were instituted to maintain the integrity of the clean rooms—including changes in plant layout and in bunny suit design. It turned out that the measures were so effective in reducing particle count that they soon became standard throughout all the fabs.

> *"A couple of people in Fab 1 got read the riot act. . . for bringing pizzas in and setting them on top of the diffusion furnaces to keep them warm.*
> *—Paul Metrovich"*

RJ Muna

"Bunny" suits were introduced at Intel in 1973 with the opening of Fab 3 in Livermore. Pictured here are the pieces of the typical clean room garb worn today.

Howard High

Inside Santa Clara's Fab 2, 1984.

William C. Eymann

Clean room standards in the early days in the Mountain View wafer fab area were primitive—all that was required was a smock.

"The first reaction was fear," recalled Alvarez, "fear of the unknown. We had no experience with ash, and small particles were death to the kind of work we were doing."

Immediately after the first eruption, a task force came up with a plan to shut everything down, bag the equipment and seal off every possible point where ash could enter the facilities. "We went out and bought 9000 rolls of duct tape, all the plastic we could get in the local hardware stores, filters, special vacuum cleaners, shoe cleaners and air showers," Alvarez said. "We were ready to bag all the wafer handling equipment in plastic if we had to. We sealed off every entrance except one, taping all the doors and cracks. Everyone entered through one door and was vacuumed." Sticky mats were installed at doorways to clean the bottoms of employees' shoes, and shoe scrubbers cleaned the tops and sides of the shoes. The crew put extra filters on the main air intake and even built special wooden buffer entrances to add further protection. Other air intakes were covered with filter blankets which were kept wet with sprinklers.

Although the volcano blew again in July, both fabs were able to keep operating. It was soon apparent that the steps taken to prevent contamination actually reduced particle count measurably in the clean rooms. Recalled Will Kauffman, vice president of Die Production, "We learned the importance of having entrances to fab areas located as far as possible from building entrances. As a result, several entrances at Fabs 4 and 5 remain closed, and we have modified entrances at Fabs 2 and 3. We also arranged to have exterior clothing such as coats and hats removed in a room separate from the change room where smocks are put on."

Even the bunny suit was improved. "We changed boot styles," remembered Alvarez, "because we found that the boots we used to wear at that time only covered the shoes, leaving a gap which exposed the pants cuffs. There was literally a trail of ash coming into the fab on those pants cuffs." A new bootie design was adopted and is now standard throughout the company.

"Mount St. Helens gave us a greater awareness of clean room practices and controls," commented Kauffman. "The things we learned helped us tighten up the system in all our fabs." The company now uses a series of pre-filters to trap coarser particles, and has installed laminar flow air shields in its newer fabs. "This system directs a parallel flow of clean air on the work station so it doesn't circulate with air elsewhere," Kauffman explained. "The shield also restricts the operator from leaning over the workplace."

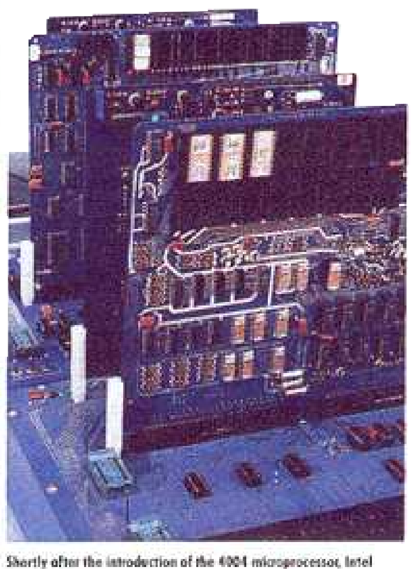
Today all of Intel's facilities are at least Class 100 (100 particles of dust per cubic meter)—a high standard for the industry—and the company is aiming to have its newer fabs ultimately reach a Class 10 rating.

"INTEL IS NOW IN THE SYSTEMS BUSINESS. NOT JUST IN THE SYSTEM."

With this advertising headline Intel in January 1984 unveiled its new supermicro system for OEMs, the 286/310, and underscored to the world that Intel systems had emerged as a force. It might have sounded like a radical departure for the company that pioneered silicon-based semiconductor components, but in fact the company had been flirting with systems almost since it began. How did an organization of components engineers become involved in designing software and building integrated systems? It was an evolutionary process, growing—sometimes logically, sometimes serendipitously—from two sources: memory products and microprocessor products.

MEMORY SYSTEMS OPERATION

The earliest inkling of systems started with one of Intel's first products, the 1103 1K dynamic RAM. Perceiving that many of its customers were having difficulty designing systems around the part—"it was probably the most difficult-to-use semiconductor device ever created by man," quipped Gordon Moore—Intel engineers Ted Hoff and Stan Mazor began to experiment putting parts together on demonstration boards to show customers how it might be done. Their work sparked the curiosity of two engineers at Honeywell's Memory Systems Division, Bill Jordan and Bill Regitz, who convinced Intel that establishing a memory systems operation was the way to go. "We put together a proposal which we TWXed to Bob Noyce," recalled Regitz, who later came to work at Intel. "He called me back late one night—I remember being in bed when he called—and he was definitely interested."



Shortly after the introduction of the 4004 microprocessor, Intel began offering design aids to help customers develop 4004-based products. The rather primitive-looking devices shown here are the MCB 410 connector board with the SIM 4-01 prototyping board and the MP7-02 PROM programming board, manufactured in 1972.

Jordan was hired by Intel to head the new Memory Systems Operation (MSO). He and three other Honeywell engineers who moved to Intel—Hank Bodio, Bob Blanding and Ross Roberts—designed the first set of memory systems products around the 1103.

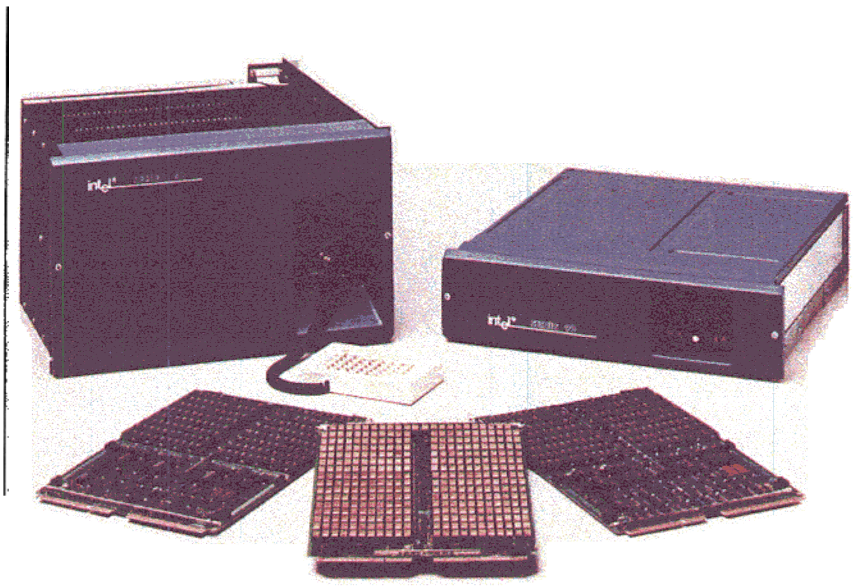
The first was the IN-10, a memory board with peripheral support components, which was developed in 1970 and introduced the following year. It sold surprisingly well, but a big break came when Univac hit a major snag in developing its memory systems technology and Intel proposed to solve their problem with the IN-10. "Within a few months we developed and delivered a solution to Univac," remembered Regitz. Univac remained a loyal customer of Intel memory systems products until MSO was sold in 1983.

Intel was quick to see the potential for memory systems. Not only did it generate healthy revenue, but it provided a way to use parts that did not meet data sheet specifications. "We knew the yield of the 1103 was bad at that point," explained Regitz, "and we wanted to find a way of using the fallout parts." Added Les Vadasz, then MOS project manager, "We were so early in both semiconductor memories and in microcomputers, that many of our customers did not have the ability to use them, because they didn't have the technical capability or could not really afford it. So we saw a business opportunity by moving up to board-level products." The IN-10 spawned a family of related products over the next decade.

The next leap forward in memory systems came in 1972 with the development of add-on memories for IBM mainframes. "When we got going with semiconductor memory, most of it went into mainframe computers," explained Gordon Moore. "Since at that time IBM didn't buy components on the outside, we were essentially excluded from 60 to 70 percent of the total market. We figured the way we could address that was to sell add-on memories directly to IBM's customers, so we developed an IBM add-on memory box."

The first of these units ("blue boxes," as they were colloquially known) were introduced in 1972 and they turned out to be very successful. Offshoots of the IBM blue box business were the FAST 3805 solid state mass storage system, introduced in 1979, and its 1982 successor, the FAST 3825.

The IBM add-on business and the memory board portions of the Memory Systems Operation flourished until the late 1970s, when the fast pace of change in the industry and in Intel forced a major reassessment of MSO's future. As Intel's memory products became easier and easier to use, and its



The Series 90 Memory System.

customers became increasingly sophisticated, more and more customers began buying at the component level. The crunch came in the recession of the early 1980s. "We began limiting what we wanted to spend R&D dollars on," explained Regitz. Memory systems no longer fit with the company's charter of going after distributed processing. "We decided we had better things to do with our people resources and our money," concluded Regitz, "and we elected to get out."

In a carefully planned rampdown, MSO was phased out in 1983. The memory board business was sold to Zitel, and the add-on business was discontinued. The only vestige to remain was the solid state disk business, which was integrated into the Commercial Memory Operation.

DEVELOPMENT SYSTEMS AND INTEGRATED SYSTEMS

Intel had backed into memory systems by developing aids to assist engineers in using the 1103. The company found itself in a similar position when it unveiled the revolutionary 4004 microprocessor in 1971.

The idea for development aids for the 4004 grew out of efforts to broaden the market for the new chip. Ed Gelbach, who headed microprocessor marketing, explained, "We felt that those chips were so complicated, and the approach to using them was so new, that we needed to teach people that they were more than just a calculator replacement."

He assembled a team of five engineers that set about finding ways to show potential customers how the parts could be used. Ted Hoff developed the idea of building simulator boards, and the resulting SIM4-01 and SIM4-02 were introduced in May 1972. They were basically kit boards with a 4004 on them, and could be hooked to an I/O device and user's EPROMs. There was a simple assembler generated for them and some very simple monitors to debug software, allowing customers to develop their own software. By today's standards they were extremely primitive, but they were a start.

Shortly thereafter the company introduced the SIM8-01, a prototyping board for the 8008 microprocessor. At first Intel thought of the SIM boards simply as marketing aids, but the company soon noticed the eagerness which greeted the products. Remembered Gelbach, "There was a little difference of opinion as to whether we should give them to customers for free so they would use them with the microcomputers, or whether we should sell them. In the end we decided what the heck, let's see if we can sell them." Simulator boards soon began to generate healthy profits.

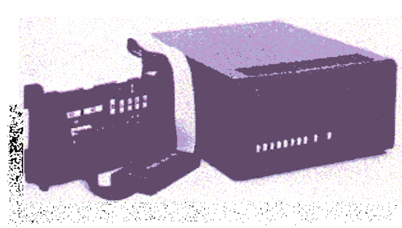
Meanwhile Gelbach's group of engineers was at work developing more sophisticated design aids for the microprocessors, and in 1973 the company unveiled the Intellec® 4 and Intellec 8 software development tools that added cross assemblers and other features to the basic simulator boards.

Intellec development systems soon became the key to Intel's microprocessor sales. "They made it easy for the customer to design the software to go into the microcomputer," explained Hank Josefcyzk, who joined Intel in 1974 as the Great Lakes regional sales manager, "and that was Intel's strength in the early years. I remember we ran promos for our distributors to get them to sell Intellec development systems: we gave away Microma watches, which at that time sold for about $250. In those days all you had to do was sell one development system and you got a watch. Our distributors would kill to get one of those watches, so they really cranked up the sales. We had a distributor in Kansas who sold five of them in 1974; we couldn't believe that you could sell even one of that kind of product in Kansas!"

The design aids were so popular that their revenues soon exceeded the sales of microprocessor components. In fact, it wasn't until 1978 that component sales would overtake those of systems. Noted Josefczyk, "A design aid was like an insurance policy. It hooked the customer, locked him into our concept, and later he'd start buying components."

Sales of development systems grew and the production atmosphere bordered on the chaotic. "There was little Intel discipline or rules," recalled Roger Nordby, who joined the company in 1975 and was soon assigned to head systems manufacturing operations. "You could pretty much do whatever you wanted. Because it was such a profitable business, if we couldn't get a board to work the first time through the test machine, we'd just put it aside. At one time I had over $1 million worth of boards sitting there. All we needed to do was to put more labor in to test them, but we didn't have enough time. We were trying to get as much product out as we could." It was not until the summer of 1978 when OEM Microprocessor Systems moved to Oregon, that its manufacturing capability took on more recognizable Intel discipline.

Intel's next advance in development aids for customers—and an industry first—came in 1975 with the introduction of the ICE™-80, an in-circuit emulator. ICE modules were devices that could be substituted for the microprocessor components that were actually used in a customer's system.



ICE™-80, the first in-circuit emulator, shown with one of Intel's microcomputer development systems. Introduced in 1975, ICE modules could be substituted for the microprocessor components that were actually used in a customer's system, providing a valuable tool for developing and debugging microprocessor-based systems.

They provided the engineer with a window through which he or she could actually look inside the component and see what was going on in the system. They proved invaluable in developing and debugging microprocessor-based systems.

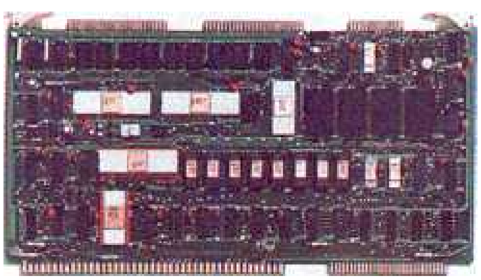
The inspiration for in-circuit emulators came from Bill Davidow. Bob Garrow and Hap Walker executed his idea.

Intel realized that in-circuit emulators were the key to letting customers debug their products, so the next set of development tools was based on that. The company knew that by designing a bus structure properly for the development system it could ultimately use those boards and set up an independent single board computer business. With conscious planning, Intel set about perfecting a bus system.

The result was MULTIBUS®, an interconnection mechanism that allowed the systems builder to link together any number of microprocessor boards to build a wide variety of computers. "We named it MULTIBUS," explained Tom Kinhan, general manager OEM Modules Operation (OMO), "because it was specifically designed to deal with multiprocessing. This means that any auxiliary board or extension module to the main system can have a processor on it, which allows functions to be performed at very high speeds. It allowed us to take advantage of the low cost of silicon to throw lots of processors at the job of building computers, rather than having to build one enormous, highly powerful processor."

In 1975 MULTIBUS was put to use in a re-engineered Intellec-like product, the MDS-800, the industry's first disk-based development system.

With in-circuit emulators and MULTIBUS in place, it was an easy step to single board computers. "At that time, most of Intel's customers were purchasing relatively low volumes of microcomputer products, like 100 a year," recalled Davidow. "That reinforced our conviction that we could build low-volume types of systems out of single boards. Our feeling was this: if customers are only going to buy 100 sets a year, why should they design the systems themselves, when we could sell them the board sets that would take their place?"



The iSBC® 80/10, the industry's first single board computer, was introduced by Intel in 1976.

The industry's first single board computer, the iSBC® 80/10, was introduced in 1976. Based on the 8080 microprocessor, it included an I/O device and 4K bytes of memory. Dedicated organizations were created under system district managers and sent out to the field to sell board-level products. Soon sales were soaring. Early customers were industrial OEMs who used the boards in applications like traffic control signals, and companies like Diebold, who used SBCs in their trend-setting automatic teller machines. More board-level systems soon followed to meet customers' needs. Explained Bill Lattin, who assumed control of single board computer operations in 1980, "We found more and more companies wanted our technology at a board or system level. These were companies that realized that their real expertise was building a set of applications software, and it was a better use of their time to buy from us at a higher level of integration."

1982 photograph of Bill Lattin, now vice president and general manager, Systems Group.

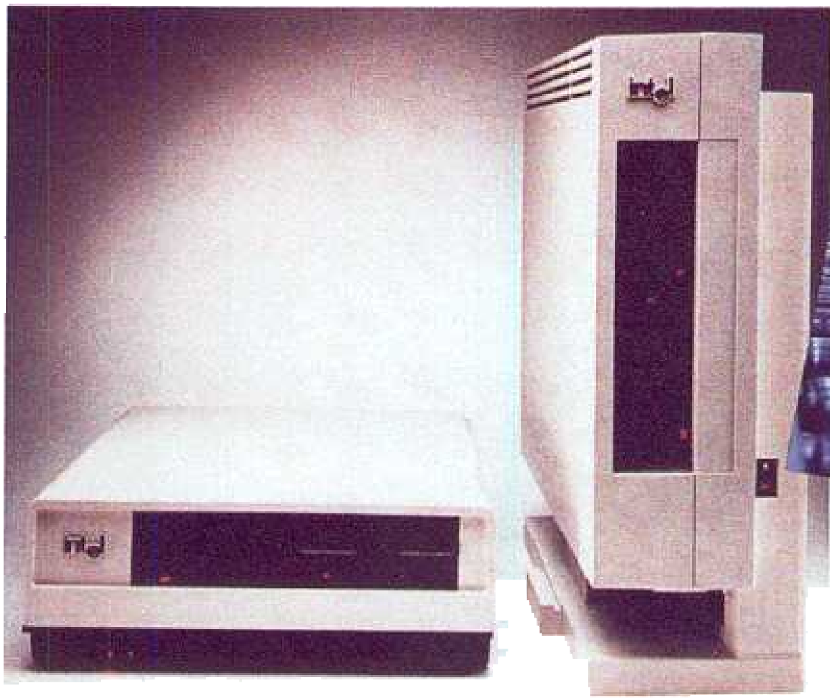
In the summer of 1978 the single board business, by then a small but rapidly growing operation, was spun off from the rest of development systems and moved to Intel's new facility in Portland, Oregon, where it became OMS (OEM Microcomputer Systems). Keith Thomson, Hank Bodio, Cliff Fahey, and Mike Maertz were among the members of the original team. Maertz and Bodio co-chaired the OMS Strategic Business Segment (SBS), which charted all the product and strategic plans.

As demand increased for higher levels of integration, Intel developed a small real-time operating system, iRMX™ 80, to accompany the 8-bit iSBC 80, and shortly thereafter began working on a 16-bit operating system. "Bodio really drove that 16-bit product development," commented Kinhan. "He recognized the importance of operating systems software, which was fairly far-sighted for Intel then, and he created a team to implement it. It was an ambitious undertaking."

Not the least of iRMX's problems was the lingering prejudice of software engineers against working for a semiconductor company. "Software was then still a relatively misunderstood concept here at Intel," remembered Kinhan. Added Lattin, "Intel tried for a long time to recruit experienced hands, but found the biggest success rate in hiring was to go to the colleges and get younger people and convince them that microcomputers were really going to amount to something."

Some within Intel felt that iRMX was not the way to go and that the company should scrap the project and go with Digital Research's CP/M operating system. OMS, however, championed the project and iRMX 86 went on to become one of the most suc-

One of Intel's newest design tools, I²ICE (Integrated Instrumentation and In-Circuit Emulator) brings together high-level language software debugging, logic analysis, and in-circuit emulation in a single, integrated package. Shown here is an I²ICE system (right) configured with the Series IV development host computer.



Intel's System 310 represents the most advanced of Intel's systems products. The 286/310, for example, combines Intel's 80286 microprocessor and 80287 numeric coprocessor with a MULTIBUS™ architecture and new systems software, yielding a product with up to four times performance improvement over competitive minicomputer systems.

System 310 assembly.

cessful real-time OEM operating systems on the market.

The next step was to combine SBCs with requisite memory boards in a rack, add an operating system disk and power supply, wrap it up in a chassis, and offer it to customers as an integrated system. All the customer had to add was application software and a display. The result of this fairly modest beginning was the 86/330, based on Intel's popular 8086 microprocessor. It was greeted enthusiastically upon its introduction in November 1981. It enabled OEMs to design and manufacture new products incorporating VLSI microprocessors more rapidly than with the board level systems and minicomputers then available.

Two years later, following the development of the 286 microprocessor, Intel introduced the System 286/310, which combined the microprocessor, a numeric coprocessor, an enhanced MULTIBUS architecture, and new systems software. It yielded a two-to-four times performance improvement over competitive minicomputer systems, and when combined with various software packages, could be used for such applications as robotics, environmental control, and engineering workstations.

Underlying Intel's move to higher levels of integration is a commitment to the concept of "open systems"—building systems with the "tinker toys" of components and boards, in which Intel has the leading edge. The approach is part of Intel's commitment to standardization, allowing other manufacturers to get into the system. By doing so, the marketplace is vastly expanded both for systems and for silicon chips. It was a boon to Intel internally as well. "It provided us with a test when we looked at a potential new product," said Lattin. "We could say, 'Yes, that's the right one to build; it adds to our tinker toys,' or 'No, we don't have critical mass of pieces to go into that market.' "

ADDING DATABASE OPERATIONS

By the late 1970s, Intel's evolution into systems had been in the OEM arena, where the company had strength and recognition based on its microprocessors and memory chips. But as the company ventured more deeply into systems, some company visionaries began to consider commercial systems as a new direction, and database management as a key software technology to get there.

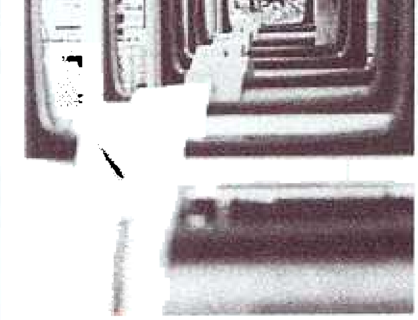
Databases use a lot of memory, and Intel thought there ought to be a way to build a database product using LSI technology. Intel learned of MRI, a small Austin, Texas database software firm looking to be acquired. Intel acquired MRI in February 1979, viewing it "as an opportunity to get a lot of software capability into the company at one shot," commented Gordon Moore.

MRI's basic business was database management systems and its principal product was SYSTEM 2000®. Introduced by MRI in 1972, SYSTEM 2000 was a mainframe database management software product that ran on IBM, Control Data Corporation (CDC) and Univac computers.

The most successful product to result from the blending of MRI's software and Intel's hardware was the iDIS™ 86/735, a microsystem introduced in 1982. It acts as a liaison between a mainframe database and a personal computer terminal, allowing the user to download centrally-maintained mainframe data.

In late 1984, Intel announced plans to move the iDIS business from Texas to Arizona. At the same time, because the SYSTEM 2000 didn't fit with the company's strategic business thrust as a microcomputer-oriented company, Intel sold the SYSTEM 2000 business to SAS Institute, Inc.

Humberto Garcia



Maria Hernandez, an employee at Intel's systems assembly facility in Puerto Rico.

WHERE TO FROM HERE?

Intel's original foray into the systems business back in the early days of MSO and design aids may not have been the result of a carefully drafted Strategic Long Range Plan, but the company's growing commitment to systems has followed a clear pattern that will shape its development in the future.

Initially, Intel's systems thrust was aimed at the low-volume user. "The board business was born out of a premise that there is a make-buy threshold," explained Kinhan, "where component customers with a low enough volume of component purchases would be willing to buy at a higher level of integration. It offered them a higher value added and faster time to market." Intel at first went after customers who built 100 or fewer boards a year.

But as technology developed at ever-increasing speeds, larger companies sought Intel's technology at a higher level. For one thing, Intel came on the scene at the right time. The emergence of the 16-bit market meant microprocessors had become powerful enough to perform an immense variety of tasks. Added to that was the company's development of supporting software and the concept of open systems, and suddenly big customers were saying to Intel, "We don't have to build systems ourselves; we'll buy from you." Soon Intel was serving customers who built 1,000 or fewer boards per year, and that figure was rapidly revised upward to 10,000.

"A good example is Diebold, the company that makes automatic teller machines," said Brannon. "At first they used our components in their machines. Then at some point we sold them on the idea of a little single board computer and much later they started buying boxes from us too."

What of the future? "Whatever it is, it will be based on Intel silicon," predicted Brannon, "and on leveraging industry standards." Intel has positioned itself as a supplier, primarily to OEMs, of "electronic building blocks"—products the customer can select, at multiple levels of integration, for the products they manufacture.

"We are devoted to the idea that systems should be 'open' or capable of providing an easy transition to the next generation of VLSI technology," stated the 1982 Annual Report. "This is why we offer software compatibility between microprocessor generations, why we offer multiple levels of integration, and why we support industry standardization programs in many areas."

"SYSTEMSTHINK"

As Intel ventured into the systems world it soon found that the components mentality with which it had been born and raised needed to change.

For starters, systems called for new marketing techniques and strategies, shifting from the spec sheet orientation of components sales to the "solutions sell" needed for systems. Whereas components were sold primarily at the engineer's desk, systems required a new approach to upper management. "The concept of open systems was the perfect format to use with top management," noted Tom Kinhan. "It appealed to management principles, rather than design principles. It addressed business issues, risks—a whole series of long-range issues—rather than the cost of some individual part."

This required special training for Intel's sales force, and a broad campaign to inform the rest of the company that Intel was in the systems business.

It also meant achieving credibility as a systems supplier and not just as a semiconductor company. To this end Intel launched a campaign of advertising, seminars and public relations.

At the same time, Intel faced a ticklish question vis-à-vis its customers: now that the company was producing systems, to what extent would it become its customers' competitor?

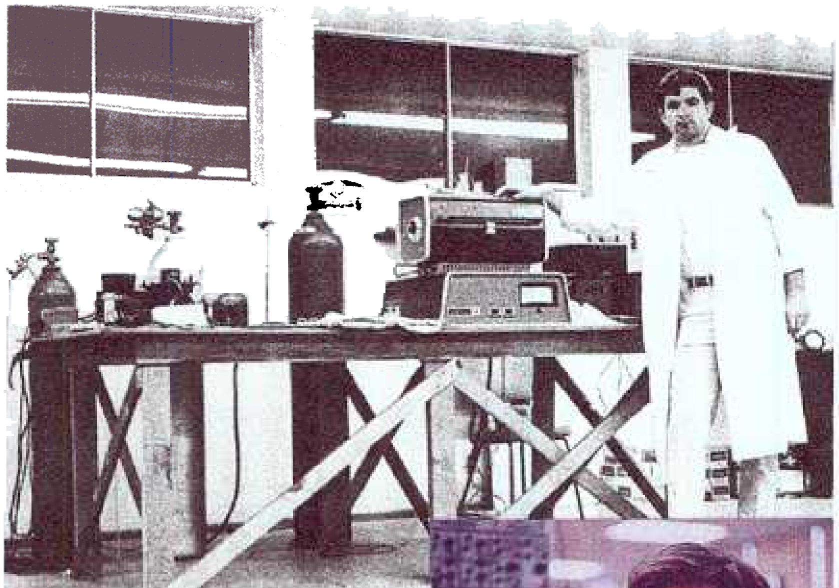
From the earliest days of moving beyond components to development aids, Intel had been keenly sensitive to this issue. One of Ed Gelbach's favorite stories involved the first ad for the Intellec development system. "We were going to call it a computer on a chip," he recalled, "but when Gordon Moore heard about it he got so angry I thought he was either going to faint or hit me. He was that sensitive about competing with our customers. We had to kill that campaign and reposition it to development systems."

"We don't really compete with our customers," said Bill Lattin. "It is not our intent to enter markets already served by Intel component customers. We want to provide tools for customers that allow them to get to the next level of integration more easily."

Systems also raised another new area of concern: product servicing. In the early days of systems, Intel's support of its products basically ended when they were shipped. In the case of certain Memory Systems products, like the IBM add-ons, Intel contracted with outside firms for service support, and if an early microcomputer system developed problems, the customer had to return it to the factory. "By the late 1970s," remembered Jim Grenier, who was hired in 1979 to build a coherent service organization, "Intel realized that the customers were not thrilled with the idea of packing up the defective product and sending it back; they wanted service on-site, so Intel recruited its first service force as part of the sales organization.

"We recognize that when we sell a systems product to an end-user we have 'womb-to-tomb' responsibility," explained Grenier. "From product inception to obsolescence we carry the responsibility of supporting it. We now offer service support of software in the field, customer hotlines, customer training, and repairs."

Such thorough customer support produces benefits within Intel as well. "It gets back to the development of the product," continued Grenier, "and the desire to have it as reliable and serviceable as possible. Seeing how the product performs after the fact, we are constantly going back to the design group and saying, 'This is what's wrong with the product. This is what needs to be changed.' "



Ted Jenkins proudly displays equipment at Intel's one-room light-emitting diode lab in Pasadena, California, circa 1969.

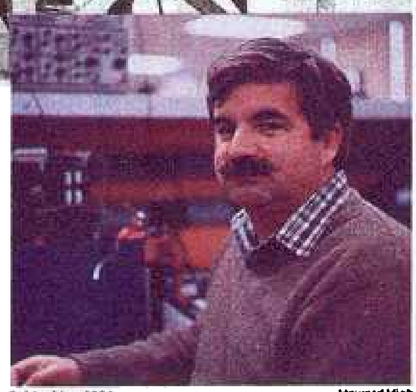
DETOURS ON THE ROAD TO FAME AND FORTUNE

Intel's road to success has not always been a smooth one. Being on the leading edge of technology necessarily entails risks, and with risks there are often mistakes. Interestingly, those stumbles have often had silver linings; they have produced lessons that have benefited later products.

JENKINS ELECTRONICS

In 1968 founder Gordon Moore became intrigued with an experimental process developed by two California Institute of Technology (Caltech) professors, Carver Mead and James McCaldin, to produce zinc sulfide light-emitting diodes, a technological innovation that offered colors other than red. Newly hired Ted Jenkins moved to Pasadena to launch Intel into the light emitter business.

Because the space was so tight, the women's restroom was converted into a chemistry lab at the Pasadena operation.



Ted Jenkins, 1984. Howard High

Jenkins established himself in a 1000-square-foot corner of a rundown warehouse, a space so small that the women's restroom had to be converted into a chemistry lab. "I was the only employee," recalled Jenkins. "I did all the lab work, the technician work and equipment maintenance."

Six months later Jenkins returned to Mountain View to join the Schottky bipolar team and was replaced by Gerry Parker, then a Caltech graduate student completing his Ph.D. "It was pretty fly-by-night," remembered Parker. "Jim McCaldin had this idea of diffusing sulphur by sealing an ampule full of sulphur and heating it up to 1000°F. Once, it exploded and shot all the way across the room and hit the wall, about two feet from another professor. After that I had a blast hood installed." The sulphur also emitted noxious fumes which did not endear Intel to its neighbors.

The business lasted only another six months. "It was a very high-risk, weird, avant garde process, more avant garde than anything we've done since," explained Andy Grove, "and we'd run into some fundamental limitations." To make a go of it would have required massive infusions of capital, which Intel—struggling in its small Mountain View plant with two new technologies—could not spare. In December 1969 the business was sold to Monsanto.

But the experience was not a total loss. "We did some good science," Jenkins acknowledged, "and we developed some good patents, particularly for ohmic contacts, which nobody else had done."

CHARGE-COUPLED DEVICES

In 1975 Intel entered the charge-coupled device memory business. A CCD was a high-density dynamic serial memory which moved a charge along through a string of capacitors rather than transistors. It utilized basic MOS technology and was thus a logical extension of the company's memory products.

The market for Intel CCDs was limited ("we had only a few customers," remarked Tom Innes, "and none of them were household names"). Those few users began to report a perplexing problem: errors reappeared sporadically in the memory, a phenomenon dubbed "soft errors." Innes and his engineering group were having difficulty tracking the problem down, when Gordon Moore, concerned about the failures, suggested that cosmic rays might be the source. There were those who thought that Moore had slipped a hinge, but his analysis, it turned out, was very close to correct.

Matters got serious shortly thereafter when Western Electric complained of a similar soft error problem with the 2107, a 4K dynamic RAM. The correlation with the charge-coupled device errors was apparent, and Intel began a furious program to determine the cause "before the roof fell in," as Gerry Parker put it.

Parker continued: "Tim May in Reliability thought it might be local radiation. He put a leak detector to one of the devices, and after considerable analysis concluded that it wasn't gamma rays, but rather alpha particles that were destroying the charge held in the memory. After more investigation, we realized the glass in the ceramic package emitted alpha particles at a steady rate."

The soft error problem caused by the rays was eventually solved by changing the

> *"Gordon Moore… suggested that cosmic rays might be the source [of soft errors]. There were those who thought Moore had slipped a hinge, but his analysis, it turned out, was very close to correct."*

glass and packaging and making modifications in the product's design. Although the company soon faced a production capacity crunch and decided to drop the more sensitive charge-coupled device entirely, Intel learned a lot from the CCD experience. The company now understood the effects of alpha radiation, not only on charge-coupled devices, but also on other memory products. This led to the development of devices which were insensitive to soft errors.

The soft error problem was becoming recognized but not understood throughout the industry at the time, and Intel shared its research widely, delivering a paper on the subject at the annual Reliability Physics Symposium.

And yet another plus: Gordon Moore acquired a lifetime source of fishing sinkers. During the weeks of frantic detective work to find the cause of the elusive errors, the Memory Systems Group bought several hundred lead bricks to build a chamber that would shield memories from cosmic rays. Once the problem was solved, the bricks became surplus, and Moore now has about a ton of lead under his house which he melts down from time to time for sinkers.

DON'T ASK THE TIME

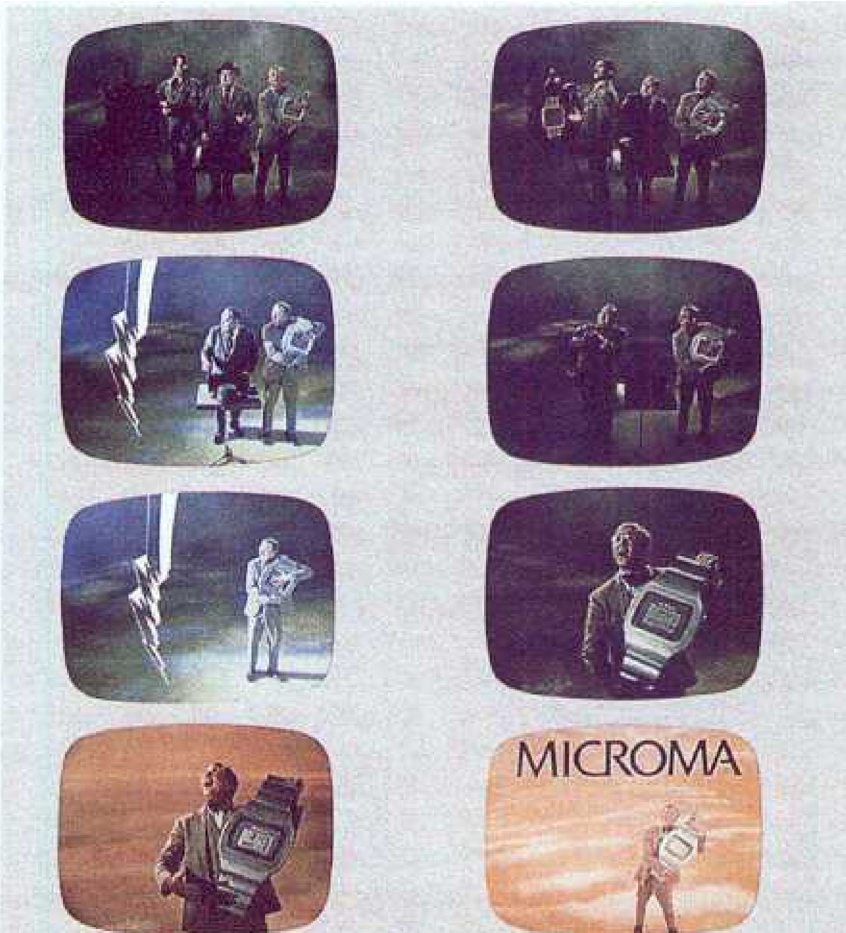
Gordon Moore still wears his Microma watch. "It is to remind me, if I ever find myself thinking of getting into other consumer products, of the trouble we'd be getting into."

> *"'We were in the jewelry business,' grimaced Andy Grove, as he recalled the $600,000 bill for Microma's one-and-only TV commercial. 'Just one ad and poof!—it was gone.'"*

In 1972 the digital watch was perceived as a great technological innovation with a potential market of some 200 million units. And, the Swiss—the world's foremost watchmakers—didn't want any part of it.

The company acquired Microma, a small firm that had a prototype liquid-crystal watch. "We went into the business because we thought we had a unique combination of capabilities: the CMOS chip, the liquid crystal display, and assembly facilities," Andy Grove explained. "We got out when we found out it was a consumer marketing game, something we knew nothing about."

Microma soon was the leading watch on the market. The Penang plant, built in 1973 primarily for memory component assembly,



Intel's one-and-only television ad for Microma watches starred William Christopher, who played Father Mulcahy on the popular M*A*S*H* television series.

This promotional photograph of a Microma watch demonstrated that because of its low power requirements, the watch could run on the small amount of electricity generated by a battery constructed from citrus fruit acid, copper rods and iron nails.

Father Time: ***"Who has a terrific digital watch?"***

Inventor #1: *"Here, Father Time. Only $200."*

Father Time: ***"Too expensive!"***

Special Effects: ***Lightning bolt.***

Inventor #2: *"Mine's cheap."*

Father Time: ***"Can't read it!"***

Inventor #2: ***"Push the button."***

Father Time: ***"Too much trouble!"***

Special Effects: ***Lightning bolt.***

Inventor #3: *"Mine's a Microma.* ***The time's*** *always there to see. You don't have to push a button.*

Father Time: ***"How much?"***

Inventor #3: ***"$69.95."***

Chorus: ***"Microma.***
Microma.
Microma."

took on the additional job of watch module assembly. But Intel's technology leverage was not enough. Texas Instruments and other competitors slashed prices to gain market share. Watches that sold for $100 and up at fine jewelry stores soon sold for $19.95, then $9.95, at discount markets. The handwriting was on the wall: unlike the memory business, Intel could not build more value into watch electronics along with high volume.

Moreover, Intel suddenly found itself in the unfamiliar world of competitive high-priced consumer advertising. "We were in the jewelry business," grimaced Andy Grove, as he recalled the $600,000 bill for Microma's one-and-only TV commercial. "Just one ad and poof—it was gone!"

Faced with the choice of sinking additional millions into a venture with unfamiliar points of leverage, Intel chose instead to abandon the watch business. In 1978 the company sold the Microma designs, equipment, and name.

Intel exited from the watch business with characteristic concern for its customers and employees. It maintained its Microma service facilities until 1981. (The early Microma watches had several reliability problems, and it was reported that the first item on the agenda of Board meetings in the mid-1970s called for Board members to return their watches for repair.)

Microma employees were placed in other jobs, a remarkable achievement, particularly in an industry noted for its wild swings in employment. After painful layoffs in 1970 and 1974, Intel management was determined to avoid a similar experience. The successful placement of Microma employees reflected this commitment to its employees.

The Microma experience strengthened Intel's resolve to be more selective about entering end-user businesses. It also provided valuable process technology that would have a substantial and favorable impact on future earnings.

Because of problems with a supplier of chips for Microma, Intel decided to build its own CMOS memory chip, a 1024-bit micropower device. This was difficult because it required an ion implant step and Intel people had to learn how to do it. The experience proved valuable a year or so later with the redesign of the 2102, a 1K NMOS static RAM, to increase its speed. The key to this project was the addition of depletion loads by means of an ion implant process, which proved very successful. The speed with which the 2102A reached the market was due largely to the knowledge gained earlier on the Microma implant.

Howard High

1982 photograph of Ken Moyle, who headed the 64K Operation which produced Intel's advanced 2164A DRAM.

BETTER THE SECOND TIME AROUND

Intel's entry into the important 64K DRAM (Dynamic RAM) market demonstrated its ability to mobilize resources and turn failure into success in a remarkably short time frame. The company's first 64K DRAM product—the 2164—suffered severe design and cost problems and was pulled from the market in mid-1981 soon after it was introduced. "We were late getting there, then we shot ourselves in the foot," said Ron Whittier, then general manager and vice president, Memory Components Division.

> *"We were late getting there, then we shot ourselves in the foot.*
> *—Ron Whittier"*

Withdrawal of the 2164 from the market caused widespread negative reaction in the industry, the financial community, and among Intel employees, many of whom lost confidence in the company's ability to execute. Meanwhile, the Japanese continued to make huge inroads into the 64K business. Intel's dilemma: repair the existing part or go directly to the second generation?

Intel chose the second option, and a team led by Youssef El-Mansy totally redesigned the original 2164 and produced the 2164A, an outstanding DRAM, in just nine months. To meet this enormous challenge, Intel formed the 64K Operation led by Ken Moyle, now manager of Fab 5 in Aloha, Oregon. "It turned out to be a good decision," Moyle acknowledged, "but the risks were very large. We were exploring new areas of stepper technology, very thin oxides, and redundancy. There were a lot of 'unknowns' that had to become 'knowns.'"

Whittier agreed. "The 64K team resolved some mighty tough technical issues: solving process problems like metal cracking and getting wafer steppers rolling, optimizing design that led to an improved stepping, getting into plastic packaging, and cutting test times by more than a factor of two." What's more, high yields were established in multiple fab and test locations in less than a year.

And there were successes in the marketplace, the most visible of these being the transfer of the 64K technology to IBM. In September 1982, after evaluating other 64K RAM products and technology, IBM selected the 2164A as the one that met its objectives. "They were here before the ink was dry on the agreement," recalled Moyle, "and we set them up in trailers at Fab 5. The transfer was completed within one month of the target date, and they were up and running, shipping product."

BEYOND THE BAY AREA

In the early 1970s it became apparent that the Santa Clara area would not be able to accommodate Intel's projected growth. With this in mind, Intel began an expansion program in 1975 which would take it to other domestic sites in the western United States.

The domestic expansion philosophy was to locate new sites within an hour-and-a-half's flight of Santa Clara, a distance that would permit one-day trips and allow the company to maintain close communications. Equally important, a proposed site was to have the infrastructure of transportation, education, housing supply, etc. to support continued growth by Intel.

DOMESTIC EXPANSION

The years listed below mark the start of Intel operations at each major domestic site outside the Santa Clara area. In many of the locations, more buildings have been added over the years since the opening of the original facilities. In order to accommodate growth, from time to time Intel has also occupied a number of leased facilities in the areas surrounding major campuses. In addition to these major sites, Intel has sales and service offices in close to 50 cities throughout the U.S.

1973 Livermore, California.
1976 Aloha, Oregon.
1976 Santa Cruz, California
1979 Deer Valley, Arizona
1979 Hillsboro, Oregon
1980 Chandler, Arizona.
1980 Rio Rancho, New Mexico.
1984 Folsom, California

THE SUN NEVER SETS ON INTEL

Intel's international network grew rapidly from its first venture, Intel Europe, which was started in 1969. By 1984, the company operated more than 30 sales, service, and training offices outside the U.S. in Australia, Canada, Europe, Hong Kong, Israel, Japan, Korea, and Singapore. The company also has design centers in Japan and Israel and, with Matra-Harris Semiconducteurs, operates a jointly funded design center called CIMATEL in Versailles, France. Intel is building its first offshore fab in Israel, and systems manufacturing, components assembly and/or test facilities are located in Malaysia, the Philippines, Singapore, Puerto Rico, and Barbados.

A hallmark of Intel's international expansion has been its sparing use of U.S. expatriates, reflecting a practical view that the innate understanding of language and customs possessed by each country's nationals provides the best opportunity for Intel's

Fab 5's young, inexperienced start-up team viewed the building of a new fab as a task challenging enough for the Star Wars crew. Here the team posed with leader Ken Moyle (wearing black Darth Vader mask) after completing successful qualifying runs.

Buttons have been created to commemorate countless occasions in Intel's history. This one marked the Microcontroller Operation's (MCO) move from California to Arizona in 1979.

1973 photograph of Livermore Fab 3's start-up team members. From left, Ted Jenkins, Steve Cooper, Paul Hoefler and Al Patterson.

Other members not shown were Chuck Dohont, John Phillips and Jim Nutter.

success. As of this writing, **fewer than 60** U.S. citizens are employed in Intel's non-domestic workforce of more than 8,500 employees.

INTERNATIONAL EXPANSION

The years listed below mark the start of Intel operations at each of its major non-domestic sites. In many of these locations, more buildings have been added since the first facilities noted here were opened. Sales, customer training, or service offices have not been listed individually.

- 1969 Intel Europe established. (Started with a sales office in Geneva, Switzerland.)
- 1969 Intel Japan–Start of sales and marketing functions.
- 1972 Penang, Malaysia–Components assembly and test.
- 1974 Manila, Philippines–Components assembly and test.
- 1974 Haifa, Israel–Design Center.
- 1977 Barbados, West Indies–Components assembly.
- 1981 Tsukuba, Japan–Design Center.
- 1981 Las Piedras, Puerto Rico–Systems assembly, components test.
- 1984 Singapore–Systems assembly.

During Intel Philippines' 10-year anniversary party in 1984, Ken Thompson presented an award to one of the 10-year employees, Cora Pascual, as Gene Flath looked on.

A Shinto ceremony marked the 1981 groundbreaking of Intel's new facilities in Tsukuba, Japan.

FAB 3: THE McINTEL APPROACH

Intel's growth spurt in the early '70s demanded manufacturing expansion and new employees, and the manner in which the company tackled the problem set the standard for all future expansion.

The company's first two fab areas—Fab 1 at Mountain View and Fab 2 at Santa Clara 1—experienced numerous difficulties. Fab 1 had been acquired from Union Carbide and rebuilt and modified many times. Fab 2, in Santa Clara 1, was Intel's first try at designing and building its own plant, and Ron Whittier, who had just joined Gene Flath's manufacturing group, remembered it well.

"Tom Rowe, Bob Holmstrom, Jerry Larson, and I were the principals in building Intel's first fab from the ground up. Essentially we were a team of rookies trying to produce something very sophisticated, and the first five years of Fab 2 were struggle, struggle, struggle." Another factor that contributed to the problems of Fab 2 was bringing it up on bipolar and MOS simultaneously.

But the learning experiences gained at Fab 1 and 2 served as the foundation for the success of Fab 3, which was built at Livermore. Fab 3 started with a clear focus: manufacture 1103s, a "big 1103 machine," as Tom Rowe called it. It was designed by Gene Flath, Ted Jenkins and Bob Holmstrom, with overall project responsibility in the hands of Jenkins.

Jenkins recalled, "My charter in late 1972 was to start this facility and not use any other Intel people. It was just Paul Hoefler and I. Management said, 'Don't bother us; just go out and do it.' "

Most of Jenkins' start-up team members were recent college grads. The new team trained for nine months at the Santa Clara plants and the Livermore plant opened in April 1973.

Gene Flath remembered the day well: "Hoefler had prepared blue Intel binders with all the up-to-date process information, one for each employee. There were about 200 identical binders spread neatly at work stations throughout the plant. Everyone was reading out of the same book, as the saying goes. How different from Fab 1 and 2 start-ups!"

Thereafter, fab start-ups would employ the same system of hiring seed employees and training them at existing Intel plants. For example, Oregon Fab 5's start-up, led by Ken Moyle, was remarkably smooth, especially since it was the first Intel plant to work solely with the new 4-inch wafer size. Moyle had successfully led the conversion at Livermore from 3-inch to 4-inch wafers, and he brought the lessons he learned there to Fab 5. As in the Fab 3 start-up, a group of "youngsters" actually brought Fab 5 into production. Moyle and Al Patterson hired people right out of college in the summer of 1978, gave them a few weeks training at other fabs, and then brought them to Oregon when Fab 5 was ready to go.

Fab 3 was really the beginning of this franchise or "McDonald's approach" to building fab facilities. The technology and equipment required for each fab would be the same, modified and updated for improvements. And the facilities themselves would be modular, duplicating previous fabs, although larger in most cases.

The result: consistency of production. Observed Keith Thomson, "Every McIntel wafer looks and tastes the same wherever it is made."

Robert [illegible]

> *"Every McIntel wafer looks and tastes the same wherever it is made.*
> *—Keith Thomson"*

Intel president, Andy Grove, contemplates the "McIntel" franchise approach to wafer fabrication in this 1973 photograph. Note his custom-designed McIntel package.

MAY DAY 1975—PENANG BURNS

On May 1, 1975 Intel's assembly plant at Penang, Malaysia was destroyed by fire. Gene Flath, then director of Manufacturing, first learned of the calamity when he was awakened by a phone call at 2:00 a.m. from John Mandel, manager of assembly. "He kept telling me that the Penang plant had burned down and I kept saying that he was kidding and this was a terrible practical joke to be pulling at that hour. But he finally convinced me, and my first reaction, since it was early May, was that this was a communist-inspired May Day plot and that we had been attacked by communist insurgents who were active in the area."

Ken Thompson, plant manager at the time, was in Manila; Ronnie Gui was running the plant in his absence. Continued Flath, "I finally got the two of them on the phone. Ronnie described the scene and wondered what to do with the operators who had shown up for work. I told him to send home those he couldn't use but to assure everyone that they had a job and we'd keep paying them, which we did. This was a loyal workforce."

Thompson returned to Penang to find "the only thing standing was the cafeteria. Everything else had burned to the ground."

Fortunately there were no injuries; the fire broke out on a weekend. The building had been constructed of cinderblock walls and steel beams with a wooden roof. "The fluorescent lights were mounted up against the wood ceilings," Thompson said, "and apparently a spark from a faulty ballast ignited the wood." Fanned by 30-mph winds, the structure burned quickly, with such intense heat that even the steel beams were reduced to twisted, melted rubble.

The Penang plant may have been destroyed because it was not equipped with a sprinkler system, which at the time was not required in Malaysia. After the fire, every manufacturing building in the area was retrofitted with sprinkler systems, and today the Malaysian building code even requires a water tower to provide sufficient water pressure to operate a sprinkler system.

Fire rages at Intel's Penang, Malaysia plant in 1975. The plant was totally destroyed but the facility was rebuilt and production was started again within a year.

> *"In just two weeks [after the fire] they had production going in rented space and with borrowed equipment. It was really a masterful piece of recovery.*
> *—Gene Flath"*

PICKING UP THE PIECES

The most remarkable aspect of the Penang disaster was the speed with which the company resumed production. This favorable outcome was the result of truly heroic efforts made by the Intel people—from managers to the Malaysian workforce—and the cooperation of other semiconductor companies in Penang.

Flath remembered arriving at night in Penang some three weeks after the fire—he had been delayed getting a passport and shots—and meeting Ken Thompson for the first time. "Ken and his crew must have been working 22-hour days, and he was running the whole thing as if it were a big war room. In just two weeks they had production going in rented space and with borrowed equipment. It was really a masterful piece of recovery."

Actually, Intel was able to put part of its force back to work within 10 days using swing and graveyard facilities offered by neighboring semiconductor manufacturers. "We were fortunate," observed Thompson, "that the disaster struck at a time when other manufacturers were not at full capacity. Most of the equipment is interchangeable, and it was standard practice to share supplies with one another."

Recalled Thompson: "We were operating out of about four locations, plus our cafeteria, and by the end of our second week we shipped 100,000 units." He also boosted production at the Manila plant and secured more subcontract capacity in the Philippines and Hong Kong.

Until production started again, employees reported to work and were paid and sent home. Nobody lost any time. The management staff worked around the clock with the aid of four or five beds at one of the locations to ease the tension. "It was a total team effort," said Thompson.

While Thompson was directing the recovery in Penang, Mandel was working overtime in the States calling vendors all over the world, marshaling equipment for shipment to Penang, and organizing people for a new start-up. The plant was rebuilt and on line in less than a year.

"It was a duplicate of what was there, with some improvements," recalled Keith Thomson, "including sprinklers. And it remains a masterful tribute to the dedication and resourcefulness of Intel people."

INTEL IN ISRAEL

In 1984 Intel completed its tenth year of operations in Israel. Intel started with a design center in Haifa and is now building its first fab facility outside the United States in Jerusalem.

Dov Frohman, the inventor of the EPROM, is largely responsible for establishing the company in Israel. In 1973, aware of the growing manpower crunch in the semiconductor industry in the U.S., he urged Intel to consider setting up a design center in Israel. "The motivation for a design center in Israel was the availability and quality of manpower there," he explained. "We selected Haifa because it had an electronics industry and the coun-

1974 photograph of Rafi Nave (front) and Tom Innes, present general manager and first general manager, respectively, of Intel's design center in Haifa, Israel.

try's major engineering school, the Technion. Graduates in Haifa tend to remain there to work."

Frohman, Andy Grove, Les Vadasz and Art Rock (who was then vice chairman of the board), conducted interviews in Haifa in April 1974. They hired the Israel Design Center's first four engineers, who would report from Israel to Vadasz in Santa Clara. A manager had not been selected, and although Frohman wanted an Israeli for the job, there were no candidates. So the company recruited Tom Innes, then project leader of the MCS 4/40 design team in the U.S., for the job.

The unsettled conditions in the Mideast have occasionally posed challenges to operations in Israel. Provisions have been made for the staff to be away on extended military reserve duty. Explained Frohman, "We have always managed. From the beginning we were determined that reserve duty would not affect operations to any large extent. Within the organization we overlap projects and responsibilities so that more than one person understands what is going on in different projects." Even during the 1982-83 crisis in Lebanon, there was virtually no slippage in deadlines, with many employees demonstrating their loyalty by returning from reserve duty to the office on the weekends.

From the early days of Intel Israel, Dov Frohman had also been pressing for a fab plant and R&D facility. Waiting judiciously until the Design Center had proved a success, he began raising the issue with Intel management. It was not until 1979, after Gordon Moore visited Israel and came away highly impressed, that Intel made the commitment to proceed with its first offshore fab.

Groundbreaking occurred in November 1981 and production in Jerusalem's Fab 8 is scheduled to begin in 1985.

INTEL MEETS THE REAL WORLD

There have been times when Intel has been caught off guard by local conditions at its various sites in the U.S. and around the globe. For example, Keith Thomson and Andy Grove learned about Malaysian weather on their first visit to the Penang site in the early 1970s. "It was the monsoon season—I'll never forget it—" Thomson related, "and Andy, myself and our wives drove out to the plant in a rental car, which promptly sank into the mud. So there we were, the American visitors, with our shoes off and pants rolled up sloshing through the mud. The construction workers at the site helped lift the car back on the road."

Gordon Moore also got a quick lesson in Far Eastern weather on his first trip to Intel in the Philippines. He happened to arrive just as a major typhoon struck the island. "We wanted desperately to create a nice impression," recalled Letty Alcasid, international employee relations and compensation manager, "but it wasn't easy because the streets were flooded, transportation was not available, and a ship had actually been blown ashore by the wind and was 'docked' along the boulevard. Half the plant, including the managers, were not in by 8 a.m. In my eagerness to be on time, I hurriedly stepped out of the car into knee-deep, dirty flood water in front of the plant. There I was, greeting Gordon Moore in a sopping wet dress and shoes. I hate to think what kind of first impression he had of Intel Philippines!"

Rain again caused problems for Intel in Arizona in 1979. Some 300 employees of the Microcontroller Operation (MCO) were occupying leased buildings in Phoenix awaiting completion of new facilities and Fab 6 in Chandler, south of the city. About two-thirds of the employees lived on the Chandler side of the Salt River, normally a dry basin. When unprecedented rains caused massive flooding during the winter, Intel faced a severe crisis. Recalled John Ekiss, then MCO general manager, "The river washed away all but two bridges, so many of our employees ended up with two- or three-hour commutes. We finally set up commuter vans to take them to and from work." The problem was compounded by a delay in construction of the Chandler facility. "We got through it," said Ekiss, "but it was a trying period."

Mother Nature has not restricted her adverse treatment of Intel locations to rain alone. An earthquake measuring 5.8 on the Richter Scale struck near Fab 3 in Livermore in 1980. Fortunately, due in part to Intel's proactive earthquake safety and building programs, the quake caused only minor disruptions in fab operations.

In Oregon, Fabs 4 and 5 were threatened in the spring of 1980 when Mount St. Helens—a supposedly dormant volcano only 50 miles away—suddenly exploded to life in a series of eruptions. Mounds of fine gray ash poured into the air, posing serious threats of contamination to the clean rooms. Remarkably, the fabs lost little production time thanks to employees' heroic all-night efforts to activate disaster contingency plans aimed at keeping the particle count down in the clean rooms.

Intel has been caught off guard not just by the natural elements, but by differences encountered in various cultures around the world. Letty Alcasid remembered how aghast Andy Grove was on his first trip to Intel's facilities in Manila when he discovered that the walls were paneled in mahogany, with managers, in closed-door offices, seated behind mahogany desks. "This surprised us," recalled Alcasid, "because most Philippine offices look like that since mahogany is plentiful and cheap there. Then we learned that Intel buildings in the U.S. had open offices and plain desks. Of course, when we built our next building in Manila the 'decadence' was eliminated."

Tom Innes, the first manager of the Israel Design Center, tells the story of Les Vadasz's visit to Intel Israel in 1975. The plant was located in Haifa in an older, run-down area of small businesses. One of these establishments was a small cafe. The cafe owner's daughter tended a small herd of sheep which foraged for food in the nearby lots and alleys.

"I used to park my car under a tree," recalled Innes, "and the sheep would climb on the roof of the car to nibble tree leaves. I got used to it after a while. But when Vadasz and I left the building one night, he was dumbfounded to see the sheep on my car. The look on his face was something to behold. It must have dawned on him how crude a place we were in trying to develop some of the world's most sophisticated products."

Monsoons hit during Andy Grove and Keith Thomson's first visit to Intel's site at Penang, Malaysia. Here local workers help rescue their rented car from the mud.

EVOLUTION OF A CULTURE

When Intel consisted of 100-or-so people housed in one building, it was easy for everyone to understand "Intel Culture"—although no one would have thought to use such a term at the time. Intel Culture was what Bob Noyce, Gordon Moore, Andy Grove, Les Vadasz, Gene Flath, et al. did; it was how they acted and what they believed. One only had to come to work every day to get a good understanding of it.

As the company grew to thousands of people at multiple sites, that kind of hands-on, daily tutorial became impossible. The need remained, however, for new people to learn "how we do things around here" so that the company could work together with a minimum of policies and procedures.

Out of this need came the idea of a corporate culture, which can be thought of as the set of values that Intel prizes and propagates throughout the company. For example:

**Openness* and a high degree of communications among employees are encouraged. Management is accessible at all levels. Meetings are considered two-way teaching sessions, and decisions are made in open forum. Employees at any level are encouraged to voice their ideas without fear of ridicule. Politicking or closed lobbying for personal gain is not tolerated. Constructive confrontation, where people expect to hear outspoken comments not only from their bosses or peers, but also from subordinates, is an effective tool to resolve problems quickly. Keith Thomson explained, "In a large organization you can get trapped in a chain of command that can't resolve a problem fast enough. We want people to go right at it—'Hey, I've got a problem with what you're doing; either justify it or let's find a better way.' "

**Decision-making*. Intel encourages decision-making at the lowest possible levels. Employees are expected to face up to difficult decisions whether they be business, organizational or personal.

**Assumed responsibility*. Intel expects its people to take on a task and deal with it without being told.

**Discipline* is highly valued. The company demands that its people be tough on themselves. It doesn't like surprises, so a high degree of planning is required. Performance to commitments is closely monitored. "We sought discipline from the second year of our existence," remarked Andy Grove. "We realized that we were a bunch of technologists, and that there was a pitfall in being free-wheeling entrepreneurs who couldn't make the transition to a profit-making business."

**Problem solving* in an open manner is important. Problems are meant to be solved, not feared or hidden. The goal is to solve problems in a direct, straightforward manner rather than focusing blame.

**Risk taking* is rewarded. The company encourages its people to extend themselves, to focus on accomplishments, and to champion projects even if there is a chance of failure.

**Meritocracy*. Intel believes that its people should be rewarded and advanced solely on the basis of their contributions to the company, not on seniority or other criteria. High achievers are compensated better than the average performer and moved along quickly. Incentives such as bonuses and stock options are widely used.

**Results oriented*. Objectives are carefully defined and results measured throughout all organizations in the company.

**Involvement*. Intel wants its employees to participate in their relationship with the company. To this end, communications are stressed heavily.

**Opportunity* for rapid development is offered to Intel employees. This requires a strong commitment to training, which is a major priority that involves the highest levels of management. A professional staff is supplemented by several hundred volunteer instructors certified to teach the extensive range of training courses offered by Intel. Through detailed written performance reviews, employees get feedback on how they are doing.

**Teamwork* is an integral part of the Intel work environment. It is fundamental that team objectives take precedence over individual objectives. The council system is an example of team action. It consists of some 90 cross-organizational groups of peers which meet regularly to set policy in their areas of common interest (i.e. engineering, materials, marketing, etc.). Councils started in the early 1970s when manufacturing spread to several sites and the need arose to standardize policies. As the company grew, people came together to discuss how they were doing things, and this evolved into the council system. The number of councils increased to the point where they had to be grouped into clusters with a senior manager overseeing each.

Task forces are another form of teamwork. These are typically small groups of specialists brought together to solve a critical short-term problem. They focus attention and responsibility on the challenge and then overwhelm it with talent. "This company has always had the ability to react quickly to problems and send a squad of top people in to fix them," commented Ron Whittier.

"Intel's culture is a living, breathing thing," noted Jim Jarrett, manager of Corporate Communications. "As the company continues to grow and change, no doubt its culture will too."

Although its appearance may not suggest so, this SLRPy award is actually revered throughout the company as it is given annually to the Intel manager who presents the best, most believable and achievable strategic long range plan.

SLRP

Each spring Intel managers undergo a unique and arduous ritual with the unlikely name of "Slurp." Actually an acronym, SLRP (Strategic Long Range Plan) consists of a series of meetings to forecast the company's next five years.

The origins of today's complex SLRP process can be traced to annual half-day sessions where Intel's senior management looked at possible directions for the next few years and to product planning meetings held from time to time in the company's early days. The latter were attended by 10 to 15 middle managers who would determine product strategy while senior managers "were kibbitzing, guiding, and critiquing, but not setting product strategy," as Andy Grove explained.

As the company grew, Gordon Moore structured the planning process so that specific company goals, as well as product and group objectives, were established each year. This required that division and group leaders prepare increasingly elaborate plans for their activities and relate them to overall corporate objectives. It was through Moore's insistence on more formalized planning that the process evolved over time into a disciplined, thorough, long-range blueprint for the company's future.

In 1979 Intel named Les Vadasz, a company senior vice president, director of Corporate Strategic Staff, thus confirming the growing commitment to corporate planning. He developed the SLRP process into a more integrated plan in which some 250-300 representatives of various planning bodies prepare strategies. These bodies include

Strategic Capability Segments (SCSs) which plan capabilities like component manufacturing, technology, human resources, etc.; Strategic Business Segments (SBSs), which plan the evolution of Intel's product line; and Strategic Business Groups (SBGs), which include SBS representatives who integrate global plans for each major business area.

Representatives from these group-level meetings deliver presentations to Executive Staff SLRP meetings held each spring. The presentations are long and precise and they are competitive. Judges informally score participants' efforts on a scale of 1 to 10, which serves to focus presentations.

Not surprisingly, the intensity of the SLRP meetings, as they became increasingly more complex, began to take its toll. "The flow of presentations was interrupted too many times and it became 'destructively confrontive' and unpleasant for people to deliver a summary of their work," explained Vadasz. Interruptions included disparaging remarks, questions that anticipated what the speaker was about to explain, and passing of notes among audience members. To curb these distractions, in 1983 Vadasz introduced the fishbowl penalty. When an attendee got out of line or interrupted the flow of the presentation, he or she was required to pay a fine into a fishbowl which sat on the conference table in front of Vadasz. The fines varied from $1 to $5, and generally got a few laughs. By and large it was deemed effective, but there will always be the impatient or outspoken participant who will reach for his billfold before making a comment, saying, "It's worth it!"

After months of hard work, the SLRP process culminates with dinners held simultaneously at major Intel sites joined together by a phone hookup. Highlight of the ceremonies is the presentation of the coveted SLRPy (slurpy) award for the most effective and believable plan.

Les Vadasz launched SLRP's fishbowl penalty in 1983. Any time a SLRP meeting attendee breaks the SLRP rules of etiquette, he or she must pay a penalty into the fishbowl. Money collected is applied against the total SLRP expenditures.

This is followed by the infamous SLRP booby prizes which make a point and poke some fun at the same time. Jean Jones, Gordon Moore's secretary, and Geri Williamson, Les Vadasz's assistant, coordinate the complex task of locating appropriate prizes and getting them to the various sites in time for the awards. This is a tough logistics assignment because the SLRP meetings end on Wednesday and the dinners are held the following night. Noyce, Moore, Grove and Vadasz determine appropriate prizes for the lucky winners. Among past awards: a size 44D bra to the general manager of Intel Magnetics for having the most inflated plans, a spray gun to the general manager of microprocessor operations to debug a new product, rubber money to the general manager of the components group for spending 130 percent of his R&D budget, a jar of muddy water for "clarity" of a presentation, the Tower of Babel award for the presentation that was highest over the heads of the audience, and a laugh machine for the most unbelievable financial plan.

Noted Vadasz, "The biggest value of the SLRP process is the work each planning group does in preparation for it. The people who do our planning are the very same people who have to execute the plans."

INTEL DELIVERS PROMPTNESS

One of the most visible examples of Intel's disciplined working environment is the late list which employees sign if they arrive after 8 a.m. The list appears in a building when more than 7 percent of its employees arrive late for two months in a row. It remains until the percentage of tardy employees drops below 5 percent for a month. This practice was launched in 1971 by Andy Grove, the driving force behind the company's operations from the beginning. It was controversial then and it remains so today.

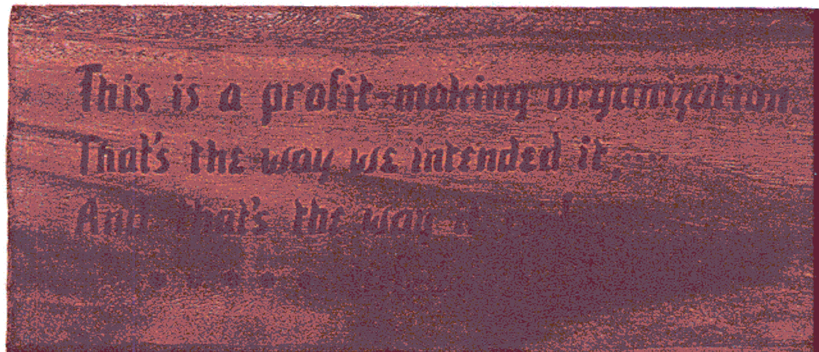
By 1971 the company had grown to about 300 employees, and Paul Metrovich remembered that many of them ignored the workday starting time. "It got to a point where as a technician I couldn't find anybody in the engineering staff until after 9 o'clock," he said. "If we had a problem, we'd put our feet up on the desk or find something else to do until they arrived."

Grove had tried everything to establish punctuality: meetings, memos, warnings—but to no avail. Then during one regular Friday morning staff meeting he decided he'd had enough.

Keith Thomson remembered the meeting, which was held in a corner conference room with a sweeping view of the parking lot. "We'd periodically look up from our discussions and glance at the parking lot, watching people straggle in long after 8:00," he said. "Finally Andy pounded on the table and said he couldn't take it anymore, that this was a manufacturing organization and we should all start at 8 o'clock."

Shortly thereafter Grove initiated a sign-in monitor for his employees. The procedure went company-wide in the mid-1970s when he assumed overall control of operations.

"It's symbolic," Thomson explained. "It says we are a disciplined organization. If reports are due on the 5th, they should be done on the 5th. If the day starts at 8:00, the day starts at 8:00 for everybody. If you commit to do something, you do it."



RJ Muna

Intel achieved its first $250 million quarter in the second quarter of 1983. Billion-dollar company status was also reached for the first time that year, as the company closed out the year at a record $1.1 billion in revenues.

"THIS IS A PROFIT-MAKING ORGANIZATION"

Gordon Moore has a small wooden plaque that reads: "This is a profit-making organization. That's the way we intended it,... And that's the way it is!"

The plaque is symbolic of the importance Intel places on successful financial management. Intel has always prided itself on being the most profitable company in the semiconductor industry, while investing heavily in research and development and facility expansion.

Larry Hootnick, who signed on in 1973 and is now senior vice president and director of Corporate Marketing, is considered the architect of the tight policies that give the company a greater probability of meeting its profit targets. Conservative financial and accounting methods were adopted early on and, having set the standard, were taken up by many other companies in the industry.

Another manifestation of Intel's desire to be—and be perceived as—a tightly managed company is its widely known history of being first with its financial reports. Rapid year-end reporting of audited company figures has been a hallmark of the company for years. Results are released within two weeks after the end of the year. The same schedule applies to quarterly results. "By getting the numbers out fast," explained Hootnick, "we get immediate feedback to the decision-makers as to what is going on, and then we can get on with the business at hand." It is part of the way Intel does things—its corporate culture—that projects should be done on time—or ahead of time, when possible.

The planning required for fast reporting is characteristic of the overall strategies that have kept the company ahead of the pack.

"We have a company profit goal," noted Hootnick, "but we also have a goal for each individual business unit—by area, by operation—so we can see if we are getting out of line in any specific area."

The company also believes in letting employees share in the profitability. Key employees are granted options to purchase shares of Intel's authorized but unissued capital stock, at fair market value at the date of grant. The Stock Participation Plan, which was launched in 1972, allows qualified employees to purchase shares of capital stock at 85 percent of market value at certain specified dates. The benefits are obvious: an employee who purchased 10 shares of stock at $208.20 under the plan in December 1972, for example, would find his or her portfolio had grown, by November 1, 1984, to 252 shares (thanks to stock splits) worth $7,056.00. And the benefit is mutual. Employee stock plans (including tax benefits) have provided capital for the company in amounts that have gone from $75,000 in 1971, when Intel went public, to $15,000,000 in 1983.

Life in a cubicle: Intel's open offices foster accessibility at all levels.

COPING WITH RECESSIONS

Intel's first experience with a recession was in mid-1970, just two years after its founding, when business turned down sharply. The company reacted by laying off employees and cutting costs. As a small company, its plight went unnoticed in the industry and community.

The gloom lifted later that year when Intel struck a deal with Microsystems International LTD., an Ottawa, Canada subsidiary of Bell Northern. MIL was to second source Intel's then-new MOS device, the 1103. The negotiating team, which included Jerry Larson, Larry Lubben, Larry Brown, Ron Whittier, Ted Jenkins, Tom Rowe, and Gene Flath, spent the winter commuting between Santa Clara and Ottawa, braving the frigid Canadian winter. In return for transferring the 1103 technology and design and the P-channel silicon gate process to MIL, Intel received a cash infusion of $1.5 million which, as Bob Noyce recalled, about equaled the net worth of Intel at the time. Intel later received a $500,000 bonus because certain yield targets were met. "The MIL deal really softened the blow of the 1970-71 downturn," said Gordon Moore. In a fitting postscript, those who participated in the project were treated to a pull-out-the-stops trip to Kauai—far from the chill of Ottawa—to celebrate their success.

"When preparing for recession, one must be careful not to emulate the generals who get ready to fight the previous war," commented Gordon Moore. "Just as no two wars are alike, recessions are all different. Each one comes at you from a different direction."

The 1974 recession hit with far greater force than the one in 1970. The oil crisis had created a hoarding mania, with businesses going on an inventory-building spree for months. "Suddenly demand just vanished," recalled Moore, and the nation plunged into a severe slump that would last 20 months. Intel was forced to lay off about 30 percent of its approximately 2,500 employees, an experience described by many as traumatic.

THE 125% SOLUTION

In 1981 the country found itself in a prolonged recession, the worst slowdown since the Depression. Intel suffered a terrible margin squeeze as component prices dropped sharply. Management rejected cutbacks in personnel and production activity and instead decided the company should fight its way out of the recession so that it would be poised for the eventual upturn. To do this, Intel decided to accelerate new product development so that it would have little competition and high margins when the recovery came. This plan would restore profitability sooner and extend the time frame of reduced competition.

The key to this novel program was the 125% Solution, which was launched in October. Exempt employees were asked to work an extra two hours a day without pay to speed product development and enhance their units' effectiveness. This extra effort was to be voluntary and was intended to last six months.

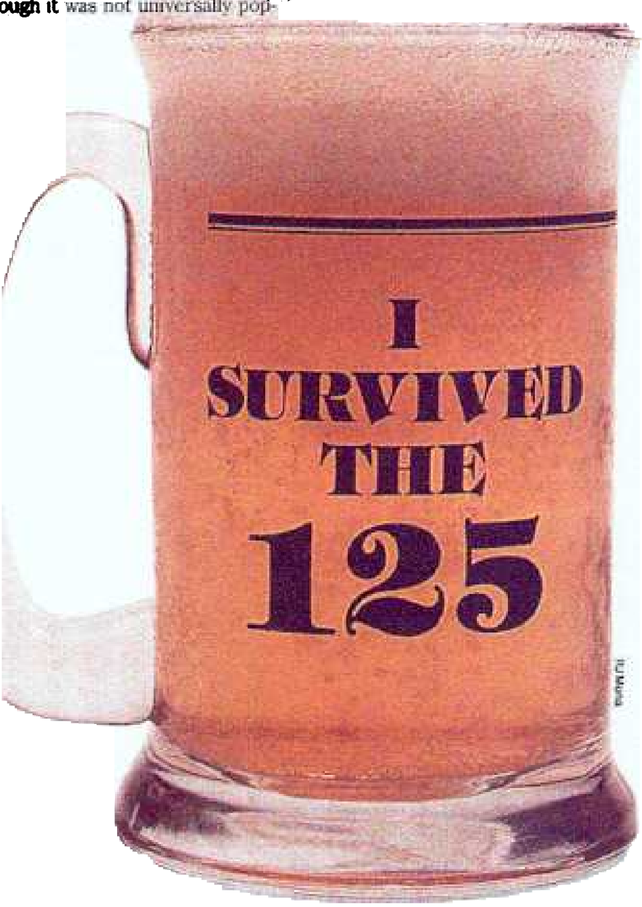
"Generally the program was well received," recalled Roger Nordby, then director of Personnel. "People could identify with the need and they were doing something positive, rather than sitting around doing nothing." He added that employees were kept informed during the period and understood the importance of the 125% Solution in advancing programs that had to be ready when the upturn came. Many nonexempt employees wanted to contribute free overtime to the program but were restrained by labor laws.

Dick Boucher, director of Marketing Communications and Business Development at the time, assessed the program as a sound move and a unique approach. "By working harder to get our products to market sooner we definitely strengthened our position," he explained. "We accomplished a lot, and although it was not universally popular, it was the right thing to do."

By March 1982, Intel's business started to pick up and the recession appeared to be ending. The 125% Solution had been a success, including among its accomplishments accelerated shipment of a new microcomputer system, acceleration of federal tax returns to obtain refunds six months earlier, speedup in the delivery of various engineering projects, and a large increase in microcontroller sales.

Intel ended the 125% Solution on March 31. Celebrations were held for exempt employees at major domestic sites. The festivities included refreshments, music, a presentation by Andy Grove, and special commemorative mugs (15 ouncers, 25 percent more than the usual mug). Within two days a videotape of Grove's presentation was shipped to employees at Intel's other locations in the U.S. and abroad.

Nordby recalled that the festive ending reaffirmed Intel's collective effort. "Unlike other companies that laid off employees, we decided to work our way out of the recession and not roll over. This gave our employees a sense of pride."



At the end of the 125% Solution program, exempt employees attended company celebrations where they received commemorative mugs (15 ouncers, 25 percent more than the usual mug).

FALSE ALARM

Although orders reached record levels in the second quarter of 1982, the euphoria faded fast. Apparently the surge had been caused by widespread inventory adjustment, particularly among distributors, and by September, bookings slumped badly. Meanwhile, Intel's costs increased sharply because it had expanded its employment by more than 3000 people in anticipation of the upturn. Despite cost-cutting measures, it appeared that a loss was likely in the first quarter of 1983.

The company faced a dilemma: it would have to slash expenditures or suffer a loss that could cripple its growth once the recession ended. It refused to mortgage its future by cutting product development or capital investment, and it didn't want to lay off employees. Furthermore, the disruption and loss of its people through a layoff would hinder the company's recovery when the upturn resumed.

After extensive deliberation, Intel management decided to impose a pay cut ranging up to 10 percent and a pay freeze that would last through 1983 unless certain profit levels were reached. This seemed to be the fairest alternative among those available. It would preserve momentum and maintain to employment stability.

During November the program was introduced to employees at over 200 meetings on the same day worldwide.

Reaction to the new program varied. A number of "Thank God We Still Have Jobs" parties were held, but there was still discontent, particularly among highly marketable employees. Most employees however, accepted the trade-off of lower pay for sustained employment.

The pay cut was not made any more palatable when in December the company announced IBM's investment of $250 million for 12 percent of the company's shares. Externally the deal was perceived as a big plus because it provided much needed equity financing to sustain Intel's growth. But internally, company employees did not understand why the IBM funds could not be used to offset their pay cuts. Despite a program of internal communications to explain the distinction, misgivings persisted among many employees. Gordon Moore acknowledged that the timing of the IBM announcement was not good in terms of gaining support for the pay cut. "But from the point of view of our future and the ability to continue to invest in spite of bad business conditions, it looked pretty good," he said.

By March, business had improved substantially, and Intel restored half of the pay cut effective April 1. Then, on June 12, the pay cut and freeze ended with a coordinated announcement over public address systems at the company's major facilities, by voice mail to field personnel, and telex to foreign offices. At the same time, the company announced retroactive pay increases for non-exempt employees who had missed a raise during the freeze. Many employees stood and cheered.

Throughout this trying period, Intel employees somehow managed to hold onto their sense of humor. Recalled Boucher, "We made up 125% Solution sweatbands to go along with the sweat shop image and sold them to employees for $2.00. The proceeds went to the United Way." His department also produced an April Fools' Day issue of the employee magazine, *Inteleads*, featuring Moore on the cover announcing once again that the recession was over.

By November Intel's profitability had improved to the extent that the company awarded two-week bonuses to all employees who had been hired in 1981 or earlier and one-week bonuses to those hired in 1982.

During the lengthy recession of 1981-82, Intel published an April Fools' parody edition of its monthly employee magazine, *Inteleads*. One article stated, "As he did in the Spring of 1981 and 1982, Gordon Moore, chairman and chief executive officer, recently predicted that the recession saddling the semiconductor industry would end soon."

LESSONS FROM THE ALOHA DOGHOUSE

Intel people tend to look on the lighter side of things, so when asked about the recession of 1974 they often tell of the doghouse at Aloha, Oregon. When the downturn hit, the new Fab 4—at the time the company's largest facility—was a nearly completed shell scheduled to go onstream in mid-1975. Management felt it could not justify continued expenditures to complete construction, so the project was completely stopped. A Doberman pinscher was installed as a security guard, and for over a year he had the huge facility all to himself. To this day, company "oldtimers" still refer jokingly to Fab 4 as the "Aloha doghouse."

When construction finally resumed in early 1976, nine more months were needed to bring the plant up and to recruit and train personnel. This delay was costly to Intel because it slowed **the company's recovery and ability to compete.**

Fab 7 in Albuquerque, which came onstream in 1983, offered an interesting contrast in corporate philosophy. This plant was scheduled for completion in the fall of 1982. As the recession of 1981-82 deepened, management put the plant in a "complete, don't start" mode: construction proceeded, but at a slower pace; equipment was delivered and employees were hired, but they were trained at other Intel locations. "We kept the plant alive," explained Gene Flath. "It was shut down for only about six months."

As conditions improved, the plant was gradually activated, starting with a pilot production line in early 1983 and the decision to bring it up in May.

The big difference between Fab 7 and the Aloha doghouse was that when the upturn was signalled, Fab 7 was much closer to start-up than Aloha. Gene Flath agreed that the two plant start-ups reflected a change in philosophy. "But it was also a question of being pragmatic," he said. "In 1982 we had better cash resources and it wasn't as painful."

Aggravating Intel management's agony over the pay cut was the matter of the memory systems business. Explained Bill Regitz, then Memory Systems Operation (MSO) general manager, "The recession forced us to make a decision. We were limited in where the R&D dollars could go, and if we continued to invest in a product line that didn't match our corporate goals we would be wasting money. Well, without R&D money you don't have a product line, so that decided it."

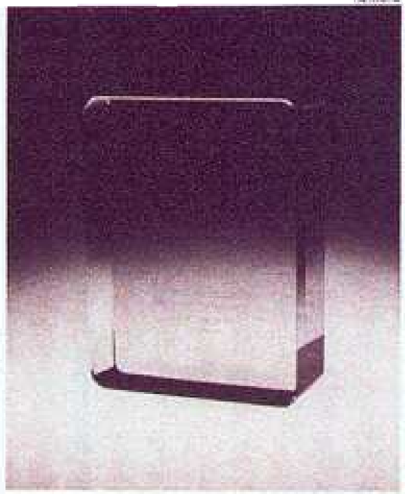
The basic reasons to shut down the business were there with or without a recession. As the company became less and less a factor in memories, it began having to buy parts from competitors. MSO just didn't match the strategic long-term thrust at all.

With some 350 employees involved—and the company's payroll already enlarged by another 3000 recent hires—Intel confronted the unpleasant possibility of a layoff.

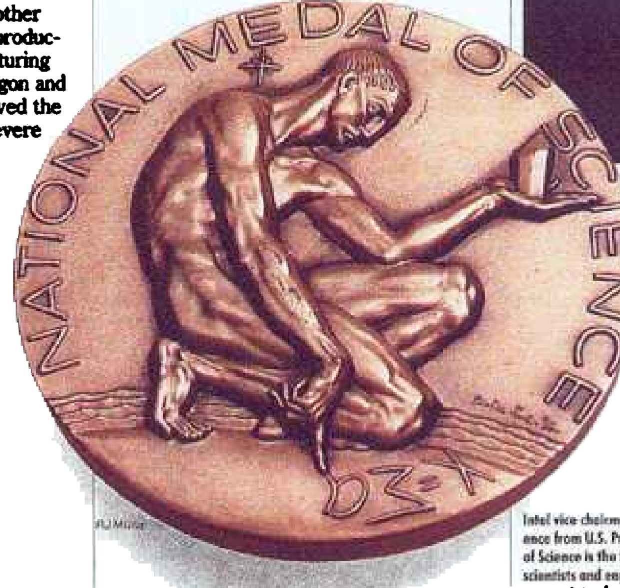
"We didn't know how we were going to do it, but we told our employees that we'd find jobs for all of them," recalled Regitz, who supervised the MSO rampdown.

The bulk of the operation was sold to Zitel, a young San Jose firm that was concentrating on memory systems. Zitel improved its benefits package for employees, which proved an added incentive for the some 30 Intel people who chose to move with the product line to Zitel.

The MSO shutdown was a trying assignment. It involved disposing of the business, placing and retraining employees (almost 250 Intel people were absorbed in other company operations), and keeping production moving smoothly until manufacturing could be transferred to Intel in Oregon and Puerto Rico and to Zitel. But it proved the company's mettle in the face of a severe recession.



One of the many awards and honors Intel and its employees have earned over the years is this Tiffany crystal piece which was presented to chairman Gordon Moore by *Dun's Review* magazine. Out of scores of companies across the nation, the magazine selected Intel one of America's five best-managed companies for 1980.



Intel vice chairman, Bob Noyce, received the National Medal of Science from U.S. President Jimmy Carter in 1979. The National Medal of Science is the federal government's highest honor accorded U.S. scientists and engineers. Noyce was honored because of his work **on a variety of semiconductor devices, especially the integrated circuit.**

Employees are the most valuable assets of any company. In a book such as this it is impossible to name individually the thousands of employees who have helped build Intel into the leading corporation it is today. The following 910 employees, however, have earned special recognition because, as of June 30, 1984, each had reached his or her ten- or fifteen-year service mark.

FIFTEEN-YEAR EMPLOYEES

Patte Beem
Larry Brown
George Chiu
Nobuko Clark
Miriam Eichelkraut
Eugene Flath
Andrew Grove
Thomas Innes
Ted Jenkins
Jean Jones
Gerald Larson
Angie Lewis
Patricia McVey
Paul Metrovich
Gordon Moore
Robert Noyce
Gerhard Parker
Alice Ray
Thomas Rowe
Norman Shanks
Leslie Vadasz
Andy Volckaert

TEN-YEAR EMPLOYEES

A. Anchale
Richard Abascal
Carol Abbey
Robert Abbott
Abdul Jalil Bin Ibrahim
Abdul Mutalib B. Ali
Stephen Abreu
Dave Accornero
Cindy Adam
Kathleen Adelman
Carmen Afanador
Patricia Affeldt
Mary Aguilar
Gregory Ahearn
Nancy Ahre
Leticia Alcaaid
Richard Aldrich
John Alfoldy
Alias Bin Ahmad
Mitsuko Allen
Quincy Allison
Josephine Alvarez
Ernestine Amaral
Aminah bt Che Wan
Aminah bt Sa'aid
Aminah bt Yusoff
Darlene Amos
Dorothy Anderson
Larry Anderson
Owe Anderson
Ang Chai Lean
Ang Geok Tin
Yolanda Antonio
Jovita Ara
Allonia Archie
Beatrice Arelliano
Maria Arenas
William Baerg
Gene Bailey
Flordivinia Bala
Helen Barieau
Carmen Barnes
Wilfreda Basa
Reijeana Batties
Mariana Bautista
Editha Baylon
John Beaston
Sharon Beckham
Ana Bedoya
Beh Yeang Hua
Neno Belecora
Pascual Bercasio
Cecile Bergeron
Dorothy Billingsley
Magdalena Birmodis
Arnida Bituin
Lourdes Blanco
Rita Blanco
Dona Blobaum
Richard Bock
Edward Boleky
Ruth Bonilla
Jack Borok
Heriberto Botello
Margaret Bowes
Dennis Brabeau
Dorothy Brenden
Carrie Brenner
Lawrence Brigham Jr.
Margie Britt
Sharon Britton
Violet Brodeaser
Lawrence Brown
William Brown
Rachael Bryant
Robert Buck
Pamela Buckley
Homer Buller
Ling Bundgaard
Erlinda Burkhart
Geoffrey Burns
Helen Burris
Margaret Burston
Richard Burton
Diane Butler
Joann Cablas
Jennie Calderon
John Calhoun
Oscar Camposagrado
Rita Canales
Ruth Cannon
Sylvia Cano
Nenita Canovas
Mary Cantere
Clarence Cantua
Emilia Canul
Cristina Cardona
Joanne Care
Edward Carpenter
Mary Carvalho
Ana Casco
Jessica Castillo
Leticia Castro
Sally Chambers
Chan Chong - Chan Seong Chong
Chan Gook Chee
Helena Chan
Chan Huan Heng
Chan Mei Lai
Chan Hooi Chin
Chan Quat Khin
Keith Chapple
Charles John
Cheah Kim Hoon
Che Bu bt Hamat
Che Jam bt Chin
Cheng Ah Ngia
Cheng Nai Choo
Cheong Saw Aing
Che' Puan Ismail
Che Saniah Bte Darus
Che Sayang bt Abdul Rahman
Che' Siah bt Ismail Tajudin
Chew Eae Hock
Robert Childress
Chin Cheng Lean
Chin Chew Fong
Ch'ng Saw Phaik
Chong Yoke Choon, Anthony
Choo Junt Boay
Choo Siew Bee
Sunlin Chou
Paul Christensen
Chuah Sow Tin
Eugene Churchill
Cik Rabhai bt Chik
Amelia Clarke
Stephen Clifford
William Clifford
Don Clinkinbeard
Mary Cobb
Colet Cochran
Nancy Cole
William Cook
Chris Cooleman
Dean Coombs
Evert Cooper
Robert Cooper
Jean Claude Cornet
Paul Corona
Evelyn Corpus
Johnnie Corpuz
Maryann Corpuz
Conchita Cotillon
William Craig Jr.
Janet Creech
Ruby Creelman
Leroy Croll
Manuel Cron
Harry Cross
Page Cross
Isola Crum
Lorrie Cruz
Nenita Cruz
Philip Dahm
Robert Dalrymple
Jene Dass
William Davidow
Lance Day
Sharon Day
Kathryn Deagen
Bea Deem
Martys Deets
Charles Dehont
Teresita Dela Cruz
Janet DeLeon
Virginia DeLeon
Rizalina Del Valle
Nobuyuki Denda
Robert DeVore
Steven Dickey
Michael Dion
Raeann Dixon
Stephen Domenik
Margie Downs
Jane Dredge
Sunja Drinkwater
Dave Duchan
Henry Dumlao
William Dunaway
F. Thomas Dunlap Jr.
J. Dunn
Catherine Earhart
Easah Bee bt Mond
Michael Edson
Alice Eduarte
Gerald Elder
Richard Elliott
Blain Erakine
Dorothy Esler
Elvira Espanto
Teresa Esparza
Abicinia Estacio
Delia Estrada
Joan Evans
Hilda Everson
Fadzilah bt Din
William Fagerstrom
Rosario Falsis
Faridah Hussain
Jose Faria Jr.
Barbara Farsaci
Fatimah Bee bt Sardar Mohamed
Fatimah bt Abd. Hamid
Fatimah bt Darwi
Fauziah bt Eusoff
Fazilah bt Osman
Shirley Fedora
Harold Feeney Jr.
Larry Feetham
Francis Fegan
Florabelle Feldbauer
Yung Feng
Remedios Fernandez
Donald Ferris
Sallee Fetter
Barbara Field
Joe Flack
Mary Flores
Maria Flores
Miguel Flores Jr.
Laurie Flores-Moore
Evelyn Fojas
Rae Forrest
Barbara Foster
Jennifer Frahs
Amor Francisco
Vickie Francone
James Frederick
Albertina Freiberger
Mary Frick
Rose Friedlund
Joseph Friedrich
Dov Frohman
James Fry
Mariano Gali
Amancia Gallegos
Joan Garber
Ruth Garcia
Esther Garcia
Jacqueline Gardner
Gazali Bin Ismail
Patricia Geary
Michael Geilhufe
Edward Gelbach
Eddie Gentry
Gerbak Singh
Pamela Gibeson
Bruce Giron
Bernard Giroud
Goh Hew Sim, Doris
Goh Poh Gaik
Goh Saik Choo
Errol Golsan
Robert Gomar
Manuela Gonzales
Debbie Gonzales
Mary Helen Gonzalez
Goon Soo Pheng
Howard Gopen
Gary Gossoo
Peter Governanti
Violeta Gracilla
Robert Greene
Jose Gregorio
Lawrence Gregory
Gert Griese
Josie Guerrero
Maria Guevara
Ronnie Gui Heng Huat
Elviro Guillen
Concepcion Guillena
Gurbachan Kaur
Joseph Gutierrez
Teresita Guting
Raymundo Guzman
Carol Hadsell
Patricia Hajduk
Verdale Hales
Halijah bt Ashari
Halimah Ashari
Andre Hall
Barbara Hall
Dorothy Hall
David Hamilton
Marcia Hamilton
Danilo Harder
Martha Haro
Harris Bin Mohd. Shariff
Cheryl Harrison
Marian Harrison
Hasnah bt Halim
Hatijah bt Yahaya
Patricia Hauser
Umar Hayat
Hasinah Osman
Michael Hernandez
Erma Herrera
Patricia Herrera
Karl Heydeck
Barbara Hill
Kirk Hirschfeld
Ho Hoay Teen
Ho Yee Hun
Paul Hoefler
Dolly Holsinger
William Holt
Laurence Hootnick
Hor Lean See
Grace Horibe
Roy Hornbaker
David House
How Lay Chin
Harold Hughes Jr.
Corazon Imbat
Raquel Ingram
Diane Irby
Ismail Nizar
Carl Ito
Michiko Itoi
Catalina Jacinto
Macaria Jacob
Arthur James
Thomas James
William James
John Janus
Jayamani
David Jeffrey
Richard Jensen
Mary Jett
Paz Jimenez
John Johansen
Elaine Johnson
James Johnson
Rose Marie Johnson
Bunpa Jones
Thomas Jones Jr.
Henry Josefczyk
Anais Kahermanes
Kaliyama Kandasamy
Kam Theam Huat
Kang Gaik Suan
Steven Kastner
Willard Kauffman
Gregory Kawabata
Kee Eng Lan
Elizabeth Kern
Dorenda Kettmann
Khalit Sin Yahaya
Kheong Cheow Chye
Khoo Chin Hoe
Khoo Kay Huat
Khoo Pek Wah
Khor Ah Moy
Kim Siew Gaik
Esther King
Glenn King
Lucille King
Theodore Kirkiles
Koay Siew Choon
Koay Siew Kooi
Deborah Koch
Tandy Koch
Judith Kochanowski
Julie Kreger
Ronald Kueber
Stephanie Kueber
Kuppusamy S/O Ramu
Jane La Fuente
Marsha La Grange
P.Y. Lai
Lalitah A/P Tannimalai
Cynthia Lamiel
Shelia Lane
Joseph Langston
Jeanne Latham
Lee Gim San
Lee Gih Siew
Lee Guat Kooi
Lee Kim Hiuk
Lee Kwee Choong
Lee Jee Siew
Lee Lay Hoon
Lee Saw Har
Dennis Lenehan
Leng Choy Fong
Evelyn Leones
Leong Mee Mee
Leow Ah Lan
Arnolfo Lesende
Isaac Levy
Norma Lias
Liew Chai Fong
Lily Jan bt Md. Joonos
Lim Ah Yang
Lim Bee Cheng
Lim Bee Keow
Lim Choon Ean
Lim Choon Seng, Joe
Lim Eng Hai
Lim Gaik Hong
Lim Geik Choo
Lim Hoe Teong
Lim Poh Keat
Lim Sau Leng
Lim Saw Sim
Lim Siew Hwah
Lim Sim Wah, Francis
Lim Swee Luan
Lim Tai Heang
Lim Teo Fung, Kathleen
Angela Lindsay
Linda Linn
Ludivina Lising
Danilo Llamas
Dolores Llamas
Loh Mei Fong
Loh Peng Kim
Loh Yuen Fatt, Steven
Loh Yuit Hoe
Frank Louie
Mark Lovestrand
Low Guk-Lan
Jose Lua
Larry Lubben
Lucas S/O Benjamen
Lupe Lujan
Terry Lundblad
Dennis Lundien
Ruth Lynch
Frank Ma
John Mack
Sylvia Madrigal
Benita Magday
Cynthia Magno
Maha Letchemi D/O Kolandeveloo
Maheswar A/P Subramaniam
Mah Mar Hak, Michael
Eugene Malatesta
Hattie Malone
Jacqueline Malsam
Ben Manny Jr.
Marian Manuel
Jerry Mar
Ted Marlbrough

Jennifer Martin
Richard Martin
Angie Martinez
Anthony Martinez
Elda Martinez
Maria Martinez
Mary Martinez
Richard Martinez
Yolanda Martinez
Sheila Marvin
Cynthia Marymee
Isla Mathews
Mathuran Thagee D/O Vasuthavan
Lorraine Matthews
Timothy May
Mazihah Osman
John McCollum
Margaret McFarland
Mary McGee
Deborah McKenna
Adeline McKinnon
Michael McNulty
Md. Mokhtar B. Hassan
Elvira Medrano
Victoria Mee
Eugene Meieran
Carmen Mendez
Beatrice Mendoza
Leone Mendoza
Patricia Mendoza
Barbara Mennell
Dennis Menta
Jose Merneio
Howard Merritt
William Messick
Ed Metzler
David Miller
Rosario Miranda
Kenneth Mitchell
Mohd. Arshad B. Abd. Karim
Mohd. Azhar
Mohd. Ghazali
Mohd. Noor B Bakar
Mohd. Sohimi Mustaffa
Mohd. Yusoff Bin Md. Ibrahim
Brian Mohondro
Dale Moore
Wynema Moore
Lita Morales
Ross Morgan
Taylor Morgan
Tom Morrison
Terrence Mudrock
John Muhawi
Muhibuh Nicha bt Abdul Subhan
Lewis Mullen III
Asuncion Mulles
Anna Munoz
Jeanne Murphy
Na Chiew Chua
Joyce Naggar
Dianne Nation
Vinaya Natu
Potenciano Nava
Felicidad Navarro
Rafi Nave
Jacquelyn Navone
Wayne Needham
Linda Nelson
Neoh Siew Eng
Mary Nesbit
Marie Nesbitt
Robert Nesbitt
David Neubauer
Robert Nichols
Michael Ng
Ng Poy Lai
Ng See Keong, John
Ng Siew Hong
Ng Tong Hoon, Dicky
Thomas Nolan
Noor Azmi Bin Mohd. Noor
Nooriyah Yusoff
Noorjahan bt Abdul Haid
Noraini bt Hassan
Normah bt Jan Mat
Normah bt Mohd. Noor
Normah Hashim
Normah Mohd.
Norman Sheikh Mohd.
Norsiah bt Mohd.
Betty Northup
James Nutter
Jacquiline Nyburg
Rosario Obar
Connie Ocana
Teresa Oceguera
Maria Ochoa
Karen O'Connell
Carlota Ogana
Oh Swee Kin
Leticia Ojeda
Janet Oliveira
Noemia Oliveira
Angelo Onalfo
Ong Ah Hock
Ong Beng Hock
Juliet Ong
Ong Cheng Huah
Ong Phaik Suan
Ong Seok Gnoh
Ooi Ah Choo
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Intel Corporation
3065 Bowers Avenue
Santa Clara, CA 95051

Printed in USA/1284/60K/D265/CG/GK

Order number: 231295