Entrepreneurship In Advanced Technology

by William J. Perry

We live in an age that I believe historians will call the Age of the Computer. The most profound technological revolution mankind has ever experienced is occurring right now, but because we are immersed in this age we take it for granted. The computer has transformed the way we work; it has transformed our companies, our industries, our economy, and our defense posture. Indeed, it is in the process of transforming society more dramatically and more rapidly that the Industrial Revolution did in the 19th century. This technological revolution is causing the same sort of turmoil and confusion in our ability to project the future as was the case with social and political revolutions of an earlier day.

Charles Babbage invented the "analytical engine" in England more than 150 years ago, but the computer was never realized in Babbage's lifetime. The enabling technologies had to be invented before the real power of the computer could be unleashed — first, the invention of electricity, then the invention of the transistor, and finally the invention of the integrated circuit 130 years later.

If the computer is the engine that drives this new technological revolution, the integrated circuits provide the fuel for that engine. That fuel has led to price/performance improvements in the computer of more than 20 percent per year for the last few decades. Such rapid and steady improvement is unprecedented and has led to the development not only of new products and new companies but of entire new industries. In fact, this technological revolution has provided the underpinnings for an economic revolution. In the 1960s and 1970s, at least, the United States not only provided leadership of this economic revolution but was also the primary beneficiary. If you look at the economic consequences, you might say that in the 19th century the new wealth in the United States came from the gold in our mountains; for the last few decades our wealth has come from the silicon in our valleys.

We would like, of course, to extrapolate this exciting past into the future, but some prophets have said that's not going to happen. Some postulate that the rapid pace of technological innovation, which has driven these economic changes forward, has flattened out and that the innovative phase of this revolution is over. Others believe that the technological revolution will continue, but the leadership of it will pass to other countries — to Japan or even to the Soviet Union — and that the U.S. will end up as a second-class technological power.

Will this technological and economic revolution continue? I believe that, not only will this revolution continue, it will accelerate. To characterize this by a number, I would say that in the next decade we can expect an improvement of about a hundred times in price-performance of computers. In the transportation field a hundred-fold improvement in performance (speed) represented a change from the horse and buggy to jet aircraft. In the same field, a hundred-fold improvement in price would require reducing the price of a $10,000 automobile to $100.

I think that the increase in density in integrated circuits, which has characterized this price/performance improvement in the last few decades, will continue for at least another 10 years. That is, we'll be going from geometries in integrated circuits of a few microns to a few tenths of a micron; this tenfold compression in linear dimension will result in about a hundred-fold increase in density. To the extent that the history of this industry is a valid predictor of the future, this increase in density will allow for approximately a hundred-fold decrease in price per bit or per transistor.

This will require a whole new set of enabling technologies, not the least of which will be a whole new class of lithographic and etching equipment. Those technologies are well

in hand, and it will be a matter of a relatively few years before they are commercially introduced. This continuing compression of the density of integrated circuits, however, will lead to what has been commonly called "Moore's dilemma." Moore's dilemma states that the more transistors you put on a chip, the harder it becomes to design it.

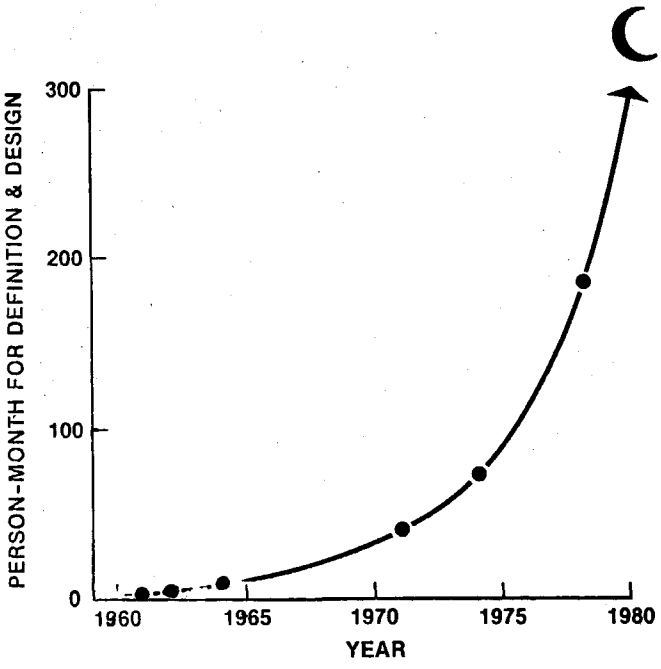
The solution to Moore's dilemma is the development of very sophisticated design tools that can be used not only by professional integrated circuit designers but by systems engineers as well. This technology was pioneered at Caltech by Carver Mead, the Gordon and Betty Moore Professor of Computer Science. But it leads us to a new dilemma: As the number and specialization of computers proliferates, the next choke point comes in software.

The solution to that problem — the development of design tools for writing software — is also under way but is not as far advanced as design tools for integrated circuits. A whole new industry is forming for companies that are building software design tools. In certain classes of problems three- to five-fold improvement in productivity has already been demonstrated, and I think that by the end of this decade we will see software design tools that will allow an order of magnitude improvement in productivity in writing code.

New architectures are also being designed for computers. After several decades of computers based on von Neumann architecture, we are now seeing a veritable explosion in concurrent computers, or parallel processors, an area in which Caltech has been a pioneer.

The economic revolution — the application of these new advantages to the development of products — follows the technological revolution. The products include not only new computers themselves but also a wide range of other goods that can be made more efficient and effective by embedding computers in them. We will be riding this price/-performance curve in two directions. Many applications will ride the price curve *downward.* Falling costs will lead to a proliferation of small, embedded computers in the home, the office, the factory, and the automobile.

Some pundits have criticized earlier forecasts of the increase of computers in the home and office as overblown. They have already been proven wrong. In my own house recently I went around room by room and counted computers. I have 17 computers, and that number will probably double in a few years. General Motors has contributed five computers to my garage — two in one car and three in the other. I never thought I was buying a computer when I bought those cars, but there they are. General Electric has contributed three computers to my kitchen. There again I didn't know I was buying them. My sprinkler system has two computers, and my hi-fi system (TVs, VCRs, and compact disk) has five. In my office I have two "real" computers, one sitting on a desk and another that I carry around with me in my suitcase.



Gordon Moore expressed the dilemma posed by the increasing complexity of integrated circuits: as it became possible to put more transistors on a chip, the design time increased at an exponential rate.

The other half of this revolution consists of products that ride *up* the performance curve. Among the applications that will be possible with 100-times improvement in performance are image processing, expert systems, and — perhaps most dramatic — simulation. We are already at the state in the design of integrated circuits, for example, where simulation plays a crucial role in the design process. No one would think today of designing a very large scale integrated circuit without the benefit of a computer to do the simulation. That same process is going to be applied to the design of missiles, automobiles, tanks, and airplanes. Where are we going to find the leadership for all of this technological innovation?

To answer that question I want to go back in history and ask where we found the leadership for the last phase of this revolution — where the leadership for the development of integrated circuits came from and why. My authority on the subject is a British engineer, G. W. Dummer. Dummer is the man who

almost invented the integrated circuit. At a technical conference in 1952, several years before the invention of the integrated circuit, Dummer said: "With the advent of the transistor and the work in semiconductors generally, it seems now possible to envisage electronic equipment in a solid block with no layers of insulating, conducting, rectifying, and amplifying materials, the electrical functions being connected directly by cutting out areas of the various layers." You don't have to be an IC designer to understand that Dummer was describing the integrated circuit. He not only described it, but he set out vigorously to try to develop it. He did this with the full support and cooperation of the British government.

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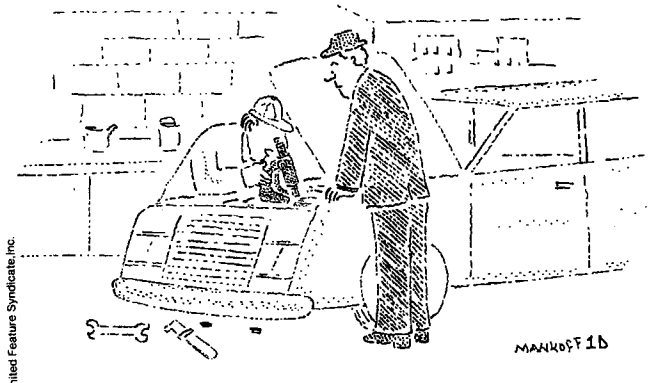

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"Yep, she's gonna cost ya—your microprocessor's shot."

But it was not Dummer who invented the integrated circuit, nor was England its primary beneficiary. The IC was invented by Jack Kilby of Texas Instruments and Bob Noyce of Fairchild, and the consequence of that development occurring in the United States has been profound.

Dummer, years later, looking back wistfully at this missed opportunity, said: "It is worth remembering that American electronic companies were formed since the war by a relatively few enterprising electronics engineers, setting up with either their own capital or risk capital from the bank. Often a government contract would start them off. Hard work was necessary and the large home market was a great asset, but the climate of innovation was such that any advanced technical product could be sold. The American system of encouraging employees to hold shares in the company is one which should be emulated, as a part share in the company's prosperity gives an increased sense of responsibility. Successful businesses are almost always dependent on a few people who are innovative and enthusiastic."

Dummer is pointing out the critical importance of the entrepreneurial spirit and the availability of risk capital in the U.S. As a case in point: If a chief engineer in a major company in Europe or Japan left his job to start up a new company to follow up an innovative idea, his friends and co-workers would think that there was something wrong with him. In the U.S. if a chief engineer did *not* leave his job to follow up an innovative idea, his friends and co-workers would think something was wrong with him. A difference in culture leads people to take action in one country that they would not take in another. These cultural traits do not change quickly. As far as I can tell from sitting near the fringes of the venture capital industry, that innovative spirit is as vigorous today as it was five years ago. I think that there are even *more* bright, enthusiastic people bringing forward interesting ideas than was true five or ten years ago.

As for the availability of risk capital, anyone who tries to form a company soon finds out that banks and public stock are not useful or available sources for such capital. Neither of these institutions is created for the purpose of providing risk capital for inventors. There are, however, other sources. A funding technique that was popular five years ago, and I think is still an appropriate form, is the R&D limited partnership. But it's currently out of favor and may not return to popularity for a number of years, because a few very large companies (Trilogy and STC Computer in particular) bombed out and took with them about $50-100 million of R&D partnership investment. Not surprisingly, that had a chilling effect on investors, and it's not likely that we'll see many more R&D partnerships start technology companies.

"Bootstrapping" — that is, doing it with your own funds — is a time-honored way of financing new companies in this country. I would like to suggest that it is a greatly underrated technique. It's the way that I used in 1964 for my own company, ESL. It never had outside investment, never had venture capital, and is now a company with over $200 million annual revenue. It was also the technique used by two engineers named Bill Hewlett and Dave Packard when they started

their company, which is now a multibillion-dollar enterprise. So it can be done, and it has been done successfully. The company founder has to accept a much slower growth than he could achieve if someone else were pouring money into the enterprise, but that's not all bad. It forces the entrepreneur to avoid the pitfalls that he would inevitably face with rapid growth of a new company.

The most popular form of risk capital in companies today is venture capital. This has undergone a remarkable transformation in the last seven to eight years. During the 1970s there was about $100-200 million a year of venture capital flowing into the venture pool, most of what was available for new company starts. This underwent a dramatic change in 1979. From then on there has been $2-4 billion a year of new money coming into the field — in other words, an order of magnitude increase in the investment in this area.

It would require a separate article to explain what really precipitated that rapid change, but certainly the change in the capital gains tax— an effective rate of 20 percent, down from 50 percent — was a primary contributor to that growth. More important, and less easy to analyze, is the fact that those venture funds that were established in the 1970s and were investing in companies during this period turned out to be fantastically successful. Many of them were showing 40 percent per year compounded growth rate return on those investments, and that attracted the attention of institutional investors. So it was a combination of several factors (primarily these two) that pulled out the throttle and caused this surge of new money to come into the venture capital business.

Another related and very important factor that is often neglected in discussions of this situation is the existence of the public over-the-counter market. Although I have already said that the public market was not a useful vehicle for a start-up company, its existence is critical, because it provides the mechanism by which venture investors and entrepreneurs eventually realize liquidity in their investments. The vigorous over-the-counter market that exists in this country has often provided the liquidity for these investors in five to seven years at 10 times their original investment, thereby making these investments very attractive. In Germany and Japan, for example, no such healthy over-the-counter market has existed, which is one reason that risk capital did not flow into start-up companies in those countries. Both of those countries are trying to change that now.

In the last year or so there has been much gloomy talk about how venture funds have fallen off and how people with bright ideas can't get venture money to start new companies anymore. This talk represents a gross misunderstanding of what the real situation is. First, today there is well over $10 billion in venture funds available for investment. That is plenty of money to invest relative to any standard, and particularly relative to the standards of the 1970s. Two factors have caused this atmosphere of reluctance on the part of venture capitalists to invest. First, the over-the-counter market was depressed for high technology stocks, and therefore the initial public offerings almost completely dried up for a year and a half. With the absence of initial public offerings, venture companies didn't have any way to graduate from a private to a public company, so their investors didn't have any way to achieve liquidity. When their companies needed a second or third round of financing, and there was no public market out there to provide it, they had to turn back to the original investors for it. So what has happened is that while the amount of money flowing into venture companies is actually greater in the last few years than previously, most of it is going into second- and third-round financing rather than into start-ups. So it indeed has been true that there has been less money for start-ups but not because of diminishing money in the venture capital pool.

The situation obviously will change rapidly as soon as the initial public offerings start up again. And there's every indication that this new wave of public offerings is already under way. To the extent that happens, there will be a dramatic transformation again in the use of funds that are now in this venture capital pool, and a much higher proportion of them will be eager to fund start-up companies.

There's another, relatively new, source of risk capital funds for start-up companies — funds from large corporations. So far I've been talking about innovation through start-up or emerging companies. But the amount of money that IBM invests in its R&D program in a given year is about the same order of magnitude as all of the venture money going into start-up companies in a year. So why don't these innovative developments all

come out of a company like IBM? Why do we depend on start-ups at all for this innovation?

The large companies are effective in using their R&D funds to develop products that evolve from predecessor products, but they are not very effective in using their funds to take an innovative technology that leads to a new product — something that really breaks ground with predecessors. The size and the bureaucratic nature of a large company is simply incompatible with seizing a new idea and taking it rapidly to the marketplace. There is also another much more subtle problem — what I call the "liability of leadership."

I know this from personal experience. At the time that the transistor was being commercialized, I worked for Sylvania Electric Products, one of the three world leaders in the production of vacuum tubes. The research director clearly saw that the transistor was the successor product to the vacuum tube, so he launched an energetic R&D program. Then the president assigned responsibility for the commercialization of the transistor to the manager of the vacuum tube division. The rest is history.

The psychological problems, not to mention the very real financial problems, of a manager vigorously introducing a new product that kills off the product that is his bread and butter are not to be underestimated. A similar situation happened when IBM stood by and watched Digital Equipment invent the minicomputer and capture that market. This was not because IBM didn't know how to build a minicomputer. But had they successfully produced a minicomputer, it would have cut the legs off the low end of their mainframe (a very profitable part of their line), and they just couldn't quite bring themselves to do that. Somewhat later Digital Equipment did the same thing with the personal computer market. Ironically, by that time IBM saw the opportunity developing for the personal computer, and, since it didn't compete with their mainframes, was able to go in and make a major impact on that market.

More and more of the large companies facing this problem are asking themselves the question: What can we do to participate in these venture or start-up activities? They are concluding that if they can't beat them they'll join them. There have been a number of attempts to participate by acquiring small companies. I believe that when the statistics on this are available they will demonstrate a high ratio of failure. The problem with the acquisition of small companies is that the large company snuffs out the very flame it is trying to capture. Realizing this, some companies have switched over to the venture capital business. Exxon and General Electric are cases in point. My opinion is that these ventures will turn out to be unsuccessful as well. The companies may be successful as venture capitalists, depending on whom they have running the activity, but what they're really trying to achieve — a transfer of technology and a head start on new products — will not come this easily.

In the past few years a number of companies have tried an innovative approach known as corporate partnering, or strategic partnering, as an alternative to acquisition or venturing. In this arrangement the large company forms a business relationship with the small company that usually involves some technology transfer, and it also makes a minority investment in the company. A number of companies have been experimenting in one way or another with the technique in the last few years — IBM, General Motors, Eastman Kodak, Lockheed, Rockwell, TRW. In each case what they are trying to do is to get access to innovative applications of technology and rapid seizure of new product opportunities. The benefits to the small company are an access to risk capital, to a broad base of technology, and to markets and credibility. Basically this marriage combines the mass of a large company with the velocity of the small company to provide momentum for both companies to move forward.

In summary, I believe that the technological revolution that has taken place these last few decades not only will continue through this decade but will in all probability accelerate in both its technical and economic manifestations. Second, the culture — the entrepreneurial spirit — that underlies this revolution in the United States is alive and well and will continue to support leadership in technological innovation in this country. Third, the large pool of risk capital that has been formed during the last seven to eight years will maintain itself and will be available in ever increasing quantities to fund these start-ups; the risk capital will come both from the conventional venture funds and from a transfer of funds from large corporations to small corporations. □