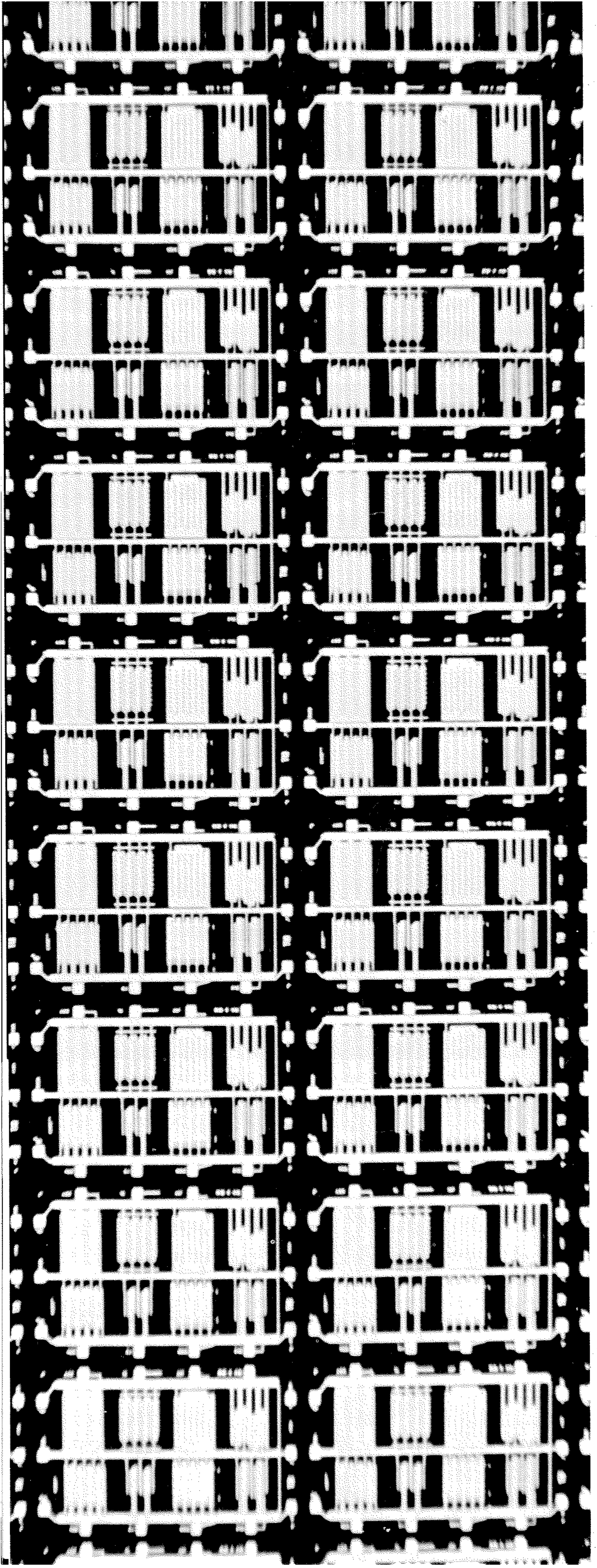


Computers That Put the Power Where It Belongs

In the next ten years almost every facet of our society will be automated to some degree. Whether this will be a change for the good or for the bad will depend on how it is done.

It will be good if it can be done in a humanizing way. If we can get machines to do things that people don't like to do, and if people can feed information into the machines in their own very human ways, this automation will be a constructive and humanizing process. The machines will do the grub work and liberate people to do more creative things.

It will be destructive if people have to learn the language of the machines and deal with them on *their* terms to exist at all—if the human beings have to learn to think like machines or else be discarded by society. The pressures in this direction are already apparent in those levels of society where the computer is heavily used —in business, in science, in engineering, and in manufacturing. Huge general-purpose computers are bent to specific tasks by elaborate programming and software systems (software being the term that describes all the written programs for computer use). But the human being must do most of the bending. He must learn the language of the computer. He must alter his logic to fit the logic of the computer. Even now he can't do certain things because they don't fit the "system." And it is going to get harder to do simpler and simpler jobs as these computers are applied to ordinary, everyday tasks.

This development is well on its way. But it needn't take over society wholly. There is another force in juxtaposition to it that may act to humanize this whole process: the development of powerful, special-purpose electronic machines that will make people more efficient in their everyday jobs, that will put more power at their fingertips.

This is an intermediate step in the miniaturizing of an integrated circuit. The designs in each of the squares represent specific electronic functions that are first plotted on large sheets of film and then reduced photographically to about a tenth of an inch. Designs are etched on silicon wafers by ultraviolet light through this plastic mask. The wafers are then superimposed one on another to produce a complete transistor "chip."

by Carver Mead

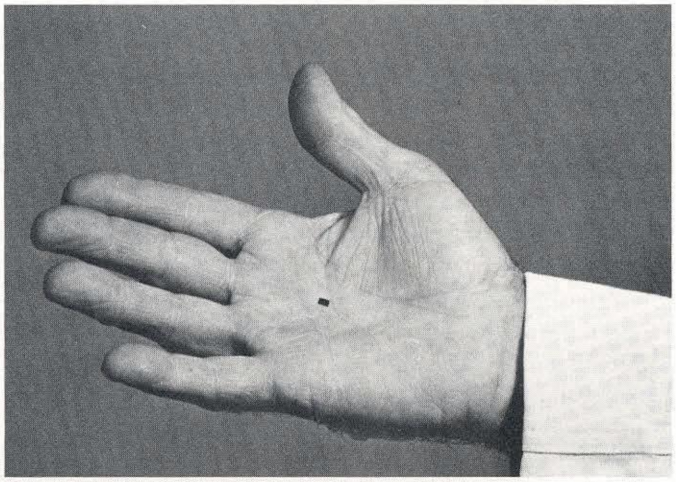
A person doesn't feel dehumanized by such a machine—one that frees him from routine tasks and is under his control. Quite the opposite. This is why people like to drive automobiles, and why they don't feel dehumanized by them. An automobile is a machine that can give you a lot of power, yet it leaves you as much in control as if you were walking. There is no reason why automation of information cannot proceed in the same way.

The next ten years will see a clash between these two forces—two philosophies, really—and society's fate will hang in the balance. The catalyst is the microelectronics technology and its ability to put more and more components into less and less space.

In the past 200 years we have improved our ability to manufacture goods and move people by a factor of 100. But in the last 20 years there has been an increase of 1,000,000 to 10,000,000 in the rate at which we process and retrieve information.

This change was brought about by development of integrated circuit technology, a development that has made individual transistors obsolete—just as transistors made electronic tubes obsolete. The number of transistors that can be placed on a silicon chip has doubled every year since 1960 until it is now possible—using advanced techniques in photolithography—to put 10,000 transistors on a chip that would have held only 1 ten years ago.

There are basically two types of microcircuits: One uses metal oxide semiconductor (MOS) transistors, and the other bipolar (NPN) transistors. (The NPN transistors were developed by William Shockley, '38, and won him the Nobel Prize in 1956.) Both of these transistors are produced in patterns on a silicon chip by a photographic process that reduces the size of each transistor to one ten-thousandth of an inch.



A transistorized "chip" of silicon that would be lost in the palm of your hand can hold as many as 10,000 of a computer's memory circuits. Soon a million circuits may fit on this size chip.

In the near future, using an electron beam for generating the very small patterns required, it will probably be possible to put a million transistors on the same chip that now holds 10,000. This would mean that an entire computer, consisting of a single chip, could be built for about $25. And with this decrease in size comes an increased ability to build more talent into smaller machines.

Up to the present time, what electronic processing machines have been best at is arithmetic. But in the future they will be doing things that aren't arithmetical. They'll be handling all kinds of information, and they will be especially useful in searching out and sorting data. The great strength of the integrated circuit isn't that we can make larger memories, which is what the computer industry has pretty well confined itself to so far. The real advantage is that we can have a tiny computer deep down inside our telephone, or our washing machine, or our car.

This technological revolution has been held up so far by the limited view of what can be done with microelectronics by the computer industry. The fundamental architecture of computers has not changed since 1946, when John von Neumann reinvented the stored-program

We are so attached to the idea of the big number-crunching machine for storing information that we don't yet see the real power of the new microelectronics technology.

computer as conceived by Charles Babbage and others 100 years before, and put the necessary new technology of electronics into it. If you read Von Neumann's instruction set for his machine, you will find that it is basically the same set we have in many machines we use today.

The use being made of microcircuits today can be compared to that of the early days of the electric motor, which was invented at a time when most industries had a big steam engine out in back driving a big shaft the length of the factory. Belts running down from the shaft powered individual machines. The industry had already invested in the pulleys, shafts, belts, and machines; so, from an economic point of view, they could not change the way things were done. Even though it was perfectly clear that the way this innovation should have been used was to put electric motors on each machine, it couldn't be done rapidly. The most that could be done economically was to replace the big steam engine with a big electric motor.

This is the dilemma the computer industry is in now. It has an enormous investment in big machines and big software programs, and the only thing the industry can do right now is to use the new microelectronics as it fits into the existing system.

We are so attached to the idea of the big number-crunching machine for storing information that we don't yet see the real power of the new technology—ability improved by a factor of 10,000 to do the logic where we need the logic done. We have computer power coming out of our ears. What we need is the kind of systems we would like to have in our automobiles, in our telephones, in our typewriters—where people now spend vast amounts of time on the repetitive and mundane operations involved in keeping track of a lot of little things.

The average man keeping track of his bank account (or even the typical engineer or scientist working on typical problems) very seldom faces huge computational problems; he usually deals with many small calculations. A large general-purpose computer, with the appropriate software, and serving a multitude of users on a time-shared basis, is the present approach to solving his need. Helpful as this may be, a small, extremely powerful calculator is much handier. I am convinced that time-sharing, as such, will gradually disappear as small electronic machines of more and more power become available at lower and lower prices.

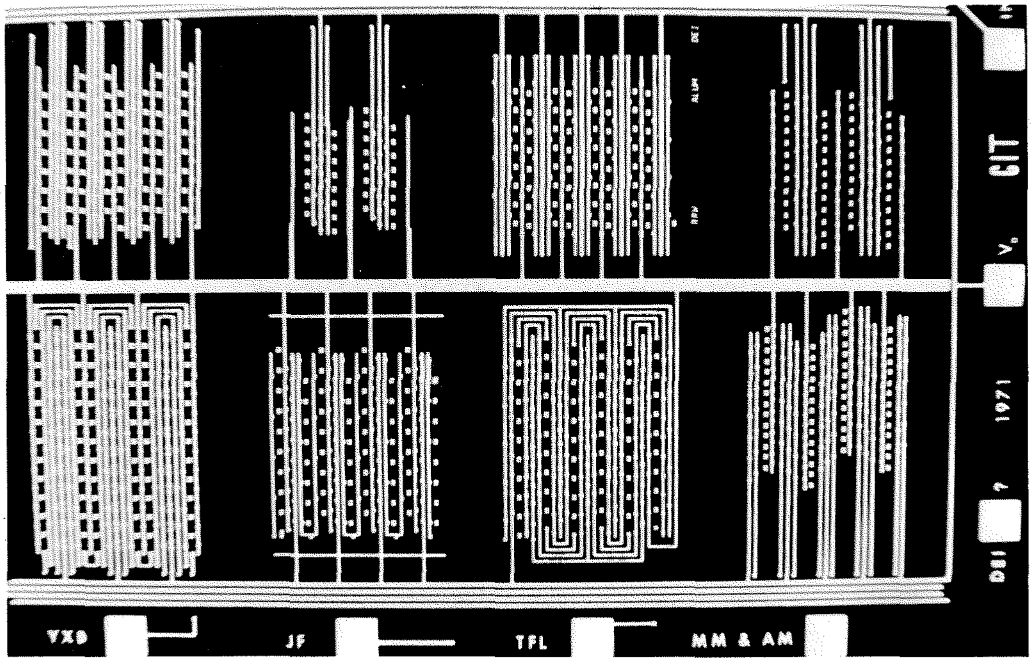
Carver Mead works out integrated circuit design with students in his microelectronics class. His students emerge from the class with the ability to design small, powerful user-oriented computers and automated machinery.

Another area of potential development is the special-purpose machine—the self-contained, stand-alone machine having nothing to do with computing—a nurse-medicine machine, a chromosome-microscope machine, an oven-cooking machine. There are hundreds of examples.

Let's look at a few in detail.

In recent years a number of hospital activities have been computerized. One particular set of functions that resist computerization are the duties of the medicine nurse, whose activities during a shift are an object lesson in how to get old fast. She doesn't have time enough on her shift to do a proper job, yet all she has to do is make one mistake and a patient is dead. All her effort is aimed at one simple problem—to translate the doctor's written orders for particular dosages for particular patients into the correct medication in the correct dispenser. And she must do this for 50 to 100 people three to four times a day.

But basically this is a simple problem with a simple answer: Design a system where all she has to do is go to



These designs were conceived by Caltech students as part of the class in microelectronics. After being reduced to a tenth of an inch, each circuit is etched on a silicon wafer. The end product must be an integrated circuit in which transistors, diodes, resistors, capacitors, and interconnectors operate as a single unit.

the medicine room, punch a patient's name into a machine, and wait briefly for the right medicine to pop out.

If this is done with a large general-purpose computer, it requires a broad data-base and extensive software programming. But the performance of such a system can be variable. The probabilities of error are rather high. If something isn't typed in just the right way, if the program isn't just so, the computer will give the nurse three pills instead of one, and the patient may die. Such variable performance is too costly in this situation; the system has to be as close to zero error as possible. A small, powerful, special-purpose computer designed to meet the specific needs of the nurse and her job eliminates most of these error-causing variables. Each hospital floor could have separate local "medicine machines" with the reliability such an operation needs. The more hardware you have—and the less software—the closer you are going to come to that zero error.

If you give the nurse such a system, she doesn't have to be solely a medicine nurse any more. She can do what she was trained to do—care for people. She can pay attention to how they are feeling. The system relieves her of inhuman kinds of activity, of doing the things that machines can do better.

Another example of work now done by big machines that could be done more efficiently by small machines is the chromosomal analysis project at Caltech's Jet Propulsion Laboratory (*E&S*, February 1971). Chromosomes are microscopic threadlike bodies present in every plant and animal cell. They carry genes that determine hereditary characteristics. They occur in pairs running from one to over 100 pairs per cell nucleus, depending on the species. Man, for example, has 24.

At JPL a large general-purpose computer with proper programming and software has been able to scan photomicrographs of chromosomes as they occur in a cell. These are then digitally reconstructed by a computer that determines the pairs by detecting the similar shapes. Using this information, a composite photograph of the chromosomes in pairs can then be prepared for study by geneticists. The present disadvantage of such a system is that only the largest hospitals and institutions can afford it.

A small special-purpose processor built right into the microscope would make such analysis available to any hospital or clinical laboratory. Anyone who does chromosome analysis could have his own. All he would have to do is to stick his sample under the microscope, position it, and push a button. In a minute or so, out would come a photograph. Such an apparatus is not only possible with the use of microelectronics, it wouldn't even be hard to make.

We could go a step further and design a multipurpose microscope adaptable to a number of special-function modules. To do chromosomal analysis would only require plugging in the module marked "chromosomes." Someone else who is doing blood cell counts would have his own module to plug into the same microscope.

With the use of microcircuitry we are putting power where it belongs, in the hands of each individual user. It has nothing to do with computing. All the researcher or technician knows is that he has a microscope that will present a photograph of what he wants, the way he wants it, by his simply pushing a button. He doesn't even have to know data processing is involved. He doesn't need to know there is any electronics in it. All he knows is that he has the world's greatest microscope. We have a user-oriented machine, not a machine-oriented user.

The computer business as structured today is a fantastic anomaly—as a business. We don't normally find businesses that are based on the nature of their technology. Businesses are characterized by the nature of their product. The automobile industry is not called the gear and wheel and pulley industry. It is called the automobile industry. The telephone industry is providing a service that can take information from here and put it there. It doesn't have anything to do with whether there are relays or transistors in the central switching system.

The computer industry, in contrast, is the only one I know that is still characterized by the nature of its technology—digital machinery. It is becoming a very mature industry, and it is inconceivable to me that at this late date it should still be characterized by its technology rather than its market.

The reason for this peculiarity lies in how computers came about. They started with vacuum tubes and were extremely unreliable. They required a covey of technicians fluttering around them to mother them through every problem. They were hard to use because they were implemented with what we now call "machine language." We then had to have people who lived, slept, and breathed this language, turning it into something that was useful.

This concentration of functions requires a big installation. And once the technicians are gathered, it is prohibitively expensive for them not to be at work solving problems. Thus, the big computing center evolved.

Now—after we have developed a relatively reliable machine and a rudimentary language—there are two alternatives. We can build another machine with a language that is more suitable for problems other than computations, or we can write some software that makes the machine with its computational language easier to use for other problems.

It is here that we run into the "frozen-in" phenomenon. It would make more sense to take the first alternative, but the industry is frozen into the second because of the vast

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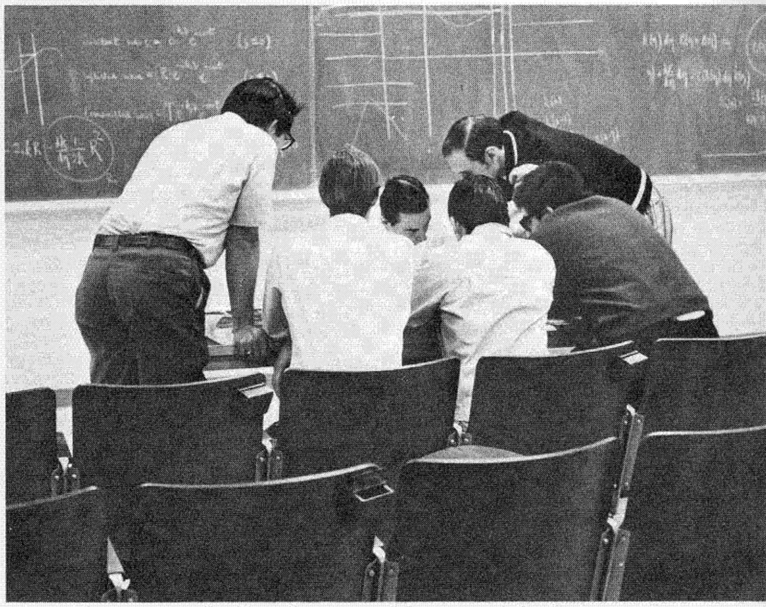
Carver Mead teaches the "little guys" who will build tomorrow's user-oriented machines.

In the view of 37-year-old Carver Mead, professor of electrical engineering, the humanization of computers will come about only through the intercession of the "little guys"—the scientists and engineers who have an intimate and working knowledge of both computers and microelectronics, but who are not a part of either technology.

It will be these men, he believes, who will build the special-function, user-oriented machines that will provide a counterbalance to a computer technology that now demands machine-oriented users.

Mead has already put this philosophy to work in a unique class—EE 281, *Semiconductor Devices*—where about 20 students from a variety of scientific and engineering disciplines receive an intensive introduction to microelectronics and its present and potential applications. Some design rules are developed in the class, and each of the students—few of whom have seen an integrated circuit before—is asked to build one on his own.

A grant from General Electric bought the computer software for Mead's class, and several local firms donate



Microelectronics technology has an exciting potential—the humanization of our automated society. And Carver Mead's class (EE 281) is the place to learn about it.

What these new developments in microelectronics will do is to make machines understand human beings rather than the other way around.

investment in the software that has already been developed.

Machines have become bigger and faster, and computer languages are sophisticated to the point where some truly amazing feats are being performed. But what has not become apparent—and the reason microelectronics technology has not yet had much of an impact—is how terribly inefficient the software approach is to many problems.

How much less costly it is to have a compact, special-purpose machine to deal with a special-purpose problem instead of having a great general-purpose machine programmed with a huge software package to try to turn it into a simple special-purpose machine. For many functions it is possible right now to design, build, and debug a special-purpose machine faster and cheaper than it would be to write the software for a big machine to do the same function. But, as it is, we are dealing with the general-purpose machines on *their* terms. What these new developments in microelectronics will do is to make the machines understand human beings rather than the other way around. People should be able to talk to these machines in English and not have to learn funny little codes.

The change probably won't come from the big companies. It will come from the little guys who are willing to change things. The next five to ten years will be crucial. That is the period in which we will decide whether the large general-purpose or the small special-function machine becomes dominant.

Large computers, elaborate software systems, and computer centers will continue. But they will do what they can do best: solve the large problems, the large accounting and filing tasks, and the scientific calculations. Probably for a while there will be a market where the choice can be made either way. Some will go for large computers and others for small. It will be a bloody battlefield by the time they are through—and we find out what the economics really are.

The next ten years are going to be a turning point for the computer industry—and society as a whole. A great many contributions can be made using the rapidly evolving technology of microelectronics to do things other than just grind numbers finer and finer. We can use it for doing operations of tremendous importance to the everyday life of society—operations which have not yet received any attention at all.

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services. Burroughs Corporation makes time on its photoplotter available, and Intel Corporation processes the silicon wafers. With this aid, Mead and his students are able to go through the whole design and fabrication process in about one-fifth the time it would take in industry. By the end of the year-long course his students are able to create "chips" the size of pinheads with as many as 10,000 transistors and the ability to do a complex variety of functions.

Mead hopes to continue teaching EE 281 to train people who can develop their own ideas for special applications of digital electronics and make the microcircuits that will do the job. He wants to create an essentially new class of scientists and engineers: people who know the technology of computers and microelectronics but are not restricted by the shibboleths and taboos inherent in each. These students, he says, will go into a dozen different fields, taking their knowledge with them. And it will be these "little guys" who will build the powerful special-purpose electronic machines that will make people more efficient in their jobs and put more power at their fingertips—and yet leave them in control.

Mead has applied his philosophy with satisfying results. For example, as consultant to Lexitron Corporation of Los Angeles, he helped design and build a sophisticated electronic typewriter for use in high-volume business offices. There are, of course, a number of automated typewriters on the market now. In addition, several computer companies have attempted to design software programs to meet this specific need. But both approaches, Mead points out, require machine-oriented users. In the software approach the cost of redesigning the programs and the terminals for each specific application is about 80 percent of what it would be to simply design a new machine to do the job. Why spend so much on a system that requires people to learn its ways when spending only a little more would yield a special-purpose, user-oriented machine?

This is what has been done with the electronic typewriter he helped design. It has a TV-like screen for visual display and for all corrections. No paper is necessary until the final letter-perfect document is typed. The keyboard and printer operate independently of one another, allowing a typist to prepare new text while a completed document is being printed out. Corrections are made in an easy, natural way. Instead of having to retype the entire manuscript to add or delete a letter, a word, or a sentence, an integrated circuit memory rearranges the document before final typing.

Mead is a product of Caltech. He received his undergraduate and advanced degrees in electrical engineering here, and he has taught at the Institute since receiving his doctorate in 1959. He also acts as a consultant to a number of electronics and financial firms.