THE COMPUTER IN YOUR FUTURE

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November 1967

P-3626
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I. INTRODUCTION

Our subject for discussion is the digital computer, or as it is often called, the information processor. What I want to do is to point out the impact that this technology is likely to have on our lives in the near future; but unless I lay some careful background for my observations, I'm afraid that they will sound like so much science fiction.

Thus, before we can talk about the future, we'll need to talk a little about the present. I suspect that this part of our discussion will also be helpful to your understanding of the computer and its role in the scheme of things. We'll need to appreciate some of the things which are currently happening in the computer field, and to see some of the expected changes of the next several years. We need to see what has happened to computer hardware—the equipment—itself: how its size, speed, and cost have

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This Paper is an expanded and popularized version of the author's P-3279 (March 1966).
changed. We also must look at the computer from the user's point of view. How does he communicate with it as a tool to work for him? What changes are taking place in the relation between the computer and the man who uses it? Then we can look toward the future.

**COMPUTER HARDWARE**

First let's see what computer hardware has been doing and how it will change. Figure 1 shows one kind of computer of the early 1960s. We will concentrate on two of its parts. One is called the **arithmetic section** and is analogous to a desk calculator that you might use to add, subtract, multiply or divide. Electronically, the arithmetic unit is built of switching circuits, all electronic high speed versions of the familiar wall switch which control lights in a home. The other section is the so-called **store** or **memory**, and it is analogous to a scratch pad on which you write notes to yourself or jot down information.

**The Arithmetic Unit**

First, let's look at the electronic circuits from which the arithmetic unit is made. Figure 2 shows how they looked in the early 1950s: vacuum tubes, resistors, and capacitors, hand-soldered together. Figure 3 shows how one kind looks today. Inside such a package (Fig. 4) we find so-called printed and deposited circuits. The silver lines are "wires" placed there by a printing process; the large
black parts are resistors whose precise value has been adjusted by sandblasting away some of the material; the small black squares are transistors. They are one twenty-fifth of an inch square, hence they come sixteen hundred to the square inch. The tiny balls are the connections.

We are just entering the era of what is called an integrated circuit. In Fig. 5, the small square in the center is a complex circuit; the rest of the structure is mechanical protection and external connections. (The material at the bottom is a piece of sewing thread.) Figure 6 illustrates two examples of a more advanced integrated circuit technology. A slab of pure silicon is treated to form various kinds of circuit elements wholly within the piece of silicon. The entire process is done by masking the surface and depositing several different chemical materials through various masks. Thus, an entire array of basic circuit structures is constructed all at once. Each small rectangular area in the grid (Fig. 7) is about one-tenth of an inch long and one-sixteenth of an inch wide. Such a small area actually contains about thirty transistors plus other electronic components. By further chemical processing, the so-called fully integrated circuit is built, layer by layer, over the background of basic elements (Fig. 8). A customized fully integrated circuit (or microcircuit) such as this is roughly 1/2 by 5/8 in., and contains a total of 800 transistors and 350 other electronic components. The density of electronic
components in these integrated circuits is about three thousand per square inch.

The expectation is that by the late 1960s, integrated circuits with a density of about two-hundred thousand electronic components per square inch will be commonplace—an improvement by a factor of about seventy over the microcircuit shown in Fig. 8. Figure 9 shows an experimental structure with 250,000 components per square inch.

Figure 10 comparatively illustrates three generations of electronic circuits. In the background is a contemporary form of what's called plug-in packaging. Transistors (the little round "cans") are mounted on boards which have printed wiring, and each board plugs into a larger frame. The array of small white boxes mounted on a larger board are commercially available integrated circuit modules. Finally, the small round circle in the foreground is the microcircuit described above. Electronically, each of these three packaged circuits can do the same job; the tremendous decrease in size is a result of the technology presently becoming available.

The Store (Memory) Unit

Now let's look at the store or memory. Here the important electronic item is the so-called magnetic core, a small ring of magnetic material. Over the years, the size of the magnetic core has decreased markedly (Fig. 11). In the mid-1950s, the size was about that represented by T-17;
the most recent ones are the X-55, too small to see at the
left of and shown much magnified at the right of Fig. 11.
This tiny ring of magnetic material has an inside diameter
of seven one-thousandths of an inch and an outside diameter
of only twelve one-thousandths of an inch. To uniformly
cover an area just 1 by 1 in. would take about seven
thousand such cores. These cores are assembled on a grid
of wires to form what is called a magnetic core plane
(Fig. 12). A number of wires go through the hole in each
core (Fig. 13). The large core plane in the background
of Fig. 14 is from the mid-fifties; the small one in the
foreground is contemporary. Each represents the same
amount of storage capacity, about twelve hundred decimal
digits; but the small core is fifteen times faster.

Core stores come in the large economy size (Fig. 15);
this one handles about 4.5 million decimal digits. Mag-
etic storage comes in other forms. Figure 16 shows a
so-called magnetic disc store which can handle about
eighteen million decimal digits. It resembles a stack of
phonograph records which are coated on both sides with a
magnetic material. The larger one shown in Fig. 17 ac-
commodates sixty million decimal digits.

Current Trends in Computer Hardware Technology

Let us see what has happened to the overall computer.
RAND's JOHNNIAC (Fig. 18) is typical of 1953 technology.
(It was recently retired, and can now be seen at the Los
Angeles County Museum of Science and Technology.) Figure 19 shows a contemporary machine. It has about eight times the storage of the old JOHNNIAC, is faster by a factor of about thirty or forty, costs less than JOHNNIAC did, and is about the same size.

In Fig. 20, we see part of a machine built from the most advanced integrated microcircuit technology—the arithmetic part of the machine. Figure 21 shows the store or memory of the machine—tiny magnetic cores and microcircuits. In Fig. 22, we are looking at the overall machine—the box in the lower left corner. This microcircuit machine is a thousand times smaller than JOHNNIAC; it has a volume of about one-third cubic foot. At fifty pounds, it is a hundred times lighter. It requires 250 times less power—only 150 watts (or about the same as an ordinary light bulb). Furthermore, it has twice the storage of JOHNNIAC, and goes about ten times as fast.

In size, the computer hardware which we have been discussing has decreased ten-fold since 1955 (Fig. 23); by 1975 it will decrease another thousand-fold. In cost of computing power, there has been a three-hundred-fold decrease since 1955 (Fig. 24); by 1975, it is expected to decline further by a factor of about three hundred. In speed, computers have grown faster about two-hundred-fold since 1955 (Fig. 25); they will speed up about two-hundred times more by 1975—we'll be doing computer operations at the rate of a billion per second.
Finally, to show you the vigor of the growth in computers, let's look at the total installed computing power in the U.S. (Fig. 26). Since 1955, the computing power of the U.S. has increased about four-hundred-fold; if this rate keeps up, we'll get another factor of four hundred by 1975.

The implications are rather clear. Beginning in the early 1970s, computers will be small, powerful, plentiful, and inexpensive. We will be able to provide computing power for anyone who needs, wants, or can use it. Will it be difficult to use such machines? Or easy? To explore this, we need to discuss the so-called software side of computing. How does a computer look to its user? How does he work with it? How does he manipulate the computer as a tool?

**COMPUTER SOFTWARE**

If one has never used a computer, today's software achievements don't appear impressive. The question is asked: Haven't computers always been like that? The answer is No. But to see the change, we'll describe how problems are solved by a computer.

**Programming**

It all starts when a man has a problem that he thinks can be solved by a computer (Fig. 27). He probably thinks he understands his problem, and he thinks he knows what
"THE PROGRAMMING PROCESS"

Fig. 27

Fig. 28

Fig. 29

Fig. 30
answers he wants. Next he engages a programmer, the professionally trained user of a computer. Together they discuss the problem until the programmer understands (or thinks he does) the problem (Fig. 28). This stage of the dialogue takes place in natural English, orally or in writing, perhaps in a technical jargon. The programmer then puts on his other head, and considers the problem in the light of the computer's capability (Fig. 29). He describes for himself on a so-called flowchart how information is to be manipulated to get the answers. He may have to go back to the man-with-the-problem at this point for more information. Finally, the programmer thinks he has everything worked out, and he converts the information on the flowcharts onto coding sheets (Fig. 30). To do this, he must write on the coding sheets in a kind of language which the computer can understand—a programming language (discussed below). This is the first time, however, that the programmer has departed from natural language or thought processes. Then the information on the coding sheets is transcribed onto the special media which the machine will accept—perhaps the ubiquitous punched card or perhaps magnetic tape similar to that used in hi-fi tape recorders (Fig. 31).

Finally, we get to the computer (Fig. 32). First of all, the programmer must be sure that the instructions which he has given to the machine are correct and will work together to produce a result. In the so-called DEBUG
"THE PROGRAMMING PROCESS"

Fig. 31

Fig. 32

Fig. 33

Fig. 34
phase, which is really a search for errors and mistakes, the programmer may have to return to previous parts of the process. He may find he needs more information from the man-with-the-problem, he may find mistakes in flowcharting, etc. Finally he thinks he has found all the errors, and he now must make sure that the problem which the machine is solving is the one which his customer wanted solved (Fig. 33). Slips may have been made along the way; or, it is even possible that the wrong problem is being solved. Hence, so-called test cases are run to convince the customer that it is really his problem that the machine is working on. At last, finished results are obtained (Fig. 34). Note that the programming process is lengthy, involved, and to some extent tedious.

Programming Languages

Let us look briefly at programming languages. Here are two coding sheets using a programming language called FORTRAN (Fig. 35). You'll notice that this language is unfamiliar, that it is highly stylized; some of the symbols—letters and numbers—are familiar, but are combined in strange ways. A programming language is an artificial language that is structured in such a way that a user of a computer can communicate with the machine as a tool. Such coding sheets are transcribed onto punched cards (Fig. 36), and after the machine has ingested and printed out this information, it appears as in Fig. 37. Most of it still
looks strange, although there is an occasional English statement. However, such lines are marked by a C, which implies that they are so-called comments; the programmer himself (not the machine) originally provided these lines as notes to himself.

Figure 38 shows what conventional machine results look like. This happens to be a problem in blood chemistry, and so you see the names of various blood components at the left; the number at the right tells how much of each is present.

Analysis and Definition of the Problem

To return to the programming process (Fig. 39): Part of the overall problem-solving process involves analysis of the problem, and definition of its details. The other part involves getting the proper processes described to the machine so that it will perform properly. The amount of effort required for each part depends on the particular problem; but for difficult problems, it can easily be "fifty-fifty." The important point is that a substantial part of the overall process involves understanding the problem and feeling one's way toward the solution; for the early stages of problem solution, the computer is not much needed, if at all.
ON-LINE, TIMESHARED COMPUTING

Finally, notice that there are two interfaces in the programming process (Fig. 40): a man-man interface between customer and programmer; and a man-machine interface between the programmer and the computer. If a computer is to be more accessible to its users, we need to improve these two interfaces. One possibility is to teach the man-with-the-problem some programming language. This is commonly being done. Another answer—and it's the important one for us—is to formulate a language that is natural to the user, matches the jargon of his profession, and has the context of his training. Then make it convenient for him to have access to the computer. In effect, the overall programming process is thus collapsed, bringing the person-with-the problem directly to a computer with which he can communicate in a language for which he doesn't need special training. We arrange for him to "think out loud" to the computer, and avoid the flowchart-coding-sheet-punched-card route (illustrated in Figs. 27 through 34 above).

Such a concept is the so-called on-line timeshared computing system (Fig. 41). It is called on-line because each user is directly tied to a central computer; time-shared, because many users share the use of the machine. The telephone system is an on-line timeshared system. The phone in your home is directly connected at all times to the central telephone office. Subscribers as a group share the use of the equipment in the central office. Users of
"THE PROGRAMMING PROCESS"

Fig. 40

ON-LINE, TIME SHARED SYSTEMS

- REMOTE INDIVIDUAL ACCESS TO LARGE COMPUTERS
- USERS-ORIENTED SOFTWARE
- COMMUNICATIONS LINKS

Fig. 41
on-line computing systems can be widespread geographically--
around a building, throughout a city, across a state or
country. Each user gets service when he wants it, and he
pays only for services rendered.

The Personal Console

Typically, an on-line user has a personal console
(Fig. 42). The particular one shown in Fig. 43 consists
of an electric typewriter with some supporting electronics.
This mobile console can be wheeled from place to place and
plugged in for computing service. All of the dialogue
between the user and the machine takes place through the
typewriter--he types to the machine and it types back.
Everything that the user needs to solve his problem is
made available to him through the typewriter.

THE LANGUAGE

An on-line system can be designed for the professional
programmer, substituting for natural English at the type-
writer the highly structured format of a programming lan-
guage. But let's instead look at an on-line system de-
signed for the casual user, who needs computing power only
every now and again, and for whom it is not worthwhile to
learn a programming language.
Figure 44 shows a sample of output produced by an on-line system called JOSS*, which was designed for use by scientists and engineers in solving small mathematical problems. This output looks a lot like English, or, at least, like algebra. The user's input is typed by the machine in green; the output is typed in black. The first statement says that \( c \) is to be calculated as the square root of \( a^2 + b^2 \)—a formulation familiar to any scientist or engineer (a computation for the hypotenuse of a right triangle of whose sides are \( a \) and \( b \)). The next statement says that \( a, b, c \) are to be typed out according to some stated form, and the form is immediately defined, leaving blanks for the calculated results. Then the user again states in a normal mathematical manner what values \( a \) and \( b \) are to have, and assigns the machine a task: Do part 2 (Fig. 45—a continuation of the previous figure).

The Man-Machine Interface

Not all users are good typists, nor are they always careful. Mistakes can be made, and a good computing system must be friendly and forgiving, yet firm. Figure 46 shows part of another problem to illustrate how JOSS tolerates errors from a user. The user has said: Go ahead. JOSS objects: It hasn't been told to do anything. The user

*JOSS is the trademark and service mark of The RAND Corporation for its computer program and services using that program.
1.1 Set \( c = \sqrt{a^2 + b^2} \).
1.2 Type \( a, b, c \) in form 1.

Form 1:
\[
a = \quad \quad b = \quad \quad c = \quad \quad
\]

2.1 Do part 1 for \( b = 1(1) a \).
2.2 Line.

Do part 2 for \( a = 1(1) 4 \).

Form 1:
\[
a = \quad \quad b = \quad \quad c = \quad \quad
\]

2.1 Do part 1 for \( b = 1(1) a \).
2.2 Line.

Do part 2 for \( a = 1(1) 4 \).
\[
a = 1 \quad b = 1 \quad c = 1.4142136
\]
\[
a = 2 \quad b = 1 \quad c = 2.2360680
\]
\[
a = 2 \quad b = 2 \quad c = 2.8284271
\]
\[
a = 3 \quad b = 1 \quad c = 3.1622776
\]
\[
a = 3 \quad b = 2 \quad c = 3.6055513
\]
\[
a = 3 \quad b = 3 \quad c = 4.2426407
\]
\[
a = 4 \quad b = 1 \quad c = 4.1231056
\]
\[
a = 4 \quad b = 2 \quad c = 4.4721360
\]
\[
a = 4 \quad b = 3 \quad c = 5.0000000
\]
\[
a = 4 \quad b = 4 \quad c = 5.6568543
\]
corrects that oversight, but JOSS immediately flashes back that some quantity h has been left undefined. Another issue comes to light: JOSS has been instructed to type something in some form, but apparently the user forgot to provide it: It can't be found. The user starts to type, but is interrupted by "Eh?" He had committed a typing error by failing to leave a space after the "m." He finally gets the form defined and JOSS starts to work. It types one line of results and runs into more trouble. These reactions continue as more errors are found (Fig. 47), corresponding to the DEBUG part of the programming process described above (p. 9). Eventually, all is well, and JOSS produces answers.

Notice the friendly responses of JOSS--the natural language and expression, the immediate flagging of errors. The figures cannot show the passage of time, but in reality the conversation between man and machine goes along at the man's pace. The machine is available and works for him when he needs it; otherwise it seemingly waits for him, meanwhile taking care of other "plugged-in" users.

The JOSS system and its language is typical of the kind we are just learning how to design and build: carefully adapted to the needs of a particular set of users; tolerant of errors; actively helpful in the solution of problems. Devices other than typewriters can serve as personal consoles in such systems. For example, Fig. 48 shows a so-called graphical terminal. The user writes on the horizontal surface
and the machine immediately and continually reacts to the pen-like stylus position and movements. The machine responds by displaying either words and numbers on the TV-display, or by displaying charts, curves, etc. With this particular device, slides can be rear-projected onto the tablet surface so that maps and other pictorial information can be traced into a computer (Fig. 49).

In summary, computers will be small, powerful, plentiful, and inexpensive; computing power will be available wherever needed. We will be able to build computers into the base of a typewriter or into tools and appliances wherever needed. Moreover, computers will be easy to use, require a minimum of special training, and be tolerant of errors. Computers will be able to both accept and reply in natural language. Although I didn't build a case for it, it's undoubtedly also true that voice communication with a computer is not far off; i.e., we will speak to it and it will speak back.
II. THE COMPUTER OF THE FUTURE

Now let's look toward the future. I hope the brief background discussions above will help to make believable my following comments. It would not do if they read like science fiction. What I suggest may not sound very flashy, perhaps not even impressive; the spreading effects of computer technology are subtle, and not without reason often referred to as the Quiet Revolution. So don't look for wizardry and flamboyance, but notice instead the pervasiveness and depth of the effects and applications that I mention. A caveat: I suggest things which in my opinion are possible because of developing computer technology; I am not predicting that such things will happen. It may be that some changes should not occur; society may wish to prevent them, or at least take measures to control the rate at which they take place.

PERSONAL COMPUTING SERVICES

It is clear that computing power will be readily available as a service to the general public. One can imagine computer-utilities that would offer services to subscribers. Such subscribers might have personal consoles in their homes or offices, connected by phone lines to a central machine. Utility perhaps is not quite the right word, because there is no reason to believe that such services would necessarily be regulated monopolies.
In the home, a small computer may conceivably become another appliance. Dad may use it for balancing the check book, doing the income tax, calculating some problem that he just remembered from work, deciding which of several offers for a home loan is the best buy, etc. Mother may use it as the treasurer of a church group, or for checking bills, and (unless things change) for figuring out which size package at the grocery store is the best buy. The children undoubtedly will use it to do homework. (We'll come back to the computer's future role in education.) Since large storage devices will be available—remember the magnetic discs with several hundred million digits capacity (and even larger ones on the way)—the whole family may use their home computing power to keep personal information files: e.g., lists of phone numbers and addresses; the Christmas card list, with a record of who sent return cards for the last several years; a list of favorite restaurants and their phone numbers, perhaps indexed in a variety of ways. Important family records may also be stored in the machine—e.g., insurance policies, indexed according to payoff privileges, dividends payments, etc. Thus, Dad can keep his family protected just as he wants at all times. If one of the family is an investor, the performance of stocks and bonds may as well be filed—histories of their performance, rates of return, etc. Similarly, the business records of any income-producing property may be maintained.
PUBLIC COMPUTING SERVICES

If personal information files are a possibility, then so are public information files. A primitive one already exists: Every time you dial an area code, and then 555-1212 in search of information, you are really asking a question of a public information file. With long-distance dialing, one has access to all the phone books in the United States and Canada (and eventually throughout the world). Will you need airline information? Consult the appropriate file. Want to know something about hotels or restaurants in a city to which you will travel? Type your way into the appropriate files in that city. If you happen to be a business man, there is likely to be a credit-reference file—not really public, but available to a restricted clientele. One can easily imagine other files serving various needs and purposes.

Since enormous amounts of inexpensive and readily available information will likely be in transit at all times, there is going to be an unprecedented demand for communication services in all sorts of places. If one needs a computer in his car, why not? It could be put under the dashboard or in the glove compartment; it will be that small. Moreover, the computer in a car might be linked by mobile telephone service to other computers, or to other information networks. Finally, what could be more logical than to use computers to operate communication
networks? The Bell System and the military have already begun to move in that direction.

Society needs all kinds of files of information--some enormously large--to govern itself. Typical are files on real estate, credit, legal, and financial matters, business licenses, auto registrations, etc. Government and business will have to utilize computers to handle their information files, some of which will be accessible to the public; others only to authorized users.

The Protection of Privacy

It should be clear, however, that access to files containing information about large numbers of people must be controlled. Information will have to be protected against accidental dissemination due to equipment failure, and also against unauthorized access. With so much available information around, we may well encounter an invasion of privacy problem. Information networks will have to be designed so that one user cannot unintentionally interfere with another. Unless we build proper safeguards into our information networks, mechanized blackmail will become possible. Think what it would mean if all the past records and personal history of a political candidate were available to his opponent? Or what it would mean if the private records and affairs of a public official were available to unscrupulous parties?
There is another twist to the invasion-of-privacy problem. By continually monitoring information files, a government agency, if it chose to do so, could maintain extensive surveillance over its employees, or over some segment of the population. We had best face this potential problem as we move ahead.

THE COMPUTER IN CRIME

A data-bank--not a public one--will undoubtedly exist on criminal activity. Even today computers support the work of police departments. This role will become even more important as larger files of information can be stored, and as computers get better at making inferences from fragmentary information. But all of this can work both ways. If computers will be useful to society in combating crime, they will be equally useful to the criminal. Why shouldn't a crime syndicate exploit readily available computer power to manage its business affairs? Why shouldn't even the lone criminal use a computer to help plan his crime? I expect to see the headline almost any time: The Computer-Planned Crime.

THE COMPUTER IN BUSINESS

Because computing power will be so cheap, all business records will likely be kept by machine—either a small computer on the premises or a console linked to a centralized
service bureau. The privacy problem arises again; no business wants its records available to competitors. Think what it would mean if one department store knew in detail what items were selling well at another store, or what items had been ordered for future delivery. On the other hand, a geographically distributed business enterprise could exploit readily available information to conduct business affairs, and to make management decisions. Computers will certainly be used extensively by businesses for such purposes.

At the personnel level, the on-line concept would work well for business secretaries. For example, letters would not have to be retyped repeatedly until the boss gets the wording just right. A secretary's typewriter may be on-line to a computer, allowing her to type material without regard to paragraphing, line length, or format; and to make easy corrections by telling the machine which word to change or which sentence to replace. Finally, she could instruct the computer to type the letter in a given format to a number of specified addresses, and to route copies to specified parties within the company. Here, as in other aspects of business, the computer ought markedly to improve efficiency.

If on-line typewriters can thus serve business, they should also be good for similar activities at home. In fact, secretarial services might find it expedient to provide typing services using private homes as outlets. Part-time work would be easy to arrange; when a person is ready
to work, he notifies the computer, which then accepts--just as it did for the company secretary--the produced correspondence.

What about the effect of computers on employment? Computing technology is helping technology in general to change very swiftly; professional skills are rapidly becoming obsolete, and large blocks of job openings disappear from one industry and reappear in another. Frequent retraining and re-education will almost certainly become the normal way of life. Change, rather than status quo, is likely to become everyone's lot.

The introduction of computers into industry has and will continue to increase productivity, but there is bound to be dislocation of jobs. However, I take an optimistic view of the situation. There are a lot of wants in our own society, let alone that of the rest of the world. The productivity of this country is not now meeting the needs of society, so we have a large market yet to serve. My guess is that there will be lots of jobs to go around, but they aren't going to be in the right places. We will have to face and solve the retraining and re-education issue. The problem will not be limited to the labor force; every professional specialist or administrative official will probably need continuing education as well. My personal feeling is that if you're more than about five years from retirement, computing technology is going to influence
your career markedly before you retire. Most of us are likely to face a retreading job at least once before we stop working.

THE COMPUTER IN EDUCATION

Let us now consider the future role of the computer in education. I think that you can see in principle how a computer could be used as a teaching machine to present material and questions to a student, and to score his responses. It could drill him on his weaknesses, and skip ahead where he is strong. It is likely that the pace of education will increase. Students will require computational power all during their school careers. In fact, even the public school systems may have to face the question of providing their students with computer support. Possibly each student in the classroom will have his personal small machine--the size of a cereal box--and/or a console at home. (The University of California at Irvine is presently moving toward a computer-centered educational technique.) If the cost of providing each student with an appropriate console ever becomes less than the cost of educating him by traditional classroom methods, then it will become economical to conduct formal training in the home. Of course, there remains the question of the importance of personal interaction between student and instructor.
If children may someday stay at home for their schooling, then it also seems reasonable that Dad may conduct his business from home. Certainly a lot of engineering and scientific work could be done at home, given that sufficient computational support--including the capability for handling graphical and pictorial material--and communications were available. Such arrangements might have interesting consequences. For one, what new strains--or benefits--might develop in the family structure with everybody at home much of the time? For another, if large numbers of people remained at home to conduct business, or to be educated, perhaps we wouldn't need as much highway coverage. So far as I know, interesting interactions such as these are not yet being studied nor even formulated.

If the pace of education does increase as I have suggested it might, presumably students will complete their formal training sooner. It follows that there will be more productive years in a person's lifetime; moreover, there will be more young years of productivity--and youth is generally argued to be the period of creativity. Such effects will drive the progress of technology even faster, and so complicate even more the issues that I'm raising. The computer may be used to cope with the necessity for retraining and re-education brought on by job displacement.
THE COMPUTER IN COMMUNICATIONS

Computer technology is likely to change communications radically. Since digital hardware will be very cheap, we will be able to use it extensively wherever needed. Why not put some computer hardware in a TV set if need be? Why not deliver newspapers and mail by facsimile methods instead of shipping pieces of paper around? Privacy can be protected by the use of secrecy codes. Computer devices can be used to encrypt and decode communications. Even better, we can use computer techniques to deal with the error problem which now troubles communication services. Perhaps every place of business—and residence—will be served by a single broadband communication cable carrying all the information services—voice, video, facsimile, data transmissions, computational service, etc.

THE COMPUTER IN RESEARCH

The computer is a powerful research tool. In fact, I think it is the most powerful research tool ever made available to mankind. As such, it is forcing the rate at which new scientific information is becoming available. The computer allows the scientist to look at data in new ways, and to seek insights by observing his experiments from different points of view. Imagine the interesting consequences of computer-supported research that would lead us to an understanding of the weather and the means for controlling it. No longer would there be any bad real estate.
We could have good climate as we wished. No more crop failures; rain and sunshine on schedule. The deserts would become breadbaskets, and Las Vegas the agricultural capital of the country. Storms could be scheduled; and anyone could buy the annual schedule from the Government Printing Office.

**Simulation**

The technique known as modeling or simulation consists of formulating a set of mathematical expressions which describe the relationships within a given system. For example, we can model a physical situation, such as the flight of an airplane; or a business situation, such as a behavior of a purchasing agent responding to demands for his service; or a biological situation, such as the transportation of oxygen from the lungs to the cells. The mathematics of the model is then solved by the computer. The net effect of this is that an experiment on some part of the real world is performed within the computer. This leads me to suggest that many experiments will be more cheaply and accurately done on a computer than in a laboratory. The role of the laboratory may very well decline; perhaps a scientist with a computer will become a more fertile and productive source of new knowledge than a scientist in a laboratory.

Engineering and manufacturing processes are likely to be completely computer-based. By means of graphical
terminals, an engineer will converse directly with a machine. He will sketch only rough outlines of what he has in mind; the computer will complete the design and provide all details. Moreover, the performance of the design will be calculated before it is ever built—prototypes and preliminary models will go out of style. Once the design is completed and proved, the necessary manufacturing information will be machine generated and sent to automatic production equipment.

THE COMPUTER IN MEDICINE AND THE BIOLOGICAL SCIENCES

The medical and biological sciences will increasingly utilize computers. Hospitals will certainly become computer supported, both administratively and medically. Computers will be used to monitor surgical and intensive-care patients. Perhaps some aspects of medical care will be relegated to computer control.

Here is a far out suggestion: Biologists are beginning to understand the structure of proteins and their interactions with enzymes. The computer is an ideal research tool for deciphering complicated molecular structures; in fact, probably the only tool for the job. So the computer may one day make it possible to completely understand the internal codes which cause some cells to develop into muscle, others into bone, others into an eye, etc. If we make that step, then the next one will be to use a computer
to design proteins to specification, and finally to grow organisms to specification. Perhaps medical treatment will become that of designing special enzymes to cause the regeneration of a damaged organ or member—or even to stimulate an entire body to resume growth and become revitalized. Such suggestions bring up some very difficult social and moral questions beyond the scope of this discussion.
III. SUMMARY AND CONCLUSIONS

This brings us to the end of our tour through Computerland. The computer is indeed the most powerful and flexible tool ever made available to man and to society. It is not a replacement for man in any large and encompassing sense, but it will replace him in many jobs. It will offer man numerous new opportunities; it will touch him everywhere and in every way, almost on a minute-by-minute basis. The computer will change and reshape the life of man; it will modify his careers, and it will force him to accept a life of continuous and probably rapid change.

Of the several possible developments that I have offered, I described none in any great detail. I do hope, however, that these ideas are credible extrapolations into the future. I hope that you appreciate that both computer hardware and the methods of using a computer will support the possibilities that I've mentioned. Many things brought about by the computer will present challenging sociological implications. I have not explored such issues, but certainly the interactions between technological possibilities and political, economic, and social factors cannot be ignored.

Let me leave you with a brief account of what I believe to be a dramatic illustration of the computer's increasingly pervasive and profound role as both a practical and creative tool. There exists a film called "Simulation of a Two Axis
Gravity-Gradient Stabilized Satellite" (produced by the Bell Telephone Laboratories). Fortunately, the subject matter is not so difficult as the title would suggest. Consider a satellite such as the Tiros, whose job it is to observe weather patterns. Its television cameras must always point toward earth--specifically, the center of the earth--as it flies along the orbit. Since gravitational forces always point toward the earth's center, we can aim the cameras correctly by utilizing on-board devices for making measurements and directing the satellite to change position. But to stabilize this system--to keep the satellite from swinging back and forth--instruments known as gyroscopes must also be installed. The film describes the engineering problems of designing such a stabilizing system. From our point of view, however, the film's most significant feature is that it was completely produced by a computer. After mathematically calculating all of the satellite's motions, the computer provided the information to a TV-like display which was then photographed.

This film affords an opportunity to look at data from a different point of view; e.g., part of the time, the observer is riding in orbit just ahead of the satellite. Anyone familiar with engineering matters takes note when the film's commentator points out that certain instability problems can be corrected by placing the gyro stops unsymmetrically. Thus, the film becomes a direct exploration
of an engineering design problem. The viewer, seated before a computer-driven console and display, watching the trial motions of the satellite, notices immediately the effects on undesired movement of adjustments in the position of the on-board gyroscopes. He is in effect conducting an experiment in outer space, yet wholly within the computer. (Needless to say, the costs of such on-the-ground experimentation are lower and the risks zero.)

This film (and others like it) can also be an impressive education instrument. By asking the computer to show how it looks to chase one satellite from another, for example, the viewer can experience for himself, as it were, the Gemini-7 space rendezvous. Such is the power of simulation or modeling implementation on a computer.

I close with two vignettes about computers. First a quotation from Dr. William Baker, Vice President of the Bell Telephone Laboratories who has characterized the computer technology with a question:

What other technology is there in which the United States has such a commanding lead, which will have as much effect on how we design and do things, which will be as pervasive, and which will both attract and appeal so strongly to the young mind?

Secondly, I leave you with a cartoon depicting a situation which may very well take place not too many years from now (Fig. 50).
It just won a Nobel Prize........

Fig. 50

*With apologies to Bo Brown of the Pennsylvania Gazette.