Since I am an enthusiast, rather than an expert, in the computer field and have been asked to talk about the future, anything may happen; but it is reassuring to find experts almost as far out as myself. In fact, it would be unwise to look only at the immediately available technology; and I have often thought of the early days of aviation, when Billy Mitchell tried very hard to convince his superiors that the airplane had a future in war and, as you know, was essentially cashiered out of the Army. He did induce a cavalry general to give airplanes a try, but the experiment was a failure. One of the "crates" of the day flew over a polo field while officers were playing and attempted to hit players with oranges. No hit was scored, which was pretty conclusive proof that there was no future for aviation in warfare!

When I became actively interested in this problem something under three years ago as we were beginning to plan for U. C. Irvine, the experts in the field whom I consulted were of limited optimism. They said, "Yes, the things you want to do will be possible in ten years." Two years ago, taking another sounding, I was told, "Yes, the things you want to do will be here in three years." Last year, at the IEEE, the speaker before me in effect said, "Look, we have available, now, large memories with rapid access, parallel processing, multiple access to the computer, improved input/output terminals, improved (richer and easier) programming languages; and I find no roaring demand for them." I was happy to get up after him and say, rather emphatically, "The roaring demand is here." Now, at this meeting, many of the items which even a year ago were merely potentially available are on exhibit and are in actual use in at least the developmental, if not the completely operational, stage.

Actually, the problem clearly before us today is minimally that of hardware and maximally that of software. This is discouraging to many people. It may take as much as 200 hours of an expert's time, with some additional programmer time, to program one hour of effective tested-out computer-aided instruction. This seems at first, indeed, a devastating problem; but second thoughts are more hopeful. The languages for programming are still relatively primitive, although they are approaching basic English, and will become more efficient. But even if they did not, please consider that since the invention of the earlier technologies of communication—of which language itself is the main one—it took several millennia before man achieved writing, let alone paper and printing; and the software composing a modern language, English or any other, and the entire literature now available in that language, could be replicated on computers (reduced to computerized handling, put in appropriate memories, and so on) in something like $10^4$ as great a time—and its usefulness probably be made $10^2$ times greater. A gain of $10^4$ is worth the time and trouble and, as I hope to show, there should be adequate funds to do the job.

Incidentally, as Dr. Ramo pointed out, people fear that computers will replace them or, as someone put it a few years ago, that artificial intelligence will replace natural stupidity! What we are really facing, of course, a symbiosis of both, combining the attributes of great speed and vast memory of the idiots that we call computer systems with the imaginative, creative, idiosyn-
cratic, pattern-forming capacities of the human brain and mind. I have felt for some years now that, of the evolutionary epochs in the rise of man from the time his brain became good enough to develop a communal culture and pass on experience, which is essentially education, the major advances were: first, the ability to have symbols at all (which may have been pre-human); second, the organized symbols of language; third, the organized tested symbols which constitute science; and fourth, the prosthesis to extend the mind which is the computer. I would put this present technological evolution as equal to the development of language; considerably more than the development of printing.

Now a few words more on the evolutionary aspects of learning and the role of education. Learning is, in effect, modifying one's behavior in the light of experience; and education, formal education, is an effort to organize the experience to which an individual is exposed so as to develop a maximal change in behavior and capacity along certain desired lines. This is nothing new nor unique to the formal level; indeed, the evolution of the nervous system itself is very clearly the consequence of responding to the species' experiences. There is good reason to think that the cerebrum developed in response to the steady barrage of the brain by nerve messages elicited at improved receptors, particularly the distance receptors. Originally smell, later vision, and to a lesser extent hearing, are the inputs that give an animal warning of changes in its environment before a predator is upon its tender skin or before it flushes its own prey. This maintained input supplied the exercise which increased the brain in the first place and, as current analysis of the anthropological evidence suggests, this process was greatly accentuated when man began to use tools—which rather explosively further enlarged the brain.

Now, in the development of the brain of the individual infant, exactly the same sort of processes are occurring. It has been demonstrated by a rich array of varied experiments that an infant deprived of certain experience fails to develop the capacities for handling such experience. A baby chimpanzee kept in the dark, or even with milk glass over its eyes so that it sees light but not patterns, until it is some weeks old (nothing done to the eye, nothing done to the brain) may never learn to discriminate patterns in the environment. It remains functionally blind. Conversely, if one enriches the experience of a young animal, a rat in this case, there is actually a hypertrophy, a thickening of the cortex of the brain; just as exercising muscles increases their size.

So evolution has depended on the impact of the environment on many generations of individuals in the species; individual development, on the impact of the environment on the single individual. It is too large a story to go into here, but as a biologist, I would maintain that the major theme of all biological evolution has been the increasing responsiveness of organisms to the environment, the developing of malleability—not merely being able to learn in response to the environment but learning how better to learn. The same is true in the education of the individual child; it also has to learn to learn and can thereby learn better. I would, therefore, add to the previous statement, that the computer will be a great supplement or prosthesis to the human brain, and that the computer can also be a great developer of the brain. Here is a tremendous opportunity for the future.

Formal education probably should be traced back to the 12th century when the great medieval universities began, led by the University of Paris. We may forget that the students there were often subteenagers, so a university was not quite what we think of today. The widespread present formal education, essentially in reading, writing, and arithmetic, was not only nonexistent but would have been utterly useless before printing and the widespread availability of books made it possible to read and therefore made it worthwhile to learn to write. It is only within five centuries that our current widespread literacy became possible and was achieved; even reckoning, especially multiplication and division, was practically unknown three centuries ago but was a special skill of highly trained expert clerks. Perhaps because education got started relatively early in the area of behavioral institutions, perhaps because of the inherent difficulty of the subject matter—the vagueness of the resources and even of the goals, the uncertainty of the outcomes, and the extremely varied artistic and uncontrolled methods of procedure—I submit that this particularly important area of human activity (perhaps the most extended and continuous and largest activity of man; wars are bigger but they come and go, science is more continuous but less extensive), education, has lagged very far behind other areas of applied behavioral science. It is not evaluated, it is not analyzed, we really don't know whether or not we have been really achieving anything with all the time and funds and human labor that have gone into this field. The most important impact on education of computer technology (and I use this in its broadest sense) will probably be by supplying a tool for finding out what we are doing, for turning anecdotal impressionistic answers into scientifically testable ones, and so turning what has been almost purely an art into a respectable science—and without eliminating the artistic aspects either. Research in education, advances in educational under-
standing, and education as a behavioral science will be, I think, the most important outcomes.

Let me give you a concrete example. There are two rather important competing theories as to the way learning occurs, either as a steady incremental process or as a step-function increment—differential or integral advances. The two theories make precise predictions as to the best reinforcement schedule for learning. According to one, those items on which an error occurred more recently should be presented oftener; according to the other, there should be no such emphasis and all items should be presented equally but at random. It would be impossible to perform an experiment of this sort without the use of computer technology, computer aided instruction; with this, Atkinson at Stanford is doing just such studies with children.

Let us, then, examine in a little more detail the impact of this new information handling technology on the procedures and the institutionalization of education and try to foresee some of the social outcomes of these changes. To give you a clearer picture of what I have in mind, I shall present our activities and goals at UCI—it will be clear which are which. The campus became interested in the possibility of really interweaving these two great information handling systems. A university is primarily a system for storing, retrieving, processing disseminating, and creating information (research, which creates information, being less present in lower institutions); and computers do exactly the same, even creating information in the sense that mathematics, though a tautology, creates usable information by manipulating existing knowledge and assumptions. Clearly they are made for each other and our hope was to build a total system for information handling by combining the resources of both. We set up, for example, a computer "facility" rather than a computer "center," to imply an interpenetration rather than a boundary.

Although we opened our doors to students only two months ago, a reasonably powerful computer resource has been on hand in trailers for a year with the cooperation of IBM. Dr. Tonge, Director of the University facility, and Dr. Kearns from IBM have led this activity and the development of CAI. There are already in action 18 on-line time-sharing consoles, and a group of some 20 professional people involved in the computer activities, penetrating all parts of the university. On the administrative side, we look to a total systems use in enrollment, in finance, in faculty and student records, in plant upkeep, in classroom assignments, etc.; and several lines are now active. Of course, the system will be used at all levels of research, up to social simulation systems. The bookkeeping aspects of the library—handling of materials, accessions, charge-outs, etc.—are being prepared for automation and we look towards processing the information rather than the documents that handle the information, to get information on an on-line rather than batch processing basis. Beyond all these, and our major thrust, has been a concern with the possibilities of computer-aided instruction in the educational process, itself; and it is only of this that I shall continue to talk.

Let me give you a vision of what is to come, whether in years or decades remains to be seen. I would suggest, however, that the reason the experts in the field almost invariably are rather pessimistic in their guesses of the future is that, while each is acutely aware of the bugs that have troubled and delayed his own developments, he is likely to overlook the countervailing effect of parallel activities by many people trying to do similar things. The total impact of this collective thrust is much greater than the frustrations and delays in the individual case, so advance moves faster than the general expectation.

I like to think of the total system as a sort of sandwich, of data bank on one side and users on the other, interacting via the information processing apparatus. The data bank includes not only the ordinary internal and external memory devices of the computer but the mobilization of any kind of material which can be recorded—on video tapes, movie tapes, micro forms, slides, phonograph records, thermoplastics, what you wish. This great data bank need not be located physically in relation to any particular processor but be made available to many by networks. Such banks can be accumulated in a very few places (conceivably in only one except for the danger of loss or damage) and, by the communication networks, be made available at least area wide to all sorts of users in all aspects of education. On the other side, I see the user sitting at a terminal, a console or carrel, at a convenient location, including his own home, and able to communicate in and out not only by typewriter, by cathode ray screen plus light-pen, and by voice, but also doing these with relatively simple buffer arrangements and using an adequate communication language. Beside the individual user, group interaction should be handled—a seminar with the instructor and a dozen or more students interacting audio-visually via a communication network and controlled through the computer processor, much as if all were in the same room.

The processor itself I like to call the tutor because here is an agent potentially updated in subject matter; and learning improved heuristics of the precise educational techniques to be used for this or that kind of individual with this or that previous training and with this or that temperament—a hostile youngster who likes
to fight back or a passive one who must be coddled and brought along. The tutor will have built into its own memory a detailed knowledge of each student with which it is working, in terms of that individual's background, personality, and achievement in the particular field; will be able to give the tutee immediate individual attention and to do so without threatening and with infinite patience.

Such an entry of computer technology into the educational process will have far-reaching and crucial consequences. I will not have time to go into all of those, but, fortunately, the problems have already been discussed: the danger of regimentation; the danger of Big Brother in "1984"; the danger of depersonalization or dehumanization or social anomic—existentialists insisting that people will lose their identity, individuality—all these certainly need more consideration than I can now give them. At least note that the book, itself, interposed between humans has not dehumanized them, nor has Othello as played by Olivier on the movie or TV screen; nor has mechanization of the kitchen ruined the home.

Now a brief look at costs. If it took, say, a hundred hours to program one hour of computer-aided instruction and this program were used by a hundred different teachers only once, the time cost would balance. In terms of financial cost, I have picked up a few figures here and there. For example, in the elementary grades it costs 27 cents per pupil per hour for teaching (this is, I believe, a national figure; the cost in California is nearly double); the work (including all development) cost $1.00 per hour per pupil per simple terminal according to Atkinson. But vastly more is done in that hour; in fact, it is reported possible to teach a child to read in 200 hours on a terminal—a cost of something like $200 per child! Since only a seventh of teacher-child contact time is spent in teaching, say five hours a week, it is easily understandable that great savings in student hours are possible. Further, if one teacher taught 25 children to read during one full year, this would cost well over $200 a child in her salary alone. There is much reason to believe that we could squeeze as much as three years out of the K to 12 period of schooling and not leave out anything of worth. In effect, during the 10th, 11th, and 12th years students are doing nothing productive in society and are costing a great deal of money; cutting these years would be nearly $7 million for 10,000 students. The largest present hardware systems rent for $0.5 million a year and require a like sum to staff; double this for capacity and add another $2 million for terminals, and the cost is still half that of human teachers. Further, if three man-years are needed to program one course, and 100 courses would cover the bulk of undergraduate needs, all this software could be produced for some $3 million. Even if obsolete in one year (three is more reasonable) this cost is trivial if the system is widely used.

Well, aside from the financial aspects, the advantages of such a learning arrangement are only to be enumerated to be recognized. For the student it offers: (1) better and more comfortable and faster learning—he can time his learning experience at his convenience, go at his own pace and catch up missed time; (2) better teaching at many levels and in many areas; (3) particularly important—personalized tutoring, individual attention (I remind you, what is so often forgotten, that Thurstone's original study on the primary mental abilities showed ratios as high as a hundred to one in favor of child A over B for ability 1 and the reverse ratio of a hundred to one in favor of child B over A—the same two children—in ability 2; there are clearly fantastic differences in human beings and it is high time that we stopped batch-processing them through the educational machine! Let them take the initiative for actively learning in their own ways); (4) automatic measurement of progress, by keeping appropriate records of responses; when the course is finished, the examination has been taken, and examination neuroses are bypassed; (5) vastly richer materials, demonstrations, exhibits, travel material, on-site work at archeological excavations or ocean bottom laboratories, are available for presentation; (6) more sophisticated problems can be included in instruction even to the level of simple research, lift-
ing the drudgery of sheer repetitive computation.

For the teacher, the system: (1) also takes away a great deal of drudgery and repetition; (2) allows the teacher herself or himself to be updated effectively, without allotting a summer or a year for subject matter refurbishing every three or five years; (3) encourages frequent changes in the actual material used; (4) makes much more time available for real teaching—recall the estimate for grade school that teaching contact between teacher and student averages less than 15% of the time they are together.

Besides student and teacher gains, there are wider social goodies: (1) the very best materials can be produced by master teachers; (2) these can be used widely and repeatedly at least for a limited time; (3) individual modifications in the program can be made almost at will, in contrast to the delay and pain of a new edition of a book; (4) the great information systems can be tapped freely; and (5) perhaps the most important of all, the desperate shortage of teachers can be relieved. In "teachers" I include good teachers or average teachers or almost any warm body (physically, not psychologically); there just cannot be enough humans for the jobs to be done. Think, further, of the teaching needs of the emerging countries which must get themselves instant education. If one teacher can teach a few dozen students who then become teachers who can teach a few dozen, the multiplying or avalanching effect is just impossibly slow; so that some of these countries are making a quantum jump into advanced technologies—just as some countries earlier went from bullock cart to airplanes and bypassed the wagon and automobile. In our own country, autistic children—who rock all day, insulated from the world—have been led into participation by interacting with computers when even master teachers have failed (nonthreatening objects, infinite patience with repetition); and the vast needs of our Headstart program, to bring mere symbolic thought to underprivileged babies now growing up practically without language, cannot be approached with the supply of human teachers present or future.

Even beyond the immediate teaching possibilities are the exciting social outcomes for education. I shall briefly mention three. First, there will be greatly increased flexibility not only in handling the individual child, but also in handling the materials. If one can break the teaching sequences into relatively small units then, as with a Mechno set, a few kinds of pieces can build a great variety of structures. Instead of having many different courses in statistics—one for psychologists, one for biologists, one for public health, one for engineers, blocks of basic elements and particular uses can be put together in well-tailored fashion. This also means that it should someday be possible to get away from the lock step of the semester or the quarter system. Large course blocks should become relatively meaningless as each student goes through a learning experience cut to his shape more or less continuously.

A particularly important consequence could be the separation of the function of certification from the function of education. They are now part of the same process; and getting good grades, in order to enter the next school and get good grades in order to enter the next one above, has so come to dominate the whole thinking of the students and the teachers that whether one gets an education or not has often been pretty much forgotten. Progress can be certified and mastery tested in a much more certain and objective way with these newer technologies, leaving the process of real education (and with teachers used in it especially) to occur as needed.

Another important outcome, already implied, is the possibility of spatial dispersion of the learning experience. If certification is covered, then actual class attendance to learn becomes immaterial. I strongly expect that, in the not-too-far future, there will be an opportunity for the individual to interact through a console with the great array of knowledge and even with other humans, so there may not be geographic entities like a campus. I am well aware of what this means—you cannot have football and orchestras without coming together; in fact, it has even been stated that "it takes two to tango"—but for dealing with ideas, physical contact hardly seems needed; and high-level seminar-type interaction is possible over video conference hook-ups.

Teachers have been doing a great deal more than merely help develop the information processing capacities and resources of their students; they have been friends, they have been hero figures, they have supplied motivation, they have been shoulders on which to cry. All these things are very important but perhaps they are not all functions of the same individual at the same time; so I see the possibility of again splitting the separate roles. Indeed, the medicine man once served his primitive community as priest, lawyer, doctor, teacher, and entertainer; these have been separated into different professions, but have sort of collapsed back together in the teacher and now may again be separated out. In fact, I think it likely that a very different kind of good teacher will come into being and that new sorts of people will surge into the field of education. The great teacher of the future is likely to be more like the author or the composer or the director than he is, as at present, like the performer or the actor or the concert player.
Well, rather than continue about changed content and goals, let me close with just one thought. Man truly no longer lives in an outside world. As the cells of the body in the multicellular organism have created an internal environment in which those cells live, and which is made possible by the collective action of the billions of cells, each group performing its own role in the body organism, so men, in the same way, have created societies, groups of individuals in a multi-individual epi-organism, have created an internal environment of the society, a culture if you will, in which we live. This is also regulated against extreme swings; we are now little concerned about the physical and biological problems of the environment, there is no worry about wild beasts, we go to the supermarket for our food; houses and clothes protect against weather; we are conquering disease. The pressing environmental problems with which we live are those that man has created for himself—by increasing the ease and frequency and range of communication, the number of people who communicate, and the richness of the material which we now can communicate to each other. We are rapidly raising a sea of information in which we must either swim or drown, and the way we must swim is by enhancing the problem-solving resources of man and society.

The new computer technology will allow effective studies of human ecology; of the distribution of, and environmental influences on, physical and mental health and disease; of employment needs and their projection, so that appropriate special training of properly selected people can produce the round pegs for the round holes. But of the many opportunities for aiding man to handle himself collectively, in my judgment, the improved teaching of the young, to be effective members in society, is the greatest of all.

I cannot close without quoting to you one verse of my favorite poem, O'Shaugnessy's Ode:

We in the ages lying
In the buried past of the earth,
Built Nineveh with our sighing
And Babel itself in our mirth;
And o'erthrew them with prophesying
To the old of the new world's worth;
For each age is an age that is dying
Or one that is coming to birth.