Editorial on Recent Advances

Computers in ophthalmology

Are computers going to take over medicine? More specifically, are computers going to take over ophthalmology?

Perhaps these questions can be answered by analogy. Did the automobile take over the practice of ophthalmology? Few ophthalmologists would answer yes. But even fewer ophthalmologists in America would hold that the advent of the automobile has not profoundly altered the practice of ophthalmology.

When ships, trains, automobiles, and airplanes entered our society each was viewed as another type of traveling machine, suitable for transporting people and goods across distances. Now that they have proliferated, we can see in retrospect that viewing them merely as traveling machines was a dangerous oversimplification. They have revolutionized our culture.

In spite of the gigantic effects that these transport mechanisms had on nearly all humans, we did not develop an effective discipline to study transportation science until quite late, long after the machines were in use in great numbers. It is fashionable to look upon the automobile as the cause of many of our problems today, but it is not automobiles that are at fault; it is the people who make and use them. If we could have seen in advance how important the automobile was going to be, could we not have developed a vigorous discipline of transportation science sooner and have behaved more wisely? We certainly could!

We are now about to get the same chance with computers. American society is rapidly moving into an era in which computers are affecting nearly all aspects of our lives. There is little doubt that this process will accelerate. Fortunately, there is already a discipline of computer science, and it is not as oblivious to the social impact of the machines that it studies as was mechanical engineering when it failed to develop an effective transportation science.

Computers carry with them the potential for even greater effects on our culture than the traveling machines have had. Traveling machines accomplish the simple purpose of moving physical objects about. But the computer is capable of far more subtle functions. It can represent, simulate, augment, and, probably, change human thought processes.

Computers were originally created to manipulate mathematical operations and do computation. But computation or calculation is now only one of the tasks that computers do. Increasingly, computers are machines that accept, store, retrieve, and manipulate all sorts of information. There is a rapidly developing and clearly demarcated discipline known as computer science that deals not only with the mechanics of computer construction and oper-
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Before we examine the uses of computers in ophthalmology, we might take a look at the state of the art in general. It is important to start with a word of caution: five or six years is a generation in the field of computers and nearly everything that is said today about computers may soon be out of date. The machines themselves are developing at such a rapid rate that people in the field are distressed by the knowledge that no matter what machines are purchased today, they will be obsolescent by the time they are in full operation. Significant advances in technology occur so rapidly and often that it is very hard for anyone to keep up with developments in the entire field. A few specifics may be in order. Computer memory systems are rapidly growing bigger, faster, and cheaper. This appears to be a continuous process and will probably go on for some time. There are memory devices, now in the development stage, that will greatly expand the computer's ability to store data. Machine-produced microcircuitry of great complexity is also developing at a rate that challenges the imagination. It is now possible to purchase for a small amount of money the central processing unit (CPU) or “brain” of a very sophisticated computer. This CPU is available as one plug-in circuit board. One may also buy cheaply any of a large variety of tiny plug-in units that have remarkable capabilities for doing computing. These micro-processors are rapidly being incorporated into a variety of machines so that each machine can be controlled by a tiny computing system that is an integral part of the machine. These devices will soon appear in large numbers in the machines used in ordinary daily and professional life.

Input and output devices, those parts of the computer that allow the user to enter information or that display the results of the computer's activity, are developing rapidly, but they are still the major limiting factor in the use of the computer by non-professionals. This general class of devices remains larger, heavier, noisier, and more expensive than we would like them to be.

There are basic philosophical considerations that are even more important than these technical ones. We must understand what computers are good at and what they are not good at. Many serious problems have arisen because people who do not understand the fundamentals of computer science have had unrealistic expectations. In general, we misjudge the capabilities of computers because they easily do things that humans find difficult, and humans easily do things that computers find difficult. Computers are very good at operations that can be successfully broken down into small, simple steps that can be repeated rapidly. Whenever we can take a task and subject it to an analysis that allows it to be divided into a series of discrete steps, the computer performs brilliantly. Humans are impressed by the “magical” capability of computers to make measurements with great rapidity, and to store, retrieve, and manipulate mathematically the data derived from such measurements. We are impressed by the lack of temporal restrictions such as those we must work with because of our relatively slow nervous and musculoskeletal systems.

But computers do badly at some things whose difficult nature we fail to appreciate because we do them so easily and intuitively. Computers do not “understand” natural language. With a few relatively unimportant exceptions, computers cannot comprehend the complex symbolic relationships that are embodied even in simple, unrestricted prose. We could probably teach computers to understand language if we knew how we did it. But since we do not comprehend how we handle linguistic symbols so well, we cannot analyze and resynthesize the process so that the computer can perform it.

Computers are also very poor at analyzing images. Most neurophysiologists today agree that the human brain devotes by far
the largest part of its sensory activity to the visual process. The manipulation of the information coming to the human brain through the eyes is the most sophisticated and complex information processing task we know of. We are just beginning to learn enough about the physiology of vision to realize that we are at the beginning of our understanding of how the human brain "sees." Efforts to make the computer analyze and "understand" information contained within images have been expensive and have had very limited success.

Perhaps we can look at the practice of ophthalmology and decide which of the functions performed by ophthalmologists are easy to computerize, and therefore likely to be computerized, and which are difficult and not likely to be computerized soon.

At first glance it appears that storing and retrieving the medical record would be an obvious and straightforward application. Failure to appreciate the great difficulties involved in medical record-keeping has led to a number of costly mistakes. Manipulation and interpretation of data are easy when the data are in numerical form and when the mathematical manipulations to be performed with these numbers are known and agreed upon. Thus, financial records can readily be stored and made available for accounting purposes.

But we must not mistake retrieval for comprehension. The computer can also store words or names. It stores them as strings of letters, each of which is represented by a group of codes that might otherwise represent numbers. The computer can reproduce these strings of letters and put them back together exactly as they were "input," but it cannot perform arithmetic manipulations on codes that have no true numerical equivalents. Neither can the computer comprehend the meanings of these words. It can go through lists of words and pick out those that are identical, but it cannot comprehend the relationships between the words. Thus, it can store and reproduce the medical record, but it cannot, on its own, abstract or edit that record. If it seems to perform abstractions, it does so because the data have been put into the computer by someone who did the abstracting mentally and then entered the appropriate groups of words under the appropriate abstraction headings. This requires that the person inputting the data understand the meaning of the information. Obviously, the person most suited to do this is the person who would otherwise handwrite the medical record, the doctor.

How can the doctor input this information? Today there are no satisfactory solutions to this problem. The computer cannot accept spoken speech or handwritten copy. It can take in the typewritten copy generated by typewriters employing a special type face that can be read by an optical character reader (OCR), which is an expensive device.

But even the OCR only reads in the letters; it performs no abstraction. In general, the input of verbal material to the computer must be through a typewriter keyboard. Doctors do not like this. They must sit at a keyboard and enter data items in the order in which the computer is ready to accept them so that they can be put into the appropriate storage categories. The doctor engages in an interaction with the computer and types in answers to specific questions. This is time-consuming and boring, and doctors usually will not do it. If it is assigned to clerks, the clerks must understand the meaning of the medical record, and even when they do, many mistakes will be entered into the system. There are experimental and rather complex programs that can accept groups of words arranged in any order, so long as those words are agreed on beforehand. The severe restrictions that must be imposed on the vocabulary, if the computer is to recognize the meanings of the words, makes flexible computerized medical record-keeping very difficult at the present time. However, ophthalmology may have
a small enough vocabulary upon which ophthalmologists could agree, so that ophthalmological record keeping might possibly be done in this way.

If the questioning structure of the interactive program for acquiring the data is appropriately designed, the inputter of information may be able to answer a complex question with a single character by selecting one of several multiple choices. As we all know, answering a lot of multiple-choice questions can be tedious. Voice synthesizers that allow the computer to speak, rather than to issue only printed statements, are now commercially available at reasonable prices. This allows the computer to question someone whose gaze is not fastened on the computer terminal. Data entry can also be accomplished merely by touching a television screen next to the appropriate answer, but this significantly increases the cost of the terminal.

Probably, computerizing the medical record will depend very much on input of information by paramedical assistants, such as technicians and clerks. Systems that rely on physicians to change their methods of record-keeping to new techniques of notation and organization of data are unlikely to succeed unless the gain for the doctor is clearly worth the effort. Significant research efforts are being made in this field, and the prospect is good for continued improvement through the exercise of much ingenuity. But, in my opinion, it would be unwise to think that medical record-keeping is likely to yield suddenly or completely to any dramatic breakthrough. Teaching computers to understand English, or any other complex human language, is a gigantic task and will probably take a long time.

It is my estimate that the computerized medical record for ophthalmologists will be suitable first for practices in which a number of people are called upon to share the task of inputting information. Practices with several assistants or several doctors and many assistants would lend themselves most readily to this.

Small, free-standing computers, generally referred to as mini-computers, are now growing so powerful and inexpensive that it is practical to have a mini-computer in the office where this type of practice is conducted. The price of such a system is not greater than the price of some instruments that ophthalmologists are now buying. This type of machine could do the patient appointments, and billing and accounting, as well as the medical records. It could significantly improve the efficiency of a busy office and probably would pay for itself in a short time.

But what of the less mundane problems: what can the computer do for the scientific aspects of ophthalmology? Can the computer help in examination, diagnosis, therapy? Will computers be used in these aspects of ophthalmological practice? The most natural application of the computer, after its clerical functions previously noted, would be reading instruments and interpreting the results. I am referring to instruments from which an electrical analog can be derived, representing the measured function. The most obvious applications are in instruments that perform objective measurements such as tonometers, tonograpbers, eye movement measuring devices, objective refractors, keratometers, and lens meters or vertometers. But even some subjective functions can be converted into objective measurements, as for instance with automatic perimeters or visual acuity measurement systems. More and more the examining functions that will be reserved for the ophthalmologist will be those requiring interpretations of image content: examination of the cornea, anterior chamber and lens, gonioscopy, and ophthalmoscopy. Although images from these examinations can be captured automatically and stored, ultimately they must be viewed by an experienced human, or much information within them will be lost. At the present time it is impossible to have the computer recognize more than certain specific details. Thus a computer can compare the two members of a stereo pair of photographs of the optic disk and calculate the...
depth contours of the disk. But we are a long way from having the computer look for images whose location and probable description are not well-known in advance.

So much for the physical observations. What about the computer’s ability to digest data and make decisions? This is an area in which research is being conducted actively, and in which considerable forward strides are probable in the near future. Decision making, like language comprehension, turns out to be more difficult than it appears, and for similar reasons. Decision making by computer would be much easier if we understood how humans make decisions. One of the remarkable capabilities of the human mind has emerged from recent computer science research. It has become evident that a given set of input information, such as the history and physical examination data, can give rise to a number of alternative hypotheses, some of which may appear equally likely. In the case of complex medical phenomena the number of hypotheses one might entertain is very large. Doctors are remarkably skilled at selecting from among these hypotheses the very few, or the one most likely to be correct. The remainder of the diagnostic and prognostic process is often an attempt to prove or disprove this one, leading hypothesis. How the clinician zeroes in on this important hypothesis is not known. The inability of computers to make these judgments is what prevents computers, for instance, from playing chess as well as expert humans do. Even the largest computers don’t have the power to run through all the alternatives that can arise in a chess game.

A subdiscipline within computer science, called artificial intelligence, has concerned itself with studying this problem of complex decision-making. Some things in medicine can be recognized by pure statistical association. Thus, given history facts: a, b, c; symptoms: d, e, f; and physical signs: g, h, i; the computer can select and print out a list of diagnoses: x, y, z; in their order of probable occurrence. It can even recommend test procedures to confirm or deny these diagnoses. However, this approach does not give satisfactory answers to doctors who want to know why the consultant came to the conclusion that was reached. Doctors have not in general been favorably impressed by “black boxes” that make pronouncements without being called upon to state their reasons, and the doctors have been correct in this judgment.

Another type of decision making program is the branching logical tree, familiar to many from programmed texts. With such systems the user is conducted through a series of choices, each of which results in proceeding along a different logical path. Even with only two choices at each branch, the number of possible branches in such a logical tree, handling a complex problem, rapidly grows immense. Another fault with such programs is that, once constructed, they are rigid and do not allow for the input of new concepts. If one branch is changed, all the branches beyond it may wither and die.

For several years our research group has been interested in creating decision making programs that are more flexible and capable of incorporating complex inter-relationships more economically than these more traditional methods. We have developed a consultation program in glaucoma that is capable of making diagnostic, prognostic, and therapeutic decisions at a high level of expertise. This program is operational and is now undergoing clinical testing at several glaucoma research centers that are linked together in a computer network sponsored by the National Institutes of Health. This program “understands” glaucoma in much the same way as does our panel of consultants. It is capable of embodying a great deal of the subtlety of thought and judgment that ophthalmologists exercise when dealing with complex glaucoma problems.

The development of this glaucoma consultation system has also tested another mechanism which may not seem at first to be part of computers in medicine, but
which is essential to further advances in medical computing. It has tested, and proved feasible, the social mechanism of a group of geographically separated clinical scientists actively collaborating in the development of a powerful computing system, even though the medical investigators are not computer scientists. This suggests that, if computer scientists can offer medical scientists sufficiently useful tools, the medical scientists will use them.

Along with the glaucoma consultation system, we are designing and building other consultation systems. It is likely that we will soon have computer-guided systems that can do sophisticated work in refraction and perimetry. Consultation systems are planned in a variety of subdisciplines within ophthalmology, such as strabismus, external diseases, and neuro-ophthalmology. Perhaps ophthalmology may one day possess a complex of overlapping, computer-assisted consultation programs in a variety of its sub-disciplines.

Such a network could provide easy access at all times to expert fellow professionals. Consultation with panels of very specialized colleagues would then be much easier. We might think of such a system as a giant electronic textbook, with each chapter kept up to date by a team of specialists. But it could be more than a text, for the consultation program can be responsive to the nuances of each individual case.

Perhaps, with such a consultation system available, the physician could resume his former honored role, that of patient listener, skilled and unhurried examiner, and wise counsellor. For too long doctors have been oppressed by the weight of a body of knowledge that grows at an increasing rate. Perhaps computers will free doctors from the need to be living encyclopedias. Computers will then have done for medicine exactly the opposite of what many people fear they will do. They will have made the practice of medicine more humane.

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