Applications of Computers to Medicine

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The purpose of this paper is to present an over-view of current applications of computers to problems in medicine and not to discuss any specific application in detail. This discussion will be concerned only with digital computers.

The modern digital computer is not very old. As a matter of fact, digital computers as we know them date from approximately 1949. Yet in this short span of time they have contributed to almost every sphere of man's activities. Computers have been applied to medical problems since about 1956, and have played an important role in increasing both the depth and breadth of medical research and practice.

It seems to me that computers have had two major impacts in medicine. *First* they have provided a focus for a true multidisciplinary approach to medical problems. Computer scientists and computer centers have contributed to this in part by their own research programs which have served to stimulate physicians and scientists to make use of computers and computer methodologies. Furthermore, the capabilities of computers has stimulated the joining together of medical scientists and physical or mathematical scientists to solve a medical problem. *Secondly,* the need for computers to have well defined problems has required physicians and scientists to better define their problems and to be more critical concerning the precision of their data and the design of their experiments. The ability of the computer to handle multivariate problems and to effectively work with the interrelationships of variables has made it possible to get more information from critical experiments than had been possible previously.

It is difficult to point to any single major contribution due solely to the use of computers. However, Dr. Shannon (1965) in his introduction to Dr. Waxman's book has pointed out that computers contributed materially to the work of Drs. Watson and Crick in elucidating the structure of nucleic acids. The effect of computers on medical activities has been subtle but nonetheless impressive.

Statistics

Since medicine is an empirical science, it seems only reasonable to begin our discussion of computer applications with the impact of computers on medical statistics and epidemiology. Let us examine some of the general experiences. Computers have had several major impacts on medical statistics. First, they have permitted statisticians to effectively summarize masses of data in informative ways. Clearly, masses of data by themselves are not necessarily informative, but when collected systematically with a good design, can be useful, especially in clinical medicine and in

MCV QUARTERLY 2(4): 238-241, 1966

public health. Furthermore, computers have permitted multivariate statistical methods developed some thirty years ago to become practical statistical tools for analyzing more realistic medical experiments. This potentiality is fraught with dangers because of the rather severe limitations of these methods from an interpretive point of view, but computers have made research into multivariate statistical methodologies practical and useful. The third major impact is related to the first two in that data arising from complex and/or unconventional experimental designs can now be analyzed more effectively. This has again permitted statisticians to assist in the design of more realistic experiments. Finally, statisticians are now able to more effectively study their own methodologies and thereby evaluate and hopefully strengthen their tools.

Epidemiology

Epidemiology and epidemiological studies have long provided the major share of clinical medical knowledge especially as it relates to etiology, natural history, and preventive and therapeutic aspects of disease. In recent years, epidemiologists have changed their focus from infectious to chronic diseases, especially lung cancer and coronary artery disease. The problems of study posed by such diseases are challenging. The usual approach has been multivariable and has involved large numbers of subjects. Therefore, one major aspect of the work of the chronic disease epidemiologist has to be the understanding of the properties of the quantities which he is measuring and the influence of each of these quantities upon the values of each of the others. It is very doubtful that the information gained from such studies would be available without the accessibility of computers to summarize collected data and their relationships to disease. The amount of data gathered in even a modestly sized epidemiological study is formidable, but the editing, storage and logic capabilities of digital computers have led to greater accuracy, faster reporting of findings and new approaches to the analysis of such data.

Mathematical Models

Computer techniques have made mathematical analysis of biological phenomena feasible. Of particular importance are mathematical models of biological systems. Dr. Eugene Ackerman (manuscript in press), a biomathematician at the Mayo Clinic, has set forth two goals for such models: description or characterization of the biological system and improvement in the understanding of the mechanisms of the system. Successful models of several biological systems have been developed including the electrophysiology of the heart (Bayley and Berry, 1964) and the body fluids and electrolytes (Maloney, 1966).

Radiation Therapy

Another application of mathematical methods to medical problems is in the realm of radiation therapy. By deriving mathematical expressions for the dose distribution within a beam or around a source, it has been possible to compute radiation doses to particular tissues and thereby to select that treatment plan which will result in the most effective dose to the desired area of the body. Work in this area has been largely due to Shalek (Shalek and Fletcher, 1962) and Adams (Adams and Meurk, 1964) with implanted radium needles and to Sterling and Perry (1962) with external beams. Evaluation of the success of these approaches must await a more complete statistical evaluation of survival data, but it certainly seems reasonable that some such method will be more successful than is otherwise available.

Analogue Applications

Analysis of bioelectric signals has been one of the more fruitful areas of computer applications to medicine. However, this success has not been without much work and frustration. The ability to work with such signals requires good data collection and recording instrumentation which will not mask the desired signal with artifact. Furthermore, since these signals are continuous relative to time, it is necessary to convert them into discrete numerical values if a digital computer is to be utilized in the analysis. This is accomplished by use of a device known as an analog-to-digital or A to D converter. Our knowledge of analog-to-digital conversion techniques is increasing and this should contribute to our ability to work with these signals. However, these data acquisition procedures have resulted in huge volumes of data, and new techniques for handling such volumes have been required. Results of such work on the electrocardiogram have been particularly interesting and this has been discussed by Pipberger (Pipberger and Stallmann, 1964). The electroencephalogram has also been studied in detail as have other biological signals.

Patient Monitoring

The ability to acquire and process bioelectric signals has given rise to still another application of computers, that of monitoring physiological events. In this application, the computer is an integral part of an experiment in that it serves to continuously monitor the input data and to process such data while the experiment is going on. This allows for modification of the conditions of the experiment on the basis of analysis of the data from earlier parts of the experiment. In this way, the computer plays an active role in the conduct of the experiment. Two terms are frequently used in physiological monitoring: "on-line" and "real-time." On-line indicates that the data source is connected directly to the computer, that is without intervening recording of the data. Real-time indicates a computational configuration in which the values of time varying parameters are generated at their actual rate. Both of these characteristics are necessary for an effective monitoring setup. It should also be pointed out that on-line monitoring systems permit the study of intact physiological specimens and thereby of the control systems responsible for maintenance of equilibrium. Work of this sort has been pioneered by Stark (1964), Macy (1964) and others. More recently, physiological monitoring techniques have been utilized clinically by Wilber and Derrick (1965) to monitor patients during surgical anesthesia, by Weil (1965) to monitor during circulatory shock and by others. Boyd (1965) has set forth four functions of a physiological monitoring system. These are: acquisition of data, recording and output of data, logical manipulation of data and provision of warning devices in the event variations exceed preset limits. Data acquisition is dependent upon the availability of sensors that are relatively artifact free, do not interfere with the physiological system under study and have a long useful life. Biological engineers have been responsible for the development of the instrumentation required for monitoring activities including the development of improved sensors. The future promises many advances in the physician's ability to care for the ill by use of monitoring instruments and techniques.

Publications

The current flood of medical literature poses one of the greatest challenges in history to medical workers. With the amount of literature currently available, it is rapidly becoming virtually impossible to screen all of it to find and read the articles of greatest interest. One solution to this problem has been developed by the National Library of Medicine (Karel, Austin, and Cummings, 1965) in the form of a computer system known as MEDLARS (Medical Literature Analysis and Retrieval System). In this system the content of the medical literature is analyzed and assigned descriptive words which summarize its content. This information can then be systematically searched for all references described by specific descriptive terms, and a list of all such references prepared.

Computer Diagnosis

One application of computers which has received a great deal of publicity and which has stirred up much controversy has been that of computer diagnosis. Part of the reason for the controversy has arisen from differences in the expectation of what a diagnosis should be. Ideally, I suppose, we would like a computer to be able to make the correct diagnosis or diagnoses from a minimum amount of easily obtainable information. At the present time, this is not feasible for many diseases. This is due, in part, to our lack of understanding concerning the relationships of specific items of information to specific diseases. If, on the other hand, one wishes the computer only to assist him in arriving at a diagnosis, then this is possible with a few diseases. However, effective use of these procedures requires the physician to know in advance that the patient has one of the diseases included in the developed system. Probably the best known work in diagnosis is that of Dr. Homer Warner with congenital heart disease (Warner et al., 1961). His procedure utilizing Bayes' Theorem has proved successful if the physician provides good information. It is unlikely that the computer will play a major role in disease diagnostic efforts for some time to come, but studies of its usefulness should continue so that we can better define its role.

Pattern Recognition

Thus far, I have discussed only a few computer applications to medicine. These applications have utilized information in three forms: numbers (for the statistical and mathematical applications), electrical signals as with the electrocardiogram and English words in the library applications. However, information in still another form, visual images, has been approached by the computer scientist. It should be stressed that all of these forms of information must be translated or converted into discrete entities such as numbers or letters before they can be processed by digital computers, however, representation of the information by such discrete quantities should not materially alter the information content. Computer processing of the information contained in visual images has primarily revolved about chromosome identification (Mendelsohn et al., 1965) and work with chest x-rays (Becker et al., 1964; Meyers et al., 1963). Work thus far accomplished has demonstrated the feasibility of applying computers to this form of information.

Medical Records

Automation of the flow of information within a hospital is currently receiving much interest. Hopefully, such automation would decrease the time required to transmit information, provide better means for maintaining the accuracy of such information and in general improve the efficiency of the hospital operation. This application is beset by many problems, but it does seem that a computer oriented system for hospital information flow may accomplish these ends.

Conclusion

This has been a brief glimpse at some of the applications of computers in medicine. This is an exciting time for all of us involved in medical problems since the availability of computers and computing methodologies has presented us with an opportunity to expand our abilities to be creative. It is not an easy road but it promises to be productive. Those of us interested in biomedical computing have learned a great deal in the last few years and we still have much to learn, but the future looks bright for increasing our knowledge of medicine to improve our care of the ill and our ability to maintain the healthy.

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