COMPUTER-ASSISTED MEDICAL DECISION-MAKING

Homer R. Warner

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Dedicated
to Kay who conceived it,
to Daisy who carried it, and
to Dorothy who delivered it,
my wife, sailboat, and secretary, respectively.

PREFACE

Over the last 30 years almost all efforts to improve medical diagnosis have been directed toward the development of better and more sophisticated data acquisition technology, such as cardiac catheterization, measurement of enzyme concentrations by electrophoresis, and computerized axial tomography. Relatively little research has approached the problem of how to interpret data and better use it for medical decision-making. The advent of the computer has not only provided a powerful tool to facilitate this type of research, but it also has become the basis for implementation of decision-making systems designed to augment the skills of physicians and other health-care providers. This book brings together facets of the problem largely derived from the research and experience of the author and his colleagues and is designed to serve in several ways: (1) as a basis for a course on the fundamentals of decision-making for junior or senior medical students and graduate students; (2) as an introduction to the use of computers in clinical medicine for the physician; (3) as an exposure to some problems in medicine that lend themselves to solution by computer technology for the engineer and computer scientist; and (4) for the nurse, administrator, laboratory technician, or other paramedical person, as a source of insight into the way data are used to make medical decisions and the role of computers in this process.

To accomplish these varied goals, the material in each chapter is presented from both the medical and technical points of view. This is done to provide the reader who has a medical background with familiar territory upon which to approach the novel technical material. For the computer science-oriented reader wishing to learn some medicine, this dual format has similar advantages. Specific examples are presented to illustrate each concept to help the reader grasp and retain the ideas presented. These also serve to convince him that indeed actual applications of the principle are in operation.

Chapter 1 is a brief introduction to decision-making. It is designed to give the reader a reason for considering the topic at this point and to stimulate his interest in acquiring a better understanding of both computers and medicine. No mathematical expertise on the part of the reader is assumed in this or other chapters and a glossary of terms is included to help bridge the gap between the medical and technological disciplines.

Chapter 2 on sources of medical data is organized into 16 sections. Each of these is primarily based on the medical discipline or hospital administrative unit involved in the activity. At the same time, each section is used to introduce a new technological concept such as analog signal sampling or man–machine interface problems in the context of solving a particular medical problem. Concepts like the ratio of signal to noise are presented in different contexts in more than one section to emphasize the general nature of each principle and its wide applicability. While the book does not include all aspects of medical data acquisition, enough are presented to give the reader a broad perspective of this complex process as well as some insight into the technological details in certain important areas. The latter were chosen to emphasize the information science considerations that must be an integral part of acquiring data from a patient if indeed these data are to provide a basis for making medical decisions. In each section emphasis is placed on defining the decisions to be made as the essential first step to determining which data to acquire, how often to acquire it, and with what accuracy.

Chapter 3 on the patient data file is an introduction to the conceptual and technological considerations that must be involved in the design and operation of a computer-based medical file. Each functional specification and its implementation is presented in the context of the role this file must play as the intermediary between the data acquisition and decision-making processes. As an example of such a system that has evolved over many years to meet the needs of an acute care general hospital, the file structure of the HELP system is outlined in some detail. Emphasis is placed on the tradeoffs involved in selection of certain features of this file along with a discussion of some alternative approaches.

Chapter 4 on decision tools provides a description and analysis of certain options for expressing the decision process. This starts with a presentation of criteria for including data items in a particular decision. The HELP decision system is presented to show how one may specify with this system decision criteria involving time sequences and logical relationships among events. This ability is often essential to express realistically the particular sequence of events required to justify a given decision. The limitations and advantages of a variety of logical, arithmetic, and probabilistic expressions for representation of decision criteria are presented with examples of each. Little or no mathematical sophistication beyond a working familiarity with algebra is required of the reader who would grasp the basic concepts presented and be able to understand effectively the way such a system is implemented with a computer. The last section of this chapter is a description of the features required of such a system if it is to serve also as a tool for deriving new medical knowledge upon which better decision criteria may be developed. That this is the key to the success of any computer-based consulting system is apparent after one has experienced the frustration of encountering gaps in the medical knowledge needed to create explicit decision criteria.

Chapter 5 on modes of consultation between clinician and machine addresses the use of reports, direct query via a terminal, and urgent communication of alerts in a variety of clinical settings. Each mode of output has its role and is illustrated by working examples. Finally, the use of patient data in the form of statistical tables as a tool for teaching decision-making through simulation is presented to expose the reader to yet another ramification of such a computer-based medical decision system.

Diagnosis is but one stage in medical decision-making. Classification of a patient into a particular disease category may in some cases be the key to all subsequent decision-making, but in others it is almost irrelevant to treatment or even prognosis. The action-oriented decisions are not only the important ones for patient care but are also the most amenable to analysis and improvement since the action is usually binary and does not require subjective estimate of whether it took place. Throughout the volume stress is placed on decisions of this type as the primary objects for study and implementation using computer methods.

In 1964 the Department of Biophysics and Bioengineering of the University of Utah was established in the School of Engineering and in 1974 became the Department of Medical Biophysics and Computing in the College of Medicine. The research that the author and his colleagues in this department have undertaken since 1964 has been carried out at the LDS Hospital in Salt Lake City. This has provided a realistic test site for the implementation of the HELP medical decision system which is used as an example throughout these chapters. Allan Pryor has played a key role in design and implementation of the HELP system. Reed Gardner, Paul Clayton, other faculty, and many graduate students have developed important applications and provided useful feedback as the system evolved. The Research Resource branch of the

National Institutes of Health, the National Heart, Lung and Blood Institute, and the National Center for Health Services Research have provided the grant support for this research. The book was written while the author was on sabbatical leave at the University of British Columbia in Vancouver.

Homer R. Warner

CONTENTS

Chapter 1

INTRODUCTION

Point Wilson lies 30 nautical miles from the breakwater at the entrance to Victoria Harbor on a heading of 100° magnetic. This morning we got an early start in order to take advantage of the incoming tide that can result in a 3 knot current, almost half our speed through the water. The wind is on our bow so we cannot head directly toward our mark but must plan for two legs, each sufficiently off the wind that our sails will fill and propel us toward our goal. Three hours out in the Straits of Juan de Fuca fog still obscures any landmarks on the southern shore and the wind has shifted sufficiently to alter both our speed and heading. Now is the time for decision-making.

First we must collect as much information as possible to arrive at the best estimate of our present location. We have available our log containing data on each change of course and the time and estimate of average speed through the water on each course. From this historical data an estimate based on "dead reckoning" can be calculated and then corrected for effects of current obtained from the tide tables. The accuracy of this dead reckoning position estimate is improved by the fact that we had obtained a "fix" 50 minutes ago when a buoy was spotted which we thought was the mid-channel marker shown on the chart (see Fig. 1). Because we still are sufficiently unsure of our position to trust a decision regarding the proper course as we near the shore, we resort to more sophisticated sources of data. Using the radio direction finder we get a bearing from Smith Island and another from Port Angelus which cross at a point 3 miles east of our dead-reckoning (DR) estimate. We know that this estimate may be influenced by factors we cannot measure such as the deflection of the radio beam by land mass or even metal objects on the boat and we try to estimate the probability of such error based on past experience and our knowledge of the local geography. A third bearing from Race Rocks back near Victoria might have resolved the dilemma but that beacon is now out of range.

We could make our decision based just on which estimate of our current position we think is most likely, but a wiser course would be to

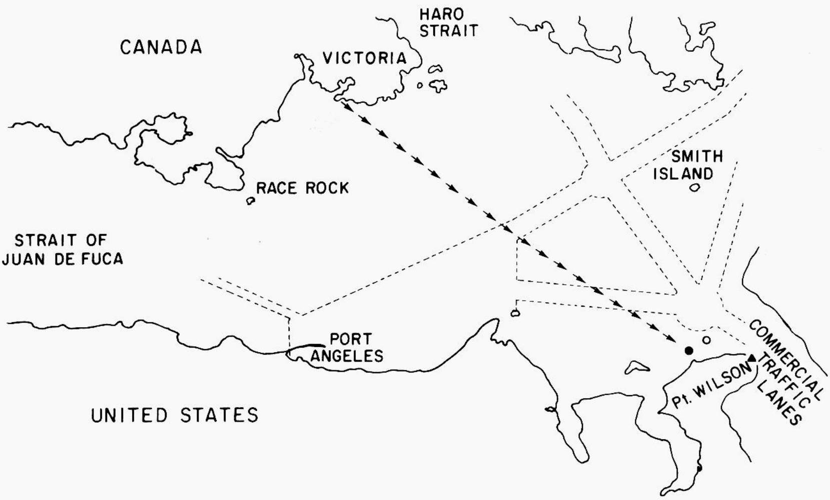

Fig. 1. Chart showing course from Victoria to Point Wilson.

consider also the consequences of each decision. A course for Point Wilson based on the DR estimate will carry us clear of the rocky shore even if we were actually further east as estimated from the radio signals. If this turns out to be the wrong position we not only would lose time in arriving at Point Wilson but also increase the risk of being run down in the fog by a larger boat in the shipping lanes. The risk of running aground can be minimized if we resort to depth readings from another instrument as we approach the shore. Only radar, which we do not have on this boat, could provide warning of an approaching ship. Thus, the preferred course is the one based on the radio fix even though the probability of that estimated location being correct may be less than the other estimate.

Our arrival at Point Wilson was not to be the end of this day's decision-making exercise. A member of the crew had awakened that morning with some cramping pains in her lower abdomen which got worse during the morning. She had little desire for breakfast but had some juice and a hot sweet roll in the hope that it would "settle her stomach." Mid morning she "lost" this over the side. We thought she was seasick until 30 minutes later when she had a loose, watery bowel movement. By the time we reached our mooring she was back in her berth content to lie quietly but obviously not well. Palpation of her abdomen revealed tenderness over the whole lower part with some suggestion of aggravation on release of pressure, particularly on the right side. A scar in this area, she told us, was due to an appendectomy 4 years ago. The medical kit thermometer indicated her temperature at

38.5°C but we had no facilities to measure her white blood count. What is her problem and what course should we take? The decision must rest upon the probability that her illness is an acute gastroenteritis, which is self-limited and short-lived, on the one hand, and, on the other, that she has a disorder of her gastrointestinal or genitourinary system which is progressive and will require diagnostic or treatment facilities only available on shore. The costs of continuing the cruise may be allowing the morbid process to progress to a point where treatment may be more difficult or even less effective while the cost of aborting the trip is small by comparison.

Decisions like these constitute the major activity of the medical practitioner. He must (1) bring to bear on these decisions his skills in gathering and evaluating new information on a patient, (2) be able to access readily the information he has already logged in the patient's record, and (3) effectively utilize the large body of medical knowledge which expresses the relationship between the data describing each patient and the diagnostic, prognostic, and therapeutic options available for managing the patient's medical problem. In this volume the decision-making process in medicine is presented as a description of the factors which influence the effectiveness of each of these three components. This is done in the context of the computer as a tool for facilitating and improving the physician's performance of each of these tasks.

Much progress has been made in developing new and more efficient methods of *gathering data* from a patient relevant to his health status. Biochemical methods have been extended to the measurement of enzymes and even trace elements and equipment for automated analysis of a single specimen for many substances has become commonplace. Catheters may now be inserted at low risk into remote areas of the body for sampling body fluids or tissues or for injecting a label or contrast material selectively into a particular anatomical location. Ultrasound may be used to locate changes in tissue density encountered as the signal traverses tissue boundaries, and computerized axial tomography has added a new dimension to our ability to visualize internal body structures with x-ray. The optimal criterion for employing each of these tools in the acquisition of data on a particular patient is not as well known as the fact that the information they provide can often be very useful. In this text the tools for gathering data will be described in relation to the nature of the signals they produce (both wanted and unwanted) and the usefulness of the resulting information.

A means for efficient *storage* and *retrieval* of medical information for future use in decision-making is as important to the physician as an accurate and well-organized ship's log is to a navigator. The design of a patient file structure as well as its content will determine the extent to which historical information contributes to high quality decision-making. The factors which determine efficiency of a medical file are discussed in Chapter 2. These result directly from a listing of the functions to be performed on that data. Intermediate decisions like the navigator's fix represent landmarks to be used in subsequent decisions and must be preserved with other data in the file. The proper mix of general features in the design to facilitate adaptation to unanticipated needs which may develop with special features which optimize the ability to perform those functions known to occur most frequently will define a truly useful medical file structure.

The physician's ability to integrate the appropriate medical knowledge with a patient's data in order to *arrive at the best decision* has become more difficult as that body of knowledge has grown. While the navigator knows which chart, pilot guide, or other reference source to consult to acquire the special knowledge needed to negotiate his vessel, the physician is often faced with difficulty in even recognizing the nature of the problem to be solved (i.e., what is the diagnosis?). This makes it difficult for him to know where to seek the knowledge he needs. The ever-increasing size and complexity of this knowledge base has been largely responsible for the trend toward specialization among medical practitioners, who find more satisfaction from mastering a small segment of this knowledge base than from having to settle for a superficial understanding of the whole.

While doctors have been specializing, however, the average patient has grown older and, as a result, is more likely now to present himself for care with two or more illnesses than in the days of the general practitioner. This means either that the specialist must call in a second specialist or be called upon to make decisions outside his own area of expertise in managing the patient's other problems. In the first instance, a new problem of communication and coordination of patient management goals and plans is introduced, and in the second, the missing expertise must somehow be introduced into the system if indeed the patient is to be treated optimally. An important goal of this book is to introduce the reader to HELP, which is a computer-based system for solving both these problems through the expression of medical knowledge as explicit decision algorithms (rules) and interfacing this knowledge to the patient data base.

That at least one such system is already operational is reason enough for acquainting this generation of medical students, physicians, and other health care providers with the material in this book. The rate of advance in computer technology, however, makes such an effort compelling. Over a period of 20 years the computing power that can be purchased for a dollar has risen by a factor of 15,000 while the value of that dollar measured by its purchasing power for most other services has fallen by a factor of three or four. Much of this increasing value has occurred in the last few years and there is no sign that it will not continue to grow. Not only is the cost decreasing but other changes in computer hardware are taking place that open up entirely new horizons for their application to our medical problem. Miniaturization, resistance to environment, easier interfacing to communication equipment, increased memory, lower power consumption, and better reliability have accompanied the increased speed of computation. We have reached the stage at which the cost of software (programs) now exceeds the cost of the computer hardware itself.

The limiting factor in the growth of computer systems for use in clinical medicine is neither hardware nor software. It is "medical ware"—the representation of medical knowledge in the form of explicit decision algorithms that can be executed by a machine. This ware must be developed by people knowledgeable in medicine and will only proceed as rapidly as such people can be motivated to devote their time and effort to this field of research. The rewards of such research will be improved patient care through better definition and dissemination of medical decision logic, better quality data acquisition as the role of this data becomes more apparent, and the creation of data files that can be used to develop improved decision logic based on past experience. The computer age is upon us—our challenge is to use this tool to the advantage of the patients we serve.

Chapter 2

DATA SOURCES

I. HISTORY

The human body comes supplied with sensors, which provide information to the conscious levels of the central nervous system concerning the functional status of many internal organ systems. For instance, stretch receptors in the wall of the appendix and neighboring bowel permit a patient to recognize unusual distension of that organ in the form of a sensation of cramping pain in the right lower quadrant of the abdomen. Like any other sensation, however, its interpretation by the individual depends upon his ability to relate it to his earlier experience. If the sensation is a novel one for a patient, he may only be able to describe it in terms of intensity, duration, location, radiation, and factors which aggravate or relieve it. It is for assistance with interpretation of his symptoms that he most often consults his doctor. Thus the first stage in a physician's management of a patient's medical problem usually involves his asking questions of the patient in order to acquire the information he needs to place this patient in a class of patients he has seen in the past who had a "similar problem," who responded to a particular form of management, and whose prognosis was predictable based on certain parameters.

The physician makes his initial attempt at classification of the patient's problem from descriptors provided by the patient who may never before have experienced anything quite like his current sensations. This kind of "soft" data is influenced by a variety of extraneous factors not always subject to direct evaluation by the decision-maker. Thus, the utilization of patient history data for making diagnostic and prognostic decisions must involve logic processes capable of dealing with uncertainty.

The experienced physician may accomplish this in a number of ways. First, he may take steps to increase his confidence in the interpretation he has placed in a patient's response to his question by asking the same question in several different ways, each of which requires a different kind of response from the patient (i.e., true–false, multiple choice, or a more detailed description). Nonverbal cues from the patient may be conveyed to the questioner in the form of changes in facial expression, emotional overtones in the voice, and relative emphasis placed on some answers compared to others. Seldom is the answer to a single question sufficient to establish with certainty the presence or absence of a particular disease.

The exchange of information between the doctor and his patient, however, is even more subtle than described above. Just as the physician is reading hidden meanings into the patient's responses to the questions he poses, the patient, too, is continually conscious of the doctor's reaction to the answers being given. This response in the form of apparent approval or disapproval may influence the way the patient responds to the doctor's next question. The patient often has his own interpretation of his symptoms, and if he senses from the questions asked or the doctor's way of asking, that the doctor is coming to a different conclusion, another source of bias in his subsequent responses may be consciously or subconsciously introduced. In other words, the personal nature of the exchange between patient and physician may in a given case be either beneficial or detrimental in terms of its net effect on the reliability and usefulness of the data collected.

This, however, does not represent the most important motivation for the development of an alternate way of collecting information from a patient by questioning him about his symptoms. Although the history is generally accepted as the single most productive source of diagnostic information (compared to physical examination and laboratory prodecures), it also takes more of the physician's time than any other aspect of the diagnostic process. Primarily for this reason a number of investigators have explored the possibility of a direct communication between the patient and a data acquisition system designed to pose questions to the patient, store and respond to his answers, and provide some interpretation of the interaction to the physician to facilitate his management of the patient's problem.

A variety of methods has been developed for acquiring information directly from a patient regarding his symptoms. There are features of each that have proved attractive in certain settings. The relative merits of a given approach must be judged in terms of accuracy of the responses generated, acceptability by the patient, and investment of personnel and facilities required to obtain the information. The acquisition process will be considered independently of the system for analyzing and reporting the history to the physician.

The most easily implemented approach involves the use of a ques-