THE USE OF INFORMATION IN CLINICAL PROBLEM-SOLVING:
A FRAMEWORK FOR ANALYSIS

L. G. Chesler
A. M. Hershdorfer
T. L. Lincoln

October 1969
This paper presents a framework to study the organization of information in the clinical decision-making process. The framework serves as the foundation for an analysis of information needs in a biomedical communication network. The study has been supported by both corporate sponsorship and by the NLM contract; it has been accepted for publication in Mathematical Biosciences, which is published quarterly by American Elsevier Publishing Company, Inc., New York.

*Any views expressed in this paper are those of the authors. They should not be interpreted as reflecting the views of the Rand Corporation or the official opinion or policy of any of its governmental or private research sponsors. Papers are reproduced by The Rand Corporation as a courtesy to members of its staff.*
PREFACE

The high-velocity, high-intensity turned on society...is the true...anarchist in our midst...we are short of talent, short of people, thin on experience, thinner on patience.

This new American life is strangely hard...yet the American pace is unrelenting. Knowledge is our industry, but the knowledge we are capable of utilizing is falling farther and farther behind the sum of knowledge we possess.

Increasingly ours is a society slipping out of phase. In sector after sector -- from the delivery of medical services to the delivery of the daily mail -- we are barely able to do what we are doing with no assurance how long we can continue.

* Horace Busby, former Special Assistant to President Johnson, from a speech before the International City Managers Association -- quoted from Tom Wicker, *The Baltimore Sun*, Friday, October 18, 1968.
I. INTRODUCTION

Developing technology, coupled with changing modes of practice and changing patterns of disease, have forced the revision of accepted medical routines with frustrating frequency. The increase in technological applications in medicine has shifted the focus of activity from individual practice to institutional practice and has led first to an increase in specialization and then to an increase in professional interdependence. There is now a growing need for physicians to cooperate with scientifically trained professionals in other fields, and a need to delegate medical decisions to a broad range of technical assistants. The impact of quantitative biological science on medicine has changed the criteria for clinical judgment, and reopened the question of how physicians make decisions, what information is needed, and how it should be gathered, organized and presented.

The analysis of medical information in terms of "user requirements" presents a series of challenges:

- Medical activities are difficult to comprehend because of the unique vocabulary and logical structure of the medical disciplines.

- There is no adequate framework upon which to structure such an analysis.

- The definition of the problem area depends ultimately on features which are difficult to quantify or which have never been successfully quantified.

- Medical information contains many interrelated aspects -- the literature on the ways that information is used is scattered in many sources and is presented from many unrelated points of view.

All of these challenges have had to be faced in this study, and the authors are acutely aware of the limitations of the result. The most significant feature of the study has been the development of a set of **tutorial constructs**, descriptions which do not summarize what we know, but rather fulfill the requirement that one "get a picture of the problem." We chose the constructs to clarify the logical structure of medicine in a way which should not require an extensive
experience with medical vocabulary. Each construct attempts a rudimentary unification of the available information on some topic. We attempt to relate these constructs so that the problems associated with medical information unfold in an understandable manner.

Limitations in our understanding of medical information has left rough spots in the exposition. However, it has seemed more fruitful to display our ignorance than to present a false consistency.
II. MEDICAL ACTIVITIES WHICH RELY ON INFORMATION

The information requirements for medical practice are related to a larger set of medical activities which rely on information. Fig. 1* sketches in overview the separate objectives of the activities in the larger medical environment and indicates how they are related. The major activities have different goals, clarified by dividing the world into action (real-world manipulations) and information handling (conceptual manipulations).

- Fundamental Research: A process of inquiry which has as its goal the building of rigorous scientific models.

A major objective is to make models which are as testable as possible. Distinctions which have been made by experiment or by fortuitous observation are coordinated into a framework -- the more precise the framework, the greater the chance of discrepancies being made visible between the model and the real world, allowing theory to evolve by revisions and extensions of the models. Theory becomes a reservoir of conceptual scientific information. The relationship between the reservoir and possible new technology is very complex. The lag time to usefulness is variable, and may be quite long. (1) Diverse areas of interest are often united in tenuous ways, producing sudden bursts in the demand for information from unexpected directions. (2)

- Clinical Practice: A set of actions which have as their goal the reliable implementation of clinical concepts for the prevention, correction, or control of illness.

The concept of disease provides a set of operational models which allow the physician to generalize about the defects and imbalances which arise from time to time in the individual. Disease descriptions bring together different kinds of information: observations on the natural course of illness, formal scientific understanding, and

*We are indebted to Tyra Hutchens, Chairman, Department of Clinical Pathology, University of Oregon, for this formulation. The diagram has been modified from one which will appear in a forthcoming monograph by Dr. Hutchens.
Fig. 1 -- The space of medical activities related to information.

Adapted from Tyra Hutchens
experience with the outcomes of particular procedures. In some respects the identification of a disease process is like a troubleshooting routine. However, there is an important distinction between troubleshooting in medicine and the troubleshooting of machines — in biological systems we have no master plan of assembly or operation. Thus there is a high level of ambiguity and uncertainty about the meaning of observations. Clinical entities are models of disease processes which are constructed in order to reduce this ambiguity.

- Clinical Research: The introduction into medicine of new applications of fundamental knowledge by means of a "prototyping process" which has as its goal the development of operational models as conceptual tools to guide medical practice.

Operational models deliberately avoid the exacting formulation needed for experiment — parameters are weighted or otherwise distorted to achieve consistent practical results despite incomplete information. The development of prototypes for such operational models is a major activity of the university medical center. The intensive development of new concepts implies rapid change in the operational models needed by the physician to remain contemporary. The demands of physicians for more and better information and for continuing education are related to the perceived rate of obsolescence of these conceptual tools.

- Medical Education: A process of exposition which has as its goal the organization and transfer of medical knowledge for use at the present time and in a manner which facilitates updating in the future.

In order to accommodate changes in the information base, scientific models and operational models should be separately identified. There is a trade-off between investing in continuing education, i.e., developing a store of information to meet some future requirement, and investing in the ability to obtain a particular piece of information on request to perform some specific task. The trade-off depends on distinctions in cost-effectiveness between educational capabilities and the technology for information storage and retrieval. It is to be expected that computer-related technologies will change the manipulation of medical information in fundamental ways. For example,
computer programs to manage difficult clinical problems* are the fore-runners of changes in medical problem-solving which will alter the distribution of activities in every branch of medicine.

*For example, the work of Schwartz on electrolyte balance.
III. DECISIONS IN CLINICAL MEDICINE: A FLOW CHART DESCRIPTION OF THE CLINICAL PROBLEM SOLVING PROCESS

We wish to get a picture of how information relates to the overall process of clinical judgment. This discussion is designed as a tutorial to present nonphysicians with an overview of clinical activities. In Section IV we generalize on this description in order to characterize the interplay between the condition of the patient, the logic of the physician, and the state of our knowledge about particular diseases.

Until recently, descriptions of medical decisionmaking were largely anecdotal. Medical problem-solving was originally designed to be learned by apprenticeship and by long exposure. The behavior of physicians was interwoven with traditional medical concepts as part of a highly developed guild attitude. Rules for decisionmaking were drawn up loosely, on the basis of particular cases. A modern analytical approach to the problem of clinical judgment has only developed in the last ten years. Studies have analyzed the process of diagnostic categorization, starting with X-rays or with clinical data. Other investigators have looked at the decisions a physician must make in order to treat a patient who has multiple problems. In some medical subspecialties, teaching aids have been developed which take the form of programmed texts. Taken together, these studies indicate that the use of information in medicine differs radically from that of physical science. Because the tasks are different, many differences in the use of information are appropriate. Nevertheless, analogous formal structures can be developed to improve information handling.

To initiate the analysis, we look at the logical processes of present medical practice. We examine the decision points which lead to different medical actions, concentrating on decisions made by the physician and include some critical decisions made by the patient. As an analytic convenience, we introduce the challenge of developing a computer-based information system as if the whole physician decision process could be simulated in some way, even though the process is not...
well enough understood and the data does not exist in the proper form to actually carry out such a simulation in detail. (Moreover, the present decision system is undergoing such rapid change and contains so many idiosyncracies that it would probably not be useful to implement most present methods on a machine.)

The flow chart description presented in Charts I and II is a tutorial construct designed to show the relationship between information and present medical practice and make the methodology of clinical problem-solving more explicit. Chart II is Chart I in greater detail.

GENERAL DESCRIPTION

The flow chart conventions are as follows: the major components are boxes and circles. The boxes consist of "subroutines" which terminate in a medical decision. The boxes are further detailed in Chart II where each diamond is a decision point and each rectangle is some intermediate state in the subroutine description. The diamonds lead from one subroutine to the next, and the rectangles support these decisions. In both charts the circles represent routines and subroutines which have not yet been explored further.

In Chart I we trace a classical sequence of physician decisions by going from "start" to "out": examination, diagnosis, therapy. The "dispensary option" represents an alternative pathway. Further alternatives (not documented in detail) are the "multiple problem routine" and the "emergency subroutine." Note that there are many loops back allowing progress through the system to be very tentative.

Three points of importance should be kept in mind in the detailed description which follows:

- The decision process is not entirely under physician control, but is influenced (and at times manipulated) in major ways by the patient.

- Traditionally, the physician makes a simplifying assumption: "one patient, one disease", which allows him to search through ambiguous information for a consistent pattern in the data.
Chart I -- Physician decisions
The average hospitalized patient is now sixty-five years old and has five active medical problems requiring separate attention — the classical assumptions of "one patient, one disease" are not so satisfactory as they were previously.

DECISIONS UNDER PATIENT CONTROL

The patient plays a major role in three decisions. The first is patient entry, which initiates the system. The second is patient compliance, which is critical for a continuing therapeutic relationship. The dispensary option is a third decision point under partial patient control. These are the three most common points where the patient can decide to leave the system or can fail to enter it. The patient is free to leave the system at any point; however, except at the points indicated, it requires an exceptionally high level of dissatisfaction to do so. All other decisions are made by the physician, but the physician's ability to control the situation is limited. For example, the patient may manipulate the system by deciding what information he will give the physician, or the patient may compare the advice of several physicians, shopping around until he finds advice with which he can agree.

Patient Entry

The patient seeks assistance when his anxiety exceeds some threshold. His perception that he has a problem can be very subjective, because the patient often lacks the information necessary to decide on the seriousness of his discomfort. This awareness is also a matter of education, so that striking differences occur among different social groups, particularly with respect to early indicators of disease. The threshold of anxiety is also variable. A high threshold might be associated with stoicism, or a strong skepticism about medicine; an overly low threshold might be the result of excessive personal worry about disease, or the result of an over-effective health campaign.

The Dispensary Option

If the patient is to remain in the clinical system, the physician must anticipate some gain from defining a diagnosis and taking a
therapeutic action. The physician makes this judgment after his initial assessment of the "chief complaint" -- which is the physician's statement of the problem "as the patient sees it." A decision is made following a history, usually a physical examination, and perhaps a preliminary set of laboratory results. The problems of many patients are self-limiting and of short duration, requiring no more than sympathy, advice and symptomatic treatment to reduce discomfort or disability. The dispensary option provides a means of treating such illnesses and at the same time equivocating in order to insure that a more serious problem is not developing. This leads to the classical test of dispensary medicine: "Take two aspirins and call me in the morning if you do not feel better."

Specific instructions are needed to flag important problems so that the patient with a serious illness will return to the system. The criteria for this judgment are generally set by the physician, but the decision to return is usually made by the patient himself. The patient's ability to judge depends upon his experience, what he has been told, and how well he understands it. Thus the effective transfer of information from the physician to the patient is a critical problem in effective therapy. It is often made more difficult by cultural and ethnic differences between doctor and patient, and by various forms of institutional obtuseness. The many facets of this problem are all too familiar in university out-patient clinics, particularly those which are located in ghettos.

Patient Compliance

The therapeutic importance of effective information transfer from physician to patient is emphasized again where the patient is asked to accept a medical regimen. If the patient is to cooperate in an active way, he can only comply if he receives information which he understands in a form that he can act upon. Before a therapeutic course of action continues for very long, the patient must be satisfied that the therapy will aid him in some way. Trust on the part of the patient is necessary because cooperation is often required before important results can be assessed. Physicians idealize this prerequisite of trust as the
"doctor-patient relationship", but in modern technological medicine, trust may also be transferred to groups of physicians and to institutions.

DESEIONS UNDER PHYSICIAN CONTROL: INITIAL WORK-UP

When a patient first enters the system, a number of preliminary steps are taken to collect and organize information. The flow chart breaks this entry sequence into component parts. In particular, the chart points out that behind the classical approach to diagnosis and therapy there is an assumption of consistency: "one patient, one disease", which is required to sort out the information.

Rapid Initial Assessment

Here the objective is to sort out (by check list) those critical problems where an emergency intervention may save a patient's life or forestall serious consequences. This list, must be often updated, given the development of new skills and technology, and changing hazards.

Emergency Subroutine

Emergencies are an enormously variable set of circumstances which require rapid action and which may have a high penalty for poor judgment. Emergency decisions duplicate the problem-solving elements of the whole decision process with an additional time constraint. Because of the time element, emergency procedures tend to be particularly well defined routines, and the enormous variability of emergencies requires special skill in the application of such routines. Optimal judgments have become more complicated as new knowledge and new technological

* The recognition of a pattern of observations or events which demand immediate action is much more complex than indicated here. Some of these actions are obvious -- to stop bleeding, to provide an airway, etc.; some are more subtle -- to prevent brain swelling, to manage an allergic reaction or a cardiac arrhythmia, etc.
alternatives have become available. Established medical regimens are packages of procedures, each of which at one time required a separate decision, but now appear as a single routine. When regimens become obsolete, or are revised, or are inappropriate to a particular case, the component decisions again become important.

Does the Patient Have a Simple or a Multiple Problem?

The usual conventions for the collection of medical information have been developed in order to sort that information in favor of a single diagnosis. Thus, in the flow chart, this critical decision is placed ahead of the initial work-up. If the patient has multiple problems which interact or multiple therapies which interact, the simplifying assumption of a single diagnosis may be so at variance with the facts of the situation that the usual work-up is self-defeating. Alternative methodologies have been proposed which promise to be effective in such difficult medical problems (see below), but initially it is often more convenient (and for a time more reliable) to follow accepted conventions. Thus, where interactions exist, logical unity is maintained by considering one disease as a "complication" or another, or as a "consequence" of another. However, with increasing complexity, defining disease combinations as new clinical entities becomes more and more tenuous and potentially misleading.**

Multiple Problem Routine

As demonstrated by Weed, the direct approach to multiple problems requires a new form of data organization and a new kind of discipline. In order to consider diseases and/or therapies which

---

*An example of a relatively simple emergency procedure which has undergone marked recent revision is artificial respiration, for example, for drowning. There have also been advances in the design of respirators. Intensive care units and coronary care units further exemplify the changing potential of technological "packages" for emergency situations.

**Consider the not uncommon situation of an elderly woman with a broken hip, heart failure, and poorly functioning kidneys, who has just come from the operating room and threatens to go into shock. No disease combination adequately describes her condition.
interact in significant ways, it is often convenient to ignore diagnostic categories and to choose clinical entities which are the physiological components of diagnoses. Where there is uncertainty which derives from the interactions among multiple problems, the relative timing of events can be emphasized by maintaining a record of a patient's problems in a parallel format. In many such cases only short forecasts about the future state of the patient can be made, i.e., the therapeutic planning horizon is short. Using this format, the plan is allowed to evolve in small steps in a disciplined, tentative way. For each problem, observations are selected which assess therapeutic success, and where necessary, additional observations are used to follow the interactions. This approach is further elaborated in Section IV.

**Assume Simple Problem: What Action?**

The work-up brings together an initial history, physical examination, and laboratory reports. This information may lead to a judgment which either commits the patient and the physician to a structured course of action designed to establish a diagnosis and to define a treatment, or else the physician may consider this whole process to be probably unnecessary or unfruitful. The negative decision is usually tentative leading to the "dispensary option," where the patient receives instructions to come back into the system if certain criteria are not met.

The work-up should provide data to choose a set of alternative clinical entities, i.e. to set up a differential diagnosis. However, our present capacity for generating data leads to a dilemma: A discrimination among alternatives can be made only on the information gathered, and thus the more the better; but when the sorting rules

---

*Eden and Rutstein* (15) have carried out some investigations on what the most important initial information might be. Parker, Adelstein, and Lincoln have examined how much additional information may be introduced by a new test. (16)
rely on consistency, there is real value in keeping the data base small in order to reduce the "noise" and keep the problem-solving process manageable.*

DECISIONS UNDER PHYSICIAN CONTROL: THE DIAGNOSTIC PROCESS

Clinical diagnoses represent classical ways of categorizing disease. A diagnosis ties together data about a patient into a unit interpretation, thus reducing the ambiguity of medical results and observations. Moreover, medical information is collected, indexed, and studied by disease category. In this way the physician links the patient's illness to broader medical experience. He can now consult any number of textbooks, which are really "encyclopedias" that contain information about such things as: the time course of events which make up the natural history of disease; speculations and facts about the processes which underlie these events; judgments about alternative therapeutic goals; assertions about the likelihood of attaining particular goals under different therapeutic policies; advice about complications and special information about unusual exceptions.** The diagnosis may also point directly to any of a number of standard regimens, which are considered at some point in time to be acceptable therapy.

However, the flux of medical information brought about by clinical research, by fundamental research, and by the heuristics of practice (Fig. 1) made it difficult to maintain a valid, updated set of diagnostic categories. The interactions which exist among diseases and therapies in the same patient further complicate this categorization. However, long before the classical system of information management breaks down, the sorting procedures designed to define a diagnosis and help lay out a therapeutic plan become markedly inefficient, and both the patient and the physician pay for this ineffective logical

* Theories of cognitive dissonance analyze these consequences in detail. (17)

** This point is stressed here because textbooks in other fields often exhibit more abstract systematization and are organized in a very different way, for example, textbooks of mathematics.
system by an increased investment in time, effort, and money. Nevertheless, with all its defects, the classical system is the major one in use today and is detailed below.

Set Up a Differential Diagnosis

This step generates a list of "impressions" -- a set of disease categories which should be inclusive enough to contain the "correct" diagnosis. Because there are many steps in the definition of an illness and the planning of therapy, the generation of such a list is a subjectively satisfying intermediate step. The physician searches his memory first, knowing that he must consider information which will turn out to be both inaccurate and incomplete. His initial selection is heavily influenced by his personal experience in practice, but this data-base is subject to only occasional control, i.e., rare disease categories that depend upon subtle distinctions may escape the attention of the busy physician in general practice who does not expect to see them. On the other hand, the specialist may ignore common diseases in an unfamiliar area. Thus, if the physician is unsure of his list, he will consult back-up material such as a treatise on differential diagnosis or an encyclopedic-textbook.

Choose a Diagnostic Alternative

This step attempts to select the "correct" diagnosis from the list of impressions. The list is used to gather more information and is then searched to choose the diagnostic category most consistent with the data.* In the best circumstances, a physiological test directly measures some critical parameter, giving a precise result.** In another case, a surgical operation might be needed to decide among

---

* The exercise of setting up a differential diagnosis has been formalized in the Clinical-Pathological Conference. Here the concept of one patient, one disease can be brought to the point of academic virtuosity through the identification of a multiple-system disease such as amyloid or lupus crythematosus, where a disease with a single origin has a complex expression.

** For example, the glucose tolerance tests for diabetes, which tests directly the physiological ability to handle a measured amount of sugar.
several alternatives. If direct verification is not available, then the presumed diagnosis must be chosen on weaker criteria.

The decision threshold to continue to the next step is set in such a way to avoid serious error. Again the selection is influenced by the expectations of practice. Three important ways of weighting judgment are: incidence of occurrence, severity of the disease process, and the ability of the physician to affect the outcome. The weights are assigned in widely differing ways -- at one extreme, the commonness of certain complaints dominates, and at the other extreme the severity of the consequences or the scientific interest in a rare case outweighs all other considerations. Ultimately the usefulness of diagnostic categories depends upon the ability which they give the physician which can influence the therapeutic plan. As knowledge about therapy changes, so too does knowledge about disease, so that a major complicating factor is the change in the diagnostic categories with time.

If no consistent picture emerges from the data (or if the threshold for consistency is set very high), the list may be considered inadequate and reassessment procedures introduced. Alternatively, more data might be gathered to see if the threshold can be exceeded.

Reassess Assumptions

No formal rules are available which fully describe the process of reassessment; however, this is a common point where consultation is requested. Through consultation the available information is reevaluated to discover whether perhaps the correct diagnosis might have been overlooked, if faulty or incomplete data obscured the choice, or if the presence of several problems requires a different structuring and analysis of the observations.

DECISIONS UNDER PHYSICIAN CONTROL: THERAPY

The objective of therapy is to affect the course of an illness in both favorable and reliable ways. Even if the diagnosis is correct, several major uncertainties remain: the biological status of the
patient presents a risk, the effect of a therapeutic procedure on the outcome is associated with uncertainty and there are uncertainties (and inconsistencies) concerning the relative value of outcomes.

A therapy may be unpredictable because it only weakly influences the underlying disease process; or the therapy may be strong enough, but exhibit many adverse consequences. One measure of therapeutic reliability is the degree to which one can disregard ancillary risks which depend upon a patient's biological status; i.e., how few additional variables need be considered to obtain a predictable, favorable result.

Because at times medicine challenges men's deepest social and personal convictions, it is not surprising that there is no unanimity of opinion about the ultimate value of medical procedures. The preferences which lead to the choice of one medical outcome over another are often only vaguely stated and may or may not exhibit some simple rule of consistency. However, commonly accepted working agreements usually define best practice, and these are only fundamentally challenged in extreme or unusual cases.

Modern medicine has stabilized the acceptable goals for therapy by putting together standard regimens which at the same time facilitate the means of achieving these goals. In a particular circumstance, such packaged regimens may be appropriate or inappropriate, but faced with rapid technological change and limited means of critique, the physician often accepts a package as a matter of necessity.

The development of "packaged" regimens has constrained the introduction of innovations so that physicians look to the authoritative advice of qualified colleagues. In serious situations therapeutic plans remain in use because they are familiar and "checked out."

Such plans are replaced only slowly by new plans when the prototype procedure is felt to be sufficiently reliable and to show a reasonably large increment of improvement over previous procedures. Where the therapy is relatively innocuous (i.e., where the impact of therapy on the outcome is not great), or where the situation itself is not serious, or where the required modification or prior experience is small, a physician may take great pleasure in being "modern" and trying the "latest thing."
Development of a Therapeutic Plan

This process makes explicit those features which are often only implied in a packaged regimen. As the flow chart indicates, the design of a plan should weigh the predictable effects of the available therapeutic alternatives against the seriousness of the disease and should also take into account various relevant characteristics of the patient. The plan should also consider the implications involved if the assumed diagnosis is wrong. This is difficult to do with a package.

Even if the diagnosis defines the probable outcomes with and without therapy, a goal for therapy consistent with best practice may remain tenuous. There are legal penalties for setting the goal too low and a professional penalty of risking the absurd by setting the goal too high. There is often a wide latitude of judgment, particularly in areas of rapid change or high uncertainty.

In the decision to implement a therapy the physician's choice is usually a conservative one, designed to minimize adverse consequences, consistent with an acceptable level of success. If the initial goal cannot be achieved by a satisfactory plan, then the goal may be revised downwards and a new plan generated. Alternatively, all of the criteria for evaluation may be changed. For example, where the prediction of the outcome is pessimistic or the available therapies are not known to be effective, the therapy chosen can be considered to be "experimental." The process is further defined in Section IV.

Verification by Therapy

This decision takes advantage of therapy to verify diagnosis. If verification fails, the whole diagnostic process is reconsidered. The judgment has all of the difficulties of an experiment with less than a minimum number of trials. The strongest criterion is consistency with a set of projected future data points so that the outcome and the path to the outcome lie within some "envelope" of possibilities. Such a test situation may be considered as an extension of physiological testing.
Is the Therapy Achieving the Desired Goal?

This decision is more exacting than diagnostic verification because the "envelope" of allowable data points is tied to a particular outcome. If the progress of the patient is judged to be unsatisfactory, a reassessment is called for. Ideally the criteria for judgment should be particularly sensitive to deviations from the desired outcome and the measures of success should ultimately reflect the best achievable result from the patient's point of view. However, these criteria may in fact be far from ideal. In serious disease, the criteria of success may be tied to some ad hoc definition, such as five-year survival, and in these cases, where in effect the medical profession defines its own success, the result may be very far from a social optimum.

Reassessment of Therapy

This often takes the form of a consultation or a conference. The process is to re-sort and reorder the available facts, to reassess the therapeutic goal and the tactics for reaching it, and possibly to reassess the validity of the presumed diagnosis.

Further Therapy Needed?

This decision examines the grounds to continue or discontinue therapy. The decision to terminate therapy implies that little can be gained by further action and that there is no further need for continued physician responsibility. The decision is in some sense equivalent to the earlier decision between the dispensary option and a more complete work-up. The criteria are very sensitive to what the physician considers his job to be and will differ markedly between specialties and between specialty practice and general practice. *

* Third-party insurance payments have had a strong influence on the discharge decision by removing the direct consideration of cost to the patient. In this case the physician needed not weigh the cost of his actions to the patient against their possible benefit. Thus the smallest increment benefit may be considered sufficient justification.
In some cases there are rituals which have been set up to define discharge, but even these exhibit enormous local variation, with many fluctuations of opinion.

If the patient is discharged, he may be advised to return under certain circumstances, or he may leave the system entirely. If the decision is made to continue therapy, the patient must concur, and the cycle of control checks is repeated.
IV. THE USES OF INFORMATION IN CLINICAL PROBLEM-SOLVING: AN ANALYSIS

Our aim is not to prescribe what a decisionmaker ought to do according to some axiomatic standards, or to learn the impact of one variable on the decision when all other factors are kept constant. The aim is to identify the variables that will influence the decision process in order to explain the process itself and to be able to predict the behavior under various conditions.


In the same spirit of inquiry as that quoted above, we now wish to look at the elements of medical decisionmaking in all of their baffling complexity. Our objective here is to understand the ways that information helps the physician to arrive at reliable conclusions in the treatment of an illness. The flow charts presented in Section III set the stage for this analysis. However, these charts do not describe the parameters used in medical decisionmaking in a general way. We would like to find a consistent way to describe not only the classical medical decision sequence, but also the decisions necessary for multiple therapy, and the more specialized kinds of judgment needed for emergency and outpatient medicine.

Aharoni(20) points out that any decision process contains the following elements: First, the process takes place in some organized decisionmaking environment — in this case the social and behavioral environment of medical practice. Second, the process takes place in time, and depends upon time, often in a critical way. Third, decisions are made subject to risk and to uncertainty. Fourth, the system has goals and generates goals. Lastly, there are many constraints on the freedom of action of the decisionmaker.

As described in Section II, basic knowledge about diseases and their therapies is part of the informational environment of medical decisionmaking. Much that physicians would like to know has not yet been discovered. The state of medical knowledge with respect to
carrying out a reliable therapy dominates the physician's approach to illness. In Fig. 2 we present four different approaches to illness, each of which represents the most reliable therapeutic policy for some sets of diseases. Each policy depends on the kind of information known about that disease.

FOUR APPROACHES TO ILLNESS IN TERMS OF THE MOST RELIABLE THERAPEUTIC POLICY

- **Supportive Therapy**: So little is known about the disease process that the most appropriate treatment can be directed only vaguely at the disease; the main therapeutic effort is directed toward affecting the patient's general biological status and the patient's environment, i.e., treatment is symptomatic.

- **Patient-specific Therapy**: A therapeutic policy exists to treat the disease process, but due to a lack of broad therapeutic effectiveness the patient's entire biological status must be considered in addition to treatment of the disease process itself; i.e., the therapy must be tailor-made to each individual patient.

- **Disease-specific Therapy**: The disease process is so well understood and the therapy available is so effective that a generally applicable treatment with few side effects can be carried out i.e., the focus of attention is on the disease rather than on individual patient differences.

- **Multiple-problem Policies**: The presence of several diseases and several therapies in a single individual introduces complicated interactions. This therapeutic process is characterized by the reassessment of actions each designed to influence the future over a short time interval, i.e., the situation is managed in an iterative fashion using a "short planning horizon."

The "amount" of information which is needed for reliable clinical problem-solving is illustrated conceptually by the height of the bar graphs in Fig. 2.*

*Types of practice, such as specialty practice, research-oriented practice, general practice, and multiple-problem medicine, are defined and discussed in Section VII. As indicated here, types of practice, and thus the social environment of medicine, stand in a natural relationship to information use, and a preferred pattern of professional behavior is related to preferred therapeutic policy.
Fig. 2 -- Four approaches to illness in terms of the most reliable therapeutic policy.
In this section we examine how each therapeutic approach serves to emphasize a different aspect of clinical problem-solving. We introduce a generalized structure for the problem-solving process in Fig. 3 where each aspect of problem-solving is presented as an intermediate stage in the decision process, with its own rules, leading from one stage to the next in the cycle. In this way the separate contribution of information to each stage can be characterized. In practice it may take numerous iterations through the entire cycle of Fig. 3 to resolve a medical problem. The time interval between these iterations may be viewed as the time interval until the physician's next reassessment of the patient — the time between clinic visits, or the daily routine of ward rounds, or the observation pattern in intensive care. The preferred interval is related to the time over which the physician expects to reliably forecast and influence the future state of the patient. To link this diagram to Fig. 2, we single out circumstances where each intermediate stage in the decision process would receive special emphasis.

SPECIAL USES OF INFORMATION IN CLINICAL DECISIONMAKING

- **To categorize patient problems:** Structuring patient data into clinical entities.

  This stage is particularly significant in cases where a specific therapy exists for a clinical entity; then the most rewarding problem-solving goal is to make the appropriate categorization so that the proper therapy can be applied. This approach, with its attention to well-defined diseases and to disease specific therapies, and with its emphasis on diagnosis is favored by physicians who limit their practice to a specialty.

- **To forecast clinical outcomes:** Relating clinical entities to future states of the patient which may result from a therapeutic policy.

  Here significant problems arise when differences between individual patients are critical to the application of the best available therapy. When a particular therapy appears valid for only a small set of individuals or when there may be serious side-effects, information
Fig. 3 -- Problem-solving cycle for clinical decisionmaking.
is used to modify the textbook forecast to formulate patient-specific therapies. This problem is characteristic of diseases where the best available therapy is "experimental," an area preferred by the university based, research-oriented clinician.

- To choose among actions: Specifying constraints which depend on the patient's values or on those of his environment.

This stage is significant wherever the best available therapy is supportive therapy, i.e., wherever so little is known that only the symptoms of the disease can be treated and the environment arranged so that the patient is more likely to improve on his own. Here the patient's style of living, his job, and his social and financial condition play dominant roles in choosing the best action. Some such diseases are minor, but many are not. The physician in general practice is particularly aware of these considerations.

- To monitor actions: Reassessing chosen policies to evaluate results.

Whenever a therapeutic policy must take account of multiple problems, the emphasis on the reassessment of previous actions is inescapable. Previous actions are monitored with each cycle of the problem-solving process. Multiple-problem medicine, requiring a simultaneous attention to numerous problems, is new as a full-time medical preoccupation. It represents an attitude of mind common to such diverse activities as intensive care and modern geriatrics.

Reviewing our statements about the components in the decision-making process, we return to the above-mentioned elements identified by Aharoni. All of these elements are present in each problem-solving stage; but a particular element can be thought to dominate each set of decisionmaking rules.

When time dominates, as it does in intensive care and in emergency situations, the rules to monitor actions (see Fig. 3) become paramount. We can identify a trade-off between the rapidity of the cycle, and the in-depth pursuit of a particular stage in the decision sequence: the shorter the planning horizon, the more rapid the cycle. (This is elaborated in Section V.)
The reduction of uncertainty in the definition of patient problems dominates where specific therapies with high effectiveness are available; and thus the precision of the rules to characterize patient problems become the critical factor.

The proper goal for therapy becomes a compromise whenever the choice is among regimens of limited effectiveness. The rules to forecast clinical outcomes help to characterize alternative investments in patient well-being so that the relevant trade-offs can be considered.

The constraints to decisionmaking become important decisions in themselves whenever the patient has requirements which force a deviation from the physician's view of best practice. The patient's willing compliance (as opposed, for example, to a court order) can only be gained if the rules to choose among actions lead to a decision in some sense compatible with the patient's life. This problem is particularly significant in areas of cultural difference between the physician and the patient such as exist in ghetto medicine.

The environment of the problem-solving process is the body of information related to medicine, i.e., all of the medical activities outlined in Fig. 1 (Section II). Changes in this environment can be understood by a reexamination of Fig. 2 -- now presented again as Fig. 4. The set of therapeutic approaches form an historical sequence in the evolution of our knowledge about the treatment of disease. The chart can be interpreted as showing the change in the informational environment for any medical problem over some unspecified time interval. In this evolution, the growth in the amount of information used in problem-solving (illustrated by the growth in the height of the bar graphs) represent the acquisition of detailed knowledge through therapeutic trials. A successful, reliable therapy reduces the amount of information needed to manage the patient (and thus reduces the height of the bar graph). These changes in information over time raise problems in the growth and storage of information and in the requirements for continuing education, aspects of which are more fully discussed in Section VIII.

We have singled out several ways in which a particular stage in the decision process can receive special emphasis. As problem-solving
Fig. 4 -- Evolution of therapeutic types.
proceeds in sequence through all of the four stages, the results are documented in the patient record.*

Four Sets of Results Which Document Decisions About the Patient

- **Patient data:** Data gathered as measurements, observations, and historical reports, ordered to facilitate the categorization of patient problems and to set the stage for a subsequent reassessment.

We define information of this sort as *observables*. They consist of data points which have some normative value with respect to health so that deviations can be used as indicators of disease. Observables may be: (1) a list of possible observations which might be made about a patient at a given time, \( x_1, x_2, x_3, \ldots \); (2) deviations \( y_1, y_2, y_3 \ldots \) of the \( x_i \) from some normative range, and (3) rates of change \( \frac{dx_1}{dt}, \frac{dx_2}{dt}, \frac{dx_3}{dt} \ldots \) observed over time.

The space of possible things to measure has become very large and is increasing. Within this framework, the value of an observation is its contribution to the reliable definition of disease processes. The other side of the coin is the cost of obtaining this observation.

- **Clinical entities:** Information incorporated in operational models to define abnormal processes so that a forecast can be made about future consequences.

The term *clinical entity* avoids the overdefinition of a patient's illness as a disease. A clinical entity may be a description which can be resolved into a number of diseases (such as hypertension), or a clinical entity may be some physiological expression of a single disease (such as sudden shortness of breath at night due to heart

---

*Weed (11) identifies four kinds of documentation applicable to the patient record: (1) a collection of patient data; (2) a "complete" list of patient problems; (3) a therapeutic plan for each problem; and (4) a set of progress notes relevant to each problem. In Fig. 3 we modify the names of these four categories, but alter the content of only one -- we replace the single therapeutic plan with the list of outcomes which are a consequence of possible alternative therapeutic plans, described in terms of probabilities and relative preferences.*
failure -- paroxysmal nocturnal dyspnea). Each clinical entity, i.e., each operational model, is a configuration of parameters defined in terms of a set of conceptual state variables. In order to achieve reproducible, practical results these variables attempt to encompass not only that which is well understood, but also areas that are poorly defined. Thus, if a set of biological variables $p_1$, $p_2$, $p_3$, ... exist, and a set of relations $R_1$, $R_2$, $R_3$ organize these variables into a scientific model which is an incomplete representation of the real world, then some transformation is used (and perhaps some additional variables or relations added) to achieve a better heuristic fit.

The documentation of a clinical entity is set up in terms of a set of conceptual state variables $\lambda_1$, $\lambda_2$, $\lambda_3$, ..., deviations of the $x_i$s from some normative range $\delta_1$, $\delta_2$, $\delta_3$, ... and changes in these variables $d\lambda_1/dt$, $d\lambda_2/dt$, $d\lambda_3/dt$, ... observed over time.

The value of a clinical entity depends upon the reliability which it adds to the forecast of the possible consequences of therapy (including no therapy). It may, for example, contribute by allowing the physician to use his capacity for pattern recognition to identify likely errors or inconsistencies in the available data.

- **Value of alternative consequences**: Information used to define value criteria which in turn specify preferences among possible therapeutic consequences.

Identification of a clinical entity makes it possible to forecast the outcomes of therapeutic policies (including the policy of no therapy). Each outcome has two important descriptors which characterize the decision process: the desirability (or value) of each outcome's occurrence and the likelihood (supplied by the forecast) that a particular outcome will be achieved, including the uncertainty associated with particular outcomes and the risk related to the overall biological status of the patient, i.e., the probability $P(r|d,c,s)$ of outcome $r$, given that therapeutic action is taken in the presence of clinical entity $c$ in a patient with biological status $s$.

The rational decisionmaker will weight his preference for each outcome by the likelihood of achieving it. If this assessment can be stated in a consistent manner, the value of each path may be said to
have an expected utility, * a numerical expression which combines these two descriptors. The decisionmaker will then choose the path with the greatest expected utility.

In medicine the patient record gives a therapeutic plan which implies a "best" choice among a set of unstated alternatives. Thus the conventional wisdom of clinical medicine at any point in time might be considered as a set of "textbook expected utilities," resulting in recommended standard regimens, i.e., "given disease c, then d is the therapy of choice." However, it would be naive to suppose that there is some universal medical norm. The complexity implied by "well-being" seems to indicate that no single dimension can encompass all of the qualitative differences important to the patient implied by medical outcomes. ** Nevertheless in medicine there is widespread professional agreement on sets of criteria based on quantitative information about disease processes. For example, the physician can use a readily definable criterion (such as hemoglobin level) to guide his actions. Such information can be used to rank the preference by possible consequences of therapeutic policies. Two physicians could be expected to agree on a preference such as this one; but it would be surprising if they agreed on the overall recommendation based on expected utility, because the latter implies that they agree both on preference and on probability. The physician may have objective and subjective reasons to consider his probable success with a therapy to differ from the average probabilities of the textbook. Subjectively, the textbook probabilities always appear to apply to colleagues. ***

* Logical systems for making a sequence of choices among outcomes are generally referred to as utility theory, further discussed in Section V. Some examples of definitions are given in Raifa and Schaefer.(21)

** The means for handling multidimensional utility functions are explored by Raifa.(22)

*** Consider, for example, the classical conflict of opinion between the internist and the surgeon about the medical or surgical treatment of a patient with a bleeding ulcer. Due to the different data-bases of their experience, the internist and the surgeon hold differing views on the probability of the complications which might result from either medical therapy or sub-total gastrectomy. Each will consider his personal probabilities to be average and will emphasize his specialty.
Because the number of alternative outcomes is circumscribed, only a few preference orderings are available in most cases. Thus alternatives can usually be considered concretely and by example. Limitations in the range of allowable preference orderings imposed by the social and professional environment rarely become explicit except when the system undergoes some challenge of a social, technological, or religious nature.*

- Benchmarks of success: Selected data categories chosen to monitor expected results.

We use the term benchmark to describe those measures of success which a physician might choose in order to monitor the course of some therapeutic policy. For example, in one circumstance a benchmark might be "five-year survival," in another, a blood pressure of 140/90. A benchmark may be considered as a structuring of information as control variables. Observations used in control variables are equivalent to Weed's definition of progress notes in the patient record.

Some control variables may verify the validity of a therapeutic policy, others document the course of an illness, others may monitor the overall status of the patient, and still others may anticipate complications and serve as early warnings. To act as control variables information may be presented as a time sequence, such as a fever chart, or may be described in terms of threshold values, for example, the diastolic blood pressure as an indicator of shock.

The value of data used as control variables depends upon the importance of what is monitored, the sensitivity of the measure to critical change, the errors to which the data is subject, and the robustness of the underlying operational model.

One peculiarity of medical benchmarks is that therapeutic success is often defined in terms of a set of professionally understood measures which are satisfying to those within the profession, but which may have very little to do with the personal goals of the patient or the broader goals of the society. In this sense, the physician

* A classic example concerns the different religious preferences for saving mother or child in a difficult birth. The acuteness of this problem is now much reduced by the increase in ability to save both.
"chooses his own game." Poignant examples occur frequently in cases of prolonged terminal illness where the patient is sustained barely above the level of existence. Here the physician often finds himself unable to propose an acceptable reason to change a clearly ineffective and often counterproductive course of action because, despite the evident lack of success, his professionally accepted criteria are being achieved.

In summary, we note that the same medical information can be used in a variety of ways. Medical usage does not always make it clear in which way a particular piece of information is being used. In Fig. 3, this ambiguity can be avoided by noting that each set of variables has different dimensions (in the sense of dimensional analysis). Thus the observables may be considered in terms of data per patient; the conceptual state variables would then have dimensions such as data per problem; decision variables time (commitment) per problem; and control variables data per time-problem. For example, an elevated blood urea nitrogen might be regarded as a piece of data, as a component of uremia, as a result which implies a physician commitment to reduce the blood level and as a blood level to be compared with other blood levels in evaluating the effectiveness of a therapeutic policy.
REFERENCES


11. Weed, L. L., Medical Records, Medical Education, and Patient Care, Case-Western Reserve University Press, Ohio, 1969.


20. Aharoni, Y. The Foreign Investment Decision Process, Harvard University Graduate School of Business Administration, Division of Research, Cambridge, Massachusetts, 1966.


22. Raiffa, H., "Preferences for Multi-Attributed Alternatives" (Draft), The Rand Corporation, Santa Monica, California, D-17640.