108

# HEALTH EVALUATION THROUGH LOGICAL PROCESSING - HELP

HOMER R. WARNER, M.D., Ph.D. Professor,
University of Utah, U.S.A.

A computer system has been developed and put into operation at the Latter-day Saints Hospital in Salt Lake City, Utah which permits convenient computer entry of medical decision-making logic where it is then stored on disc and accessed to process each new pertinent item of medical data as it is added to any patient's file. These decisions may then be brought to the attention of the appropriate medical personnel via reports, scope displays and alarm indicators, and are stored in the form of a problem list for each patient. In this presentation three components of the system will be described: 1) the structure and sources of the patient data file, 2) the tools available to the user for creating HELP sectors, and 3) the file of decision criteria (HELP sectors) and the mode in which this file is used to efficiently process patient data.

## Patient Data File

The patient data file consists of a list of numbers, each of which uniquely identifies one patient and its position in the list points to the location of the patient's ID (identification) file. The ID file contains his number, name, date of birth, height, weight, sex, room number, doctor number, and pointers to other files. These other files are for specific types of data such as ECG, heart catheterization, medications, spirometry, history, diagnoses, blood gas, micro biology, clinical chemistry, hematology, urinalysis, x-ray, intensive care monitoring, and exercise laboratory. Within any type data file for a given patient, the data is stored chronologically in variable length fields. Each field begins with a word containing the code which identifies the type of data and the number of data words in this field. This is followed by a word containing a time and date which is most appropriate for this information, ie., in the case of the blood gas measurement, this is the time the blood sample was drawn from the patient. This is followed by the data. The last word in the field is a repeat of the field code and field length to permit backward searching through the file when this is most efficient.

Once a user program has accessed a patient's file, the location of his ID file is returned to the user in order to facilitate future accesses to this record. Each page is represented as a bit in a page directory, where 1 indicates a page is already assigned. If more than two pages (128 or 512 words each) are needed for a given type of data on a patient, a special directory is created to keep track of his page assignments.

In addition to this main file which contains patient data, a higher level file is maintained which consists of a list of the patient's problems and current medications. These problems are defined either by the physician or by HELP as it processes each new data entry for this patient. This file is called the

Problem Oriented Record (POR). With each problem entry is stored a pointer to the data in the patient's main file which was used to define that particular problem. For instance, if a diagnosis of acute respiratory acidosis is made, the values for $pCO_2$, pH, and bicarbonate will be stored in the main file and retrieved on demand to "explain" this problem to the clinician should he request it. The time each problem is defined is also stored for future reference. When a problem is resolved or the state of the patient changes (ie., a new ECG is analyzed and a different diagnosis is made), the old problem is set to an inactive status and the new problem is added to the POR. Thus a current problem list is always readily accessible on each patient without having to access his main file.

Sources of Data for the Patient File

At the time a patient is admitted to the hospital he is referred to an admission screening clinic. Here the admission process begins by a clerk entering through a terminal the basic identification data contained in the ID file described above. Following this the patient is seated at a TV type terminal with a numeric keyboard and instructed by a technician as to how to execute a self administered history. The patient responds to sets of 1-5 questions presented on the terminal by entering an index number opposite each question to which his answer is "yes". When he is ready for more questions he presses the return key. When he has responded to the first set of questions the program calculates the probability that a patient giving these responses has each one of a set of 142 diseases using a Bayesean approach and a matrix of statistics regarding the probability of each symptom occurring in each disease. From these new probabilities the computer next calculates the information content and probability of getting a "yes" answer for each remaining question. From these calculations the next set of five questions is chosen and presented to the patient. This process continues until one of two things happens. Either the probability of one of the diseases exceeds 90%, thus establishing a diagnosis with sufficient certainty that other questions need not be asked, or the information content of the remaining questions becomes so low that the information to be gained by asking them does not justify the time and effort. At this point the program resets the probabilities to their initial values and proceeds through a review of systems. The diagnostic suggestions from this history are included in the problem list.

A program has been developed for entering diagnoses made by the physician at various stages of the patient's hospital stay. This is built on the system for coding medical diagnoses developed by the American College of Pathology called SNOP (Systematized Nomenclature of Pathology). This coding system contains four fields of information: the first describes the anatomical location, the second the nature of the disease process itself, the third the etiology, the fourth the functional abnormality associated with the disease process. A fifth field has been added to describe procedures and operations.

The coding itself is completely hidden from the physician. He simply enters words by typing the first two characters at a terminal. The computer then searches its library of approximately 40,000 terms for words beginning with these two characters. If less than 12 terms are found, they are displayed at the terminal. Otherwise the program waits until the third character has been added and again conducts a search. When a small enough number of terms are found which match those entered, they are displayed on a terminal and the user simply selects the one desired. If additional detail is required, a second list is presented which contains sub classes of the one selected. The user may continue this process until he has entered his description in as much detail as he is able. Any number of terms may be entered for any of the five fields. This same system is used to describe not only the admitting diagnosis, but also additional diagnoses and complications, operative procedures, pathologic diagnoses, and the final discharge diagnoses. Such a system allows the user all the flexibility of free test input and output coupled with economy of storage in the computer and flexibility and accuracy for recovery of information. Mis-spelling is not a problem since a mis-spelled word will not bring up a list of terms containing the one desired and will cause the user to repeat his entry. Many terms have been added to the SNOP library in order to make it suitable for clinical use.

Next the patient is asked to take a maximum inspiration and then expire as much air as he can as rapidly as possible into a spirometer. The displacement of the spirometer is sensed by a potentiometer which is one limb of a resistance bridge. The voltage across the bridge is fed to an analog to digital converter where it is sampled 50 times per second by the computer until the expiration is complete. The program next determines the forced vital capacity and the one second volume and performs the necessary temperature and pressure corrections. The program then displays the calculated values at a terminal in the test area as absolute volumes and as percent of predicted values using regression equations from the patient's sex, age and height. These values along with diagnostic statements generated by HELP are stored in the patient's computer file.

Following this, ECG electrodes are placed on the patient which permit recording of the 12 standard leads and the 3 Frank vector leads automatically, three leads at a time. As the machine switches to the 3 vector leads, the computer is interrupted and begins sampling each lead at 200 samples per second. The analysis continues until three hearth cycles have been analyzed. Following the recognition of key points on the ECG signal such as the onset and end of the QRS complex, parameters are extracted which are later used in the classification of the ECG into normal and disease categories using HELP. When analysis of the ECG waveform (morphology) is complete a single lead is chosen by the operator and fed to the computer for rhythm analysis. The ECG parameters and diagnostic statements are stored in the patient file, but the raw digitized data are discarded. From this stored information serial interpretation of the electrocardiogram is also performed when repeat determinations are made at a later time.

Also in the screening area blood and urine samples are taken from the patient to be analyzed in the clinical laboratory. Here analyses are made for 12 chemical constituents using an autoanalyzer interfaced directly to the computer. Also, automatic cell counting equipment is directly interfaced and these values are appropriately calibrated and stored automatically in the patient's computer file. Other tests such as urinalysis, bacteriology, and serology are performed manually and the values entered by the technician using a computer terminal. HELP logic is being generated to define problems from this laboratory data.

In the heart catheterization laboratories measurement of pressure, oxygen saturation, and indicator dilution curves are made directly from instruments connected to the patient and sampled by an analog to digital converter in real time. The computed values and sampled waveforms are displayed on a computer terminal in the laboratory for quality control of the data being collected. Diagnostic statements derived by the HELP program may be obtained on demand as the testing procedure is under way, thus permitting the acquisition of additional data if indicated from the analysis while the catheter is still in the patient's heart.

Blood gas measurements may be ordered by the nurse or clerk at the nursing station using a touch tone telephone. The computer queries the caller and responds to his input be generating "spoken words" using a vocoder. These words are assembled under program control from a large library of coded words stored in digital form on disc. After accepting responses to such questions as the patient's number, room number, the percent oxygen in the inspired gas mixture, etc., a test request is printed in the blood gas laboratory. The technician collects the blood sample from the patient and brings it to the laboratory where analysis is performed on-line to the computer. The program prompts the technician at each step in the procedure, samples the output of the instrument directly, performs the calculations, and using HELP, generates a diagnostic statement regarding the results which is included in the report and stored in the patient's computer file. Spirometric measurements are done in the same laboratory directly on-line to the computer and interpreted through HELP logic previously entered and stored by the pulmonary physiologist for this purpose.

An exercise laboratory is also on-line to the computer. Here three ECG leads are recorded as the patient performs a staged exercise procedure on a treadmill. At each stage, a series of ECG complexes are averaged to improve the signal to noise ratio and plotted for the clinician. Extrasystoles are eliminated by the program from the averaging process. From the averaged complex, measurements are made and displayed of the ST depression and slope of the ST segment. These constitute not only the basis for diagnostic statements regarding this patient, but also may alert the physician during the performance of the test of potentially dangerous ischemia should it occur.

Sophisticated measurements of cardiac performance are accomplished by recording the fluoroscopic image of the heart on video disc. The video frames are then replayed in the stop action mode, sampled by the computer using an A-D converter, and subjected to a probablistic border detection algorithm. The border coordinates from each successive frame during systole are used to define the parameters of a mathematical model of left ventricular border motion. Deviation of these parameters from normal values in a particular segment may be used to define and quantitate areas of abnormal dynamics in the left ventricle. This may be particularly important for the patient who is being considered as a candidate for a bipass vien graft to a coronary artery.

As drug orders are received in the pharmacy and a prescription is filled, the drug name, dose, route and other information are entered by the pharmacist into the patient's computer file using a computer terminal in the pharmacy. HELP sectors are used to define potential drug reaction and interaction logic using not only drug information but other data from the patient file such as his diagnosis and laboratory data to make these decisions. Such alarm conditions, if satisfied, result not only in a message to the pharmacist, but also generate a problem in the patients POR.

Tools Available to the User for Creating HELP Sectors

A HELP sector consists of a list of variables and modifiers and a statement of operations to be performed on these variables in order to decide whether the HELP sector statement is true or produce a number which may be printed out along with the HELP sector message. Also, the output of one HELP sector may be used as a variable item in another HELP sector.

The variables in a HELP sector are in the form of an index list and the values for these variables are referred to in a HELP sector statement by their index value. The user first enters the index number for a variable and then types in a character string as described above for SNOP. He chooses the desired variable from the items displayed and the appropriate field code and word number or bit number which defines this variable is saved. He may then choose one of the following modifiers which describe for HELP the transformations to perform on the variable listed under this item when the values are retrieved from this patient's file. These values are saved in the list under this index for later use by the HELP statement. These modifiers are first, last, maximum, minimum, average, mode, trend and frequency. All but the last two are self explanatory. A trend is a slope of the least squares regression line of the variable in time units later to be indicated and the frequency is the number of times this variable is encountered. Next the variable is indicated as being probabilistic or deterministic and if probabilistic, must be designated as binary or distributed. In the case of a binary probabilistic variable two other parameters are now entered. First, being the probability that this attribute will occur in a patient falling into the class represented by this HELP sector and the second parameter is the probability of this attribute occurring in a patient who does not fall into this class. In the case of the distributed variable, three parameters are stored to describe the distribution of the values for this variable in the disease group and three parameters are stored to represent the distribution of values for this variable in a population not having this disease. Next, a time constraint may be entered to limit the time over which entries in the patient record should be used in generating a value for the item under this index. The user may specify in minutes, hours, days or months the time before or after the present time or relative to another event specified under an earlier index in the item list. For example, one may wish to look at the minimum blood pressure value occurring within three hours following the administration of a drug. This provides the user with a very powerful tool for defining the time course of the events appropriate to a given decision.

Any item in a list of HELP sector variables may be the name of another HELP sector or a reference to a problem previously recognized by HELP and stored in the patient's POR. When a reference to a HELP sector is encountered, that HELP sector is analyzed and its truth or numeric value is stored in the item list along with the other variables. Thus a hierarchy of decisions may be constructed to any degree of complexity.

The HELP sector statement is a series of algebraic and/or logical operators referring to a combination of terms in the item list. If only algebraic operators are used the statement results in a numeric value for the sector which may then be referenced as an item in the list of variables for one or more other sectors or may be inserted into the message for this sector. If the message contains any logical operators, its ultimate value is either true or false. This too may be referenced by other sectors or if true may cause the sector message to be printed and the problem to be added to the patient's POR.

HELP sectors may be entered by a user from any terminal using a program which allows him to use each of the tools described above in a very natural way to create of modify decision criteria. Diagnostics are incorporated into the program to alert the user of logical inconsistencies if they are encountered, such as reference to non-existing sectors or ambiguities in a HELP sector statement. The system is designed for easy use by physicians who are expert in a particular medical problem areas, but who may not have an interest in or understanding of computer programming.

## How is the HELP File Organized and Used Efficiently to Process Patient Data?

Just as the patient data is organized into sub files by data type, such as ECG, history, etc., so are the HELP sectors arranged according to the type of data employed for each decision. Since one HELP sector may reference one or more other HELP sectors in its list of variables, it is important that the HELP sectors within a given data type are recorded into physical locations on disc which will minimize the number of disc reads that need to be undertaken during HELP execution. At the end of an editing session on a series of HELP sectors of a given type, these sectors are re-ordered so that those sectors which make no reference to other sectors are analyzed first, following in turn by sectors which make reference only to sectors which have already been analyzed. Such a sequencing procedure permits the sectors to be read into core in blocks of ten, analyzed, and logical or numerical values stored for reference by other sectors. This is extremely important since the limiting factor in the speed of operation of the HELP system is the time required for reading from disc.

The HELP program itself is core resident as part of the basic operating system. Most of the programs which have been written for data collection which store data in the patient file will access HELP and cause those sectors which utilize the data just collected to operate on the data in the patient's file. This results in automatic elimination of previously defined problems in this category from the POR and entry of new problems if they are generated as a result of the new state of the patient's data resulting from the latest data acquisition. Depending upon the station from which the data originates, a message may be displayed and an alarm might be turned on or no action may be taken other than the setting of a new problem in the POR. Report programs generally will not call HELP but will directly access the POR in order to generate diagnostic statements.

Still another useful mode in which HELP may be employed is in generating the criteria for a search across patients in the patient file. For instance, a committee charged with reviewing the quality of medical care may specify using HELP sectors the criteria for appropriate management of a particular medical problem. All patient files are then searched, the data subjected to this criteria, and patients are listed who fail to meet these standards. In a similar fashion HELP sectors may be created to define criteria for certain research goals. For instance, one might wish to generate a sub file on disc of those patients satisfying particular criteria in order to perform statistical operations on that data, test effectiveness of the treatment, or some other hypothesis. Thus, HELP is a language by which medical people can define decision criteria generated by experts and make it available to even the inexpert whenever the conditions are appropriate. In this way perhaps the time lag between the acquisition of new knowledge and its application to clinical practice may be effectively shortened.