

HELP - A MEDICAL INFORMATION SYSTEM WHICH COMBINES
AUTOMATED MEDICAL DECISION-MAKING WITH
CLINICAL DATA REVIEW AND ADMINISTRATIVE SUPPORT

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HELP is a hospital information system that has been developed at the LDS hospital in Salt Lake City during the last 15 years. It is routinely used to order tests, review results, capture costs, schedule procedures, and provide management information. It's pervasive influence in the hospital is illustrated by the number of users: there are 545 printers and terminals in the 520 bed hospital. In addition to these clinical and administrative functions that constitute the traditional role of hospital information systems, the HELP system supports automated medical decision-making. Whenever logical conditions for a specific decision (alarm, alert, diagnosis, interpretation, therapeutic recommendation) are satisfied by data which are present in an individual patient's computerized medical record, the system will automatically present this decision to the appropriate health care provider (nurse, physician, technologist, or pharmacist).

Before describing the mechanisms which provide these capabilities, we shall mention three specific reasons for the successful acceptance of the system which is now also being transferred to other institutions.

1. The data from many different sources are integrated into one comprehensive clinical data base for common reference by all types of users. When reporting the results of a clinical laboratory test, it does not take much extra effort to log the charges associated with the test. Such an integration of clinical and administrative functions serves to make both types of employees anxious to
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maintain the quality and integrity of the common database instead of separately trying to worry about their own concerns. The integration also makes it worthwhile for clinical personnel to regard the computer record as the single most authoritative source and all ancillary departments are anxious that the results of their services are prominently and correctly displayed.

The decision logic can be developed in a modular form. The logical criteria for a single decision are stored together in a procedurally (rather than declarative) oriented frame called a HELP sector. Because the evaluation logic is contained within each sector, the inference mechanism (the HELP interpreter) can accommodate a wide variety of decision models. Thus probability sectors may be used to rank likely diagnoses and logical IF...THEN... rules may be used to determine when a drug is contraindicated. The modularity assures that correct decisions will be produced for the existing sectors even though the breadth of medical knowledge contained in the system is not completely comprehensive.

3. The mechanism for producing the decisions is constructed so that the medical personnel are always recipients of the clinical information and decisions; they do not ask for assistance. When data which are referenced in a decision sector are entered into the data base, that sector is automatically activated and evaluated. Thus the decisions are "data driven" (also called forward chaining - the data lead to the results). The percentage of cases in which an alert (for example a contraindicated drug) is generated is so low that if the user always had to ask for assistance the payoff would rarely justify the effort. This low rate of return is more pronounced when the breadth of the knowledge base is limited (as is the case in all present systems for decision support); without the data driven activation the system would not be accepted by the actual health care providers.

In the sections that follow, we shall describe the functional aspects of the HELP system and then discuss the issues which relate to our choices for knowledge representation, inference mechanism, and logic activation.

The HELP system:

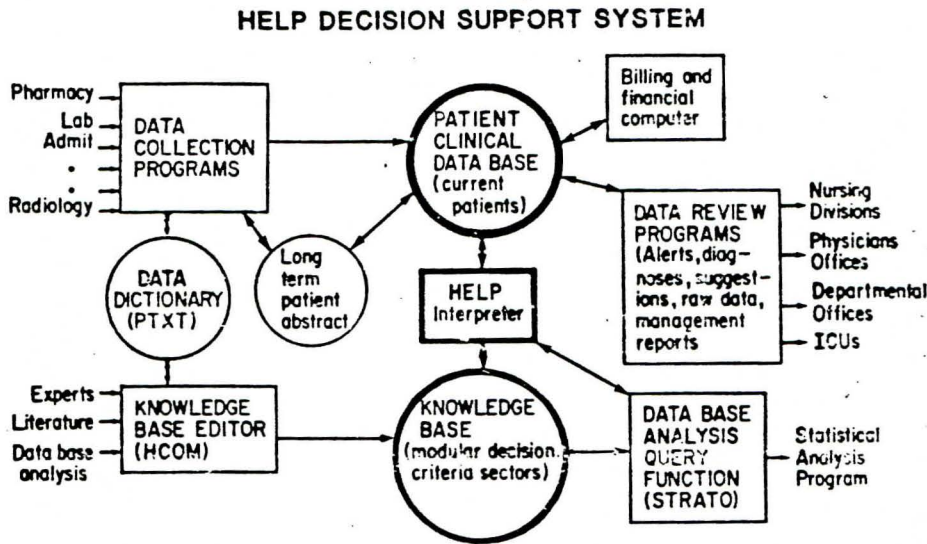


Figure 1: A functional overview of the HELP system

As can be seen in figure 1, the system essentially consists of three main parts: a comprehensive clinical patient database, a separate knowledge base which contains expert logic, and an interpreter which controls the evaluation of the expert knowledge.

Those elements in the upper half of figure 1 (data collection programs, the long term patient file, the current clinical patient file, the reporting functions and the link to the financial system) are fairly standard components which are found in many hospital information systems. The central data base should integrate data from and communicate with computer systems in ancillary departments in order for test ordering and results review to be possible at all terminals. We have chosen to use the Tandem computer for the central system because it is easily expandable and has built in hardware redundancy which helps to insure that the system is always operational. There are multiple microprocessors attached to the central system which may act as signal processors or contain distributed copies of the central

database for selected patients (e.g. those in an intensive care unit).

The long term file contains selected on-line data for all previously admitted patients and consists of abstracts of clinical and demographic information likely to be useful if a patient is readmitted. The clinical data base contains all data gathered during the current admission, and after the patient is released, this record is stored in archives which are available for statistical assessment.

All clinical data are stored in a coded format which is defined using a data dictionary. This coded format is necessary in order to allow all users who write the logic contained in the expert knowledge base, the data gathering programs or the report programs to accurately reference specific data which may be stored in the patient data base. An important aspect of this dictionary is the hierarchal structure of the medical terminology. Each major area of medicine (e.g. pharmacy, clinical laboratory, physical examination, EKG, catheterization laboratory, surgery and medical records) is assigned a specific data class. Within the data class, the terms are further subdivided into separate field codes for pain relievers, antibiotics, heart medication etc.

The elements in the lower half of figure 1 represent the additional features (knowledge base editor, knowledge base and the HELP interpreter) which we have developed in order to build a decision support system. Expert knowledge can be obtained from the opinion of an expert, medical literature, or statistical experience represented in the patient database. The knowledge is stored as frames or "HELP sectors" which contain the logic necessary to make a specific decision. The medical knowledge base supports a variety of decision-making models (IF...THEN... rules, patient specific probability revision, query for missing data etc.) and allows the medical expert to enter criteria using a high level language contained within the knowledge base editor.

When new results are stored in the patient record or a specific block of the knowledge base is otherwise activated, the HELP interpreter evaluates each item of logic in the appropriate HELP sectors and queries the patient database to see if the data specified in the

expert logic exist and meet the criteria specified in that logic. The sectors themselves contain the logic which determines how they are to be evaluated. An arithmetic statement can be used to perform tasks ranging from Boolean logic to calculation of a discriminant function. Chronologic statements can be used to retrieve the time of a specified event so that time may be used for data limitations or action flags. Existence statements use the presence or absence of a piece of data rather than the value as the basis for logical calculations. Data retrieval statements are used to cause the interpreter search the clinical database for specific items within specified time limits. These search items may also trigger the evaluation of additional HELP sector modules or ask for missing but necessary data. When all necessary items for a decision are satisfied, the interpreter forms a new data string which reflects this result and stores the string in the patient record as well as activating other specified reporting mechanisms.

Knowledge representation

The representation of the knowledge base in the HELP system is procedural. This means that isolated semantic statements and IF...THEN... rules (a declarative type of representation) do not exist as stand alone entities but are found inside a specific frame and are evaluated whenever that frame is evaluated. Every frame (HELP sector) contains the necessary logic to make a single decision. If a series of logical IF statements are sufficient to determine a decision, then they are all contained within the frame and the answer (true, false) returned when the frame is evaluated is the equivalent to the THEN result. On the other hand the procedural representation also allows the same inference mechanism (the HELP interpreter) to evaluate a stochastic (Bayes formula, discriminant function, logistic regression) model for a decision. The presently perceived primary disadvantage of this type of representation is the limited capability to explain why a decision has been made.

We have also chosen to store the clinical information in a hierarchal, coded representation rather than as symbols. This distinction is somewhat artificial because the codes can also be regarded as symbols and

have some advantages that textual symbols do not have, i.e. the hierarchal structure. If a symbolic representation were used for drug names, all types of digitalis preparations would have to be listed in the antecedant (IF) clauses of a rule which only was concerned about any type of digitalis medication, or a series of rules would have to exist (and be evaluated repeatedly with every new decision) to duplicate the hierarchy that exists in the coded representation. Another advantage of the coded representation is the speed with which data can be retrieved in a practical application. The final major factor influencing the choice of a coded representation is the ease with which clinical data can be modified (in the sense of limiting the meaning of the symbol by attaching qualifying statements) by attaching time constraints, searching for the most recent value or the maximum value etc.

Inference Mechanisms

If the procedural model does not exist in the knowledge base, it must be implemented in the so called inference engine. In a PROLOG application, this model is implicitly assumed to be classical logical calculus. In the LISP applications the model has typically been programmed. These approaches limit the application of concurrent use of more than one particular decision model. The bottom line is that one must somewhere deal with the procedural aspects. We have chosen to have the HELP interpreter be more general and imbed the procedural (i.e. knowledge about the type of decision - stochastic or deterministic) mechanisms inside each frame. Because the logic items contained in one HELP sector may reference (or cause to be evaluated) the results of other HELP sectors, the path which the logical interpreter follows may be implicit rather than explicit, i.e. the author of one particular frame need not know about all the possible logical pathways through which the sector will be evaluated. Thus on the lowest level of the knowledge base (frames) the logic is explicit and procedural while on the global level the pathway is data driven and implicit. The data driven activation of specific blocks or frames in the knowledge base is explicit (for reasons of execution speed) rather than implicit (as might be found in systems which are modelled upon a generalized search

control strategy), but the ultimate pathway through the knowledge base and the circumstances in which a frame may be evaluated are implicit to some degree.

Control Mechanisms for Logical Activation

Most declarative knowledge representations have inference mechanisms that are based upon generalized search techniques in which attempts are made to satisfy antecedents of rules. As the breadth of the rule base increases, these search approaches are limited by the "combinatorial explosion". In an effort to limit the search time, procedural, context dependent rules of thumb or heuristics are added to the knowledge base and used to guide the search. In some systems, a substantial fraction of the knowledge base is composed of these procedural types of rules. In contrast, those specific modules in the knowledge base of the HELP representation are evaluated whenever data referenced in those sectors are stored in the clinical data base. This approach to control mechanisms is primarily dictated by the desire to limit the response time of the system so that users can receive their answers in real time.

In summary, HELP is a functional decision support system which has been shown to influence physician behaviour and affect patient care. Aside from overcoming the efficiency problems which are typically associated with interpretive applications, the principal goals of further development are to expand the breadth of decisions contained in the knowledge base and to develop ways of analyzing and managing the contents of this knowledge base.

References:

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