CLINICAL GUIDELINES IN THE MANAGEMENT OF MEDICAL KNOWLEDGE: POTENTIALS FOR ACTIVE AND PASSIVE USE TO SUPPORT PATIENT CARE.

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ABSTRACT

Clinical guidelines constitute a valuable aid for patient care and management. New computing tools are being developed by medical informatics researchers in order to translate guidelines into an electronic format. Two different methods are presented in this report: (1) an authoring tool for developing clinical algorithms, and (2) an automata model to combine clinical guidelines and decision analysis. Knowledge engineering techniques can also provide new methods for developing clinical guidelines.

Keywords: clinical guidelines. decision analysis. automata theory. knowledge engineering.

1. Introduction

A. Computers in medical care: old and new perspectives.

The development of computing applications in medicine has been a main objective for a wide variety of researchers since the 1950s. The technical approaches considered have included algorithmic, statistical, decision analytic, and artificial intelligence (AI) methods [Sox, 1988; Kassirer, 1991; Reggia, 1985]. Each approach is based on a different cognitive model of human behavior and, particularly, medical diagnosis.

The introduction of AI techniques and knowledge engineering methods seemed to give a new and powerful direction to medical informatics. Nevertheless, the use of computers in the management of medical knowledge has been limited as the result of several factors, such as the limitations of technology, reluctance of physicians to accept computers as decision makers, unsatisfactory user interface, and the necessity of manually entering large quantities of data required by the programs. Furthermore, complexities of knowledge acquisition and knowledge representation have remained as major challenges in the effort to build intelligent systems in medicine.

Medical informatics seeks to provide the physician with new kind of scientific tools to manage medical data and knowledge [Greenes and Shortliffe, 1989]. Practical usefulness is a primary goal of researchers, and the development of computing tools is a consequence of this goal.

One current approach is to support patient care through the use of computing methods to model, implement, validate, and actualize clinical practice guidelines.

B. Clinical guidelines.

Guidelines can be viewed as a representation of an acceptable methodology for practice, whether derived via a consensus of experts' knowledge or as the result of an analytic or inference process. Guidelines may be aimed broadly at support of various aspects of patient diagnosis, workup and management.

Clinical practice guidelines can be considered as "systematically developed statements to assist practitioner and patient decisions about appropriate health care for specific clinical circumstances" [Audet, 1990]. It is also accepted that each guideline must have the strength of scientific and expert knowledge behind it and must reflect health and cost outcomes [Field and Lohr, 1990].

Clinical guidelines can be elaborated by several methods, but all are based on two basic sources: scientific literature and expert judgment. The tasks of the guideline developers are to (a) define the goals of guidelines (e.g., cost control, quality care, ethical and legal issues), (b) establish methods of guideline development (individual expert opinion, group judgment, modeling, literature review), (c) implementation and dissemination of guidelines , and (d) methods for evaluating the use of guidelines [Audet, 1990].

Different approaches are being taken within medical informatics to build computing tools for implementing clinical guidelines [Rucker and Shortliffe, 1989; Abendroth and Greenes, 1989]. We describe below two different approaches for implementing clinical guidelines in an electronic format.

2. An authoring tool for developing clinical algorithms.

Many standards groups are using printed algorithms to concisely represent the complex branching structure of diagnostic, workup and management strategies in practice guidelines. Printed algorithms are useful visual representations of the logic of clinical decision making.

We have implemented an algorithm authoring and navigation entity in the DeSyGNER framework (a multimedia, object-oriented environment developed by our laboratory) [Greenes, 1990]. The DeSyGNER-based algorithm authoring tool is an evolution of previous work on interactive algorithm display [Abendroth 1988]. The author can link any node of an algorithm to any supporting information or to another algorithm. Since the display is both dynamic and interactive, the algorithm need not be overly simplified as may be required for paper formats. Portions of the algorithm can be hidden or collapsed so that it becomes easier to use and understand.

We feel that algorithms serve to reduce the cognitive span [Blois, 1984] required of the physician during a patient encounter. Clinical algorithms can be viewed as a representation of changes in the state of knowledge about a patient or the state or the patient's condition. Each unit of an algorithm can be viewed as an observation of the current state of the patient followed by an intervention or decision that changes the state of that patient followed by a new state, or the unit may instead be several observations in sequence or decisions in sequence. In this regard each change in state can be encoded as a rule in a knowledge base. These rules can then be subject to validation.

Decision nodes in an algorithm show alternative paths based on the current state of information about the patient. By necessity the decision branches in published guidelines represent only a framework for making clinical decisions. This framework defines a limited world on which to focus the physicians attention.

The National Heart, Lung, and Blood Institute recently released guidelines for the diagnosis and treatment of asthma. We have discovered a number of problems associated with converting published guidelines into electronic format. [McClay 1992] An example [figure 1] is represented in the decision to admit a patient presenting to the Emergency Department with an exacerbation of acute asthma who has not responded immediately to treatment.

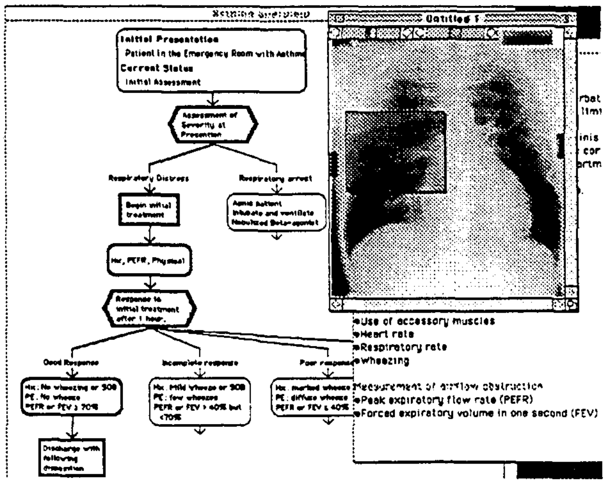

Fig 1: An authoring tool in the development of clinical guidelines for asthmatic patients.

According to the guidelines the treating physician is to take a number of factors into account in making this decision. There are no mechanisms offered for weighing these factors. Since knowledge of these factors can be incomplete or uncertain and there are not specific standards for introducing probabilities or utilities into clinical guidelines, we have developed a new knowlege representation. This representation combines the discrete sensitivity-analysis method of decision analysis with an automata model according to approximate Bayesian inference. This model provides us with alternative clinical algorithms in terms of differential diagnosis and associated utilities.

3. An automata model to combine clinical guidelines and decision analysis.

In computer science, the language theory of Chomsky is one of the great classics. This theory indicates the precise relations between languages (or grammars) and computational machines. According to the theory, any computational machine can be assigned to some class in his hierarchy, in which a Turing machine is located at the highest level, while a finite state automaton is at the lowest level. In formalizing medical processes of diagnoses or treatments, it is interesting to investigate how these medical processes can be reduced to their basic components such as finite state automata. The medical processes of diagnoses or treatments are often represented in a flow-chart style to show practical guidelines. Such clinical algorithms implicitly involve at least three parameters: (1) quantitation of human verbal reasoning (e.g. 'probably abnormal'), (2) probabilities of medical findings, and (3) utilities (or preferences) for actions. Modeling of the relations among such parameters must be investigated in the context of associating the basic components of clinical algorithms with finite state automata.

The first question is how we assign probabilities to human verbal reasoning. The likelihood of our judging a particular condition being true is based on the information we have. There are an infinite number of exact probabilities for any situation. Humans generally do not think in terms of the infinite—we categorize. For example, we might say that something is good, very good, bad, very bad, or neutral. Physicians often use five broad categories that express our evaluation of the probability of a clinical situation: highly likely normal, probably normal, equivocal, probably abnormal, highly likely abnormal. These categories can be mapped onto the Shannon model using an entropy function (fig 4). For example, the low entropy domain corresponds to both "highly likely normal and highly likely abnormal" categories. Based on Shannon, we can say that there is reason to relate the human qualitative model to a probabilistic exact model. [Shannon and Weaver, 1978].

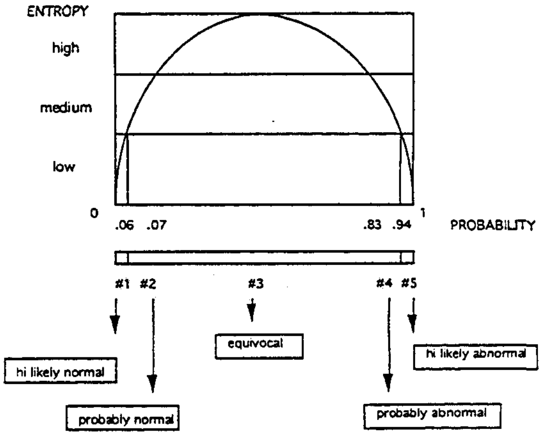

Fig. 2: Relation between entropy and probablity (Shannon's Information theory)

The second question is how we incorporate probabilistic revisions of diagnostic belief in terms of clinical algorithms and finite state automata. For example, consider the following substage of a clinical algorithm:

Sub-algorithm A
a)Adult with apparent thyroid nodule
b)-> if the patient is pregnant
c)-> then refer to Endocrinology Department
d)-> else .....

The medical finding "pregnant positive" causes the transition from one state (line a) to another (line c), each of which has probabilities for differential diagnosis, i.e., prior probabilities and the revised (i.e., posterior) probabilities in Bayesian inference.

The third question is how we associate clinical algorithms with utility theory in decision analysis. State transitions in guidelines reflect "optimal" pathways where optimality should be a function of the probabilities and utilities associated with alternative pathways. In order to conduct decision analysis, we need a structuring of the decision tree which explicitly specifies the three factors in a sub-stage of a multi-workup clinical algorithm: (1) a set of "final" actions at the end of the sub-stage ("Refer to Emergency Room" at line c in Sub-algorithm A is an example of one of the "final" actions.), (2) the probabilities for differential diagnosis, and (3) the utilities for the "final" states of the sub-stage. Usually physicians assume implicit utilities for "final" actions at any sub-stage of a multi-stage workup and management process.

Therefore, a heuristic or standard gambling approach is required to estimate the utilities. According to the estimated utilities, the expected utility functions can be calculated by the standard "averaging out and folding back" method in the decision tree.

These concepts can be combined into a "vending machine" model for medical strategies. A vending machine for dispensing soft drinks is an example of a finite state automaton. In our model, medical findings are taken as input (coins) and the finite state automaton returns expected utilities for final actions as output (soft drinks). We call such a model a utility-combined diagnostic automaton (UCDA). In a UCDA, the states are defined as a set of probability sub-intervals with their respective midpoint probabilities. The state transitions are repeated from the initial state to the final states as a directed graph according to the input sequence of medical findings. The non-final states output nothing, while the final state outputs a final action with the maximal expected utility. Any pathway from the initial state to the final state in the state transition diagram of the UCDA can be converted to a pathway in a clinical algorithm. This relation between the UCDA model and clinical algorithms provides us with clinical algorithms that have increased flexibility by decreasing dependence on specific sequences of medical findings based on the equivalent pathways determined in a UCDA [Kamae and Greenes, 1991] (Fig 3).

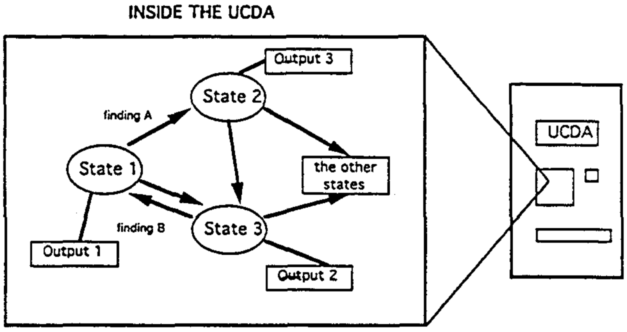

Fig. 3: a network of state transitions, with clinical findings as input and returning utilities as output.

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The major advantages of this model are:

- Increase flexibility in clinical algorithms by decreasing dependence on specific sequence of clinical findings based on the equivalent pathways determined in UCDA.
- Reduce the number of computations of Bayes to the linear order of the number of clinical findings, compared with the case of continuous exact Bayes such as decision table approach.
- Systematically convert UCDA to clinical algorithms.
- Incorporate human categorical reasoning into Bayesian medical diagnosis.
- Able to expand the model, e.g., to identify the most cost effective medical test sequence.

Despite the several limitations as probabilistic modeling, we believe that this approach could have a potential as a computer-based decision aid. Several theoretic problems to overcome the limitations remain for further investigation. These include the analysis of approximation errors to Bayes' inference, the extension of the model to conditional non-independency or Dempster Schafer theory, and the incorporation of multi-stage workups in the model.

Our concept to link decision analyses with clinical algorithms by means of an automata model proposes a new class of "regular" clinical algorithms and their equivalency in theory as well as finite state automata accept regular language in Chomsky hierarchy. Also, our approach provides developers of clinical algorithms with a means to relate the algorithms to quantitative estimates. This combination may enhance the usefulness of clinical guidelines in actual practice.

4. Conclusions and future directions.

The use of clinical guidelines can be a valuable resource in medical care. It has been proposed that the electronic format of clinical guidelines constitute a kind of knowledge base similar to that used in some rule-based expert systems [Shiffman, 1992].

Methodologies for dealing with such matters as knowledge consensus and validation must be developed. In this respect, knowledge or software engineering techniques can be of great use.

Computing tools can also facilitate the use of guidelines as education resources, as guidance for clinical input, and as a means for structuring and managing the care process (e.g., generating patient reminders and other printouts, producing forms, and so forth).

The development of computing tools that facilitate the translation of guidelines from paper to an electronic form can give the physician an additional means for providing patient management and care.

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