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by

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PROBLEMS OF DESIGNING AN INFERENTIAL MEDICAL CONSULTING SYSTEM

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'Medicine is a science of uncertainty and an art of probability.'

Sir William Osler

ABSTRACT

The paper gives an outline of basic problems involved in designing an inferential medical computer consultant, and then discusses the methods of implementing deductive and inductive capabilities of such a system. To implement the latter capabilities the paper advocates logical methods (specifically methods employing concepts of a variable-valued logic system) rather than statistical or syntactic methods which are currently most common.

1. INTRODUCTION

The amount of diagnostic and therapeutic knowledge existing today surpasses by far what a single physician or a group of physicians can encompass even if they have a sizable library in their offices. The situation is becoming worse as this knowledge grows rapidly. An augmentation of a physician's memory by developing computer medical data bases is an important step forward, but in the long run it will not be sufficient. To improve the quality of his decision making a physician will need a medical computer consultant with significant inferential and learning capabilities.

By 'inferential capabilities' we mean deductive and, as well, inductive capabilities. The deductive capabilities will allow such a medical computer consultant (MCC) to apply various decision rules, stored in its data base, to the specific new situations in order to come up with a diagnostic, therapeutic or other advice. The inductive capabilities will allow the MCC to modify, generalize or determine various decision rules from new facts, observations, feedback information, 'experience', etc. By 'learning capabilities' we mean capabilities to accept various facts and rules, and to link them with already known facts and rules.

A need for such an inferential computer consultant is clearly seen from the following.

A data base without inferential and learning capabilities would just be a bank of known specific facts about diseases, therapy, disease-symptom, therapy-symptom, and other relationships.* Such a system could answer only the questions directly related to the situations identical to those stored in its memory, and would be useless for answering questions related to any new situations. A system with deductive capabilities would be able to answer questions related to new situations, but only if decision rules pertinent to these new situations were available. To formalize and program, however, all the known, usually very informal, intuitive, and sometimes contradictive rules developed by the medical profession is a monumental task. But even if such a task was achieved in a certain point in time, the system would become quickly obsolete, if it would not have inductive and learning capabilities. The latter capabilities will enable a system to learn rules from examples, specific cases, to modify and update rules, using feedback information to make new generalizations, etc.

2. OUTLINE OF BASIC PROBLEMS OF DESIGNING A MCC

Designing an inferential medical computer consultant is a very complex task consisting of many different problems:

- Development of a system of programs for executing learning and inferential processes, i.e., programs which

  (1) can accept, 'comprehend', and easily handle, and also update medical knowledge about 'symptom-disease', 'cause-effect', 'disease-therapy' and other relationships (learning capabilities)

  (2) can infer decision rules expressing these relationships from given single facts, examples, cases, etc. (inductive capabilities)

  (3) can advise, based on the directly obtained or inferred decision rules and the given information about a patient, about diagnosis, therapy, tests to assign or other medical action (deductive capabilities)

*There are approximately 6000 diseases and 20,000 medical symptoms and measurements.(1) With each disease, there can be associated a large number of known cases and facts, thus the development of a complete medical data base presents a very serious problem by itself.

(3) ignore 'cause-effect', structural and other relationships which often exist among symptoms, signs, results of medical tests, etc.

(4) produce decision rules which are difficult to comprehend by humans; the rules do not relate well to human inferential processes.

(5) are often feasible only when independence of tests, symptoms, etc., is assumed, which is often too strong an assumption in real situations.[4]

(6) do not give any insight how to divide decision problems into subsystems, which, as indicated by Patric,[1] would be a necessity for a large-scale system.

(7) produce decision rules which are not easy to modify (in order, e.g., to accommodate new information) or to correct (e.g., when some errors were introduced in gathering statistics).

(8) are primarily oriented toward situations described by absolute and ratio variables; they are not well suited for situations where ordinal or nominal variables are used.

Analytical methods also are not particularly promising, since they share many of the above disadvantages. As an example of a rule produced by such methods, consider thyroid index developed by Overall and Williams[5] using a factor analysis method:

$$
\begin{aligned}
Y = {} & 0.8380X_1+1.4070X_2+1.1780X_3+1.6810X_4 \\
& +0.8440X_5+1.8450X_6+1.3940X_7+1.0690X_8 \\
& -0.8780X_9-0.8700X_{10}-2.7400X_{11}-0.1630X_{12} \\
& -0.4800X_{13}-1.2790X_{14}-1.0900X_{15}-0.9010X_{16} \\
& +2.4350X_{17}+1.6610X_{18}+0.0251X_{19}+0.0043X_{20} \\
& +0.0067X_{21}-0.0036X_{22}-0.0075X_{23}+0.0260X_{24} \\
& +0.0491X_{25}+0.0456X_{26}.
\end{aligned}
$$

where X_i are various measurements and symptoms, such as 'recent increase of sweating', 'dry puffy coarse skin', 'blood glucose', etc.

The value of Y, computed for given X_i, is compared with two thresholds, and based on the result of this comparison the patient is assigned one of the three diagnosis -- hypothyroid, euthyroid or hyperthyroid.

Disregarding other features of this method, let us observe that the above decision process has little in common with the way humans make decisions. Such a decision rule seems to be dogmatic, it does not give 'reasons' for a given decision, it is difficult to check correctness of the rule, to have the 'confidence' in such decisions.

Syntactic methods also seem to be not very promising. They require that each decision class be described by a formal grammar.* But it is not clear how to construct such grammars. It is quite difficult to construct the grammars from the knowledge in medical books, and, on the other hand, it seems unrealistic that grammatical inference methods could be advanced sufficiently to construct grammars automatically. Grammars are also not easy to modify, they require a sequential process for evaluation, they don't give a 'degree of confidence' in a decision, they are not adequate for handling numerical information, etc.

*See, e.g., paper by R. S. Ledley, p. 152 in the book.[2]

The methods from the above 3 groups can, of course, be quite useful in various specific situations, but they do not seem to be adequate for providing the basic philosophy for development of a large-scale inferential MCC.

The methods which the author considers most promising here stem from the development of logic, specifically multi-valued logic.

In the next chapter we will give a brief outline of inferential methods which are based on logical concepts, in particular on the concept of a 'variable-valued logic system'.

4. A LOGIC-BASED APPROACH TO IMPLEMENTATION OF INFERENTIAL PROCESSES

4.1 General Remarks

In the logic-based methods decision rules are expressed as statements of a logic system. A deduction process consists of testing whether a specific input information satisfies conditions implied by the logical decision rules. An inductive process consists of creating the general decision rules (hypotheses) from the specific examples of decisions and available problem knowledge.

A logic system which seems to be very adequate for implementing such processes is a variable-valued logic system called VL_1.[6-8,11] This system assumes that logic formulas and the variables in them can be assigned independent domains from which they draw their values. Thus, the domains of formulas and variables may have different numbers of elements and the elements may have different meaning. Below are examples of VL_1 variables (x_i) and formulas (v_i), and their domains.

Variables	Domains
x_1='body temperature'	$D(x_1)$={below normal, normal, above normal}
x_2='sex'	$D(x_2)$={male, female}
x_3='age'	$D(x_3)$={numbers of years}

Formulas	
v_1='biliary cirrhosis'	$D(v_1)$={not present, present}
v_2='chronic hepatitis'	$D(v_2)$={not present, moderate, severe}

The definition, properties and VL_1 formula synthesis algorithms are described in papers[11-13]. Here we will give only an informal outline of VL_1 and then, in the next section, will illustrate its application by some results from an experiment on the diagnosis of 3 liver diseases.

For example, description A for postnecrotic cirrhosis (P) was:

P(A):	COV	NEW	IND	TOT
$[x_{17}=0][x_{24}=0][x_{30}=1][x_{42}=0,1] \vee [x_{48}=1][x_{49}=0]$	52	52	20	52
$[x_5=0][x_{24}=0,1][x_{31}=0][x_{36}=1] \vee [x_{39}=0,1][x_{48}=1]$	41	21	16	73
$[x_{27}=1,2][x_{39}=1][x_{43}=0] \vee [x_{48}=1,2]$	25	7	6	80
$[x_1=1,2][x_2=1][x_8=0][x_{23}=0] \vee [x_{24}=0][x_{27}=0,1][x_{42}=0]$	9	3	3	83

Substituting names for the variables and their values the formula becomes:

[liver nodules = no][albumin = low] [regeneration: bile ducts, fibrosis;diff or focal = present] [fat:diff or zonal ≠ strongly present][fibrosis: portal or central = absent]

or

[nausea = no][albumin ≠ above normal][regeneration: retic. endo. = absent][cells:central or portal, fibrosis:diff or focal = present][cells:monos. or epithel ≠ strongly present]

or

[necrosis:diff or focal, fibrosis:diff or focal = present, strongly present][cells:monos. or epithel = present][fat:1-2+ or 3-4+ = absent]

or

[age > 39][sex = female][jaundice = no][protein, albumin = low][necrosis:diff or portal < strongly present][fat:diff or zonal = absent]

Note that the description involves in toto 17 out of the original 50 symptoms and individual terms in the formula involve 6,6,4 and 7 variables, respectively. (Note that to make a 'positive' decision only 1 term of the formula has to be satisfied.) Each product of selectors (term) in the formula is assigned a sequence of 4 numbers:

(COV, NEW, IND, TOT)

which mean, respectively:

COV -- number of cases covered ('explained') by the term out of original 83 learning cases

NEW -- number of cases covered by the term but not covered by the terms preceding given term in the formula

IND -- number of cases covered only by the term and not covered by any other term

TOT -- number of cases covered by the given term and all the preceding terms (the last value of TOT must just be the total number of learning cases used)

Description B (a three-formula description) for the same disease (P) was:

P(A):

1st formula:	COV	NEW	IND	TOT
$[x_{17}=0][x_{25}=1,2][x_{34}=0][x_{42}=0,1] \vee [x_{48}=1]$	61	61	19	61
$[x_{16}=0][x_{23}=0,1][x_{39}=0,1] \vee [x_{42}=0][x_{43}=0][x_{48}=1,2]$	44	15	9	76
$[x_4=0][x_5=0][x_{13}=1][x_{29}=0] \vee [x_{39}=0,1][x_{42}=0,1]$	30	6	6	82
$[x_2=1][x_6=1][x_{12}=1]$	3	1	1	83
2nd formula:	**COV**	**NEW**	**IND**	**TOT**
$[x_{42}=0][x_{43}=0,1][x_{48}=1] \vee$	72	72	30	72
$[x_5=0][x_{20}=1][x_{39}=0,1][x_{42}=0,1] \vee [x_{48}=1,2]$	49	9	9	81
$[x_3=1][x_{30}=1][x_{39}=0]$	12	2	2	83
3rd formula:	**COV**	**NEW**	**IND**	**TOT**
$[x_{26}=1,2][x_{48}=1][x_{49}=0] \vee$	65	65	10	65
$[x_3=0][x_{20}=1][x_{32}=0,1][x_{35}=1,2] \vee [x_{39}=0,1][x_{43}=0,1][x_{48}=1,2] \vee$	46	14	6	79
$[x_5=0][x_{24}=0][x_{48}=1]$	56	4	4	83

The obtained descriptions were then applied to the testing events to see how well they discriminate between diseases. The results are given in Figure 2 (columns 5, 6, and 7).

In Column 7 are listed numbers of correctly classified diseases, by the best* of 10 models used by Croft.[14] It should be noted, however, that Croft's results were obtained when the learning and testing cases were drawn from data which included cases of 20 liver diseases rather than 3, as in our example.

The classification decisions using descriptions A and B were made as follows:

Description A

Suppose V_k is a single-formula description of disease k, k = P,G,F, and e is a description of a patient to be diagnosed. The patient is assigned a diagnostic decision(s) $\hat{k}$ if

$$D(V_{\hat{k}},e) = \max_{k=P,G,F} \{D(V_k,e)\} \pm T$$

*The Bayes' formula conditional probability model.

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5) Interactive Language Design and Development
6) VL Based Deductive and Inductive Diagnostic Systems
7) Data Base and Format Design
8) Comparative Study and Review of Other Systems (Similar to MIDAS)
9) Real Time Patient Monitoring, Security, and Personal Medical Data Dossier