

CONCEPTUAL LATTICE: A UNIFIED MODEL FOR MEDICAL INFERENCE PROCESSES

Tsuguchika Kaminuma
Medical Informatics Group
The Tokyo Metropolitan Institute of Medical Science
3-18-22 Honkomagome, Bunkyo-ku
Tokyo 113, JAPAN

The conceptual system in medicine can be ordered by a relation between two concepts. We can then define a lattice structure over the ordered conceptual system. Such a lattice whose elements are the aggregates of concepts can be used to simulate the inferential process of medical decision making. This model can potentially unify all models so far proposed for computer-based medical decision making, from both the statistical and empirical (AI) approaches. When combined with the semi-empirical approach, the model is able to constitute the computer algorithm which is most suited to attack the diagnostic problems, even where neither number of sample data per disease categories are large nor reliable medical knowledge has been provided. The model is also a good guideline by which one can clarify relations between medical terms and concepts, and to organize logical thinking into a knowledge system.

1. INTRODUCTION

The history of attempting to use the computer as a tool for clinical decision making goes beyond two decades. Since the beginning there have been two approaches in designing the computer algorithm for medical decision making: The statistical approach [1]-[3] and the empirical approach [4]-[6], the latter has been customarily called the artificial intelligence (AI) approach by its school.

The statistical approach is successful whenever enough samples can be accumulated for each category of diseases, but quite useless for more complicated differential diagnosis where reliable data samples are small. The AI approach illustrates its strength when the decision categories are extensive but also where sound medical knowledge for reasoning exists. Here the statistical reasoning based on the objective probabilities calculated from data is replaced by a decision criteria based on an expert confidence measure. But these theories seem to show their weaknesses when applied to the areas where empirical knowledge is neither well organized nor reliable.

Since 1971, the author has been working on the computer diagnosis of heart diseases based on a third approach, called "semiempirical" [7]. In the semiempirical approach, the specialist's diagnostic reasoning is first analyzed and

broken down into more elementary processes. Then the decision process is reconstructed by a hierarchy of elementary decision compartments. The logic at each decision compartment may be given empirical knowledge at the beginning, but these empirical logics can gradually be replaced by probabilistic decision logics as statistically reliable data accumulates. The semiempirical approach thus builds a bridge between the statistical theories and the AI theories, and overcomes the limitations of the both approaches.

One of the gists of the computer-based clinical decision making is the modelling of diseases and simulating the expert's thinking processes based on the resultant model. In this paper a representation model for human inference processes based on a structure disease model is proposed. This model is a refinement and extension of the algorithmic frame, developed in the semiempirical approach. The model is called conceptual lattice model, because it uses relation among medical concepts. The model is not only relevant for the models proposed up to now, but also useful to unify the semiempirical approach, from the statistical to AI approaches.

2. CONCEPTUAL SYSTEM FOR MEDICAL KNOWLEDGE

Medical knowledge, as a conceptual system, has two embedded structures: biostructural (i.e., etiological, pathological, physiological, and

anatomical) semantics and hierarchical human information processings. If we consider any disease etiologically, we see casual relations between concepts parallel to the biological hierarchy. But the present biostructural knowledge in medicine is far from complete, and the biostructural conceptual systems cannot directly be modelled into computer programs.

The structure of human information processing for medical decision making is better ordered, and suitable to a multi-stage and multi-level information reduction process model. Usually a patient takes several tests in sequence. At each test the primary information concerning the patient's body or his specimens are reduced into symptoms and signs, and the medical consultant determines probable diseases from the information.

The ideal situation is that of human guessing based on observations going side by side with the biostructural casual reasoning. Conversely, the biostructural conceptual system may suggest the necessity for new observations. However in reality the medical consultant's mind works neither purely by observation nor on a biostructural basis. His thinking is somewhere in between. The conceptual lattice model thus intends to abstract the conceptual system structure embedded in the human mind.

3. CONCEPTUAL LATTICE

3.1 Definition

Let concepts used in medical decision making be $a, b, c, \dots, x, y$, and z , etc. In the case of necessity we distinctively use a, b , and c for definite expression with yes/no or with constant values included such as "having cyanosis" or "age less than 5 years old", while the x, y , and z are used to express variables, such as "the number of white blood cells," or "the systolic blood pressure" without specifying their values. In general the a, b and c symbols correspond to propositions appearing in medical textbooks. If a concept a appears as an element to explain concept b , we write $a \rightarrow b$, in other words, we need the concept a in order to define the concept b in some knowledge frame in current medicine. We assume $a \rightarrow a$ always holds.

Let $\alpha, \beta, \gamma, \dots$ be the aggregate of concepts, we introduce lattice structure between the aggregate of concepts, which are called "conceptual lattices". For example, we may extract a partially ordered set of concepts from any given conceptual system having the relation $\rightarrow$.

a disjoint set of subsets (aggregate of concepts) $\alpha, \beta, \dots$, and introduce a new relation $\Rightarrow$ which is defined by " $\alpha \Rightarrow \beta$ iff for any $a_i \in \alpha$ there exists a $b_i \in \beta$ such that $b_i \rightarrow a_i$ and for any $a_i \in \alpha$ there exists a $b_i \in \beta$ such that $b_i \rightarrow a_i$ ", we again obtain a new lattice under certain additional conditions. The operations $\cap$ and $\cup$ can be introduced as l.u.b. (α, β) and g.l.b. (α, β) respectively, as usual [8].

To illustrate that the conceptual lattice model originates from a common language in science, few examples of conceptual lattices will be given. From an extremely reductionistic viewpoint a patient is considered a physical system, whose state may either be represented by a boolean propositional lattice (classical case) or a weak modular lattice (quantum case) [9]. In usual pattern recognition language, a patient is represented by a n -tuple observation, and the diseases correspond either to regions or subspaces in the n -dimensional space. These pictures are again examples of a boolean and a modular lattice system [10].

3.2 Inference Compartments

Between any two conceptual lattice elements $\alpha = (a_1, a_2, \dots, a_m)$ and $\beta = (b_1, b_2, \dots, b_n)$ which satisfy $\alpha \Rightarrow \beta$, we say that there existsⁿ an inter-nodal logic, which is a mapping between the two element concepts of the lattices. Since there may be several other lattice elements $\alpha', \alpha'', \dots$, for the element β with the same relation $\Rightarrow$, the values of b_i cannot uniquely be specified unless giving a mapping which determines the values of b_i uniquely based on the outputs of the above mapping. This new input-output relation within the lattice element, when specified by an explicit function relation, is called the compartment logics.

When compartment logics are specified, the conceptual lattice is called a state lattice. Elements of the state lattice are called state nodes. Concepts included in the state nodes are called state variables. Thus a state lattice which corresponds to a computer algorithm of diagnosis, is the model of physicians inference process for diagnosis. However a conceptual lattice only gives an algorithmic frame, and not the algorithm itself.

In order to specify a compartment logic one needs an empirical logic. Usually these logics are given by "If..., then..." sentences written by a medical consultant [4]. But for checking logical consistency, and for improving and updating the logic, a logic table is preferable, because the size of the logics is usually very

large. Moreover table logic can easily be transformed into a probabilistic logic, such as linear discriminant function, as data is gathered. Thus a translator, which generates a table logic matrix from conversational "If... then..." type sentences becomes useful [7].

3.3 Models for Prognosis

The applicability of the conceptual lattice model for prognosis problems is briefly explained. Prognosis is the prediction of patient state transitions. In our model, state transitions are represented by transitions between two state lattices. Symbolically we represent a patient's state at time t by a state lattice $\Psi(t)$ having $X_1(t), X_2(t), \dots$ as its nodes. As was explained, these nodes may either be the concept (physiological variables) or an aggregate of concepts. We then denote the transition probability between two states $\Psi(t_i)$ and $\Psi(t_j)$ by

$$\{ \Psi(t_i), \Psi(t_j) \}. \quad (1)$$

We may also consider the two probabilities

$$\{ X_1(t_i), \Psi(t_j) \}, \quad (2)$$

and

$$\{ X_1(t_i), X_m(t_j) \} \quad (3)$$

If we take X 's in (3) to be a same physiological parameter such as blood pressure, (3) predicts its change. However such predictive probability may not be known in general.

4. DISCUSSIONS

As we have emphasized the conceptual lattice model is not an algorithm for computer-based decision making, but it is a methodology to generate an algorithmic "frame" with which one can draw in the body of logic which is "squeezed" from human empirical thinking. One of the salient feature of the above methodology is that the computer algorithm accepts some incomplete data, which a usual probabilistic logic can not handle. Another big advantage of the conceptual lattice model is its evolutionary feature, which usual AI approaches do not emphasize.

Despite such partial success the model is still in its development stage. Several applications of the model has been attempted for heart, metabolic, and hematological diseases.

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REFERENCES

- [1] Warner, H.R., Toronto, A.F., and Veasy, L.G. "Experience with Bayes' Theorem for Computer Diagnosis of Congenital Heart Disease." Ann. N. Y. Acad. Sci., 115, (1964) 558-567.
- [2] Gorry, G.A. and Barnett, G.O. "Experience with a Model of Sequential Diagnosis." Comp. Biomed. Res. 1, (1968) 490-507.
- [3] Nordyke, R.A., Kulikowski, C.A., and Kulikowski, C.W. "A Comparison of Methods for the Automated Diagnosis of Thyroid Dysfunction." Comp. Biomed. Res. 4 (1971) 374-389.
- [4] Shortliffe, E.H., Computer-Based Medical Consultation: MYCIN. N.Y.: Elsevier/NH, 1976.
- [5] Weiss, S.M., Kulikowski, C.A., Amarel, S., and Safir, A. "A Model-Based Methods for Computer-Aided Medical Decision-Making." Artificial Intelligence. 11 (1978) 145-172.
- [6] Svolovits, P. and Pauker, S.G. "Categorical and Probabilistic Reasoning in Medical Diagnosis." Artificial Intelligence. 11 (1978) 115-144.
- [7] Kaminuma, T. and Machii K. "Semiempirical approach to computer diagnosis." In Proc IJCPR-78. Kyoto, November, 1978 pp. 889-891.
- [8] Birkhoff, G. Lattice Theory. Providence: Am. Math. Soc, 1973.
- [9] Piron, C. Foundations of Quantum Physics. Reading: Benjamin, 1976.
- [10] Watanabe, S. Knowing and Guessing. N.Y.: John Wiley, 1969.