LOGIC BASED
MEDICAL CONSULTANT SYSTEMS

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GIRDHAR PRASAD

SCHOOL OF COMPUTER AND SYSTEMS SCIENCES
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI - 110067
INDIA
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TO MY PARENTS

JAWAHARLAL NEHRU UNIVERSITY
SCHOOL OF COMPUTER & SYSTEMS
SCIENCES, NEW DELHI

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CERTIFICATE

It is certified that the contents of this dissertation which carries the title LOGIC BASED MEDICAL CONSULTANT SYSTEMS has been submitted by Girdhar Prasad, has not been previously submitted for any other degree of this or any other University.

Prasad
GIRDHAR PRASAD
(student)

N.P. Mukherjee
N.P.MUKHERJEE
DEAN
SCSS/JNU

R. Sadananda
R. SADANANDA
(supervisor)
SCSS/JNU

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CONTENTS

CHAPTER - I

INTRODUCTION

According to Claud Bernard, "Fundamentally, all Sciences reason in the same way and aim at the same object. They all try to reach knowledge of the Law of Phenomena, so as to foresee, vary, or master Phenomena".[1]

The medical scene can be looked upon as a struggle to organise medical knowledge in a way so that it will be useful to clinicians.[2] This is particularly true in view of the tremendous explosion of medical knowledge, i.e. taking place now with the enormous amount of effort all over the world in studying biology and medicine. The volume of the relevant information for a clinical situation is going to be so enormous that no individual will be able to process it himself. Infact, it can be easily shown that an experienced medical man is at any time using only a very small fraction of the knowledge which he carries with him, which, in turn is a microscopic part of the available knowledge.

Needless, therefore, to emphasise the importance of an information system to aid clinical diagnosis. Due to historical reason, medicine and biology have grown under a style and culture different from mathematics and and engineering, on account of these reasons it has become difficult to introduce concept familiar in computer science into medicine profitably. In mathematics one is used to precise statements and clear conclusions. Medicine being an area handling human beings in real life situation the mathematical methodology cannot be directly applied as it is difficult to get precise facts and much more difficu to make precise conclusions. However, mathematics and logic represents accumulated human efforts to know, understand, process and decision making. The computer is a physical realisation of this process.[3]

During the last two decades the progress has been made considerably in the development of the Computer-Based Medical Consultant Systems, and upto what extent the computer may be useful in the aid to the Physician in diagnosis continue to be a topic of lively interest.

Here in Chapter II we have discussed about some of the well known Medical Consultant System, like MYCIN, CASNET and INTERNIST. The aim of the designers of these systems has been attempted to capture the special knowledge of experts in a given subject matter field and represent this in a knowledge Base which will be computer processable.

In these consultant systems two types of Medical Knowledge have been represented. (a) The general knowledge of diseases including manifestations, causal - mechanism, and diagnostic procedures; and (b) Specific knowledge about Patient, including the current medical history. In MYCIN the medical knowledge is represented by a set of production rules augmented by certainty factors. These factors express the strength of beliefness on the basis of evidence for a particular hypothesis. In CASNET knowledge Base is represented by causal - network in which each CAUSES link is qualified by a number representing the strength of causality. In INTERNIST knowledge Base is represented in the form of a Tree, where each terminal nodes is referred to a disease entity and non-terminal nodes and its subtrees are referred to as a disease area.

All these systems use some thresholding techniques. If the numerical score of a hypothesis exceeds a certain preset threshold, the hypothesis is believed to be true.[1] In MYCIN the premise of a rule is considered true. If the combined value of the associated certainty factors exceeds a preset threshold. In CASNET, a status measure is linked with each state in the causal network. A state is considered confirmed if its status is greater than a preset threshold. In INTERNIST, disease hypotheses are scored by a procedure that depends on the strength of association among the manifestation, (1) shown by the patient and disease; and (2) associated with the disease that are not present in the Patient; and (3) confirmed diseases causally related to this disease. Disease hypotheses are ranked, and the top-ranked diseases are taken into further investigation. If the difference between the scores of the top two disease hypotheses reaches a criterion, then the top-ranked disease is confirmed.

In Chapter III we have discussed about the logic used by Medical Consultant Systems. The Medical knowledge can be represented and an inference engine can be made on the basis of First-order predicate calculus logic. The first order predicate calculus is rich enough to model many real life problems. The resolution principle indicates a procedure of proof handling which is both sound and effective.

In Chapter IV we have discussed about the Logic-Based Medical Consultant System. Here we have considered two important parts of this system (1) Patient data Base; and (2) Knowledge - Base, where Patient Data Base having the available information about patient and the Knowledge-Base is having information about the diseases. We assume that all these knowledge are represented in the form of First-Order Predicate Calculus. Here we have applied the Resolution Principle between the patient data Base and the Knowledge-Base which gives the confirmation of a disease.

We have described a diagnostic procedure which gives the final diagnosis. We have also described a technique which will give the certainity of diseases in percentage. In all these techniques Resolution principle plays main role.

As we know that like most of the problems in Artificial Intelligence, the resolution process causes combinatorial explosion in terms of space and time. Most of these problems are solved by accepting some heuristic procedure to tackle th situation. In this connection we have also described some strategies to tackle these problems.

CHAPTER - II

MYCIN

This system was developed in 1976 at the Stanford University. This is several years work of a group of Physicians and computer scientists.[4] This system provides consultative advice on diagnosis of and therapy for infections diseases.

The main components of the system are:

1. Consultation Program
2. Explanation Program
3. Question-answering Program
4. Knowledge acquisition Program
5. Knowledge Base
6. Patient Data Base

These components are organized by this fashion given in Fig.

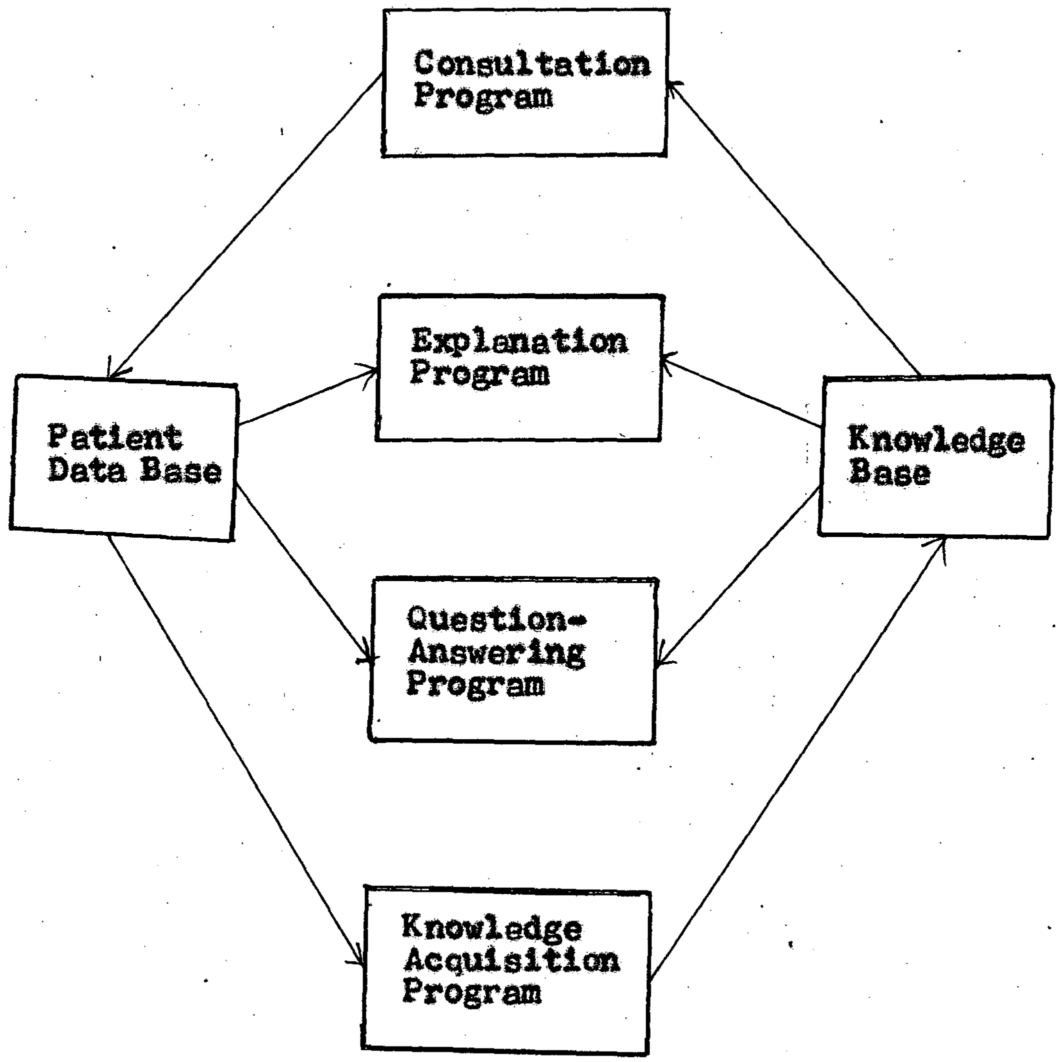


Fig. 1

All of the system's knowledge of infectious disease is contained within the knowledge Base. Data about a specific patient collected during a consultation is stored in the Patient Data Base Arrows indicate the direction of information flow.[11]

MYCIN Knowledge Base

The medical knowledge in MYCIN is encoded as Production Rules of the sort shown in Fig (2).[11]

RULE 050

PREMISE: ($ AND (SAME CNTXT INFECT PRIMARY - BACTEREMIA)
(MEMBF CNTXT SITE STERILESITES)
(SAME CNTXT PORTAL GI)).

ACTION: (CONCLUDE CNTXT IDENT BACTEROIDES TALLY . 7).

MYCIN English Translation

IF:
1. The infection is Primary-Bacteremia, and
2. The site of the culture is one of the sterilesites, and
3. The suspected portal of entry of the organism is gastrointenstinal tract,

Then: There is a suggestive evidence (.7) That the identity of the organism is bateroides.

Fig.2. A rule from knowledge Base AND and OR are the multi-valued analogues of the Standard Boolean AND and OR.

The premise of each rules always have a conjunction of clauses and the action part can also have more then one conclusion. Each rule is stored in the IF - THEN formate coded in LISP Language a Translation Program explain Program's inferences to the expert in English language. The current MYCIN Knowledge Base contains 450 such rules.

Knowledge Representation

MYCIN knowledge represented by simple statements of the facts about the domain. These statements are represented in the form of Attributes Object-Value, and Predicate Function -

Example (The Site of the culture is one of the Sterilesites) or

in LISP	(MEMBF	CNTXT	SITE	STERILESITES
	Predicate	Object	Attributes	Value

A Standardized set of some 24 domain - independent Predicate Function (e.g. SAME, KNOWN, DEFINITE)' and a range of domain specific attributes (e.g. IDENTITY, SITE), Objects (e.g. ORGANISMS, CULTURE) and associated values (e.g. E. COLI, BLOOD) from the vocabulary of conceptual Primitives for constructing rules.[1]

MYCIN Model for Evidential Strength[4]

MYCIN has choosen two units of measurements initiall

1. Belief   2. disbelief

and finally comes to the certainty Factor. The certainty Factor is a measurement of the association between the Premise and action clauses of each rule.

MB (h,e)   Gives the measure of increased Belief in the hypothesis h on the basis of evidence e.

MD (h,e)   Gives the measure of increased disbelief in the hypothesis h on the basis of evidence e.

$CF(h,e) = MB(h,e) - MD(h,e)$

$CF(h,e) = 0$ gives that the evidence e neither confirms nor disconfirms hypothesis h.

Range of degrees of the MB, MD and CF are:

$0 \leq MB(h,e) \leq 1$

$0 \leq MD(h,e) \leq 1$

$-1 \leq CF(h,e) \leq +1$

MYCIN also proves that

CF (h,e) + CF (Not h,e) = 0.

Diagnostic Procedure

The mechanism is based on the rules in the knowledge Base and the current date base of the patients. When the Program attempt to determine the goal, it retrieves all the rules that makes a conclusion about the goal. In some cases (because of the lack of information about a patient) another subgoal is set up, that is a generalized form of the original goal. Since the rules are inexact. It leads to a conclusion of less than total certainty. In this situation, MYCIN collects all evidence about the subgoal using other applicable rules. If the weight of the evidence about a hypothesis falls under the area of determined threshol value, system asks the user to give the value of subgoal.

MYCIN uses the other techniques (in addition to the first) also to increase the efficiency of the Inference Engines, one is when the subgoal is set up. In this situation, the attempt is made to find a set of rules to establish the main goal on the basis of known information, Before going to retrieve the entire list of rules for subgoal, and the other is evaluation of rules premises. If the value of one clause in a premise is established, while the rests are still unknown, and the known clause alone makes the premise false. Then there is no need to do all search to establish the other clauses, because the rule is guaranteed to fail according to Boolian combination of Truth, False and unknown.

F X U = F

F = False

U = Unknown

MYCIN was one of the first of a new breed of computer systems - system that step out of the Toy Worlds of AI into real world.[1] Modularity, representation of knowledge, reasoning in specific domain, explanation of a system's logic, all these important issues are considered which are realy aid to the clinicians in the real world.

CASNET

'The causal Associational NET work'. It was developed in 1978 by weiss, Kulikowski, and Safir at the University of Rutgers.[1] The system diagnoses a patient by determining the pattern of Pathophysiological causal pathways present in the patient and by identifying this pattern with a disease category. The major application of CASNET has been in the domain of Glaucoma.

Knowledge Representation -

It consists of three planes of knowledge.

1. The plane of Pathophysiological.
2. The plane of observations.
3. The plane contains the classification tables for the diseases.

The plan of Pathophysiological state is the important part of the model, elementary hypotheses are represented by nodes and, arcs represent a causal connections between two elementary hypotheses. To confirming and disconfirming the presence of a Pathophysiological State, there is a confidence value, a number on a scale of 1 through 5,1 represents 'Rarely causes' and 5 represents 'Almost causes'. The confidence value with which observations are linked to Patho-physiological States are predetermined by the designers of CASNET.

The Plane of observations contains all the information about a Patient (Sign, Symptoms, results of the various laboratory tests) represented by nodes. Nodes in this plane are linked with the nodes in the Pathophysiological plane. The links are associated with certain degree of confidence on a scale of 1 through 5.

Example[1]

A scotoma (a Perimetry measurement) strongly indicates VISUAL FIELD LOSS, so it has a confidence value of 5.

The classification tables consist of a set of confirmed and disconfirmed Pathophysiological states and treatment statements of a disease.

Example[1]

The Classification table in Fig.

STATE	DISEASES	TREATMENTS
Angle Closure		
INCR IOP	Angle Closure Glaucoma	Treatment 1
CUPPING		
VFL	Chronic Angle Closure Glaucoma	TR 1 TR 2

Fig. indicates that if a Patient is found to have ANGLE CLOSURE and INCREASED INTRAOCULAR PRESSURE but neither CUPPING nor VISUAL FIELD LOSS, then he (or she) has ANGLE CLOSURE GLAUCOMA. If he has ANGLE CLOSURE, INCREASED INTRAOCULAR PRESSURE, CUPPING, and VISUAL FIELD LOSS, than he has CHRONIC ANGLE CLOSURE GLAUCOMA.

Diagnostic Procedure

The main aim of the CASNET is to maximize the likelihood of findings causal pathways between the States on the basis of the available Patient informations (Sign, Symptoms and results of the various Tests).

Firstly, the Program asks the questions about the Patient to the Physician. The Physician gives the available patient information (Sing, Symptom and Results of the various Tests) with values.

On the basis of the confidence associated with the each test with value and the weight associated with the causal arcs, status of each node in the causal Net is computed.

Status of a state is dependent upon the result of its associated tests and the status values of the states arround it. A state is marked confirmed or disconfirmed, if its status is greater than a preset threshold or less than a second threshold, otherwise it is undermined.

After computing a status value and entering all available information about a patient, the classification table determines diagnoses and treatments.

INTERNIST

It was developed in 1975 by H. Pople a computer scientist and J. Myers a specialist in internal medicine.[1] It has an extensive knowledge base and also uses the huristic techniques.

INTERNIST - I way of diagnosis is somehow same as the physician does diagnosis. After getting information about a patient, the physician makes hypothesis in his mind and concentrates on some disease area ignoring the other disease area. INTERNIST - I. Program also follows the same path. Data are considered as manifestation, and hypotheses as diseases.

INTERNIST - I gets a set of diseases on the basis of some or all symptoms and it selects one disease among these diseases on the basis of scoring scheme. Again it finds another set of diseases on the basis of remaining symptoms and again selects the possible disease. The process continues till all symptoms have been taken into consideration.

Knowledge Representation

INTERNIST - I knowledge about diseases is represented in the form of disease tree. Where each node is connected by the relation "Form of". The Terminal nodes represent the individual disease. The non-terminal nodes and its subtrees represent the disease area.

Diseases and their manifestation are related by two ways.

1. A manifestation can evoke a disease.
2. A disease can manifest certain sign and symptoms.[1]

The strength of these relations is represented by a number on a scale of 0 through 5, where 0 represents that no conclusion can be drawn about the disease and the manifestation, and 5 represents that the manifestation is always associated with the disease. For each non-terminal nodes of the Tree, a list of manifestation is calculated by taking the common of the manifestation lists of that node's off spring. The manifestation associated with two important properties called TYPE and IMPORT. The TYPE property measures the expenses for a manifestation in terms of financial cost and physical risk to the patients and also order the question asked by the consultation program. The IMPORT is a property of manifestation to the ignored itself easily in diagnosis.

Diagnostic Procedure

At the begining a list of manifestation is entered and it evokes one or more nodes of the disease Tree. For each evoked disease node a model of four list is created. A diagnosis corresponds to set of evoked Terminal nodes that account for all of the symptoms. Again program ask for further information because generally at this stage very few of the Terminal nodes are evoked. To get this further information, the program focus on a disease area and formulate a problem. Each disease model is scored by getting a positive and negative score for each manifestati that it can explain and cannot explain respectively. Both are weighted by IMPORT. It gets a bonus, if it is linked causally to a disease that has already been confirmed. Th disease models are partitioned into two sets:

1. The Top ranked model and the diseases that are alternative to it.
2. The diseases that are complementary to the top ranked model.

After partitioning the disease model, the problem is formulated. The system uses one or several strategies depending on the number of candidate disease in the problem set.

If there are many alternative hypotheses, it attempts to rule out as many as possible questions about manifestation, that strongly indicates a disease (high P (M/D) are selected first.[1] If these manifestatio are not present, this disease can be ruled out. If there are between two and four possibilities, the porgram attempts to discriminate between them. Then the questions about manifestation that strongly indicates one disease D_1 (high $P(M/D_1)$, and weakly indicate another disease D_2 (Low $P(M/D_2)$, are selected.[1] These questions are used to differentiate the one disease from an another. In some cases because of lack of information, terminal nodes will not be confirmed. In this situation a general diagnosis is given. After confirmation of a disease, its manifestati are marked "accounted for", and bonus scores are given to all the diseases those are linked with this disease. The focus shifts to the new top ranked disease and the formulat of new problem.

CHAPTER - III

PREDICATE CALCULUS & RESOLUTION PRINCIPLE

Predicate calculus is a mathematical language consisting of statements expressed in the form of well formed formulae. The basic vocabulary consists of predicate symbols, function letters and terms, these are well defined in the literature.[8]

Components of the first order Predicate Calculus

1. Predicate symbols - P, Q, R - - - -
2. Function symbols - f, g, h - - - -
3. Variable symbols - x, y, z - - - -
4. Connectives - $\cap$, $\cup$, $\Rightarrow$
   - (and), (or), (implies)
5. Quantifiers - ($\exists$) (Existential quantifier)
   - ($\forall$) (Universal quantifier)
6. Parenthesis, brackets and commas.

Now we are giving some examples - illustrating the above components.

Example : 1

'Ram's mother is married to Ram's father'

We can write it in formula.

MARRIED (father (Ram), mother (Ram)) where MARRIED is Predicate symbols father, mother are function letters.

Example : 2[5]

'All elephants are gray', represented by

$(\forall x)(\text{ELEPHANT}(x) \Longrightarrow \text{COLOUR}(x, \text{GRAY}))$.

and ,

'There is a person who wrote computer chess'

Represented by

$(\exists x)$ WRITE (x, Computer - chess)[8]

To define the statements we are giving following definitions.

Definitions: According to Zohar Manna

Constant:

(a) n - ary function constants f_i^n ($i \geqslant 1$, $n \geqslant o$); f_i^o is called an individual constant and is also denoted by a_i.

(b) n - ary Predicate constant p_i^n ($i \geq 1$, $n \geq o$); p_i^o is called a propositional constant.

<u>Variables</u>:

(a) n - ary function variables f_i^n ($i \geq 1$, $n \geq o$), F_i^o is called an individual variable and is also denoted by x_i.

(b) n - ary Predicate variables P_i^n ($i \geq 1$, $n \geq o$), P_i^o is called a propositional variables.

<u>Terms</u>:

(a) Each individual constant a_i and each individual variable x_i is a Term.

(b) If t_1, t_2, ...t_n. ($n \geq 1$) are terms then so are f_i^n (t_1, t_2------- t_n) and F_i^n (t_1, t_2---------t_n).

(c) If A is a wff and t_1 and t_2 are terms (then, if A then t_1 else t_2) is a Term.

<u>Atomic Formula</u>:

(a) T and F are atfs

(b) Each Propositional constant P_i^o and each Propositional variables P_i^o are atfs.

(c) If t_1, t_2 ---- t_n $(n \geqslant 1)$ are terms, then $P_i^n(t_1, t_2$ ----- $t_n)$ and $P_i^n(t_1, t_2$ ----- $t_n)$ are atfs where $i, n \geqslant 1$.

Well formed Formulas:

(a) Each atf is a wffs.

(b) If A, B and C are wffs, then so are $(\sim A)$, $(A \supset B)$, $(A \cap B)$, $(A \cup B)$ $(A \Rightarrow B)$.

INTERPRETATION of Formula in the first order logic[3]

To define an interpretation for a formula in the first order logic we have to specify two things, namely, the domain and an assignment to constant, function symbols and predicate symbols, occuring in the formula. The following is the formal definition of an interpretations of a formula in the first order logic.

Definition:[3]

An interpretation of a Formula F in the first order logic consists of a non-empty domain D, and an assignment of 'values' to each constant, function symbol, and predicate symbol occuring in F as follows:

1. To each constant, we assign an element in D.
2. To each n-place function symbol, we assign a mapping from D^n to D.
3. To each n-place Predicate symbol, we assign a mapping from D^n to (T, F).

Sometimes, to emphasize the domain D, we speak of an interpretation of the formula over D. When we evaluate the Truth value of a Formula in an interpretation over the domain D, ($\forall x$) will be interpreted as "for all elements x in D" and ($\exists x$) as "There is an element in D".

For every interpretation of a formula over domain D the formula can be evaluated to T or F according to the following rules.

1. If the Truth Values of formulas G and H are evaluated, then the Truth Valuesof the formula $\sim G$, $(G \cap H)$, $(G \cup H)$, $(G \Rightarrow H)$ and $(G \Leftrightarrow H)$ are evaluated by using this Table.

TABLE

G	H	$\sim G$	$(G \cap H)$	$(G \cup H)$	$(G \Rightarrow H)$	$(G \Leftrightarrow H)$
T	T	F	T	T	T	T
T	F	F	F	T	F	F
F	T	T	F	T	T	F
F	F	T	F	F	T	T

2. $(\forall x)$ G is evaluated to T if the Truth Value of G is evaluated to T for every x in D, otherwise, it is evaluated to F.
3. $(\exists x)$ G is evaluated to T if the Truth value of G for at least one x in D, otherwise, it is evaluated to F.

Any Formula containing free variables cannot be evaluated. We assume either that formula do not contain free vatiables or that free variables are treated as constant.

Interpretations are defined, all the concepts such as validity, inconsistency and logical consequence for formulas of the first order logic.

Definition[3]

A Formula G is consistent (Satisfiable) if and only if there exists an interpretation I such that G is evaluated to T in I. If a formula G is T in an interpretation I, we say that I is a model of G and I satisfies G.

Definition[3]

A formula G is valid if and only if every interpretation of G satisfies G.

Definition[3]

A Formula G is inconsistent (unsatisfiable) if and only if there exist no interpretation that satisfies G.

Definition[3]

A formula G is a logical consequence of formulas $F_1, F_2,$ ------- F_n if and only if for every interpretation I if $F_1 \cap F_2 \cap$ -------$\cap F_n$ is true in I, G is also True in I.

In the first order logic, since there are an infinite number of domains in general, there are an infinite number of interpretations of a formula so it is not possible to verify a valid or an in consistent formula by evaluating the formula under all the possible interpretations.

PRENEX NORMAL FORMS IN THE FIRST ORDER LOGIC

The prenex normal form of a formula is to simplify proof procedure in the first order logic.

Definition[3]

A Formula F in the first-order logic is said to be in a Prenex normal form if and only if the formula F is in the form of

$$(Q_1 \ x_1) \text{ ---------- } (Q_n \ x_n) \quad (M)$$

where every $(Q_i \ x_i)$, $i = 1$ ---------- n is either $(\forall x_i)$ or $(\exists x_i)$ and M is a formula containing no quantifiers $(Q_1 \ x_1)$ ------ $(Q_n \ x_n)$ is called the Prefix and M is called the matrix of the Formula F.

Transforming Formulas into Prenex normal form[3]

Step I Use the Law

$$F \Leftrightarrow G = (F \Rightarrow G) \quad (G \Rightarrow F)$$

$$F \Rightarrow G = \sim F \cup G$$

to eliminate the logical connective and

Step II Repeatedly use the Law

$$\sim(\sim F) = F$$

Demorgan's Law

$$\sim(F \cup G) = \sim F \cap \sim G$$

$$\sim(F \cap G) = \sim F \cup \sim G$$

and the Laws

$$\sim((\forall x) \ F(x)) = (\exists x) \ (\sim F(x))$$

$$\sim((\exists x) \ F(x)) = (\forall x) \ (\sim F(x))$$

To bring the negation sign immediately before atoms.

Step III Rename bound variables if necessary.

Step IV Using the Law

$$(Q\,x)\;\; F(x) \cup G \;=\; (Q\,x)\;\; (F(x) \cup G)$$

$$(Q\,x)\;\; F(x) \cap G \;=\; (Q\,x)\;\; (F(x) \cap G)$$

$$(\forall\,x)\;\; F(x) \cap (\forall x)\;\; H(x) = (\forall x)\;\; (F(x) \cap H(x))$$

$$(\exists\,x)\;\; F(x) \cup (\exists x)\;\; H(x) = (\exists x)\;\; (F(x) \cup H(x))$$

$$(Q_1 x)\;\; F(x) \cup (Q_2\,x)\;\; H(x) = (Q_1 x)\;\; (Q_2 Z)\;\; (F(x) \cup H(Z))$$

$$(Q_3 x)\;\; F(x) \cup (Q_4 x)\;\; H(x) = (Q_3 x)\;\; (Q_4 Z)\;\; (F(x) \cap H(Z))$$

to move the quantifiers to the left of the entire formula to obtain a Premex normal form.

The first order Predicate calculus introduce some restrictions on the usage of quantifies. If one limits the quantification to variables one gets a simpler system of well formed formula.

$$(\exists\,x)\;\; (\forall\,Y)\;\; ((P\,(\,x,\,Y) \cap Q\,(Y,\,x)) \Longrightarrow R\,(\,x))$$

is an example of first order predicate calculus statement.

Representation of Statements in the form of Predicate calculus

Here we are giving some examples of the statement represented in the form of predicate calculus logic.

Example I[8]

Every city has a dogeatcher who has been bitten by every dog in the town.

Represented in the form.

$$(\forall x) \quad (\text{CITY}\ (x) \Rightarrow (\exists Y) \quad (\text{DOG} \quad \text{CATHER}\ (x, Y)$$

$$\cap\ (\forall Z)\ ((\text{DOG} \quad (Z) \cap \text{LIVES - IN} \quad (x, Z)) \Rightarrow \text{BIT}\ (Y, Z)))).$$

Example II[8]

For every set x, there is a set Y, such that cardinality of Y is greater than the cardinality of x.

Represented in the form.

$$(\forall x) \quad (\text{SET}\ (x) \Rightarrow (\exists Y) \quad (\exists U) \quad (\exists V)$$

$$(\text{SET}\ (Y) \cap \text{CARD}\ (x, U) \cap \text{CARD}\ (Y, V) \cap G(U, V))).$$

Example III[8]

All blocks on Top of blocks that have been moved or that are attached to blocks that have been moved have also been moved can be Represented in the form.

$$(\forall x) \quad (\forall Y) \quad ((\text{BLOCK} \quad (x) \cap \text{BLOCK}\ (Y)$$

$$\cap\ (\text{ON TOP}\ (x, Y) \cup \text{ATTACHED}\ (x, Y))$$

$$\cap\ (\text{MOVED}\ (Y)) \Rightarrow \text{MOVED}\ (x)).$$

Typically one could represent medical knowledge in terms of the first order Predicate calculus[1] then a medical inference is simply the development of a Proof for a theorem. The medical knowledge can be of any kind. It could be a diagnosis, if given a set of symptoms and results of various tests, all expressed in Predicate calculus. It would be a decision towards a therapy based on symptoms, available drugs, compelling constraints etc.

Resolution Principle

The resolution Principle offers a mechanical procedure which combines various kinds of inferences into one form. There are substitution, modus ponens and other form of inference systems.

The resolution method is a form of proof by contradiction that involves producing new clauses, called resolvents, from the union of the axioms and the negated theorem. These resolvents are then added to the set of clauses from which they were derived, and new resolvents are derived. This process continues, recursively, until it produces a contradiction. Resolution is guaranteed to produces a contradiction if the theorem follows from the axioms.[2]

Before using the resolution principle, any predicate calculus wffs converted to a set of clauses.[1]

Definitation[8]

Clause - A clause is defined as a wff consisting of a disjunction of titerals.

Converting a Formula to clausal form[2]

Conversion into a clausal form is done by a series of steps.

1. Negate F : Replace F by $\sim F$.
2. Remove: $\Rightarrow$ and $\Leftrightarrow$ by replacing ($A \Rightarrow B$) by ($\sim A \cup B$) and ($A \Leftrightarrow B$) by $((\sim A \cup B) \cap (\sim B \cup A))$
3. Move $\sim$ inward, using the rules

$$\sim(\sim A) = A$$

$$\sim(A \cap B) = \sim A \cup \sim B$$

$$\sim(A \cup B) = \sim A \cap \sim B$$

$$\sim \forall x\, A(x) = \exists x \sim A(x)$$

$$\sim \exists x\, A(x) = \forall x \sim A(x)$$

4. Move $\forall$ and $\exists$ inward.

5. Rename variables so that no two quantifiers quantify the variables.

6. Exchange $\exists$ for skolen functions and then drop $\forall$'s.

7. Convert to CNF (Conjective normal form) by repeatedly applying Demorgan's Law:

$$\sim(A \cap B) = \sim A \cup \sim B$$

$$\sim(A \cup B) = \sim A \cap \sim B$$

Given a well formed formula describing the condition of required for infering a diagnosis it is simply a mechanical process to achieve, at it given a set of available symptoms expressed in the form of statements in the calculus.[2]

Given four clauses (well formed form ula reduced by substituting logical equivalence to a form suitable for resolution), resolution looks like

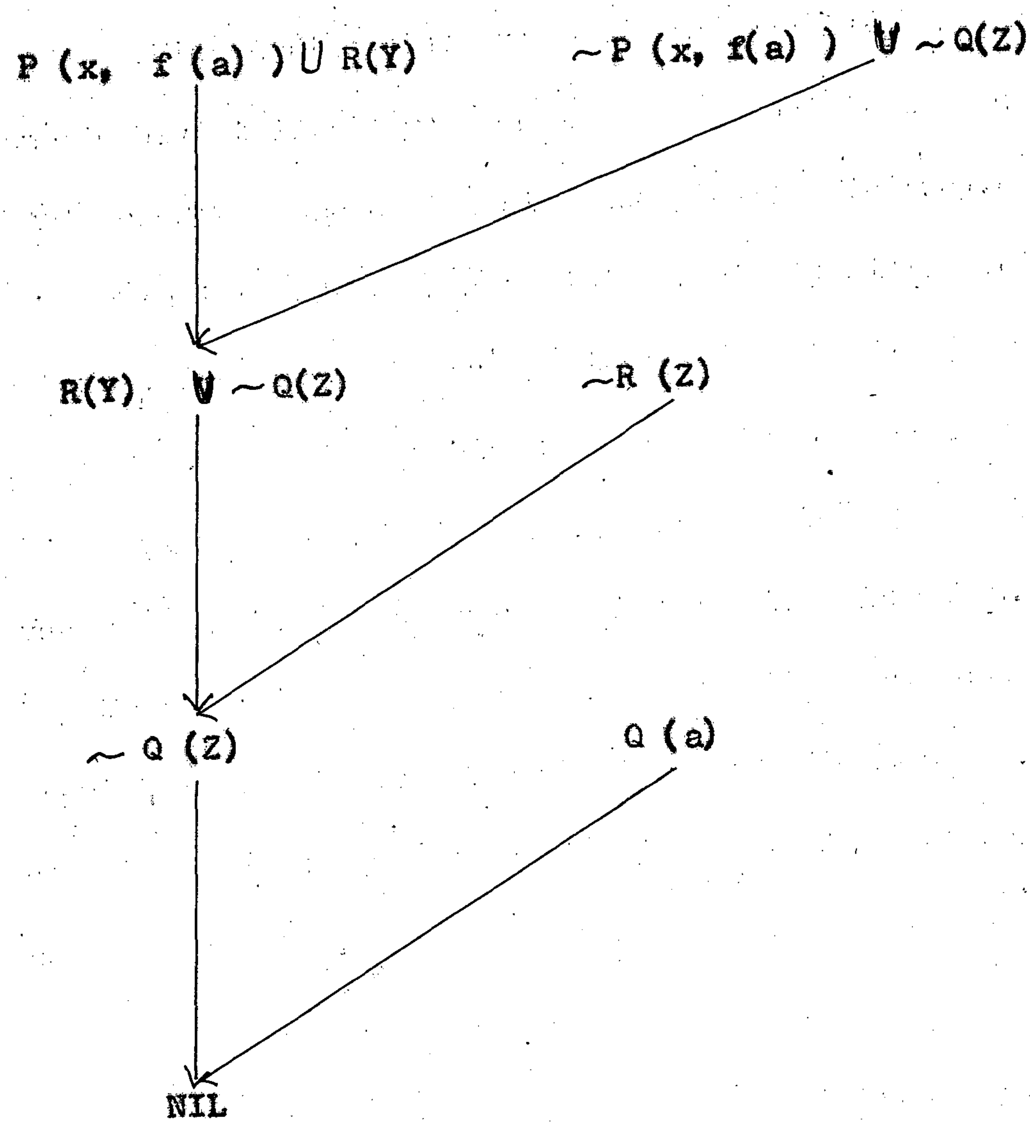


Fig. 3

A NIL clause indicates a contradiction. The usual way of proving a theorem is to introduce the negation of the proposition to be established and add it to the corpus of clauses. If a resolution tree yields a 'NIL' clause, th proposition is established.

Strategies and the Interactive Environment

Like most problem of Artificial Intelligence the resolution process can cause combinatorial explosion in terms of space and time. Most of these problems are solved by accepting some heuristic procedure to tackle the situation.

Here we are discussing some of the strategies used by theorem proven.

Simplification Strategies

The literals or clauses can be elimiated from a set of clauses in a manner that. It does not effect the unsatisfiability or satisfiability of the clauses. There are three ways to simplifying a set of clauses. To eliminate tautologies, evaluate predicate where possible and eliminate clauses that are subsumed by other clause.

Linear - input form Strategy

This strategy involves choosing resolvent so that one resolvent is always from the set of original clauses. It is used because of its simplicity and efficiency.

Medical men always do this precisely at any point of time, the doctor has a hypothesis when he is diagnosing a problem. He directs his tests and studies the result of these tests with this in mind. A resolution system is very well suited for a such an interactive situation. A hypothesis can be tested and the resolution tree can be heuristically directed through the most likely paths. In case the results do not promise in one path, another path can be attempted.

CHAPTER - IV

LOGIC BASED MEDICAL CONSULTANT SYSTEMS

Here we have considered two important parts of the system

1. Patient Data Base.
2. Knowledge Base (which are based on the logic given in Chapter III.)

A resolution principle is called to act between Patient Data Base and Knowledge Base. On the basis of the resolved and unresolved literals in the clause, a formula is described to find out the certainty factor of diseases.

Patient Data Base

It consists of the available information about a patient like (History, Signs, Symptoms, and results of the various laboratory tests e.g. Blood, Urine, X-ray etc.) represented in the form of wff using first order Predicate calculus logic.

One can make a Patient Data Base in the following formate:

Patient Data Base

Patient No.	Patient Name	Age	Sex	History	Signs	Symptoms	Results of various Laboratory tests

In the above formate Patient No. and name gives the identification of a Patient. It does not play any role in diagnosis but the remaining part plays vital role in diagnosis. All these information are represented in the form of first-order Predicate calculus. Here we are assuming that the represented form of these information into first order Predicate calculus logic are S_1, S_2, S_3.. where S_1, S_2........S_n are clauses. These clauses are stored in sequence where the sequence could be done accordingly the priority of information in addition it also depends on the physician's criteria.

Knowledge Base

It consists of the information about diseases. The facts, inferences, heuristics about diseases are stored. All these knowledge are represented in the form of first-order Predicate calculus logic. Here we assume that the facts of the diseases are represented in the form of $S_1, S_2, S_3 \ldots\ldots\ldots S_n$ and the hypothesis or rules or inferences are represented in the form of $S_1 \cap S_2 \cap S_3 \ldots \cap S$ $> D_1 \cap D_2 \cap D_3 \ldots\ldots \cap D_n$. Here we have also considered one table of common and diagnostic symptoms of each diseases. The heuristics are also stored because of combinational explosian.

Knowledge Base can be seen by following formate.

Knowledge Base

Diseases	D_1	D_2	D_3	....	D_n
Facts	S_1, S_2, S_3, S_4, and Table in Fig.5	S_1, S_2, S_4, S_5 and Table in Fig.5	S_1, S_2, S_3, S_6, and Table in Fig.5		S_{n-2}, S_{n-1}, S_n, S_1 and Table in Fig. 5
Hypotheses	$S_1 \cap S_2 \cap S_3 \cap S_4 \Rightarrow D_1$	$S_1 \cap S_2 \cap S_4 \cap S_5 \Rightarrow D_2$	$S_1 \cap S_2 \cap S_3 \cap S_6 \Rightarrow D_3$		$S_1 \cap S_{n-2} \cap S_{n-1} \cap S_n \Rightarrow D_n$
Table	Common symptoms: S_1, S_4; Diagnostic symptoms: S_2, S_3	Common symptoms: S_1, S_5; Diagnostic symptoms: S_2, S_4	Common symptoms: S_1, S_2; Diagnostic symptoms: S_3, S_6		Common symptoms: S_1, S_{n-2}; Diagnostic symptoms: S_{n-1}, S_n
Heuristics					

Fig. 4

TABLE

Symbol	Statements
S_1	E_1
S_2	E_2
S_3	E_3
S_4	E_4
"	"
"	"
"	"
S_n	E_n

[illegible]

Mathematical Model for evidential strength[4]

Here we are also considering the same unit of measurement given in Chapter II (MYCIN).

1. MB (h, e) = x Means "The measure of increased belief in the hypothesis h, based on evidence e is x".
2. MD (h, e) = Y Means "The measure of increased disbelief in the hypothesis h, based on evidence e is Y".
3. We are also applying the same theory here.

   Total No. of Literals in the hypothesis
   = No. of resolved literals in the hypothesis
   + No. of unresolved literals in the hypothesis.

   MB = (Total No. of literals in the hypothesis - No. of unresolved Literals in the hypothesis).

   MD = (Total No. of Literals in the hypothesis - No. of resolved Literals in the hypothesis).

Here we have also considered a certainty factor (CF)

$$CF = MB - MD$$

and

$$\%CF = \frac{CF \times 100}{\text{Total No. of Literals in the hypothesis}}$$

Here the range of degrees of the MB, MD and CF are

$$0 \leq MB \leq n$$

$$0 \leq MD \leq n$$

$$-n \leq CF \leq +n$$

Diagnostic Procedure

The Physician gets the available information about a Patient like (History, Signs, Symptoms, Results of the various Tests). The user enters these information into the computer. These information stored in the computer as a Patient data base. The knowledge about diseases are already stored in Knowledge Base.

Firstly the information about a Patient in Patient Data Base is compred with the facts about the diseases in Knowledge Base. All those diseases are taken into consideration whose facts mached with all or any subset of the Patient information. These diseases are arranged in the descending order of the maximum matched facts, disease.

Secondly the first disease is taken from the List into consideration. The resolution Principle is called to act between the Patient Data Base and the related hypothesis of the first disease in Knowledge Base. If the NIL clause obtained then the occurence of this disease is confirmed. If not i.e. (NIL clause does not obtained) and resolution is continued then after n steps (n depends on the situation and environment) stop the resolution processing, and come to the calculation which gives the certainty factor of the disease.

The unresolved Literals are, displayed on the terminal with the English Statements written in the Table stored in Knowledge Base. The resolution shifts to the next disease of the list, and adopts the same diagnostic procedure till the last disease of the list has been processed. After seeing the unresolved part of the hypothesis clause, Physician again endevours to find out the information like (Signs, Symptoms, Various Laboratory Tests). If he gets any positive information then the Patient Data Base is updated and again same diagnostic procedure is followed. Otherwise the result of the first processing is taken into consideration.

Sometimes two diseases get the same percentage of certainty factors. In this situation the unresolved literals of both diseases are compared with the Table (for diagnostic symptoms area and common symptoms area) stored in Knowledge Base. The disease whose literals falls under the common symptoms area gets the positive marks for each literals. If it falls, under the diagnostic symptoms area gets the negative marks for each literals. Finally the disease of the maximum marks is considered first in the list followed by others in decending order. Now we are giving examples assuming some cases.

Example 1

Suppose S_1, S_2, S_3, S_4 are the Patient information in Patient Data Base. After comparing these information to the facts of the diseases in Knowledge Base we get

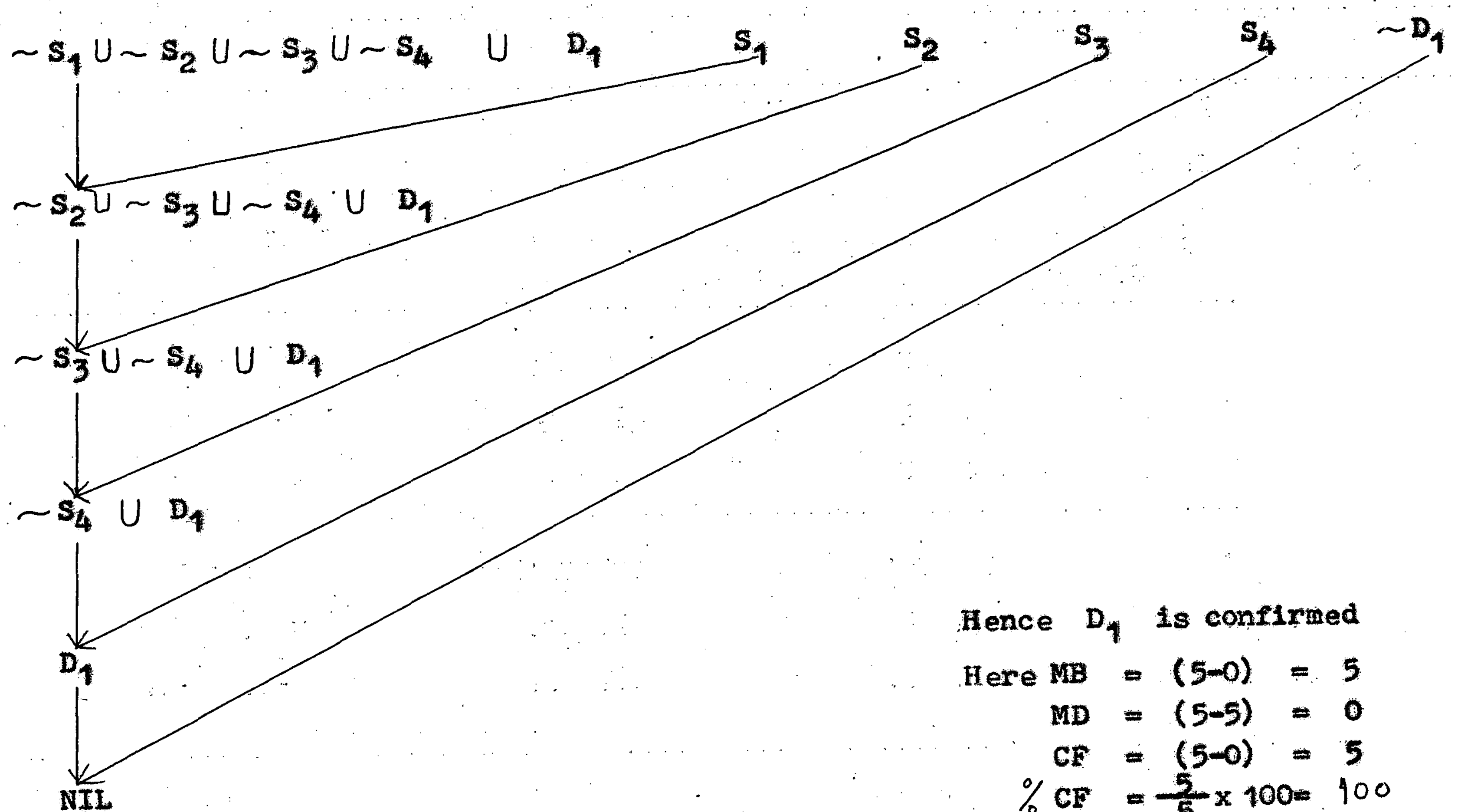
D_1, D_2, D_3, D_4

where D_1 is the maximum mached Facts disease followed by D_2, D_3, D_4. Now to prove the occurence of the disease D_1, we put negative sign before D_1 and store it in Patient Data Base. Now the resolution starts between the hypothesis of disease D_1 in Knowledge Base and the Patient Data Base.

Assume hypothesis of D_1 in Knowledge Base is

$$S_1 \cap S_2 \cap S_3 \cap S_4 \Rightarrow D_1$$

In this case we assume that S_1, S_2, S_3, S_4 are unit clauses of literals S_1, S_2, S_3, S_4.



Hence D_1 is confirmed

Here MB = (5-0) = 5

MD = (5-5) = 0

CF = (5-0) = 5

% CF = $\frac{5}{5}$ x 100= 100

CF = 100%

Fig. 6

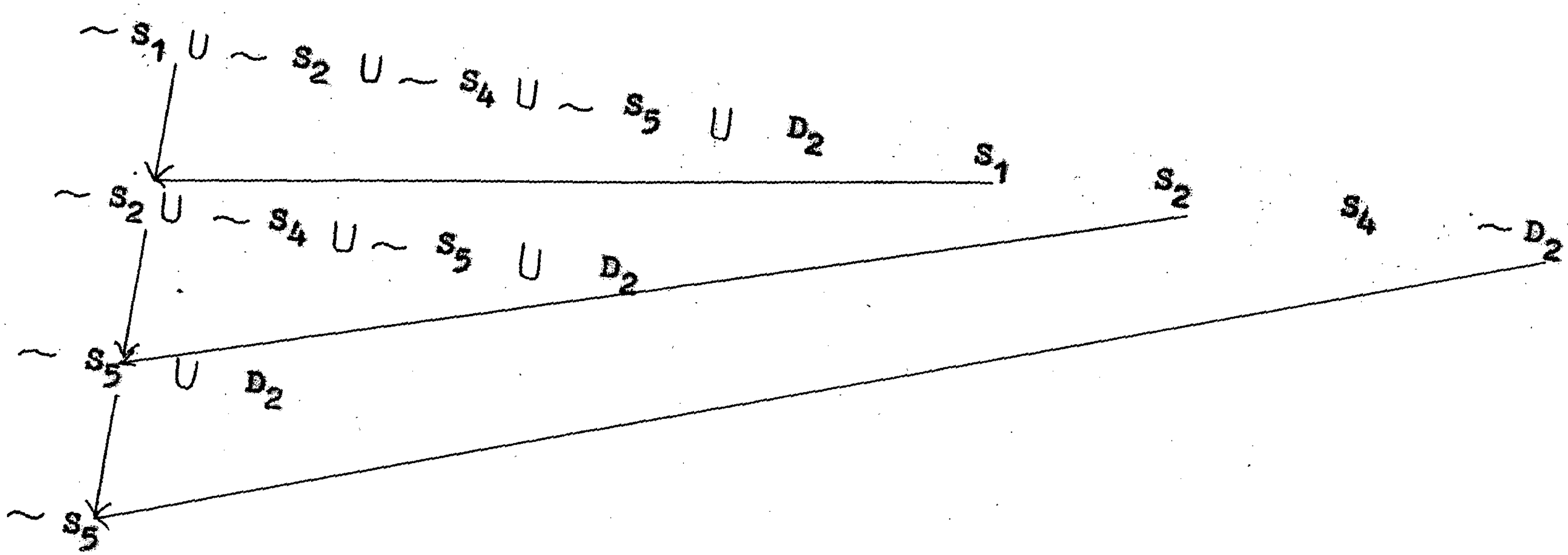
Now we will see the possibility of occurence of disease D_2 put negative sign before D_2 and store it in Patient Data Base. Assume hypotheses of D_2 in Knowledge Base is

$$S_1 \cap S_2 \cap S_4 \cap S_5 \Rightarrow D_2$$

$$\sim S_1 \cup \sim S_2 \cup \sim S_4 \cup \sim S_5 \cup D_2$$

Here also we assume that the each S_1, S_2, S_4, S_5 are unit clauses of literals S_1, S_2, S_4, S_5.

The Resolution shown in Fig.7.



Here

$$MB = (5-1) = 4$$

$$MD = (5-4) = 1$$

$$CF = (4-1) = 3$$

$$\%\ CF = \frac{3}{5} \times 100 = 60$$

$$CF = 60\%$$

Fig. 7

In this case we stop the resolution process at this level, and unresolved part of the hypothesis are displayed on the terminal.

The Physician tries to find out S_5 in the Patient. If he gets, then the Patient Data Base is updated by S_5 and again same diagnostic procedure adopted. If not, then the D_2 is considered with certainty of 60%.

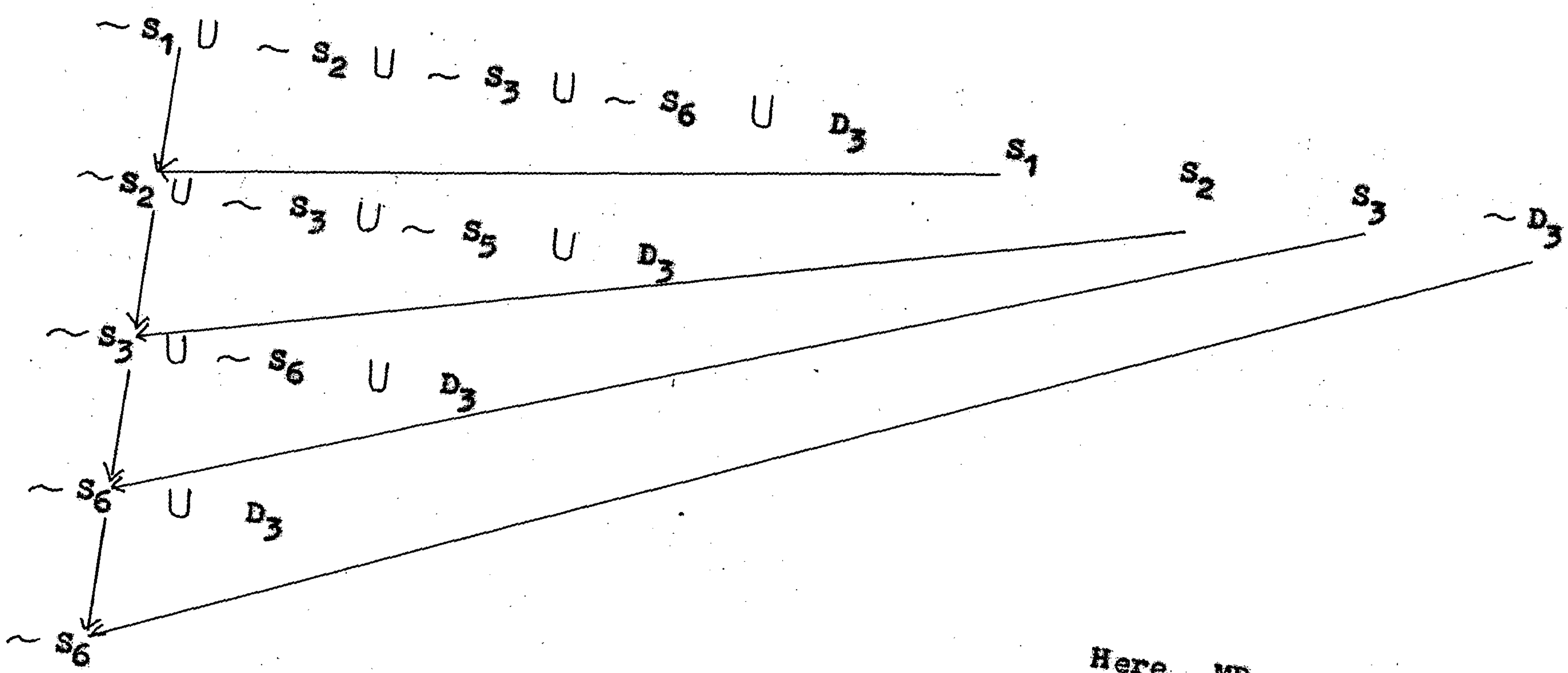
Now we are considering D_3 put the negation before D_3 and store it in Patient Data Base. Suppose hypotheses in D_3 is

$$S_1 \cap S_2 \cap S_3 \cap S_6 \Rightarrow D_3$$

$$\sim S_1 \cup \sim S_2 \cup \sim S_3 \cup \sim S_6 \cup D_3$$

and we also assume that S_1, S_2, S_3, S_6 are unit clauses of literals S_1, S_2, S_3, S_6.

The Resolution Tree shown in Fig. 8.



Here $MB = (5-1) = 4$

$MD = (5-4) = 1$

$CF = (4-1) = 3$

$\% CF = \frac{3}{5} \times 100 = 60\%$

$CF = 60\%$

Fig. 8

We stop the resolution process at this level, and unresolved part of the hypothesis clause (S_6) are displayed on the terminal and again follow the same diagnostic procedure.

Suppose D_3 comes with the same certainty factor i.e. 60%. In this situation the unresolved literals of the hypothesis of both the diseases are compared with the table in Knowledge Base. Whether they belong to the common symptom area or diagnostic symptom area. If S_5 belongs to diagnostic area and S_6 belongs to the common symptom area then D_3 has more weight then D_2 and vice-versa. If S_5 and S_6 belongs to the same area then both D_2 and D_3 consider with the same weight and certainty Factor.

Now we consider the (Last disease of the List) D_4.

Put negation before D_4 and store it in Patient Data Bas

Suppose hypothesis of D_4 is

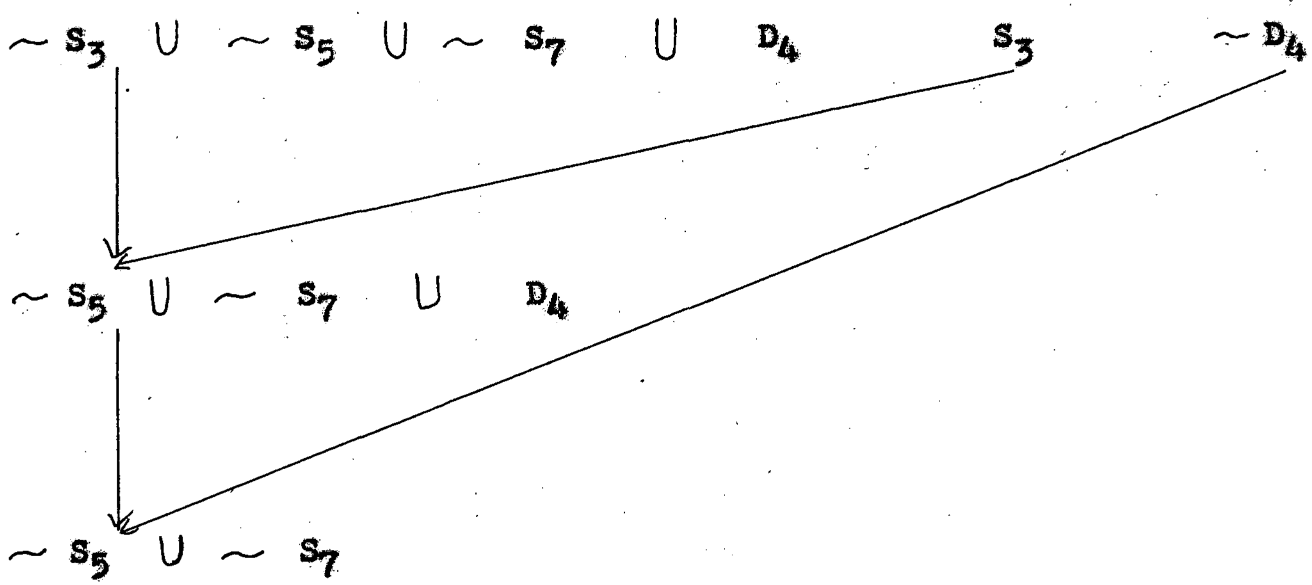
$$S_3 \cap S_5 \cap S_7 \Rightarrow D_4$$

$$\sim S_3 \cup \sim S_5 \cup \sim S_7 \cup D_4$$

Also assume that S_3, S_5, S_7 and D_4 are unit clauses.

We come to the resolution process.

The Resolution Tree shown in Fig. 9.



Big. 9

We stop the resolution process at this level. The unresolved Literals S_5 and S_7 displayed on the terminal

MB	=	(4-2)	=	2
MD	=	(4-2)	=	2
CF	=	(2-2)	=	0
% CF	=	0		
CF	=	0		

Physicians try to find out S_5 and S_7 if theygets then again follow the same diagnostic procedure otherwise the first result in considered i.e. D_4 is not considered.

Finally we get the following results

D_1	with	100%	certainty	
D_2	with	60%	certainty	+ Extra weight
D_3	with	60%	certainty	
D_4	with	0	certainty	

Combinatorial Explosion

Like most problems of Artificial Intelligence, the resolution process can cause combinatorial explosion in terms of space and time. Most of these problems are solved by accepting some heuristic procedure.

Here we have also developed two strategies,

1. The resolution take place between the hypothesis clause in Knowledge Base and one clause from the set of clauses in Patient Data Base. No other resolution will take place at this level.
2. The next resolution will take place between the derived clause and next clause in the sequence of clauses in patient Data Base. No other resolution will take place with the same derived clause at the same level.
3. This process continue till last clause of the sequence in the patient Data Base is processed.

These strategies have been applied in the example shown in Fig. 5 and through this, we get the result in 5 steps. Same example is solved in arround 300 steps, without using these strategies. The example which we have taken is having only five clauses which are simple while the literals are also in simplest form.

CHAPTER - V

CONCLUSION

Computer may not replace physicians but can very well assist their decisions. Francis T.[12] says "The early systems attempted to do diagnosis for the doctors which is crazy." Even still today there are several functioning Knowledge-Based decision systems, called 'Knowledge-Based'. According to Dombal "What we are really trying to do."[12] "is to get the experienced doctor's level of performance upto that of the Senior clinicians within a few weeks, as opposed to ten years," [12] while building A I systems, researchers discover additional information about human expertise which they add to later versions of their systems. Shortliffe used trail-and-error technique in his system MYCIN. According to Shortliffe's trial-and-error method, it is "Easier than asking an expert for everything he knows about meningitis and writing it down. It's very hard for people to analyse their own knowledge."[12]

The other systems using AI, technique for a much larger area of medicine, like INTERNIST which has currentl a Knowledge-Base of more than 600 disease. The system is designed to guide Physicians in order to solve difficult diagnostic problems. According to Jack Myres.[12]

"If you put this all together, you have got a Knowledge-Base in internal medicine alone that is many times what the human brain could possibly remember."

The system which we have described is also Knowledge-Based. The medical knowledge is represented in the form of First-order Predicate calculus logic. This logic can represent many real life problems in the world.

The result of this model could be easily generalized We can adopt these techniques for a variety of situation involving large number of diseases and patients.

The resolution principle of the first-order Predicate calculus suffers from the issues associated with combinational explosion as in most problems of

Artificial Intelligence. Further it has been shown that predicate calculus is semi-decidable.

We can, however, overcome these difficulties, partially, by adopting some strategies for handling the resolution tree. The number of clauses and steps can be reduced very well by adopting the strategies described earlier in Chapter IV. Interestingly enough, we get the result through this method in 5 steps and 5 clauses, only. Without using these strategies, it takes around 300 steps and clauses to get the result.

However, we don't claim that the system which we have described or the systems which are already developed, are fulproof methods. However, we can claim that it is proof procedure for medical diagonosis and it has a number of distinct advantages as a clinical aid. It can store enormous amount of factual data more than any single physician can manage. It can be used by a number of physicians at a time, where the physicians are restricted to one situation at the given time.

It can be made available wherever and whenever it is needed. It can be made available in situations like Rural Hospitals or Ship at Sea where the physician needs more advice and information.[6]

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