HiP : A MEDICAL EXPERT SYSTEM FOR THE DIAGNOSIS OF HYPERTENSIVE DISORDERS IN PREGNANCY

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ABSTRACT

This thesis describes and discusses the implementation of a medical expert system for the diagnosis of hypertension in pregnancy.

The system named HiP, consists of a consultation program and a knowledge base editor. The consultation program of HiP is an interactive program that attempts at assisting nurses in absence of a specialist, in the diagnosis of hypertension and its associated disorders in pregnant women. The system uses the much publicised rule-based approach of MYCIN, largely because of its favourable performance.

Hip employs a depth-first search with a backward chaining of rules as its control strategy. The system always starts its inference with a goal to establish and the system works on establishing this goal by examining the rules, condition by condition.

HiP's performance is evaluated by running the system through a set of real cases of hypertensive and pregnant patients over the past years at the University Hospital, Kuala Lumpur. The diagnoses made by HiP are compared against that made by the doctors in charge and the result of the comparison is shown to an expert for comments.

Written in GCLISP and developed on an IBM or IBM compatible personal or micro-computers, HiP is targeted for use at the rural clinics where computer facilities are usually scarce.

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CHAPTER 1

INTRODUCTION

Expert system is an area of research in the field of Artificial Intelligence (AI). To introduce expert systems, we must first have an idea of what AI is. The following definition from Barr and Feigenbaum (1981) is a representation of opinion in the field :

"Artificial Intelligence is part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics we associate with intelligence in human behaviour - understanding language, learning, reasoning, solving problems and so on."

In other words, AI is a branch of computer science that attempts to incorporate human intelligence into machines. To be considered as an AI machine, the system must be able to undertake a task that is comparable to human intelligent behaviour.

Systems that are designed with human ability, such as seeing images, hearing sounds and understanding speech are still under development, but these systems usually fail to match the competence of its human counterpart [Gevater 83]. However, systems in the area of reasoning with knowledge in a limited domain have been proven to be successful, where the performance of these systems has been rated comparable or in some cases better than a human expert [Gevater 83]. These systems which are known as expert systems use knowledge, intuition and experience of a human expert in a chosen field together with a method of applying these

knowledge to make inferences. Unlike conventional computer programs, expert systems is non-algorithmic and most of the time they are expected to make conclusions based upon incomplete or uncertain information.

Ever since the emergence of one of the earliest and most often applied expert system, Dendral devised by Feigenbaum and Lederberg at Stanford University back in late 1960's, the interest in the development of expert system has grown rather rapidly. In a time period of just over a decade many more similar systems have been constructed with various functions for various domains. Table 1 of Appendix 1 shows a list of known and established expert systems as at 1983.

1.1 ARTIFICIAL INTELLIGENCE IN MEDICINE

The AI in medicine (AIM) field emerged in the early 1970's in response to several simultaneous needs, oppurtunities and interests [Szolovits 82]. With all the new medical discoveries and the increasing public awarenes for highest quality health care, medical knowledge has been growing very rapidly. A physician is often without enough time to concentrate on each case and to keep up with the latest developement in his field. The involvement of computers that would help in storing, organizing and retrieving medical knowledge in dealing with complicated cases and systems that would assist in making appropriate diagnostic, prognostic and therapeutic decision are very much welcomed in this field. Seeing this oppurtunity, the AI researchers, who at the same time

were at the peak of formalizing general problem-solving techniques, has chosen medicine as a field of focus in which to apply practically their developing techniques.

When AIM was first introduced, the main concentration was the construction of AI programs that perform diagnosis and make therapy recommendations. Since these AI programs behave like an expert who is asked to provide advice on some difficult problem, they became known as consultation programs. However by late 1970's, these programs were referred to as expert systems. Four major medical expert systems were developed by 1975 and these systems are known as PIP [Pauker et al. 85], CASNET [Kulikowski and Weiss 82], MYCIN [Shortliffe 85] and INTERNIST-1 [Pople, 82].

Today, medical AI has broaden its research area from the construction of expert systems into other subfields such as patient monitoring systems, x-ray and ultrasounds imaging systems and prosthetic devices [Clancey and Shortliffe 84].

1.2 AIM OF RESEARCH

This thesis describes the development of a medical expert system named **HiP - Hypertension in Pregnancy**, that is able to assist nurses with the diagnosis of hypertension and its associated disorders in pregnant women. This system is intended to be used as a tool for nurses and

midwives, in the absence of a specialist, in diagnosing hypertensive disorder in pregnant women or act as a "second opinion" to confirm the user's diagnosis. The frequent inavailability of specialist in rural clinics makes it the target area for the system.

HiP is a purely rule-based expert system. The knowledge of HiP is constructed in the form of rules. The rule structure of MYCIN was used as a model for the design of HiP's rules. The system provides a consultation program that interacts with the user and a knowledge base editor for the ease of editing the knowledge base. The consultation program of HiP, though not as sophisticated as MYCIN due to the time constraint, is able to assist in the diagnosis of hypertensive disorders and provide explanations and justifications of its conclusions when asked. The knowledge base editor is able to add new rules, delete or change existing rules, list the name of all rules in the rule based and display an English translation of a specified rule on the screen.

HiP was jointly developed at the Computer Centre, University of Malaya and the Obstetric and Gynaecology Department, University Hospital, Kuala Lumpur.

1.2.1 WHY MYCIN MODEL WAS CHOSEN?

The knowledge base of HiP is made up of rules. These rules are designed based upon the rule structure used in MYCIN. In MYCIN, each of the premises and conclusions of a rule are actually an executable LISP code. A premise is composed of a predicate function that works on knowledge that is stored as an associative triples of object, attribute and value. The rule interpreter need only to use the function EVAL in LISP on these premises and conclusions for it to be evaluated. The use of these predicate functions and the way knowledge is stored in MYCIN is found to be a particularly attractive and efficient way of processing and storing knowledge in HiP. Furthermore MYCIN was also chosen as a model for HiP because of its favourable performance which had been rated to be comparable with that of experts. However, even with the favourably rated performance, MYCIN is not routinely used in wards because of the system's size and the language it is written in (Interlisp), is slow and heavy on memory and running the system required more computing power than most hospitals can afford. Based upon these shortcomings of MYCIN, HiP is designed on a personal computer and uses about 640K of memory. It is hoped that with these minimum requirements, the system would be accepted and used daily in wards by the end users.

1.3 STATEMENT OF THE PROBLEM

Hypertension in pregnancy constitutes one of the most serious medical complications encountered by the pregnant patient. The incidence of these problems is remarkably constant at 8% - 10% in developed countries, but does vary in relation to patient population groups [Zuspan 85]. It has been and still is the leading cause of maternal mortality and is one of the significant factor in perinatal death in the world today. The onset of the disorders is often subtle and early diagnosis is often difficult to make. The challenge for the clinician is to identify those individuals who are at high risk for the disease in order to institute appropriate preventive measure, and hence to eliminate the severe forms. It is the aim of HiP to be able to assist clinicians in this task.

1.4 HARDWARE AND SOFTWARE SPECIFICATION

As HiP is targeted to be used in rural clinics and hospitals, where funds are limited and computer facilities may not be a top priority item, the system has been designed to run on inexpensive computers that most clinics and hospitals can afford. The moderately cheap and easily available IBM or IBM compatible personal computer with memory capacity of at least 640K, is the hardware needed to run the system.

One of LISP dialects , Golden Common LISP (GCLISP) is the sole programming language used in developing HiP. Therefore in order for the system to work, the support of GCLISP interpreter will be needed. The minimum requirements that should be regarded in using a GCLISP interpreter will have to be observed when running HiP.

1.4.1 WHY LISP ?

Formally it is possible to write any programs in any language, but by using a programming language that provides support for a variety of common structures, both for data and for control, may facilitate the process of building and AI systems such as an expert system, considerably.

There are quite a number of programming languages that are used in AI programming. By far the most important member of the AI family is LISP (RICH83). LISP is the second oldest programming language after FORTRAN and it has been a great influence on the development of other languages.

Among the features that LISP provides that makes it a desirable language for an AI systems are :

- easy manipulation of lists, where much of the knowledge used in expert system are represented in lists form.
- the availability of association lists and property list, a list of attribute-value pairs, that can be used to present data or facts regarding an individual.

late binding time of data structures.

flexible control structures that allows recursion almost

naturally makes it appropriate for many problem solving tasks.

its interactiveness makes writing a truly interactive programs

easy, which is usually important in an expert system.

1.5 ORGANIZATION OF THE THESIS

Chapter 2 describes the hypertension problem. It gives the reader a general understanding of hypertensive disorders, its classifications and diagnosis.

Chapter 3 presents a literature review of medical expert system. Brief descriptions of a few of the existing expert systems in medicine today are given. This chapter also examines the limitation of the system in this field.

Chapter 4 provides a description of the system's design. It describes HiP's control structure,rule-structure and inference mechanism.

Chapter 5 gives a short review of a few methods of reasoning used in medical expert systems. The reasoning used by MYCIN which is adopted by HiP is described in more detail.

The testing and evaluation of HiP are decribed in chapter 6.

Conclusion of the thesis is presented in chapter 7 with a review of the goals and the aims achieved. Future work is also reviewed in this chapter.

CHAPTER 2
AN OVERVIEW OF THE DOMAIN

The first step in creating an expert system is to choose a suitable domain for the system. Not all fields of knowledge are suitable for an expert system. Medicine however has been a popular field for the application of expert systems. HiP is built as a medical diagnostic expert system in the diagnosis of hypertensive disorders in pregnancy. This chapter provides a brief description of the domain, giving the reader a general understanding of the behaviour of blood pressure in pregnancy, the definitions of hypertensive states, the classifications of hypertensive disorders and its diagnosis.

2.1 PHYSIOLOGY OF BLOOD PRESSURE IN PREGNANCY

The physiological response to pregnancy evokes changes which produce values that would be considered markedly pathological in the non-pregnant female. In early pregnancy, important changes to the blood pressure may occur. One of the major actions of the hormone progesterone is to cause relaxation of the involuntary muscle of the blood vessels as well as the uterus, the bladder and intestine. Relaxation of the muscular wall of the blood vessels causes some delay in circulation through some of the tissues. The slowing in the blood circulation causes a fall in blood pressure which is very common in early pregnancy [Bourne 72]. This fall of blood pressure is usually only small in amount and is

perfectly normal. The blood pressure however, rapidly returns to normal after the 14th week of pregnancy as the body increases the amount of blood within its circulation. It will remain at or about the same level until the onset of labour.

2.2 DEFINITIONS OF HYPERTENSIVE STATES OF PREGNANCY

Different levels of blood pressure has been taken as the upper limit of normal during pregnancy by doctors over the years. The level to which the blood pressure can rise in late pregnancy is uncertain and the borderline between normal physiology and pathology has not been clearly established. However, the Committee on Terminology of the American College of Obstetricians and Gynecologist has suggested the folowing definitions of the hypertensive states of pregnancy [Taber 79] :

Hypertension

- a rise in systolic pressure of at least 30 mm Hg, or a rise in diastolic pressure of at least 15 mm Hg, or systolic blood pressure of at least 140 mm Hg or diastolic pressure of at least 90 mm Hg.

Proteinuria

- the presence of urinary protein in concentrations greater than 0.3 gram (300 mg) per litre in a 24 hour collection of urine or the presence of at least 1 gram (1000 mg) per litre of urinary protein in a random urine collection on two or more occasions at least 6 hours apart.

Edema

- commonly demonstrated by the swelling of the extremities and face which are caused by a general and excessive accumulation of fluids in the tissue.

The above diagnostic criteria is adopted throughout this research work as it is the criteria approved and used by the collaborating expert.

A diagnosis of hypertension can only be made after several seperate measurements of blood pressure and it is best achieved by meticulous measurement of the blood pressure. HiP system will assume that the blood pressure had been correctly taken and recorded by the user. HiP assumes that the user is aware of all the steps and precautions that should be taken in recording the blood pressure and that he/she has his/her own method of taking blood pressure that is approved by doctors.

2.3 HYPERTENSIVE DISORDERS IN PREGNANCY

Hypertensive disease in pregnancy, as mentioned in chapter one, is one of the most serious medical complications in pregnancy. If undetected and untreated hypertension can become severe and complicates labour and thus endanger the life of both mother and child. Severe forms of hypertensive disorders are often impossible to treat and an early

termination of pregnancy is often the only way to save the life of the mother. In table 2.1 [Khairuddin and Khairuddin 79], that shows common obstetric diseases among Malaysian women, it can be seen that the two hypertensive disorders which are pre-eclampsia and chronic hypertension or also known as essential hypertension are among the leading obstetric diseases in Malaysia.

Table 2.1 Common Obstetric Diseases Among Malaysians Women

Race	Malays		Chinese		Indians	
	No.	%	No.	%	No.	%
Pre-eclampsia	344	26	669	51	308	23
Anemia	330	25.1	448	34.3	532	40.6
Diabetes	7	15.3	24	52.1	15	32.6
Chronic Hypertension	15	32	15	52	39	57.3
Anterpartum Heamorrage	14	20.7	39	57.3	15	22.0

Source: Khairuddin Yusof (1974)
University Hospital
Kuala Lumpur (Unpublished)

Hypertension occuring in pregnancy may either be a manifestation of pre-existing hypertensive disease or a hypertensive disorder induced by and related only to pregnancy. There are many diseases that can be associated with hypertension in or out of pregnancy. However the hypertensive disorders that are covered by HiP are as below: 1. Pre-eclampsia (pregnancy induced hypertension)

   a. Mild

   b. Severe

2. Essential hypertension

3. Essential hypertension with super-imposed pre-eclampsia

4. Acute glomerulonephritis

5. Chronic glomerulonephritis

6. Phaeochromocytoma

7. Hydatidiform mole

The frequency of hypertensive disorders in pregnancy is illustrated by Table 2.2.

Diagnosis	Number	Percentage
No toxemia (8%)	97	8.0
Gestational hypertensive disorders (75.5%)		
Pre-eclampsia	775	64.4
Eclampsia	21	1.7
Gestational hypretension(mild)	55	4.6
Gestational hypertension(severe)	13	1.1
Gestational edema	32	2.7
Gestational proteinuria	12	1.0
Hypertensive diseases in pregnancy (15.75%)		
Essential hypertension	87	7.2
Essential hypertension with superimposed mild pre-eclampsia	51	4.2
Essential hypertension with superimposed severe pre-eclampsia	21	1.7
Malignant hypertension	6	0.5
Kimmelstiel-Wilson disease	3	0.25
Renal hypertension (1.9%)		
Chronic glomerulonephritis	11	0.95
Acute glomerulonephritis	3	0.25
Chronic pyelonephritis	8	0.7
Psuedopreeclampsia (0.75%)		
Lupus erythematosus, nephrotic syndrome, hyperuricemia, phaeochromocytoma	9	0.75

Table 2.2. Final diagnoses among 1204 patients initially admitted to hospital with a diagnosis of toxemia of pregnancy [Alvarez 82].

2.3.1 PRE-ECLAMPSIA

Pre-eclampsia which is also known as pregnancy-induced hypertension, is a disease peculiar only to pregnancy or the immediate period after delivery. It is defined as the occurence of hypertension after the 20th week of pregnancy and may or may not be in combination with generalized edema, proteinuria or both. The diagnosis of pre-eclampsia can be made postive if the patient develops the signs and symptoms of the disease late in pregnancy, but if on the other hand she is not seen until the 25th week of pregnancy or later, it may be difficult or impossible to differentiate among pure pre-eclampsia, essential hypertension, essential hypertension with superimposed pre-eclampsia or some other condition not peculiar to pregnancy causing hypertension with proteinuria.

Following are the signs and symptoms that is used by HiP and approved by the expert in the diagnosis of pre-eclampsia.

Mild pre-eclampsia

1. Rise of >= 30/15 mm Hg but <= 60/30 mm Hg in blood pressure after the 20th week of pregnancy or blood pressure reading of >= 140/90 mm Hg but < 160/110 mm Hg.
2. mild proteinuria
3. generalized edema but no pulmonary edema

Severe pre-eclampsia

1. rise in blood pressure of greater than 60/30 mm Hg or blood pressure reading of greater than 160/110 mm Hg.
2. massive edema or pulmonary edema
3. massive proteinuria
(protein concentration > 5g/l in 24 hour collection of urine).
4. excessive weight gain (weight gain of > 1 kg/week)
5. headache - frontal or occipital
6. development of epigastric pain
7. blurring of vision
8. hyper-reflexia

2.3.2 ESSENTIAL HYPERTENSION

Essential hypertension was defined by [Miall 62] as,

" a condition in which arterial pressure is raised above some arbitrary threshold by some causes which cannot at present be detected. "

The diagnosis of the disorder can be made confidently if in the absence of secondary causes of hypertension, blood pressure is raised prior to pregnancy or detected before the 20th week of pregnancy and it persist even after rest. In essential hypertension patient's urine is free of protein, or any casts or pus cells, however if blood pressure is greater

than 180/100 mm Hg a trace of protein may be accepted. A history of hypertension in the patient's family is an important factor to consider in diagnosing this condition because of its hereditary origin. Essential hypertension is more likely in a multigravida than a primigravida, and it is more common amongst patient who is above 35 years of age.

2.3.3 ESSENTIAL HYPERTENSION WITH SUPERIMPOSED PRE-ECLAMPSIA

This condition is a result of acute aggravation of the already existing, underlying hypertension with the rapid development of edema and proteinuria. The diagnosis of the disorder can be made easy if the patient has been identified as having essential hypertension and then begins to develop edema and proteinuria later in her pregnancy.

2.3.4 ACUTE GLOMERULONEPHRITIS

Acute glomerulonephritis is a renal disease. The signs and symptoms of the disorder are similar to pre-eclampsia, therefore the diagnosis of the disorder can be made more correctly in early preganancy rather than in late pregnancy. A correct differential diagnosis is important because even brief episodes of acute glomerulonephritis of mild degree may result in spontaneous abortion or premature delivery. The disorder usually apprear 10 to 14 days after an acute infectious process for example, pharyngitis, tonsillitis, sinusitis, furunculosis or scarlet fever. The clinical features of the disorder includes mild hypertension,

proteinuria, urinary sediment containing red cells, renal epithelial cells, granular, hyaline and red cell casts, nausea and vommitting, slight edema, and retinal hemorrhages.

2.3.5 CHRONIC GLOMERULONEPHRITIS

The disorder is very rare and when occurs with pregnancy it can be mistaken for pre-eclampsia. Occasionaly, a past history of acute glomerulonephritis may be the underlying cause of chronic glomerulonephritis. As in acute glomerulonephritis, interruption of pregnancy is often the best treatment since the continuation of pregnancy may greatly increase renal damage. The symptoms and signs of the disorder are proteinuria, mild hypertension, abnormalities of urinary sediment (as in acute glomerulonephritis) and a history of previous attacks of acute nephritis. As renal damage progresses the symptoms develop insidiously and the patient will be suffering from edema, weight loss, extreme fatigue, progressive retinal hemorrhages and anemia.

2.3.6 PHAEOCHROMOCYTOMA

Phaeochromocytomata are tumours which arise from the adrenal medulla. The outstanding clinical effect of the tumour is the production of hypertension which is usually episodic but may be sustained. Pregnancy tends to make the episodes of hypertension more frequent and more severe and thus increased the risk to the pregnant patient. The diagnosis of the disease is usually accompanied by bouts of hypertension that may be sustained, severe pounding headache, pallor of extremities, profuse sweating, vomitting and visual disturbances.

2.3.7 HYDATIDIFORM MOLE

Hydatidiform mole is a hydropic swelling or 'degeneration' of the connective tissue of immature chorionis villi resulting in segmental grapelike accumulation of fluids within the villious branches. Patient who carries the mole may think she is pregnant but in actual fact she is not carrying a feutus but grapelike structure of fluids. The disorder is easier to diagnose if the patient passed whittish grapelike structures in her urine, no fetal heart tone or fetal skeleton is detected, the size of the uterus is unusually large for the period of gestation, the patient vomits excessively and she suffers from vaginal bleeding.

A patient does not need to have all the listed signs and symptoms of a disorder before the diagnosis of the condition can be made. Each of the signs and symptoms are attached with a certainty factor (refer to section 5.3 for definition) that are provided by the expert. The final certainty factor for the diagnosis of the condition will be the accumulation of all the certainty factors of the signs and symptoms that the patient had, computed together by using a combining function (refer to section 5.3). The more signs and symptoms the patient has, the greater the certainty factor will be and therefore the more certain the diagnosis is.

CHAPTER 3

A LITERATURE REVIEW

3.1 INTRODUCTION

Before AI was first introduced in the field of medicine, computers were already used for keeping administrative and financial records of hospitals and health centers. Besides doing administrative work, computers were also incorporated in imaging systems such as CAT scanners and gamma cameras, in calculating radiation doses in radiotherapy treatment planning and in automating some laboratory instruments. However the high costs of such systems limits the usage of computers in hospitals and clinics. When AI techniques were introduced in this domain, computer scientists and physicians began to join hands in constructing consultation programs that could assist in making diagnoses and treatment recommendations. These consultation programs are also known as expert systems because they undertake a task that resembles that of an expert/specialist. With the introduction of such AIM systems, computers are expected to play a more intellectual function in making diagnoses, recommending tests and treatments and monitoring patients progress and it is also hoped that computers will be more widely used and such systems as the above becomes indispensable to physicians and nurses.

3.2 PHYSICIANS REQUIREMENT

To build a system and then to be rejected by the community that it is supposed to serve would be a waste of time and money. In order to avoid such a situation , a study of the physicians' attitude towards clinical consultation programs was made by Teach and Shortliffe [Teach and Shortliffe 85]. The purpose of this study was to learn from the physicians' suggestions on the desirable features for future consultation systems so that they can be clinically accepted. In this study it showed that a significant number of medical community believes that assistance from computer-based consultation systems will ultimately benefit medical practice. The recommended features made by the physicians were :

1. the system should be able to provide explanations of their diagnsotic and treatment decisions to physicians users.
2. the system should be made portable and flexible for the easy access of medical doctors regardless of the time and place.
3. the system should be able to show an understanding of their own medical knowledge.
4. the system should be capable of learning new knowledge during the interaction process with the medical experts.
5. the system should have some common sense.
6. the system should improve cost-efficiency of tests and therapies.

Although no current medical experts sytems were able to meet all the above criteria, these criteria have become the main focus of AIM researchers today.

3.3 MEDICAL EXPERT SYSTEMS

This section presents a number of expert systems that are known today in the area of medicine. A brief overview of the systems and an account of the systems evaluation are also presented.

3.3.1 THE EARLY SYSTEMS

Systems that are discussed in this section are described by Peter Szolovits as "first generation" of AIM programs [Szolovits 83]. These programs are among the first batch of systems that were developed using AI techniques in the field of medicine. The four expert systems that are considered poineers to the rest of medical experts systems to come, are briefly described in this section.

MYCIN

MYCIN [Shorltiffe 85;Buchanan and Shorliffe85b;VanMelle 85] is one of the first and best known medical expert system. It was developed at Stanford University by Shortliffe and his co-researchers . It is constructed as an expert system in the domain of infectious diseases. MYCIN uses a goal-directed control strategy that is also known as backward-chaining. It starts with a top-level goal, i.e. to prescribe appropriate theraphy, and selects the set of rules that would help to conclude the goal that is decribed in the action part. The premise of

each rule is evaluated and in the process if a fact needed to evaluate this premise is unknown or not available, the system would identify other rules that would help in concluding the needed fact. If no rule can be used to gather the needed fact, the user will be asked to provide the information wanted. This manner of search techniques minimizes the search space where only the set of rules that are relevant for the particular patient is invoked and examined. Besides providing consultation for infectious disease MYCIN is also capable of justifying its actions and decision making and it was the first consultation program to provide an explanation facility [Clancey and Shortliffe 85]. MYCIN has undergone formal evaluations by a number of independent consultants and it was demonstrated that the system was able to perform at a level comparable to that of experts [Yu et.al. 85].

CASNET/Glaucoma

CASNET [Kulikowski and Weiss 82] which stands for causal-associational network was developed at Rutgers University as a consultation program (CASNET/Glaucoma) for making diagnoses and theraphy recommendations for glaucoma. Unlike MYCIN that uses productions rules, CASNET introduces the notion of causality in which it uses network to represent the descriptive knowledge of the disease. The causal-associational network represents the pathogenesis of a disease, in terms of which the patient's findings are interpreted. Normative knowledge is in the form of inferential rules linking patient's findings to the intermediate hypothese about pathophysiological states and preference rules linking

findings to treatments. CASNET employs an event-driven control strategy, where incoming data triggers the inference rules that assign weights to the pathophysiological states which were then evaluated to the states of "confirmed", "unconfirmed" and "undetermined". The subgraph of these states forms "patient-specific interpretation model" and the system uses the model to constrain the search for possible hypotheses by guiding the requests for further patient data.
The consultation model of CASNET was tested with many cases of disease, from the U.S. and Japan and paritipated in a national symposium on glaucoma, performing at an expert level.

INTERNIST

INTERNIST [Pople 82;Miller et.al. 85] is a medical expert system that emphasizes a very broad coverage of clinical diagnostic situations, and currently it covers approximately 80% of the diagnoses of internal medicine [Pople 82], making it the largest of the first generation AIM programs. Given a patient's initial history, results of physical examination or laboratory findings, INTERNIST was designed to aid the physician with the patient's work-up in order to make multiple and complex diagnoses. The system was constructed at the University of Pittsburg during the 1970's as a colloboration work of Harry Pople, a computer scientist with an interest in AI and Jack Myers a university professor (medicine) and a prominent clinician. The knowledge base of the INTERNIST is constructed in the form of a hierarchy of diseases,

from the general to the specific, with typical findings linked to the most specific form of each disease group. INTERNIST uses an event-driven reasoning strategy, where the initial data presented to the system evoke a set of related disease hypotheses or a differential diagnosis. It then follows one of a number of different strategies in an attempt to confirm or deny the top-ranking hypothesis. For these hypotheses, INTERNIST will work at the aim of ruling out the hypotheses rather than confirming others.

INTERNIST was evaluated by comparing its clinical acumen to that of a human experts. It was found that the program had several shortcomings. One of them was its inability to attribute findings to their proper causes due to the structure or content of the knowledge base. The structure of the knowledge base, especially the form of the disease profiles, limits the program's ability to reason anatomically or temporally and the handling of the explanation was shallow [Miller et. al. 85]. The shortcomings and limitations of INTERNIST was revised and this resulted into the construction of a new system called CADUCES.

PIP

PIP [Pauker et. al. 85] was developed at the M.I.T. and Tufts-New England Medical Center. PIP was constructed for the understanding of the problem-solving methods used by physicians for patients who had varied and potentially large set of complaints. The system's knowledge was

represented in the form of frame schemes. Each of the frame was a structure with a name and a number of slots, which can be filled by various properties, logical and semantic relations and associated inference rules. PIP's reasoning was event-driven where the initial data activate a number of hypotheses which were later confirmed or ruled out as the reasoning process began "filling in the frame" of hypotheses. PIP was an experimental system and it was tested with a knowledge base of about 70 hypothesis frames in renal disease and related disorders. PIP's problem was uncovered in the maintance of a sufficiently focused and clinically acceptable line of reasoning [Kulikowski 85].

3.3.2 THE LATER SYSTEMS

Systems that are described in this section are systems that were constructed mostly based upon the shortcomings of the earlier systems. To this day there are many medical expert systems, published or unpublished, that have been developed. In Malaysia, works in the area of AI have been initiated and in 1987 a prototype medical expert system that is considered the first in Malaysia has emerged. DISTRESS [Ng et.al. 87] as the system was named, was developed on an expert system shell for the management of labour ward complications and the implementation of the system is still undergoing today.

In this section we present a brief overview of a few published medical expert system that is known and often refered to today.

PUFF

PUFF [Aikins et.al. 85] is an expert system that was bulit using EMYCIN, a generalization of MYCIN. Initially developed on the SUMEX computer, a large research machine at Stanford University, it was later rewritten to run on Pacific Medical Center (PMC) own minicomputer.PUFF's task was to interpret measurement function laboratory at PMC, and to produce a set of interpretation statements and a diagnosis for the patient. The knowledge base of PUFF system consist of a set of 64 production rules dealing with the interpretation of pulmonary function tests. PUFF was evaluated and its performance was found to be good that it is used daily in clinical service with the support of both the hospital staff and its administration [Aikin et.al. 85]. Although the system is simple in nature, PUFF is considered sucessful as it is one of the very few medical expert system that is routinely used in clinical service.

VM

The Ventilator Manager (VM) [Fagan et. al. 85] is a program designed to interpret on-line quantitative data in the intensive care unit (ICU). The system which was developed by Larry Fagan who at the time was a graduate student at Stanford University, had its beginnings in the MYCIN project but quickly diverged due to the dynamic nature of the ICU for which it was designed. VM is an extension of MYCIN design for which it has been used as a test-bed to investigate methods for increasing the capabilities of symbolic processing approaches by extending the production rule methodology.

ONCOCIN

ONCOCIN [Shortliffe et. al. 85b] is an expert system designed to aid physicians in the management of patients receiving cancer chemótheraphy. Much of the effort on this project was focused on getting the program implemented for use clinically by physicians. After its clinical introduction in May 1981. it was found that in order to provide a congenial high-speed interface, the reasoning and interactive components of the system need to be separated. Besides providing recommendations for the management of cancer chemotheraphy, ONCOCIN has also provided a productive environment for research on methods to ensure knowledge base completeness and consistency and on specialized explanation techniques.

Due to the project initial success, as at 1983, plans have been made to convert the program to run on professional workstations and to use them as a vehicle for disseminating the technology to non-academic settings [Shortliffe and Clancey 83]. As at 1987, the system has been reported to be used routinely in the Stanford Oncology Clinic [Banks 87].

IRIS

IRIS was designed more as a tool for experimenting with different reasoning and control strategies, rather than as a complete consultation system. It uses a semantic net to represent the descriptive knowledge of disease processes, reasoning primitives and control states. Applied in ophthalmology, IRIS provided the user with a general mechanism for instantiating domain-specific facts and hypotheses and a mechanism for propogating inferences between them based on production rules.

3.3.3 MICRO-COMPUTER BASED SYSTEMS

Most of the systems mentioned in the previous sections were developed on powerful and mostly expensive mainframe computers. Not many hospitals and clinics, however, are able to afford such computers and usually for this reason the systems were rejected by the end-users. Recent development in computer technology has managed to solve this problem whereby the power and capability of mainframe computers can now be found in affordable microcomputers on the desk top of many physicians. Medical expert systems developed nowadays are often designed to be easily acessible on affordable micro or personal computers. In this section a review of a few expert systems developed on microcomputers are given. Most of the systems discussed below are recently developed or still under development and therefore has not acquired much publicity.

COMMES

The COMMES [Evans 87] system is an AI-based expert sytem that serves as a nursing decision-support system. It addresses the issue of creating, maintaining and updating nursing knowledge directly and fortnightly, and as claimed by the author [Evans 87], it is the only system to do so. COMMES is backed by the Health Sciences Center of Creighton University. The knowledge base and system is continually updated and supported by the School of Nursing, the Office of Instructional Science Research for Health Sciences and the associated University Clinical Facilities. All

system users are themselves incorporated in a unified feedback crop with the Health Sciences Center which leads to continued input and system assessment via this feedback mechanism. Clinicians, educators and researchers in the School of Nursing at Creighton Unviersity and a few outside experts spent over eight years in defining and describing the initial knowledge base of COMMES. At present the system consist of a well-defined consultant programs of special interest to nursing professional as the following :

Educational Consultant, which constructs a detailed mini-study guide or tutorial tailored to meet a specific problem described by the nurse.

Protocol Consultant, which directs care plan development to assure quality patient care.

Evaluation Consultant, which creates tests to evaluate mastery of any instruction provided by any COMMES consultant.

Testwriter Consultant, which provides even more extensive pool of questions to test understanding of concepts within the COMMES domain of knowledge.

COMMES was intially developed on a Sperry 1100 system, but in order to increase portability the program was converted to operate within a UNIX environment. Now, it can operate on a Sperry 5000 series micro-minicomputers and also on a number of equally powerful but even less expensive micro-minicomputer such as AT&T 3B series and works has also been done to port the system to single-station, powerful microcomputers (i.e. personal computers).

SCAN

SCAN [Banks 87] is an expert system under developement for the understanding and interpreting neuroimages as produced by computed tomography (CT) and magnectic resonance imaging (MRI). In imaging techniques, data are gathered in form of arrays of numeric values which are associated with regions in 3-dimensional space inside the object being imaged. Feature extraction of the images produced are based on the shapes of regions of the scan having radiodensities in a specific range. Identification are done by first segmenting out the regions from the array of all pixels in the image and then compared for best fit with templates of candidate objects from the knowledge base of normal and abnormal scans. In the case of abnormalities, if no template will fit, then identification of the segmented object are based only on available data. In order to perform segmentation and to represent 3-dimensional arrays of data from scans, computer programs were developed to display and manipulate 3-dimensional images. All programming was done in the C-programming language under the UNIX operating system environment and a multicoloured display is produced by the program on a SUN MC68000 microcomputer workstation.

DIS : the NIMH-Diagnostic Interview System.

For more than 2 decades, efforts have been taken to apply computer technology to psychiatric assessment process, however only in the recent years that this tool has begun to move from the laboratory to the consulting room. DIS [Mathisen 87] is one of the expert systems in the field of psychiatric that conduct interactive interviews with patients. Beside conducting interviews DIS includes a teaching section that helps the patients in understanding how to respond to the types of questions asked. After the patient has completed the interview a summary report which contains a list of positive diagnoses, probable diagnoses and exclusion diagnoses can be obtained within minutes on a standard printer. DIS was orginally written in the MIIS language, a dialect of MUMPS. The interview was written at the University of Wisconsin Medical School using the CONVERSE interview driver. The interview, however has been recently converted to run in the MUMPS standard language which allows the interview to run on numerous computers ranging from microcomputers to mainframes. The interview is reported to be successfully utilised at several settings on a standard IBM PC with a minimum of 256K byte of memory and a 10M byte of disk drive. DIS has been evaluated [Mathisen 87] and in regard to patient acceptance, out of 135 patients that completed DIS interview, 57% stated that they liked using the computer 'quite a bit' or extremely while only 2% did not like the interview at all. The evaluation also showed that about 60% of the computer diagnostic reports were rated by the treating psychiatrist as 'somewhat' or 'very' accurate in summarising the patients' problems and 54% of the reports were judged as helpful to the psychiatrist.

3.4 FUTURE RESEARCH DIRECTIONS

In 1960's when medical decision-making research was still in its early stage emphasized has been mainly on the use of computer to deal with probabilistic informations, to recognize patterns using numerical techniques to model physiological processes that were amenable to mathematical simulation or to encode algorithmic approaches to routine clinical chores. When AI decision-making techniques were discovered, the area of reasearch then shifted more on how to get machines to make decisions that were both accurate and reliable. In the 70's however investigators had come to realize that besides developing techniques for reaching good decisions there are other problem areas that need attention. These areas were the problem of data acquisition, the problems of knowledge acquisition and representation and also the problem of explanation. Over the last decade several approaches to these problems had been developed, however current result of studies have shown that there are a few more significant areas of problem that require attention in the decade ahead [Shortliffe and Clancey 84].

The predicted future research directions are :

a) conducting more psychological studies that will help to provide insights into optimal methods for simulating expert decision-making performance.

b) improving techniques for representing knowledge and using causal and mechanistic relationships.

c) improving methods for acquiring expert knowledge, encoding it, and checking it for inconsistencies or incompleteness since this have been the major drawbacks to expert systems development.

d) enhancing explanation capabilities to a level that would be accepted as the same as its human counterpart.

e) producing high-performance decision-making programs by experimenting with new machine architecture such as parallel processors and networks of multiple coordinated processors.

f) conducting more researches on technologies for personal computing and graphics that would help to heighten both the acceptability and cost-effectiveness of the systems.

Besides the research areas outlined above, two other issues that are expected to be the top-most agenda of the medical computing of the 80's are to improve education of medical students and practicing physicians regarding computers and decision-making and to enhance acceptance of medical computer science as an intrinsic component of the modern academic medical environment. The issues above are expected to help in improving recognition of the field's potential and with that the financial and academic support that are very much needed for the ongoing research in this field will be more easily available.

CHAPTER 4

THE DESIGN OF HiP SYSTEM

```
                    WELCOME TO HiP

        A MEDICAL EXPERT SYSTEM FOR THE DIAGNOSIS OF
          HYPERTENSIVE DISORDERS IN PREGNANT WOMEN

    Please specify your options :

          C  -  Consult
          I  -  display Instruction
          K  -  Knowledge base editor
          X  -  eXit

    Your choice : _
```

Figure 4.1 The main menu of HiP system.

HiP is designed as a medical expert system that helps in the diagnosis of hypertensive disorders in pregnant women. Figure 4.1 shows the main menu of the system displaying the options that HiP has to offer. The function of each option will be decribed in Appendix 4 (User Guide). The main option provided by the system for its end users is the consultation session and for the ease of the expert and the knowledge engineer , Hip also provides a knowledge base editor as a means for editing the knowledge base.

HiP is composed of three major components that are responsible for the functions that the system has to offer. The organization of the system is visualized in Figure 4.2.

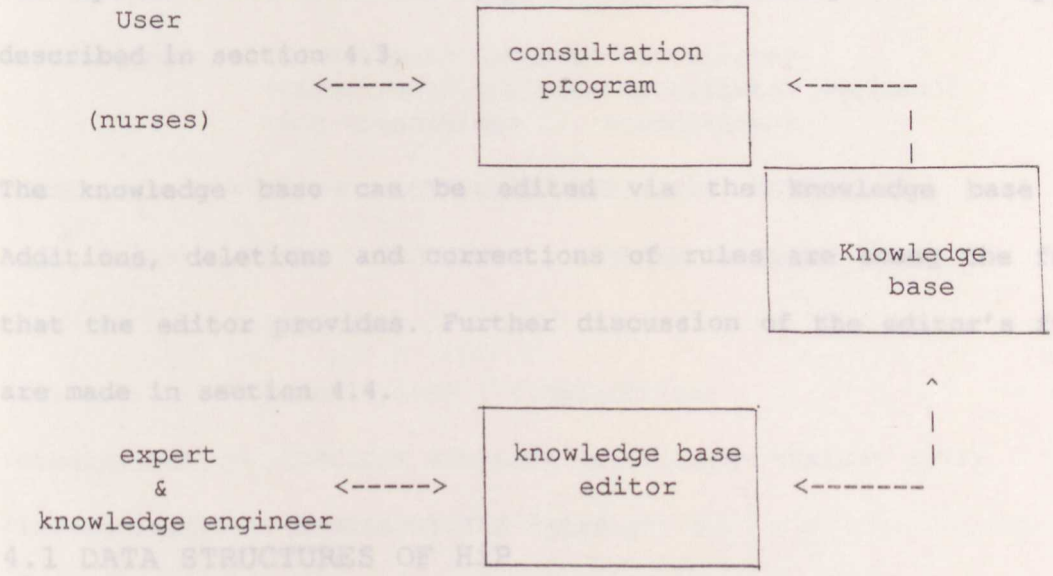

Figure 4.2 The organization of the HiP system.

HiP is made up of a knowledge base, a consultation program and an editor. The knowledge base is an area of storage for all the knowledge of the domain that has been acquired from the expert. Inferences and conclusions made by the system are based upon the knowledge that is stored here. The knowledge base is composed of rules that are written as executable LISP codes. The rule structure of the system will be described in detail in section 4.1.

The consultation program is the component that is responsible for the main task of the system. It is an interactive program that provides the diagnosis of hypertensive disorders by making use of the knowledge in the knowledge base. Section 4.2 gives a detailed description of the mechanism used by the consultation program. This program is also

equipped with an explanation capability that provides justifications of the system's actions. The explanation capability of the system is described in section 4.3.

The knowledge base can be edited via the knowledge base editor. Additions, deletions and corrections of rules are among the functions that the editor provides. Further discussion of the editor's functions are made in section 4.4.

4.1 DATA STRUCTURES OF HiP

HiP is a rule-based system. The rule structure of HiP is developed from a few simplifications of the rule structure used by MYCIN. Each rule in the knowledge base is named in the form of RULExxx, where xxx is a three-digit number. The rules are stored in no particular order and the digit attached to the rule has no other significance except for the purpose of identification. However there must be a rule in the rule-set that is named GOAL-RULE. This rule must contain the goal of the system and it will be the first rule to be invoked by the system.

The rules are stored as LISP data structure and it can be described by the following Backus-Naur-Form (BNF) :

```
<rule>       ::= <premise> <action>

<premise>    ::= ($AND <condition> ... <condition>)

<condition>  ::= (<function1> <object> <attribute>)|
                 (<function2> <object> <attribute> <value>)|
                 ($OR <condition> ... <condition>)

<function1>  ::= KNOWN | NOTKNOWN | DEFINITE | NOTDEFINITE

<function2>  ::= SAME | THOUGHNOT | NOTSAME |MOGHTBE | DEFIS

                 | DEFNOT

<action>     ::= <conclusion> | <instruction>

<conclusion>::= (CONCLUDE <object> <attribute> <Value> <CF>)

<instruction>::= (DISPLAY-TITLE "string") |

                 (DISPLAY <object> <attribute>)
```

Further explanations of <function1>, <function2>, <conclusion> and <instruction> are given in the later sections of this chapter.

A rule is a set of premise-action pair. The premise of a rule must always consist of a conjunction of one or more conditions. Before the action part can be executed, the premise must first be proven true. If the premise is proven false or the truth of the premise is not strong enough, i.e. it's degree of certainty is below a certain level set by the system, the rule will be ignored.

Since a premise can only have a conjunction of conditions, in a case of disjunctions of conditions, the rule has to be broken into several rules with the same action clause. A condition however, may have disjunctions of conditions. A few examples of legal and illegal rules are illustrated below :

```
Legal :   [1] IF  A and B and C  THEN D
          [2] IF  A and (B or C) THEN D
          [3] IF (A or B or C) and (D or E)  THEN F

Illegal : [4] IF  A or B or C  THEN D
          [5] IF  A and (B or (C and D)) THEN E

Legal representation of [4]
          [6] IF  A  THEN D
          [7] IF  B  THEN D
          [8] IF  C  THEN D

Legal representation of [5]
          [9] IF  A and B  THEN E
         [10] IF  A and C and D  THEN E
```

All data are stored in the system as an object-attribute-value triple. The concept of this triple is common within the AI field and it is the foundation for the property-list formalism in LISP (RICH 83). Many facts can be expressed as triples which state that some object has an attribute with some specified value. For example, the fact regarding a ball which is small and red can be expressed in an object-attribute-value triple as follows :

```
(BALL COLOR RED)

(BALL SIZE SMALL)
```

The object being a ball has two attributes which are color and size with corresponding values. Information stored using this convention can be easily retrieved and updated in a language as LISP. This is one of the reason why all the data and inferences of HiP are stored using the object-attribute-value concept.

Each of the objects, attributes and values possesses a set of properties. The uses of these properties will be explained as this chapter progresses. The properties are:

TRANS

The English translation of the expression. This property will be used in translating a rule into its English representation.

ASK-USER

This property carries a value which is either T or NIL. T indicates that the value of the attribute can be confirmed by the user, while NIL indicates that the value can be inferred from the rule set.

PROMPT

This property is a sentence that will be displayed by the system to the user when it requests from the user the value of the attribute. An attribute that is an ASK-USER will need to have this property.

UPDATED-BY

This property contains a list of all the rules in the system that will help in concluding the value of the attribute.

4.1.1 THE NATURE OF TRANSLATING A RULE

In translating a rule, the TRANS property will be used in order to get the ENGLISH representation of the rule. The conditional expression of a rule will be translated in the form of :

<attribute> OF <object> IS <value>

Let's say, we have a conditional expression that has HYPER, CLASS and SEVERE as its object, attribute and value respectively, and their respective TRANS property are *hypertension*, *classification* and *severe*. Therefore the translation for the expression

(HYPER CLASS SEVERE)

would be,

the classification OF *hypertension* IS *severe*.

However if the attribute is an ASK-USER where the values are usually YES or NO, then the format of translation will be different. In translating an expression that has YES as its value, the YES will be suppressed. Therefore the expression,

(PAT PREG YES)

will translated as

patient IS *pregnant*.

4.1.2. EVALUATING FUNCTIONS OF THE PREMISE CONDITIONS

The method of evaluating the premise conditions of a rule is a simplification of the method used in MYCIN model. This section gives a description of the predicates that are used in evaluating the premise conditions of rules.

The conditions of a premise, as shown in the previous section is composed of :

```
<condition> ::= (<function1> <object> <attribute>)|
                (<function2> <object> <attribute> <value>)|
                ($OR <condition> ... <condition>)
```

There are two types of evaluating functions for a condition.

<Function 1>

There are four different predicates in this category. The predicates of this category are not concerned with the specific value of the attribute but rather on the more general status of knowledge regarding the attribute in question.

e.g. (KNOWN PAT HYPER-DISORDER)

The predicate KNOWN will return T (true) if it is known that the patient in consideration suffers from any kind of hypertensive disorders, no matter what the classification of the disorder is. That means predicate KNOWN will just check if the attribute of the object has any value without examining what the value is.

The predicates of <function1> can be formally defined as follows :

Let VALS = VALUE[x,y] be the set of all hypotheses regarding the value of attribute y for object x.

MVals = Max[VALS] be the most strongly supported hypothesis in VALS.

MaxCF = CF[MVals,E] where E is the total available evidence (refer to section 5.3 for the definition of CF).

FUNCTION	IF	THEN	ELSE
KNOWN	MaxCF >= .2	T	NIL
NOTKNOWN	MaxCF <= .2	T	NIL
DEFINITE	MaxCF = 1	T	NIL
NOTDEFINITE	MaxCF < 1	T	NIL

<Function 2>

There are six different types of predicates used as evaluating functions in <function2>. The predicate functions in this category check for the specific value of the attribute against the value given in the condition. If the value specified is not found as one of the attribute's value then the function returns NIL.

e.g. (SAME PAT HYPER-DISORDER PRE-ECLAMPSIA)

The predicate SAME will return a non-NIL value if the patient's hypertensive disorder is Pre-eclampsia.

Below are the formal definition of all the predicates in <function2>.

Let VALS = VALUE[y,z] be the set of all hypotheses on the value z for the attribute y.

I = the set of all hypotheses in VALS that is also in the set LST , where LST is the possible value of y given in the condition.

MAXi = the most strongly supported hypothesis in I

CFi = CF[MAXi,E] where E is the total available evidence.

FUNCTION	IF	THEN	ELSE
SAME	CFi > .2	CFi	NIL
THOUGHTNOT	CFi < -.2	-CFi	NIL
NOTSAME	CFi <= .2	T	NIL
MIGHTBE	CFi >= -.2	T	NIL
DEFIS	CFi = +1	T	NIL
DEFNOT	CFi = -1	T	NIL

4.1.3 THE ACTION PART OF A RULE

<action> ::= <conclusion> | <instruction>

This sub-section of the chapter describes the action part of the rule. As described by the above BNF description, the action part of a rule may be a statement that concludes some value of an attribute or it may just be an instruction.

<conclusion>

The conclusion clause of a rule will be in the form of ,

(CONCLUDE <object> <attribute> <value> <cf>).

CONCLUDE is a function that takes all the above arguments, and stores the given <value> as the value of the <attribute> for the <object>. <cf> is the certainty factor (refer to section 5.3 for a definition) given by the expert that reflects the expert's belief while concluding the statement. If, for example a rule has the following action clause,

(CONCLUDE HYPER CLASS SEVERE .6),

and no other inferences have been so far made on the severity of the hypertension, then the function CONCLUDE would save the value of CLASS for HYPER as SEVERE with a certainty factor (CF) of 0.6 ,

Value[HYPER,CLASS] = ((SEVERE .6)).

But if by other evidence in a different rule the value of CLASS has been inferred as SEVERE, then the action clause of this rule will only be an additional evidence to the assertion that the patient's hypertension is severe. The CF of this rule will then be added to the existing CF of SEVERE by using Combining Function 1 (refer section 5.3). This will increase the CF and hence increase the confirmation of the hypertension's severity.

```
----------conclusion window----------
THE PATIENT'S SIGN
1. hypertension with the certainty factor of 0.87
2. proteinuria with the certainty factor of 0.32
------------------------------------------------------------
Do you want to know how the conclusions are established ? _

The default is NO
```

Figure 4.3 An example of the conclusion window displaying the patient's sign.

<instruction>

There are only two types of instruction that are allowed by the system. These instructions are :

(DISPLAY-TITLE "string")

(DISPLAY <object> <attribute>).

Any of these instructions will invoke the conclusion window of the system. DISPLAY-TITLE will display the specified string on to the screen of the conclusion window. This function will only accept string as its argument. The DISPLAY instruction will display on the conclusion window the value of the attribute for the object specified. As an example, the statement (DISPLAY PAT SIGN) will display all the signs of the patient.

The example shown in Figure 4.3 would be obtained if the following two statements in the action part of a rule is executed :

```
((DISPLAY-TITTLE "THE PATIENT'S SIGNS")
 (DISPLAY PAT SIGN))
```

At this point, the user may ask HOW any of the conclusion or the value is established. The nature of the HOW command and how it works are explained in section 4.3.

4.2 THE CONSULTATION PROGRAM

The consultation program or the control structure of HiP is the part that acts as the brain of the system. It uses knowledge stored in the knowledge base to make its judgements and conclusions. As the aim of the system is to diagnose hypertensive disorders in pregnant women, assuming that the patient consulting the system is pregnant, then the tasks of HiP can be summarized as :

1)Determine if the patient is hypertensive.

2)Determine the classification of the patient's hypertensive disorders.

The above tasks can be defined by the system's goal rule :

```
GOAL-RULE
IF   :1)it is definite that the patient is pregnant, and
      2)the patient is hypertensive, and
      3)patient's hypertensive disorders is known
THEN  Display the result of the consultation.
```

4.2.1 THE INFERENCE MECHANISM

The consultation program of HiP employs the depth-first search with the backward-chaining strategy of rules. The work of the system is to establish the premise of the goal-rule before the action part can be taken. After the premise of this one rule has been established the consultation is over. In the process of establishing a premise, rules that would help in establishing the premise will be invoked. The manner of how the system knows which rule is responsible for concluding the premise will be described later in this section. Once these rules are known to the system, the system will search over the rules exhaustively in which it tries the rule one by one. This section provides an explanation of how the simple attempt of invoking the goal-rule may cause a lengthy consultation.

When HiP first tries to evaluate the premise of the goal-rule, the conditions of the premise requires it to know whether the patient is pregnant and has hypertensive disorder. Bearing these goals in mind, the system begins to reason backwards where it tries to gather as much facts needed to establish the goals. In the process of gathering information, more rules will be invoked and if the rules are unable to conclude on the information needed, the user will be asked to provide the answer.

The two main procedures that are responsible for the invoking of rules and selecting questions are MONITOR and FINDOUT. MONITOR is the procedure that analyzes the premise of a rule, condition by condition, and when the value of an attribute that is under consideration is not yet known, the procedure FINDOUT is called in order to obtain the needed value. FINDOUT would then search for the value required.

The main function of the procedure FINDOUT is to deduce the value of an attribute. There are 2 ways of achieving this task, one is by asking the user for the information needed and the other is by deducing it from the set of rules. When FINDOUT receives an attribute from MONITOR, it would first have to decide which of the two ways should be used. This is where the properties of an attribute is used. In order to decide how to obtain the information, FINDOUT will have to examine the ASK-USER property of the attribute. If the ASK-USER property is true, then FINDOUT knows that the value of the attribute can be asked from the user. FINDOUT will then prompt the user with the appropriate question and save the user's response as the value of the attribute. The question that is prompted to the user in order to obtain the value of the attribute is actually the PROMPT property of the attribute. That means if the attribute is an ASK-USER, FINDOUT would then retrieve its PROMPT property and display it to the user.

```
FINDOUT : PROCEDURE

IF (ASK-USER PROPERTY OF ATTR = TRUE) THEN
  BEGIN
    DISPLAY PROMPT TO USER;
    READ USER-RESPONSE;
    SET VALUE OF ATTR = USER RESPONSE;
  END;
ELSE
  BEGIN
    SET RULES-LIST = UPDATED-PROPERTY OF ATTR;
    WHILE RULES-LIST <> EMPTY
      SEND EACH RULE TO PROCEDURE MONITOR;
  END;

END : FINDOUT
```

Fig 4.4 The pseudo-code of FINDOUT

For an attibute that is not an ASK-USER, FINDOUT will make use of the UPDATED-BY property of the attribute in getting at the value needed. UPDATED-BY is a property of the attribute that stores a list of rules that would help in deducing the information required, that is rules that conclude on the value of the attribute. Once this property is retrieved, FINDOUT would send each of the rule in the list to MONITOR to be analyzed. When MONITOR discovers an attribute in the rule that the value is unknown FINDOUT will be invoked again and FINDOUT will try to deduce the value in the same manner as explained above. The recursion between this two procedure allows only the necessary rules and questions be selected. Note also that FINDOUT does not check to see if the value of an attribute matches the value that is specified in the conditional expression of the premise. FINDOUT is only responsible for tracing the attribute exhaustively in order to get its value and returns this value to MONITOR for the evaluation of the conditional expression.

```
MONITOR : PROCEDURE

IF (RULE MEMBER-OF LIST OF RULE-INVOKED) THEN
  RETURN
ELSE
  BEGIN
    IF (RULE HAS NOT BEEN TRACED) THEN
      BEGIN
        ADD RULE TO LIST OF RULE-INVOKED;
        SET PREMISS = PREMISS OF RULE;
        SET TALLY = EVALUATION OF PREMISS;
      END;
    IF TALLY <> NIL THEN
      BEGIN
        MARK RULE AS BEEN TRACED;
        SET ACTION = ACTION PART OF RULE;
        WHILE ACTION <> EMPTY DO
          BEGIN
            EVALUATE EACH ACTION;
            IF (ACTION = CONCLUSION STATEMENT) THEN
              CALL SET-HOW*

          END;
      END;
  ELSE
      BEGIN
        SET RULE AS HAS NOT BEEN TRACED;
        PRINT NO CONCLUSION;
      END;

END : MONITOR
```

* SET-HOW is a procedure that will store the rule as the list of rule responsible for deducing the conclusion.

Fig 4.5 The pseudo-code of MONITOR.

The procedure that does the evaluation of the premise is called MONITOR. It checks to see if all conditions in the premises are true. The first rule to be passed to MONITOR is the goal-rule. Consider the internal LISP representation of the premise part of the goal-rule :

```
(GOAL-RULE ($AND (DEFIS PAT PREG YES)
                 (SAME PAT SIGN HYPERTENSION)
                 (KNOWN PAT HYPER-DISORDER)) )
```

The first condition is to establish that the patient is pregnant. MONITOR would first examine the attribute which is PREG. Since the goal-rule is the first rule to be invoked, value of PREG at this time would be unknown, MONITOR would send PREG to FINDOUT. PREG is an ASK-USER so FINDOUT would ask the user if the patient is pregnant. The response entered by the user will be passed back to MONITOR. If the value received by MONITOR matches the value in the condition (in this example the value is YES), MONITOR would establish that the first condition is true and proceed to next condition, if not the rule will be abandoned and the system will display a statement informing the user that no conclusion can be made. In the second condition, the goal is to determine if the patient is hypertensive. SIGN, the attribute of this condition, has no value yet, so the same action as the above is taken. In this case, SIGN is not an ASK-USER and it has to be deduced from other rules. FINDOUT will retrieve the UPDATED-BY property of SIGN and pass each of it to MONITOR. When all the rules has been passed and the value of SIGN is known, FINDOUT will pass it over to MONITOR. If one of the patient's sign is hypertension,that means the second condition of the rule is true, MONITOR will proceed on examining the third condition of the goal-rule. Here the task is even bigger because the third goal is to identify the classification of the hypertensive disorders. In this process, many things have to be considered, such as, all the patient's signs, symptoms, past and present medical histories of the patient and her family. Therefore a bigger set of rules will have to be invoked.

Only after all these information have been gathered and examined, can only the hypertensive disorder be classified. This is how the simple attempt of invoking the goal-rule may cause a long chain of rules to be invoked backwardly when the consultation session takes place.

4.3 THE EXPLANATION CAPABILITY OF HiP

To be accepted, an expert system not only need to have the ability of giving expert-level solutions but also the capability of explaining its actions and justifying its conclusions. In fulfilling this requirement HiP is designed with an explanation capability that responds to the following queries :

- o why it requires a certain piece of information
- o why it is trying to establish a certain goal
- o how it comes to a certain conclusion

Whenever HiP asks a question, the user is allowed to examine the current reasoning chain by asking WHY the system is seeking that particular information. Since questions are asked in order to establish the truth of the premise of some rule, which would be the current sub-goal, a simple answer to WHY would be to display the rule that is currently invoked.

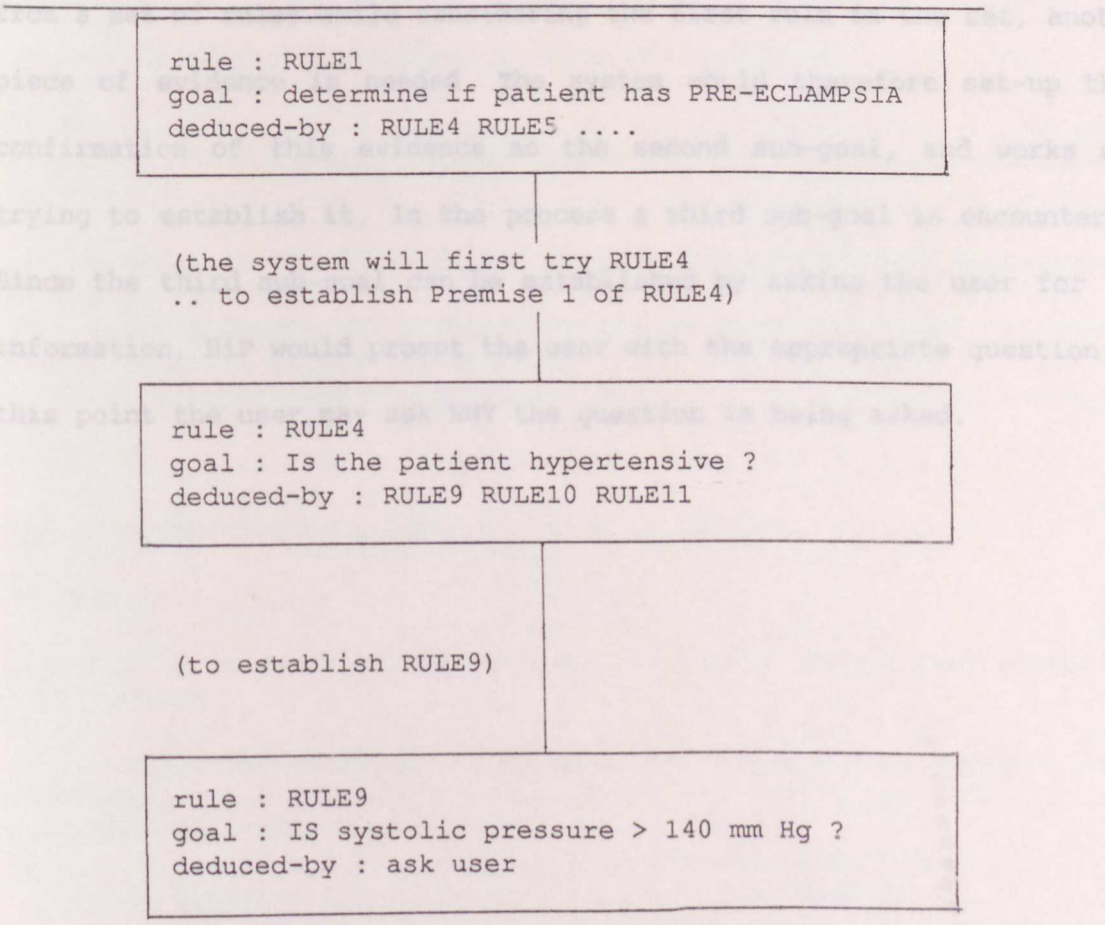

Figure 4.6 a portion of the reasoning chain

For every sub-goal that is under consideration the system will maintain its chain of reasoning as shown in figure 4.6.

In this example, the establishment of the first sub-goal has to be made from a set of rules.While considering the first rule in the set, another piece of evidence is needed. The system would therefore set-up the confirmation of this evidence as the second sub-goal, and works on trying to establish it. In the process a third sub-goal is encountered. Since the third sub-goal can be established by asking the user for the information, HiP would prompt the user with the appropriate question. At this point the user may ask WHY the question is being asked.

```
PLEASE ENTER PATIENT'S SYSTOLIC PRESSURE READING :

** WHY
[i.e. WHY it is important to determine patient's  systolic pressure
reading. ]

... in order to determine if one of the patient's sign is hypertension.
According to : RULE9
IF   : current systolic pressure >= 140 mm Hg
THEN : There is suggestive evidence (0.8) that one of the
       patient's sign is hypertension


PLEASE ENTER PATIENT'S SYSTOLIC PRESSURE READING :

** WHY

[i.e WHY is it important to determine if one of the patient's sign is
hypertension ]
... in order to determine if the patient's hypertensive disorder is PRE-
ECLAMPSIA
According to : RULE4
IF   : 1) one of the patient's sign is hypertension, and
       2) hypertension is discovered after 20th week of
          pregnancy
THEN : There is suggestive evidence (.6) that the patient's
       hypertensive disorder is PRE-ECLAMPSIA


PLEASE ENTER PATIENT'S SYSTOLIC PRESSURE READING :

** 140
```

Figure 4.7 An excerpt of the consultation session which explains part of the system's line of reasoning.

In order to avoid an extensive natural language processing in interpreting the WHY command, the system will display its understanding to the meaning of user's WHY followed by the explanation, which is the current sub-goal and the rule it uses in establishing the goal. This example is illustrated in Figure 4.7. Succesive WHY commands would allow the user to examine the higher links in the reasoning chain in which the system would go on citing the rules that led to the current rule being tried. The repetition of the commands can be made until the final system-goal is reached. At this point another WHY command will only redisplay the system's goal and the goal-rule.

Besides examining the current line of reasoning, the user can also ask HOW a conclusion is made. For every conclusion that has been succesfully established, the system will maintain a property list named HOW. Rules that are used in establishing the conclusion will be saved into this property list. In response to the user's HOW command, the system will retrieve the property list and display the set of rules that are used in concluding the fact. The user may ask the system to list the content of each rule in the list. If the fact is not concluded by any of the rule in the knowledge base but instead by the information given by the user the system will explain so.

4.4 KNOWLEDGE BASE EDITOR

In order to ease the editing of the knowledge base by the knowledge engineer or the expert, HiP is equipped with a simple yet functional knowledge base editor. Expanding knowledge base in order to cater for new learned knowledge and experience is important. An expert system should be able to withstand such expansion with minimum fuss. Since the control structure of the system is designed independently of the knowledge base, changes in the size of the knowledge base will not affect the consultation program of HiP. In order to be a useful system, the editor of HiP allows essential operations to be made to the knowledge base such as adding new rules, deleting, changing or correcting existing rules and displaying an English translation of a specified rule onto the screen.

In adding new rules to the existing rule-base, an understanding of the rule structure and the knowledge in formulating information in the form of object-attribute-value triples are essential. Since HiP is not focused on extensive natural language processing, the user will not be able to enter rules in the form of English phrases. Instead the editor will ask the user for the object, attribute and value of the premise and action clauses. Therefore the user will need to have the basic knowledge of formulating the rules in its LISP codes.

Deletion of rule is one of the other functions that is allowed by the editor. Once the user enter the name of the rule to be deleted, the system will retrieve the rule from the rule-based and display its English representation on to the screen. If the user reconfirmed that the rule is to be deleted, the rule will then be removed from the knowledge base.

Instead of deleting a rule that contains errors and then adding the correct version of the rule back into the knowledge base, a user may use the corrections of rule option that is provided by the editor. A user may delete or change any part of the premise or action clauses of a rule. After corrections has been made the editor will display the rule again for the user to check. If no more corrections are to be made, the corrected rule will be stored, in replacement of the old version of the rule. For the purpose of reviewing the rules stored, the editor is provided with operations like listing the names of all the currently existing rules and displaying rules on the terminal screen. A user is able to review the English version of a rule by selecting the display option.

CHAPTER 5

METHODS OF REASONING IN MEDICAL EXPERT SYSTEMS

Diagnosing a disease is not a simple process. Usually a diagnosis can be made only after all relevant data or evidence are analyzed. In assigning a probability to a specific diagnosis, let all available evidence be denoted by e, and d_I is the ith diagnosis (or "disease") under consideration, then $P(d_i|e)$ is the conditional probability that the patient has disease i in light of evidence e. However in the process of diagnosing a disease, evidence is actually gathered piece by piece. That means the probability of $P(d_i|e)$ has to be calculated incrementally. If we are to use the modified version of Bayes theorem that provides calculation for sequantial diagnosis, huge amounts of statistical data will be needed. As an alternative to the process of exhaustive data collection, an expert's knowldege regarding the disease is used [Shortliffe and Buchanan 85]. Since the knowledge of an expert is partly based on experience and partly on general principles ,the knowledge would be highly judgemental and therefore the conditional probabilities cannot be acquired in an exhaustive manner. Opinions however, can be sought to quantify them.

A conditional statement can be viewed as statement of decision criterion or rule. The expression $P(d_i|s_k) = x$ written in rule form would be :

IF : The patient has sign or symptom s_K

THEN : Conclude that he has disease di with probablility x

The model of inexact medical reasoning used by MYCIN has been devise as an approximate method that allows the computation of a value for $P(d_i|e)$ solely in terms of $P(d_i|s_k)$, where e is the composite of all observed s_k. According to Shortliffe and Buchanan (1985), "such technique will not be exact, but since the conditional probabilities reflect judgemental and thus highly subjective knowledge, a rigourous application of Bayes Theorem will not necessarily produce accurate cummulative probabilities either". The next sub-section provides a brief account of a few reasoning methods used in medical expert system today. In section 5.3 a more detailed description of MYCIN's reasoning method is presented since this is the method of reasoning employed by HiP.

5.1 REASONING METHOD OF PIP

PIP uses both categorical and probabilistic reasoning mechanism. Before the reasoning method of PIP can be explained, lets see the kind of data that is available to the system. PIP deals with a large set of possible findings, which are facts about the patient that are reported to the program by its user, and a set separate of hypotheses. Associated with the hypotheses are sets of prototypical findings that can either support or refute the hypothesis. If a reported finding matches one of the prototypical findings, that hypothesis is immediately activated. If a finding is accounted for by a clinical state that is related to a disease, then the binding score of the disease hypothesis should reflect that relation, and its matching score should reflect that the finding has improved the fit of the facts of the case to the hypothesis. To effect this behaviour, PIP uses a score of propogation scheme. A local score reflects the degree to which the facts found, support the hypothesis directly. The local score of a hyppothesis is the sum of the values of the clauses, normalized by the maximum possible total score. Thus it ranges from a maximum of 1 (complete agreement) downward to arbitrary large negative number (complete disagreement). PIP now computes the matching score by revising the local score to include the effects of propogated information deriving from related hypotheses. For example if PIP is to compute the score for the hypothesis, H_i, the system must first identify all other hypotheses, H_j. PIP then computes the matching-score by adding up the contributions of every scoring clause of H_i and each H_j and normalizing by the maximum possible total for this virtual scoring function.

5.2 REASONING METHOD OF INTERNIST

INTERNIST is a diagnostic program that covers a very large diagnostic situations. Every possible diagnosis, D_i, in its data base is associated with a set of manifestations ,$\{M_j\}$, which is actually a finding, symptom, sign, laboratory datum or another diagnosis that may be associated with the diagnosis. There are two likelihood that are entered for every M_j listed under D_i, one is called the *evoking strength* which is denoted by $L_{Di|Mj}$ and the other is known as the *frequency*. Compared to probability theory the evoking strength is analogous to conditional probability where it is the likelihood that if manifestation M_j is seen in a patient, its cause is D_i, while the frequency is very much like the posterior probability where it is the likelihood that a patient with a confirmed diagnosis, D_i, would exhibit M_j. Although these two factors have similarities to proabability theory, the computation of scoring function used by INTERNIST is in no sense probabilistic. For each active hypothesis, that is hypothesis that has at least one of its manifestations with a nonzero evoking strength, a score is computed by summing the scaled evoking strengths of all its manifestations that have been observed, adding "bonus" points for confirmed causally consequent diagnoses, subtracting the sum of frequencies of those of its manifestations that are known to be absent, and also subtracting a weight importance for each significant finding that is reported to be present but that is not explained by either the diagnosis or some other confirmed diagnosis.

5.3 MYCIN'S MODEL OF INEXACT MEDICAL REASONING

The MYCIN's reasoning model introduces a new set of terms for measurement of evidential strength. The terms are 'belief' and 'disbelief'. The notation for it will be :

o MB[h,e] = x

which means " the measure of increased belief in hypothesis h, based on the evidence e, is x".

o MD[h,e] = y

which means "the measure of increased disbelief in hypothesis h, based on evidence e,is y".

The evidence e, may be an observed event or a hypothesis which is subjected to confirmation. So, MB[h_1,h_2] can be written to indicate the measurement of incresed belief in hypothesis h_1 given that h_2 is true, and MD[h_1,h_2] as the measurement of increased disbelief in h_1 given that hypothesis h_2 is true.

In getting a ratio for MB[h,e], it can be argued, as in subjective probability theory, that P(h) (the expert's personal probability) reflects the expert's belief in h at any given time, and therefore 1 - P(h) can be taken as an estimate to expert's disbelief regarding the truth of h. A greater P(h/e) than P(h) indicates that the observation e increases the expert's belief in h, while decreasing his or her disbelief in the truth of h. Therefore, MB[h,e] can be estimated by the following ratio :

$$\frac{P(h|e) - P(h)}{1 - P(h)}$$

Meanwhile MD[*h*,*e*] which is the measure of increased disbelief regarding the truth of *h* can be calculated if P(*h*|*e*) were less than P(*h*). This reflects that the observation *e* would decrease the expert's belief in *h* while increasing his or her disbelief regarding the truth of *h*. The ratio for MD[*h*,*e*] will be

$$\frac{P(h) - P(h|e)}{P(h)}$$

In summary, lets consider MB[*h*,*e*] and MD[*h*,*e*] as defined above to be respectively the proportionate decrease in disbelief *h* and the proportionate decrease in belief regarding hypothesis *h* that results from the observation *e*, where belief is estimated by P(*h*) at any given time and disbelief is estimated by 1 - P(*h*). To be noted also that an evidence cannot both favor and disfavor a single hypothesis, when MB[*h*,*e*] > 0, MD[*h*,*e*] = 0, and when MD[*h*,*e*] > 0, MB[*h*,*e*] = 0. When P(*h*|*e*) = P(*h*) which means that evidence *e* is independent of the hypothesis *h* than MB[*h*,*e*] = MD[*h*,*e*] = 0. Therefore MB[*h*,*e*] and MD[*h*,*e*] can be specified formally as

$$MB[h,e] = \begin{cases} 1 & \text{if } P(h) = 1 \\ \dfrac{\max[P(h|e),P(h)] - P(h)}{\max[1,0] - P(h)} & \text{otherwise} \end{cases}$$

$$MB[h,e] = \begin{cases} 1 & \text{if } P(h) = 0 \\ \dfrac{\min[P(h|e),P(h)] - P(h)}{\min[1,0] - P(h)} & \text{otherwise} \end{cases}$$

[Shortliffe and Buchanan 85]

The third measure termed as *certainty factor* (CF) is introduced in order to facilitate comparisons of the evidential strength of competing hypothesis. CF that combines the MB and MD is defined as follows :

$$CF[h,e] = MB[h,e] - MD[h,e]$$

CF can also be viewed as an indicator of the *net* belief in a hypothesis in light of current evidence. Negative CF's indicates that there are stronger evidence disfavoring the hypothesis. Positive CF's indicate that the hypothesis is more strongly confirmed than disconfirmed and a CF of zero indicates either the absence of both confirming and disconfirming evidence (MB = MD = 0) or the observation of pieces of evidence is equally confirming and disconfirming (MB = MD).

As previously mentioned, in diagnosing a patient's disease, evidence is actually gathered piece by piece.This means the MB and MD of a hypothesis has to be calculated incrementally. In satisfying this criteria, MYCIN introduces the use of combining functions. The combining function for the MB's and MD's of incrementally acquired evidence is as follows :

$$MB[h,s_1 \ \& \ s_2] = \begin{cases} 0 & \text{if } MD[h,s_1 \ \& \ s_2] = 1 \\ MB[h,s_1] + MB[h,s_2](1-MB[h,s_1]) & \text{otherwise} \end{cases}$$

$$MD[h,s_1 \ \& \ s_2] = \begin{cases} 0 & \text{if } MB[h,s_1 \ \& \ s_2] = 1 \\ MD[h,s_1] + MD[h,s_2](1-MD[h,s_1]) & \text{otherwise} \end{cases}$$

[Shortliffe and Buchanan 85]

There are three more combining functions that are used for the conjunctions and disjunctions of conditions and to estimate the strength of evidence. These functions and the rest of the defining criteria for MB, MD and CF can be refered to in Appendix 3. The clarification and detail description of MYCIN's model of reasoning in medicine are available in [SHOR85a, SHOR85b].

CHAPTER 6
THE EVALUATION OF HiP'S PERFORMANCE

Before the performance of HiP is evaluated, it is best if the system's goal be outlined again. As an expert system in the domain of hypertension in pregnancy, HiP is expected to diagnose hypertensive disorders in pregnant women even with the possibility that an important piece of evidence may be unknown or uncertain. In order to be a useful tool, HiP must be able to produce results that is comparable if not better that the human experts. System's performance must be tested and evaluated in order to check for the accuracy of the diagnosis. The purpose, method and results of the evaluation are presented here in this chapter.

6.1 PURPOSE OF EVALUATION

Providing an accurate and reliable advice is the main role of an expert system, therefore it logically becomes an area to emphasize in evaluation. However there are other aspects of the system that has to be rated in order to ensure the system be accepted by the end users. The areas that are checked upon in the evaluation are as follows :

- o the accuracy of the system's diagnosis
- o the ability of the system to explain the basis of its decisions
- o the appropriateness of the questions and responses generated by the program.

The above areas are thought to be as important as the quality of the systems's diagnosis to the ultimate success of HiP as an expert system.

6.2 THE EVALUATION

The process of evaluation is a continual one. In the early stages of development, the system is tested in an informal manner and as the system begins to develop towards real-world implementation, its evaluation gets more and more structured.

Early in the development of HiP, as a prototype system was created, the testings that were carried out was not aimed to show an expert-level performance, but rather on the feasibility of the system design. Reasoning structures of the system was tested and corrections were made to increase feasibility. The second stage of the system's testing was done as the knowledge base is growing. Every now and then informal test cases were run through the system. These test cases were either manually generated or collected from examples in books. The system's performance on these cases were observed and feedback was either sought from the colloborating expert or from comparing results of text books and notes collected from the expert. The feedback helped in defining the major problem area. As the problems were identified, measures such as refining the rules and reasoning structures were made to correct the mistakes. Once the corrections has been made, testing was carried out again and

new problems may be discovered and corrected. This iterative process may go on for months and it is considered an important stage of the system's development as it helps in improving the accuracy of the diagnosis.

Once the system is found to perform well on most cases with which it is presented, testing method as above is no longer adequate. A more structured evaluation is considered more appropriate. Real cases where evidence is sometimes unavailable and incomplete, are needed in evaluating the system's performance. Choosing an evaluation method is just as important in the evaluation process. One of the ways to evaluate the system would be by having a few experts of the domain to review and critisize on cases that was run on HiP. But this "unblinded" fashion of evaluation where the evaluators know that they are assessing a computer program may be a little bias, as it was discovered in Study 1 of the MYCIN's evaluation [Yu et. al. 85]. Because the evaluators knew they were assesing a computer program, there was evidence that they were using a different criteria which is perhaps more stringent in evaluating its performance than they would use in assesing the recommendations of a human consultant. In the evaluation of HiP this technique was avoided. Instead the testing process was carried out by using past years cases; cases which had been diagnosed by doctors. These cases were run through HiP and the results produced were compared against the doctors' diagnoses.

As medical records are considered confidential matter especially to a person who is not one of the hospital staff, getting hold of patients' medical records are difficult. To obtain these records, permission from the hospital's top management was sought. The hospital used in the evaluation process was the University Hospital of Kuala Lumpur. When permission was granted, 40 random cases of patients who were hypertensive and at the same time pregnant were collected. Note that only cases of hypertensive and pregnant patients were chosen. The reason for this selection is because, to take random cases of pregnant patients would be a waste of time. There are thousands of such cases in a year and to run each of it through the system in order to obtain hypertensive cases would involve a lot of hard work and too time consuming and furthermore obtaining medical records involves quite a long procedure therefore only cases of hypertensive and pregnant patients were chosen. Manner of identifying hypertension is quite deterministic. Once the exact blood pressure reading of the patient is obtained, hypertension can be diagnosed if the blood pressure is above a certain level. It is determining the hypertensive disorders that is judgemental and involves a lot of considerations and examinations and therefore the accuracy of the system's diagnosis would be heavily depended on it. Hence, selecting only cases of hypertensive and pregnant patients will have no effect on the evaluation of the system's performance.

As the medical records were obtained a detailed clinical summary of each cases were recorded. The summary contains the patient's past and present medical history, physical examination, laboratory data and

summary is shown in Appendix 2. These cases were then tested on HiP. The diagnosis produced by HiP on each case was compared against the diagnosis written by the doctors on the medical record. The result of this comparisons which reflects the system's performance is presented in the next section.

6.3 RESULT

Unlike conventional computer programs, an expert system does not have a right or wrong answers because it does not deal with determinstic problems. It is hard to demostrate that the system is "correct" and then to prove its correctness. In the evaluation of an expert system, one can only compare the result produced by the expert systems with that of a human expert or have an expert to review the system's results. The analysis of the comparison or the expert's opinion will be considered the result of the evaluation.

In comparing the result of HiP's consultations with that of the doctors, it was hard to conclude which of the two is incorrect in the case of discrepancy. Therefore the view of another expert was sought. After the comparison was made, the table which contained the patients' clinical summaries, the diagnoses of the doctors and that of HiP's was shown to the expert.

	Pre-eclampsia	Essential Hypertension	No Conclusion	Total
HiP's Diagnosis	33	5	2	40
Doctor's Diagnosis	35	5	-	40

Table 6.1 Comparison table between Hip's diagnoses and the doctors diagnoses.

As shown in table 6.1, from the 40 cases that were tested, HiP diagnosed 33 cases as Pre-eclampsia, 5 cases as essential hypertension and no disorders were diagnosed for 2 cases, whereas the doctors had diagnosed 35 cases of pre-eclampsia and 5 cases of essential hypertension. For the two cases that HiP did not conclude on,the doctors diagnosed it as Pre-eclampsia. When the expert was consulted regarding the discrepancies, without knowing which diagnoses were HiP's, the expert agreed that even if the patients' symptoms may suggest Pre-eclampsia, the patients were not suffering from any hypertensive disorders because the blood pressure level of the two patients were slightly lower than the hypertension level. As for the rest of the cases, the expert rated the diagnoses of both the doctors and HiP as "acceptable", that is, the diagnoses were considered comparable to the diagnoses of an expert of the domain.

As a summary, in the evaluation of HiP's performance in diagnosing hypertensive disorders, 40 random cases were selected and run through the system. The result produced by HiP was compared against the doctors'

diagnosis. The patients data and the comparison made were then shown to another expert of the domain. As an outcome of the evaluation, HiP's diagnoses were accepted as comparable to that of a human expert with the percentage of a 100%. However the result may not reflect the overall performance of HiP because the cases tested only cover the diagnosis of two disorders while HIP covers the diagnosis of six disorders. That means only the accuracy of two disorders were tested. Since the rest of the disorders are rare diseases, real cases of patients suffering from these disorders were unobtained and the accuracy of HiP's diagnosis for these hypertensive disorders were untested. Therefore no matter how impressive the result of the evaluation was, it was unable to represent the system's overall performance.

6.4 OTHER ASPECTS OF EVALUATION

As mentioned in section 6.1 the purpose of the evaluation was not only to check on the accuracy of the system's diagnosis but also on its ability to explain its actions and the appropriateness of the program's questions and responses. For these purposes two nurses were asked to test HiP's consultation program. As a result both agreed that most of the questions generated were as what they would expect in their work and that the system was able to give an understandable justification of its actions.

To be accepted by the end users, HiP not only need to produce reliable results but also to be able to produce its result in a reasonable time. Maybe because its knowledge base is not too huge, HiP consultation session takes only about 4 to 6 minutes depending on how complicated the diagnosis is. Since the consultation takes not too much time and therefore would not bore the users, it is hoped that the system would be able to acheived its aim and be used regularly in rural clinics.

CHAPTER 7

CONCLUSION

7.1 REVIEW OF GOAL

The goal of this research work has been to develop a medical diagnostic expert system in the domain of hypertension in pregancy. This system is expected to :

o assist in diagnosing hypertensive disorders in pregnancy,

o explain its actions and the basis of its decision

If the system is able to undertake the above tasks satisfactorily, it can be said to have achieved its aim.

As far as the second task is concerned, the system has shown a satisfactory ability of explaining why it is asking the user for a piece of information and how it comes to a certain conclusion. This has been proven when two nurses were asked to use the system.

As for diagnosing hypertensive disorders, HiP's performance was tested on 40 random cases of hypertensive and pregnant patients. The result produced by HiP was compared against the diagnoses of the doctors in-charge and then shown to an expert for comments. HiP's diagnoses were found to be comparable to that of a human expert of the domain. The result of the evaluation however, does not portray HiP's overall capability in diagnosing hypertensive disorders. Cases that were covered in the testing were only cases of pre-eclampsia and essential

hypertension. The rest of the disorders that are covered by HiP are considered rare diseases and unfortunately real cases of these disorders were unavailable during the testing process. Hence the result of the evaluation is quite incomplete. However in the earlier stages of developemnt, when HiP was tested against informal test cases, the system was able to produce a "correct" diagnoses (results were compared to text books and notes) on most cases including cases of all the rare disorders. As a conclusion, taking both the result of the final and ealier evaluation processes, HiP can be considered to have achieved its aim as an expert system in the domain of hypertension in pregnancy.

7.2 LIMITATION OF THE STUDY

To build an expert system with a task as crucial as a medical diagnosis requires quite a lot of time. However the time allocated for this research work is limited. Due to the time constraint the system design was made to be simple. The natural language processing capability of the system was limited and so the system can only accept certain responses from the user. The responses are Yes or Y, No or N, Maybe or M and numerical values for some questions. The system is unable to understand English phrases and therefore the "friendliness" of the system is restrained.

Apart from the above mentioned limitation, another area of concern in the development of the system is memory capacity. As at this time the system is able to perform reasonably well with a memory capacity of 640K. As stated before this , the system can only diagnose but not recommend any treatment or management of hypertensive disorders. If the system is to be extended to cover the treatment and management of the disease, the knowledge base of the system will have to be enlarged. It has been tested that in order for the system to work with the minimum memory capacity of 640K, the system can only have at most 150 rules in its knowledge base. A knowledge base of more than 150 rules will cause a problem of frequent "garbage collection" in the GCLISP environment and this usually would later cause the flow of the system be abruptly halted. Therefore if the system is to be extended, than it is suggested that the extension be done on a machine with a bigger memory capacity.

7.3 FUTURE WORK

As time is limited, HiP is developed only to diagnose diseases. It does not handle the treatment and management of the disease. To be a really useful tool for the nurses, HiP should not only diagnose but also to suggest treatments and managements of the disorders. For further developemnt, treatment and management can be incorporated into the system by expanding the knowledge base. The expansion of knowledge base can be easily done via the knowledge base editor.

A more extensive naural language processing can be added to the system interface to enhance the system "friendliness" during consultation. An interface that is natural and human like would increase the probability of the system being accepted by the end users.

With the existing groundwork, this section introduces a few areas for future work in the further development of the system.

APPENDIX 1

LIST OF EXISTING EXPERT SYSTEMS AS AT 1983

Function	Domain	System	Institution
Learn from experience	Chemistry	Metadendral	Stanford University
	Heuristics	Eurisko	Stanford University
Concept-formation	Mathematics	AM	CMU
Monitoring	Patient respiration	VM	Stanford University
Use advice	Structural analysis computer program	Sacon	Stanford University
Computer-aided instruction	Electronic trouble-shooting	Sophie	Bolt,Beranek & Newman (BBN)
	Medical diagnosis	Guidon	Stanford University
	Mathematics	Excheck	Stanford University
	Steam propulsion plant operation	Steamer	BBN
	Diagnostic skills	Buggy	BBN
	Causes of rainfall	Why	BBN
	Coaching a game	West	BBN
	Coaching a game	Wumpus	MIT
	Coaching a game	Scholar	BBN
Knowledge acquisition	Medical diagnosis	Teiresias	Stanford University
	Geology	KAS	SRI
Expert system construction		Rosie	Rand
		AGE	Stanford University
		Hearsay 111	University of Southern California Information Sciences Institute(USC-ISI)
		Emycin	Stanford University
		OPS 5	CMU
		Rainbow	IBM
	Medical diagnosis	KMS	University of Maryland
	Medical consultation	Expert	Rutgers University
	Electronic systems diagnosis	ARBY	Yale University /ITT
	Medical consultation using time-oriented data	MECS-AI	Tokyo University
Intelligent assistant	Battlefield weapons assignments	Battle	U.S. Navy Center for applied research in AI
	Medicine	Digitalis Therapy Advisor	MIT
	Radiology	Ratdex	Rutgers University
	Computer sales	XSEL	CMU/DEC
	Medical treatment	Oncocin	Stanford University
	Nuclear power plant configuration	CSA	Georgia Tech.
	Diagnostic prompting in medicine	Reconsider	University of California at San Francisco

Function	Domain	System	Institution
Diagnosis	Medicine	PIP	Massachusetts Institute of Technology (MIT)
	Medicine	Casnet	Rutgers University
	Medicine	Internist/ Caduces	University of Pittsburgh
	Medicine	Mycin	Stanford University
	Medicine	Puff	Stanford University
	Computer faults	DART	Stanford University
	Medicine	MDX	Ohio State University
	Computer Faults	IDT	Digital Equipment Corp.(DEC)
	Nuclear Reactor accidents	Reactor	EG&G Idaho
Data analysis	Geology	Dipmeter Advisor	MIT/Schlumberger-Doll Research Center(SDRC)
	Chemistry	Dendral	Stanford University
	Chemistry	GA1	Stanford University
	Geology	Prospector	SRI International Inc.
	Protein crystallography	Crysalls	Stanford University
	Determination of causal relationships in medicine	RX	Stanford University
	Oil-well logs	Abel	MIT
		ELAS	Amoco Corp.
Analysis	Electrical circuits	EL	MIT
	Mechanics problems	Mecho	Edinburgh University
	Naval task force threat analysis	TECH	Rand Corp. and Naval Ocean Systems Center
	Earthquake damage assessment for structures	Speril	Purdue University
	Digital circuits	Critter	Rutgers University
Design	Computer system configuration	XCON/R1	Carnegie-Mellon University and DEC
	Circuit synthesis	SYN	MIT
	Chemical synthesis	Synchem	State University of New York, Stony Brook
Planning	Chemical synthesis	Sechs	University of California at Santa Cruz
	Robotics	NOAH	SRI
	Robotics	Abstrips	SRI
	Planetary flybys	Deviser	Jet Propulsion Laboratory
	Errant planning	OP-Planner	Rand
	Molecular genetics	Molgen	Stanford University
	Mission planning	Knobs	Mitre Corp.
	Job shop scheduling	ISIS-11	CMU
	Design of molecular genetics experiments	SPEX	Stanford University
	Medical diagnosis	Hodgkins	MIT

APPENDIX 2

CLINICAL SUMMARY OF PATIENTS

CLINICAL SUMMARIES OF PATIENTS

Registration no.	717101	709921	717458	717134	874223
Age	25	42	29	39	28
Gravida/Para	1/0	7/6	2/1	1/0	1/0
Current B/P	140/90	150/80	120/80	110/70	130/80
Raise in B/P	10/20	20/10	10/5	0/10	10/10
Hy. discover before 20th week	no	unk	no	no	no
Weight gain (in a week)	1.4kg	0.3kg	1.1kg	0.4kg	1.7kg
Medical history					
Present	vomits backache	-	vomits cramps backache	vomits cramps	nausea headache cramps
Previous	ovarian cypts	PET	PET (fetus died)	-	-
Family	multiple preg.	-	Es. Hy. Diabetes	-	-
Proteinuria	nil	nil	trace	nil	nil
Edema	yes	-	-	-	-
Doc's Diagnosis	PET	PET	Sev.PET	PET	PET
HiP's Diagnosis	PET	PET	PET	PET	

(Note : PET means Pre-Eclampsia Toxemia)

APPENDIX 3

DEFINING CRITERIA AND COMBINING FUNCTIONS OF MYCIN'S REASONING MODEL

A. Characteristics of belief measures

Following is the summary of the characteristics of all the three measures defined

1. Range of degrees:

a. $0 <= MB[h,e] <= +1$
b. $0 <= MD[h,e] <= +1$
c. $-1 <= CF[h,e] <= +1$

2. Evidential strength and mutually exclusive hypothesis :

If h is shown to be certain [P(h|e)=1] :

a. $MB[h,e] = \frac{1 - P(h)}{1 - P(h)} = 1$

b. $MD[h,e] = 0$

c. $CF[h,e] = 1$

If negation of h is shown to be certain [P(h|e)=1]

a. $MB[h,e] = 0$

b. $MD[h,e] = \frac{0 - P(h)}{0 - P(h)} = 1$

c. $CF[h,e] = -1$

3. Commutativity

If s_1 & s_2 indicates an ordered observation of evidence, first s_1 than s_2:

a. $MB[h,s_1 \& s_2] = MB[h,s_2 \& s_1]$
b. $MD[h,s_1 \& s_2] = MD[h,s_2 \& s_1]$
c. $CF[h,s_1 \& s_2] = CF[h,s_2 \& s_1]$

4. Missing information

If $s_?$ denotes a piece of potential evidence, the truth or falsity of which is unknown :

a. $MB[h,s_1 \& s_?] = MB[h,s_1]$
b. $MD[h,s_1 \& s_?] = MD[h,s_1]$
c. $CF[h,s_1 \& s_?] = CF[h,s_1]$

C. Combining Functions

Combining functions is used as a mechanism to calculate cumulative CF[h,e] based on incrementally acquired MB[h,e] and MD[h,e]. The first function below is used to satisfy the above criteria and the rest of it are necessary conventions for implementation of the model.

1) Incrementally acquired evidence :

$$MB[h,s_1 \ \& \ s_2] = \begin{cases} 0 & \text{if } MD[h,s_1 \ \& \ s_2] = 1 \\ MB[h,s_1] + MB[h,s_2](1 - MB[h,s_1]) & \text{otherwise} \end{cases}$$

$$MD[h,s_1 \ \& \ s_2] = \begin{cases} 0 & \text{if } MB[h,s_1 \ \& \ s_2] = 1 \\ MD[h,s_1] + MD[h,s_2](1 - MD[h,s_1]) & \text{otherwise} \end{cases}$$

2) Conjunctions of hypotheses :

$$MB[h_1 \ \& \ h_2,e] = \min(MB[h_1,e],MB[h_2,e])$$
$$MD[h_1 \ \& \ h_2,e] = \max(MD[h_1,e],MD[h_1,e])$$

3) Disjunctions of hypotheses :

$$MB[h_1 \ \& \ h_2,e] = \max(MB[h_1,e],MB[h_2,e])$$
$$MD[h_1 \ \& \ h_2,e] = \min(MD[h_1,e],MD[h_1,e])$$

APPENDIX 4

USER GUIDE

USER GUIDE

Below are the steps that the user has to undertake in starting the HiP system.

1. Since the system is written in GCLISP, version 1.01, it will need the support of a GLCLISP interpreter before it can be used. To load the interpreter, from DOS environment, insert diskette labelled "DISK1" into drive A and diskette labelled "DISK2" into drive B. From drive A, type "GCLISP" .

e.g. A>GCLISP

The loading of the GCLISP interpreter takes approximately 1.5 minutes on an IBM PC XT. Once the loading is completed a screen display such as shown below appears.

Top Level

Initialization file loaded.

*

The "*" sign is the GCLISP interpreter input prompt. That prompt shows that we are now in the GCLISP environment and the interpreter is now ready to take our commands.

2. To invoke the HiP system, replace DISK1 in drive A with DISK3 and then typed (LOAD HiP-SYSTEM). Once the "*" prompt reapprears you may invoke HiP by entering the following command (HiP). Below is the illustration of the actions to be taken.

* (LOAD HiP SYSTEM)

* (HiP)

Note : In GCLISP enviroment you need not enter a carriage return because GCLISP starts its evaluation as soon as it finds a matching close parentheses.

3. As you typed (HiP), a statement

"Please wait ..... loading in progress"

appears on the screen. You will have to wait for a few seconds before the main menu of HiP will be displayed.

4. Once the main menu of HiP is displayed you may select any of the options provided by entering the corresponding keys. The "I" option which is the Display Instruction option is strongly recommended for users who are using HiP for the first time. This option provides a brief instruction of what is expected of the user during the consultation session. The consultation session may be invoked by selecting the "C" option. During this session the user will be asked a few question regarding the patient. These questions include the signs, symptoms and medical histories of the patient. When the answers provided is enough for the system to reached a diagnosis the system will then displayed its conclusions. At this point the user may ask how HiP comes to the diagnosis by entering a command. The command for this action is provided

as a menu on the conclusion window. To use the knowledge base editor, the user may choose the "K" option. A user who is not the expert or the knowledge engineer is advised not to tamper with the knowledge base as the changes made will be made permanent to knowledge base, and any errors made to the knowledge base may result in an incorrect diagnosis.

APPENDIX 5

A SAMPLE OF HIP'S CONSULTATION SESSION

y

(Note : The user input is in lower caps letter)

IS THE PATIENT PREGNANT ?
yes

IS THE PATIENT PREVIOUS BLOOD PRESSURE READING AVAILABLE ?
no

ENTER CURRENT READING OF PATIENT'S SYSTOLIC PRESSURE :
140

ENTER CURRENT READING OF PATIENT'S DIASTOLIC PRESSURE :
90

HAS THE PATIENT'S URINE BEEN TESTED FOR PROTEIN CONCENTRATION ?
yes

IS THE URINE SAMPLE TAKEN FROM 24 HOURS COLLECTION OF URINE?
yes

ENTER THE WEIGHT OF PROTEIN CONCENTRATION IN PATIENT'S URINE
(PLEASE ENTER YOUR ANSWER IN GRAMS ONLY.)
0.4

ARE THERE ANY CELLULAR AND/OR GRANULAR CASTS IN THE PATIENT'S URINARY SEDIMENT ?
no

DOES THE PATIENT PASSED ANY WHITISH GRAPE-LIKE STRUCTURES IN HER URINE ?
unknown

IS THERE AN ELEVATION IN THE PATIENT'S CREATININE-LEVEL ?
no

IS THERE DOCUMENTED EVIDENCE SHOWING THAT THE PATIENT HAS A HISTORY OF HYPERTENSION BEFORE HER PREGNANCY OR DURING HER PREVIOUS PREGNANCY ?
unknown

IS THERE A HISTORY OF HYPERTENSION IN THE PATIENT'S FAMILY?
no

DOES THE PATIENT HAS A HISTORY OF PREVIOUS ATTACK OF ACUTE NEPHRITIS BEFORE THE 24TH WEEK OF HER PREGNANCY?
no

IS THIS THE PATIENT'S FIRST PREGNANCY ?
no

WHAT IS THE PATIENT'S AGE ?
26

IS THE HYPERTENSION EPISODIC IN NATURE ?
no

BELOW IS A LIST OF SYMPTOMS THAT ARE HELPFUL IN THE DIAGNOSIS OF HYPERTENSIVE DISORDERS

S1. Weigth gain of > .7 kg in a week
S2. Swelling of legs, hands or face
S3. Frontal or occipital headache
S4. Severe pounding headache
S5. Epigastric pain (abdominal pain)
S6. Visual disturbances, such as blurring of vision, flashes of light in front of the eyes, etc.
S7. Retinal hemorrhages
S8. Hyper-reflexia
S9. Weight loss
S10. Extreme fatigue
S11. Excess vomitting
S12 Pallor of extremities or flushing
S13. Profuse sweating
S14. Vaginal bleeding
S15. Extra large uterus
S16. No fetal heart tone
S17. No fetal skeleton

IF THE PATIENT HAS ANY OF THE ABOVE SYMPTOMS,
PLEASE ENTER THE SYMPTOMS ACCORDING TO ITS NUMBER
PRESS RETURN FOR EACH ENTRY.

PATIENT'S SYMPTOMS : S1
S2

----------CONCLUSION WINDOW----------

PATIENT'S SIGN

1. PROTEINURIA with the certainty factor of 0.96 (96%)
   With the certainty factor of 0.89 (89%) PROTEINURIA is considered MILD.

2. HYPERTENSION with the certainty factor of 0.90 (90%)
   With certainty factor of 0.83 (83%) HYPERTEENSION is considered MILD.

HYPERTENSIVE DISORDERS THAT THE PATIENT MIGHT HAVE.

1. PRE-ECLAMPSIA with certainty factor of 0.72 (72%)
2. CHRONIC GLOMERULONEPHRITIS with certainty factor of 0.24 (24%)

(Any disorders that have certainty factor of below 0.2would not be listed.)

NOTE :

Each of the question prompted by the system will be displayed in the consultation window as shown in the example below.

consultation window

IS THE PATIENT PREGNANT ?

YOUR ANSWER : _

The default value is UNKNOWN

An example of a consultation window

APPENDIX 6

HiP'S RULE-BASED

```
(goal-rule ($AND (DEFIS PAT PREG YES)
                 (SAME PAT SIGN HYPER)
                 (KNOWN PAT HYPER-DISORDER))
           ((DISPLAY-TITLE " PATIENT'S MEDICAL HISTORY ")
            (DISPLAY PAT MEDICAL-HIST)
            (DISPLAY-TITLE " PATIENT'S SIGNS ")
            (DISPLAY PAT SIGN)
            (DISPLAY-TITLE " PATIENT'S SYMPTOMS ")
            (DISPLAY PAT SYMPTOM)
            (DISPLAY-TITLE
            " HYPERTENSIVE DISORDERS THAT PATIENT MIGHT HAVE")
            (DISPLAY PAT HYPER-DISORDER)) )

(RULE1      ($AND (DEFIS BP-REC AVAIL YES)
                  (DEFIS SYSTOLIC RISE-SYS (GE 30 mmHg)))
           ((CONCLUDE PAT SIGN HYPER .68)))

(RULE2      ($AND (DEFIS BP-REC AVAIL YES)
                  (DEFIS DIASTOLIC RISE-DIA (GE 15 mmHg)))
           ((CONCLUDE PAT SIGN HYPER .68)))

(RULE3      ($AND (DEFIS SYSTOLIC READ-SYS (GE 140 mmHg)))
           ((CONCLUDE PAT SIGN HYPER .82)))

(RULE4      ($AND (DEFIS DIASTOLIC READ-DIA (GE 90 mmHg)))
           ((CONCLUDE PAT SIGN HYPER .82)))

(RULE5      ($AND (DEFIS BP-REC AVAIL YES)
                  (DEFIS SYSTOLIC RISE-SYS (GE 30 mmHg))
                  (DEFIS SYSTOLIC RISE-SYS (LT 60 mmHg))
                  (DEFIS DIASTOLIC RISE-DIA (LT 30 mmHg)))
           ((CONCLUDE HYPER CLASS-H MILD .68)))

(RULE6      ($AND (DEFIS BP-REC AVAIL YES)
                  (DEFIS DIASTOLIC RISE-DIA (GE 15 mmHg))
                  (DEFIS DIASTOLIC RISE-DIA (LT 30 mmHg))
                  (DEFIS SYSTOLIC RISE-SYS (LT 60 mmHg)) )
           ((CONCLUDE HYPER CLASS-H MILD .68)) )

(RULE7      ($AND (DEFIS BP-REC AVAIL YES)
                  (DEFIS SYSTOLIC RISE-SYS (GE 60 mmHg)))
           ((CONCLUDE HYPER CLASS-H SEVERE .68)))

(RULE8      ($AND (DEFIS BP-REC AVAIL YES)
                  (DEFIS DIASTOLIC RISE-DIA (GE 30 mmHg)))
           ((CONCLUDE HYPER CLASS-H SEVERE .68)))

(RULE9      ($AND (DEFIS SYSTOLIC READ-SYS (GE 140 mmHg))
                  (DEFIS SYSTOLIC READ-SYS (LT 160 mmHg))
                  (DEFIS DIASTOLIC READ-DIA (LT 110 mmHg)))
           ((CONCLUDE HYPER CLASS-H MILD .68)))
```

```
(RULE10     ($AND (DEFIS DIASTOLIC READ-DIA (GE 90 mmHg))
                  (DEFIS DIASTOLIC READ-DIA (LT 110 mmHg))
                  (DEFIS SYSTOLIC READ-SYS (LT 160 mmHg)))
            ((CONCLUDE HYPER CLASS-H MILD .68)))

(RULE11     ($AND (DEFIS SYSTOLIC READ-SYS (GE 160 mmHg)))
            ((CONCLUDE HYPER CLASS-H SEVERE .68)))

(RULE12     ($AND (DEFIS DIASTOLIC READ-DIA (GE 110 mmHg)))
            ((CONCLUDE HYPER CLASS-H SEVERE .68)))

(RULE13     ($AND (DEFIS URIN-OUT CONT-PRO YES))
            ((CONCLUDE PAT SIGN PROTEINURIA .8)))

(RULE14     ($AND (SAME PAT SIGN PROTEINURIA)
                  (DEFIS PRO-CONT MASSIVE-P YES))
            ((CONCLUDE PROTEINURIA CLASS-P MASSIVE .8)))

(RULE15     ($AND (SAME PAT SIGN PROTEINURIA)
                  (DEFIS PRO-CONT MASSIVE-P NO))
            ((CONCLUDE PROTEINURIA CLASS-P MILD .8)))


(RULE16     ($AND (DEFIS PAT HIST-HYPER YES))
            ((CONCLUDE PAT MEDICAL-HIST HYPER 1)))

(RULE17     ($AND (DEFIS FAMILY HYPER-HIST YES))
            ((CONCLUDE FAMILY MEDICAL-HIST HYPER 1)))

(RULE18     ($AND (DEFIS PAT MEDICAL-HIST HYPER)
                  (NOTHAVING PAT SIGN PROTEINURIA))
            ((CONCLUDE PAT HYPER-DISORDER ESSEN-HYPERTENSION .68)
             (CONCLUDE PAT HYPER-DISORDER PRE-ECLAMPSIA -.36)))

(RULE19      ($AND (DEFIS PAT HIST-HYPER NO)
                   (DEFIS HYPER-DISCOVER AFTER-20 YES))
             ((CONCLUDE PAT HYPER-DISORDER PRE-ECLAMPSIA .52)
             (CONCLUDE PAT HYPER-DISORDER ESSEN-HYPERTENSION -.36)))

(RULE20     ($AND (DEFIS FAMILY MEDICAL-HIST HYPER)
                  (DEFIS PAT HIST-HYPER UNK)
                  (NOTHAVING PAT SIGN PROTEINURIA))
            ((CONCLUDE PAT HYPER-DISORDER ESSEN-HYPERTENSION .52)
             (CONCLUDE PAT HYPER-DISORDER PRE-ECLAMPSIA -.15)))

(RULE21    ($AND (SAME PROTEINURIA CLASS-P MILD))
           ((CONCLUDE PAT HYPER-DISORDER CHRONIC-GLOMERULONEPH .36)
            (CONCLUDE PAT HYPER-DISORDER PRE-ECLAMPSIA .36)))

(RULE22     ($AND (SAME PROTEINURIA CLASS-P MASSIVE))
            ((CONCLUDE PAT HYPER-DISORDER PRE-ECLAMPSIA .68)
             (CONCLUDE PAT HYPER-DISORDER CHRONIC-GLOMERULONEPH .68)))
```

```
(RULE23     ($AND (SAME URIN-SEDIMENT CELL-CASTS YES))
            ((CONCLUDE PAT SIGN URIN-CELL-CASTS 1)))

(RULE24     ($AND (SAME PAT SIGN URIN-CELL-CASTS))
            ((CONCLUDE PAT HYPER-DISORDER CHRONIC-GLOMERULONEPH .36)
             (CONCLUDE PAT HYPER-DISORDER ACUTE-GLOMERULONEPH .36)))

(RULE25     ($AND (SAME PAT HIST-HYPER UNK)
                  (SAME FAMILY HYPER-HIST UNK)
                  (SAME HYPER CLASS-H SEVERE)
                  (NOTHAVING PAT SIGN PROTEINURIA))
            ((CONCLUDE PAT HYPER-DISORDER ESSEN-HYPERTENSION .68)))

(RULE26     ($AND (MIGHTBE PAT HYPER-DISORDER PRE-ECLAMPSIA)
                  (NOTHAVING PAT HIST-HYPER UNK)
                  (SAME PAT PRIMI YES)
                  (SAME PAT AGE (LT 35 yrs)))
            ((CONCLUDE PAT HYPER-DISORDER PRE-ECLAMPSIA .52)))


(RULE27     ($AND (SAME PAT HIST-HYPER UNK)
                  (SAME PAT PRIMI YES)
                  (SAME PAT AGE (LE 34 yrs)))
            (
            ;(CONCLUDE PAT HYPER-DISORDER ESSEN-HYPERTENSION .36)
             (CONCLUDE PAT HYPER-DISORDER PRE-ECLAMPSIA .52)))

(RULE28     ($AND (SAME PAT PRIMI NO)
                  (SAME PAT AGE (GT 35 yrs))
                  (SAME PAT HIST-HYPER UNK))
            (
            ;(CONCLUDE PAT HYPER-DISORDER PRE-ECLAMPSIA .36)
             (CONCLUDE PAT HYPER-DISORDER ESSEN-HYPERTENSION .52)))

(RULE28A    ($AND (MIGHTBE PAT HYPER-DISORDER ESSEN-HYPERTENSION)
                  (NOTHAVING PAT HIST-HYPER UNK)
                  (SAME PAT AGE (GT 35 YRS)))
            ((CONCLUDE PAT HYPER-DISORDER ESSEN-HYPERTENSION .52)))

(RULE29     ($AND (DEFIS PAT SYMPTOM S1))
            ((CONCLUDE PAT HYPER-DISORDER PRE-ECLAMPSIA .4)))

(RULE30     ($AND (DEFIS HYPER CLASS-H MILD)
                  (DEFIS PAT SYMPTOM S9)
                  (DEFIS PAT SYMPTOM S10))
            ((CONCLUDE PAT HYPER-DISORDER CHRONIC-GLOMERULONEPH .36)))

(RULE31     ($AND (MIGHTBE PAT HYPER-DISORDER CHRONIC-GLOMERULONEPH)
                  (DEFIS PAT SYMPTOM S7))
            ((CONCLUDE PAT HYPER-DISORDER CHRONIC-GLOMERULONEPH .68)))

(RULE32     ($AND (MIGHTBE PAT HYPER-DISORDER PRE-ECLAMPSIA)
                  (SAME HYPER CLASS-H SEVERE))
            ((CONCLUDE PAT HYPER-DISORDER SEVERE-PET .68)))
```

```
(RULE33    ($AND (MIGHTBE PAT HYPER-DISORDER PRE-ECLAMPSIA)
                 (SAME PROTEINURIA CLASS-P MASSIVE))
           ((CONCLUDE PAT HYPER-DISORDER SEVERE-PET .68)))

(RULE34    ($AND (MIGHTBE PAT HYPER-DISORDER PRE-ECLAMPSIA)
                 (DEFIS PAT SYMPTOM S5))
           ((CONCLUDE PAT HYPER-DISORDER SEVERE-PET .68)))

(RULE35    ($AND (MIGHTBE PAT HYPER-DISORDER PRE-ECLAMPSIA)
                 (DEFIS PAT SYMPTOM S3))
           ((CONCLUDE PAT HYPER-DISORDER SEVERE-PET .68)))

(RULE36    ($AND (DEFIS HYPER EPISODIC YES))
           ((CONCLUDE PAT HYPER-DISORDER PHAEOCHROMOCYTOMA .68)))

(RULE37    ($AND (DEFIS PAT SYMPTOM S4))
           ((CONCLUDE PAT HYPER-DISORDER PHAEOCHROMOCYTOMA .36)))

(RULE38    ($AND (MIGHTBE PAT HYPER-DISORDER PHAEOCHROMOCYTOMA)
                 (DEFIS PAT SYMPTOM S6))
           ((CONCLUDE PAT HYPER-DISORDER PHAEOCHROMOCYTOMA .36)))

(RULE39    ($AND (MIGHTBE PAT HYPER-DISORDER PHAEOCHROMOCYTOMA)
                 (DEFIS PAT SYMPTOM S13)
                 (DEFIS PAT SYMPTOM S15))
           ((CONCLUDE PAT HYPER-DISORDER PHAEOCHROMOCYTOMA .36)))

(RULE40    ($AND (DEFIS PAT SYMPTOM S17)
                 (DEFIS PAT SYMPTOM S18)
                 (DEFIS PAT SYMPTOM S19))
           ((CONCLUDE PAT HYPER-DISORDER HYDATIDIFORM-MOLE .52)))

(RULE41    ($AND (DEFIS PAT SYMPTOM S17)
                 (DEFIS PAT SYMPTOM S16)
                 (DEFIS PAT SYMPTOM S18))
           ((CONCLUDE PAT HYPER-DISORDER HYDATIDIFORM-MOLE .68)))

(RULE42    ($AND (DEFIS PAT HIST-HYPER YES)
                 (SAME PAT SIGN PROTEINURIA))
           ((CONCLUDE PAT HYPER-DISORDER ESSEN-SUPERIMPOSED-PET .68)))

(RULE43    ($AND (MIGHTBE PAT HYPER-DISORDER PRE-ECLAMPSIA)
                 (DEFIS PAT SYMPTOM S6))
           ((CONCLUDE PAT HYPER-DISORDER SEVERE-PET .68)))

(RULE44   ($AND (DEFIS PAT SYMPTOM S2))
          ((CONCLUDE PAT HYPER-DISORDER PRE-ECLAMPSIA .4)) )

(RULE45   ($AND (MIGHTBE PAT HYPER-DISORDER HYDATIDIFORM-MOLE)
                (SAME URIN-SEDIMENT GRAPE-LIKE YES))
          ((CONCLUDE PAT HYPER-DISORDER HYDATIDIFORM-MOLE .6)) )
```

```
(RULE46 ($AND (DEFIS URIN-SEDIMENT GRAPE-LIKE YES))
        ((CONCLUDE PAT SIGN URIN-GRAPE 1)))

(RULE47    ($AND (DEFIS PAT HIST-ACUTE-NEPH YES))
           ((CONCLUDE PAT MEDICAL-HIST ACUTE-NEPH 1)))

(RULE48    ($AND (SAME PAT SIGN PROTEINURIA)
                 (DEFIS PAT MEDICAL-HIST ACUTE-NEPH))
           ((CONCLUDE PAT HYPER-DISORDER CHRONIC-GLOMERULONEPH .68)) )

(RULE49    ($AND (SAME PAT SIGN PROTEINURIA)
                 (SAME PAT SIGN CREATININE-ELEVATION))
           ((CONCLUDE PAT HYPER-DISORDER CHRONIC-GLOMERULONEPH .68)) )

(RULE50    ($AND (SAME CREATININE-LEVEL ELEVATED YES))
           ((CONCLUDE PAT SIGN CREATININE-ELEVATION .8)) )

(RULE51    ($AND (DEFIS PAT SYMPTOM S16)
                 (DEFIS PAT SYMPTOM S15)
                 (DEFIS PAT SYMPTOM S11)
                 (DEFIS PAT SYMPTOM S18))
           ((CONCLUDE PAT HYPER-DISORDER HYDATIDIFORM-MOLE .68)) )

(RULE52    ($AND (SAME PAT HYPER-DISORDER PRE-ECLAMPSIA)
                 (SAME PAT HYPER-DISORDER ESSEN-HYPERTENSION))
           ((CONCLUDE PAT HYPER-DISORDER ESSEN-SUPERIMPOSED-PET 1)))

(RULE53     ($AND (DEFIS URIN-OUT TEST-PROT YES)
                  (DEFIS URIN-SAMPLE COLLECT-24 YES)
                  (DEFIS URIN PROT-CON (GE 0.3 g)) )
            ((CONCLUDE PAT SIGN PROTEINURIA .82)) )

(RULE54     ($AND (DEFIS URIN-OUT TEST-PROT YES)
                  (DEFIS URIN-SAMPLE COLLECT-24 YES)
                  (DEFIS URIN PROT-CON (GE 0.3 g))
                  (DEFIS URIN PROT-CON (LT 5 g)))
            ((CONCLUDE PAT SIGN PROTEINURIA .82)
             (CONCLUDE PROTEINURIA CLASS-P MILD .68)))

(RULE55    ($AND (DEFIS URIN-OUT TEST-PROT YES)
                 (DEFIS URIN-SAMPLE COLLECT-24 YES)
                 (DEFIS URIN PROT-CON (GE 5 g)))
           ((CONCLUDE PAT SIGN PROTEINURIA .82)
            (CONCLUDE PROTEINURIA CLASS-P MASSIVE .68)))

(RULE56     ($AND (DEFIS URIN-OUT TEST-PROT YES)
                  (DEFIS URIN-SAMPLE COLLECT-24 NO)
                  (DEFIS URIN PROT-CON (GE 1 g)))
            ((CONCLUDE PAT SIGN PROTEINURIA .82)))

)
```

APPENDIX 7

AN ILLUSTRATION OF A "HOW" COMMAND

----------conclusion window----------

HYPERTENSIVE DISORDERS THAT THE PATIENT MIGHT HAVE

1. Pre-Eclampsia with certainty factor of 0.9 (90%)
   With certainty factor of 0.68 (68%) Pre-eclampsia
   is considered severe.

Do you want to know HOW a conclusion is established? yes

Enter conclusion number : 1

---

1. SCREEN ONE

----------explanation window----------

[i.e HOW was it established that the patient has Pre-Eclampsia]

It was established by the following rule/s :

RULE44 RULE33
RULE27 RULE22

Type C to continue, L to see the contents of the rule/s : l

2.SCREEN TWO

```
---------------- explanation window ----------------------

RULE44
  IF :
    it is definite that one of the symptoms of the patient
    is edema
  THEN
     there is suggestive evidence (0.4) that hypertensive
     disorder of the patient is Pre-Eclampsia


------------------- ENTER Q TO QUIT ----------------------

Type C to continue : C


------------------------------------------------------------
```

3. SCREEN THREE

```
---------------- explanation window ----------------------

RULE33
  IF :
    1. there maybe some evidence that hypertensive disorder
       of the patient is Pre-eclampsia, and
    2. classification of proteinuria is massive
  THEN
    1. there is strongly suggestive evidence (0.9) that
       hypertensive disorder of the patient is Pre-eclampsia
    2. there is suggestive evidence (0.68) that
       classification of Pre-eclampsia is severe

------------------- ENTER Q TO QUIT ----------------------

Type C to continue : Q


------------------------------------------------------------
```

4. SCREEN FOUR

(When the user enter "q" , the system will stop listing the rules and redisplay screen one.)

APPENDIX 8

A PORTION OF THE CONSULTATION PROGRAM

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;          C O N S U L T A T I O N   S E G M E N T                  ;;
;;                                                                   ;;
;;   This segment is in charge of the consultation session           ;;
;;   Function HIP will load the knowledge base if it is invoked      ;;
;;   for the first time and it will then display the main menu.      ;;
;;                                                                   ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN HIP ()
  (IF (NULL rule-base)
      (LOAD-KBASE))
  (DISPLAY-MENU))
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; FUNCTION HYPER does all the initializaton                         ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN HYPER ()
   (CLEAR-PROP)
   (SETQ signs-list NIL)
   (SETQ symptoms-list nil)
   (SETQ rule-invoked NIL)
   (MONITOR 'goal-rule)
)

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; FUNCTION LOAD-KBASE loads the knowledge base                      ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN LOAD-KBASE ()
 (LET ((fname NIL)
       (file NIL))
      (CLS2)
      (CURSORPOST 5 12)
      (SETQ fname "RULE-BASE.HIP")
      (LOAD fname)
      (SETQ rule-set NIL)
      (DOLIST (arl rule-base)
        (SETQ rule-set (CONS (CAR arl) rule-set))
      )
      (SET-UPDATE)
      ))
```

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; SET-UPDATE retrieves the list of rules from the                          ;;
;;   UPADTED-BY property of an attribute                                    ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN SET-UPDATE ()
  (DOLIST (rl rule-set)
    (LET ((concs (GET-ACTION rl)))
       (DOLIST (then concs)
          (IF (EQUAL (FIRST then) 'CONCLUDE)
              (SETF (GET (THIRD then) 'updated-by))
          )))
  )
  (DOLIST (arule rule-set)
    (LET ((thens (GET-ACTION arule)))
      (DOLIST (conc thens)
        (LET ((inst (FIRST conc))
              (attr (THIRD conc)) )
          (IF (EQUAL inst 'CONCLUDE)
              (SETF (GET attr 'updated-by) (CONS arule
                    (GET attr 'updated-by)))
              )
        )))
   )
)

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;  DISPLAY-MENU displays the main menu of the system                       ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN DISPLAY-MENU ()
 (LET ((choice NIL))
 (LOOP
   (SETQ choice (MENU))
   (CASE choice
                ('C (WAIT)
                    (HYPER))
                ('I (INSTRUCTION))
                ('K (COND ((EQ num-call-kb 0)
                           (WAIT)
                           (LOAD "EDITOR.HIP")
                           (SETQ num-call-kb
                                 (1+ num-call-kb)) ))
                    (MENU-KB))
                ('X (SEND *TERMINAL-IO* :CLEAR-SCREEN)
                    (SEND *TERMINAL-IO* :SET-CURSORPOS 0 10)
                    (FORMAT T " ~%
                              THANK YOU FOR USING HiP

                                    GOOD BYE ! !          ")
                    (SEND *TERMINAL-IO* :SET-CURSORPOS 0 24)
                    (RETURN))
                (OTHERWISE (BEEP-USER) ))

 )))
```

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; CHK-EXPECT checks if the user input is valid;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN CHK-EXPECT (an1 cl-para)
  (COND ((EQUAL (GET cl-para 'expect) 'number)
         (COND ((NUMBERP an1) T)
               (T NIL)))
        (T
          (COND ((MEMBER an1 (GET cl-para 'expect)) T)
                (T NIL))
        )))

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; CHECK-ATTRIBUTE checks if an attribute has a value  ;;
;;  if not then the attribute will be send to FINDOUT  ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN CHECK-ATTRIBUTE (condition)
  (COND ((EQUAL (CAR condition) '$OR))
        (T
          (COND ((CHK-SYM condition))
                (T
                 (COND ((NULL (GET (CADR condition) (CADDR
condition)))
                        (FINDOUT condition)
                  )))))))

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; $AND is a MACRO that is in charge of testing the              ;;
;;   conditions of a premise                                     ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFMACRO $AND (prem1 &rest premises)
  (LET ((min1 1)
        (min2 1))
    (CHECK-ATTRIBUTE prem1)
    (SETQ min1 (EVAL prem1))
    (COND ((NULL min1) NIL)
          (T
           (COND ((NOT (NUMBERP min1))
                  (SETQ min1 1))
           )
           (COND ((NULL premises)
                 )
                 (T
                  (DOLIST (condition premises)
                     (CHECK-ATTRIBUTE condition)
                     (SETQ temp (EVAL condition))
                     (COND ((NULL temp)
                            (SETQ condition NIL)
                            (SETQ min2 temp)
                            (RETURN NIL)
```

```
                    )
                   (T
                    (COND ((NOT (NUMBERP temp))
                           (SETQ temp 1)))
                    (COND ((AND (NOT (NULL temp))
                                (NOT (NULL min2)))
                           (SETQ min2 (MIN min2 temp))
                    ))
                  )
                 ))
                ))
          (COND ((NULL min2) NIL)
                (T
                 (COND ((OR (< min1 .2)
                            (< min2 .2)) NIL)
                       (T (MIN min1 min2))) )))))
)

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; $OR is in charge of testing the conditions that is joined ;;
;;  by the boolean operator OR                                ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFMACRO $OR (pr1 &rest prs)
  (LET ((max-val -1)
        (temp -1))
       (COND ((NULL prs)
              (SETQ premi (LIST pr1)))
             (T
              (SETQ premi (CONS pr1 prs))))
       (DOLIST (pr premi)
               (CHECK-ATTRIBUTE pr)
               (SETQ temp (EVAL pr))
               (COND ((NULL temp)
                      (SETQ max-val NIL)
                      )
                     (T
                      (COND ((NOT (NUMBERP temp))
                             (SETQ temp 1)))
                      (COND ((NULL max-val)
                             (SETQ max-val temp))
                            (T
                             (SETQ max-val (MAX max-val temp))
                            ))
                      ))) max-val ))
```

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; ASK-USER display the prompt that is required to the user    ;;
;; in getting the value of a premiss                           ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN ASK-USER (apremiss)
 (LET ((cntxt (GET-CNTXT apremiss))
       (cp (GET-ATTR apremiss))
       (valu (CAR (LAST apremiss)))
       )
   (IF (LISTP valu)
       (SETQ ans1 (BACA-NUM cp))
       (SETQ ans1 (BACA cp))
       )
   (COND ((EQUAL ans1 'WHY)
          (WHY apremiss))
         (T
          (COND ((EQUAL ans1 'MAYBE)
                 (LOOP
                   (SETQ ans2 (READ-FROM-STRING (GET-NUM-ANS
"On a scale of 0 to 10 : 0 being a definite NO and 10 is a definite
YES
How would you rate your answer ? ")))
                   (IF (OR (> ans2 10)
                           (< ans2 0))
                       (SIGNAL-ERROR)
                       (RETURN))
                 )
                 (IF (= ans2 0)
                   (PROGN
                     (SETQ ans1 'NO)
                     (SETQ ans2 1))
                   (PROGN
                     (SETQ ans1 'YES)
                     (SETQ ans2 (* ans2 .1)))
                 ))
                (T
                  (SETQ ans2 1) ))
          (ATTACH-VALUE cntxt cp ans1 ans2) ))
 ))
```

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; FINDOUT gathers  the value of an attribute                     ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN FINDOUT (premis)
 (LET ((attribute (GET-ATTR premis))
  (cntxt (GET-CNTXT premis)))
   (COND ((EQ (GET attribute 'labdata) T)
        (ASK-USER premis)
         (COND ((NOT (EQ (GET cntxt attribute) 'UNK)))
              (T (SETQ Y (GET attribute 'updated-by))
                 (MAPCAR 'MONITOR Y)
                 (COND ((EQ (GET cntxt attribute) NIL)
                        (ASK-USER cntxt attribute))))))
        (T (SETQ Y (GET attribute 'updated-by))
           (DOLIST (X Y)
                   (MONITOR X))
          ;(COND ((EQ (GET cntxt attribute) NIL)
          ;       (ASK-USER premis)))
         ))) )

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; MONITOR monitors the evaluation of all the premisses            ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN MONITOR (rule-sym)
  (COND ((MEMBER rule-sym rule-invoked))
       (T
        (COND ((EQ (GET rule-sym 'traced) NIL)
               (SETQ rule-invoked (CONS rule-sym rule-invoked))
               (SETQ premise (get-premiss rule-sym))
               (SETQ tally (EVAL premise))
               (COND ((NOT (EQ tally NIL))
                      (PUTPROP rule-sym T 'traced)
                      (SETQ ACTION (GET-ACTION rule-sym))
                      (DOLIST (an-action action)
                              (EVAL an-action)
                              (COND ((EQUAL
                                      (FIRST an-action) 'CONCLUDE)
                                     (SET-HOW (THIRD an-action)
                                      (THIRD (CDR an-action))
                                      rule-sym)))))

                     (T
                      (PUTPROP rule-sym 'false 'traced)
                      (COND ((EQUAL rule-sym 'goal-rule)
                             (NO-CONCLUSION)))))
       (POP rule-invoked)))
)))
```

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; CALCULATE-CF calculates and updates the certainty factor                  ;;
;; of an object.                                                             ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN CALCULATE-CF (obj)
 (COND ((NUMBERP obj) 1)
       (T
        (LET ((belief (GET obj 'mb))
              (disbelief (GET obj 'md)))
             (COND ((NULL belief)
                    (COND ((NULL disbelief) 0)
                          (T
                           (- 0 disbelief))))
                   ((NULL disbelief)
                    (COND ((NULL belief) 0)
                          (T
                           belief)))
                   (T
                    (- belief disbelief)))))))

(DEFMACRO CONCLUDE (cntxt param val cf)
  (LET* ((cf-if tally)
         (newcf (* cf-if cf)))
        (ATTACH-VALUE cntxt param val newcf)
        (COND ((AND (EQUAL cntxt 'sign)
                    (NOT (MEMBER param signs-list)))
               (SETQ signs-list
                 (CONS param signs-list))))
) T)
```

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; ATTACH-VALUE attach the value of an attribute and                        ;;
;; at the same time updates its certainty factor.                           ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN ATTACH-VALUE (cntxt para val val1)
  (LET ((values (GET cntxt para)))
       (COND ((MEMBER val values)
              (COND ((MINUSP val1)
                     (UPDATE-MD val (* val1 -1)))
                    (T
                     (UPDATE-MB val val1))))
             (T
              (COND ((NULL values)
                     (COND ((NUMBERP val)
                            (PUTPROP cntxt val para))
                           (T
                            (PUTPROP cntxt (LIST val) para))))
                    (T
                     (PUTPROP cntxt (CONS val (GET cntxt para))
                              para)))
              (COND ((NUMBERP val))
                    (T
                     (COND ((MINUSP val1)
                            (PUTPROP val (* val1 -1) 'md))
                           (T
                            (PUTPROP val val1 'mb)
                     ))))))
                     ))
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; UPDATE-MD updates the measure of disbelief                               ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN UPDATE-MD (att mds2)
 (COND ((NULL (GET att 'md))
        (SETF (GET att 'md) mds2))
       (T
   (LET ((mds1 (GET att 'md)))
        (SETQ mds1s2 (+ mds1 (* mds2 (- 1 mds1))))
        (SETF (GET att 'md) mds1s2)))))

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; UPDATE-MB updates the measure of belief                                  ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN UPDATE-MB (att mbs2)
  (COND ((NULL (GET att 'mb))
         (SETF (GET att 'mb) mbs2))
        (T
   (LET ((mbs1 (GET att 'mb)))
        (SETQ mbs1s2 (+ mbs1 (* mbs2 (- 1 mbs1))))
        (SETF (GET att 'mb) mbs1s2)))))
```

```
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; Below are all the predicates of FUNCTION1 and FUNCTION2                    ;;
;; that are used in the conditions of a premiss                               ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFMACRO KNOWN (cntxt attribute)
   (COND ((> (MAX-CF cntxt attribute) .2) T)
         (T NIL)))

(DEFMACRO NOTKNOWN (cntxt attribute)
   (SETQ temp (MAX-CF cntxt attribute))
   (COND ((OR (< temp .2) (= temp .2)) T)
         (T NIL)))

(DEFMACRO DEFINITE (cntxt attribute)
   (COND ((= (MAX-CF cntxt attribute) 1) T)
         (T NIL)))

(DEFMACRO NOTDEFINITE (cntxt attribute)
   (COND ((< (MAX-CF cntxt attribute) 1) T)
         (T NIL)))

(DEFMACRO SAME (cntxt attribute val)
   (SETQ temp (CHECK-VALUE cntxt attribute val))
   (COND ((NULL temp) NIL)
         (T (COND ((> temp .2) temp)
                  (T NIL)))))

(DEFMACRO THOUGHTNOT (cntxt attribute val)
   (SETQ temp (CHECK-VALUE cntxt attribute val))
   (COND ((NULL temp) NIL)
         (T (COND ((< temp -.2) temp)
                  (T NIL)))))

(DEFMACRO NOTSAME (cntxt attribute val)
   (SETQ temp (CHECK-VALUE cntxt attribute val))
   (COND ((NULL temp) NIL)
         (T (COND ((OR (< temp .2) (= temp .2)) T)
                  (T NIL)))))

(DEFMACRO MIGHTBE (cntxt attribute val)
   (SETQ temp (CHECK-VALUE cntxt attribute val))
   (COND ((NULL temp) NIL)
         (T (COND ((OR (= temp -.2) (> temp -.2)) T)
                  (T NIL)))))

(DEFMACRO VNOTKNOWN (cntxt attribute val)
   (SETQ temp (CHECK-VALUE cntxt attribute val))
   (COND ((NULL temp) NIL)
         (T (COND ((MINUSP temp) (SETQ temp (* temp -1))))
            (COND ((OR (= temp .2) (< temp .2)) T)
                  (T NIL)))))
```

```
(DEFMACRO DEFIS (cntxt attribute val)
  (SETQ temp (CHECK-VALUE cntxt attribute val))
  (COND ((NULL temp) NIL)
        (T (COND ((= temp 1) T)
                 (T NIL)))))

(DEFMACRO DEFNOT (cntxt attribute val)
  (SETQ temp (CHECK-VALUE cntxt attribute val))
  (COND ((NULL temp) NIL)
        (T (COND ((= temp -1) T)
                 (T NIL)))))

(DEFMACRO NOTDEFIS (cntxt attribute val)
  (SETQ temp (CHECK-VALUE cntxt attribute val))
  (COND ((NULL temp) NIL)
        (T (COND ((AND (> temp .2) (< temp 1)) T)
                 (T NIL)))))

(DEFMACRO NOTDEFNOT (cntxt attribute val)
  (SETQ temp (CHECK-VALUE cntxt attribute val))
  (COND ((NULL temp) NIL)
        (T (COND ((AND (> temp -1) (< temp -.2)) T)
                 (T NIL)))))

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; Below are the functions responsible in translating a rule   ;;
;; into its English representation                              ;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

(DEFUN TRANSLATE (cur-win rulesym)
  (LET ((prems (CDR (GET-PREMISS rulesym)))
        (count 1)
        (actions (GET-ACTION rulesym)))
    (FORMAT cur-win "~a " rulesym)
    (FORMAT cur-win "~%IF    ")
    (FORMAT cur-win  "~%  ")
    (TRANS-IF cur-win prems)
    (TERPRI cur-win)
    (TERPRI CUR-WIN)
    (FORMAT cur-win "THEN  ")
    (FORMAT cur-win "~%  ")
    (TRANS-THEN cur-win actions)
 ))

(DEFUN TRANS-IF (win-nm prem)
 (LET ((count 1))
 (DOLIST (premiss prem)
   (COND ((> count 1)
          (FORMAT win-nm ", and")
          (FORMAT win-nm "~%  ")) )
   (CHK-LEN win-nm count prem)
   (TRANS-EACH-PREM win-nm premiss)
   (SETQ count (1+ count))
 )))
```

```
(DEFUN TRANS-EACH-PREM (win-nm premis)
   (LET ((eval-fnc (FIRST premis))
         (obj (SECOND premis))
         (attr (THIRD premis))
         (valu (CAR (LAST premis))))
   (EACH-IF-TRANS win-nm eval-fnc obj attr valu)
  ))

(DEFUN EACH-IF-TRANS (win-nm funct obj attr valu)
  (IF (MEMBER funct FNC1)
      (PROGN
        (FORMAT win-nm "~a of ~a "
          (CAR (GET attr 'trans)) (CAR (GET obj 'trans)) )
        (CASE funct
            (KNOWN (FORMAT win-nm "is known "))
            (NOTKNOWN (FORMAT win-nm "is not known "))
            (DEFINITE (FORMAT win-nm "is definitely known"))
            (NOTDEFINITE (FORMAT win-nm "is not definitely known"))
       ))
       (PROGN
          (CASE funct
              (DEFIS (FORMAT win-nm "it is definite that "))
              (DEFNOT (FORMAT win-nm "it is definitely disconfirmed
that "))
              (MIGHTBE (FORMAT win-nm "there maybe some evidence that
"))
              (THOUGHTNOT (FORMAT win-nm "there is weak evidence that
"))
              (NOTSAME (FORMAT win-nm "there is disconfirming
evidence that "))
              (NOTHAVING (FORMAT win-nm "it is disconfirmed that "))
              )

       (COND ((EQUAL valu 'YES)
              (FORMAT win-nm "~a is ~a "
               (CAR (GET obj 'trans)) (CAR (GET attr 'trans)) ))

             ((EQUAL valu 'NO)
              (FORMAT win-nm "~a is not ~a"
                (CAR (GET obj 'trans)) (CAR (GET attr 'trans)) ))

             ((EQUAL valu 'UNKNOWN)
              (FORMAT win-nm "it is unknown that ~a is ~a"
                (CAR (GET obj 'trans)) (CAR (GET attr 'trans)) ))

             (T
              (FORMAT win-nm "~a of ~a is"
                   (CAR (GET attr 'trans))
                   (CAR (GET obj 'trans)))
              (COND ((LISTP valu)
                     (DOLIST (aval valu)
                       (IF (NUMBERP aval)
```

```
                        (FORMAT win-nm " ~a" aval)
                        (FORMAT win-nm " ~a"
                            (CAR (GET aval 'trans))))))
                    (T
                     (FORMAT win-nm " ~a" (CAR (GET valu 'trans)))
                ))))
  )))

(DEFUN CHK-LEN (win cnt thelist)
 (IF (> (LENGTH thelist) 1)
     (FORMAT win "~a. " cnt)))

(DEFUN TRANS-THEN (win acts)
 (LET ((count 1)
       (text NIL))
  (DOLIST (act acts)
    (CHK-LEN win count acts)
    (EACH-CONS-TRANS win act)
    (FORMAT win "~%  ")
    (SETQ count (1+ count)) )

   ))

(DEFUN EACH-CONS-TRANS (win act)
  (LET ((obj (SECOND act))
        (attr (THIRD act))
        (val (THIRD (CDR act))) )
    (CASE (FIRST act)
          ('CONCLUDE
              (GET-DEF win (CAR (LAST act)))
              (FORMAT win "~a of ~a is ~a"
                     (CAR (GET attr 'trans)) (CAR (GET obj 'trans))
                     (CAR (GET val 'trans)) ))
          ('CLS
              (FORMAT win "Clear screen") )
          ('PRINT-LINE
              (FORMAT win "Print ~a blank lines " (LAST act)) )
          ('DISPLAY
              (FORMAT win "Display ~a of ~a "
                 (CAR (GET attr 'trans)) (CAR (GET obj 'trans))) )
          ('DISPLAY-TITLE
              (FORMAT win "Display title : ~a" obj )    )
     )
  ))
```

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