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**A RULE-BASED PATIENT SIMULATION SYSTEM
FOR TEACHING MEDICAL STUDENTS**

by

Hans Aggarwal, B. Comm. (Honours)

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of

Master of Management Studies

School of Business

**Carleton University
Ottawa, Ontario**

Thursday, January 9, 1992.

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the degree of Master of Management Studies

Thesis Supervisor

Chair, School of Business

Carleton University

January 9, 1992

Abstract

This study investigates the role of patient simulation systems in the instruction of medical students. A conceptual model of the medical decision making environment, involving diagnosis and treatment, is developed. This model is then implemented in a prototype of a patient simulation system, incorporating Expert System (ES) techniques. The methodology followed in the development and implementation of the model is detailed. Finally, it is determined whether such a system is considered useful in supporting the acquisition and development of medical decision making skills.

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INTRODUCTION

Decision making is a common task undertaken daily. One is continually making decisions of all types, from trivial ones, such as choosing a flavour of ice cream, to those decisions involving the solution of complex problems, such as purchasing a house. The field of study which examines decisions and the process by which they are made is that of decision analysis (Gregory, 1988; von Winterfeldt and Edwards, 1986; Lee and Moore, 1975).

Decision analysis tries to simplify and add structure to the task of making difficult, complex decisions. In attempting to understand the process, several main components of decisions have been identified (Gregory, 1988):

- a list of alternative courses of action,
- a list of possible outcomes of the alternative courses of action under consideration,
- data on the consequences of all feasible combinations of actions and outcomes, for both tangible (e.g., profit and loss) or intangible (e.g., changes in customer goodwill) outcomes,
- the likelihoods of all the possible outcomes under consideration, and
- a decision criterion used to make the decision (e.g., the price of a house)

Each of these components is considered during the decision making process, bringing some organization to the task. However, there are complicating factors involved with these decision components, making the process of decision making a complex one. These complicating factors are uncertainty and time.

Uncertainty enters the decision making process when the outcomes of the alternative courses of action or the likelihood (probability) of their occurrence are unknown or unidentifiable. In other words, the decision maker is uncertain about the risks, costs, and benefits of the outcomes (von Winterfeldt and Edwards, 1986). The collection of more data can reduce the amount of uncertainty, but it can never be entirely eliminated. Thus, decision making under uncertainty remains a difficult task to perform.

The task becomes more complicated when the element of time is added to the decision problem (von Winterfeldt and Edwards, 1986). A particular course of action may have immediate consequences as well as some results which may occur six months, one year, or two years from the time the decision is made. Also, future outcomes may be dependent upon past outcomes and decisions. For example, an outcome which occurs one year from now, may be dependent upon what happens six months from now, which in turn

may be dependent upon the course of action undertaken now. In this way, time considerations can further hinder the decision-maker in her or his task.

Due to the difficulties involved, the process of decision making with time and uncertainty considerations receives much attention and study. In the field of business, the process is studied as it occurs within organizations, with the manager as the decision maker (Davis and Cosenza, 1988). Through the study of the process, new computer-based tools known as Information Systems (IS) were designed to provide information and support to various levels in an organization.

One type of IS is aimed specifically at supporting decision making performed by the manager in an organization. This type of IS is described as "an integrated, user-machine system for providing information to support the operations, management, and decision-making functions in an organization. The system utilizes computer hardware and software; manual procedures; models for analysis, planning, control and decision making; and a database." (Olson and Davis, 1985, p.6).

IS research combined with decision analysis, has been applied to decision making environments other than business. One area is that of medical decision making, which is investigated in this paper.

In the field of medicine, the process of decision making is that of medical diagnosis and treatment, occurring in the clinical situation. It is a complex task which involves conditions of uncertainty and time considerations (Weinstein and Fineberg, 1980).

Briefly, the process of medical diagnosis involves the physician as the decision-maker who must decide what the causes of a patient's condition are and which treatment(s) will eliminate the condition or improve the state of the patient's health.

During the diagnostic process, the physician is faced with uncertainty in the relationship between the symptoms exhibited by a patient and the actual presence of a disease condition. That is, there is some chance that the disease does not actually exist even if the patient displays all of the requisite symptoms. There is also the chance that the clinical data (patient histories, physical examinations, and laboratory tests), which a physician uses in the process of diagnosing the condition, may be inaccurate. Finally, there is some uncertainty in whether the treatment prescribed will have the desired effects on the patient, for this is dependent upon the individual.

Also complicating the task of medical diagnosis and treatment is the consideration of long term effects of decisions. For example, the patient may be treated now for certain

symptoms, however, side effects to the treatment may appear six months into the future, and the physician will have to deal with these as well. In another example, the physician may decide to wait to treat the patient or take some action immediately. Thus, timing does complicate the physician's task.

The medical decision making process is one of many problem areas which decision analysts have studied. When studying any decision making process, one of three approaches can be taken (Bell, Raiffa, and Tversky, 1988). Research can be:

- descriptive in studying how decisions *are* made,
- normative in describing how decision making *should be* performed, or
- prescriptive in giving advice on how to improve the decision making process resulting in better decisions.

As Bell, Raiffa, and Tversky (1988) describe prescriptive analysis, it answers the questions, "What should an individual do to make better choices? What modes of thought, decision aids, conceptual schemes are useful...for real people?". The research described in this thesis investigates the complex process of medical diagnosis under conditions of uncertainty and with time considerations. It is mostly descriptive in nature as it investigates how medical students are trained to make diagnostic decisions. It is also partly prescriptive in that it addresses the question of whether a particular type of decision aid is useful for training medical students in medical diagnosis and treatment.

Before a fuller discussion of the research conducted can begin, some basic concepts and working definitions should be presented. These concepts originate in the fields of medical decision making, medical education, and artificial intelligence.

Medical Decision Making

The process of decision making in medicine can be considered to consist of two phases: the diagnostic phase and the treatment phase. Elstein, Shulman, and Sprafka (1978) describe the diagnostic phase as a process in which four distinct stages are undertaken, involving the physician and the patient. These stages are shown below in Figure 1.

The process begins with the acquisition of cues from the observed symptoms, patient's history, further physical examinations, laboratory tests, and x-rays, etc. Based on these data, the physician generates hypotheses as to the causes (disease conditions) of the cues. Then the data is interpreted according to each hypothesis, determining whether it is supported or negated by subsequent cues. In the final stage, the hypothesis which is the most consistent with the cues is selected. If no hypothesis is clearly confirmed by the cues, then the process iterates with more clinical data being collected.

The diagnostic process described by Elstein, Shulman, and Sprafka (1978) only deals with part of the whole medical decision making process. The remaining phase involving treatment has yet to be explored. Laska and Abbey (1980) describe the treatment phase one in which the physician first defines possible interventions or treatments for the problem. She or he then considers the possible outcomes and the probability of their occurrence for each possible intervention. Finally, one treatment is prescribed and the physician waits for feedback (observation, test results) from the patient. If the treatment has an undesired effect on the patient, the generation of treatments begins once more. The phase, and thus the decision making process, ends when some satisfactory resolution is reached.

An illustration of the entire medical decision making process, as it occurs in the clinical situation, is presented in Figure 2.

Laska and Abbey (1980) describe the process in five stages, labelled A to E. In stage A, the problems, signs and symptoms of the patient's disease are identified. In B, the physician orders tests to be made and interprets the results of these tests. Stage C is the diagnostic stage, followed by the selection of treatment in stage D. The treatment is administered in the final stage, E, and the process ends.

Medical students must learn this complex process of medical decision making as part of their medical training. They must also acquire, develop, and practice their decision making and diagnostic skills. The methods with which this is accomplished form the basis of medical instruction, to be discussed in the following section.

Medical Education

The complex process of medical decision making and the skills with which to perform this task form a major part of the knowledge to be gained by medical students. Knowledge of the process comes from the clinical sciences, but also some material to be absorbed by medical students is from the basic sciences, such as physics, chemistry, and especially biology (Patel, Evans, and Groen, 1989). In order to perform medical decision making, one must draw upon knowledge of the basic sciences (biomedical facts and their relationships) and the clinical sciences (application of these facts and relationships) (Rodolitz and Clancey, 1989).

In the instruction of the basic sciences, lectures, textbooks, and laboratory exercises are traditionally used (Barnett, Hoffer, and Famiglietti, 1986). Similar methods are used in the instruction of the clinical sciences, augmented by the "hospital round" (Evans and Gadd, 1989). In this practice, students present and analyze cases at the the patient's bedside in the presence of the teaching physician. Whether in basic or clinical sciences, traditional methods do have limitations in their ability to impart medical material.

Lectures have been regarded as the most efficient and convenient method of relaying medical information. They can take less time and are less labour intensive than

some of the other instructional methods, such as lab exercises, hospital rounds, and the use of actors. However, as instructors strive to keep pace with the expansion of biomedical and clinical knowledge, lectures are becoming very information intense. This forces students to simply memorize facts, rather than use their skills of decision making (Barrows, 1983).

Similarly, written material, such as textbooks and journals, promote memorization skills in their presentation of detailed, factual information. They do not provide an environment in which the skills of decision making can be acquired, strengthened, and tested (Barnett, Hoffer, and Famiglietti, 1986).

The acquisition and practice of decision making skills is left to the hospital rounds. However, in this instructional method, students are confined to the variety and severity of cases which are available at the teaching hospital. Also, the students' ability to follow the evolution of diseases is constrained by the length of time the given patient stays in the hospital (Barnett, Hoffer, and Famiglietti, 1986).

Limitations with hospital rounds and the other traditional methods have led to innovation in the instruction of medical material. One of the newer methods involves the use of actors who are trained by the teaching physicians to act as patients with particular conditions. These "standardized patients" are then presented in simulated patient-doctor encounters. Through these sessions, the medical student is primarily practicing interpersonal skills, such as communications, courtesy, consideration, and patient handling, as well as receiving training in decision making (Hollobon, 1984).

There are major limitations in using standardized patients for clinical instruction. Teaching physicians believe that this method is very labour intensive and time consuming in the training of actors (Brennan, 1990), and that too much effort is required in examining many students (Hollobon, 1984). Also, there are questions regarding the ability of the actors to be accurate and consistent in their presentations (Tamblyn et al., 1988).

Another method of instruction which is becoming more popular, is the use of small groups of students in diagnostic sessions. This is similar to hospital rounds in that the sessions can be held at the patient's bedside. They can also be held in a laboratory setting. In whatever format, the sessions have been found to be useful in the testing of student's skills.¹

¹ In conversation with Dr. S. Rubin.

A final innovation in the instructional methods is the use of computer systems to support the instruction and learning of the material. The application of computer technology to education in general is referred to as computer-assisted or computer-aided instruction (CAI).

The goals of CAI are to reinforce lectures and text, not to replace them, and to provide a means for self-instruction where students actively participate in instruction or direct their own learning (Hause et al., 1985). In trying to reach these goals, CAI can take one of the following forms: drill and practice, tutorial, and simulation (Anderson, 1986). This research focuses on simulations, involving the presentation of a hypothetical patient case, used to develop decision making skills in medicine.

Patient simulations systems may incorporate mechanisms from the Expert System (ES) technology area, which has been used in supporting instruction (Clancey, Shortliffe, and Buchanan, 1984). In order to understand the functioning of a patient simulation system as developed in this research, several basic concepts of Expert Systems (ESs) must be reviewed.

Expert System Concepts

ES technology aims at providing solutions to problems in a particular domain which are similar to those given by a human who has expertise in the same problem domain (Holsapple and Whinston, 1987). In other words, they attempt to mimic expert behaviour.

In order to accomplish this, an expert system must rely on its three major components (Holsapple and Whinston, 1987):

- the user interface,
- the knowledge base, and
- the inference engine.

The user interface allows the decision maker (user) to interact with the system through the presentation of queries, or through the use of English-like, statements. The knowledge base contains widely shared facts, heuristics (rules of thumb, expert intuition), and data, i.e. an expert's knowledge, relevant to the specific problem domain. Lastly, the inference engine contains the reasoning methods used to explore the knowledge base in search of a solution to a problem.

Along with the main components described above, Harmon and King (1985) include two additional modules to the ES architecture:

- the explanation subsystem, and
- the knowledge acquisition subsystem.

The full ES architecture is shown in Figure 3.

The explanation subsystem gives the reasoning processes and assumptions used by the ES to arrive at a solution. The remaining module, the knowledge acquisition subsystem, allows the expert's knowledge (data, facts, and heuristics) to be translated into

a computer-understandable format. The task of acquiring and modelling the expert's knowledge is known as knowledge engineering. The individual who performs the task is the knowledge engineer. Either the domain expert, or an outside professional skilled in these techniques, may be the knowledge engineer.

The knowledge engineer, in the process of formulating the knowledge base, may use one of several methods of representing the expert's knowledge, such as predicate logic (Klein and Methlie, 1990), semantic nets, frames, and rules² (Harmon and King, 1985).

² Predicate logic (Klein and Methlie, 1990) is a form of knowledge representation using logical values of the objects and involving the concepts similar to the proving of theorems. Semantic nets represent facts about objects in a network in which concepts are represented by nodes, and arcs represent their associations. Frames are used to represent typical knowledge about groups of objects which inherit some properties from

All representation methods have their strengths and weaknesses. Klein and Methlie (1990) adapt a comparison of these methods made by Pinson (1981). They are compared on the basis of several attributes (as shown in Table 1) including their ability to :

- represent descriptions of objects (declarative knowledge) and situations or actions (procedural knowledge),
- incorporate uncertainty,
- reason from conclusions to hypothesis (provide explanations),
- allow for grouping of knowledge structures (modularity), and
- allow for changes in structure to be made (maintenance).

Table 1

Knowledge Representation Comparison

	Predicate Logic	Rules	Semantic Nets	Frames
Declarative knowledge	3	3	3	3
Procedural knowledge	1	2	1	3
Uncertainty	1	3	2	3
Meta-knowledge	2	3	2	3
Explanations	2	3	2	1
Ease of use by expert	2	3	2	1
Modularity	3	3	3	2
Maintenance	3	3	3	2
Processing efficiency	1	2	1	2
Theoretical basis	3	2	3	1

1 = Bad, 2 = Average, 3 = Good

Klein and Methlie, 1990, p. 139

From the Table 1, it can be seen that rules have the highest rating of 'Good' in almost every category, showing that it is a better knowledge representation tool than the others. Therefore, it was decided to represent knowledge in this study using rules and further discussion of their use is required here.

Rules are relatively simple to use, allow for good readability of the knowledge base, allow for modularity and flexible maintenance (Klein and Methlie), and are particularly good at representing heuristic knowledge (Waterman, 1986). However, they are also difficult to use in the representation of static, descriptive knowledge of different

the others. Finally, rules represent knowledge as a set of antecedent and consequence pairs, and are especially good for the representation of knowledge gained with experience (Waterman, 1986).

entities (Klein and Methlie, 1990). But, since the nature of the problem discussed in the thesis is not static, that is, the patient's condition changes with time and as a result of actions taken by the physician, rules are suitable for the representation of this problem. It should also be noted that, the processing efficiency declines as the number of rules increases (Klein and Methlie, 1990).

A rule is composed of two parts. The first part contains a rule's hypothesis, called an antecedent, followed by a consequent containing a rule's conclusion. An example of a simple rule in a common format is:

IF patient is diagnosed as having a parasitic infection
THEN prescribe oral medication.

Here, the antecedent is the statement beginning with 'IF', while the consequent is the prescription action, beginning with 'THEN'. A set of rules representing the domain knowledge is usually evaluated using the facts of a current situation. When the rule's hypothesis (antecedent) is satisfied (i.e. it is "true"), then the conclusion in the rule's consequent is reached. A rule is said to "fire" in this way. The chain of fired rules constitute a reasoning process about the facts from a knowledge base.

Rules can be made more complex through the use of logical operators, such as NOT, AND, and OR. Logical operators can link simple expressions into multiple ones in both the antecedent and consequent of a rule. An example of a more complex rule is found below:

IF patient is diagnosed as having a bacterial infection
AND bacteria is found in the blood
THEN treat with intravenous antibiotics
AND continue observation.

The use of rules, complex and simple, to represent knowledge for an ES, is found in many knowledge domains, such as manufacturing, education, finance, and in the professions of law, medicine, geology, chemistry, and engineering (Rauch-Hindin, 1986). This study focuses on the use of a rules and ES technology in the development of a patient simulation system, in which a hypothetical patient case must be diagnosed and treated. It is the nature of patient simulation systems which will be discussed next.

Patient Simulation

In a simple patient simulation, the system presents a case of a patient exhibiting certain symptom(s). The student is then asked to diagnose the condition(s) and to prescribe an appropriate treatment(s).

A session usually begins with a scenario which describes the problem at hand (Anderson, 1986). The student is then required to take some action, such as requesting more information, having laboratory tests performed, conducting physical exams, and prescribing treatment (Dooling, 1987). Eventually, the medical student works through to the conclusion of the case. At this time, the results of the session are stated in positive or negative terms depending on the decisions made during the session (Dooling, 1987). The final stage can provide the student with a measure of her or his problem solving abilities.

In a realistic clinical diagnostic situation, the patient's condition could improve or worsen as a direct result of the physician's decisions. The patient could also exhibit new and different symptoms which may or may not be related to the original illness for which the physician was initially consulted. This is the nature of the changing environment which exists in the real clinical situation.

A dynamic environment has been listed as an important factor to include in patient simulations (Freidman, 1986; and Barnett, Hoffer, and Famiglietti, 1986) and in the modelling of the decision making environment (Doubilet and McNeil, 1988). However, the patient simulation systems, so far, lack such an environment. For this, and other problems associated with patient simulation systems, they are in limited use (Bergeron, 1989; Barnett, Hoffer, and Famiglietti, 1986). Determining whether a dynamic and changing environment can be captured in a patient simulation system with the help of ES technology is the focus of this study. It is also argued that such a system would significantly contribute to medical CAI.

A REVIEW OF THE LITERATURE

The Association of American Medical Colleges released a report (GPEP Report, 1984) assessing current medical education practices. Some of the recommendations for improvement included reducing the amount of scheduled time and lecture hours in order to give the students time to pursue self-directed learning. The report also suggested that medical schools should promote situations in which students are "active, independent learners and problem solvers, rather than passive recipients of information". These recommendations highlight the problems associated with the traditional methods of medical instruction and indicate directions for the future.

Due to the limitations of traditional methods of instruction (Barnett, Hoffer, and Famiglietti, 1986; Allan and Walrave, 1986; Harless, Zier, and Duncan, 1986), a different approach to instruction, involving the student in self-directed learning was suggested (GPEP Report, 1984). CAI was seen as useful for addressing these needs (Hause, et al., 1985; Harless, Zier, and Duncan, 1986).

In order to meet its goals of reinforcing and complementing the traditional methods of instruction (Wigertz et al., 1983), CAI can take one of several forms, as classified by Kurland and Kurland (1987):

- drill and practice programs allow the student to practice the contents of a knowledge domain that the student has previously been taught,
- tutorials teach specific skills or contents of a knowledge domain,
- simulations give realistic representations of the basic operating principles of a complex knowledge domain,
- construction kits allow the student to practice problem solving by using given components to create complex environments,
- productivity tools aid in servicing or supporting a knowledge domain, such as wordprocessing, spreadsheets, database management software,
- games which are for educational purposes, such as to teach typing skills, and
- laboratories which allow for the actual performance of science experiments on the microcomputer.

These forms of CAI can be incorporated with ES technology to produce Intelligent CAI (ICAI), which is also described by Kurland and Kurland (1987).

Kurland and Kurland's (1987) categorization is in much more detail than that given by Anderson (1986). The latter one only contains the drill and practice, tutorial, and simulation forms of CAI, all of which are described in similar terms as Kurland and Kurland. The use of ES technology is not included, nor is ICAI mentioned.

The difference in detail between the two categorizations may be due to the fact that Kurland and Kurland (1987) review all forms of CAI, including those used in elementary education, while Anderson (1986) concentrates on those forms primarily used in the education of medical personnel. Although dealing with the subject matter most closely related to this study, Anderson's (1986) list does seem incomplete in comparison to Kurland and Kurland (1987).

Hause, et al. (1986) categorization of CAI systems consists of text mode, simulation, and ESs. The text mode and simulation forms are comparable to Anderson's and Kurland and Kurland's tutorial and simulation systems, respectively. Hause, et al. (1986) differentiate simulation and ESs according to what they model. For instance, simulations deal with the graphical demonstration of functions and concepts (as in the representations of chemical molecules and nerve systems), while ESs apply to decision making and diagnostics. Although ES technology is included in their categorization, Hause et al. (1986) do not describe ICAI.

However, Kurland and Kurland's definition is supported by Clancey, Shortliffe and Buchanan (1984) who state that ICAI is formed by incorporating a knowledge base to the various forms of CAI.

In each of the above categorizations, ICAI, and thus ES technology, and simulations have been considered to be separate tools in the CAI toolbox. However, they are combined by O'Keefe (1989) who forms a new hybrid, the knowledge-based simulation, in which a knowledge base is added to a simulation program. This, in fact, points to a new co-operative environment between simulation systems and ESs, in which techniques from both areas are combined in order to support the decision maker (O'Keefe, 1986). Knowledge-based simulations can be considered as a form of ICAI, as they derive from CAI programs incorporating ES technology, following Kurland and Kurland's (1987) definition.

From this discussion, it can be seen that although there are many terms and definitions used, the researchers in the field are basically describing the same thing - the combination of expert systems and CAI programs, or ICAI.

Now that ICAI and CAI have been clarified, the more practical issues of using instructional aids (either CAI or ICAI) for medical education will be discussed.

Goldman (1990) presents a list of CAI programs used in the teaching of primary care. As Anderson (1986), this researcher discusses tutorials and simulations, but includes

a third form of CAI not found elsewhere, that is, the self-assessment program. Such a program presents multiple choice questions to a user and keeps track of the students' grades. This can be viewed as an automated multiple choice exam with the added feature of providing feedback (suggestions as to which areas should be further studied) on the students' performance.

Under simulations, Goldman (1990) specifically describes patient simulation which presents a clinical problem to be solved, establishes consequences of decisions made by the student, and scores the student's decision making skills. Its main goal is to provide an environment in which the student can gain new knowledge in a realistic patient care setting, without the risk of harming the patient.

Patient simulation systems are designed specifically to aid in the acquisition of decision making skills (Barnett, Hoffer, and Famiglietti, 1986; Harless, Zier, and Duncan, 1986). Through the use of these systems, the student can gain and develop decision making skills which include collecting data, forming and testing hypothesis, and prescribing appropriate treatment (Clancey, Shortliffe, and Buchanan, 1984).

In order to be of aid in the acquisition of problem solving skills, patient simulation systems must model the clinical situation in which medical diagnosis is performed (Harless, Zier, and Duncan, 1986). They must also model the disease process and its response to prescribed treatments (Barnett, Hoffer, and Famiglietti, 1986). Even though they represent a simplified version of reality, the simulations are still thought to be a useful experience for teachers and students (Barnett, Hoffer, and Famiglietti, 1986).

Patient simulation sessions are described as the progression through a series of sequential, interdependent decision stages (Dooling, 1986). A typical patient simulation session begins with an opening scene, or scenario (Anderson, 1986), which describes the patient case and an initial decision stage. Depending upon what action is taken in the initial decision stage, a subsequent stage follows in which students apply more actions. Eventually, the final decision stage is reached in which the session ends, either with a positive or negative outcome (Dooling, 1987).

There are many examples of patient simulation systems in actual use and some existing only in the laboratory. These systems tend to support either the interpretation of diagnostic aids (laboratory tests, x-rays, electrocardiograms, etc.) or the diagnostic process. Very few support the treatment phase of medical decision making. Some examples and short descriptions are presented in Table 2.

Table 2

Examples of Patient Simulation Systems

Name or Researcher	Type	Description
Varet (1984)	patient simulation	static simulation of patient no treatment phase
CAMPS Deserens et al	patient simulation	static simulation of patient no treatment phase
DDS Tira (1980)	patient simulation	dentistry system static simulation of patient no treatment phase
OMNI Shulz, Albisser (1986)	patient simulation	training in diabetic treatments treatment phase only
Patient Simulator II	patient simulation	dynamic simulation of patient includes treatment phase

It can be seen that there are gaps in the patient simulation systems in what they do have and what they should have. This study hopes to address some of these gaps.

The use of patient simulations in medical training provides many advantages over the traditional learning methods described earlier. These include the fact that problem solving skills can be acquired and developed without risk to the patient, allowing for mistakes and learning from those mistakes to occur (Barnett, Hoffer, and Famiglietti, 1986; Harless, Zier, and Duncan, 1986; Goldman, 1990).

Patient simulations provide the opportunity for students to gain experience in hypothesis generation (as part of the diagnostic process), as well as in many different conditions. As it was found that errors in diagnosis were made simply due to a lack of knowledge of the correct set of hypotheses on which to concentrate when performing medical diagnosis (Elstein, Shulman and Sprafka, 1987). That is, there was no direct correlation between errors made and the actual number of hypotheses considered in the diagnostic process. Thus, as the selection of the correct hypothesis is a matter of experience and expectation, then patient simulation systems would be very beneficial in the training of this activity.

In the training of medical diagnosis, it has been found that errors in the diagnosis of a condition are not due to the student (or physician) considering too few hypotheses. That is, there is no direct correlation of errors to the number of hypotheses under consideration

(Elstein, Shulman, Sprafka, 1978). Errors are made by simply overlooking the correct hypothesis. The selection of the correct cause of a condition is a matter of experience and expectation. Thus, a tool which would allow students to practice hypotheses selection in many different condition situations would be highly beneficial in their education. Patient simulation is such a tool and provides the opportunity for students to perform case management involving many different diagnostic settings.

Patient simulation also provides an opportunity for a time component to be included in the problem analysis. It is recommended that the element of time be included in the modelling of a medical problem, as future decisions are so dependant on decisions a physician makes at the current time (Doubliet and McNeil, 1988). Inclusion of such a component is reflective of reality, as in a real clinical situation, the patient's condition changes with time. Thus, patient simulation, and the decision making models on which it is based, must incorporate the timing of decisions and actions (Barnett, Hoffer, and Famiglietti, 1986; Friedman, 1986).

Although advantageous, patient simulation systems still face major problems related to their application to medical education. According to Bergeron (1989), simulations are found to be deficient due to:

- high expense of development time and cost of computer hardware and software,
- lack of portability of an application to other situations, and
- the difficulty of evaluating systems.

Of interest is the last problem of evaluating systems. Included in a system's evaluation is the determination of whether an application adequately reflects reality. Obviously, building a more realistic simulation is still a difficult task and its importance for CAI in medicine cannot be undervalued.

The review of literature has identified a problem in the use of patient simulation in medical CAI. The current patient simulation systems are not representative of the true clinical situation in that they are not seen as very realistic. Thus, they are limited in their ability to aid in the instruction of decision making skills, although they are still better than the traditional methods.

Thus, the main thrust of this research was to determine whether patient simulation can be made more effective in aiding the medical student to acquire and develop decision making skills.

METHODOLOGY

At the outset of this research, an overall framework was sought which would guide the entire study. The methodological options for the overall framework came from the area of IS research. IS is a multidisciplinary research area and this cross-discipline attribute is illustrated by Nolan and Wetherbe (1980) in Figure 4. Here, the areas of management science, management accounting, general management, human behaviour (psychology), data processing, and computer science studies all influence research in IS.

ESs are often used to support management functions, especially decision making. Thus, when studying ESs one may be subject to the similar influences as when studying IS in general. In this investigation of ES technology, the areas of computer science, simulation, decision analysis, medical decision making, and medical education are the major influences. They are shown in Figure 5 (on the following page), following the Nolan and Wetherbe (1980) format. Material from all of these areas have been incorporated into this study, as was discussed in Chapters 1 and 2.

The areas of influence all have inherent research methodologies associated with them. Thus, along with providing source material to the study, they also provide methodological options from which to choose. At least thirteen methodologies have been identified for the study of IS (Jenkins, 1985), which have been used in the various influencing areas. For example, there are the case study, field experiment, and the opinion

research methodologies. The methodology followed in this study is known as participative or action research (Sandberg, 1985), in which the researcher is active in shaping a problem; she or he is not only an observer or designer of the study. This methodology for the overall study and the phases involved will be discussed in detail below.

Action Research

This research methodology is characterized by "a close interaction between action and research, between practice and theory, in a process of change." (Sandberg, 1985, p. 87). Both the practitioners (those involved in the problem situation, that is, the physicians and medical students) and the researcher contribute to and learn from the research process.

The core of action research is to participate in change by supplying knowledge which contributes to the understanding of a problem situation and the development of action alternatives. According to Sandberg (1985), the knowledge which the researcher contributes to the problem situation can consist of concepts, theories, methods for clarifying problems, and conditions for action or change. Under the methods for clarifying problems, are those for: investigation, planning, change, and the articulation of everyday knowledge.

The knowledge contributed within this framework consisted of a methodology for solving the research problem of better supporting skill acquisition and skill development through the use of patient simulation. As part of the method of investigation, the

knowledge from the various influencing fields was separated and presented in a coherent manner. In this way, the knowledge was articulated in an effort to clarify the research problem.

Other contributions of the study involve indications of future courses of action to change the nature of CAI programs used for medical education, and the process of educating students itself.

The actual process by which the researcher gains the knowledge to be contributed is illustrated in Figure 6, as developed by Antill (1985). Action research begins with an examination of the literature in the problem's domain. In this study, this entailed examining the literature from the influencing fields: computer science, simulation, patient simulation, decision analysis, medical decision making, and medical education.

The revision of the literature combined with the experience of others in the problem domain, allowed the researcher to gain, or refine, her knowledge. Experiential knowledge was gained from the domain expert, who was involved from the early stages of the research process. This knowledge was in the nature of insights to the process of teaching diagnostics to medical students and the beliefs regarding the stages of the process by which students learn this material.

After the data is amassed, the researcher must select a particular approach to investigate and solve the research problem. The approach chosen was that of developing a conceptual model of the medical decision making and testing it in a form of a prototype patient simulation system. At this point the research has moved into the iterative phase of "Design and Try a Better Practice" of action research.

This phase is iterative in that the domain expert is continually consulted in the development of the conceptual model, until such a time as there is agreement on its completeness for the purpose of the research project. But, the iterations do not end here; they continue during the development of the prototype patient simulation system.

The prototype developed contained those elements necessary to verify the conceptual model. It was designed to be used by medical students to develop their skills in medical diagnosis. Once the prototype is considered to be complete, a larger system can be developed.

The prototype's validity was assessed by the teaching physician. To determine the validity of the system, the question "Does the system adequately predict reality?" was answered (Bergeron, 1989). In order to determine its adequacy, an experiment in which a previously "solved" case was presented and evaluated was performed. Here, the physician was asked to determine whether such a system would be useful for students. As qualitative evaluation of systems is found in the literature (Diserens et al., 1986; Varet, 1984), it was deemed to be sufficient for the purposes of this study. Any suggestions for improvements to the system from the expert were undertaken at that time. The results of the evaluation are presented in Chapter 4.

At this point, the design phase of action research is complete and the phase of "New Theories" begins. During the research process, the researcher formed hypotheses regarding the model development, the prototype design, the design process itself, and the problem domain all of which will be added to the general body of knowledge in the respective subject areas.

The hypotheses formed during the research, usually indicate directions for future research in the same subject area. These indications can lead others to investigate the same

subject area using other types of research methodologies, such as lab experiments, case studies, and surveys, etc., thus, entering the final phase of action research.

A discussion of the hypotheses and conclusions formed from the development experience is found in the "Conclusions" section of Chapter 5. A thorough description of the prototype system is presented in Chapter 4. And finally, the future indications are discussed in Chapter 5.

Since the framework of action research has been described, the issue of its suitability as a methodology for this study can be addressed.

There are many aspects of this study's research problem which would require the use of the action research methodology. First, the use of ES technology was chosen as part of the solution for the research problem. This requires the involvement of a domain expert who would provide input during the development of a patient simulation system. As direct input from the domain expert is a required activity in action research, during the "Design and Try a Better Practice" phase, it is very suitable for this study.

As the participating subjects must provide input to the building of a patient simulation system, thus availability and time are important factors in the design of the study. Constraints in time and in access to the domain experts are major problems encountered in the building of ESs (Cullen and Bryman, 1988). Thus, such a methodology is required which has flexibility in its design, accommodating the constraint of the expert's time and availability. The action research methodology is considered to have this flexibility in design options (Jenkins, 1985).

This methodology is also considered to be able to provide a high degree of naturalness in the research environment in which the research is being conducted (Jenkins, 1985).

Action research is also very suitable for prototyping. The researcher wished to take an active part in affecting change; to have a greater impact on the current practices in medical education. It was believed that using the action research methodology, could result in a movement towards change in the teaching of medicine. This movement would be facilitated by the participation of the medical teaching staff in the research and their interaction with the researcher. For these reasons, the action research methodology was chosen as the methodology to follow in this study.

Knowledge Acquisition

The development of the conceptual model of medical decision making began with a look at its theory. Since the model was to be implemented as a simulation system, ES literature was also reviewed. With this background, the teaching physician's input was then sought through a series of interviews. Then, an initial model was developed, using the concepts and relationships derived from both the physician and the literature.

In the literature, first the theory regarding medical decision making was consulted. The medical decision making process was determined to consist of two stages: the diagnostic stage (Elstein, Shulman, and Sprafka, 1978) followed by the treatment stage (Moidu, Drainkov, and Wigertz, 1988). The stages of the medical diagnostic process formed the basis of the conceptual model.

At this point, consultation with the teaching physician to verify the theory and to provide further clarifications and concepts to the decision making process was required. It was determined that knowledge acquisition techniques, from the ES literature, would be most suitable to derive the required knowledge from the domain expert. Knowledge acquisition is "the process of locating, organizing and representing knowledge. [It] involves observation, interviews, research, and introspection." (Tuthill, 1990, p. 359). This definition is supported by other researchers (Harmon and King, 1985).

There are several techniques used in knowledge acquisition: observation, introspection, and interviews. The interview is most commonly used as it is easiest to perform and allows the researcher to use a combination of the other techniques during the interview (Waterman, 1986). A series of interviews were conducted, all with different formats, objectives, and results.

The first interview served an introductory purpose: to introduce the research participants and begin discussion on the research area. The aspects of a research project for thesis purposes were also explained to the domain expert and he was given an idea of the nature of his involvement in the project. Most importantly, there was a discussion of the research problem itself. In the physician's opinion, the computer-based aids to teaching diagnosis available were inadequate as they did not present patient cases realistically. His chief concern was that they did not allow corrective action to be taken when mistakes were made by the students. The investigation into medical decision making proceeded with this problem in mind. The results of this, and all interviews, were recorded on standard forms, found in Appendix A.

The second and third interviews consisted of unstructured and open-ended questions. The purpose of the second interview was to establish the expectations of the physician (domain expert) and the researcher (knowledge engineer). This is known as an exchange of needs (Tuthill, 1990), where each side explains what is required from the other. This interview also served to identify the expert's view of the problem and to familiarize the expert with ES concepts, such as the knowledge base and rules.

The third interview was aimed at gaining knowledge of key medical concepts and their relationships resulting in the formulation of an initial "map" of the problem. Basically, the map identifies the central idea of the problem and the links between it and associated key concepts (Buzan, 1983). Also, during this interview, a case problem was selected by the physician. The chosen case was that of an ill infant, which is especially interesting as an infant is incapable of speech and, thus, a physician must rely solely on her or his knowledge and experience. In order to assist in setting up the case problem, the physician developed a preliminary sketch of the key concepts and the reasoning pathways used to move between them. This sketch was in the form of similar to an AND/OR tree and, together with the map, it can be found in Appendix A.

The map and tree also served as the basis of review of concepts in future interviews with the physician. This started the fourth interview, which was semi-structured with closed questions being asked. The main purpose of this interview was to review the key concepts and their relationships as developed in the initial map and tree. For this interview, a worksheet was prepared in order to guide the review and to determine the reasoning used to solve the ill infant problem. This worksheet is attached to the session form for Interview Four, in Appendix A. Also found there, is a refinement of the main knowledge structures and the reasoning pathways used. One item of importance which came out of this interview, was the conceptualization of certain actions to be taken in the form of rules. The physician did express these actions in a form close to IF...THEN statements. This is important as it suggested the use of the rule format for the representation of knowledge in the knowledge base of the patient simulation system.

With a clearer conceptualization of the problem and the preliminary indication of some usable rules, the researcher's next task was to organize the knowledge acquired about the case problem and the medical decision making process used to solve the case. A series of AND/OR trees was developed to depict the acquired knowledge. These trees are a useful tool in analyzing a decision making environment, especially if a series of decisions is

involved (Lee and Moore, 1975). The alternative courses are actions to be taken in the future and are represented as branches of a tree, stemming from the its root, which represents the decision to be made at the present moment in time. The tree also shows the linkage from one decision to another, indicating the sequential nature of decision making.

Through the series of trees, the medical knowledge involved in the diagnosis of the ill infant and the process by which that knowledge is used is presented. Each tree shows the temporal decision problem facing a physician or student at different stages of the diagnosis and treatment. Usually a choice amongst several options for actions must be made. Depending upon which action is taken, the decision problem changes, thus, moving to a different representation of the problem. In this way, the sequential nature of decision making is shown.

The dynamic nature of the model is important as it reflects the true nature of the clinical situation in which changes in the patient's condition must be captured. A model with a fixed or predetermined tree structure cannot capture this aspect of medical decision making (Langlotz, Shortliffe, and Fagan, 1988).

In developing the AND/OR trees, the researcher found ambiguities in the knowledge. A fifth interview was sought with the purpose of eliminating these ambiguities. From this interview, the results of the specific tests and their implications on the eventual diagnosis were clarified. This resulted in a better model, with clear links between the physician's actions, the test results, the diagnosis, and the treatment plan, which was incorporated into the trees.

Once formulated, the AND/OR trees can be easily converted into rules which constitute the conceptual model of the medical decision making problem involving the case of the ill infant. From here, the model must be implemented as patient simulation system. The transformation of the acquired knowledge is known as knowledge engineering and will be further discussed in the following section.

Knowledge Engineering

While knowledge acquisition uses tools (observation, interviews, research, and introspection) with which to obtain the necessary data, knowledge engineering incorporates the data (through knowledge representation methods) into a system. It is "the process of acquiring knowledge from a human expert and representing that knowledge in a knowledge base" (Tuthill, 1990, p. 360).

It was decided to implement a prototype using the programming shell NEGOPLAN (Kersten et al, 1991); a non-commercially available software. NEGOPLAN was originally designed for supporting the decision makers involved in two party negotiations (Matwin et al, 1989), such as police and terrorist negotiation (Michalowski et al, 1988) and labour/union negotiations (Matwin et al., 1989), but was later expanded to cover any forms of sequential decision making (Michalowski et al., 1991; Kersten et al, 1991). In supporting decision making, NEGOPLAN offers advantages such as:

- it allows for changes in problem representation,
- it accommodates the sequential nature of decision making, and
- it allows for control over the decision making process.

The most beneficial aspect of NEGOPLAN for this study, is the ability to change the problem's representation known as restructurable modelling. These changes of the representation of the decision problem are a result of responses to the actions taken from the environment and the other parties involved in the negotiations. This ability is especially important to this study as it will enable the researcher to capture the changes in the patient's condition due to time and as a result of the actions taken (decisions made) by the physician.

The conceptual model of the ill infant and the medical decision making process was implemented in the form of rules. The particular structure of this rule-based model, much of which is taken from Kersten et al. (1991) and Michalowski et al. (1991), is further discussed in the next section.

The Rule-Based Model

In NEGOPLAN, acquired knowledge is organized in a hierarchy of goals, to be achieved by the decision maker at each stage of the decision problem. Higher level goals are decomposed into more detailed, lower level goals and the lowest level of goals which are to be achieved are known as facts. Goals in the hierarchy are linked through statements of equivalence, in the following way:

goal <- subgoal₁ & subgoal₂ & subgoal₃ & ... & subgoal_n.

This can also be expressed in the equivalent form as:

**IF subgoal₁ AND subgoal₂ AND subgoal₃ AND ... AND subgoal_n
THEN goal.**

There is no difference in interpretation of either of the formats above. However, for the remainder of this discussion, the former rule format will be followed in order to clearly indicate a direction of reasoning (identified by an arrow <-). Thus, the arrow denotes equivalence in that the "goal" is equivalent to achieving subgoal₁ and subgoal₂ and subgoal₃, etc. In another example, the goal of determining a preliminary diagnosis may be written with the help of the following set of rules:

**preliminary_diagnosis <- interim_treatments.
preliminary_diagnosis <- general_examination.**

Here, the higher goal of determining a preliminary diagnosis is equivalent to achieving the subgoals of performing interim treatments or performing a general examination. As further decomposition occurs, more details can be given about the subgoals, with the most detailed ones called "facts". Goals and facts can be assigned the logical values of "true" or "false", indicating that the goal or fact is achieved (true) or not achieved (false).

A set of all the rules which represent the decomposition of goals in a particular decision problem is known as the Goal Representation (GR). In a GR, there are usually several alternative paths to achieving the main goal. Any one of these alternative paths is known as a candidate solution of the GR. The candidate solutions of a GR are presented to the user, who then selects which course of action to follow. The chosen candidate solution is known as the Goal Solution (GS). By definition, all goals and facts in the selected GS are assigned truth values.

The facts with their logical values attached are known as metafacts and take the following format:

**interim_treatments := true
general_examination := false**

Here, the "!=" denotes that the fact has been assigned a logical value. Usually, a metafact is labelled with an indication as to which party or side it belongs. In the case discussed here, the sides are the physician and the patient. Examples of metafacts with side indications are:

```
physician: interim_treatments := true.  
physician: general_examination := false.  
patient: patient_condition_better := true.
```

The physician is the party which is being supported in her or his decision making and the patient is the "opponent" which responds to the physician's actions. There can be a third side in the problem, usually referred to as the environment. The environment responds to the actions taken by the physician and provides information to be used in choosing future alternative paths to achieving goals. All three sides are modelled in the implementation of this study's conceptual model.

The solution taken by the physician (composed of metafacts) triggers responses in the environment and the patient. This trigger / effect pair is modelled with the help of metarules of the following format:

triggers ==> effects

The arrow ==> indicates reasoning from the antecedents to the consequents, which are composed of metafacts. A specific example is:

```
physician: interim_treatments ::= true and  
physician: general_examination ::= false  
==>  
patient: patient_condition_better ::= true
```

where the physician's actions, such as beginning interim treatments, trigger an improvement of the patient's condition (patient_condition_better ::= true). The metarules of this format are known as response rules as they identify the responses from the opponent and the environment. There is another format which metarules follow, known as modification rules.

Modification rules are used to change the representation of the decision problem at a particular point in time, due to the responses from the patient and environment, as inferred

by the response rules. In changing the representation of the problem, a new GR is created and solved. An example of a modification rule is:

```
physician: interim_treatments ::= true and  
physician: general_examination ::= false and  
patient: patient_condition_better ::= true.  
==>  
modify (preliminary_diagnosis <- patient history  
        preliminary_diagnosis <- general_tests ).
```

Whereas previously the goal of `preliminary_diagnosis` was defined by `interim_treatments` or `general_examination`, now it is decomposed into the subgoals of reviewing the patient's history or performing general tests. This modification is governed by the occurrence of metafacts identified in the antecedent of the modification rules.

After the knowledge was translated into rules in NEGOPLAN, an sixth interview with the physician was sought for two purposes. First, the researcher wanted to familiarize the physician with the representation of the knowledge in NEGOPLAN and to verify the decision making process implemented. When presented with a combination of tree diagrams and the rule base (as found in Appendix B), the physician detected incorrectness in the modelling of the diagnosis and treatment phases. It was recommended that in the case of proper patient case management, the treatment and diagnosis would begin at the same time and that they would continue to be performed in parallel.

All of the required changes were made and the resulting AND/OR trees and rule base are presented in Appendix B. Appendix C presents the rule base in the format followed in the discussion so far.

THE CASE OF THE ILL INFANT

The patient selected for simulation exercise is that of a six month old infant. When diagnosing an infant, there is only a specific set of conditions which can exist. For example, the infant cannot suffer from conditions which are more likely to afflict a fifty year old adult. The case of an infant was also selected as there is less likely to be complicating factors, such as multiple conditions existing simultaneously.

The condition the infant is suffering from is that of a infection of the intestinal tract. Usually, an infant with this condition displays the following symptoms:

- vomiting,
- fever,
- loss of weight, and
- diarrhoea.

In addition, he is irritable and is refusing to eat. With these initial cues, the physician begins to manage the patient case.

Case management requires that diagnosis and treatment of the infant are performed in parallel. To begin the treatment process, the physician should undertake a set of initial interim treatments in order to alleviate some of the symptoms and reduce the infant's suffering. These treatments are:

- re-hydration of infant,
- changing the infant's diet, and
- continued hospitalization of the infant.

If these actions are not taken, the infant could die.

To begin the diagnostic process, the physician should examine the infant's medical history. Such an examination may reveal past illnesses and any changes in the infant's behaviour which may have a bearing on the current condition of the infant. In this case, the infant's history confirmed the recent, acute weight loss.

The physician next proceeds to a general examination of the infant. The infant's behaviour, weight, pulse and blood pressure, respiration, head size and fontanel, hydration, temperature, and skin are examined. In cases of intestinal infections, the following results are usually obtained:

- the behaviour is normal with some drowsiness,
- the weight is abnormal,
- the pulse is increased,
- blood pressure is decreased, but may not be,
- the head size is normal,
- the fontanel is abnormal, but may not be,

- the hydration is abnormal,
- the temperature is high and abnormal, and
- the skin is normal, but may not be.

At this point, the physician should be able to give a preliminary diagnosis of an intestinal infection. From now on, any actions taken should either confirm or disprove this preliminary diagnosis.

The general examination is followed by a series of general tests. These tests examine the infant's blood, specifically the red and white cells. The urine is also examined for any abnormalities, such as the presence of blood, sugar, ketones, and proteins. The results of these tests are usually as follows:

The blood test:

- the red cells count is normal,
- the white cells count is elevated, and
- the cell smear is normal.

The urine analysis:

- there is no presence of sugar,
- there is some presence of ketones,
- there is no presence of proteins, and
- there is no presence of red or white blood cells.

The presence of some ketones in the urine indicates that there is an acute nutritional problem. At this point, the physician should be moving towards a more specific diagnosis of the condition.

In order to give a more specific diagnosis, the physician must try to identify the type and site of the infection. For this, a body system which is believed to contain the possible site of infection is selected for further examination. From the test results obtained thus far, the physician could be led to select either the gastrointestinal system or the neurological system for further examination. In an examination of either system, the physician must re-examine the infant's history and perform an in-depth physical examination.

If the physician chooses to examine the infant's gastrointestinal system, the infant's medical history should be evaluated for:

- any other family members displayed similar symptoms,
- a family history of some gastrointestinal disorder,
- any recent changes in diet, or
- any contact with someone else with similar symptoms.

Usually, other family members displaying similar symptoms and a family history of some gastrointestinal disorder may be either true or false. In this particular case, an examination of the infant's history would not reveal any of the above situations. Moving to the physical

examination, the physician is simply checking the severity of the symptoms displayed. Under the circumstances, the results of the physical examination would be:

- the number of times urine is passed per day is normal,
- the abdomen is tender and there is an increase in the intestinal sounds, and
- the rectal exam showed diarrhoea.

If the physician chooses to examine the infant's neurological system, the infant's history should be examined to see if there were any recent, unusual facial or limb movements. An examination of this infant's history would not reveal any unusual occurrences. Then in the physical examination, the physician should look for abnormalities in the head and face of the infant. The results would be:

- no neck stiffness,
- no raised intracranial pressure,
- the eye movements are normal,
- the size of pupils are normal, and
- the face appears to be normal.

These results should indicate to the physician that the incorrect body system was selected for examination, thus the physician should move to investigate the gastrointestinal system.

Along with a specific examination, there should be specific tests of the stool and blood performed. The results of these tests should confirm the intestinal infection. An examination of the stool would reveal the absence of blood and negative bacterial cultures. There would be no pus or parasites in the stool. The viral studies of the stool would be positive, but not necessarily so. The results of the blood analysis may reveal either a normal or an elevated white blood cell count, but no bacterial culture.

At this point, the physician should diagnose the infant as having a viral infection of the intestinal tract. Now, a continuation of the treatment process is required with the best treatment plan being to continue the re-hydration, continued hospitalization, and the gradual resumption of solids and liquids.

As a result of the treatment, the infant's symptoms should be alleviated and the infant can be released from the hospital. Diagnosis and treatment of the condition is complete and the case has been successfully managed.

The diagnosis and treatment of the viral infection in the infant was modelled in NEGOPLAN, using the structure and format already described.

NEGOPLAN Model of the Ill Infant

In NEGOPLAN, the two parties involved in the simulation are the physician and the patient. The physician is the decision maker while the patient responds to the actions taken by the physician.

The initial goal representation of the problem for the physician is as follows:

```

physician: goal <- look.
physician: goal <- dont_look.

```

Here, the physician has an initial choice of either proceeding to examine the infant or to basically do nothing (dont_look).

A possible solution to this Goal Representation (GR) is represented by the metafacts:

```

physician: goal ::= true.
physician: look ::= true.

```

After this solution is accepted by the physician, the general symptoms (vomiting, fever, loss of weight, and diarrhoea) displayed by the infant are revealed. The infant's general state is found to be ill. This response is represented by the metarule:

```

physician: look ::= true
=>
patient: patient_condition_ill ::= true.

```

With knowledge of the infant's state of health and the general symptoms displayed, the problem at hand changes for the physician. This change is represented by the following rules:

```

physician: look ::= true and
patient: patient_condition_ill ::= true
=>
modify ( goal <- preliminary_diagnosis
          preliminary_diagnosis <- [interim_treatments;
                                   general examination;
                                   general tests;
                                   patient history]
          preliminary_diagnosis <- consult_specialist ).

```

Here, the main goal is decomposed into the subgoal of achieving a preliminary diagnosis. This in turn is made up of either performing interim treatments and a general examination and general tests and patient history or seeking a consultation with a specialist.

In this way, the physician progresses through the diagnostic and treatment process to some conclusion. In the patient simulation system, there are four ways in which to conclude a session:

- failure,
- error,

- success, and
- specialist.

If the physician fails to prescribe the interim treatments which alleviate some of the general symptoms and lessen the infant's suffering, execution stops and the session ends in "failure". Failure can be interpreted as death of the infant. An "error" situation occurs when the physician takes two consecutive, incorrect actions. In the next case, if the physician prescribes the correct treatment for the right condition, then the session ends with "success". This can be interpreted as the infant was cured. Finally, if the physician prescribes an incorrect treatment to the correct diagnosis, then the session ends with "specialist", which is interpreted as referring the case to a specialist.

Progression from the initial GR to the termination of a session is done through a series of correct or incorrect actions or a combination of these. These situations are shown in the following section.

Sample Sessions

The sample sessions to be presented here are the cases of :

- all correct actions being taken (C-C-C),
- all incorrect actions being taken (IC-IC-error), and
- a combination of actions being taken (C-IC-C).

The sessions are shown below with both metarules and decision tree diagrams.

All Correct Actions: C-C-C

The initial GR is:

Rules:

```

goal <- look.
goal <- dont_look.
  
```

GS - Correct Solution:

```

goal ::= true.
look ::= true.
  
```

Patient Responses to Physician's Actions:

```

physician: look ::= true
=>
patient:   patient_condition_ill ::= true.

```

Environment Responses:

```

symptom_vomiting ::= true.
symptom_fever    ::= true.
symptom_weight_loss ::= true.
symptom_diarrhoea ::= true.

```

Modifications:

```

physician: look ::= true and
patient:   patient_condition_ill ::= true
=>
modify ( goal <- preliminary_diagnosis
        preliminary_diagnosis <- [interim_treatments;
                                   general examination;
                                   general tests;
                                   patient history]
        preliminary_diagnosis <- consult_specialist ).

```

After firing a modification rule, the next GR is:

Rules:

```

goal <- preliminary_diagnosis.
preliminary_diagnosis <- [patient history;
                           general examination;
                           general tests;
                           interim treatments].
preliminary_diagnosis <- consult_specialist.

```

GS - Correct Solution:

```

goal ::= true.
preliminary_diagnosis ::= true.

```

```
[patient history;
general examination;
general tests;
interim treatments] ::= true.
```

Patient Responses to Physician's Actions:

```
physician: [patient history;
            general examination;
            general tests;
            interim treatments] ::= true and
patient:    patient_condition_ill ::= true
=>
patient:    patient_condition_stable ::= true.
```

Environment Responses:

In the patient history:
acute weight loss ::= true.

In the general examination:
the behaviour is normal with some drowsiness ::= true.
the weight is normal ::= false.
the pulse is increased ::= true.
the blood pressure is decreased ::= true.
the head size is normal ::= true.
the fontanel is abnormal ::= true.
the hydration is normal ::= false.
the temperature is high ::= true.
the skin is normal ::= true.

In the blood test:
the red cells count is normal ::= true.
the white cells count is elevated ::= true.
the cell smear is normal ::= true.

In the urine analysis:
there is a presence of sugar ::= false.
there is a presence of ketones ::= true.
there is a presence of proteins ::= false.
there is a presence of red blood cells ::= false.
there is a presence of white blood cells ::= false.

Modifications:

```
physician: [patient history;
            general examination;
            general tests;
            interim treatments] ::= true and
patient:    patient_condition_stable ::= true
=>
modify ( goal <- specific diagnosis
        specific_diagnosis <- examination of gastrointestinal system with
                                specific tests
```

specific_diagnosis <- examination of neurological system with specific tests).

The modified GR is:

Rules:

goal <- specific_diagnosis.
 specific_diagnosis <- examination of gastrointestinal system with specific tests.
 specific_diagnosis <- examination of neurological system with specific tests.

GS - Correct Solution:

goal ::= true.
 specific_diagnosis ::= true.
 examination of gastrointestinal system with specific tests ::= true.

Patient Responses to Physician's Actions:

physician: examination of gastrointestinal system with specific tests ::= true
 and
 patient: patient_condition_stable ::= true
 =>
 patient: patient_condition_better ::= true.

Environment Responses:

Re-examination of medical history:

other family members displayed similar symptoms ::= false.
 family history of some gastrointestinal disorder ::= false.
 recent changes in diet ::= false.
 contact with someone else with similar symptoms ::= false.

In the physical examination:

the number of times urine is passed per day is normal ::= true.
 the abdomen is tender and there is an increase in the intestinal sounds ::= true.

In the rectal exam:

```

there is a presence of diarrhoea ::= true.
there is a presence of blood ::= false.
there is a presence of mucous ::= false.
there is a presence of pus ::= false.

```

In the specific stool tests:

```

there is a presence of blood ::= false.
there is a presence of bacterial cultures ::=false.
there is a presence of pus ::= false.
there is a presence of parasites ::= false.
there is a presence of virus ::= true.

```

In the specific blood tests:

the white cell count is elevated ::= true.
there is a presence of bacterial cultures ::= false.

Modifications:

```

physician: examination of gastrointestinal system with specific tests ::= true
and
patient: patient_condition_better ::= true
=>
modify ( goal <- specific_diagnosis
specific_diagnosis <- diagnose infection of intestinal
tract
specific_diagnosis <- examination of neurological system with
specific tests
).

```

All Incorrect Actions: IC-IC-error

Assuming that a session is in progress, let us continue with the following GR :

Rules:

```
goal <- specific diagnosis.  
specific_diagnosis <- examination of gastrointestinal system with specific  
tests.
```

specific_diagnosis <- examination of neurological system with specific tests.

GS - Incorrect Solution:

```
goal ::= true.
specific_diagnosis ::= true.
examination of neurological system with specific tests ::= true.
```

Patient Responses to Physician's Actions:

```

physician: examination of neurological system with specific tests ::= true
and
patient: patient_condition_stable ::= true
=>
patient: patient_condition_worse ::= true.

```

Environment Responses:

Re-examination of medical history:

unusual facial or limb movements ::= false.

In the physical examination:

neck stiffness ::= false.
raised intracranial pressure ::= false.
the eye movements are normal ::= true.
the size of pupils are normal ::= true.
the face appears to be normal ::= true.

In the specific stool tests:

```

there is a presence of blood ::= false.
there is a presence of bacterial cultures ::=false.
there is a presence of pus ::= false.
there is a presence of parasites ::= false.
there is a presence of virus ::= true.

```

In the specific blood tests:

the white cell count is elevated ::= true.
there is a presence of bacterial cultures ::= false.

Modifications:

```

physician: examination of neurological system with specific tests ::= true
and
patient: patient_condition_worse ::= true
=>
modify ( goal <- specific_diagnosis
        specific_diagnosis <- examination of gastrointestinal system with
                                specific tests
        specific_diagnosis <- infection of neurological
                                system
        ).

```

The problem then changes to the following:

Rules:

```

goal <- specific_diagnosis.
specific_diagnosis <- examination of gastrointestinal system with specific tests.
specific_diagnosis <- diagnose infection of neurological system.
  
```

GS - Incorrect Solution:

```

goal ::= true.
specific_diagnosis ::= true.
diagnose infection of neurological system ::= true.
  
```

Patient Responses to Physician's Actions:

```

physician: diagnose infection of neurological system ::= true and
patient: patient_condition_worse ::= true
=>
patient: patient_condition_worse ::= true.
  
```

Environment Responses:

None.

Modifications:

```

physician: diagnose infection of neurological system ::= true and
patient: patient_condition_worse ::= true
=>
modify ( goal <- error).
  
```

And finally, the resulting GR is:

Rules:

```
goal <- error.
```

GS:

```
goal ::= true.
error ::= true.
```

Patient Responses to Physician's Actions:

None

Environment Responses:

None

Modifications:

```
physician: error ::= true
=>
modify ( goal <- end_of_session).
```

Combination of Actions: C-IC: C

Once again, assuming that a session is in progress, let us continue with the following GR:

Rules:

```
goal <- specific_diagnosis.
specific_diagnosis <- examination of gastrointestinal system with specific tests.
specific_diagnosis <- examination of neurological system with specific tests.
```

GS - Correct Solution:

```
goal ::= true.
specific_diagnosis ::= true.
examination of gastrointestinal system with specific tests ::= true.
```

Patient Responses to Physician's Actions:

```

physician: examination of gastrointestinal system with specific tests ::= true
and
patient: patient_condition_stable ::= true
=>
patient: patient condition better ::= true.

```

Environment Responses:

Re-examination of medical history:

other family members displayed similar symptoms ::= false.
family history of some gastrointestinal disorder ::= false.
recent changes in diet ::= false.
contact with someone else with similar symptoms ::= false.

In the physical examination:

the number of times urine is passed per day is normal ::= true.
the abdomen is tender and there is an increase in the
intestinal sounds ::= true.

In the rectal exam:

there is a presence of diarrhoea ::= true.
there is a presence of blood ::= false.
there is a presence of mucous ::= false.
there is a presence of pus ::= false.

In the specific stool tests:

```

there is a presence of blood ::= false.
there is a presence of bacterial cultures ::=false.
there is a presence of pus ::= false.
there is a presence of parasites ::= false.
there is a presence of virus ::= true.

```

In the specific blood tests:

the white cell count is elevated ::= true.
there is a presence of bacterial cultures ::= false.

Modifications:

```

physician: examination of gastrointestinal system with specific tests == true
and
patient: patient_condition_better == true
=>
modify ( goal <- specific_diagnosis
        specific_diagnosis <- diagnose infection of intestinal tract
        specific_diagnosis <- examination of neurological system with specific tests ).

```

The resulting GR is:

Rules:

```

goal <- specific_diagnosis.
specific_diagnosis <- diagnose infection of intestinal tract.
specific_diagnosis <- examination of neurological system with specific tests.
  
```

GS - Incorrect Solution:

```

goal ::= true.
specific_diagnosis ::= true.
examination of neurological system with specific tests ::= true.
  
```

Patient Responses to Physician's Actions:

```

physician: examination of neurological system with specific tests ::= true
and
patient: patient_condition_better ::= true
=>
patient: patient_condition_worse ::= true.
  
```

Environment Responses:

Re-examination of medical history:

```

unusual facial or limb movements ::= false.
  
```

In the physical examination:

```

neck stiffness ::= false.
raised intracranial pressure ::= false.
the eye movements are normal ::= true.
the size of pupils are normal ::= true.
the face appears to be normal ::= true.
  
```

In the specific stool tests:

```

there is a presence of blood ::= false.
there is a presence of bacterial cultures ::= false.
there is a presence of pus ::= false.
there is a presence of parasites ::= false.
there is a presence of virus ::= true.
  
```

In the specific blood tests:

the white cell count is elevated ::= true.
 there is a presence of bacterial cultures ::= false.

Modifications:

physician: examination of neurological system with specific tests ::= true
 and
 patient: patient_condition_worse ::= true
 =>
 modify (goal <- specific_diagnosis
 specific_diagnosis <- diagnose infection of neurological
 system
 specific_diagnosis <- diagnose infection of intestinal
 tract
).

The new GR is:

Rules:

goal <- specific_diagnosis.
 specific_diagnosis <- diagnose infection of intestinal tract.
 specific_diagnosis <- diagnose infection of neurological system.

GS - Correct Solution:

goal ::= true.
 specific_diagnosis ::= true.
 diagnose infection of intestinal tract ::= true.

Patient Responses to Physician's Actions:

physician: diagnose infection of intestinal tract ::= true and
 patient: patient_condition_worse ::= true
 =>
 patient: patient_condition_better ::= true.

Environment Responses:

None

Modifications:

```
physician: diagnose infection of intestinal tract ::= true and
patient    patient_condition_better ::= true
=>
modify ( goal <- treatment
          treatment <- [rehydration;
                        resumption of solids and
                        liquids;
                        continued hospitalization]
          treatment <- intravenous_treatment ).
```

And the case management continues until some conclusion is reached.

All of the possible scenarios in the simulation can be found in Appendix B. Each scenario is organized in the manner described in this section. The patient's responses are included and directions as to how the case management progresses from scenario to scenario are given. Further instructions for the interpretation of these scenarios can be found in Appendix B.

The scenarios from Appendix B were used during a session with the physician. The prototype was presented in this manner for the evaluation of the system by the physician.

In evaluating the system, the physician believed that the prototype patient simulation system had four main features which made it truly reflective of the clinical situation. The first feature was that of the changing patient condition which responded to the physician's actions and to the passing of time.

The next feature of the prototype was the inclusion of both the diagnostic and treatment phases which constitute the entire medical decision making process. Also, within these phases, the physician was given the opportunity to rectify previous incorrect actions which may have been taken. Thus, the session was not ended in 'error' or 'specialist' with the taking of only one incorrect action.

The final feature of the prototype was the realistic case management environment it provided, in which the treatment and diagnosis phases began simultaneously. At some point in the model, the treatment phase stopped while diagnosis continued, thus modelling proper case management.

These features and the results of the study are discussed further in Chapter 5.

CONCLUSIONS AND FUTURE DIRECTIONS

As part of the action research methodology, the researcher formed conclusions during the design process of the conceptual model and the prototype. These conclusions also indicate future directions of research and development work.

Conclusions

The prototype patient simulation system was found to be realistic and useful to medical students. This was mainly due the following features incorporated in the prototype:

- the patient's condition changed as a result of the physician's actions and due to the passing of time,
- the entire medical decision making process, involving both the diagnostic and treatment phases, was modelled,
- the opportunity to correct previous incorrect actions was provided, and
- the treatment and diagnostic phases began at the same time, as it would in the true case management.

Therefore, the prototype is realistic in that it captures many of the necessary elements which were identified in the literature review.

For these reasons, the research question posed for this study - Can patient simulation systems be made more effective in supporting the training of medical students in medical decision making? - was answered in the affirmative.

An affirmative answer indicates that the same model and prototype structure can be used to represent other patient cases. Although it may seem that the results of this study can only be used by those who are studying patient simulation of pediatric patients (children), the conceptual model and the prototype it is implemented in are flexible enough to represent patients of any kind. The results are generalizable to other cases.

Although they are generalizable, the results of the study are limited in one aspect. They may be questioned as only one physician acted as a source of expertise and as the evaluator of the prototype. It would have been advisable to use multiple sources of knowledge and have a multi-expert evaluation of the prototype in order to better substantiate the study's results. However, due to resource and time limitations, this was not possible. Nonetheless, the results of the study are still of value as they prove that better support of the development of medical decision making skills is possible.

The study is useful to other researchers in showing how the process of model development and implementation may be performed. The process occurred within the action research methodology, which was followed in the study. The methodology

structured and directed study, which the researcher found very useful. The study ended in giving directions for future research and prototype development.

The Future

The results of this study indicated future directions in the enhancements to the system and other areas of research which may be undertaken.

A key enhancement to the prototype would be the addition of a user interface to NEGOPLAN. This would improve the interaction between the medical student and the simulation system. The interface should use: a mouse, pull-down menus, icons, etc., in order to make it more user friendly (Linton and Willcutt, 1985). A menu-driven user interface is also suggested (Hudson and Cohen, 1985).

The addition of a library of cases, with a variety of conditions and patients, should be made. The medical student can then select cases to be simulated, gaining experience with a range of diagnostic situations.

The current prototype could also be combined with a scoring mechanism, forming an "automated tester". However, such a system would be more of an aid to the teaching physician than aiding in the student's learning (Diserens et al, 1986). An automated tester may be converted into a self-assessment system in which the student can assess their own decision making skills (Kossekkova, Vrabchev, Sirakov, 1989; Goldman, 1990), making it useful to both the teaching physician and the medical student.

Any of these future directions may be undertaken following the action research methodology and continuing the research in medical decision making.

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APPENDIX A

Session Form

Session Interview One

Format Phone

Objectives

1. Identify the research problem.
2. Describe the nature of the research project for thesis purposes.
3. Introduce researcher.

Results

1. Research Problem.

Physician finds currently available computer-based aids to teaching diagnosis and patient management to be inadequate because they:

- do not present patient cases realistically, and
- are too simplistic in that they do not permit correcting past mistakes.

Session Form

Session Interview Two

Format Phone

Objectives

1. Exchange of needs.

Researcher wishes that:

- physician be available for consultation on the development of a conceptual model. The number of interviews necessary for this is unknown.
- physician be available for evaluation of the prototype patient simulation system. If time permits, at least one other physician be available for the evaluation.
- If time permits, a medical student or resident be made available for evaluation of prototype patient system.

2. Determine expert's view of the problem.

Results

1. Exchange of needs.

Physician agrees to:

- be available for consultation on the development of a conceptual model,
- to evaluate the model and its implementation, and
- be the external member on examination committee.

Physician is doubtful of whether another physician, medical student, or resident can be made available for the evaluation of the prototype.

Researcher agrees to:

- develop a conceptual model of medical diagnostic environment,
- implement model in a computer prototype, and
- disclose research results to the physician.

2. Expert's view of the problem.

Physician is under the impression that research will result in a fully implemented system. Informed that a full system development and system is beyond the scope of such a research project. Physician understands and agrees.

Session Form

Session Interview Three

Format In person, CHEO

Objectives

1. Gain idea of key concepts and their relationships.
2. Form initial "map" of the problem.

Results

1. Example case problem: ill infant suffering from bacterial infection of intestinal tract.
2. Map of key concepts in problem environment:

3. Preliminary graphical representation of diagnostic problem:

Session Form

Session Interview Four

Format In person, CHEO

Objectives

1. Review of key concepts and their relationships from preliminary graph of problem and sketch.

Results

1. Refinement of the main knowledge structures and the reasoning pathways used.

(Worksheet attached.)

THE CASE OF THE ILL BABY

The knowledge obtained from the physician is classified into four sections: symptoms, actions, diagnosis and treatment, responses to treatment. One should progress from the general symptoms to the patient's responses to treatments. In each section, several actions are described, generally they are diagnostic tests and examinations, and the results of these actions are given.

SYMPTOMS

1. General Symptoms:

vomiting
fever
loss of weight
diarrhoea
irritability
refusal to eat

2. Time Period

ACTIONS

1. Examination of Patient History

age of patient: less than one year
weight loss: acute

2. General Exam

1. behaviour: normal, little drowsiness
2. weight: abnormal
3. pulse/blood pressure: abnormal
IF blood pressure is high THEN pulse is high and abnormal.
4. respiration: normal

5. head size/fontanel (soft spot): normal
IF fontanel is enlarged THEN head size is abnormal.
6. hydration: abnormal
7. temperature: abnormal
8. skin rash: none

[Actions 1 and 2 lead to a preliminary diagnosis 95% of the time.]

3. Interim Treatments

[for short term]

1. re-hydrate patient
IF hydration is not done THEN patient will die.
2. change diet
3. hospitalize

Other options for short term treatments:

4. do nothing (observe)

4. General Tests

1. blood count - red cells (haemoglobin): normal
 - white cells: normal
 - cell smear: normal
2. urine analysis - blood: none
 - sugar: none
 - ketones: some
IF ketones in urine THEN acute nutritional problem.
 - proteins: none

[Move to determination of specific diagnosis.]

5. Specific Exam

1. re-examine patient history and existing symptoms
2. choose body system for further investigation
 - a) gastro-intestinal system
[Correct selection of a body system for investigation]
patient history - family members
 - changes in diet
 - contact with someone with similar symptomsphysical - severity of symptoms
 - no. of times passed urine
IF passed 5 times/day THEN normal
IF passed < 5 times/day THEN abnormal
 - abdomen - tenderness
 - increased intestinal sounds
 - rectal exam - diarrhoea
 - blood in stool
 - pus in stool
 - mucous in stool

b) neurological system

[Incorrect system for investigation for this example.]

patient history - unusual movements

physical - menengerial irritation (neck stiffening): no

- raised intracranial pressure (large head/

bulging fontanel): no

- nerve malfunctioning - eye movements: normal

- size of pupils: norm

- face: normal

[Change in time: 5 minutes with no change in patient's condition.]

6. Specific Tests**1. stool - blood**

- pus

- bacterial cultures

- parasites

2. blood - bacterial culture**DIAGNOSIS AND TREATMENTS****1. IF diagnosis is virus THEN**

-continuation of interim treatments

-isolation of patient

-reporting to health authorities

2. IF diagnosis is bacterial culture THEN

-if in stool, then continue interim treatments

-if in blood culture, then intravenous antibiotics

3. IF diagnosis is parasite THEN

-prescribe specific oral medication

RESPONSES TO TREATMENTS**1. symptoms alleviated, patient better/cured**

actions: none

[Main goal is achieved.]

2. symptoms continue

actions:

1. endoscopy

2. biopsy

3. rerun specific tests (stool and blood)

IF all negative test results OR biopsy suggests histology

THEN diagnosis is chronic inflammatory bowel disease

actions: follow a specific treatment plan for this

Worksheet

Case of Ill Infant

1. Baby's initial symptoms

2. Actions for Diagnosis

Responses

3. Actions for Treatment

Responses

Session Form

Session Interview Five

Format Phone

Objectives

1. Review some ambiguities in knowledge.

Results

1. Refinement of the acquired knowledge.

6. Specific Tests

1. stool - blood
 - pus
 - bacterial cultures
 - parasites
2. blood - bacterial culture

DIAGNOSIS AND TREATMENTS

1. IF pus in stool THEN diagnosis is virus
IF diagnosis is virus THEN
 - continuation of interim treatments
 - isolation of patient
 - reporting to health authorities
2. IF bacterial culture and no pus in stool THEN diagnosis is bacterial infection of intestinal tract
IF diagnosis is bacterial infection of intestinal tract THEN
 - continue interim treatments
3. IF bacterial culture in blood THEN diagnosis is bacterial infection of other system
IF diagnosis is bacterial infection of other system THEN
 - intravenous antibiotics
4. IF diagnosis is parasite THEN
 - prescribe specific oral medication

Session Form

Session Interview Six

Format In person, CHEO

Objectives

1. To evaluate the conceptual model and its implementation.

Results

1. Correction of actions.

In the start of the session, it was recommended that the interim treatments should be combined with the examination of patient history, general examination, general tests. The reason for this is that in proper case management, the treatment and diagnostic phases should begin at the same time.

2. Corrections of terms.

Several incorrect actions were temporary labels in the original prototype. Actual actions were suggested and the changes were made to the prototype.

APPENDIX B

Model Scenarios

The scenarios presented here represent the possible paths of case management through the diagnosis and treatment phases. In each scenario, the representation includes the responses regarding the patient's condition which are represented in the rectangle:

At the end of each scenario there are instructions as to which is the next scenario to move. These instructions are in the following format:

{ Problem continues to Scenario 5. }

Scenario 1 **Rules:**

goal <- look.
goal <- dont_look.

GS:

goal ::= true.
dont_look ::= true.

Patient Responses to Physician's Actions

physician: dont_look ::= true
=>
patient: patient_condition_unknown ::= true.

Environment Responses

None

Modifications

physician: dont_look ::= true
=>
modify (goal <- failure).

{Problem continues to Scenario 5.}
{If this solution is rejected, problem continues to
Scenario 2.}

Scenario 2 **Rules:**

```

goal <- look.
goal <- dont_look.

```

GS:

```

goal ::= true.
look ::= true.

```

Patient Responses to Physician's Actions

```

physician: look ::= true
=>
patient:   patient_condition_ill ::= true.

```

Environment Responses

```

symptom_vomiting ::= true.
symptom_fever ::= true.
symptom_weight loss ::= true.
symptom_diarrhoea ::= true.

```

Modifications

```

physician: look ::= true and
patient:   patient_condition_ill ::= true
=>
modify
(goal <- preliminary_diagnosis

```

```

preliminary_diagnosis <-

```

```

[
  patient history
  general examination
  general tests
  interim treatments
]

```

```

preliminary_diagnosis <- consult_physician

```

```

{ Problem continues to Scenario 3. }

```

Scenario 3 **Rules:**

goal <- preliminary_diagnosis.
 preliminary_diagnosis <- consult_specialist.

preliminary_diagnosis <- [patient history
 general examination
 general tests
 interim treatments]

GS:

goal ::= true.
 preliminary_diagnosis ::= true.

[patient history
 general examination
 general tests
 interim treatments] ::= true.

Patient Responses to Physician's Actions

physician: [patient history
 general examination
 general tests
 interim treatments] ::= true and

patient: patient_condition_ill ::= true
 =>
 patient: patient_condition_stable ::= true.

Environment Responses**In the patient history :**

acute weight loss ::= true.

In the general examination :

the behaviour is normal with some drowsiness ::= true.

the weight is normal ::= false.

the pulse is increased ::= true.

the blood pressure is decreased ::= true.

the head size is normal ::= true.

the fontanel is abnormal ::= true.

the hydration is normal ::= false.

the temperature is high ::= true.

the skin is normal ::= true.

In the blood test :

the red cells count is normal ::= true.

the white cells count is elevated ::= true.

the cell smear is normal ::= true.

In the urine analysis :

there is a presence of sugar ::= false.

there is a presence of ketones ::= true.

there is a presence of proteins ::= false.

there is a presence of red blood cells ::= false.

there is a presence of white blood cells ::= false.

Modifications

physician:

patient history
general examination
general tests
interim treatments

::= true and

patient: patient_condition_stable ::= true

=>

modify

(specific_diagnosis <-

examination of gastrointestinal system with specific tests

specific_diagnosis <-

examination of neurological system with specific tests

).

{ Problem continues to Scenario 6. }

{ If this solution is rejected, the problem continues to Scenario 4. }

Scenario 4 **Rules:**

```

goal <- preliminary_diagnosis.
preliminary_diagnosis <- consult_specialist.

```

```

preliminary_diagnosis <-
  patient history
  general examination
  general tests
  interim treatments

```

GS:

```

goal ::= true.
preliminary_diagnosis ::= true.
consult_specialist ::= true.

```

Patient Responses to Physician's Actions

```

physician: consult_specialist ::= true and
patient: patient_condition_ill ::= true
=>
patient: patient_condition_worse ::= true.

```

Environment Responses

None

Modifications

```

physician: consult_specialist ::= true and
patient: patient_condition_worse ::= true
=>
modify (goal <- failure).

```

{Problem continues to Scenario 5.}

Scenario 5

Rules:

goal <- failure.

GS:

goal ::= true.
failure ::= true.

Patient Responses to Physician's Actions

None

Environment Responses

None

Modifications

physician: failure ::= true
=>
end_of_session.

Scenario 6 **Rules:**

goal <- specific_diagnosis.

specific_diagnosis <-

examination of
gastrointestinal
system with
specific tests

specific_diagnosis <-

examination of
neurological
system with
specific tests

GS:

goal ::= true.

specific_diagnosis ::= true.

examination of
gastrointestinal
system with
specific tests

::= true.

Patient Responses to Physician's Actions

physician:

examination of
gastrointestinal
system with
specific tests

::= true and

patient: patient_condition_stable ::= true

=>

patient: patient_condition_better ::= true.

Environment Responses**Re-examination of medical history :**

other family members displayed similar symptoms ::= false.
 family history of some gastrointestinal disorder ::= false.
 recent changes in diet ::= false.
 contact with someone else with similar symptoms ::= false.

In the physical examination :

the number of times urine is passed per day is normal ::= true.
 the abdomen is tender and there is an increase in the
 intestinal sounds ::= true.

In the rectal exam :

there is a presence of diarrhoea ::= true.
 there is a presence of blood ::= false.
 there is a presence of mucous ::= false.
 there is a presence of pus ::= false.

In the specific stool tests :

there is a presence of blood ::= false.
 there is a presence of bacterial cultures ::= false.
 there is a presence of pus ::= false.
 there is a presence of parasites ::= false.
 there is a presence of virus ::= true.

In the specific blood tests :

the white cell count is elevated ::= true.
 there is a presence of bacterial cultures ::= false.

Modifications

physician: examination of
gastrointestinal
system with
specific tests ::= true and

patient: patient_condition_better ::= true
 =>

modify

(goal <- specific_diagnosis

specific_diagnosis <- diagnose
infection of
intestinal tract

specific_diagnosis <- examination of
neurological
system with
specific tests).

{Problem continues to Scenario 8.}

{If this solution is rejected, problem continues to
 Scenario 7.}

Scenario 7 **Rules:**

goal <- specific_diagnosis.

specific_diagnosis <- [examination of gastrointestinal system with specific tests]

specific_diagnosis <- [examination of neurological system with specific tests]

GS:

goal ::= true.
specific_diagnosis ::= true.

[examination of neurological system with specific tests] ::= true.

Patient Responses to Physician's Actions

physician: [examination of neurological system with specific tests] ::= true and

patient: patient_condition_stable ::= true
=>

patient: patient_condition_worse ::= true.

Environment Responses**Re-examination of medical history :**

unusual facial or limb movements ::= true.

In the physical examination :

neck stiffness ::= false.

raised intracranial pressure ::= false.

the eye movements are normal ::= true.

the size of pupils are normal ::= true.

the face appears to be normal ::= true.

In the specific stool tests :

there is a presence of blood ::= false.

there is a presence of bacterial cultures ::= false.

there is a presence of pus ::= false.

there is a presence of parasites ::= false.

there is a presence of virus ::= true.

In the specific blood tests :

the white cell count is elevated ::= true.

there is a presence of bacterial cultures ::= false.

Modifications

physician: examination of
neurological
system with
specific tests ::= true and

patient: patient_condition_better ::= true

=>

modify

(goal <- specific_diagnosis

specific_diagnosis <- examination of
gastrointestinal
system with
specific tests

specific_diagnosis <- diagnose
infection of
neurological
system).

{ Problem continues to Scenario 10. }

Scenario 8 **Rules:**

goal <- specific_diagnosis.

specific_diagnosis <-

diagnose
infection of
intestinal tract

specific_diagnosis <-

examination of
neurological
system with
specific tests

GS:

goal ::= true.

specific_diagnosis ::= true.

diagnose
infection of
intestinal tract ::= true.

Patient Responses to Physician's Actions

physician: diagnose
infection of
intestinal tract ::= true and

patient: patient_condition_better ::= true

=>

patient: patient_condition_better ::= true.

Environment Responses

None

Modifications

physician:

diagnose infection of intestinal tract
--

 ::= true and

patient: patient_condition_better ::= true

=>

modify

(goal <- treatment

treatment <-

re-hydration continued hospitalization resumption of solids and liquids
--

treatment <- intravenous_treatment).

{Problem continues to Scenario 12.}

{If this solution is rejected, problem continues to
Scenario 9.}

Scenario 9 **Rules:**

goal <- specific_diagnosis.

specific_diagnosis <- [diagnose infection of intestinal tract]

specific_diagnosis <- [examination of neurological system with specific tests]

GS:

goal ::= true.
specific_diagnosis ::= true.

[examination of neurological system with specific tests] ::= true.

Patient Responses to Physician's Actions

physician: [examination of neurological system with specific tests] ::= true and

patient: patient_condition_better ::= true
=>

patient: patient_condition_worse ::= true.

Environment Responses**Re-examination of medical history :**

unusual facial or limb movements ::= true.

In the physical examination :

neck stiffness ::= false.

raised intracranial pressure ::= false.

the eye movements are normal ::= true.

the size of pupils are normal ::= true.

the face appears to be normal ::= true.

In the specific stool tests :

there is a presence of blood ::= false.

there is a presence of bacterial cultures ::= false.

there is a presence of pus ::= false.

there is a presence of parasites ::= false.

there is a presence of virus ::= true.

In the specific blood tests :

the white cell count is elevated ::= true.

there is a presence of bacterial cultures ::= false.

Modifications

physician:

examination of neurological system with specific tests

 ::= true and

patient: patient_condition_worse ::= true

=>

modify

(goal <- specific_diagnosis

specific_diagnosis <-

diagnose infection of neurological system
--

specific_diagnosis <-

diagnose infection of intestinal tract
--

).

{ Problem continues to Scenario 14. }

Rules:

```
goal <- specific_diagnosis.
```

```
specific_diagnosis <- [examination of gastrointestinal system with specific tests]
```

```
specific_diagnosis <- [diagnose infection of neurological system]
```

GS:

```
goal ::= true.
specific_diagnosis ::= true.
```

```
[examination of gastrointestinal system with specific tests] ::= true.
```

Patient Responses to Physician's Actions

```
physician: [examination of gastrointestinal system with specific tests] ::= true and
```

```
patient: patient_condition_worse ::= true
=>
patient: patient_condition_better ::= true.
```

Environment Responses**Re-examination of medical history :**

other family members displayed similar symptoms ::= false.
 family history of some gastrointestinal disorder ::= false.
 recent changes in diet ::= false.
 contact with someone else with similar symptoms ::= false.

In the physical examination :

the number of times urine is passed per day is normal ::= true.
 the abdomen is tender and there is an increase in the
 intestinal sounds ::= true.

In the rectal exam :

there is a presence of diarrhoea ::= true.
 there is a presence of blood ::= false.
 there is a presence of mucous ::= false.
 there is a presence of pus ::= false.

In the specific stool tests :

there is a presence of blood ::= false.
 there is a presence of bacterial cultures ::= false.
 there is a presence of pus ::= false.
 there is a presence of parasites ::= false.
 there is a presence of virus ::= true.

In the specific blood tests :

the white cell count is elevated ::= true.
 there is a presence of bacterial cultures ::= false.

Modifications

physician:

examination of gastrointestinal system with specific tests

 ::= true and

patient: patient_condition_better ::= true
 =>

modify
 (goal <- specific_diagnosis

specific_diagnosis <-

diagnose infection of intestinal tract
--

specific_diagnosis <-

diagnose infection of neurological system
--

).

{ Problem continues to Scenario 16. }

{ If this solution is rejected, problem continues to
 Scenario 11. }

Rules:

goal <- specific_diagnosis.

specific_diagnosis <- [examination of gastrointestinal system with specific tests]

specific_diagnosis <- [diagnose infection of neurological system]

GS:

goal ::= true.
specific_diagnosis ::= true.

[diagnose infection of neurological system] ::= true.

Patient Responses to Physician's Actions

physician: [diagnose infection of neurological system] ::= true and

patient: patient_condition_worse ::= true
=>

patient: patient_condition_worse ::= true.

Environment Responses

None

Modifications

```
physician: [diagnose  
            infection of  
            neurological  
            system] ::= true and  
patient:    patient_condition_worse ::= true  
=>  
modify (goal <- error).
```

{Problem continues to Scenario 20.}

Scenario 12 **Rules:**

goal <- treatment.

treatment <-

re-hydration
continued hospitalization
resumption of solids and
liquids

treatment <- intravenous_treatment.

GS:

goal ::= true.

treatment ::= true.

re-hydration
continued hospitalization
resumption of solids and
liquids

::= true.

Patient Responses to Physician's Actions

physician:

re-hydration
continued hospitalization
resumption of solids and
liquids

::= true and

patient: patient_condition_better ::= true

=>

patient: patient_condition_better ::= true.

Environment Responses

None

Modifications

physician:

re-hydration continued hospitalization resumption of solids and liquids
--

 ::= true and

patient: patient_condition_better ::= true
=>
modify (goal <- success).

{ Problem continues to Scenario 21. }
{ If this solution is rejected, problem continues
to Scenario 13. }

Scenario 13 **Rules:**

goal <- treatment.

treatment <-

re-hydration
continued hospitalization
resumption of solids and
liquids

treatment <- intravenous_treatment.

GS:

goal ::= true.

treatment ::= true.

intravenous_treatment ::= true.

Patient Responses to Physician's Actions

physician: intravenous_treatment ::= true and

patient: patient_condition_better ::= true

=>

patient: patient_condition_worse ::= true.

Environment Responses

None

Modifications

physician: intravenous_treatment ::= true and

patient: patient_condition_worse ::= true

=>

modify

(goal <- treatment

treatment <-	[	re-hydration	]
		continued hospitalization	
		resumption of solids and	
		liquids	

reatment <- antibiotic_treatment).

{Problem continues to Scenario 18.}

Scenario 14 **Rules:**

goal <- specific_diagnosis.

specific_diagnosis <- [diagnose infection of intestinal tract]

specific_diagnosis <- [diagnose infection of neurological system]

GS:

goal ::= true.

specific_diagnosis ::= true.

[diagnose infection of intestinal tract] ::= true.

Patient Responses to Physician's Actions

physician: [diagnose infection of intestinal tract] ::= true and

patient: patient_condition_worse ::= true

=>

patient: patient_condition_better ::= true.

Environment Responses

None

Modifications

```
physician: [ diagnose  
             infection of  
             intestinal tract ] ::= true and  
  
patient:   patient_condition_worse ::= true  
=>  
modify  
( goal <- treatment  
  treatment <- [ re-hydration  
                 continued hospitalization  
                 resumption of solids and  
                 liquids ]  
  
  treatment <- intravenous_treatment ).
```

```
{Problem continues to Scenario 12.}  
{If this solution is rejected, problem continues  
to Scenario 15.}
```

Scenario 15 **Rules:**

goal <- specific_diagnosis.

specific_diagnosis <- [diagnose infection of intestinal tract]

specific_diagnosis <- [diagnose infection of neurological system]

GS:

goal ::= true.

specific_diagnosis ::= true.

[diagnose infection of neurological system] ::= true.

Patient Responses to Physician's Actions

physician: [diagnose infection of neurological system] ::= true and

patient: patient_condition_worse ::= true

=>

patient: patient_condition_worse ::= true.

Environment Responses

None

Modifications

physician:

diagnose infection of neurological system
--

 ::= true and

patient: patient_condition_worse ::= true
=>
modify (goal <- error).

{Problem continues to Scenario 20.}

Scenario 16 **Rules:**

goal <- specific_diagnosis.

specific_diagnosis <- [diagnose infection of intestinal tract]

specific_diagnosis <- [diagnose infection of neurological system]

GS:

goal ::= true.

specific_diagnosis ::= true.

[diagnose infection of intestinal tract] ::= true.

Patient Responses to Physician's Actions

physician: [diagnose infection of intestinal tract] ::= true and

patient: patient_condition_better ::= true

=>

patient: patient_condition_better ::= true.

2

PIONEERS IN METHYLENE BLUE TESTING SINCE 1974

Micro-P

10000 COUNTY ROAD 6, DUFFELVILLE, OH 44027 USA
TEL 012 420 7007 FAX 012 420 7007 TLE 8000000000

Environment Responses

None

Modifications

```
physician: [diagnose
             infection of
             intestinal tract] ::= true and
patient:   patient_condition_better ::= true
=>
modify
(goal <- treatment
 treatment <- [re-hydration
               continued hospitalization
               resumption of solids and
               liquids]
 treatment <- intravenous_treatment ).
```

```
{Problem continues to Scenario 12.}
{If this solution is rejected, problem continues
to Scenario 17.}
```

Scenario 17 **Rules:**

goal <- specific_diagnosis.

specific_diagnosis <- [diagnose infection of intestinal tract]

specific_diagnosis <- [diagnose infection of neurological system]

GS:

goal ::= true.

specific_diagnosis ::= true.

[diagnose infection of neurological system] ::= true.

Patient Responses to Physician's Actions

physician: [diagnose infection of neurological system] ::= true and

patient: patient_condition_better ::= true
=>

patient: patient_condition_worse ::= true.

Environment Responses

None

Modifications

```
physician: [diagnose
             infection of
             neurological
             system] ::= true and
patient:    patient_condition_worse ::= true
=>
modify ( goal <- error ).
```

{Problem continues to Scenario 20.}

Scenario 18 **Rules:**

goal <- treatment.

treatment <-

re-hydration
continued hospitalization
resumption of solids and
liquids

treatment <- antibiotic_treatment

GS:

goal ::= true.

treatment ::= true.

re-hydration
continued hospitalization
resumption of solids and
liquids ::= true.

Patient Responses to Physician's Actions

physician: re-hydration
continued hospitalization
resumption of solids and
liquids ::= true and

patient: patient_condition_worse ::= true

=>

patient: patient_condition_better ::= true.

Environment Responses

None

Modifications

```
physician: [ re-hydration
              continued hospitalization
              resumption of solids and
              liquids ] ::= true and

patient:  patient_condition_better ::= true
=>
modify ( goal <- success ).
```

```
{Problem continues to Scenario 21.}
{If this solution is rejected, problem continues
to Scenario 19.}
```


Scenario 19 **Rules:**

goal <- treatment.

treatment <-

re-hydration
continued hospitalization
resumption of solids and
liquids

treatment <- antibiotic_treatment

GS:

goal ::= true.

treatment ::= true.

antibiotic_treatment ::= true.

Patient Responses to Physician's Actions

physician: antibiotic_treatment ::= true and

patient: patient_condition_worse ::= true

=>

patient: patient_condition_worse ::= true.

Environment Responses

None

Modifications

physician: antibiotic_treatment ::= true and

patient: patient_condition_worse ::= true

=>

modify (goal <- specialist).

{Problem continues to Scenario 22.}

Scenario 20

goal
 \
 success

Rules:

goal <- success.

GS:

goal ::= true.
success ::= true.

Patient Responses to Physician's Actions

None

Environment Responses

None

Modifications

physician: success ::= true
=>
end_of_session.

Scenario 21

goal
\
error

Rules:

goal <- error.

GS:

goal ::= true.
error ::= true.

Patient Responses to Physician's Actions

None

Environment Responses

None

Modifications

physician: error ::= true
=>
end_of_session.

Scenario 22

goal
 \
specialist

Rules:

goal <- specialist.

GS:

goal ::= true.
specialist ::= true.

Patient Responses to Physician's Actions

None

Environment Responses

None

Modifications

physician: specialist ::= true
=>
end_of_session.

APPENDIX C

The Knowledge Base

Note: The subgoals labelled with double letters, such as xx, jj, cc, etc., are used to force the reasoning process to follow certain paths. Additional comments are added to the rule base, enclosed in curly brackets {}.

Abbreviations Used:

look - start examination of patient

dont_look - dont start examination of patient

gen_exam_tests - patient history, general examination, and general tests combined with interim treatments (rehydration, changing diet, and hospitalization)

consult_specialist - a consultation with a specialist

gi_exam - examination of the gastrointestinal system with specific tests

neuro_exam - examination of the neurological system with specific tests

diag_bac_inf_intestinal_tract - diagnose patient as having a bacterial infection of the intestinal tract

diag_inf_neuro_sys - diagnose patient as having an infection in the neurological system

combo_treatment - combination of rehydration, changing patient's diet, and continued hospitalization

iv_treatment - giving patient an intravenous treatment

antibiotic_treatment - giving patient antibiotics

p_diag - preliminary diagnosis

s_diag - specific diagnosis

pt_condition_unknown - condition of patient is unknown

pt_condition_ill - condition of patient is ill

pt_condition_stable - condition of patient is stable

pt_condition_better - condition of patient is better

pt_condition_worse - condition of patient is worse

failure - the actions taken have resulted in failure to examine the patient correctly

error - the actions taken have resulted in incorrect diagnosis or treatment of patient

success - the actions taken have resulted in the correct diagnosis and treatment of patient

specialist - the actions taken have resulted in the incorrect diagnosis or treatment of patient

stop - ends the session

The Rules

rules

physician: goal <- look;
physician: goal <- dont_look;

sides patient, environment;

response

{patient responses}

if physician: look = true
=> patient: pt_condition_ill := true.

if physician: dont_look = true
=> patient: pt_condition_unknown := true.

if physician: p_diag = true and
physician: gen_exam_tests = true and
patient: pt_condition_ill = true
=> patient: pt_condition_stable := true.

if physician: p_diag = true and
physician: consult_specialist = true and
patient: pt_condition_ill = true
=> patient: pt_condition_worse := true.

if physician: gen_exam_tests = true and
physician: gi_exam = true and
patient: pt_condition_stable = true
=> patient: pt_condition_better := true.

if physician: gen_exam_tests = true and
physician: neuro_exam = true and
patient: pt_condition_stable = true
=> patient: pt_condition_worse := true.

if physician: gi_exam = true and
physician: diag_inf_intestinal_tract = true and
physician: ee = true and

```
patient: pt_condition_better = true
=> patient: pt_condition_better := true.

if physician: gi_exam = true and
  physician: neuro_exam = true and
  physician: dd = true and
  patient: pt_condition_better = true
=> patient: pt_condition_worse := true.

if physician: neuro_exam = true and
  physician: gi_exam = true and
  physician: cc = true and
  patient: pt_condition_worse = true
=> patient: pt_condition_better := true.

if physician: neuro_exam = true and
  physician: diag_inf_neuro_sys = true and
  physician: jj = true and
  patient: pt_condition_worse = true
=> patient: pt_condition_worse := true.

if physician: diag_inf_intestinal_tract = true and
  physician: combo_treatment = true and
  patient: pt_condition_better = true
=> patient: pt_condition_better := true.

if physician: diag_inf_intestinal_tract = true and
  physician: iv_treatment = true and
  patient: pt_condition_better = true
=> patient: pt_condition_worse := true.

if physician: neuro_exam = true and
  physician: diag_inf_intestinal_tract = true and
  patient: pt_condition_worse = true
=> patient: pt_condition_better := true.

if physician: neuro_exam = true and
  physician: diag_inf_neuro_sys = true and
  physician: yy = true and
  patient: pt_condition_worse = true
=> patient: pt_condition_worse := true.

if physician: gi_exam = true and
  physician: diag_inf_intestinal_tract = true and
  physician: xx = true and
  patient: pt_condition_better = true
=> patient: pt_condition_better := true.

if physician: gi_exam = true and
  physician: diag_inf_neuro_sys = true and
  patient: pt_condition_better = true
=> patient: pt_condition_worse := true.
```

```

if physician: iv_treatment = true and
  physician: combo_treatment = true and
  patient: pt_condition_worse = true
=> patient: pt_condition_better := true.

```

```

if physician: iv_treatment = true and
  physician: antibiotic_treatment = true and
  patient: pt_condition_worse = true
=> patient: pt_condition_worse := true.

```

{environment responses}

```

if physician: look = true
=> environment: symptom_vomiting := true;
  environment: symptom_fever := true;
  environment: symptom_weight_loss := true;
  environment: symptom_diarrhoea := true.

```

```

if physician: gen_exam_tests = true
=> environment: pt_history_acute_weight_loss := true;
  environment: behaviour_normal := true;
  environment: weight_normal := false;
  environment: pulse_increased := true;
  environment: blood_pressure_decreased := true;
  environment: head_size_normal := true;
  environment: fontanel_normal := false;
  environment: hydration_normal := false;
  environment: temperature_normal := false;
  environment: skin_normal := true;
  environment: blood_red_cells_count_normal := true;
  environment: blood_white_cells_count_elevated := true;
  environment: blood_cell_smear_normal := true;
  environment: urine_presence_of_sugar := false;
  environment: urine_presence_of_ketones := true;
  environment: urine_presence_of_proteins := false;
  environment: urine_presence_of_red_blood_cells := false;
  environment: urine_presence_of_white_blood_cells := false.

```

```

if physician: gi_exam = true
=> environment: pt_history_other_family := false;
  environment: pt_history_family_history := false;
  environment: pt_history_changes_in_diet := false;
  environment: pt_history_contact_with_others := false;
  environment: phys_exam_times_urine_passed_normal := true;
  environment: phys_exam_abdomen_tender := true;
  environment: phys_exam_intestinal_sounds_increased := true;
  environment: rectal_exam_diarrhoea := true;
  environment: rectal_exam_blood := false;
  environment: rectal_exam_mucous := false;
  environment: rectal_exam_pus := false;

```



```

environment: stool_presence_of_blood := false;
environment: stool_presence_of_bac_cultures := false;
environment: stool_presence_of_pus := false;
environment: stool_presence_of_parasites := false;
environment: stool_presence_of_virus := true;
environment: blood_white_cell_count_elevated := true;
environment: blood_presence_of_bac_cultures := false.

```

```

if physician: neuro_exam = true
=> environment: pt_history_unusual_facial_or_limb_movements := false;
environment: phys_exam_neck_stiffness := false;
environment: phys_exam_raised_intracranial_pressure := false;
environment: phys_exam_eye_movements_normal := true;
environment: phys_exam_pupils_size_normal := true;
environment: phys_exam_face_normal := true;
environment: stool_presence_of_blood := true;
environment: stool_presence_of_bac_cultures := true;
environment: stool_presence_of_pus := false;
environment: stool_presence_of_parasites := false;
environment: stool_presence_of_virus := true;
environment: blood_white_cell_count_elevated := true;
environment: blood_presence_of_bac_cultures := false.

```

{modification rules}

```

if physician: look = true and
patient: pt_condition_ill = true
=> replace goal <- p_diag;
add p_diag <- gen_exam_tests;
add p_diag <- consult_specialist.

if physician: dont_look = true and
patient: pt_condition_unkown = true
=> replace goal <- failure.

if physician: p_diag = true and
physician: gen_exam_tests = true and
patient: pt_condition_stable = true
=> replace goal <- s_diag;
add s_diag <- gen_exam_tests;
add gen_exam_tests <- gi_exam;
add gen_exam_tests <- neuro_exam.

if physician: p_diag = true and
physician: consult_specialist = true and
patient: pt_condition_ill = true
=> replace goal <- failure.

if physician: gen_exam_tests = true and
physician: gi_exam = true and
patient: pt_condition_stable = true

```

```
=> replace goal <- s_diag;  
add s_diag <- gi_exam;  
add gi_exam <- ee;  
add gi_exam <- dd;  
add ee <- diag_inf_intestinal_tract;  
add dd <- neuro_exam.
```

```
if physician: gen_exam_tests = true and  
physician: neuro_exam = true and  
patient: pt_condition_worse = true  
=> replace goal <- s_diag;  
add s_diag <- neuro_exam;  
add neuro_exam <- cc;  
add neuro_exam <- jj;  
add cc <- gi_exam;  
add jj <- diag_inf_neuro_sys.
```

```
if physician: gi_exam = true and  
physician: diag_inf_intestinal_tract = true and  
physician: ee = true and  
patient: pt_condition_better = true  
=> replace goal <- treatment;  
add treatment <- diag_inf_intestinal_tract;  
add diag_inf_intestinal_tract <- combo_treatment;  
add diag_bac_inf_intestinal_tract <- iv_treatment.
```

```
if physician: gi_exam = true and  
physician: neuro_exam = true and  
physician: dd = true and  
patient: pt_condition_worse = true  
=> replace goal <- s_diag;  
add s_diag <- diag_inf_intestinal_tract;  
add s_diag <- yy;  
add yy <- diag_inf_neuro_sys.
```

```
if physician: neuro_exam = true and  
physician: gi_exam = true and  
physician: cc = true and  
patient: pt_condition_better = true  
=> replace goal <- s_diag;  
add s_diag <- gi_exam;  
add gi_exam <- xx;  
add gi_exam <- diag_inf_neuro_sys;  
add xx <- diag_inf_intestinal_tract.
```

```
if physician: neuro_exam = true and  
physician: diag_inf_neuro_sys = true and  
physician: jj = true and  
patient: pt_condition_worse = true  
=> replace goal <- error.
```

```
if physician: diag_inf_intestinal_tract = true and
  physician: combo_treatment = true and
  patient: pt_condition_better = true
=> replace goal <- success.
```

```
if physician: diag_inf_intestinal_tract = true and
  physician: iv_treatment = true and
  patient: pt_condition_worse = true
=> replace goal <- treatment;
  add treatment <- iv_treatment;
  add iv_treatment <- combo_treatment;
  add iv_treatment <- antibiotic_treatment.
```

```
if physician: neuro_exam = true and
  physician: diag_inf_intestinal_tract = true and
  patient: pt_condition_better = true
=> replace goal <- treatment;
  add treatment <- diag_inf_intestinal_tract;
  add diag_bac_inf_intestinal_tract <- combo_treatment;
  add diag_bac_inf_intestinal_tract <- iv_treatment.
```

```
if physician: neuro_exam = true and
  physician: diag_inf_neuro_sys = true and
  physician: yy = true and
  patient: pt_condition_worse = true
=> replace goal <- error.
```

```
if physician: gi_exam = true and
  physician: diag_inf_intestinal_tract = true and
  physician: xx = true and
  patient: pt_condition_better = true
=> replace goal <- treatment;
  add treatment <- diag_inf_intestinal_tract;
  add diag_inf_intestinal_tract <- combo_treatment;
  add diag_inf_intestinal_tract <- iv_treatment.
```

```
if physician: gi_exam = true and
  physician: diag_inf_neuro_sys = true and
  patient: pt_condition_worse = true
=> replace goal <- error.
```

```
if physician: iv_treatment = true and
  physician: combo_treatment = true and
  patient: pt_condition_better = true
=> replace goal <- success.
```

```
if physician: iv_treatment = true and
  physician: antibiotic_treatment = true and
  patient: pt_condition_worse = true
=> replace goal <- specialist.
```

{termination conditions}

**if physician: failure = true
=> stop.**

**if physician: error = true
=> stop.**

**if physician: success = true
=> stop.**

**if physician: specialist = true
=> stop.**

END

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FIN