Knowledge Based Solution Strategies in Medical Reasoning

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The techniques of propositional analysis are used to examine the protocols of seven cardiologists in a task involving the diagnosis of a case of acute bacterial endocarditis and an explanation of its underlying pathophysiology. It is shown that the explanations of physicians making an accurate diagnosis can be accounted for in terms of a model consisting of pure forward reasoning through a network of causal rules, actuated by relevant propositions embedded in the stimulus text. These rules appear to derive from the physician's underlying knowledge base rather than any information in the text itself. In contrast, subjects with incorrect diagnoses tend to make use of a mixture of forward and backward reasoning, beginning with a high level hypothesis and proceeding in a top-down fashion to the propositions embedded in stimulus text, or to the generation of irrelevant rules.

Up to now, the study of clinical reasoning in medicine from a cognitive science point of view has had a rather one-sided development. A considerable amount of success has been obtained in the area of expert systems. In contrast, empirical research has yielded little in the way of unambiguous results. In particular, there are major inconsistencies between these results and the well-known results concerning expert performance in other domains of knowledge.

To a great extent, this empirical research has been characterized by a single process notion: that the main approach used in clinical diagnosis is

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some form of hypothesis testing. The pioneer work of Elstein, Shulman, and Sprafka (1978) did establish that physicians appear to generate hypotheses (i.e., tentative diagnoses) very early in the process of solving a diagnostic problem and that the number of hypotheses is very limited. However, this clearcut result was clouded considerably by the fact that no differences were found between experts and relative novices except in the extent of underlying knowledge. Although no formal analysis was made of the protocols, and hence no attempt was made to formulate a precise process model, the analyses that were performed seemed consistent with the notion that some form of hypothesis testing or some form of hypothetico-deductive reasoning was being used. Although the general issue of the use of the hypothetico-deductive method is open to some question (Gale & Marsden, 1983; Groen & Patel, 1985), the finding that experts primarily generate and test hypotheses in the same way as novices is inconsistent with the results that have been obtained in other domains. Studies of problem solving in physics (e.g., Larkin, McDermott, Simon, & Simon, 1980) suggest that experts use a process of forward reasoning based on a highly elaborated representation of the problem. In constrast, novices tend to use processes such as means-ends analysis and generate-and-test that involve backward reasoning. The purpose of the present study is to explore whether the use of precise process models can clarify the issue of when forward and backward reasoning in fact occur in the clinical reasoning of expert physicians.

In the domain of medicine, the number of empirical studies that have used explicit process notions is surprisingly small. Rubin (1975) analysed a set of protocols obtained from experts in a diagnostic task and found that they were consistent with the notion that some form of hypothetico-deductive reasoning was being used. Feltovich (1981) and Johnson et al. (1981), both of whom also worked within the hypothetico-deductive framework, showed that experts differed from novices in the nature of the knowledge base they utilised and also in the kinds of errors they made. Lesgold, Feltovich, Glaser, & Wang (1981) showed that experts have more highly automated perceptual processes than novices. These are the product of more elaborated and flexible schemata that are slowly built up over the course of training. They also showed that expert behavior was characterized by a rapid recognition skill that involves an interaction between lower and higher levels of representation, which was not purely top-down or bottom up. This argues against at least a simple model of the hypothetico-deductive process, which would have to be purely top-down, and also against a purely bottom-up model of hypothesis formation through automatic pattern recognition. This is consistent with the model of the diagnostic process suggested by Clancey’s NEOMYCIN system in which the diagnostic process is mediated by a network of causal rules. Clancey (1985) also takes issue with the hypothetico-deductive model, explicitly showing that data of the
type that Rubin used as evidence for hypothesis testing can be explained by a very different kind of process.

Up to now, this research has been characterized by a lack of an explicit connection between data and processes. Although quite precise process models have sometimes been formulated, the empirical data has been used for suggestive purposes rather than precise empirical tests. One problem seems to be that the Newell-Simon methodology (Newell & Simon, 1972) becomes less applicable in verbally complex situations that depend on a rich knowledge base. This is indicated by the fact that weak sufficiency is no longer such a useful criterion for determining the adequacy of a process model. The Newell-Simon methodology has been extensively and successfully used in the development of expert systems (Hayes-Roth, Waterman, & Lenat, 1983). However, a variety of systems with quite different properties can account for very similar protocols (Clancey, 1984). This may explain a trend in the research which we have cited, toward an empirical method based on answers to probes rather than pure "thinking-aloud" protocols.

Our approach is based on the notion that the weakness of current research lies in the fact that the methods of analysis concentrate on the surface features of complex verbal material. The processes used to solve problems of this level of complexity must include a comprehension process that generates or accesses an appropriate data base. In recent years, a considerable amount of evidence has accumulated which indicates that the techniques of propositional analysis may provide a solution to this problem. Propositional analysis assumes that comprehension deals with units that are not directly representable in terms of surface structure. It provides a set of techniques for generating such units and representing the relationships between them. A number of studies (e.g., Van Dijk & Kintsch, 1983) have shown that propositions correspond to chunks in the sense that the more elementary ones represent units of encoding in long-term and working memory. Although these techniques have primarily been used in the area of reading comprehension, the recent work of Kintsch and Greeno (1983), in the simpler domain of arithmetic word problems, indicates that these techniques are also useful in the direct analysis of problem solving. They use propositional analysis to develop a comprehension model that acts as a front end to a conventional production system.

Our concerns are different, however, from those of Kintsch and Greeno. They were dealing with a well-defined class of relatively simple problems that had been studied for many years and for which a quite well-developed process theory already existed (Riley, Greeno, & Heller, 1982). Their concern was primarily with the comprehension aspect. In contrast, we are dealing with a messy class of complex problems. The controversial issues lie in the nature of the problem-solving processes of expert physicians. Hence, the present study is more concerned with problem solving rather than compre
hension. We also use a different method of propositional representation, developed by Frederiksen (1975, in press). The differences are primarily in the notation used, although Frederiksen's method may have a slightly wider scope and a more precisely defined set of rules.

Some additional support for an approach of this kind in the domain of medicine is indicated by the fact that there has been a tendency in recent research on expert systems towards an extremely precise notation for the underlying conceptual content of verbal protocols. Indeed, the analysis of Kuipers and Kassirer (1984) is not too far removed from our own. There is, however, an important difference: The rules used by these investigators to generate the conceptual representation from the surface structure of the protocol are highly domain specific. In contrast, the rules of propositional analysis are completely general and have been designed to apply in any coherent domain of knowledge. Also, it provides us with a general theory of comprehension and explicit notions of how text and prior knowledge interact (Van Dijk & Kintsch, 1983). The need for such a theory in the analysis of verbal protocols has been emphasized by Ericsson and Simon (1983).

There is also an important empirical reason that stems from our own previous research (Patel & Frederiksen, 1984; Patel, Groen, & Frederiksen, 1986). Greeno and Simon (in press) suggest that there is a close connection between forward reasoning and the enhanced performance in free recall which was first systematically studied by Chase and Simon (1973) in chess and has since been observed in many other areas. Here, too, there is inconsistency between the results obtained in medicine and those obtained in other areas. Norman and his colleagues at McMaster University (Muzzin et al., 1982) conducted a series of experiments that attempted to replicate those of Chase and Simon as closely as possible using a complex verbal task. They obtained differences between experts and novices in chunking but not in recall. In other words, experts might represent information in a more efficient fashion but did not seem to use this to enhance their memory. We have shown, both in a reanalysis of some of the data from McMaster University and in original experiments of our own that, when propositional analysis techniques are used, coherent differences between experts and novices emerge. Expert physicians have a greater ability to isolate relevant from irrelevant material and they make more inferences from the relevant material. If these factors are taken into account, the anticipated differences emerge. Other efforts (Claessen & Boshuizen, 1985; LeClere & Bordages, 1984) to find such differences without the use of propositional analysis techniques have not been successful.

CAUSAL NETWORKS AND DIAGNOSTIC EXPLANATION

The starting point of our investigation is the notion of a causal network. This is used by Lesgold et al. (1981) as a basis for explaining part of their
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Data. It also occurs as an important component of some expert systems. As formalized by several workers in the field of AI (Clancey, in press; Kuipers & Kassirer, 1984; Patil, 1981) it consists of a network of antecedents linked to consequents. Equivalently, it can be viewed as a network of if-then rules or productions.

Sometimes, such networks are referred to as causal models. We wish to avoid this terminology here, because of the variety of ways in which this term has been applied. In particular, we wish to avoid the notion that we view a causal network as something akin to a device model. In the terminology of deKleer and Brown (1983), we are primarily interested in what underlies the "running" of a diagnostic process. It seems reasonable to assume that causal rules provide something resembling a procedural data base that enables the diagnoses to be made. It seems unreasonable to assume, in a complex knowledge-based domain such as medicine, that such rules derive from the envisionment of a finite set of well-defined devices.

We are interested in two issues. The first is developing a technique for isolating such a network from subjects' protocols. To do this, we use the fact that a propositional analysis does not merely identify propositions. It also yields information regarding how propositions are related. It is possible to use this information to generate a relational structure with labelled links and possibly empty nodes. In Frederiksen's system this is called a frame because its definition corresponds quite closely to that originally proposed by Minsky (1975). It also corresponds closely to the notion of a macrostructure in Kintsch's system as extended by Van Dijk and Kintsch (1983).

In order to use this technique for our purposes, it is necessary to have a task that generates causal information. Patil & Szolovits (1981) and Feltovich and Barrows (1984) have suggested that the subject's causal knowledge can be probed by requesting the subject to explain the underlying pathophysiology of a clinical case. A preliminary analysis of a protocol used by Feltovich and Barrows for illustrative purposes indicates that it is possible to use propositional techniques to yield a frame representation that has many of the properties that one would expect in a causal network (Patel, Frederiksen, & Groen, 1983).

The second issue is to identify at least some of the processes that might be used in utilizing such a model to give a diagnostic explanation. Although a system such as NEOMYCIN incorporates mechanisms for making diagnoses in this fashion, we cannot directly use them as sources of models because the scope of expert systems in medicine is, of necessity, too broad. In general, medical problem solving has four aspects: data gathering, diagnosis, therapeutic plan, and patient management. The first of these must be an important component of an expert system. However, it involves an interactive process of history taking from a patient, which introduces serious complications to the task of designing and analyzing appropriate experiments. We wish to restrict our attention to the second component in which a
subject is given a description of a case, with all the desired data present, and is asked to make a diagnosis.

Broadly speaking, we assume that an initial representation of such a case is stored in the subject's working memory and is used to access relevant causal information. The two kinds of information are then combined to yield a diagnosis. The initial representation can be probed by an appropriate free-recall task, which can then be propositionally analyzed. This suggests the following empirical paradigm:

1. Present the subject with a description of a case.
2. Obtain a free-recall protocol.
3. Ask the subject to describe the underlying pathophysiology of the case.
4. Ask for a diagnosis.

We can then use our propositional analysis techniques to obtain two frames: a recall frame and a pathophysiology frame. These can be related using techniques that we will describe later in the context of an actual analysis. In the case of our analysis of the Feltovich-Barrows protocol, we found that we needed an additional source of data to yield a well-defined relationship. This was information from an expert regarding the minimal causal knowledge required to yield an accurate diagnosis. This information can be represented as a relational structure which we call the canonical knowledge. In correct diagnoses by experts, we expect the pathophysiology frame to be the union of the recall frame with some subset of the canonical knowledge.

Using these notions, it is possible to be more precise regarding the more controversial aspects of the processes used by expert physicians, especially where the hypothetico-deductive method is concerned. To see this, let us suppose that the pathophysiology frame of a subject is representable as a causal network and the propositions in the recall protocol can be viewed as bottom-level inputs to the network. We can then examine the order in which rules fire, and thus distinguish between forward reasoning, backward reasoning and a mixture of the two. If the protocol were completely hypothesis driven, we would expect pure backward chaining. A mixture of forward and backward chaining would indicate the possibility of some kind of hypothetico-deductive reasoning. Pure forward chaining, however, would be incompatible with the notion that a hypothetico-deductive process was being used.

A CASE OF INFECTIOUS ENDOCARDITIS

To examine these notions empirically, seven specialists in cardiology from a Montreal area hospital (one of the teaching hospitals associated with the McGill Faculty of Medicine) were shown a written description of a case that
was based on one that had actually occurred in a clinical setting. The procedure described in the preceding section was followed. Each subject was tested individually and was allowed 2.5 min to read the case description, which was then removed. The subject was then asked to write down as much of the text as he/she remembered, and then to describe (again in writing) the underlying pathophysiology of the case without reference to either the text or the previous recall response. Finally, the subject was asked to provide a diagnosis. Interestingly enough, this final question turned out to be redundant, because all subjects gave the diagnosis as part of their response to the pathophysiology question.

The case is shown in Table I. It describes a patient with acute bacterial endocarditis. Bacterial endocarditis is a bacterial infection affecting the heart valves. A typical case of endocarditis is subacute (not serious) and the heart valve affected is usually the mitral valve.

<table>
<thead>
<tr>
<th>Text: Bacterial Endocarditis</th>
</tr>
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</table>

This 27 year old unemployed male was admitted to the emergency room with the complaint of shaking chills and fever of four days' duration. He took his own temperature and it was recorded at 40°C on the morning of his admission. The fever and chills were accompanied by sweating and a feeling of prostration. He also complained of some shortness of breath when he tried to climb the two flights of stairs in his apartment. Functional inquiry revealed a transient loss of vision in his right eye which lasted approximately 45 s on the day before his admission to the emergency ward.

Physical examination revealed a toxic looking young man who was having a rigor. His temperature was 41°C, pulse 120, BP 110/40. Mucus membranes were pink. Examination of his limbs showed puncture wounds in his left antecubital fossa. The patient volunteered that he had been bitten by a cat at a friend's house about a week before admission. There were no other skin findings. Examination of the cardiovascular system showed no jugular venous distention, pulse was 120 per minute, regular, equal, and synchronous. The pulse was also noted to be collapsing. Auscultation of his heart revealed a 2/6 early diastolic murmur in the aortic area and funduscopic examination revealed a flame shaped hemorrhage in the left eye. There was no splenomegaly. Urinalysis showed numerous red cells but there were no red cell casts.

In our case, the patient contacted the infection from a contaminated needle, possibly from intravenous drug use. The heart valve affected was the aortic valve. Furthermore this patient displayed signs of acute infection which is a serious case of endocarditis. This made the case atypical and difficult to diagnose. Only four of the seven specialists gave the correct diagnosis of acute bacterial endocarditis. In a related experiment, which used an almost identical case but with a somewhat different procedure, the medical students who lacked clinical experience did not obtain the correct answer.

In the present study we are primarily concerned with the processes used by our experts in generating a diagnostic explanation. Our basic strategy is to map the propositions in the text and the recall protocol onto those in the pathophysiology protocol. The propositional analysis of the text is given in
Appendix I. This begins with a division of the text into segments on the basis of Winograd's (1972) classification of discourse into major and secondary clauses. For example, consider the following sentence:

Urinalysis showed numerous red cells, but there were no red cell casts.

Winograd's system of clausal analysis is used to determine the following two clausal segments: a declarative major clause and a bound adjunct. The bound adjunct is the only secondary clause in Winograd's system that we consider as a separate segment. The result is two segments, consisting of a major clause: (1) Urinalysis showed numerous red cells and a secondary bound adjunct; (2) but there were no red cell casts. We then perform a propositional analysis of each segment. The conceptual structures encoded in the first segment are the following three propositions:

1.0 CAU [URINALYSIS], [1.1];
1.1 SHOW IHN:1.2 = INS:PAST;
1.2 CELLS(NUM:NUMEROUS) ATT:RED;

Encoded in the second segment is the following proposition:

2.0 CASTS (NUM:NULL(NO)) ATT:CELL;
2.1 CELL ATT:RED;

In the appendix, the text of each segment is given in full and is followed by the propositions it contains. Each proposition is formally an n-place relation. It is identified by a head element which is followed by a list of its labelled arguments, separated by commas. The head element may be an action, an object, or a relation which connects propositions (e.g., CAU, a causal relation; or COND, a conditional relation). We will call the relations which connect propositions linking propositions. They are extremely important for our purposes because, as we shall see, they can be used to define rules. There are only 10 propositions of this type in the text, 8 of which are causal relations (CAU), one is an equivalence relation (EQUI), and the remaining one refers to temporal ordering (ORD: TEM).

It should be emphasized that the names of linking propositions are labels whose meaning may vary depending on the context. Thus, a label such as CAU or COND does not necessarily refer to a “cause” or “condition” in the logical or semantic sense. In the previous example, CAU refers to a clinical procedure. In much of our analysis to follow, CAU refers to some statement regarding the functioning of the underlying pathophysiology. This is a natural consequence of the fact that propositional analysis is intended as a domain-independent representational language.

ANALYSIS OF A SINGLE SUBJECT

To make our analysis as clear as possible, we will begin by concentrating in some detail on the results of a single subject who made a correct diagnosis.
We will discuss the results of the other subjects in the next section. As before, we relegate all the propositional analyses to the appendices. We give only the raw protocols in the main body of the present study.

The recall protocol is shown in Table II and the corresponding propositional analysis is shown in Appendix II. The recall is essentially a compact version of the text in which there are two main features of interest. First, there are only two links, both of which are causal relations, compared to eight in the text. Second, the patient's attribution of his skin punctures to a "cat bite" is moved from the middle of the text to the beginning of the protocol. This is consistent with the notion that our expert is making use of a "standard schema" which is extensively taught at medical school. It divides a case description into three components: characterization of patient, history, and physical examination. Thus, the information about a cat bite moves from the physical examination component into the history, where it belongs from this point of view. This is the only evidence of a constructive process in the entire recall protocol. Otherwise, it is a verbatim summary with no essential information omitted.

In contrast, the explanation of the underlying pathophysiology seems quite different, bearing a much more remote relation to the original text. Table III contains a summary of the protocol. The propositional analysis is given in Appendix III. The chief difference is that there are once again many

| TABLE II |
| Expert Recall Protocol #5 |

This (unemployed) 27-year-old male presented to the emergency room with history of fever of 40°C and shaking chills of 4 days duration. He also complained of shortness of breath (SOB) while going up stairs. He recalled having been bitten by a friend's cat the week before. He also had a transient loss of vision in his right eye the day prior to admission.

He had a blood pressure of 110/40 and collapsing pulse. His heart rate was elevated. He had puncture wounds in the left antecubital fossa and no other skin findings. Fundoscopic examination revealed a flame shaped hemorrhage. His JVP was not increased. His apex was not displaced. He had an early diastolic murmur at the left stomach border. His spleen was not enlarged. Urinalysis showed casts which I believe were granular.

| TABLE III |
| Expert Pathophysiology Protocol #5 |

The important points are the acute onset of chills and fever in a young male with puncture wounds in the left antecubital fossa indicating high probability of drug abuse and therefore susceptible to endocarditis.

The history of transient blindness in one eye supports an embolic phenomenon for a left valvular vegetation. The shortness of breath (SOB) on exertion and the early diastolic murmur plus wide pulse pressure support aortic insufficiency and thus aortic valve endocarditis. The normal spleen size indicates a more acute process. The urinary findings support renal emboli. The history of being scratched by a cat raises the differential diagnosis of cat scratch fever, but there are no other supporting findings.
linking propositions. In contrast to the two in the recall protocol, there are now nine. Although this is approximately the same as in the text, there are considerably fewer propositions in the pathophysiology protocol (41 versus 87) so the proportion of linking propositions is far greater. Seven of the linking propositions are causal (most involve reverse causality indicated by SUPPORTS). One is a condition (COND) and the other is an identity relation (IDEN). They are quite different from the linking propositions in the text, most of which say that if a certain physical examination procedure is undertaken then a certain pattern of findings is obtained. Most of those in the pathophysiology protocol say that a certain pattern of findings supports the notion of some causal mechanism or vice versa.

A more exact picture of the relationship between the propositions in the text and the two protocols can be obtained by performing the same recall-inference analysis that we used in our earlier work (Patel, Frederiksen, & Groen, 1983). For each text proposition in the protocol we determine whether it was recalled or inferred. Broadly speaking, a recall is either a direct match or a proposition that results by replacing a word with one of its synonyms. An inference is a transformation that preserves at least part of the meaning of the original proposition. This scoring procedure is based on a set of highly specific rules (Frederiksen, in press). For example, consider the following sentence from the text:

This 27 year old unemployed male was admitted to the emergency room with the complaint of shaking chills and fever of 4 days duration.

The physician's recall protocol reads as follows:

This young unemployed male is admitted to the emergency room with an acute onset of chills and fever.

We give the propositional analysis of the text in Appendix I. The analysis of the segment from the recall protocol is as follows:

<table>
<thead>
<tr>
<th>Proposition Number</th>
<th>Head Element</th>
<th>Arguments</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1.0</td>
<td>ADMIT</td>
<td>OBJ:MALE(THIS), RSLT:1.1, ACT: (WITH)1.2 = TNS:PAST:</td>
</tr>
<tr>
<td>R1.1</td>
<td>MALE(THIS)</td>
<td>LOC:EMERGENCY ROOM;</td>
</tr>
<tr>
<td>R1.2</td>
<td>ONSET</td>
<td>ACT:(OF)CHILLS, FEVER = DEG: ACUTE;</td>
</tr>
<tr>
<td>R1.3</td>
<td>MALE(THIS)</td>
<td>ATT:UNEMPLOYED, ATT:YOUNG;</td>
</tr>
</tbody>
</table>

If we compare the analysis of the text with that of the protocol, we see that propositions 1.0 and 1.1 in Appendix I are identical to propositions R1.0 and R1.1. These would be classified as recalls in our system. On the other hand propositions 1.2-1.4 of the text correspond to proposition R1.2 of the protocol. In this case, there is a replacement of the original text-based con-
cept "4 days duration" by a new superordinate concept "acute onset" in the protocol. The concept of acute onset is inferred by the subject from the concept 4 days duration based on the knowledge that a complaint of short duration is likely to be acute. This is classified as an inference.

Similarly, proposition 1.5 of the text is identical to proposition R1.3 of the protocol, except for the one slot where the original concept "27 year old" is replaced by another superordinate concept "young." This is also classified as an inference. Both of these inferences involve operations on propositions in a text that result in new propositions more general than the propositions in the original content of the text.

The results of the analysis using this recall and inference coding procedure is shown in Figure 1. The solid lines indicate recalls and the dotted lines indicate inferences. The numbers refer to proposition numbers in the various analyses in the appendices. This defines what we call a propositional mapping between the text base and the two protocols. Reference to the appendices should make it clear that it is a mapping of factual information. None of the linking propositions in the text can be mapped to any of the linking propositions in the pathophysiology protocol.

Until now, we have not used the frame notation. We have simply used propositions and mappings of propositions. This is primarily because there appears to be little correspondence (at the level of linking propositions) between the relational structure of the text and the recall protocol and that of the pathophysiology protocol. There are a variety of ways to construct frames. The most direct way is simply to use the linking propositions as

<table>
<thead>
<tr>
<th>Text</th>
<th>Recall</th>
<th>Pathophysiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fever, chills</td>
<td>4.0, 4.1</td>
<td>1.4, 1.5</td>
</tr>
<tr>
<td>Puncture wounds</td>
<td>14.1</td>
<td>R 7</td>
</tr>
<tr>
<td>Transient blindness in one eye</td>
<td>7.3</td>
<td>4.2</td>
</tr>
<tr>
<td>Shortness of breath</td>
<td>5.1</td>
<td>2.2</td>
</tr>
<tr>
<td>Early diastolic murmur</td>
<td>21.4</td>
<td>14.2</td>
</tr>
<tr>
<td>Wide pulse pressure</td>
<td>12.0</td>
<td>6.2</td>
</tr>
<tr>
<td>Normal spleen size</td>
<td>23.0</td>
<td>15.1</td>
</tr>
<tr>
<td>Urinary findings</td>
<td>24.0, 24.2</td>
<td>16.1, 17.1</td>
</tr>
<tr>
<td>Cat scratch</td>
<td>15.1</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Figure 1. Propositional mapping of text ond protocols for Expert-Subject #5. The proposition numbers refer to those in the corresponding text (Appendix I) and protocols (Appendices II and III)
links and the remaining propositions as nodes. However, this does not yield a coherent structure for the text or the recall protocol. The alternative way is to impose some kind of compelling “natural” structure upon the propositions from outside, as it were. Thus, in the case of the text which is primarily a narrative, we could impose a “narrative frame” based on event sequences. In the case of the recall protocol we could impose a structure based on the patient description/patient history/physical examination schema that we outlined earlier. With the pathophysiology protocol, on the other hand, we can proceed directly. The result of this is shown in Figure 2. In this diagram, the numbers denote propositions, numbered according to Appendix III. The lines, of course, correspond to the linking propositions. The arrows indicate directionality. These will be referred to as links and the other propositions as nodes. The diagram also indicates the nodes that correspond to propositions appearing in the text or the recall protocol according to the propositional mapping we defined in Figure 1.

Figure 2 defines a process that leads to a diagnosis. It can be viewed as a finite-state parallel device with each node an “and-node.” The input nodes are those that correspond to propositions in the text base or the recall protocol. When one of these nodes is “fired,” the node to which it is linked

![Diagram of Figure 2]

Figure 2. Representation of the relational structure of the pathophysiology of the patient problem from Expert-Subject #5. The proposition numbers refer to those in Appendix III and the arrows indicate directionality.

PROX: Proximity relation SUP: Supports
LOC: Locative COND: Conditional relation
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together registers this fact. However, because it is an and-node, it waits to "fire" until all its other antecedents fire. The outcome is the correct diagnosis. All this is probably easier to describe in terms of a production system notation that we will describe in the next section. Before leaving this single subject, however, one important point needs to be made. The device makes use of pure forward reasoning. No backward chaining is involved at all, and hence there is no evidence of any use of a hypothetico-deductive process.

FORWARD AND BACKWARD CHAINING

We now turn to the issue of the extent to which the other subjects are using a similar process. To investigate this, it is convenient to consider the canonical knowledge that is being used. As we pointed out earlier, this is the knowledge that exists in textbooks or more informally in the common knowledge base of expert cardiologists. To discover this, we asked a cardiologist who had not been a subject in the experiment to describe the basic causal mechanisms underlying the case that led to a diagnosis of acute endocarditis. We also specifically asked him to account for the responses of the four subjects who achieved a correct diagnosis. The result is summarized in Figure 3 which gives the rules necessary to explain the diagnoses of all these subjects.

Figure 3. Canonical frame for acute bacterial endocarditis (ABE) with aortic insufficiency.

CAU: Causal relation
COND: Conditional relation
The rules in this diagram are represented as causal rules, because this kind of information was simpler to obtain from our independent expert. It is important to note, however, that such causal rules can be reversed into conditions, and hence represent reasoning of the type the subject in the preceding section was using. This diagram therefore provides a general framework that allows forward or backward reasoning depending on the direction in which the rules are applied. It should be noted, however, that the COND rules leading to the actual diagnosis cannot be reversed in this fashion.

For example, the causal rule “if infection, then fever” implies the conditional rule “if fever, then infection.” On the other hand, the purely conditional rule “if intravenous drug use, then bacterial infection” cannot be reversed, because bacterial infection clearly does not indicate intravenous drug use.

<table>
<thead>
<tr>
<th>Rule (#)</th>
<th>Antecedent (if)</th>
<th>Consequent (then)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Puncture wounds and young unemployed male</td>
<td>Intravenous drug use</td>
</tr>
<tr>
<td>2</td>
<td>Intravenous drug use</td>
<td>Bacterial infection</td>
</tr>
<tr>
<td>3</td>
<td>Bacterial infection and emboli</td>
<td>Bacterial endocarditis</td>
</tr>
<tr>
<td>4</td>
<td>Fever</td>
<td>Bacterial infection</td>
</tr>
<tr>
<td>5</td>
<td>Transient blindness</td>
<td>Emboli</td>
</tr>
<tr>
<td>6</td>
<td>Red blood cells in urine</td>
<td>Emboli</td>
</tr>
<tr>
<td>7</td>
<td>Intravenous drug use and bacterial endocarditis</td>
<td>Bacterial endocarditis from intravenous drug use</td>
</tr>
<tr>
<td>8</td>
<td>Low diastolic pressure and normal systolic pressure</td>
<td>Aortic valve insufficiency</td>
</tr>
<tr>
<td>9</td>
<td>Early diastolic murmur</td>
<td>Aortic valve insufficiency</td>
</tr>
<tr>
<td>10</td>
<td>Shaking chills and bacterial endocarditis</td>
<td>Acuteness of bacterial endocarditis</td>
</tr>
<tr>
<td>11</td>
<td>Rigor and bacterial endocarditis</td>
<td>Acuteness of bacterial endocarditis</td>
</tr>
<tr>
<td>12</td>
<td>Normal spleen and bacterial endocarditis</td>
<td>Acuteness of bacterial endocarditis</td>
</tr>
<tr>
<td>13</td>
<td>Short duration of illness and bacterial endocarditis</td>
<td>Acuteness of bacterial endocarditis</td>
</tr>
<tr>
<td>14</td>
<td>Normal heart size and bacterial endocarditis</td>
<td>Acuteness of bacterial endocarditis</td>
</tr>
<tr>
<td>15</td>
<td>Bacterial endocarditis from intravenous drug use, aortic valve insufficiency, and acuteness of bacterial endocarditis</td>
<td>Acute bacterial endocarditis with aortic insufficiency from drug use.</td>
</tr>
</tbody>
</table>
To compare what subjects actually do, it is convenient to consider these rules as production (if-then) rules rather than as links in a causal chain. They are listed in this form in Table IV. The antecedents and consequents (which determine the direction in which the rules are being applied) were directly obtained by matching linking propositions with elements of the canonical frame from the protocols of the three subjects who generated accurate diagnoses. All of these rules are in a forward direction toward the diagnosis. There is no instance of backtracking. This implies that all four subjects were using pure forward reasoning. In fact, an identical analysis to that performed for the single subject in the preceding section indicates an identical pattern for the three remaining subjects, with the relevant propositions of the recall protocols being used as input to the frames derived from the pathophysiology protocols.

Some of these rules were also used by the three subjects who generated inaccurate diagnoses. The use made by all subjects of these rules is shown in Table V. This table indicates that the critical rules for an accurate diagnosis are Rule 2 (IF intravenous drug use, THEN bacterial infection), and Rule 9 (IF early diastolic murmur, THEN aortic insufficiency). None of the subjects who generated an inaccurate diagnosis used these rules, whereas they were used by all subjects who generated an accurate diagnosis.

The subject who generated inaccurate diagnoses made use of additional rules. These are of two kinds: irrelevant rules and backward chaining rules. This is shown in Figure 4, which contains the frame for the pathophysiology protocol of subject 6, who gave a diagnosis of subacute aortic

<table>
<thead>
<tr>
<th>Production Rule (#)</th>
<th>Subjects (#) with Accurate Diagnosis</th>
<th>Subject (#) with Inaccurate Diagnosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule (1)</td>
<td>2 3 4 5</td>
<td>1 6 7</td>
</tr>
<tr>
<td>1</td>
<td>X X X X</td>
<td>X X</td>
</tr>
<tr>
<td>2</td>
<td>X X X X</td>
<td>X X</td>
</tr>
<tr>
<td>3</td>
<td>X X X X</td>
<td>X X</td>
</tr>
<tr>
<td>4</td>
<td>X X X X</td>
<td>X X</td>
</tr>
<tr>
<td>5</td>
<td>X X X X</td>
<td>X X</td>
</tr>
<tr>
<td>6</td>
<td>X X X X</td>
<td>X X</td>
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<tr>
<td>7</td>
<td>X X X X</td>
<td>X X</td>
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<td>8</td>
<td>X X X X</td>
<td>X X</td>
</tr>
<tr>
<td>9</td>
<td>X X X X</td>
<td>X X</td>
</tr>
<tr>
<td>10</td>
<td>X X X X</td>
<td>X X</td>
</tr>
<tr>
<td>11</td>
<td>X</td>
<td>X X</td>
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<td>12</td>
<td>X</td>
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<td>13</td>
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<td>X X</td>
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<tr>
<td>14</td>
<td>X</td>
<td>X X</td>
</tr>
<tr>
<td>15</td>
<td>X X X X</td>
<td>X X</td>
</tr>
</tbody>
</table>
insufficiency. It contains an irrelevant branch that deals with a perceived lack of severity of the illness rather than linking "no cardiomegaly" to signs of acuteness. Most interesting, however, is the fact that the reasoning is mainly top-down. It begins with a general hypothesis regarding bacteremia and works backward to the text-based knowledge. This use of backward reasoning is also found in the other two subjects whose diagnoses were inaccurate, although the pattern emerges most clearly with the present subject.

DISCUSSION

In the present study, we set out to develop a method that would enable us to represent the processes used by physicians in generating a diagnostic explanation. Our method of using probes (i.e., the recall and pathophysiology tasks) appear to be successful in generating empirical protocols from which it is possible, through the use of propositional analysis techniques, to identify both the problem-solving processes and the structure of at least parts of
the underlying database. Although one outcome of our analysis is a system of production rules that do not make use of the propositional notation, we feel that these techniques are necessary to yield unambiguous results. When we have attempted to do without them, we have been faced with the need to make arbitrary choices between excessively large numbers of antecedents and consequents. We have also found it impossible to make explicit mappings from the text base and the recall protocol onto the pathophysiology protocol and thus determine that the text information serves as bottom-level input to the forward chaining process.

It is impossible to prove that other approaches not using propositional analysis might yield the same results. However, it seems reasonable to assert that some kind of representational language and a method for using it is necessary. It seems simpler, however, to use an existing and relatively well-documented method rather than develop either a special purpose language or a uniform methodology for applying one of the general-purpose artificial intelligence languages (e.g., Sowa, 1984). A domain-specific language, such as Kuipers and Clancey use, might yield a simpler notation and a less elaborate methodology. However, there may be major difficulties in comparing performance between different cases or between subjects with different knowledge bases.

Our most significant result is that all of the experts with accurate diagnoses used bottom-up forward reasoning whereas the experts with inaccurate diagnoses used at least some top-down backward reasoning. It is compelling to interpret this latter kind of reasoning as involving some kind of process of generating a hypothesis and testing it in the light of whatever the subject has recalled about the facts of the case. It is wrong to conclude, however, that a subject’s inaccurate diagnosis is due to the use of a hypothesis testing strategy. In order to use forward chaining it is necessary to access certain critical rules. If even one such rule is not accessed, the method cannot possibly work. In this case, a physician might be expected to begin generating and testing hypotheses because he is trained to do this in uncertain situations. In a realistic setting, the physician is not limited to a case description. New information can be acquired by further examination of the patient. This is not possible in our experiment.

On the other hand, there is evidence that the use of forward chaining is not limited to fragile domains where the application of one or two critical rules is vital. Kuipers and Kassirer (1984) found that a rather similar process of forward propagation through a causal network was being used by their subject. This research is in a completely different speciality of medicine (nephrology). Also, the causal network is based on an underlying physical model of an equilibrium process. This makes it reasonable to speculate that some form of forward reasoning or forward propagation through a causal network is characteristic of expert diagnostic explanation in a variety of
domains. Hypothesis testing and other forms of backward reasoning may, of course, play an important role in other situations and different kinds of problems from those considered here. It may also be the case that novices use forward reasoning in certain situations. However, the techniques we have described in the present study appear to yield models of forward reasoning with a high degree of falsifiability. It seems far more difficult to generate testable models for backward reasoning. Hence, the systematic exploration of the validity of forward reasoning models could be an important tool for determining when and why hypothesis testing is used in the diagnostic process.

It should be noted that our results are not necessarily contradictory to those of previous investigators who found evidence of hypothetico-deductive reasoning (Elstein, Shulman, & Sprafka, 1978; Feltovich, 1981; Rubin, 1975). The extent to which backward chaining occurs seems highly dependent on two factors: the matching of task to expertise and the nature of the task itself. The previous research frequently used extremely difficult cases or used empirical paradigms specifically requesting hypothesis generation.

Although we feel we have succeeded in giving an explicit account of the rule system for generating a diagnostic explanation, we do not yet have an equally explicit account of the comprehension processes. We have identified a rule system that appears to be effective in generating diagnostic explanations in terms of causal patterns. The question remains of how the rule system is accessed or generated. We do make use of the working assumption that the rules are generated by the union of canonical knowledge with text-based information. However, we characterize it in a post-hoc fashion and furthermore, we make use of a task designed to elicit such knowledge, so we cannot claim to have tested this notion. One possibility is that this knowledge constitutes a "model" for the disease. However, it is unlikely that every disease has a different model. There is also some reason for believing that canonical knowledge is not a unitary whole but is accessed by coordinating basic science knowledge from a variety of sources. This is supported by the fact that one difference between experts and novices is the former's ability to coordinate prior knowledge from different frames (Patel, 1984; Patel & Groen, 1985).

It remains for something to be said about expert systems. The crucial issue here is the extent to which a system such as MYCIN (Shortliffe, 1976), which uses backward chaining as its basic mechanism for making inferences, is an adequate model for the diagnostic process. Our results indicate that it is not adequate. What they support is a model more like NEOMYCIN which makes extensive use of forward chaining but uses hypothesis testing as a backup. Our research therefore offers some hope that ultimately there may develop a two-way interaction between cognitive psychology and knowledge engineering. Expert systems may become more accurate and user-friendly if they reflect the human capability more closely. Psychology will benefit if it can use expert systems as a source of explicit and valid formal theories.
APPENDIX I: PROPOSITIONAL REPRESENTATION OF THE TEXT ON BACTERIAL ENDOCARDITIS

1. THIS 27 YEAR OLD UNEMPLOYED MALE WAS ADMITTED TO THE EMERGENCY ROOM WITH THE COMPLAINT OF SHAKING CHILLS AND FEVER OF 4 DAYS DURATION

1.0 ADMIT OBJ:MALE(THIS), RSLT:1.1, ACT:(WITH)1.2, TNS:1.3
1.1 MALE(THIS) LOC:EVENRGY ROOM
1.2 COMPLAIN TMS:1.3, 1.4
1.3 SHAKE ACT:CHILLS=ASPECT=CONT, DUR:4 DAYS DURATION
1.4 FEVER PAT:HUM:40, DUR:4 DAYS DURATION
1.5 MALE(THIS) ATT:UNEMPLOYED, DES:27 YEAR OLD

2. HE TOOK HIS OWN TEMPERATURE

2.0 TAKE PAT:HE OBJ:TEMPERATURE=TNS:PAST
2.1 (POSS):OWN

3. AND IT WAS RECORDED AT 40°C ON THE MORNING OF HIS ADMISSION

3.0 RECORDED ACT:TEMPERATURE=TMS:40, TMS:MORNING
3.1 ADMIT OBJ:(HIS), TMS:MORNING
3.2 EQUIV:TEMP [3.0], [3.1]

4. THE FEVER AND CHILLS WERE ACCOMPANIED BY SWEATING AND A FEELING OF PROSTRATION

4.0 PROXI(ACCOMPANY) [FEVER, CHILLS], [SWEATING, 4.1], TNS:PAST
4.1 FEEL ACT:PROSTRATION=ASPECT=CONT

5. HE ALSO COMPLAINED OF SOME SHORTNESS OF BREATH

5.0 COMPLAIN AGT:HE, TMS:5.1, TNS:PAST
5.1 BREATH ATT:SHORTNESS

6. WHEN HE TRIED TO CLIMB THE TWO FLIGHTS OF STAIRS IN HIS APARTMENT

6.0 TRY PAT:HE, GOAL:TO6.1, TNS:PAST
6.1 CLIMB PAT:HE, LOC:FLIGHTS(NUM:2)
6.2 STAIRS LOC:IN APARTMENTS
6.3 (POSS) OBJ:APARTMENT
6.4 EQUIV:ITEM [5.0], [6.0]

7. FUNCTIONAL INQUIRY REVEALED A TRANSIENT LOSS OF VISION IN HIS RIGHT EYE WHICH LASTED APPROXIMATELY 45 SEC.

7.0 CAU [7.1], [7.2]
7.1 INQUIRY ATT:functional
7.2 REVEAL TMS:7.3, TNS:PAST
7.3 LOSE ACT:VISION=LOC:IN(EYE, DUR:TRANSIENT, DUR:APPROXIMATELY 45 SEC, ASPECT=CONT(LAST), TNS:PAST

8. THIS HE DESCRIBED THE DAY BEFORE ADMISSION TO THE EMERGENCY WARD

8.0 DESCRIBE AGT:HE, TMS:THIS, TNS:PAST
8.1 ADMIT PAT:HE = LOC:EMERGENCY WARD, TMS:BEFORE
8.2 ORD:ITEM [8.0], [8.1]

9. PHYSICAL EXAMINATION REVEALED A TOXIC LOOKING YOUNG MAN WHO WAS HAVING A RIGOR

9.0 CAU [9.1], [9.2]
9.1 EXAMINE ATT:PHYSICAL
9.2 REVEAL TMS:9.3, 9.4, 9.5, TNS:PAST
9.3 LOOK PAT:HUM:TOXIC, ASPECT=CONT
9.4 MAN ATT:YOUNG
9.5 HAVE RIGOR PAT:HE, = ASPECT=CONT, TNS:PAST
His temperature was 41°C.


Pulse 120

Pulse deg: 120;

BP 110/40

BP deg: 110/40;

Mucous membranes were clear

Membranes att: mucous;

Mucous membranes att: clear, tens: past.

Examination of his limbs showed puncture wounds in his left antecubital fossa

Examination of limb loci (of) limb;

Wounds att: puncture;

Wounds loci (in) fossa;

Fossa att: antecubital, att: left;

Wounds att: puncture;

Wounds loci (in) fossa;

Fossa att: his, obj: fossa;

Fossa att: his, obj: limbs;

The patient volunteered that he had been bitten by a cat at friend's house a week before admission

Volunteer att: patient, tens: past;

Bite obj: he, instr: by cat loc: at (at) house;

Temp: a week, temp: aspectic compl, tens: past;

Antecubital:

Diff: item att: past;

Item att: past;

Patient, obj: house.

There were no other skin findings

Skin (num: ind: null) cat: other;

Examination of the cardiovascular system showed no jugular venous distention

Examination of system act: 17: 2;

Systems att: cardiovascular;

Wounds tens: past;

Distend act: venous tens: (no);

Venous att: jugular;

Pulse was 130 per minute, regular, equal and synchronous

Pulse deg: 130 per minute, tens: past;

Pulse att: regular;

Pulse att: equal;

Pulse att: synchronous;

The pulse was also noted to be collapsing

Pulse tens: past;

Pulse act: pulse = aspectic cont;

The apex beat was not displaced
SOLUTION STRATEGIES IN MEDICAL REASONING 111

20.0 BEAT
20.1 DISPLACE
21 AUSCULTATION OF HIS HEART REVEALED A 2/6 EARLY DIASTOLIC
MURMUR IN THE AORTIC AREA
21.0 CAUS
21.1 AUSCULTATE
21.2 (POSS) PAT: HIS, OBJ: HEART =
21.3 AUDIT NRM = 21.4 = TNS: PAST,
21.4 MURMUR
21.5 MURMUR
21.6 AREA
21.7 MURMUR
22 AND FUNDUSCOPY REVEALED A FLAME SHAPED HEMORRHAGE
IN THE LEFT EYE
22.0 CAUS
22.1 REVEAL
22.2 SHAPE
22.3 HEMORRHAGE
22.4 EYE
23 THERE WAS NO SPLENOMEGALY
23.0 SPLENOMEGALY (NUM: NULL (NO) = TNS: PAST;
24 URINALYSIS SHOWED NUMEROUS RED CELLS
24.0 CAUS
24.1 SHOW
24.2 CELLS (NUM: NULL (NO) = ATT: RED;
25 BUT THERE WERE NO RED CELL CASTS
25.0 CASTS (NUM: NULL (NO) = ATT: CELL,

APPENDIX II: PROPOSITIONAL REPRESENTATION OF
EXPERT RECALL PROTOCOL (Subject No. 5)

1 THIS 27 (UNEMPLOYED) YEAR OLD MALE PRESENTED TO THE
EMERGENCY ROOM WITH HISTORY OF FEVER OF 40 DEG C. AND
SHAKING CHILLS OF 4 DAYS DURATION
1.1 PRESENT
1.2 HISTORY
1.3 ROOM
1.4 FEVER
1.5 SHAKING
1.6 MALE
1.7 IDENT
2 HE ALSO COMPLAINED OF SHORTNESS OF BREATH (SOB) WHILE
GOING UP STAIRS
2.1 COMPLAIN
2.2 BREATH
2.3 ROOM
3 HE RECALLED HAVING BEEN BIT BY A FRIEND'S CAT THE WEEK
BEFORE
4. ME also had a transient loss of vision in his right eye the day prior to admission.

5. On examination he was febrile.

6. He had a blood pressure of 110/40 and collapsing pulse.

8. He had puncture wounds in the left antecubital fossa.

9. And no other skin findings.

10. Fundoscopic examination revealed a flame hemorrhage.

11. His chest was clear.

14. He had an early diastolic murmur at the left sternal border.
14.1 HAS PAT:THM:14.2;TNS:PAST;
14.2 MURMUR ATT:DIASTOLIC,TEM:EARLY;
14.3 MURMUR LOC:(AT):BORDER;
14.4 BORDER ATT:STERNAL,ATT:LEFT;

15 HIS SPLEEN WAS NOT ENLARGED
15.1 SPLEEN ACT:ENLARGED=TNS:PAST,NEG:(NOT);
15.2 (FOSS) PAT:HAS,OBJ:SPLEEN;

16 URINALYSIS SHOWED CASTS
16.1 CASTS [URINALYSIS],[16.21];
16.2 SHOW TNS:PAST;

17 WHICH I BELIEVE WERE GRANULAR
17.1 BELIEVE PAT:THM:17.2;
17.2 IDENT WHICH[17.2],TNS:PAST;

APPENDIX III: PROPOSITIONAL REPRESENTATION OF EXPERT PATHOPHYSIOLOGY PROTOCOL
(Subject No. 5)

1 THE IMPORTANT POINTS ARE THE ACUTE ONSET OF CHILLS AND FEVER IN A YOUNG MALE WITH PUNCTURE WOUNDS IN THE LEFT ANTECUBITAL FOSSA INDICATING HIGH PROBABILITY OF DRUG ABUSE AND THEREFORE SUSCEPTIBLE TO ENDOCARDITIS

1.1 POINTS ATT:IMPORTANT;
1.2 IDENT [1.1],[1.3],[1.4],[1.5]TNS:PRES;
1.3 ONSET ACT:(OF)CHILLS,FEVER,DEG:ACUTE,LOC:(IN) MALE;
1.4 MALE ATT:YOUNG,ACT:(WITH),5;
1.5 WOUND ATT:PUNCTURE,LOC:(IN)FOSSA;
1.6 FOSSA ATT:ANTECUBITAL,ATT:LEFT;
1.7 INDICATE TNS:1.9,1.10,DEG:HIGH(PROBABILITY),ASPCT: CONT;
1.9 ABUSE ATT:DRUG;
1.10 SUSCEPTIBLE OBJ:(TO)ENDOCARDITIS;
1.11 CON0 C1.5,C1.6,C1.7,C1.8,C1.9,C1.10,THEREFDRE;

2 THE HISTORY OF TRANSIENT BLINDNESS IN ONE EYE SUPPORTS AN EMBOLIC PHENOMENA FOR A LEFT VALVULAR VEGITATION

2.1 HISTORY TNS:(OF)BLINDNESS;
2.2 BLINDNESS LOC:(IN)EYE(NUM:ONE),DUR:TRANSIENT;
2.3 CON0 (SUPPORTS) [2.1],[2.2],TNS:PRES;
2.4 PHENOMENA ATT:EMBOLIC
2.5
2.6 VEGITATION ATT:VALVULAR;
2.7 VALVULAR ATT:LEFT;

3 THE SHORTNESS OF BREATH (SOB) ON EXERTION AND THE EARLY DIASTOLIC MURMUR PLUS WIDE PULSE PRESSURE SUPPORT AORTIC INSUFFICIENCY AND THIS AORTIC VALVE ENDOCARDITIS

3.1 BREATH ATT:SHORTNESS,TEM:(ON)EXERTION;
3.2 MURMUR ATT:DIASTOLIC,ATT:EARLY;
3.3 PRESSURE ATT:PULSE,ATT:WIDE;
3.4 CON0 [3.1,3.2,3.3],[3.4],TNS:PRES;
3.5 INSUFFICIENCY ATT:AORTIC;
3.6 CON0 [3.5],[3.6];
3.7 ENDOCARDITIS LOC:AORTIC VALVE;
5 THE URINARY FINDINGS SUPPORT RENAL EMBOLI

5.1 FIND TMM:URINARY, ASPCT: CONT;
5.2 EMBOLI LOC: RENAL;
5.3 COND 5(1), 5(2);

6 THE HISTORY OF BEING SCRATCHED BY A CAT RAISES THE DIFFERENTIAL DIAGNOSIS OF CAT SCRATCH FEVER

6.1 HISTORY TMM:6;
6.2 BE SCRATCHED, ASPCT: CONT;
6.3 SCRATCH INST: CAT;
6.4 Cau 5(1), 5(2);
6.5 RAISES TMM:DIAGNOSIS;
6.6 DIAGNOSIS ATT: DIFFERENTIAL, TMM: FEVER;
6.7 COND 5(1), 5(2);

7 BUT THERE ARE NO OTHER SUPPORTING FINDINGS

7.1 FIND TMM:7, INST: PRES, ASPCT: CONT;
7.2 SUPPORT (NUM: NULL( NO)) CAT: OTHER, ASPCT: CONT;

APPENDIX IV: PROPOSITIONAL REPRESENTATION OF EXPERT PATHOPHYSIOLOGY PROTOCOL
(Subject No. 6)

1 GENERAL BACTEREMIA AND SEPTICAEMIA ARE SECONDARY TO B. RESULTING IN CNS RESPONSE TO SEPTICAEMIA (CHILLS, FEVER) AND WITH SEEDING OF ORGANISMS ON THE AORTIC VALVE RESULTING IN SUBACUTE AORTIC INSUFFICIENCY DUE TO LEAFLET DESTRUCTION AND HENCE A COLLAPSING PULSE

1.0 OR:ITEM 5(BACTEREMIA),(SEPTICAEMIA);
1.1 PROX (SECONDARY) TO 5(SEPTICAEMIA),(1, 2);
1.2 BACTEREMIA CAT: GENERAL;
1.3 CAU RESULT 5(SEPTICAEMIA),(1, 2, 3), ASPCT: CONT;
1.4 RESPONSE PAT: CNS, TMM: (TO) SEPTICAEMIA;
1.5 IDENT 5(1), TMM: (CHILLS, FEVER);
1.6 CAU 5(1), TMM: (CHILLS, FEVER);
1.7 SEED OBJ: ORGANISMS, LOC: ON, VALVE, ASPCT: CONT;
1.8 VALUE ATT: AORTIC;
1.9 CAU RESULT 5(1), 5(2), ASPCT: CONT;
1.10 INSUFFICIENCY ATT: AORTIC, DEG: SUBACUTE;
1.11 CAU DUE TO 5(1), 5(2);
1.12 DESTRUCT OBJ: LEAFLET, RELT: 5(1, 2);
1.13 COLLAPSE ACT: PULSE, ASPCT: CONT;
1.14 CAU 5(1), 5(2);

2 BUT WITHOUT SUFFICIENT SEVERITY OR DURATION TO CAUSE CLINICAL HEART FAILURE OR CARDIOMEGALY

2.1 UND 5(1, 2, 3);
2.2 SEVERITY DEG: SUFFICIENT, NEG(WITHOUT);
2.3 OR-ALT 5(2, 2), DURATION;
2.4 CAU TO CAUSE 5(2, 2, 3);
2.5 FAILURE OBJ: HEART, ATT: CLINICAL;
2.6 OR-ALT 5(2, 2), CARDIOMEGALY;

3 POSSIBLE EMBOLI FROM THE VALVE

3.1 EMBOLI (NUM: 2) LOC: FROM, VALVE, MOD: DUAL(POSSIBLE);
3.2 IDENT 5(1, 4, 5, 1);
4 TRANSIENT BLINDNESS IN LEFT EYE
4.1 BLIND DUR:TRANSIENT/Images/LOC:EYE;
4.2 EYE ATT:LEFT;
5 AND FLAME HEMORRHAGE IN THE OTHER
5.1 HEMORRHAGE ATT:FLAME,LOC:OTHER;

REFERENCES


