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Computer-Based Consultations in Clinical Therapeutics: Explanation and Rule Acquisition Capabilities of the MYCIN System*

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This report describes progress in the development of an interactive computer program, termed MYCIN, that uses the clinical decision criteria of experts to advise physicians who request advice regarding selection of appropriate antimicrobial therapy for hospital patients with bacterial infections. Since patients with infectious diseases often require therapy before complete information about the organism becomes available, infectious disease experts have identified clinical and historical criteria that aid in the early selection of antimicrobial therapy. MYCIN gives advice in this area by means of three subprograms: (1) A Consultation System that uses information provided by the physician, together with its own knowledge base, to choose an appropriate drug or combination of drugs; (2) An Explanation System that understands simple English questions and answers them in order to justify its decisions or instruct the user; and (3) A Rule Acquisition System that acquires decision criteria during interactions with an expert and codes them for use during future consultation sessions. A variety of human engineering capabilities have been included to heighten the program's acceptability to the physicians who will use it. Early experience indicates that a sample knowledge base of 200 decision criteria can be used by MYCIN to give appropriate advice for many patients with bacteremia. The system will be made available for evaluation in the clinical setting after its reliability has been shown to approach that of infectious disease experts.

INTRODUCTION

We have previously described (*1*) a computer program, written in a dialect of the LISP programming language called INTERLISP (*2*), that uses clinical decision criteria acquired from experts to advise physicians who request advice concerning

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antimicrobial therapy selection. The program has been named MYCIN after the common suffix for several antibiotics. MYCIN relies heavily upon artificial intelligence (AI) techniques that were originally developed for problem solving outside the environment of clinical medicine. In the present communication we clarify certain aspects of the program's control structure and describe recently added features that improve the program's interactive capabilities and thus heighten MYCIN's acceptability as a clinical tool. These new features will become important components of the MYCIN System when it is implemented for evaluation in the clinical setting. Currently the program exists as a prototype system that is used by the collaborators as they develop its capabilities.

Summary of the Program

The ultimate aim of the project has been to develop a computer-based system to which physicians will refer for antimicrobial therapy advice. Since clinicians are not likely to accept such a system unless they can understand why the recommended

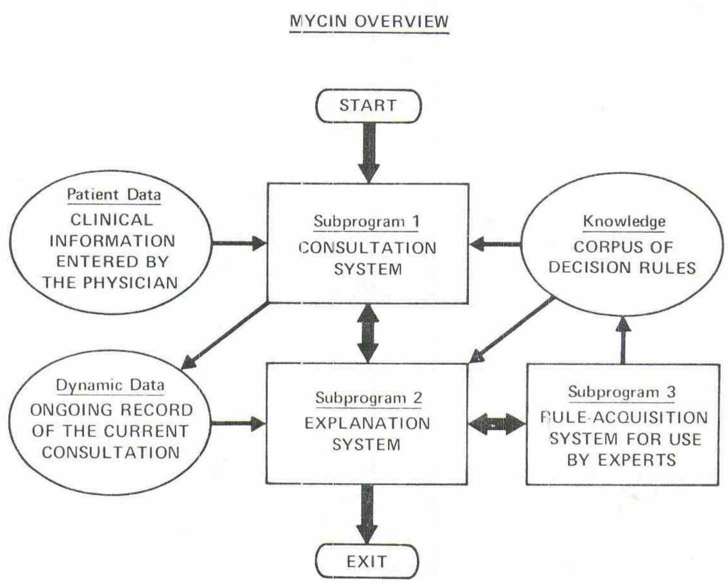

FIG. 1. Diagram demonstrating the flow of control and the flow of information within the MYCIN System. The three subprogram components are enclosed in boxes. Control passes from one subprogram to another as shown by the heavy arrows. Light arrows indicate program access to information used by the system. The program's knowledge base is contained in the corpus of rules shown on the right. Each rule is of the form:

$$\text{Condition-1 \& Condition-2 \& } \cdots \text{ \& Condition-n} \rightarrow \text{Conclusion}$$

The way in which the Consultation System uses such rules is represented in Figs. 2 and 3.

therapy has been selected, the system has to do more than give dogmatic advice. It is also important to let the program explain its recommendations when queried, and to do so in terms that suggest to the physician that the program approaches problems in much the same way that he does. This permits the user to validate the program's reasoning, and to reject the advice if he feels that a crucial step in the decision process cannot be justified. It also gives the program an inherent instructional capability, allowing the physician to learn from each consultation session. Furthermore, we feel it is desirable that an expert in infectious disease therapy who notes omissions or errors in the program's reasoning should be able to augment or correct the knowledge base so that future consultations will not repeat the same mistakes.

Progress towards these goals has been made in development of the MYCIN System. It is composed of three interrelated subprograms as shown in Fig. 1. The Consultation System (Subprogram 1) uses MYCIN's knowledge base and patient data entered by the physician to generate therapeutic advice. The Explanation System (Subprogram 2) is available during the consultation and is also automatically entered at the end of each session. Finally, experts may choose to enter the Rule Acquisition System (Subprogram 3) to update MYCIN's knowledge base. The explanation and rule acquisition capabilities are new features that we will describe in some detail. However, we begin by acquainting the reader with the consultation program itself, and by clarifying the control structure which allows MYCIN to ask only those questions that are appropriate for the patient under consideration.

The Consultation Program

All knowledge used by MYCIN during a consultation session is contained in therapeutic decision rules that have been coded and stored in the machine. The MYCIN Project members have identified approximately 200 such rules during discussions of representative case histories. Each rule consists of a set of preconditions (called a PREMISE) which, if true, permits a conclusion to be made or an action to be taken, according to the ACTION part of the rule. The rules are coded internally in LISP but are translated into English when displayed to the user. The translations are understandable, but at times stilted because natural language processing is not a focus of our research.
For example:

IF: 1) THE STAIN OF THE ORGANISM IS GRAMNEG, AND
2) THE MORPHOLOGY OF THE ORGANISM IS ROD, AND
3) THE AEROBICITY OF THE ORGANISM IS ANAEROBIC
THEN: THERE IS SUGGESTIVE EVIDENCE (.6) THAT THE IDENTITY OF THE ORGANISM IS BACTEROIDES

is a translated version of a rule which is internally coded as:

```
PREMISE: ($AND (SAME CNTXT GRAM GRAMNEG)
               (SAME CNTXT MORPH ROD)
               (SAME CNTXT AIR ANAEROBIC))
ACTION:  (CONCLUDE CNTXT IDENT BACTEROIDES TALLY .6)
```

The interactive Consultation System uses these rules to recommend therapy, relying upon a strategy for rule selection that is described below. A complete consultation session was reproduced in the earlier report (*1*). However, a brief excerpt of a sample session is included here to illustrate the interaction between the clinician and the MYCIN System. An average consultation requires 15–20 min and involves approximately 45 questions; these figures vary with the complexity of the patient case being considered.

After asking a few initial questions regarding the patient's name, sex, and age, MYCIN begins a discussion of recent cultures (the physician's responses are italicized for clarity throughout the paper and program excerpts set off by horizontal bars):

The most recent positive culture for which you desire therapeutic advice will be called:

------CULTURE-1------

4) From what site was the specimen for CULTURE-1 taken?

** *BLOOD*

5) How many days ago was this blood culture (CULTURE-1) obtained?

** *4*

The first offending organism from this blood culture (CULTURE-1) will be called:

------ORGANISM-1------

6) Enter the identity (genus) of ORGANISM-1:

** *UNKNOWN*

7) Staining characteristics of ORGANISM-1 (gram):

** *GRAMNEG*

Since the user in this example does not yet know the identity of the infecting organism(s), as is often the case, MYCIN asks for data that may permit a reasonable deduction regarding the range of possible organisms. The interaction continues until there is no more available information that might allow MYCIN to reduce further the range of possibilities. At that point the program offers a list of its conclusions regarding the identities of the offending organisms:

The therapy recommendation will be based on the following possible identities of the organism(s) that require therapy:

⟨Item 1⟩ The identity of ORGANISM-1 may be PSEUDOMONAS
⟨Item 2⟩ The identity of ORGANISM-1 may be E. COLI
⟨Item 3⟩ The identity of ORGANISM-1 may be KLEBSIELLA

The program now attempts to formulate an appropriate therapy as it asks a few more questions about the patient's allergies, his renal and hepatic status, the site(s) of his infection, his age, and his degree of sickness. The recommended therapy is then displayed:

```
[Recommendation 1] My preferred therapy is as follows:
  In order to cover for Items ⟨1⟩ ⟨2⟩ ⟨3⟩:
    Give the following in combination:

      1  GENTAMICIN
         Dose: 1.7 MG/KG Q8H - IV OR IM
         Comments: MODIFY DOSE IN RENAL FAILURE
      2  CARBENICILLIN
         Dose: 25 MG/KG Q2H - IV
         Comments: MODIFY DOSE IN RENAL FAILURE
```

Since all of MYCIN's knowledge of infectious disease therapy is stored in decision rules, each consultation requires selecting those rules that apply to the patient under consideration. This search problem could be a source of considerable inefficiency because the rules already number 200 and many more are anticipated. We therefore implemented a goal-oriented control structure that allows MYCIN to select appropriate rules and ignore those which are not applicable to the current patient. This approach depends upon two interrelated procedures, a MONITOR that analyzes rules and a FINDOUT mechanism that searches for data needed by the MONITOR.

The MONITOR analyzes the PREMISE of a rule, condition by condition, as shown in Fig. 2. As soon as a condition is found to be false the rule is rejected. However, when a rule is first examined, it often will not be known whether some or all of its conditions are true. When the clinical parameter referenced in a condition is unknown, the MONITOR calls FINDOUT in an attempt to obtain the missing information. FINDOUT then either derives the necessary information (from other rules) or asks the user for the data.

FINDOUT has a dual strategy depending upon the kind of information required by the MONITOR. This distinction is demonstrated in Fig. 3. In general, a piece of data is requested from the user if it is considered in some sense "primitive," as are, for example, most laboratory data. Thus, if the physician knows the identity of an organism (e.g., from a lab report), we would prefer that the system request that information directly rather than try to deduce it via decision rules. However, if the user does not know the identity of the organism, MYCIN uses its knowledge base in an effort to deduce the range of likely organisms.

"Nonlaboratory data" are those kinds of information which require inferences even by the clinician, e.g., whether an organism is a contaminant or whether a previously administrated drug was effective. FINDOUT always attempts to deduce such information first, asking the physician only if MYCIN's knowledge base is inadequate for making the deduction from the information at hand.

Note that FINDOUT is accessed from the MONITOR, but the MONITOR may

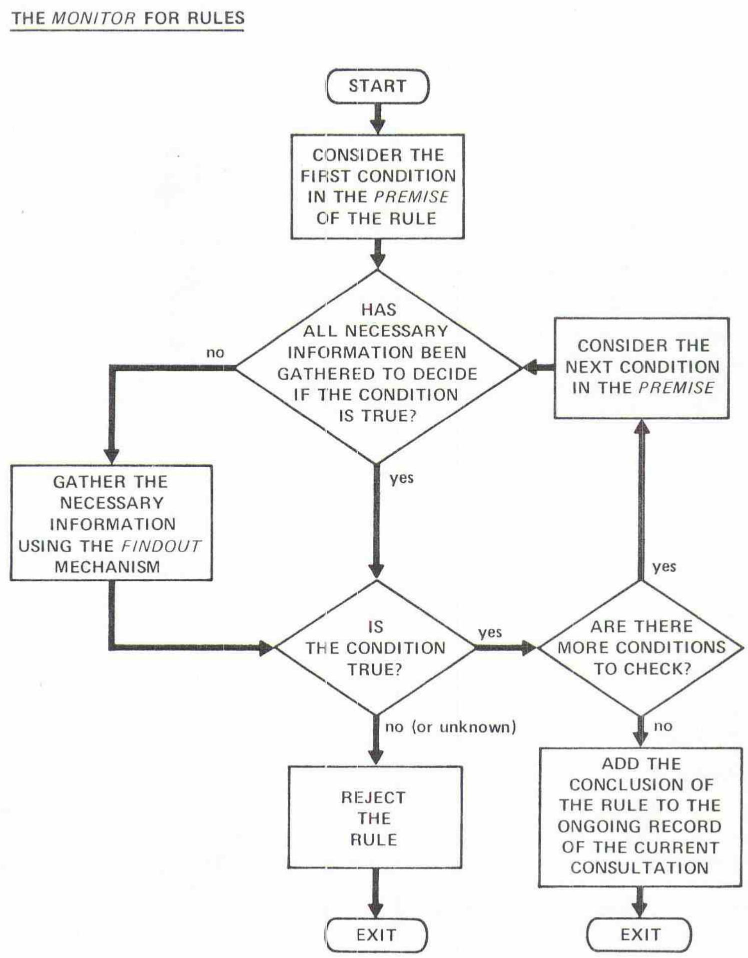

FIG. 2. Flow chart describing the rule MONITOR which analyzes a rule and decides whether it applies in the clinical situation under consideration. Each condition in the PREMISE of the rule references some clinical parameter, and all such conditions must be true for the rule to be accepted.

also be accessed from FINDOUT. This recursion allows self-propagation of a reasoning network appropriate for the patient under consideration and selects only the necessary questions and rules. The Consultation Program starts, therefore, by passing a single goal rule to the MONITOR. All questions and conclusions then occur via recursive calls between FINDOUT and the MONITOR. The goal rule is:

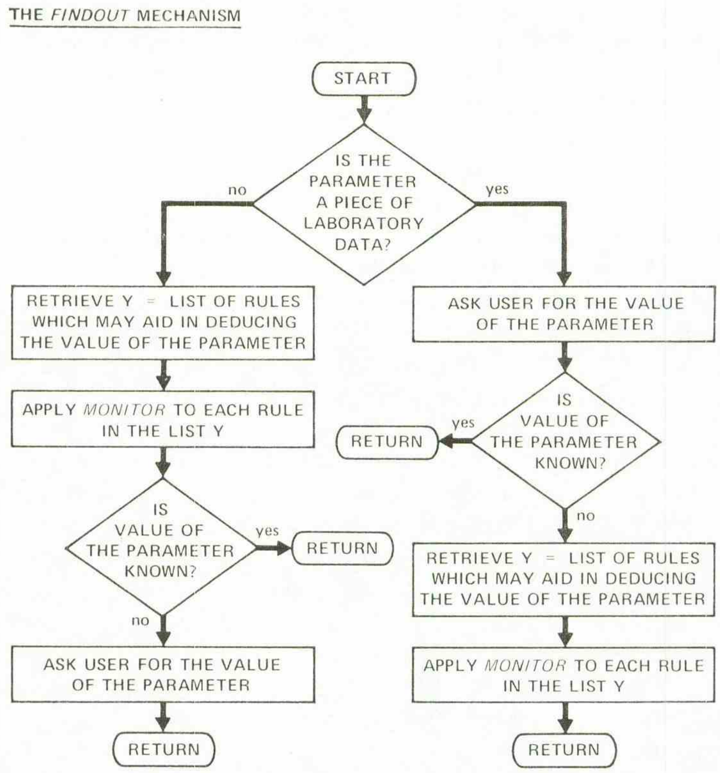

FIG. 3. Flow chart describing the strategy for determining which questions to ask the physician. The derivation of values of parameters may require recursive cells to the MONITOR, thus dynamically creating a reasoning chain specific to the patient under consideration.

IF: 1) THERE IS AN ORGANISM WHICH REQUIRES THERAPY, AND
2) CONSIDERATION HAS BEEN GIVEN TO THE POSSIBLE EXISTENCE OF ADDITIONAL ORGANISMS REQUIRING THERAPY, EVEN THOUGH THEY HAVE NOT ACTUALLY BEEN RECOVERED FROM ANY CURRENT CULTURES

THEN: 1) COMPILE THE LIST OF POSSIBLE THERAPIES WHICH, BASED UPON SENSITIVITY DATA, MAY BE EFFECTIVE AGAINST THE ORGANISMS REQUIRING TREATMENT, AND
2) DETERMINE THE BEST THERAPY RECOMMENDATIONS FROM THE COMPILED LIST

THE EXPLANATION CAPABILITIES

Physicians often voice pessimism about the potential usefulness of a computer-based diagnostic or consultation system, asserting that few clinicians will ever be willing to place life-and-death decisions in the hands of a computer. Many clinicians feel that if errors are going to be made, they would prefer to have made the mistakes themselves rather than to have put misplaced confidence in a machine. It is our belief, therefore, that a consultation program will gain acceptance only if it serves to augment rather than replace the physician's own decision making processes. Gorry has reached a similar conclusion (*3*), stating that one reason for the limited acceptance of Bayesian inference programs (*4*) has been their inability to explain the reasoning behind their decisions.

An important way to emphasize a program's role as a helpful tool, and to establish its credibility, is to permit the clinician to evaluate the program's advice before he acts upon it. Such a capability permits the physician to reject advice which he feels is based upon incomplete or incorrect decision criteria. In addition, the capability can serve an educational role by pointing out decision rules that the physician may wish to incorporate into his own knowledge of clinical medicine.

A major design consideration for the MYCIN System has therefore been the development of an interactive explanation capability (Subprogram 2). Several aspects of the Consultation System's design facilitate the accomplishment of this goal—the modularity of the program's rules simplifies the task of maintaining a record of the program's chain of reasoning, while the use of an interpretive language like LISP makes feasible the examination by the program of its own knowledge base, as well as the translation of the rules into English for display to the user. This ability of the program to keep track of its reasoning and to examine its own knowledge and data is the central component in its ability to explain itself. Using these techniques, the system has been designed to provide explanations in two different situations, each described below.

1. *Examination of the Reasoning Chain during a Consultation*

MYCIN normally takes the initiative during a consultation session; the system asks questions of the physician and uses his answers to determine the applicability of the decision rule it has retrieved. The user who desires an explanation of the program's motivation for a particular question has available to him a set of commands designed to make the examination of the program's reasoning both simple and effective.

WHY Questions: Looking at Goals. Since every question is the result of an attempt to determine the truth of a precondition of a given subgoal, the simplest explanation of MYCIN's motivation for asking a question is a statement of the current subgoal. By typing WHY, the user gets a detailed explanation from the system of the type of conclusion it is trying to draw, and how the current rule is to be applied in this case to establish that conclusion. The system first examines its current reasoning chain to determine the "purpose" of the question, then examines the current rule to determine how it applies in this particular case, and finally translates all of this information from its internal LISP representation into understandable English. The following interaction demonstrates this capability:

In light of the site from which the culture was obtained, and the method of collection, do you feel that a significant number of ORGANISM-1 were obtained?
***WHY*

[1.0] It is important to find out whether there is therapeutically significant disease associated with this occurrence of ORGANISM-1
It has already been established that:
[1.1] the site of the culture is not one of those which are normally sterile, and
[1.2] the method of collection is sterile
Therefore, if:
[1.3] the organism has been observed in significant numbers
Then: there is strongly suggestive evidence (.9) that there is therapeutically significant disease associated with this occurrence of the organism
[Also: there is strongly suggestive evidence (.8) that the organism is not a contaminant]

The user may now understand why this particular question was asked, but may be unsure as to the program's reason for seeking the conclusion mentioned. He can examine this next step in the reasoning by simply repeating "WHY":
***WHY*
[i.e., WHY is it important to find out whether there is therapeutically significant disease associated with this occurrence of ORGANISM-1?]

[2.0] ··· in order to find out a locus of infection in PATIENT-1
It has already been established that:
[2.1] the site of the culture is known, and
[2.2] the number of days since the specimen for the culture was obtained is less than 7
Therefore, if:
[2.3] there is therapeutically significant disease associated with this occurrence of the organism
Then: it is definite (1.0) that the site of the culture is a locus of infection in the patient
***WHY*
[i.e., WHY is it important to find out a locus of infection in PATIENT-1?]

[3.0] ··· in order to find out about an organism or class of organisms for which therapy should cover
It has already been established that:
[3.1] the site of the culture is blood, and

[3.2] the stain of the organism is grampos, and
[3.3] the portal of entry of the organism is GI
Therefore, if:
[3.4] [A- abdomen is a locus of infection in the patient, or B- pelvis is a locus of infection in the patient]
Then: there is strongly suggestive evidence (.9) that enterobacteriaceae is a class of organisms for which therapy should cover

This process may be repeated as often as desired, until the entire current reasoning chain has been displayed.

One problem we anticipated in the use of the WHY command, and one that is common with explanations in general, is the issue of presenting an explanation with the appropriate level of sophistication. Depending on the user, we might want to (a) display explicitly all steps in the chain of reasoning, (b) omit those which are definitional or trivial, or perhaps, for the most sophisticated user, (c) display only the highlights and allow him to supply the details. We have provided this capability by allowing the physician to indicate his level of sophistication with an optional argument to the WHY command. This parameter indicates how large a step in the reasoning process must be before it is displayed. The numerical argument does not indicate how many steps should be encompassed in a single answer, but is in fact a slightly more complex measure intended to reflect the information content of a portion of the reasoning chain. It runs from 0 to 10, where 0 corresponds to a single rule and 10 indicates the extreme case of jumping to the very top of the reasoning chain. The quantification system upon which it is based has been described elsewhere (5). Thus, rather than the multiple WHY's seen above, the user might have asked:

In light of the site from which the culture was obtained, and the method of collection, do you feel that a significant number of ORGANISM-1 were obtained?
** *WHY 2*

We are trying to find out whether the organism has been observed in significant numbers in order to determine an organism or class of organism for which therapy should cover

Once again, this command may be repeated as often as necessary, allowing the user to follow the reasoning chain in step sizes of his own choosing.

We also anticipate that the user may occasionally choose a step size which is too big, and hence leave himself with an explanation which is not at all clear. In the example above, for instance, each individual step in the reasoning chain is straightforward, yet the short explanation which encompassed all the steps can be confusing. In cases like this, the user can invoke the EXPLAIN command, which re-explains the current reasoning step in more detail.

HOW Questions: Looking at Preconditions. We have seen that as the user examines the current reasoning chain, he is informed of the various subgoals the system needs in order to achieve the main goal. At some point he may wish to examine all the ways any subgoal may be achieved. For this examination of additional reasoning chains, he can use the HOW command. Its use is perhaps best explained by the example shown below, which continues the dialog above. Numbers following the HOW command refer to the corresponding item in the preceding example; they should not be confused with the step size indicator used in the WHY command.

** *HOW 3.0*

[i.e., HOW were you finding out about an organism or class of organisms for which therapy should cover?]

[4.0] At that point RULE095 was being used.
In addition:
[4.1] RULE162 was used to conclude that bacteroides is an organism for which therapy should cover, and
[4.2] RULE115 will be tried later, as well.

** *HOW 4.1*

[i.e., HOW was RULE162 used?]

[5.0] We have already established that:
[5.1] the site of the culture is blood, and
[5.2] the portal of entry of the organism is GI, and
[5.3] the patient is a compromised host
Therefore: it is definite (1.0) that bacteroides is an organism for which therapy should cover (RULE162)

** *HOW 4.2*

[i.e. HOW will RULE115 be used?]
[6.0] If:
[6.1] brain-abscess is an infectious disease diagnosis for the patient
Then: there is weakly suggestive evidence (.2) that streptococcus-anaerobic is an organism for which therapy should cover

** *HOW 5.1*

[i.e. HOW was it determined that the site of the culture is blood?]
You said so, in answering question 4.

Note that by numbering each of the answers, we make it possible for the user to trace through any part of the reasoning network. The answers are given in terms of rules already used (e.g., 4.1), those still to be tried (e.g., 4.2), or the user's own responses.

Two points should be noted about the design of the program which generates these explanations. First, consistent with the general philosophy of MYCIN, the approach is domain-independent. Although we have written programs with explicit knowledge of what is required for acceptable explanations, all medical knowledge is obtained by referring to the information stored in the knowledge base of rules.

Second, in attempting to supply information to the user, the system examines its own actions and knowledge base in order to discover what it is trying to do. The explanation program thus monitors the actions of the consultation program by keeping a record of all of its past actions and mimicking its normal control structure when examining possible future actions.

2. *Explaining a Consultation after Advice is Given*

Although the WHY option described above permits MYCIN to explain any question that it asks, the system draws many inferences without requesting information from the physician. This can happen either because the preconditions of a rule were satisfied by deductions from previous information (using other decision rules) or because the needed data had already been requested in the context of a different rule. Thus, even though the physician may understand each question during the consultation itself, MYCIN's final recommendations may puzzle him and he may want to see them justified. Only if he is convinced that the program has valid reasons for its final decisions will he be inclined to accept the advice offered. MYCIN therefore must be able to (a) remember the details of a consultation, (b) understand English-language questions regarding its reasoning, and (c) answer such questions in a fashion that adequately reflects the system's decision processes. We have therefore implemented a question-answering program as a second component of the Explanation System (Subprogram 2).

MYCIN answers questions about its decisions by retrieving and printing the relevant rules. Much of the intelligence of the system thus lies in the portion of the program that finds these "relevant rules." The two types of questions the physician may ask are (a) specific questions about the current consultation, or (b) general questions about any of MYCIN's judgmental rules, whether used in the current consultation or not. The following question-answering (QA) session demonstrates these explanation capabilities:

(a) Specific questions:

> ** *WHAT IS THE IDENTITY OF ORGANISM-1?*
> THE IDENTITY OF ORGANISM-1 IS E. COLI (.30) PROTEUS (.26) PSEUDOMONAS (.24) KLEBSIELLA (.21)
> ** *HOW DID YOU DECIDE THAT ORGANISM-1 MIGHT BE A PSEUDOMONAS?*
> I USED RULE085 TO CONCLUDE THAT THE IDENTITY OF ORGANISM-1 IS PSEUDOMONAS. THIS GAVE A CUMULATIVE CERTAINTY FACTOR OF .24.

(b) General questions:

** *PRINT RULE085*

IF: 1) THE STAIN OF THE ORGANISM IS GRAMNEG, AND
2) THE MORPHOLOGY OF THE ORGANISM IS ROD, AND
3) THE PATIENT IS A COMPROMISED HOST
THEN: THERE IS SUGGESTIVE EVIDENCE (.4) THAT THE IDENTITY OF THE ORGANISM IS PSEUDOMONAS

** *DO YOU EVER PRESCRIBE CARBENICILLIN FOR PSEUDOMONAS INFECTIONS?*

RELEVANT RULES: RULE064 RULE119 RULE120
WHICH ONES DO YOU WISH TO SEE?
** *RULE064*
IF: 1) IT IS KNOWN WITH CERTAINTY THAT THE IDENTITY OF THE ORGANISM IS PSEUDOMONAS, AND
2) THE DRUG UNDER CONSIDERATION IS GENTAMICIN
THEN: RECORD THE FOLLOWING AS A MORE APPROPRIATE THERAPY: GENTAMICIN-AND-CARBENICILLIN

It is also possible to ask the system (c) to explain questions in retrospect (e.g., "Why did you ask question 17?") and (d) to confirm the user's own decision rules (e.g., "Is chloramphenicol okay for Salmonella infections?"). The problem of computer understanding of natural language is a major area of current AI research, but we use several simplifying assumptions that reflect the language processing approaches used in Green (*6*), Colby (*7*), and Quillian (*8*). These include fixed format retrieval requests (*6*), simplified sentence templates (*7*), and semantic word association (*8*). The simplifications permit us to avoid many of the complicated and time-consuming problems of current natural language QA systems (*9*), and are described in more detail elsewhere (*10*).

The Rule Acquisition System

Our recent work has emphasized interactive techniques to permit experts in infectious disease therapy, unfamiliar with the system's programming details, to teach the program new information or to correct old rules. MYCIN can learn from the expert by acquiring new rules that the physician believes are missing. MYCIN then codes the rule for use by the Consultation Program, and FINDOUT is automatically informed so that the new knowledge may be invoked at appropriate times during future advice-giving sessions.

Once an expert has determined what information is missing (a process to which the explanation capability described above is central), he indicates to the Rule Acquisition System (Subprogram 3) that he wishes to enter a new rule. He is then asked to enter the rule in English, following the format of the other rules in the system. MYCIN attempts to translate the rule into a LISP representation and then uses its LISP-to-English routines to print out a version of the rule as it has understood the meaning. The expert is asked to approve the paraphrased version of his new rule or to make further modifications as necessary. A similar procedure allows correction of old rules that the expert finds to be inaccurate or incomplete.

Although MYCIN's early rules were manually coded into LISP, some of the more recent rules have been acquired using the Rule Acquisition System. The system still has difficulty understanding certain kinds of rules, particularly those referencing clinical parameters not already utilized elsewhere in its knowledge base. However, the following sample session shows the kind of rule that the system does know how to learn correctly.

```
—** NEW RULE
The new rule will be called RULE125

      IF:  1—THE ORGANISM IS A GRAM NEGATIVE ROD
     and   2—IT IS ANAEROBIC
     and   3—IT ENTERED THE BLOOD FROM THE GI TRACT
     and   4—
   THEN:   1—IT IS PROBABLY A BACTEROIDES
             On a scale of 1 to 10, how much certainty would you affix to this
             conclusion?
             —** 9
     and   2—

This is my understanding of your rule:
     IF:  1) THE SITE OF THE CULTURE IS BLOOD, AND
          2) THE SITE OF THE CULTURE IS GI, AND
          3) THE STAIN OF THE ORGANISM IS GRAMNEG, AND
          4) THE MORPHOLOGY OF THE ORGANISM IS ROD, AND
          5) THE AEROBICITY OF THE ORGANISM IS ANAEROBIC
   THEN:  THERE IS STRONGLY SUGGESTIVE EVIDENCE (.9) THAT
          THE IDENTITY OF THE ORGANISM IS BACTEROIDES.
```

The user notices that MYCIN has incorrectly interpreted his statement concerning the gastrointestinal tract (GI). He therefore indicates that the program's understanding of the rule is not yet correct.

```
Okay? (YES or NO):
—** NO
Change PREMISE? (YES or NO)
—** YES
Want to see the current version? (YES or NO)
—** NO
```

Change(C), Delete(D), or Add(A) a component:
—** *C*
Which component? (Enter number)
—** *2*
Enter the new component:
New—*PORTAL OF ENTRY IS THE GI TRACT*
More changes to this PREMISE? (YES or NO)
—** *NO*
Change ACTION? (YES or NO)
—** *NO*

This is my understanding of your rule:
IF: 1) THE SITE OF THE CULTURE IS BLOOD, AND
2) THE STAIN OF THE ORGANISM IS GRAMNEG, AND
3) THE MORPHOLOGY OF THE ORGANISM IS ROD, AND
4) THE AEROBICITY OF THE ORGANISM IS ANAEROBIC, AND
5) THE PORTAL OF ENTRY IS GI TRACT
THEN: THERE IS STRONGLY SUGGESTIVE EVIDENCE (.9) THAT THE IDENTITY OF THE ORGANISM IS BACTEROIDES

Note that the PREMISE conditions have been reordered for efficiency; clauses with properties which are most likely to have been referenced before (and whose value will thus be known) are placed near the beginning of the PREMISE.

Okay? (YES or NO)
—** *YES*

Since the new rule is now acceptable to the expert, MYCIN attempts to incorporate the information into its knowledge base. The program recognizes that the rule applies to organisms, but needs help from the user in order to decide with which organisms the rule may be invoked:

This rule may be best described as a rule which:
1—Applies to all organisms
2—Applies to prior organisms only
3—Applies to current organisms only
—** *1*
Do you wish to see the internal representation of the rule? (YES or NO)
—** *YES*

```
   PREMISE: ($AND (SAME CNTXT SITE BLOOD)
                  (SAME CNTXT GRAM GRAMNEG)
                  (SAME CNTXT MORPH ROD)
                  (SAME CNTXT AIR ANAEROBIC)
                  (SAME CNTXT PORTAL GI))
   ACTION: (CONCLUDE CNTXT IDENT BACTEROIDES TALLY .9)
```

An important related problem is how best to avoid undesirable interactions between new rules and the previously acquired knowledge base. Duplicate rules and rules which subsume one another can be handled rather simply by a program designed to identify such problems, but contradictory rules or knowledge inconsistencies are more complex and require interactive "discussion" of the problem with the expert. Our approach to these difficulties is described elsewhere (*10*).

SIGNIFICANCE

Preliminary evaluation of MYCIN's advice has shown that the program currently provides therapeutic recommendations that are acceptable to experts for approximately 75% of randomly selected patients with bacteremia (*10*). When MYCIN has failed to give acceptable advice, it has always been because some crucial rule or rules are missing. Thus, although we anticipate that identification and formulation of the necessary additional rules will make the system sufficiently reliable for introduction and evaluation in the clinical setting, we have not yet made MYCIN available on the wards at Stanford Hospital. Since the attitudes of medical personnel towards computers are often negative (*11*), the premature introduction of a consultation system that performs inadequately might well prevent its eventual acceptance once its advice has improved. We are therefore currently emphasizing the acquisition of new rules for MYCIN and intend to introduce the program in the clinical setting only after its performance is approved by experts at the 90% level or greater.

Once it has been implemented on the hospital wards, MYCIN and its clinical effectiveness will be formally evaluated. Only then can we determine who uses the system, how often it is utilized, and to what extent the program influences the prescribing practices of physicians plus the clinical status of their patients.

When physicians begin to use the system on a regular basis, we will also examine the effectiveness of the explanation and rule acquisition capabilities described in this report. As discussed above, we believe these capabilities strongly contribute to a system which attempts to avoid the recognized pitfalls (*3*) experienced with other diagnostic or consultative programs. Explanation and rule acquisition, plus a variety of human-engineering considerations described in detail elsewhere (*12*), reflect our belief that a consultation program will gain acceptance only if it serves as a useful tool augmenting rather than replacing the physician's own decision making processes.

As MYCIN's decision making strategy has developed and has begun to show its validity, we have become increasingly interested in the possible application of the methodology to other areas of clinical medicine. MYCIN's programs (as opposed to its knowledge base) are not limited to infectious disease therapy because all of its clinical information is isolated in the knowledge base of rules. It is therefore tempting to write new rules for additional medical problem areas and to see whether the MYCIN formalism will allow valid consultations in those areas as well.

Use of the same approach for another problem area has not yet been attempted, however, because we have found that the formulation of decision rules is no straightforward matter. Physicians have not in general structured their own decision processes, and a clinical expert who consistently makes excellent recommendations may have great difficulty describing the steps in reasoning that he uses to make his decisions. One important contribution MYCIN has made to those of us involved in its development has been the analytical rigor it has demanded as we have tried to understand the way in which we make decisions. Many hours of thoughtful analysis and discussion have been distilled in the 200 rules MYCIN uses at present. Since the program can quote these rules in response to queries from users, we anticipate that MYCIN will help the nonexpert physician (as well as the expert–teacher) formulate a logical and ordered approach to the clinical problem that is under consideration during a consultation session.

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