26

Use of MYCIN's Rules for Tutoring

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How can we make the expertise of knowledge-based programs accessible to students? Knowledge-based programs (Davis et al., 1977; Lenat, 1976; Pople, 1977; Goldstein and Roberts, 1977) achieve high performance by interpreting a specialized set of facts and domain relations in the context of particular problems. These knowledge bases are generally built by interviewing human experts to extract the knowledge they use to solve problems in their area of expertise. However, it is not clear that the organization and level of abstraction of this performance knowledge is suitable for use in a tutorial program.

A principal feature of MYCIN's formalism is the separation of the knowledge base from the interpreter for applying it. This makes the knowledge accessible for multiple uses, including explanation of reasoning (Davis, 1976) and tutoring. In this chapter we explore the use of MYCIN's knowledge base as the foundation of a tutorial system called GUIDON. The goal of this project is to study the problem of transferring the expertise of MYCIN-like systems to students. An important result of this study is that although MYCIN-like rule-based expert systems constitute a good basis for tutorial programs, they are not sufficient in themselves for making knowledge accessible to students.

In GUIDON we have augmented the performance knowledge of rules by adding two other levels: a *support level* to justify individual rules, and an *abstraction level* to organize rules into patterns (see Section 26.3.3). The GUIDON system also contains teaching expertise that is represented explicitly and that is independent of the contents of the knowledge base. This

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is expertise for carrying on a tutorial dialogue intended to present the domain knowledge to a student in an organized way, over a number of sessions. Section 26.2 describes design considerations for this tutorial dialogue, given the structure of the knowledge in MYCIN-like problem areas (described in Section 26.1).

GUIDON is designed to transfer the expertise of MYCIN-like programs in an efficient, comprehensible way. In doing this, we overlap several areas of research in intelligent computer-aided instruction (ICAI), including means for structuring and planning a dialogue, generating teaching material, constructing and verifying a model of what the student knows, and explaining expert reasoning.

The nature of MYCIN-like knowledge bases makes it reasonable to experiment with various teaching strategies. The representation of teaching expertise in GUIDON is intended to provide a flexible framework for such experimentation (Section 26.3). To illustrate the use of this framework in the first version of GUIDON, we present in this chapter two sample interactions and describe the domain knowledge and teaching strategies used by the program (Section 26.4 and Section 26.5). The sample interactions and rule listings were generated by the implemented program.

26.1 Description of the Knowledge Base

MYCIN's knowledge base of infectious diseases that we use for tutoring has been built over four years through interactions with physicians. It currently contains approximately 450 rules. In addition, there are several hundred facts and relations stored in tables, which are referenced by the rules. In this chapter, each precondition is called a *subgoal.* If all of the subgoals in the premise can be achieved (shown to be true), then a conclusion can be made about the goal in the action.

The tutoring system we are developing will also work with problems and rules in another domain, assuming some parallels between the structure of the knowledge in the new domain and the structure of the existing medical knowledge. Thus GUIDON is a multiple-domain tutorial program. The overall configuration of this system is shown in Figure 26-1. One advantage of this system is that a fixed set of teaching strategies can be tried in different domains, affording an important perspective on their generality. This method of integrating domain and teaching expertise is quite distinct from the design of early frame-oriented computer-aided instruction (CAI) systems. For example, in the tutor for infectious diseases by Feurzeig et al. (1964), medical and teaching expertise were "compiled" together into the branching structure of the frames (dialogue/content situations). In GUIDON, domain and teaching expertise are decoupled and stated explicitly.

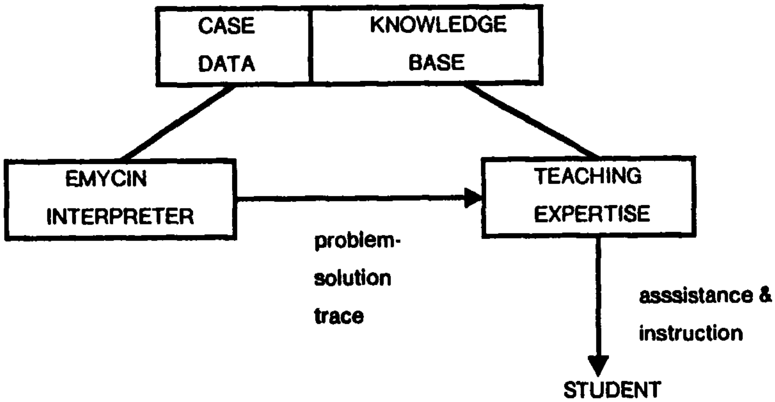

FIGURE 26-1 Modules for a multiple-domain tutorial system.

26.2 Development of a Tutorial Program Based on MYCIN-like Systems

In addition to the domain knowledge of the expert program, a tutorial program requires expertise about teaching, such as the ability to tailor the presentation of domain knowledge to a student's competence and interests (Brown and Goldstein, 1977). The GUIDON program, with its teaching expertise and augmented domain knowledge, is designed to be an active, intelligent agent that helps make the knowledge of MYCIN-like programs accessible to students.

With the original MYCIN system, it was clear that even rudimentary explanations of the system's reasoning could provide some instruction to users. For example, one can ask why case data are being sought by the program and how goals will be (were) achieved. However, we believe that this is an inefficient way for a student to learn the contents of the knowledge base. The MYCIN program is only a passive "teacher": it is necessary for the student to ask an exhaustive series of questions in order to discover all of the reasoning paths considered by the program. Moreover, the MYCIN program contains no model of the user, so program-generated explanations are never tailored to his or her competence or interests. On the other hand, GUIDON acts as an agent that keeps track of the knowledge that has been presented to the student in previous sessions and looks for opportunities to deepen and broaden the student's knowledge of MYCIN's expertise. GUIDON's teaching expertise includes capabilities to measure a student's competence and to use this measure as a basis for selecting knowledge to present. Some of the basic questions involved in converting a rule-based expert program into a tutorial program are:

- What kind of dialogue might be suitable for teaching the knowledge of MYCIN-like consultation systems?
- What strategies for teaching will be useful?
- Will these strategies be independent of the knowledge base content?
- How will they be represented?
- What additions to the performance knowledge of MYCIN-like systems might be useful in a tutorial program?

As the first step in approaching these questions, the following sections discuss some of the basic ways in which MYCIN's domain and formalism have influenced design considerations for GUIDON. Section 26.2.1 describes the nature of the dialogue we have chosen for tutorial sessions. Section 26.2.2 discusses the nature of MYCIN's performance knowledge and argues for including additional domain knowledge in the tutorial program. Sections 26.2.3 and 26.2.4 argue that the uncertainty of MYCIN's knowledge and the size of its knowledge base make it desirable to have a framework for experimenting with teaching strategies. This framework is presented in Section 26.3.

26.2.1 A Goal-Directed Case Dialogue

In a GUIDON tutorial session, a student plays the role of a physician consultant. A sick patient (the *case*) is described to the student in general terms: age, sex, race, and lab reports about cultures taken at the site of the infection. The student is expected to ask for other information that might be relevant to this case. For example, did the patient become infected while hospitalized? Did the patient ever live in the San Joaquin Valley? GUIDON compares the student's questions to those asked by MYCIN and critiques the student's line of reasoning. When the student draws hypotheses from the evidence collected, GUIDON compares these conclusions to those that MYCIN reached, given the same information about the patient. We refer to this dialogue between the student and GUIDON as a *case dialogue*. Because GUIDON attempts to transfer expertise to students exclusively through case dialogues, we call it a *case method tutor*.

GUIDON's purpose is to broaden the student's knowledge by pointing out inappropriate lines of reasoning and suggesting approaches the student did not consider. An important assumption is that the student has a suitable background for solving the case; he or she knows the vocabulary and the general form of the diagnostic task. The criterion for having learned MYCIN's problem-solving methods is therefore straightforward: when presented with novel, difficult cases, does the student seek relevant data and draw appropriate conclusions?

Helping the student solve the case is greatly aided by placing constraints on the case dialogue. A *goal-directed dialogue* is a discussion of the rules applied to achieve specific goals. In general, the topics of this dialogue are precisely those "goals" that are concluded by MYCIN rules.[1] During the dialogue, only one goal at a time is considered; data that cannot be used in rules to achieve this goal are "irrelevant." This is a strong constraint on the student's process of asking questions and making hypotheses. A goal-directed dialogue helps the tutor to follow the student as he or she solves the problem, increasing the chance that timely assistance can be provided.[2]

Our design of GUIDON has also been influenced by consideration of the expected sophistication of the students using it. We assume the students are well motivated and capable of a serious, mixed-initiative dialogue. Various features (not all described in this paper) make the program flexible, so that students can use their judgment to control the depth and detail of the discussion. These features include the capability to request:

- descriptions of all data relevant to a particular goal
- a subgoal tree for a goal
- a quiz or hint relevant to the current goal
- a concise summary of all evidence already discussed for a goal
- discussion of a goal (of the student's choice)
- conclusion of a discussion, with GUIDON finishing the collection of evidence for the goal and indicating conclusions that the student might have drawn

26.2.2 Single Form of Expertise

The problem of multiple forms of expertise has been important in ICAI research. For example, when mechanistic reasoning is involved, qualitative and quantitative forms of expertise may be useful to solve the problem (Brown et al., 1976). De Kleer has found that strategies for debugging an electronic circuit are "radically different" depending on whether one does local mathematical analysis or uses a higher-level, functional analysis of components (Brown et al., 1975). One might argue that a tutor for electronics should also be ready to recognize and generate arguments on both of these levels.[3]

For all practical purposes, GUIDON does not need to be concerned about multiple forms of expertise. This is primarily because reasoning in

[1]A typical sequence of (nested) goals is as follows: (a) reach a diagnosis, (b) determine which organisms might be causing the infection, (c) determine the type of infection, (d) determine if the infection has been partially treated, etc.

[2]Sleeman uses a similar approach for allowing a student to explore algorithms (Sleeman, 1977).

[3]See Carr and Goldstein (1977) for a related discussion.

infectious disease problem solving is based on judgments about empirical information, rather than on arguments based on causal mechanisms (Weiss et al., 1978). MYCIN's judgments are "cookbook" responses that address the data directly, as opposed to attempting to explain it in terms of physiological mechanisms. Moreover, the expertise to solve a MYCIN case on this level of abstraction constitutes a "closed" world (Carbonell and Collins, 1973): all of the objects, attributes, and values that are relevant to the solution of a case are determined by a MYCIN consultation that is performed before a tutorial session begins.[4]

Even though MYCIN's domain makes it possible for cases to be solved without recourse to the level of physiological mechanisms, a student may find it useful to know this support knowledge that lies behind the rules. Section 26.3.3 describes the domain knowledge we have added to MYCIN's performance knowledge in developing GUIDON.

26.2.3 Weak Model of Inquiry

Even though the MYCIN world can be considered to be closed, there is no strong model for ordering the collection of evidence.[5] Medical problem solving is still an art. While there are some conventions to ensure that all routine data are collected, physicians have no agreed-upon basis for numerically optimizing the decision of what to do next.[6] During a tutoring session, it is not only difficult to tell a student what is the "next best" piece of evidence to gather but also difficult to decide what to say about the evidence-gathering strategy. For example, when offering assistance, should the tutor suggest the domain rule that most confirms the evidence already collected or a rule that contradicts this evidence?[7]

26.2.4 Large Number of Rules

MYCIN provides to GUIDON an AND/OR tree of goals (the OR nodes) and rules (the AND nodes) that were pursued during consultation on a case. This tree constitutes a trace of the application of the knowledge base

[4]There is always the possibility that a student may present an exotic case to GUIDON that is beyond its expertise. While MYCIN has been designed to detect simple instances of this (i.e., evidence of an infection other than bacteremia or meningitis), we decided to restrict GUIDON tutorials to the physician-approved cases in the library (currently over 100 cases).

[5]In the WUMPUS program (Carr and Goldstein, 1977), for example, it is possible to rank each legal move (analogous to seeking case data in MYCIN) and so rate the student according to "rejected inferior moves" and "missed superior moves." The same analysis is possible in the WEST program (Burton, 1979).

[6]See, for example, Sprosty (1963).

[7]MYCIN's rules are not based on Bayesian probabilities, so it is not possible to use optimization techniques like those developed by Hartley et al. (1972). Arguments against using Bayes' Theorem in expert systems can be found in Chapter 11.

to the given case.[8] Many of the 450 rules are not tried because they conclude about goals that do not need to be pursued to solve the case. Hundreds of others fail to apply because one or more preconditions are not satisfied. Finally, 20% of the rules typically make conclusions that contribute varying degrees of belief about the goals pursued.

Thus MYCIN's interpreter provides the tutorial program with much information about the case solution (see Figure 26-1). It is not clear how to present this to a student. What should the tutor do when the student pursues a goal that MYCIN did not pursue? (Interrupt? Wait until the student realizes that the goal contributes no useful information?) Which dead-end search paths pursued by MYCIN should the tutor expect the student to consider? For many goals there are too many rules to discuss with the student; how is the tutor to decide which to present and which to omit? What techniques can be used to produce coherent plans for guiding the discussion through lines of reasoning used by the program? One solution is to have a framework that allows guiding the dialogue in different ways. The rest of this paper shows how GUIDON has been given this flexibility by viewing it as a discourse program.

26.3 A Framework for a Case Method Tutorial Program

One purpose of this tutorial project is to provide a framework for testing teaching methods. Therefore, we have chosen an implementation that makes it possible to vary the strategies that the tutor uses for guiding the dialogue. Using methods similar to those used in knowledge-based programs, we have formalized the tutorial program in rules and procedures that codify expertise for carrying on a case dialogue.

This section is a relatively abstract discussion of the kinds of knowledge needed to guide a discourse and the representation of that knowledge. The reader may find it useful to consider the sample dialogues in Figures 26-6 and 26-7 before proceeding.

[8]Before a tutorial session, GUIDON scans each rule used by MYCIN and compiles a list of all subgoals that needed to be achieved before the premise of the rule could be evaluated. In the case of a rule that failed to apply, GUIDON determines all preconditions of the premise that are false. By doing this, GUIDON's knowledge of the case is independent of the order in which questions were asked and rules were applied by MYCIN, so topics can be easily changed and the depth of discussion controlled flexibly by both GUIDON and the student. This process of automatically generating a solution trace for any case can be contrasted with SOPHIE's single, fixed, simulated circuit (Brown et al., 1976).

26.3.1 Discourse Knowledge

Our implementation of GUIDON's dialogue capabilities makes use of knowledge obtained from studies of discourse in AI (Bobrow et al., 1977; Bruce, 1975; Deutsch, 1974; Winograd, 1977). To quote Bruce (1975, emphasis added):

> [It is] . . . useful to have a model of how social interactions typically fit together, and thus a model of discourse structure. Such a model can be viewed as a heuristic which suggests likely *action sequences*. . . . There are places in a discourse where questions make sense, others where explanations are expected. [These paradigms] . . . facilitate generation and subsequent understanding.

Based on Winograd's analysis of discourse (Winograd, 1977), it appears desirable for a case method tutor to have the following forms of knowledge for carrying on a dialogue:

- Knowledge about *dialogue patterns*. Faught (1977) mentions two types of patterns: interpretation patterns (to understand a speaker), and action patterns (to generate utterances). GUIDON uses action patterns represented as *discourse procedures* for directing and focusing the case dialogue. These are the *action sequences* mentioned by Bruce. They are invoked by tutoring rules, discussed in Section 26.3.2.[9]
- Forms of *domain knowledge* for carrying on a specific dialogue. Section 26.3.3 surveys the augmented domain knowledge available to GUIDON.
- Knowledge of the *communication situation*. This includes the tutorial program's understanding of the student's intentions and knowledge, as well as the tutor's intentions for carrying on the dialogue. These components are represented in GUIDON by an *overlay student model* (in which the student's knowledge is viewed as a subset of the expert program's), a *lesson plan* (a plan of topics to be discussed, created by the tutor for each case), and a *focus record* (to keep track of factors in which the student has shown interest recently) (Section 26.3.4). Knowledge of the communication situation controls the use of dialogue patterns.

The following sections give details about these forms of knowledge.

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[9]Because of the constraints a goal-directed dialogue imposes on the student, we have not found it necessary to use interpretation patterns at this time. They might be useful to follow the student's reasoning in a dialogue that is not goal-directed.

26.3.2 Dialogue Patterns: Discourse Procedures and Tutoring Rules

The sequences of actions in discourse procedures serve as an ordered list of options—types of remarks for the program to consider making. For example, the procedure for discussing a domain rule (hereafter, d-rule) includes a step that indicates to "consider mentioning d-rules related to the one just discussed." Thus a discourse procedure step specifies in a schematic form *when* a type of remark might be appropriate. *Whether* to take the option (e.g., is there an "interesting" d-rule to mention?) and *what* to say exactly (the discourse pattern for mentioning the d-rule) will be dynamically determined by tutoring rules (hereafter, t-rules) whose preconditions refer to the student model, case lesson plan, and focus record (hereafter referred to jointly as the communication model).

T-rules are generally invoked as a *packet* to achieve some tutorial goal.[10] T-rule packets are of two types:

1. *T-rules for accumulating belief.* Updating the communication model and determining how "interesting" a topic is are two examples.[11] Generally, a packet of t-rules of this type is applied exhaustively.
2. *T-rules for selecting a discourse procedure to follow.* Generally, a packet of this type stops trying t-rules when the first one succeeds. The form of t-rules of this type is shown in Figure 26-2. Knowledge referenced in the premise part of a t-rule of this type is described in subsequent sections. The action part of these t-rules consists of stylized code, just like the steps of a discourse procedure.[12] A step may invoke:
   a. a packet of t-rules, e.g., to select a question format for presenting a given d-rule
   b. a discourse procedure, e.g., to discuss sequentially each precondition of a d-rule
   c. a primitive function, e.g., to accept a question from the student, perform bookkeeping, etc.

Below is an outline of the t-rules currently implemented in GUIDON. Except where noted, examples of these t-rules are presented in discussions of the sample tutorial dialogues in this chapter.

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[10]Packets are implemented as stylized Interlisp procedures. This should be contrasted with the interpreter used by the expert program that invokes d-rules directly, indexing them according to the goal that needs to be determined.

[11]GUIDON uses MYCIN's certainty factors (Chapter 11) for representing the program's belief in an assertion.

[12]Discourse procedure steps also contain control information (e.g., for iteration) that is not important to this discussion.

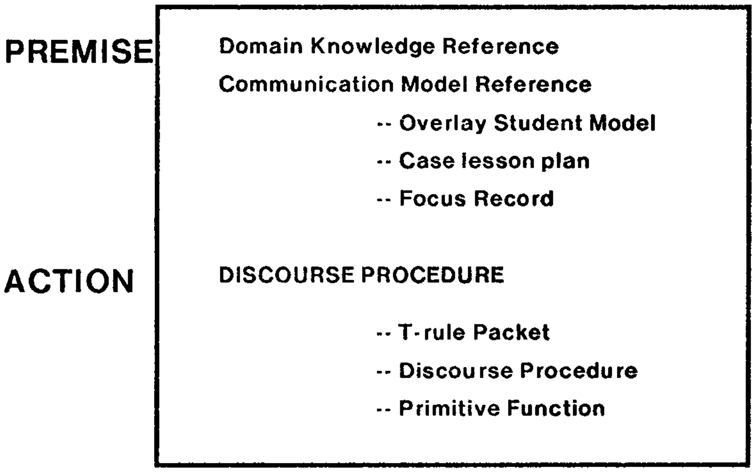

FIGURE 26-2 **Form of a tutorial rule for selecting a discourse procedure.**

1. T-rules for selecting discourse patterns
   a. guiding discussion of a d-rule
   b. responding to a student hypothesis
   c. choosing question formats
2. T-rules for choosing domain knowledge
   a. providing orientation for pursuing new goals (not demonstrated in this paper)
   b. measuring interestingness of d-rules
3. T-rules for maintaining the communication model
   a. updating the overlay model when d-rules fire
   b. updating the overlay model during hypothesis evaluation
   c. creating a lesson plan (not implemented)

All t-rules are translated by a program directly from the Interlisp source code, using an extension of the technique used for translating MYCIN's rules. This accounts for some of the stilted prose in the examples that follow.

I. META-LEVEL ABSTRACTIONS:	rule models rule schemata	
II. PERFORMANCE:	rules lists and tables	
III. SUPPORT:	definitions mechanism descriptions justifications literature references	

FIGURE 26-3 Organization of domain knowledge into three tiers.

26.3.3 Augmented Representation of Domain Knowledge

The representation of domain knowledge available to GUIDON can be organized in three tiers, as shown in Figure 26-3. Subsequent subsections briefly describe the components of each tier, starting with the middle one.

Performance Tier

The performance knowledge consists of all the rules and tables used by MYCIN to make goal-directed conclusions about the initial case data. The output of the consultation is passed to the tutor: an extensive AND/OR tree of traces showing which rules were applied, their conclusions, and the case data required to apply them. GUIDON fills in this tree by determining which subgoals appear in the rules. In Figure 26-4 COVERFOR signifies the goal to determine which organisms should be "covered" by a therapy recommendation; d-rule 578, shown in Figure 26-5, concludes about this goal; BURNED is a subgoal of this rule.

Tutorial rules make frequent reference to this data structure in order to guide the dialogue. For example, the response to the request for help shown in Figure 26-6 (line 17) is based first of all on the rules that were used by MYCIN for the current goal. Similarly, the t-rules for supplying the case data requested by the student check to see if MYCIN asked for the same information, e.g., the WBC (white blood count) in the sample

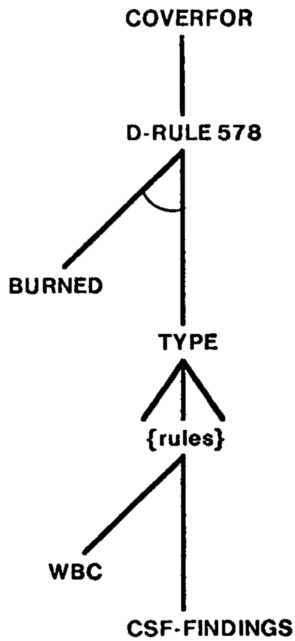

FIGURE 26-4 The portion of the AND/OR tree of goals and rules created by the expert program that is relevant to the dialogue shown in Figure 26-6. Figure 26-5 shows the contents of d-rule 578.

dialogue of Figure 26-6.[13] Associated documentation for d-rule 578 is also shown in Figure 26-5.

Support Tier

The support tier of the knowledge base consists of annotations to the rules and the factors used by them.[14] For example, there are "canned-text" descriptions of every laboratory test in the MYCIN domain, including, for instance, remarks about how the test should be performed. Mechanism descriptions provided by the domain expert are used to provide some explanation of a rule beyond the canned text of the justification. For the infectious disease domain of MYCIN, they indicate how a given factor leads

[13]Other possibilities include: the question is not relevant to the current goal; the case data can be deduced by definition from other known data; or a d-rule indicates that the requested data are not relevant to this case.

[14]Rule justifications, author, and edit date were first proposed by Davis (1976) as knowledge base maintenance records.

Abstraction Level

RULE-SCHEMA: MENINGITIS.COVERFOR.CLINICAL
RULE-MODEL: COVERFOR-IS-MODEL
KEY-FACTOR: BURNED
DUAL: D-RULE577

Performance Level

D-RULE578

IF: 1) The infection which requires therapy is meningitis, and
2) Organisms were not seen on the stain of the culture, and
3) The type of the infection is bacterial, and
4) The patient has been seriously burned

THEN: There is suggestive evidence (.5) that pseudomonas-aeruginosa is one of the organisms (other than those seen on cultures or smears) which might be causing the infection

UPDATES: COVERFOR
USES: (TREATINF ORGSEEN TYPE BURNED)

Support Level

MECHANISM-FRAME: BODY-INFRACTION.WOUNDS
JUSTIFICATION: "For a very brief period of time after a severe burn the surface of the wound is sterile. Shortly thereafter, the area becomes colonized by a mixed flora in which gram-positive organisms predominate. By the 3rd post-burn day this bacterial population becomes dominated by gram-negative organisms. By the 5th day these organisms have invaded tissue well beneath the surface of the burn. The organisms most commonly isolated from burn patients are Pseudomonas, Klebsiella-Enterobacter, Staph., etc. Infection with Pseudomonas is frequently fatal."
LITERATURE: MacMillan BG: Ecology of Bacteria Colonizing the Burned Patient Given Topical and System Gentamicin Therapy: a five-year study, J Infect Dis 124:278-286, 1971.
AUTHOR: Dr. Victor Yu
LAST-CHANGE: Sept. 8, 1976

FIGURE 26-5 Domain rule 578 and its associated documentation. (All information is provided by a domain expert, except for the key factor, which is computed by the tutor from the rule schema and contents of the particular rule. See third subsection of Section 26.3.3.)

to a particular infection with particular organisms by stating the origin of the organism and the favorable conditions for its growth at the site of the infection. Thus the frame associated with the factor "a seriously burned patient" shows that the organisms originate in the air and grow in the exposed tissue of a burn, resulting in a frequently fatal infection.

Abstraction Tier

The abstraction tier of the knowledge base represents patterns in the performance knowledge. For example, a rule schema is a description of a *kind* of rule: a pattern of preconditions that appears in the premise, the goal concluded, and the context of its application. The schema and a canned-text annotation of its significance are formalized in the MYCIN knowledge base by a physician expert. This schema is used by the tutor to "subtract off" the rule preconditions common to all rules of the type, leaving behind the factors that are specific to this particular rule, i.e., the *key factors* of this rule. Thus the key factor of d-rule 578 (see Figure 26-5), the fact that the patient has been seriously burned, was determined by removing the "contextual" information of the name of the infection, whether organisms were seen, and the type of the infection. (Examples of the use of key factors occur throughout the hypothesis evaluation example in Figure 26-7, particularly lines 4–9.)

Rule models (Davis, 1976) are program-generated patterns that represent the typical clusters of factors in the expert's rules. Unlike rule schemata, rule models do not necessarily correspond to domain concepts, although they do represent factors that tend to appear together in domain arguments (rules). For example, the gram stain of an organism and its morphology tend to appear together in rules for determining the identity of an organism. Because rule models capture the factors that most commonly appear in rules for pursuing a goal, they are valuable as a form of orientation for naive students.

Use of Meta-Knowledge in Tutorial Rules

Meta-knowledge of the representation and application of d-rules plays an important role in t-rules. For example, in the dialogue excerpt shown in Figure 26-6 GUIDON uses function templates[15] to "read" d-rule 578 and discovers that the type of the infection is a subgoal that needs to be completed before the d-rule can be applied. This capability to examine the domain knowledge and reason about its use enables GUIDON to make multiple use of any given production rule during the tutorial session. Here are some uses we have implemented:

- examine the rule (if it was tried in the consultation) and determine what subgoals needed to be achieved before it could be applied; if the rule failed to apply, determine all possible ways this could be determined (perhaps more than one precondition is false)
- examine the state of application of the rule during a tutorial interaction (what more needs to be done before it can be applied?) and choose an appropriate method of presentation
- generate different questions for the student
- use the rule (and variations of it) to understand a student's hypothesis
- summarize arguments using the rule by extracting the key point it addresses

[15]A function's template "indicates the order and generic type of the arguments in a typical call of that function" (see Chapter 28).

The ability to use domain knowledge in multiple ways is an important feature of a "generative" tutor like GUIDON.[16] Flexible use of knowledge permits us to write a variety of tutoring rules that select and present teaching material in multiple ways. This is important because we want to use the MYCIN/GUIDON system for experimenting with teaching strategies.

26.3.4 Components of the Communication Model

The components of the communication model are

1. an overlay student model,
2. a case lesson plan, and
3. a focus record.

The Overlay Student Model

The d-rules that were fired during the consultation associated with the given case are run in a forward direction as the student is given case data.[17] In this way, GUIDON knows at every moment what the expert program would conclude based on the evidence available to the student. We make use of knowledge about the history and competence of the student to form hypotheses about which of the expert's conclusions are probably known to the student. This has been termed an *overlay model* of the student by Goldstein, because the student's knowledge is modeled in terms of a subset and simple variations of the expert rule base (Goldstein, 1977). Our work was originally motivated by the structural model used in the WEST system (Burton and Brown, 1982).

Special t-rules for updating the overlay model are invoked whenever the expert program successfully applies a d-rule. These t-rules must decide whether the student has reached the same conclusion. This decision is based on:

- the inherent complexity of the d-rule (e.g., some rules are trivial definitions, others have involved iterations),
- whether the tutor believes that the student knows how to achieve the subgoals that appear in the d-rule (factors that require the application of rules),
- background of the student (e.g, year of medical school, intern, etc.), and
- evidence gathered in previous interactions with the student.

[16]Generative CAI programs select and transform domain knowledge in order to generate individualized teaching material. See Koffman and Blount (1973) for discussion.

[17]This is one application of the problem solution trace. The structure of this trace permits the program to repetitively reconsider d-rules (indexing them by the case data referenced in the premise part), without the high cost of reinterpreting premises from scratch.

These considerations are analogous to those used by Carr and Goldstein for the WUMPUS tutor (Carr and Goldstein, 1977).

The Case Lesson Plan

Before a human tutor discusses a case with a student, he or she has an idea of what should be discussed, given the constraints of time and the student's interests and capabilities. Similarly, in later versions of GUIDON a lesson plan will be generated before each case session.[18] We'd like the lesson plan to give GUIDON a global sense about the value of discussing particular topics, especially since the depth of emphasis will impact on the student's understanding of the problem's solution. The lesson plan of the type we are proposing provides consistency and goal-directedness to the tutor's presentations.

The lesson plan will be derived from:

- The student model: where does the student need instruction?
- Professed student interests (perhaps the case was chosen because of features the student wants to know more about)
- Intrinsic importance of topics: what part does this information play in understanding the solution of the problem?
- Extrinsic importance of topics: given the universe of cases, how interesting is this topic? (A datum that is rarely available is probably worth mentioning when it is known, no matter how insignificant the evidence it contributes.)

We believe that these considerations will also be useful for implementing automatic selection of cases from the consultation library.

The Focus Record

The purpose of the focus record is to maintain continuity during the dialogue. It consists of a set of global variables that are set when the student asks about particular goals and values for goals. T-rules reference these variables when selecting d-rules to mention or when motivating a change in the goal being discussed. An example is provided in Section 26.4.1.

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[18]Goldstein's "syllabus" and BIP's "Curriculum Information Network" are fixed networks that relate skills in terms of their complexities and dependencies. The lesson plan discussed here is a program-generated plan for guiding discussion of a particular problem with a particular student. We believe that a skill network relating MYCIN's rules will be useful for constructing dialogue plans.

26.4 T-Rules for Guiding Discussion of a Goal

In this section we consider an excerpt from a dialogue and some of the discourse procedures and tutoring rules involved. Suppose that a first-year medical student has just read about treatment for burned patients suspected to have a meningitis infection. His microbiology text mentioned several organisms, but it wasn't clear to him how other factors such as the age and degree of sickness of the patient might affect diagnosis of an actual case. GUIDON is available to him, so he decides to ask the program to select a relevant case from the MYCIN library for a tutorial session.

The program begins by invoking the discourse procedure CASE-DISCUSSION. One of the first steps is to choose a case. At this point the student described the case he wanted using keywords ("burned meningitis patient").[19] GUIDON selected the case and set the scene for the student. There is one pending culture from the CSF (cerebral spinal fluid, where meningitis infections occur). In the excerpt in Figure 26-6, the dialogue has reached the subtask of determining the organisms that might be causing the infection.

When the student requested help (line 17), the program had been following the pattern for discussing a goal. The request for help led to the invocation of tutoring rules. The teaching strategy represented by these t-rules is to provide help for a goal by suggesting a d-rule to the student. The discourse procedure that provides help in this context first invokes a packet of t-rules that will choose a d-rule to mention to the student. The second step is to invoke a packet of t-rules that will choose a presentation method.

26.4.1 Choosing a D-Rule to Mention in Order to Provide Help for a Goal

D-rule 578 (Figure 26-5) was chosen because it became the focus of the discussion when the student asked about the relevance of the "burned" factor. That is, when the student asked the question in line 8, a variable was set to indicate that the most recent factor referred to for this goal was "burned" (the focus topic). Then when the packet of t-rules for choosing a d-rule to present was invoked, the following t-rule succeeded:[20]

[19]Student input to the GUIDON program is in the form of menu options and simple English phrases that are parsed using keyword analysis and pattern-matching routines developed for MYCIN's question-answering module (see Chapter 18).

[20]T-rule numbers are of the form <procedure number that invokes the rule>.<index of the rule>. Thus t-rule 26.03 is the third rule in discourse procedure number 26.

You should now proceed to ask questions that will enable you to make a hypothesis about the organisms (other than those seen on cultures or smears) which might be causing the infection.

{Initiative is given to the student; he or she may ask for more data, make a hypothesis, or use a special option.}

**** HOW IS THE FACT THAT THE PATIENT IS BURNED RELEVANT?**

{One option is to ask how a piece of data is relevant to the current goal.}

The fact that patient-326 is seriously burned will be used to conclude that pseudomonas-aeruginosa is one of the organisms which might be present (in addition to those seen on cultures or smears) [Rule 578].

**** HELP**

{The HELP option is a request for assistance: the student asks "where do I go from here?"}

Try to determine the type of the infection: bacterial, fungal, viral, or Tb.

{To provide help, GUIDON chose: (1) a rule to discuss (d-rule 578 was chosen because the dialogue just focused on it); and (2) a method of presentation—"tell the student to finish incomplete subgoals mentioned in the rule." Thus, a new topic is set up, "the type of the infection." Initiative is returned to the student. . . . }

**** WHAT IS THE PATIENT'S WBC?**

The white count from the patient's peripheral CBC is 1.9 thousand.

{The tutor observes that this question is relevant to the new topic and provides the requested data. The dialogue continues in this goal-directed manner . . . }

FIGURE 26-6 Sample interaction: gathering data. Input from the student follows double asterisks; annotations appear in italics within curly brackets. Lines are numbered for reference within the text.

T-RULE26.03

IF: The recent context of the dialogue mentioned either a "deeper subgoal" or a factor relevant to the current goal

THEN: Define the focus rule to be the d-rule that mentions this focus topic

This example illustrates how the communication model guides the session by controlling t-rules. Often there is no obvious d-rule to suggest to the student. It is then useful for the tutor to have some measure of the interestingness of a d-rule at this time in the discussion. The t-rules presented below are applied to a set of d-rule candidates, ranking them by how strongly the tutor believes that they are interesting.

Change in Belief Is Interesting

One measure of interest is the contribution the d-rule would make to what is currently known about the goal being discussed. If the d-rule contributes evidence that raises the certainty of the determined value of the goal to more than 0.2, we say that the value of the goal is now significant.[21] This contribution of evidence is especially interesting because it depends on what evidence has already been considered.

As is true for all t-rules, this determination is a heuristic, which will benefit from experimentation. In t-rule 25.01 we have attempted to capture the intuitive notion that, in general, change in belief is interesting: the more drastic the change, the more interesting the effect. The numbers in the conclusion of t-rule 25.01 are certainty factors that indicate our belief in this interestingness.

T-RULE25.01

IF: The effect of applying the d-rule on the current value of the goal has been determined
THEN: The "value interest" of this d-rule depends on the effect of applying the d-rule as follows:
a. if the value contributed is still insignificant then .05
b. if a new insignificant value is contributed then .05
c. if a new significant value is contributed then .50
d. if a significant value is confirmed then .70
e. if a new strongly significant value is contributed then .75
f. if an insignificant value becomes significant then .80
g. if an old value is now insignificant then .85
h. if belief in an old value is strongly contradicted then .90

Use of Special Facts or Relations Is Interesting

In contrast to that in t-rule 25.01, the measure of interest in t-rule 25.06 below is static. We'd like to make sure that the student knows the information in tables used by the expert program, so we give special consideration to a d-rule that references a table.

T-RULE25.06

IF: The d-rule mentions a static table in its premise
THEN: Define the "content interest" to be .50

26.4.2 Guiding Discussion of a D-Rule

Returning to our example, after selecting d-rule 578, the tutor needed to select a method for presenting it. The following t-rule was successfully applied:

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[21]For example, if the goal is the "organism causing the infection" and the certainty associated with the value "pseudomonas" is 0.3, then this value is significant.

T-RULE2.04

IF: 1) The number of factors appearing in the d-rule which need to be asked by the student is zero, and
2) The number of subgoals remaining to be determined before the d-rule can be applied is equal to 1

THEN: Substep i. Say: subgoal-suggestion
Substep ii. Discuss the goal with the student in a goal-directed mode [Proc001]
Substep iii. Wrap up the discussion of the rule being considered [Proc017]

The premise of this t-rule indicates that all preconditions of the d-rule can be evaluated, save one, and this d-rule precondition requires that other d-rules be considered. The action part of this t-rule is a sequence of actions to be followed, i.e., a discourse pattern. In particular, substep (i) resulted in the program printing "try to determine the type of the infection . . . " (line 22).[22] The discourse procedure invoked by substep (ii) will govern discussion of the type of the infection (in simple terms, a new context is set up for interpreting student questions and use of options). After the type of the infection is discussed (relevant data are collected and hypotheses drawn), the tutor will direct the dialogue to a discussion of the conclusion to be drawn from d-rule 578.

Other methods for suggesting a d-rule are possible and are selected by other t-rules in the packet that contains t-rule 2.04. For example, the program could simply tell the student the conclusion of the d-rule (if the d-rule can be evaluated based on data currently available to the student), or quiz the student about the d-rule, or sequentially discuss each precondition of the d-rule, and so on.

26.5 T-Rules for Responding to a Student's Hypothesis

A student's hypothesis provides the tutor with considerable evidence about the student's knowledge of the d-rules. It is an excellent opportunity for the tutor to update the model of the student's understanding and use that model to make instructive remarks. The chief strategy behind the tutorial remarks illustrated in Figure 26-7 is to state evidence directly, or to use simple true-false questions when the overlay model shows that student is probably ignorant of the rules to apply (lines 10–16), or otherwise to use fill-in and multiple choice questions that are intended to "entrap" the stu-

[22]"Say <label>" designates something the program will "say" to the student. The label is useful for debugging, because every print statement is uniquely labeled.

{After presentation of relevant case data . . . }

**** I THINK THAT THE ORGANISMS PRESENT ARE DIPLOCOCCUS-PNEUMONIAE, PSEUDOMONAS-AERUGINOSA, AND NEISSERIA-MENINGITIDIS.**

Good. The age of the patient gives evidence for concluding that Diplococcus-Pneumoniae might be present (Rule 507). The fact that the patient has been *seriously burned is good reason to suspect* Pseudomonas-Aeruginosa (Rule 578). Both conclusions apply because the infection which requires therapy is meningitis, no organisms were seen on a gram stain of the culture, and the type of the infection is bacterial.

The age of the patient also leads one to suspect Neisseria-Meningitidis (Rule 507). Do the fact that the infection was acquired while the patient was hospitalized and information about the diseases to which the patient has been exposed support this conclusion?

**** NO**

Right, this would be good reason to rule out Neisseria-Meningitidis (Rule 561).

What facts about this case tell you that the organisms that might be present are: E.Coli and Klebsiella-Pneumoniae?

**** HELP**

{The student was expected to describe each factor with a phrase, one per line. Help is provided by listing all relevant factors for the current goal.}

Choose from:

1. The patient does not have a TB risk factor and the patient's x-ray is not abnormal
2. Otitis-media and Epiglottitis are not among the diagnoses which are consistent with the patient's clinical history
3. The white count from the patient's peripheral CBC is less than 2.5 thousand
4. The infection was acquired while the patient was hospitalized
5. The patient has been seriously burned
6. None of these

**** 1 3 4** *{This question was a form of "entrapment." Notice that the choices all appear in Figure 26-8.}*

You're right about the WBC (Rule 557) and the evidence gained from the *fact that the infection was acquired while the patient was hospitalized* (Rule 545). However, the fact that the patient does not have a TB risk factor and the patient's x-ray is not abnormal is weak evidence that Mycobacterium-TB is not one of the organisms which might be present (Rule 160).

FIGURE 26-7 Sample interaction continued: hypothesis evaluation.

dent (lines 17–32). "Entrapment," as used here, involves forcing the student to make a choice that will reveal some aspect of his or her understanding.[23] In this example, all choices listed (lines 24–32) actually

[23]Many of GUIDON's question-asking strategies resemble the "Socratic" strategies formalized by Collins (1976), probably because our production rule representation of domain knowledge makes it convenient to think in terms of "relevant factors" for determining the "value of a goal" (terms we share with Collins). However, the relation between factor and goal in MYCIN is not necessarily causal as it is in the network representation used by Collins.

appear in rules applied by MYCIN (see Figure 26-8). When the student wrongly chose number 1 ("no TB risk factor and no abnormal x-ray"), GUIDON indicated how that evidence actually was used by MYCIN.

26.5.1 Updating the Overlay Student Model After a Student Hypothesis

Figure 26-8 illustrates how the overlay model is updated for the hypothesis in line 1 of Figure 26-7. T-rules are invoked to determine how strongly the tutor believes that the student has taken each of the relevant d-rules into account. That is, a packet of t-rules (packet number 6 here) is tried in the context of each d-rule. Those t-rules that succeed will modify the cumulative belief that the given d-rule was considered by the student. T-rule 6.05 succeeded when applied to d-rules 545 and 557. The student mentioned a value (PSEUDOMONAS) that they conclude (clause 1 of the t-rule) but missed others (clause 3). Moreover, the student did not mention values that can *only* be concluded by these d-rules (clause 2), so the overall evidence that these d-rules were considered is weak (−0.70).[24]

T-RULE6.05

IF: 1) The hypothesis does include values that can be concluded by this d-rule, as well as others, and
2) The hypothesis does not include values that can only be concluded by this d-rule, and
3) Values concluded by the d-rule are missing in the hypothesis
THEN: Define the belief that the d-rule was considered to be −.70

After each of the d-rules applied by MYCIN is considered independently, a second pass is made to look for patterns. Two judgmental tutorial rules from this second rule packet are shown below. T-rule 7.01 applied to d-rule 578: of the d-rules that conclude *Pseudomonas,* this is the only one that is believed to have been considered, thus increasing our belief that d-rule 578 was used by the student. T-rule 7.05 applies to d-rules 545 and 561: the factor NOSOCOMIAL appears only in their premises, and they are not believed to have been considered. This is evidence that NOSOCOMIAL was not considered by the student, increasing our belief that each of the d-rules that mention it were not considered.

T-RULE7.01

IF: You believe that this domain rule was considered, it concludes a value present in the student's hypothesis, and no other rule that mentions this value is believed to have been considered
THEN: Modify the cumulative belief that this rule was considered by .40

T-RULE7.05

IF: This domain rule contains a factor that appears in several rules, none of which are believed to have been considered to make the hypothesis
THEN: Modify the cumulative belief that this rule was considered by −.30

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[24]The certainty factor of −0.70 was chosen by the author. Experience with MYCIN shows that the precise value is not important, but the scale from −1 to 1 should be used consistently.

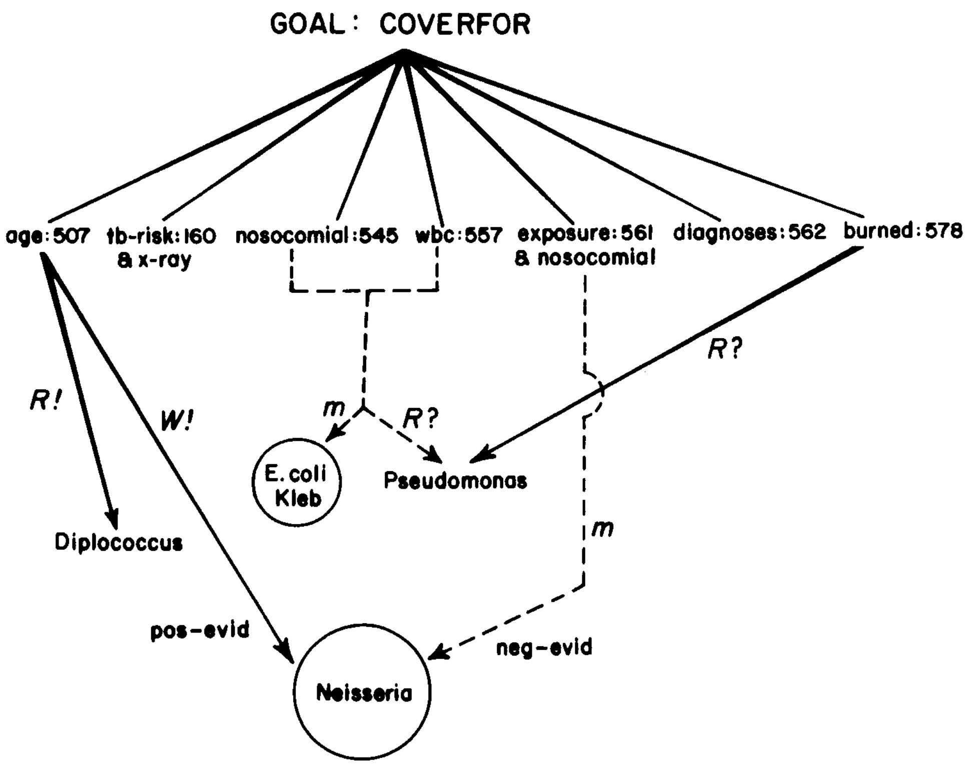

FIGURE 26-8 Interpreting a student hypothesis in terms of expert rules. Key: D-rules that conclude about organisms to cover for are shown with their key factors (see Figure 26-5). Circled values are missing from the student's hypothesis (e.g., E.coli) or wrongly stated (e.g., Neisseria). Dotted lines lead from rules the student probably did not use. Also, *m* = evidence link that the tutor deduced is unknown to the student; *R* and *W* = links to right and wrong values that the tutor believes are known by the student; *!* = unique link, expert knows of no other evidence at this time; *?* = questionable, tutor isn't certain which evidence was considered by the student. For example, *R?* means that the student stated this value, it is correct, and more than one d-rule supplies evidence for it.

Future improvements to this overlay model will make it possible to recognize student behavior that can be explained by simple variations of the expert's d-rules:

1. *Variation in the premise of a d-rule:* The student is using a d-rule that fails

to apply or applies a successful d-rule prematurely (is misinformed about case data or is confused about the d-rule's premise).

2. *Variation in the action of a d-rule:* The student draws the wrong conclusion (wrong value and/or degree of certainty).

26.5.2 Presentation Methods for D-Rules the Student Did Not Consider

Returning to our example, after updating the overlay model, the tutor needs to deal with discrepancies between the student's hypothesis and what the expert program knows. The following t-rules are from a packet that determines how to present a d-rule that the student evidently did not consider. The tutor applies the first tutorial rule that is appropriate. In our example, t-rule 9.02 generated the question shown in lines 10–14 of Figure 26-7. T-rule 9.03 (a default rule) generated the question shown in lines 17–32.

T-RULE9.01

IF: 1) The d-rule is not on the lesson plan for this case, and
2) Based on the overlay model, the student is ignorant about the d-rule
THEN: Affirm the conclusions made by the d-rule by simply stating the key factors and values to be concluded

T-RULE9.02

IF: The goal currently being discussed is a true/false parameter
THEN: Generate a question about the d-rule using "facts" format in the premise part and "actual value" format in the action part

T-RULE9.03

IF: True
THEN: Generate a question about the d-rule using "fill-in" format in the premise part and "actual value" format in the action part

26.5.3 Choosing Question Formats

When the tutor responds to a hypothesis, the context of the dialogue generally determines which question format is appropriate. However, during other dialogue situations it is not always clear which format to use (e.g., when quizzing the student about a rule that MYCIN has just applied using case data just given to the student). Our strategy is to apply special t-rules to determine which formats are logically valid for a given d-rule, and then to choose randomly from the candidates.

T-rule 3.06 is part of a packet of t-rules that chooses an appropriate format for a question based on a given d-rule. The procedure for formatting a question is to choose templates for the action part and premise part that are compatible with each other and the d-rule itself.

T-RULE3.06

IF: 1) The action part of the question is not "wrong value," and
2) The action part of the question is not "multiple choice," and
3) Not all of the factors in the premise of the d-rule are true/false parameters
THEN: Include "multiple choice" as a possible format for the premise part of the question

T-rule 3.06 says that if the program is going to present a conclusion that differs from that in the d-rule it is quizzing about, it should not state the premise as a multiple choice. Also, it would be nonsensical to state both the premise and action in multiple-choice form. (This would be a matching question—it is treated as another question type.) Clause 3 of this t-rule is necessary because it is nonsensical to make a multiple-choice question when the only choices are true and false.

As can be seen here, the choice of a question type is based on purely logical properties of the rule and interactions among question formats. About 20 question types (combined premise/conclusion formats) are possible in the current implementation.

26.6 Concluding Remarks

We have argued in this chapter that it is desirable to add teaching expertise and other levels of domain knowledge to MYCIN-like expert programs if they are to be used for education. Furthermore, it is advantageous to provide a flexible framework for experimenting with teaching strategies, for we do not know the best methods for presenting MYCIN-like rules to a student.

The framework of the GUIDON program includes knowledge of discourse patterns and the means for determining their applicability. The discourse patterns we have codified into procedures permit GUIDON to carry on a mixed-initiative, goal-directed case method dialogue in multiple domains. These patterns are invoked by tutoring rules, which are in turn controlled by a communication model. The components of this model are a lesson plan (topics the tutor plans to discuss), an overlay model (domain knowledge the tutor believes is being considered by the student), and a focus record (topics recently mentioned in the dialogue). Finally, we observed that meta-knowledge about the representation and use of domain rules made it possible to use these rules in a variety of ways during the dialogue. This is important because GUIDON's capability to reason flexibly about domain knowledge appears to be directly related to its capability to guide the dialogue in multiple, interesting ways.

Furthermore, we have augmented the performance knowledge of MYCIN-like systems by making use of support knowledge and meta-level abstractions in the dialogue. The problem-solving trace provided by the interpreter is augmented by GUIDON to enable it to plan dialogues (by looking ahead to see what knowledge is needed to solve the problem) and *to carry on flexible dialogues* (by being able to switch the discussion at any time to any portion of the AND/OR solution tree).

Early experience with this program has shown that the tutor must be selective about its choice of topics if the dialogues are not to be overly tedious and complicated. That is, it is desirable for tutorial rules to exert a great deal of control over which discourse options are taken. We believe that it is chiefly in selection of topics and emphasis of discussion that the "intelligence" of this tutor resides.