**Introduction to Expert Systems: MYCIN**

MYCIN was the first large expert system to perform at the level of a human expert and to provide users with an explanation of its reasoning. Most expert systems developed since MYCIN have used MYCIN as a benchmark to define an expert system. Moreover, the techniques developed for MYCIN have become widely available in the various small expert system building tools.

MYCIN was developed at Stanford University in the mid-1970s. It was designed to aid physicians in the diagnosis and treatment of meningitis and bacteremia infections. MYCIN was strictly a research system. AI investigators wanted to advance the state of expert system building by undertaking a hard problem with clear, practical ramifications.

**MYCIN'S EXPERTISE**

MYCIN provides consultative advice about bacteremia (infections that involve bacteria in the blood) and meningitis (infections that involve inflammation of the membranes that envelop the brain and spinal cord). These infectious diseases can be fatal and often show themselves during hospitalization. A patient, for example, might develop such an infection while recovering from heart surgery. The need to act quickly further compounds the problem. The attending physician typically takes samples to determine the identity of the infectious organisms, but positive identification normally takes 24 to 48 hours. In many cases, the physician must begin treatment in the absence of complete lab results. The diagnosis and treatment of these diseases are complex enough that an attending physician will often seek the advice of an expert.

MYCIN is a computer program designed to provide attending physicians with advice comparable to that which they would otherwise get from a consulting physician specializing in bacteremia and meningitis infections. To use MYCIN, the attending physician must sit in front of a computer terminal that is connected to a DEC-20 (one of Digital Equipment Corporation's mainframe computers) where the MYCIN program is stored. When the MYCIN program is evoked, it initiates a dialogue. The physician types answers in response to various questions. Eventually MYCIN provides a diagnosis and a detailed drug therapy recommendation.

MYCIN reasons about data associated with a patient. It considers, for example, laboratory results of body fluid analyses, symptoms that the patient is displaying, and general characteristics of the patient, such as age and sex. MYCIN obtains this information by interrogating the physician. A MYCIN consultation proceeds in two phases. First a diagnosis is made to identify the most likely infectious organisms. Then one or more drugs are prescribed that should control for all of the possible organisms.

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The antibiotics prescribed must rid the patient of the disease. They must also interact favorably with each other, and be appropriate for the specific patient.

MYCIN may ask for the results of a test that has not yet been completed. In this case the physician must answer UNKNOWN. This is proper because, when diagnosing infections, doctors rarely have the luxury of perusing a complete set of laboratory data. Rather, because early treatment is important, doctors have learned to work from partial information. MYCIN accommodates to this situation by accepting UNKNOWN as a response. Like a human specialist, MYCIN will reason with incomplete information.

In addition to unknown information, there also may be information of which the doctor is uncertain. Ambiguities arise in reading cultures, for example, in labeling symptoms. To accommodate uncertainty, all information given to MYCIN may be qualified by a certainty factor - a number between -1 and +1 - that indicates the doctor's degree of confidence in the answer to a question. Thus, if a doctor is only moderately certain that a particular symptom is present, he or she can respond to a question by typing "YES .4" to indicate a limited confidence in the response.

Doctors, like most consumers of expertise, are often interested in how a conclusion is reached or why information is requested. MYCIN is able to respond to such queries and, within constraints, can explain its reasoning. Users can ask "WHY?" when MYCIN is asking for data, and MYCIN will explain what hypotheses it is considering and how the present question will provide data that will add support or help to rule out that hypothesis. After diagnosis and prescription are complete, the physician can if desired, trace MYCIN's entire diagnostic trail.

A CONSULTATION WITH MYCIN

Perhaps the best way to grasp the flavor of MYCIN is by looking at a transcript of a consultation. The dialogue between MYCIN and the physician is below, with the physician's responses underlined. Our italicized comments are interspersed throughout.

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MYCIN begins by asking for four pieces of information about the patient name, age, sex, and race. All are essential to any diagnosis, so they are asked at the onset of the session.

1) Please enter information about the patient.

Name: Sally
Age: 42 years
Sex: Female
Race: Caucasian

The physician enters the information and MYCIN continues.

2) Are there any positive cultures obtained from SALLY? No
3) Are there any pending cultures of SALLY? **Yes**

4) **Site:** CSF  
   **Date collected:** 3-jun –75  
   **Stain examined?** Yes  
   **Method of Collection:** (urine, sputum only) N/A

5) **Stain of smear: Morph:** (type NONE if no organism was seen on the smear) **None**

The second piece of information that MYCIN wants concerns the availability of cultures with positive readings. Rather than attempting to deduce the results of tests, MYCIN allows the physician to state what is known. In this case the how the physician does not have any positive cultures, and so MYCIN probes further (question 3), asking whether this patient has pending cultures. The patient does—and so MYCIN provides headings for the physician, who enters CSF to indicate that a cerebrospinal fluid culture has been taken but that no organism has yet been seen. MYCIN is unable to reach conclusions from laboratory findings, but like the physician, MYCIN continues to ask questions. Eventually MYCIN reaches this:

13) **Has SALLY recently had symptoms of persistent headache or other abnormal neurologic symptoms (dizziness, lethargy, etc.)?** **Yes**

14) **Has SALLY recently had objective evidence of abnormal neurologic signs (nuchal rigidity, coma, seizures, etc.) documented by physician observation or examination?** **Yes**

The CSF cultures will be considered to be associated with MENINGITIS.

MYCIN's questions 13 and 14 show a more traditional approach to the diagnosis by symptoms, and after receiving the answer to question 14, MYCIN reports its first conclusion: The CSF Infection is likely to be meningitis. MYCIN then begins another line of reasoning aimed at identifying the particular organisms responsible for the meningitis infection. Further questions lead to the following:

34) **Is the meningitis a hospital-acquired infection?** **No**

35) **Is SALLY's clinical history consistent with EPIGLOTTITIS?** **No**

36) **Is SALLY's clinical history consistent with OTITIS-MEDIA?** **No**

37) **Has the patient ever been to an area that is endemic for coccidiomycoses?** Unknown

38) **Is SALLY a burn patient?** **Why**
When asked whether the patient is a burn victim (question 38), the physician responds by typing WHY MYCIN responds by restating its understanding of "why" in this context, and then explains what the information will be used for. To explain, MYCIN displays the particular heuristic rule it was considering, Rule 578, and MYCIN explains how the requested information would be useful.

[i.e. WHY is it important to determine whether SALLY has been seriously burned?]

[4.0] This will aid in determining the organisms (other than those seen on cultures or smears) which might be causing the infection.

It has already been established that
[4.1] the infection which requires therapy is meningitis, and
[4.2] organisms were not seen on the stain of the pending csf culture (CULTURE-1), and
[4.3] the type of the infection may be bacterial

Therefore, if [4.4] SALLY has been seriously burned then there is suggestive evidence that Pseudomonas-aeruginosa is one of the organisms (other than those seen on cultures or smears) which might be causing the infection [RULE578]

[back to question 38 . . .]

**How 4.3**

The physician is curious about how MYCIN was able to conclude that the type of infection is bacterial. "HOW 4.3" is a request to explain how MYCIN established clause [4.3] of the rule it is considering. MYCIN responds with its understanding of the question, and then reports the rules it used in determining this fact. The physician can press for greater detail by asking HOW 4.5 to track down what heuristic Rule 500 is and how it was confirmed. By repeatedly asking HOW, the physician can backtrack right to the beginning of the consultation.

Notice that MYCIN has four rules that support the likelihood that the infection is bacterial, and one rule that suggests (certainty factor of .17) that the infection is not bacterial. MYCIN is considering both possibilities. Momentarily, it is following up on the more probable one.

[i.e. HOW was it established that the type of the infection may be bacterial?]

The following rules concluded about: the likelihood that the type of the infection may be bacterial

<table>
<thead>
<tr>
<th>Rule</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>[4.5] RULE500</td>
<td>(.4)</td>
<td></td>
</tr>
<tr>
<td>[4.6] RULE501</td>
<td></td>
<td>(.17)</td>
</tr>
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</table>
Thus, it has been established that the type of the infection may be bacterial.

*We rejoin MYCIN several questions later as it reports its conclusions about the culprit organisms, and then turns to the final phase of its consultation, the prescription of a set of antibiotics. MYCIN checks for known allergies (question 43), for other characteristics that relate to the use of particular medications, and then for the patient's weight.*

My therapy recommendations will be designed to treat for organisms that either are very likely or, although less likely, would have a significant effect on therapy selection if they were present. It is important to cover for the following probable infection(s) and associated organism(s):

**INFECTION-1 is MENINGITIS**

+ <ITEM-1> MYCOBACTERIUM-TB [from clinical evidence only]
+ . . . COCCIDIOIDES [from clinical evidence only]
+ . . . CRYPTOCOCCUS [from clinical evidence only]

43) *Does SALLY have a clinically significant allergic reaction to any antimicrobial agent? No*

[Considering ETHAMBUTAL-AND-INH-AND-RIFAMPIN for use against INFECTION-1 . . .]

44) *Is SALLY pregnant or breast feeding? No*

45) *Do you have reason to suspect that SALLY may have impaired renal functions? No*

46) **SALLY’s weight in kilograms (or <number> POUNDS): 51.3**

*From these 46 questions MYCIN makes a prescription (REC-1), explains its reasoning, and proposes additional tests and procedures.*

[REC-1] My preferred therapy recommendation is as follows: Give the following in combination:

♦ **ETHAMBUTAL**

Dose: 1.289 (13.0 100mg-tablets) q24h PO for 60 days [calculated on basis of 25 mg/kg] then 770 mg (7.5 100mg-tablets) q24h PO [calculated on basis of 15 mg/kg]

[The dose should be modified in renal failure. One can adjust the dose only if a creatinine clearance or a serum creatinine is obtained.]
Comments: Periodic vision screening tests are recommended for optic neuritis.

2) INH
Dose: 513 mg (5.0 100mg-tablets) q24h PO [calculated on basis of 10 mg/kg]

3) RIFAMPIN
Dose: 600 mg PO q24h
Comments: Administer dose on an empty stomach.

Although I suspect that fungus may be a possible pathogen, in the absence of definitive evidence I will not recommend antifungal therapy at this time. Please obtain samples for fungal, TB, and viral cultures, cytology, VDRL (blood and CSF), cryptococcal antigen (blood and CSF), viral titers (blood and CSF). An infectious disease consult may be advisable.

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MYCIN's explanations, although quite useful, are limited to a review of its reasoning process and a display of its knowledge. MYCIN cannot justify or explain the rules themselves, nor can it define the terms it is using. That is, the physician cannot ask WHY RULE578 or WHAT IS PSEUDOMONAS AERUGINOSA. Rules contain the knowledge gleaned from an expert.

It is assumed that the terms MYCIN uses and the answers it requests are familiar to the physicians using the program. Knowledge systems like MYCIN must be carefully tailored to match characteristics of their user communities. The knowledge engineers who built MYCIN were responsible for making sure that terms such as "culture," "staining," and "Mycobacterium-TB" would be familiar terms to MYCIN's users.

HOW GOOD AN EXPERT IS MYCIN?

MYCIN has been evaluated in several different ways. Its success with several hundred cases has confirmed its competence in identifying the infectious agents, selecting appropriate doses of effective drugs, and recommending additional diagnostic tests.

In one complex evaluation, eight independent evaluators with special expertise in the management of meningitis compared MYCIN's choice of medicines with the choices prescribed by nine human diagnosticians for difficult cases of meningitis. The task used for this test was the selection of drugs for cases of infectious meningitis before the causative agent had been identified. In the first phase of the evaluation, MYCIN and faculty members in the Stanford University Medical School's Division of Infectious Diseases each evaluated 10 cases that had been chosen to offer a wide variety of difficult problems. In the second phase, prominent infectious disease specialists assessed each set of cases and reviewed the diagnoses and prescriptions without knowing either the identity of the prescribers or that one was a computer.

Two evaluative criteria were used: First, prescriptions were evaluated to see whether the recommended drugs would be effective against the actual infective agent.
after it was finally identified. MYCIN and three of the faculty prescribers consistently prescribed therapy that would have been effective in all 10 cases. The second criterion was whether the dose only prescribed drugs adequately covered for other plausible pathogens while avoiding overprescribing. Using this criterion, MYCIN received a higher rating than N any of the human prescribers. In this double-blind study, the evaluators rated MYCIN’s prescriptions correct in 65 percent of the cases, whereas the ratings for the prescriptions of the human specialists ranged from 42.5 to 62.5 percent.

MYCIN's strength in this test against highly qualified human physicians is based on at least four factors:

- MYCIN’s knowledge base, derived from some of the best human practitioners, is extremely disease detailed and is as comprehensive as that of most physicians in the domain of meningitis.
- MYCIN does not overlook anything or forget any details. It considers every possibility. There is a popular saying among doctors that "One has to think of the disease in order to recognize its symptoms." MYCIN considers every possible disease it knows about.
- The program never jumps to conclusions or fails to ask for key pieces of information. No matter how obvious the disease is, MYCIN method of medically checks for all of the details and considers all alternatives.
- MYCIN is maintained at a major medical center and is, consequently, completely current. Several of its therapy recommendations are based on recent data published in specialized journals. Such information is not in textbooks, and would be known only by specialists who monitor the journals and who remember to incorporate new information into their diagnostic procedures.

The various evaluations that have been undertaken all suggest that MYCIN is as good or better than most very skilled human experts.

The original MYCIN program has been changed a number of times for various research purposes. Unlike traditional computer programs, which are very difficult to modify, MYCIN is easy to change. Each of MYCIN's rules is a separate module. Any particular rule can be removed and the system will still run. Likewise, a rule can be modified or a new rule can be added, and the system will immediately be ready to provide advice. Rules can be changed in minutes using English-like input. Compared with software packages of its size, MYCIN is easy to modify.

The ability to add rules and modify reasoning is a key characteristic of expert systems. This feature is as necessary as the ability of the system to reason with uncertainty or to explain its reasoning. Expert systems are developed and maintained incrementally with the active involvement of one or more experts. To remain current and effective, the programs must be easy for users to update.
SUMMARY

MYCIN represents the first of a new generation of computer programs that reason about the world, explain their reasoning, and provide advice that is comparable to advice provided by human experts. MYCIN's development marks a transition in AI research. MYCIN's success proved that expert systems technology was strong enough to leave the laboratory, with its academic and well-circumscribed problems, and enter commercial environments with their incomplete and uncertain information, skeptical users who demand justifications, and domains where substantial amounts of knowledge are the prerequisite of good judgment.