Rule-Based Expert Systems

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Why Do AI Systems Work?

- Knowledge-based AI theories depend on both
  - Process
  - Content (necessitating "content theories")

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The Knowledge-Based Stance to AI Applied to Rule-Based Systems

A system exhibits intelligent understanding and action at a high level of competence primarily because of specific rules

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Recall Key Questions for Knowledge-Based AI

- Knowledge representations
  - What forms can they take?
  - What are the ramifications of different forms?
  - What are the issues and problems for KR?
- Knowledge acquisition/refinement
  - What sources can be harnessed?
  - How can the acquisition process be facilitated?
- Knowledge access and utilization
  - How can knowledge be shared
  - How can it be brought to bear for different tasks?

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Answers from Rule-Based Systems

- Knowledge representations
  - Primary knowledge form: If-then rules, facts, hierarchies
  - Primary knowledge content: Deep knowledge about narrow domains
- Knowledge acquisition/refinement
  - Primary acquisition: Knowledge engineer interacts with domain expert
- Knowledge access and utilization
  - Heuristic search through rules
  - Matching facts in a database

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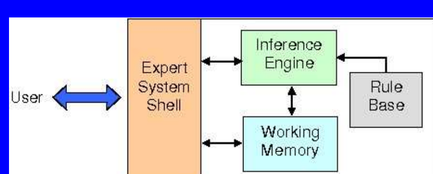
Architecture of a Rule-Based System



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When They're Useful

- Problems hard to solve conventionally (due to lack of good algorithms or computational cost)
- Problems for which knowledge plays bigger role than computation
- Problems for which domain expertise exists

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Why Rule-Based Systems Instead of People?

- Constant availability/accessibility
- Low-cost scaleup to large populations
- Fast response
- Reliability/consistency
- Explanation
- Persistence of knowledge

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Applications

Classification - identify a class member based on characteristics

Diagnosis - infer malfunction or disease from observable data

Monitoring - compare data from a continually observed system to prescribe behavior

Process Control - control a physical process based on monitoring

Design - configure a system according to specifications

Scheduling & Planning - develop or modify a plan of action

Generation of Options - generate alternative solutions to a problem

From Joshi,
http://www.umsl.edu/~joshik/msis480/chapt11.htm

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Rule-Based Systems Examples

- Bagger (simple demo)
- Mycin (landmark system)

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MYCIN

- Developed at Stanford University in 1972
- Regarded as the first true “expert system”
- **Assist physicians in the treatment of blood infections**
- Many revisions and extensions to MYCIN over the years

Mycin slides adapted from John MacIntyre

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The MYCIN Problem

- Physician wishes to specify an “antimicrobial agent” - basically an antibiotic - to kill bacteria or arrest their growth
- Why is this a good task for an expert system?

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Why an Expert System

- High stakes task: Some agents are poisonous!
- Requires expert knowledge: No agent is effective against all bacteria
- Most physicians are not expert in the field of antibiotics, so
  - Antibiotics were prescribed (still huge problem!)
  - Additional expertise could be needed fast

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Breakout groups (10 minutes)

- Define ~3-5 main process phases for an expert system that interacts with a new patient and prescribes antibiotics
- Give an example of one rule (expressed in English) that the system might use for each phase
- Prepare a slide to share with the class

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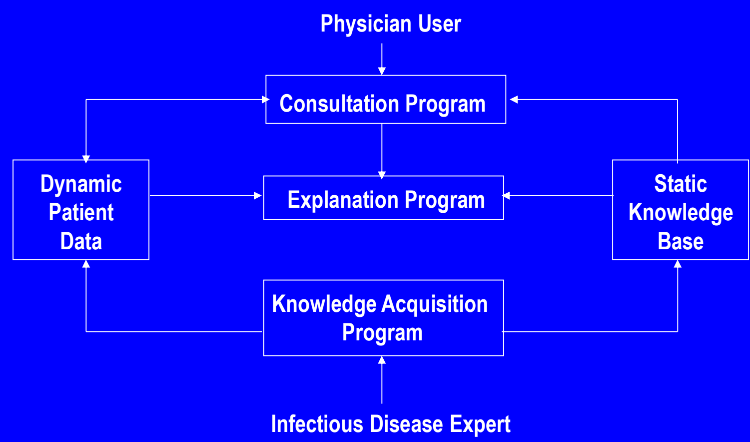
Mycin's Decision Process

- Mycin asks four questions in the process of deciding on treatment:
  - **Does the patient have a significant infection?**
  - **What are the organism(s) involved?**
  - **What set of drugs might be appropriate to treat the infection?**
  - **What is the best choice of drug or combination of drugs to treat the infection?**

MYCIN Components

- **KNOWLEDGE BASE:**
  - **facts and knowledge about the domain**
- **DYNAMIC PATIENT DATABASE:**
  - **information about a particular case**
- **CONSULTATION MODULE:**
  - **asks questions, gives advice on a particular case**
- **EXPLANATION MODULE:**
  - **answers questions and justifies advice**
- **KNOWLEDGE ACQUISITION PROGRAM:**
  - **adds new rules and changes exisiting rules**

Basic MYCIN Structure



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The MYCIN Knowledge Base

- Where the rules are held
- Basic rule structure in MYCIN is:

  if* condition$_1$ *and....and* condition$_m$ *hold

  ***then draw* conclusion$_1$ *and....and* condition$_n$**
- Rules written in the LISP-like form
- Rules can include certainty factors to help weight the conclusions drawn

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An Example Rule (English)

IF:(1) The stain of the organism is Gram negative, and

(2) The morphology of the organism is rod, and

(3) The aerobicity of the organism is aerobic

THEN:

There is strongly suggestive evidence (0.8) that the class of the organism is *Enterobacteriaceae*

Example Rule (Lisp)

```
(defrule 73
if (site culture is blood)
   (gram organism is neg)
   (morphology organism is rod)
   (aerobicity organism is anaerobic)
then .9
   (identity organism is bacteroides))
```

Example Metarule (English)

If The infection is pelvic-abscess
AND There are rules that mention in their premise Enterobacteriaceae
AND There are rules that mention in their premise gram positive rods
THEN There is suggestive evidence that the rules dealing with Enterobacteriaceae should be invoked before those dealing with gram positive rods

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Calculating Certainty

- Rule certainties are related to probabilities
- Therefore must ~ apply the rules of probability in combining rules
- Multiplying probabilities which are less than certain results in lower and lower certainty!
- Eg 0.8 x 0.6 = 0.48

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MYCIN Control Structure

- Uses a goal-based strategy to attempt to solve a **TOP LEVEL GOAL**
- Establishes sub-goals required to satisfy the top level goal
- Therefore, is using backward chaining

Selection of Therapy

- Done after the diagnostic phase is complete
- Two phases:
  - Selection of a list of candidate drugs
  - Choice of preferred drugs or combinations of drugs from the list
- Therapy rules use information on:
  - Sensitivity of organism to drug
  - Contraindications on the drug

Example Recommendation

IF: The identity of the organism is *Pseudomonas*

THEN:

I recommend therapy from the following drugs:

1 - COLISTIN (0.98)

2 - POLYMYXIN (0.96)

3 - GENTAMICIN (0.96)

4 - CARBENICILLIN (0.65)

5 - SULFISOXAZOLE (0.64)

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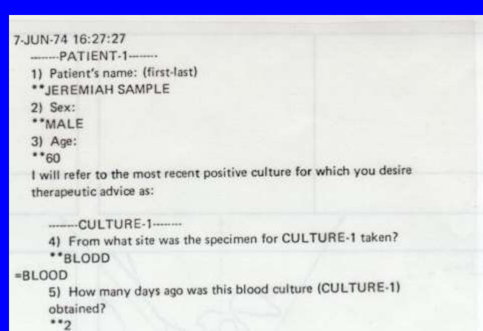
Sample System Output



```
7-JUN-74 16:27:27
   --------PATIENT-1--------
   1) Patient's name: (first-last)
   **JEREMIAH SAMPLE
   2) Sex:
   **MALE
   3) Age:
   **60
   I will refer to the most recent positive culture for which you desire
   therapeutic advice as:

      --------CULTURE-1--------
      4) From what site was the specimen for CULTURE-1 taken?
      **BLODD
=BLOOD
      5) How many days ago was this blood culture (CULTURE-1)
      obtained?
      **2
```

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I will refer to the first offending organism from this blood culture (CULTURE-1) as:

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

6) Enter the identity (genus) of ORGANISM-1:
**UNK
7) Staining characteristics of ORGANISM-1 (gram):
**?
WHAT IS THE STAIN OF ORGANISM-1?
Expected responses are: ACIDFAST GRAMPOS GRAMNEG
Enter HELP for list of user options.
**GRAMNEG
8) Is ORGANISM-1 a rod or coccus (etc.):
**ROD
9) Were any organisms that were significant (but no longer require therapeutic attention) isolated within the last approximately 30 days?
**YES

-------CULTURE-2-------

10) From what site was the specimen for CULTURE-2 taken?
**SPUTUM
11) How many days ago was this upper-resp culture (CULTURE-2) obtained?
**4 1/2 DAYS
PLEASE USE DECIMAL NUMBERS FOR FRACTIONS
4 1/2 DAYS NOT A RECOGNIZED RESPONSE
WHAT IS THE NUMBER OF DAYS SINCE THE SPECIMEN FOR THIS UPPER-RESP CULTURE WAS ACQUIRED?
Expected responses are: NUMBER OF DAYS
Enter HELP for list of user options.
**4.5
I will refer to the prior organism from this upper-resp culture (CULTURE-2) as:

-------ORGANISM-2-------

12) Enter the identity (genus) of ORGANISM-2:
**PSEUDOMONAS
13) Any other significant organisms isolated from this upper-resp culture (CULTURE-2)?
**YES

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After Additional Questions

44) How many of the cultures were positive for ORGANISM-1?
**2

[Note that the certainty factor (CF) *for* RULE044 *is calculated from the answers to questions 43 and 44.* CF's *are explained in Chapter 4.]*

45) Any other organisms isolated from this blood culture (CULTURE-1) for which you would like a therapeutic recommendation?
**NO
46) Does Jeremiah Sample (PATIENT-1) show any evidence of infection at a site inaccessible to culture (e.g., brain, bone, liver, etc.)?
**NO
47) Were any additional positive specimens recently drawn from Jeremiah Sample (PATIENT-1) which revealed one or more organisms for which you wish therapeutic advice?
**NO

[MYCIN *has now asked all questions necessary in order to decide (a) whether* ORGANISM-1 *is significant, and (b) the likely identities of* ORGANISM-1.]

My therapy recommendation will be based on the following possible identities of the organism(s) that seem to be significant:
<Item 1> The identity of ORGANISM-1 may be PSEUDOMONAS
<Item 2> The identity of ORGANISM-1 may be KLEBSIELLA
<Item 3> The identity of ORGANISM-1 may be ENTEROBACTER
<Item 4> The identity of ORGANISM-1 may be E.COLI
<Item 5> The identity of ORGANISM-1 may be PROTEUS (Subtype unknown)

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MYCIN

[MYCIN *now begins asking questions to assist with drug selection.*]

48) On a scale of 0 to 4, where higher numbers indicate increasing severity, how would you rate Jeremiah Sample (PATIENT-1)'s degree of sickness?
**4
49) Does Jeremiah Sample (PATIENT-1) have a clinically significant allergic reaction to any antimicrobial agent?
**NO
[Considering GENTAMICIN for use against ORGANISM-1 . . .]

[Rec 1] My preferred therapy recommendation is as follows:
In order to cover for Items <1> <2> <3> <4> <5>:
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

Do you wish to see the next choice?
**YES
[Considering COLISTIN for use against ORGANISM-1 . . .]
[Rejecting SULFISOXAZOLE for use against ORGANISM-1 . . .]

[Rec 2] Next best therapy recommendation:
In order to cover for Items <1> <2> <3> <4>:
Give: COLISTIN
Dose: 1.25 MG/KG Q6H - IM
Comments: MODIFY DOSE IN RENAL FAILURE
Do you wish to see the next choice?
**NO

[*The Consultation System (Subprogram 1) is now finished. Control therefore automatically passes to the Explanation System (Subprogram 2).*]

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Evaluating MCYIN

- Many studies show that MYCIN's recommendations compare favourably with experts for diseases like meningitis
- Study compared on real patients with expert and non-expert physicians:
  - MYCIN matched experts
  - MYCIN was better than non-experts

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Example Evaluation

Blind evaluation of prescriptions from MYCIN and 9 other providers, for 10 real cases.

Prescriber	%Acceptable	Pathogen Missed
MYCIN	70	0
Prior Rx	70	0
Faculty-4	50	0
Faculty-1	50	1
Faculty-2	50	1
Fellow	50	1
Faculty-3	40	0
Faculty-5	30	0
Resident	30	1
Student	10	3

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MYCIN Limitations

- Research tool with limited knowledge base - only covers a small number of infectious diseases
- Doctors reluctant to use it
- Poor interface

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Mycin Lessons

- Expert systems can match domain experts
- The control structure was simple---backwards chaining search---but was sufficient
- High quality performance arose from system knowledge, in the form of rules
- MYCIN lead to emycin, an expert system “shell” for to which developers could add their own rules

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Knowledge Engineering

- Rule-based system rules are *declarative* (vs. *procedural* programming, as in most programming languages)
- How are rule-based system rules generated?
- Process:
  - Interview experts
  - Determine right level of abstraction
  - Determine units of knowledge
  - Code rules
  - Test and repeat

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Form of Rules

- Rules are "If-then" rules
- Rules may refer to specific assertions in memory or may include variables to match any fact with the correct form
- To avoid a flood of specific rules, rules should infer aspects of the environment one bit at a time
- You'll need to "blur" some details

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Breakout Groups: Developing Rules

- Pick topic for forward-chaining system (e.g., controlling traffic lights, deciding a class to take, deciding whether to go to a restaurant)
- Thinking of Russell and Norvig PEAS* description for domain
- Develop 3-5 rules connecting sensor inputs to intermediate conditions and then actions.

*Performance measure, environment, actuators, sensors

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Illustration for Self-Driving Car

- Sensors include car engine warning lights
- Sample rules:

```
IF (and (warning-light ?light)
        (illuminated? ?light)
        (severe-condition-indicator ?light))
THEN (add (goal stop-car))

IF (and (goal stop-car)
        (current-speed high))
THEN (add (goal slow-car))
```

-

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Considerations for Driving Rules

- Safely slowing a car may depend on closeness of other vehicles and their speed
- Safely stopping may depend on the lane you’re in and whether the shoulder is clear

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If-then in Programming vs. in Rule-Based Systems

- In programming, "If-then-else" is for control: determines what the program does next.
- In rule-based systems, "If-then" is usually for updating system beliefs: If one belief holds, another can be added.
- Example:
  - If the fire alarm is going off and it isn't raining, there's a fire
- In RBSes, what's important is that the conclusion can be drawn, not necessarily when
- For RBSes, when could "when" matter?

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If-then in Programming vs. in Rule-Based Systems (continued)

- Rule-based systems rules have no "else" clause. If rule doesn't fire, rule has no effect.
- Rule-based systems rules could be applied in any order.
  - At each step, system collects rules which are triggered (conditions are met)
  - Conflict resolution strategies determine which one to fire
  - Cycle repeats

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Search Strategy for Rule Application

- Forward vs. backward chaining
- Search strategy for applying chaining

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