Rule-based Systems

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Modi of usage:

- **Query:** Facts are retrieved from database or user is interrogated
- **Explanation:** System answers questions how a decision was concluded

Example rule base:

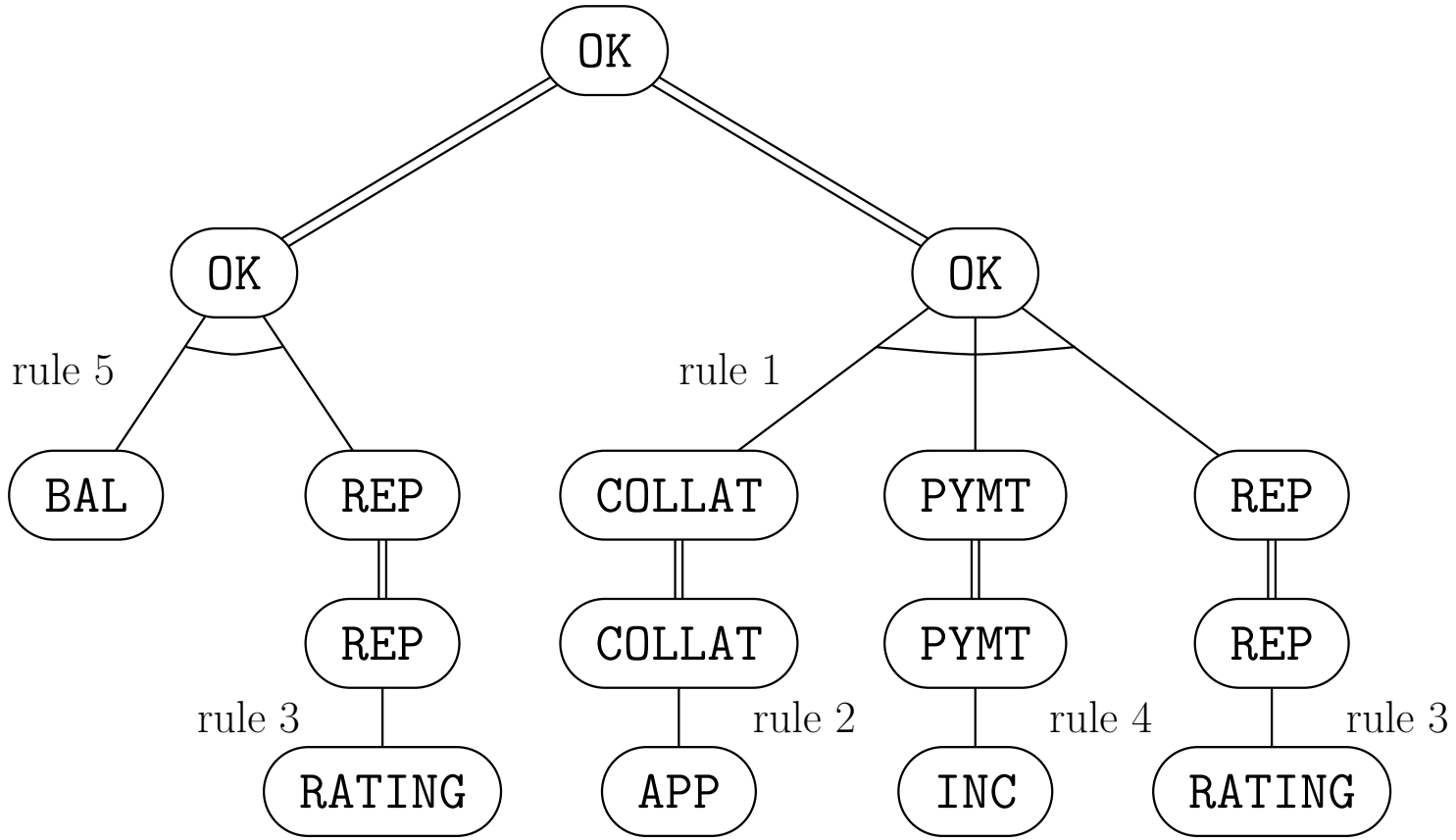
1. $\texttt{COLLAT} \wedge \texttt{PYMT} \wedge \texttt{REP} \Rightarrow \texttt{OK}$
2. $\texttt{APP} \Rightarrow \texttt{COLLAT}$
3. $\texttt{RATING} \Rightarrow \texttt{REP}$
4. $\texttt{INC} \Rightarrow \texttt{PYMT}$
5. $\texttt{BAL} \wedge \texttt{REP} \Rightarrow \texttt{OK}$

Description:

COLLAT	satisfactory collateral
PYMT	payments undisputed
REP	good reputation
APP	high appraisal
RATING	good rating
INC	positive income
BAL	excellent balance
OK	loan will be approved

Decision Rule Tree

Corresponding `and/or`-Tree:



Example Queries

- **User:** Why do you believe that the loan should be approved?
- **System:** Because the collateral for the loan is satisfactory, and the applicant is able to make the loan payments, and the applicant has a good financial reputation.
- **User:** Why did you ask me about whether or not the applicant's income exceeds his/her expenses?
- **System:** Because I was trying to establish whether or not the applicant is able to make the loan payments.
- **User:** Why do you believe that the applicant has a good financial reputation?
- **System:** Because the credit rating service said that the applicant has a good credit rating.

Rules

- A rule in general is a *if-then*-construct consisting of a *condition* and an *action*.

  If *condition* then *conclusion*

- These two parts may be interpreted differently according to the context:
  - **Inference rules**: If *premise* then *conclusion*
  - **Hypotheses:** If *evidence* then *hypothesis*
  - **Productions:** If *condition* then *action*

- Rules are often referred to as *productions* or *production rules*.

Rules

- A rule in the ideal case represents a unit of knowledge.
- A set of rules together with an execution/evaluation strategy comprises a program to find solutions to specific problem classes.
- Prolog program: rule-based system
- Rule-based systems are historically the first types of AI systems and were for a long time considered prototypical expert systems.
- Nowadays, not every expert systems uses rules as its core inference mechanism.
- Rising importance in the field of business process rules.

Rule Evaluation

Forward chaining

- Expansion of knowledge base: as soon as new facts are inserted the system also calculates the conclusions/consequences.
- Data-driven behavior
- Premises-oriented reasoning: the chaining is determined by the left parts of the rules.

Backward chaining

- Answering queries
- Demand-driven behavior
- Conclusion-oriented reasoning: the chaining is determined by the right parts of the rules.

Components of a Rules-based System

Data base

- Set of structured data objects
- Current state of modeled part of world

Rule base

- Set of rules
- Application of a rule will alter the data base

Rule interpreter

- Inference machine
- Controls the program flow of the system

Rule Interpretation

- Main scheme forward chaining
  - Select and apply rules from the set of rules with valid antecedences. This will lead to a modified data base and the possibility to apply further rules.
- Run this cycle as long as possible.
- The process terminates, if
  - there is no rule left with valid antecendence
  - a solution criterion is satisfied
  - a stop criterion is satisfied (e. g. maximum number of steps)
- Following tasks have to be solved:
  - Identify those rules with a valid condition
    $\Rightarrow$ **Instantiation** or **Matching**
  - Select rules to be executed
    $\Rightarrow$ need for **conflict resolution**
    (e. g. via partial or total orderings on the rules)

Certainty Factors

Mycin (1970)

- **Objective:** Development of a system that supports physicians in diagnosing bacterial infections and suggesting antibiotics.
- **Features:** Uncertain knowledge was represented and processed via *uncertainty factors*.
- **Knowledge:** 500 (uncertain) decision rules as static knowledge base.
- **Case-specific knowledge:**
  - static: patients' data
  - dynamic: intermediate results (facts)
- **Strengths:**
  - diagnosis-oriented interrogation
  - hypotheses generation
  - finding notification
  - therapy recommendation
  - explanation of inference path

Uncertainty Factors

- Uncertainty factor $\quad \mathrm{CF} \in [-1, 1] \quad \approx \quad$ degree of belief.
- Rules:

$$\mathrm{CF}(A \to B) \begin{cases} = 1 & B \text{ is certainly true given } A \\ > 0 & A \text{ supports } B \\ = 0 & A \text{ has no influence on } B \\ < 0 & A \text{ provides evidence against } B \\ = -1 & B \text{ is certainly false given } A \end{cases}$$

A Mycin Rule

```
RULE035

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

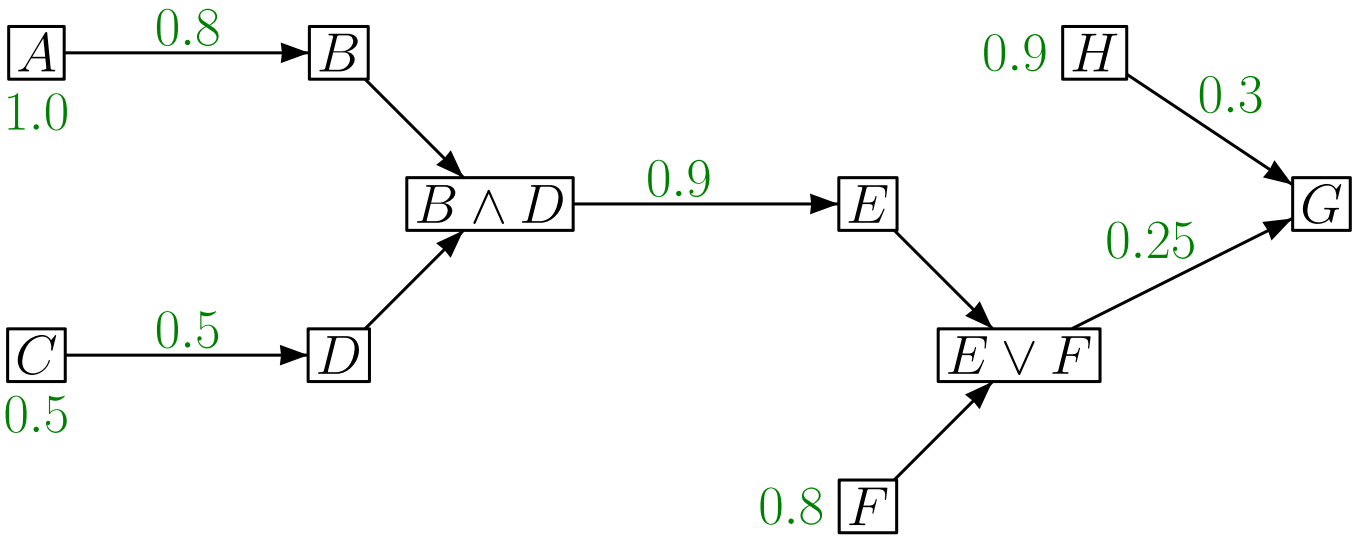
If 1) the *gram stain* of the organism is *gramneg*, and
2) the *morphology* of the organism is *rod*, and
3) the *aerobicity* of the organism is *anaerobic*

then there is suggestive evidence (0.6) that the
identity of the organism is *bacteroides*

Example

$$A \rightarrow B\,[0.80]$$
$$C \rightarrow D\,[0.50]$$
$$B \wedge D \rightarrow E\,[0.90]$$
$$E \vee F \rightarrow G\,[0.25]$$
$$H \rightarrow G\,[0.30]$$

$$A\,[1.00]$$
$$C\,[0.50]$$
$$F\,[0.80]$$
$$H\,[0.90]$$



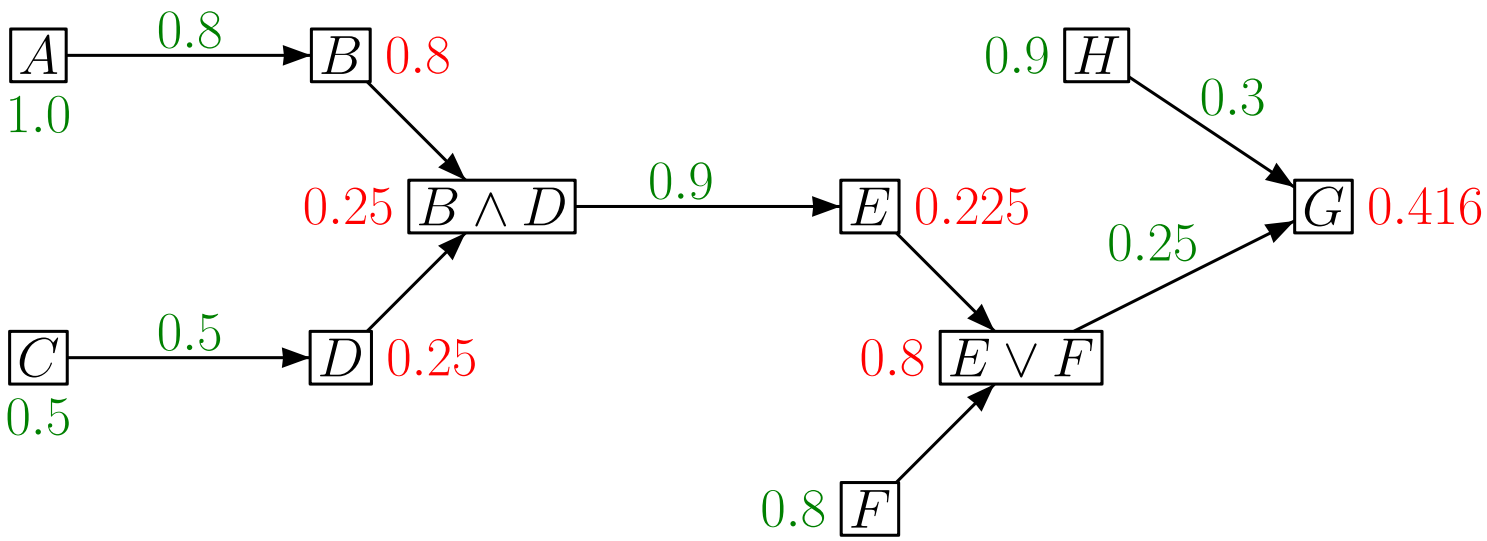
Propagation Rules

- **Conjunction:** $\mathrm{CF}(A \wedge B) = \min\{\mathrm{CF}(A), \mathrm{CF}(B)\}$
- **Disjunction:** $\mathrm{CF}(A \vee B) = \max\{\mathrm{CF}(A), \mathrm{CF}(B)\}$
- **Serial Combination:** $\mathrm{CF}(B, \{A\}) = \mathrm{CF}(A \to B) \cdot \max\{0, \mathrm{CF}(A)\}$
- **Parallel Combination:** for $n > 1$:
  $\mathrm{CF}(B, \{A_1, \ldots, A_n\}) =$
  $f(\mathrm{CF}(B, \{A_1, \ldots, A_{n-1}\}), \mathrm{CF}(B, \{A_n\}))$

with

$$f(x, y) = \begin{cases} x + y - xy & \text{if} \quad x, y > 0 \\ x + y + xy & \text{if} \quad x, y < 0 \\ \dfrac{x + y}{1 - \min\{|x|, |y|\}} & \text{otherwise} \end{cases}$$

Example (cont.)



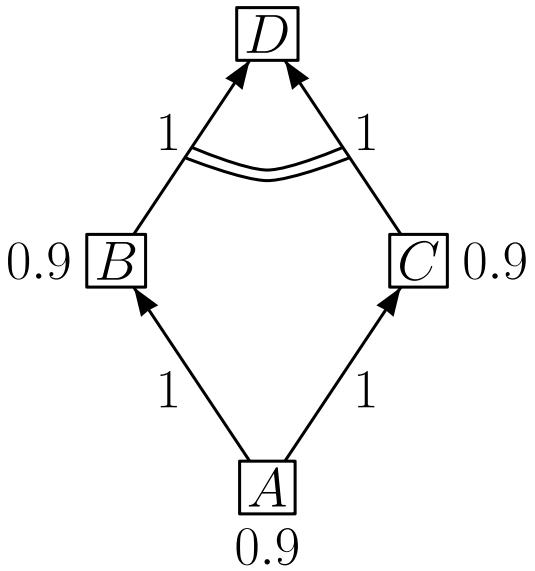
$$f(0.3 \cdot 0.9, 0.25 \cdot 0.8) \;=\; 0.27 + 0.2 - 0.27 \cdot 0.2 = 0.416$$

Was Mycin a failure?

- It worked in the Mycin case because the rules had tree-like structure.
- It can be shown that the rule combination scheme is inconsistent in general.

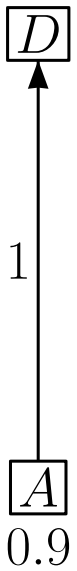
Example: $\mathrm{CF}(A) = 0.9$, $\mathrm{CF}(D) = ?$

$$\mathrm{CF}(D) = 0.9 + 0.9 - 0.9 \cdot 0.9 = 0.99$$



vs.

$\mathrm{CF}(D) = 0.9$



Certainty factor is increased just because (the same) evidence is transferred over different (parallel) paths!

Was Mycin a failure?

Mycin was never used for its intended purpose, because

- physicians were distrustful and not willing to accept Mycin's recommendations.
- Mycin was too good.

However,

- Mycin was a milestone for the development of expert systems.
- it gave rise to impulses for expert system development in general.

Probabilistic Rules

How to assign probabilities to rules (implications)?

$$\boxed{P(B \mid A) \;\leq\; P(A \to B) = P(\neg A \vee B)}$$

A	B	$P(\cdot)$
0	0	0.04
0	1	0.95
1	0	0.01
1	1	0

$P(B \mid A) = 0$, but $P(A \to B) = 0.99$!

In the following, probabilistic rules are evaluated with conditional probabilities.