Rule Based Systems

Simplest method for building an Intelligent System

Example: Rule base

1. COLLAT ∧ PYMT ∧ REP ⇒ OK
2. APP ⇒ COLLAT
3. RATING ⇒ REP
4. INC ⇒ PYMT
5. BAL ∧ REP ⇒ OK

Description

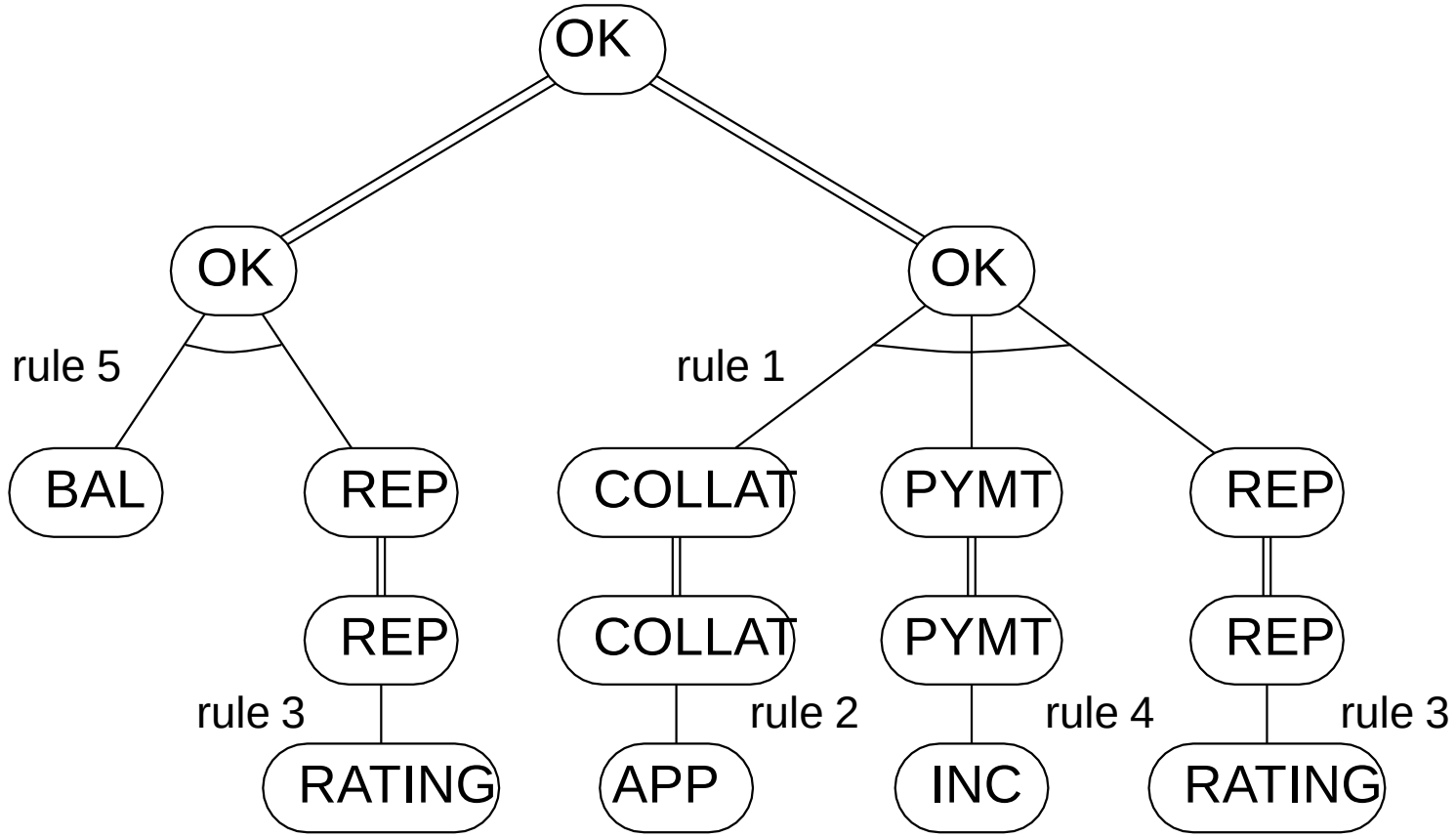
COLLAT	satisfactory collateral
PYMT	payments undisputed
REP	good reputation
APP	high appraisal
RATING	good rating
INC	positive income
BAL	excellent balance
OK	loan will be approved

Two modi of usage

Decision about loan: Facts are retrieved from database or user

Explanation of Decision: System answers the why question

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 a conclusion.

If *condition* then *conclusion*

These two parts may be interpreted differently according to the context:

- Inference rules: If *premise* then *conclusion*
- Hypotheses support: If *evidence* then *hypothesis*
- Productions: If *condition* then *action*

Rules

A rule 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 (Expert System).

The Prolog (logical programming language) is perfect for building rule-based system

Rule-based systems are historically the first types of AI systems and were for a long time considered prototypical AI Systems.

Nowadays, AI system are often developed by use data-driven systems (Big Data, Deep Learning) for decision and learning.

The trends goes to hybrid AI systems, in which data AND rules are used.

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
  ⇒ Instantiation or Matching
- Select rules to be executed
  ⇒ need for conflict resolution
  (e. g. via partial or total orderings on the rules)

Simple Example: Intelligent Assistent Systems

Suppose you are trying to determine if a patient has inhalational anthrax. You observe the following symptoms:

- The patient has a cough
- The patient has a fever
- The patient has difficulty breathing

Simple Example: Intelligent Assistant Systems

You would like to determine how likely the patient is infected with inhalational anthrax given that the patient has a cough, a fever, and difficulty breathing

We are not 100% certain that the patient has anthrax because of these symptoms. We are dealing with uncertainty!

Example:Intelligent Assistant Systems

Now suppose you order an x-ray and observe that the patient has a wide mediastinum.

Your belief that the patient is infected with inhalational anthrax is now much higher.

Qualities of Knowledge

In this example and in most real world cases our knowledge about the present world is

incomplete/missing (knowledge is not comprehensive)

- e. g. “I don’t know the bus departure times for public holidays because I only take the bus on working days.”

vague/fuzzy/imprecise (knowledge is not exact)

- e. g. “The bus departs roughly every full hour.”

uncertain (knowledge is unreliable)

- e. g. “The bus departs probably at 12 o’clock.”

In most real world applications we have to decide nonetheless in the presence of incompleteness, imprecision uncertainty!

So handling uncertainty is a major part of all „**intelligent systems**“!

Topic of the course: How to handle uncertainty (**subjective belief**).

One possibility to express this partial belief is by using (subjective) **probability theory**. Probabilities are used to formally describe the “uncertainty (belief) ” of an agent.

The first „intelligent“ Systems (expert system1975) used a non standard method for the quantification of partial belief, the so called **certainty factors**.

Certainty Factors

First Expert systems: 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

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*

Uncertainty Factors

Probabilistic modelling of Mycin: Handling of a 500-dim probability space is needed
Therefore, the developper in Stanford used the concept of certainty factors

Uncertainty factor $\mathrm{CF} \in [-1, 1]$ ≈ degree of belief

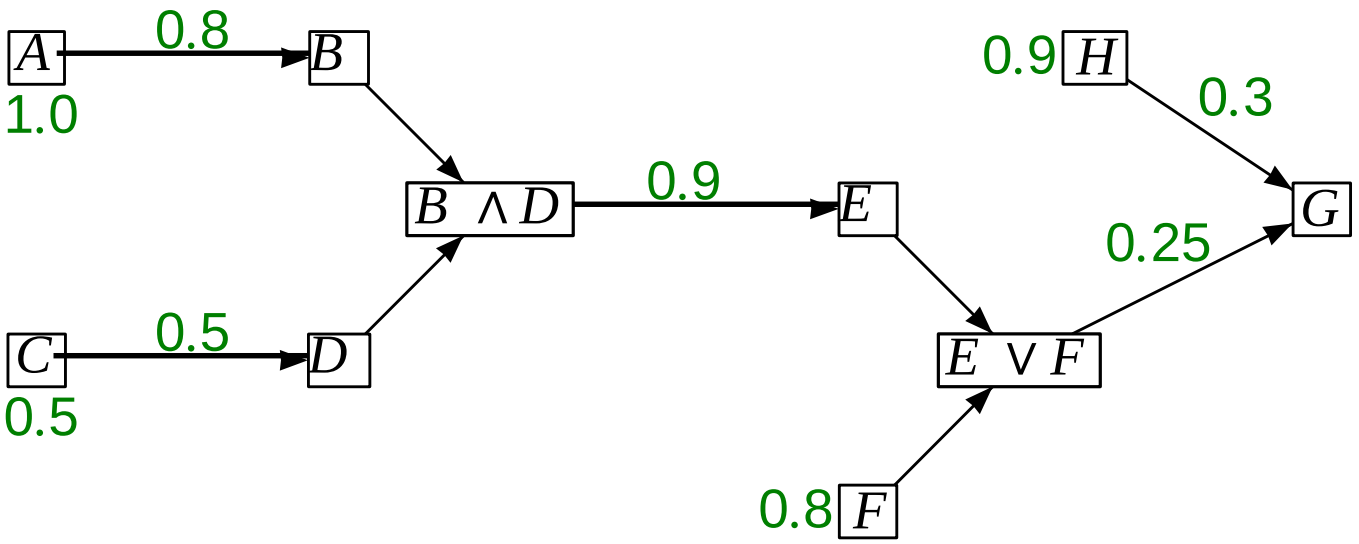
Rules:

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

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: $\mathrm{CF}(B, \{A\}) = \mathrm{CF}(A \rightarrow B) \cdot \max\{0, \mathrm{CF}(A)\}$

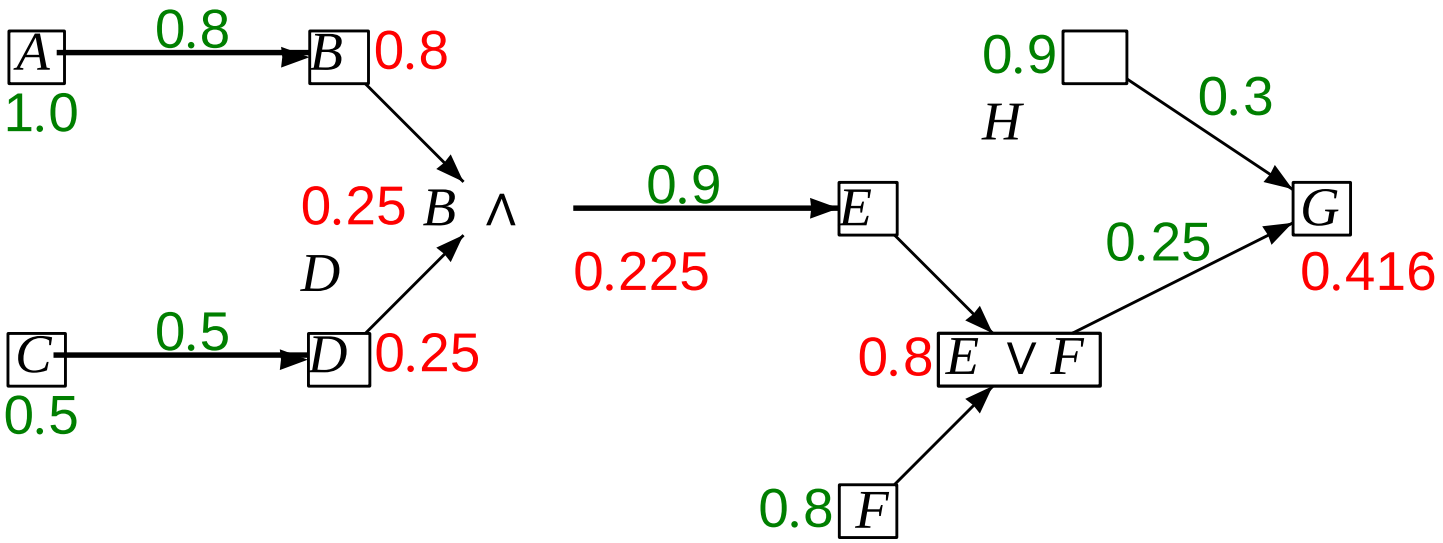
Parallel Combination: for $n > 1$:

$$\mathrm{CF}(B, \{A_1, \ldots, A_n\}) = f\,(\mathrm{CF}(B, \{A_1, \ldots, A_{n-1}\}), \mathrm{CF}(B, \{A_n\}))$$

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.)



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

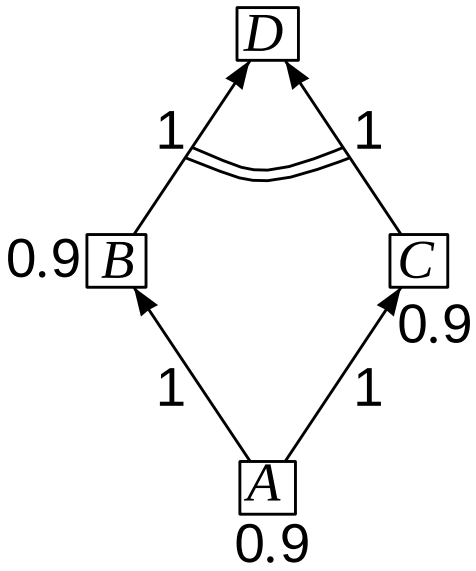
Was Mycin a failure?

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.

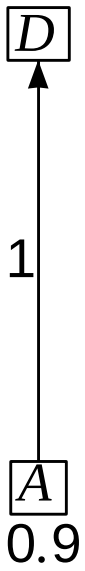
Example: CF(A) = 0.9, CF(D) =?

CF(D) = 0.9 + 0.9 − 0.9 · 0.9 = 0.99 CF(D) = 0.9



A→B
A→C
B→ D
C→ D

vs
.



A→D

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

Was Mycin a failure?

The certainty factor approach should not be used: It is a simple extension fo rule based systems, but often inconsistent.

In the case of MYCIN it worked quite well (with probabilistic methods one can show, why!). In other applications the result was a desaster…

Mycin was never used for its intended purpose, doctors physicians were distrustful and not willing to accept Mycin's recommendations (nor other recommendations by computers).

However,

Mycin was a milestone for the development of expert systems.

It gave rise to impulses for expert system development in general.

Nowadays most intelligent systems use **probabilistic methods** for handling uncertainty.