Bayesian Networks

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About me: Rudolf Kruse

- in 1979 diploma in mathematics (minor computer science) at TU Braunschweig
- there dissertation in 1980, rehabilitation in 1984
- 2 years full-time employee at Fraunhofer Institute
- in 1986 offer of professorship for computer science at TU Braunschweig
- since 1996 professor at the University of Magdeburg
- **research**: data mining, explorative data analysis, fuzzy systems, neuronal networks, evolutionary algorithms, Bayesian networks
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- **consultation**: Wednesdays, 11 a.m. – 12 noon
About the working group Computational Intelligence

teaching:

- Intelligent Systems Bachelor (2 V + 2 Ü, 5 CP)
- Evolutionary Algorithms Bachelor (2 V + 2 Ü, 5 CP)
- Neuronal Networks Bachelor (2 V + 2 Ü, 5 CP)
- Fuzzy Systems Master (2 V + 2 Ü, 6 CP)
- Bayesian Network Master (2 V + 2 Ü, 6 CP)
- Intelligent Data Analysis Master (2 V + 2 Ü, 6 CP)

(pro-)seminars: Information Mining, Computational Intelligence

research examples:

- dynamic graph analysis in brain networks (C. Moewes)
- analysis of social networks (P. Held)
- planet search by astronomical data analysis (C. Braune)
About the lecture

• lecture dates: Thursday, 3:15 p.m.–4:45 p.m., G22A-218

• information about the course:
  ◦ weekly lecture slides as PDF
  ◦ also assignment sheets for the exercise
  ◦ important announcements and date!
Content of the lecture

- Introduction
- Rule-based Systems
- Elements of Graph Theory
- Decomposition
- Probability Foundations
- Applied Probability Theory
- Probabilistic Causal Networks
- Propagation in Belief Networks
- Learning Graphical Models
- Decision Graphs / Influence Diagrams
- Frameworks of Imprecision and Uncertainty
About the exercise

• active participation and explanations of your solutions
• tutor will call attention to mistakes and answer questions
• pure ‘calculations’ of sample solution is not the purpose
• tutor: Pascal Held mailto:pheld@ovgu.de
• consultation: Just knock on the door and see if he is there :-)
• first assignment due October 18, 2012
• Thursday, 3:15 p.m.–4:45 p.m., G22A-208
Conditions for Certificate ("Schein") and Exam

Certificate will get who...  
- contribute well in exercises every week,
- present $\geq 2$ solutions to written assignment during exercises.
- tick off $\geq 66\%$ of all written assignments,
- small colloquium ($\approx 10$ min.) or written test (if $> 20$ students).

Exam or marked certificate will get who...  
- just pass the oral exam ($\approx 25$ minutes) or written exam (if $> 20$ students).
- active participation in the exercises will help getting a good grade ;-)
Books about the course

http://www.computational-intelligence.eu/
• **Human Expert**

A human *expert* is a specialist for a specific differentiated application field who creates solutions to customer problems in this respective field and supports them by applying these solutions.

• **Requirements**

  ○ Formulate precise problem scenarios from customer inquiries
  ○ Find correct and complete solution
  ○ Understandable answers
  ○ Explanation of solution
  ○ Support the deployment of solution
• “Intelligent” System

An intelligent system is a program that models the knowledge and inference methods of a human expert of a specific field of application.

• Requirements for construction:
  ◦ Knowledge Representation
  ◦ Knowledge Acquisition
  ◦ Knowledge Modification
Qualities of Knowledge

In most 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.”

We have to decide nonetheless!

- Reasoning under Vagueness
- Reasoning with Probabilities
- ...and Cost/Benefit
Objective: *Be at the university at 9:15 to attend a lecture.*

- There are several plans to reach this goal:
  - $P_1$: Get up at 8:00, leave at 8:55, take the bus at 9:00 …
  - $P_2$: Get up at 7:30, leave at 8:25, take the bus at 8:30 …
  - …

- All plans are *correct*, but
  - they imply different *costs* and different *probabilities* to actually reach that goal.
  - $P_2$ would be the plan of choice as the lecture is important and the success rate of $P_1$ is only about 80–95%.

- Question: *Is a computer capable of solving these problems involving uncertainty?*
Example: We are given a simple expert system for dentists that may contain the following rule:

$$\forall p : [\text{Symptom}(p, \text{toothache}) \Rightarrow \text{Disease}(p, \text{cavity})]$$

This rule is *incorrect*! Better:

$$\forall p : [\text{Symptom}(p, \text{toothache}) \Rightarrow \text{Disease}(p, \text{cavity}) \lor \text{Disease}(p, \text{gumdisease}) \lor \ldots]$$

Maybe take the *causal* rule?

$$\forall p : [\text{Disease}(p, \text{cavity}) \Rightarrow \text{Symptom}(p, \text{toothache})]$$

Incorrect, too.
Problems with propositional logic:

- We cannot enumerate all possible causes, even though …
- We do not know the (medical) cause-effect interactions, and even though …
- Uncertainty about the patient remains:
  - Caries and toothache may co-occur by chance.
  - Were (exhaustively) all examinations conducted?
    - If yes: correctly?
  - Did the patient answer all questions?
    - If yes: appropriately?
- Without perfect knowledge no correct logical rules!
Uncertainty and Facts

Example:

• We would like to support a robot’s localization by fixed landmarks. From the presence of a landmark we may infer the location.

Problem:

• Sensors are imprecise!
  ○ We cannot conclude definitely a location simply because there was a landmark detected by the sensors.
  ○ The same holds true for undetected landmarks.
  ○ Only probabilities are being increased or decreased.
• We (or other agents) are only believing facts or rules to some extent.

• One possibility to express this *partial belief* is by using *probability theory*.

• “The agent believes the sensor information to 0.9” means: In 9 out of 10 cases the agent trusts in the correctness of the sensor output.

• Probabilities gather the “uncertainty” that originates due to ignorance.

• Probabilities ≠ Vagueness/Fuzziness!
  ○ The predicate “large” is fuzzy whereas “This might be Peter’s watch.” is uncertain.
Rational Decisions under Uncertainty

- Choice of several actions or plans
- These may lead to different results with different probabilities.
- The actions cause different (possibly subjective) costs.
- The results yield different (possibly subjective) benefits.
- It would be rational to choose that action that yields the largest total benefit.

Decision Theory = Utility Theory + Probability Theory
### Decision-theoretic Agent

**input** perception  
**output** action  

1. \( K \leftarrow \) a set of probabilistic beliefs about the state of the world  
2. calculate updated probabilities for current state based on available evidence including current percept and previous action  
3. calculate outcome probabilities for actions, given action descriptions and probabilities of current states  
4. select action \( A \) with highest expected utility given probabilities of outcomes and utility information  
5. **return** \( A \)

**Decision Theory:** An agent is rational if and only if it chooses the action yielding the largest utility averaged over all possible outcomes of all actions.