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:
  `http://fuzzy.cs.ovgu.de/wiki/pmwiki.php?n=Lehre.BN1213`
  - 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

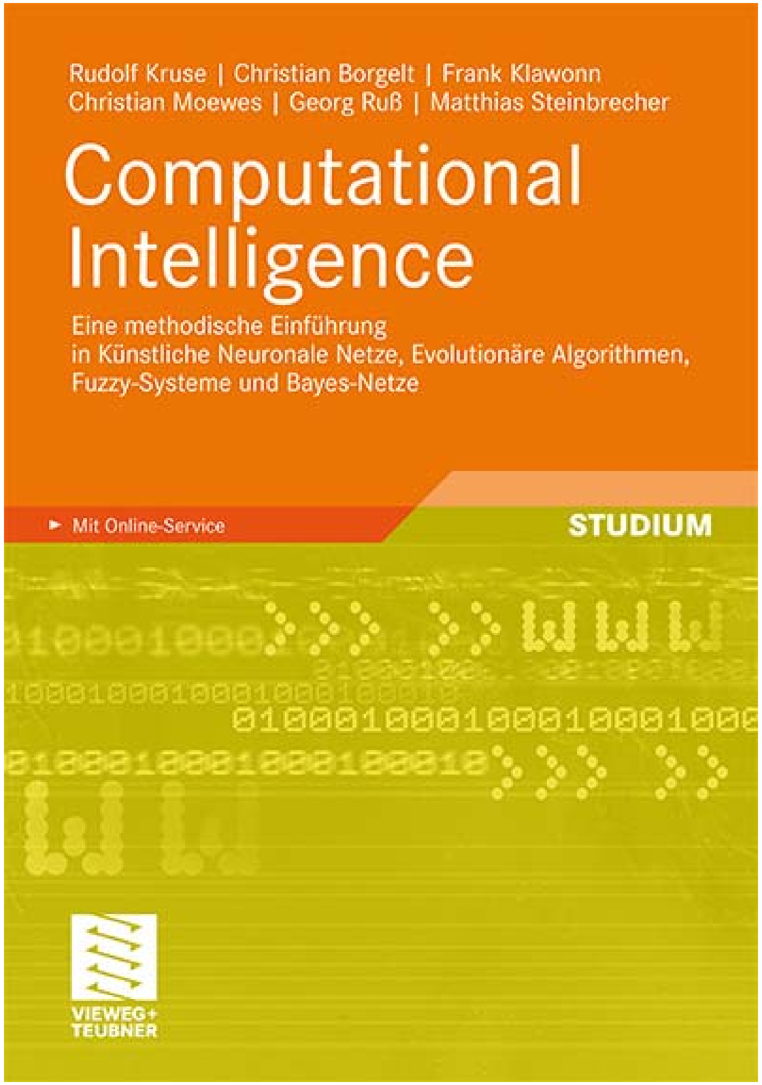
Certificate will get who...

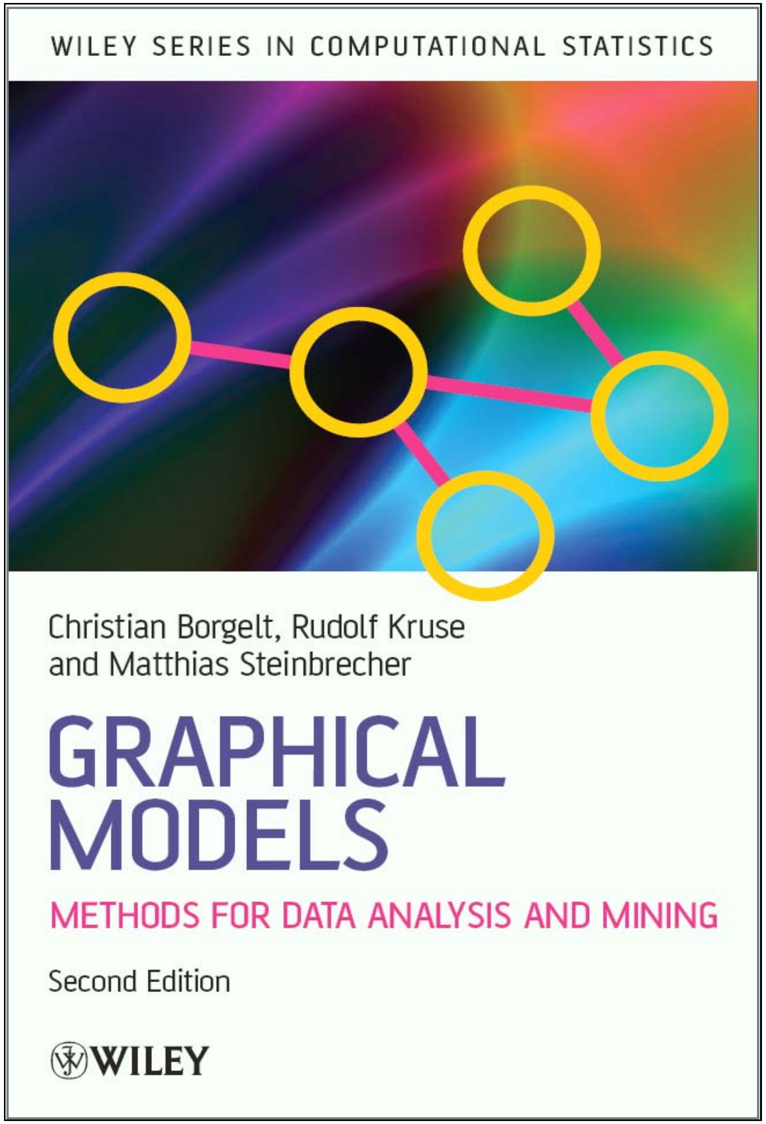
- contribute well in exercises every week,
- present ≥ 2 solutions to written assignment during exercises.
- tick off $\geq 66\%$ of all written assignments,
- small colloquium (≈ 10 min.) or written test (if > 20 students).

Exam or marked certificate will get who...

- just pass the oral exam (≈ 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

Knowledge Based Systems (2)

- **“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

Example

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?*

Uncertainty and Rules (1)

- Example: We are given a simple expert system for dentists that may contain the following rule:

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

- This rule is *incorrect*! Better:

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

- Maybe take the *causal* rule?

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

- Incorrect, too.

Uncertainty and Rules (2)

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-occurr 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.

Degrees of Belief

- 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 $\neq$ 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.

$$\text{Decision Theory} = \text{Utility Theory} + \text{Probability Theory}$$

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.