Knowledge Representation and Reasoning

Bernhard Nebel   Jussi Rintanen   Stefan Wölfl

Albert-Ludwigs-Universität Freiburg

Winter term 2004/2005

Lectures: Where, When, Webpage

Where

Lecture hall 52-02-017

When

Wednesday 14:15–15:50, Friday: 14:15–15:00 (+ exercises)

Christmas break

Last lecture before Christmas: Wednesday, December 22
First lecture after Christmas: Friday, January 7

Web page

http://www.informatik.uni-freiburg.de/˜ki/teaching/ws0405/krr/

Lecturers

Prof Dr. Bernhard Nebel

Room 52-00-028
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Dr. Stefan Wölfl

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Exercises I

Where

Lecture hall 52-02-017

When

Friday 15:05-15:50

exercise assistant: Malte Helmert

Room 52-00-030, Phone: 0761/203-8225
email: helmert@informatik.uni-freiburg.de

Exercises II

- Exercises will be given at the web page on Wednesdays. (However, first exercise on Friday, October 22.)
- Solutions can be given in English and German.
- Students can work in pairs and hand in one solution.
- Larger groups and copied results will not be accepted.
- Previous week's exercises have to be handed in before the lecture on Wednesday.

Examination & Schein

- A written examination takes place in the semester pause.
- The examination is obligatory for *ACS Master* students.
- Grade:
  - max 100 points from the exam
  - max 10 bonus points from exercises
  - max 10 bonus points from projects (programming exercises)

Course Prerequisites & Goals

Goals

- Acquiring skills in representing knowledge
- Understanding the principles behind different knowledge representation techniques
- Being able to read and understand research literature in the area of KR&R
- Being able to complete a project in this research area

Prerequisites

- Basic knowledge in the area of AI
- Basic knowledge in formal logic
- Basic knowledge in theoretical computer science

AI and Knowledge Representation

- **AI** can be described as: The study of intelligent behavior achieved through computational means
- **Knowledge representation and reasoning** could then be viewed as the study of how to **reason** (compute) with **knowledge** in order to decide what to do.
- Before we can start reasoning with knowledge, we have to represent it.

Knowledge

- We understand by “knowledge” all kinds of facts about the world.
- Knowledge is necessary for intelligent behavior (human beings, robots).
- What is knowledge? We shall not try to answer this question!
- Instead, in this course we consider “representations of knowledge”.

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Representation

- If A represents B, then A stands for B and is usually more easily accessible than B.
- In our case we are interested in groups of symbols that stand for some proposition.

Knowledge Representation

The field of study concerned with representations of propositions (that are believed by some agent)

Reasoning

- Reasoning is the use of representations of propositions in order to derive new ones.
- While propositions are abstract objects, their representations are concrete objects and can be easily manipulated.
- Reasoning can be as easy as arithmetics $\rightsquigarrow$ mechanical symbol manipulation.
- For example:
  - `raining` is true
  - IF `raining` is true THEN `wet street` is true
  - `wet street` is true

Why is Knowledge Representation and Reasoning Useful?

- Describing/understanding the behavior of systems in terms of the knowledge it has.
- Generating the behavior of a system!
  - Declarative knowledge can be separated from its possible usages.
    (compare: procedural knowledge)
  - Understanding the behavior of an intelligent system in terms of the represented knowledge makes debugging and understanding much easier.
  - Modifications and extensions are also much easier to perform.

Knowledge-Based Systems: An Example


```
printC(snow) :- !, write("It’s white").
printC(grass) :- !, write("It’s green").
printC(sky) :- !, write("It’s yellow").
printC(X) :- !, write("Beats me").
```

```
printC(X) :- color(X,Y), !, write("It’s "), write(Y).
printC(X) :- write("Beats me").
color(snow,white).
color(sky,yellow).
color(X,Y) :- madeof(X,Z), color(Z,Y).
madeof(grass,vegetation).
color(vegetation,green).
```

Advantages of Knowledge-Based Systems

- Why not use the first variant of the Prolog program?
- We can add new tasks and make them depend on previous knowledge.
- We can extend existing behavior by adding new facts.
- We can easily explain and justify the behavior.

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Why Reasoning?

- Note: there was no explicit statement about the color of grass in the program.
- In general: many facts will be there only implicitly.
- Use concept of entailment/logical implication.
- Can/shall we compute all implicit (all entailed) facts?
- It may be computationally too expensive.

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The Role of Formal Logic

- Formal logic is the field of study of entailment relations, formal languages, truth conditions, semantics, and inference.
- All propositions are represented as formulae which have a semantics according to the logic in question.
- Formal logics gives us a framework to discuss different kinds of reasoning.

Different Kinds of Reasoning

- Usually, we are interested in deriving implicit, entailed facts from a given collection of explicitly represented facts
  - in a logically sound (the derived proposition must be true, given that the premises are true)
  - and complete way (all true consequences can be derived)
- Sometimes, however, we want logically unsound derivations (e.g. reasoning based on assumptions.)
- Sometimes, we want to give up completeness (e.g. for efficiency reasons.)

Model-Finding and Satisfiability

- In planning and configuration tasks, we often get a set of constraints and a goal specification. We then have to find a solution satisfying all the constraints.
  - Either `round` or `square`
  - Either `red` or `blue`
  - If `red` and `round` or if `blue` and `square` then `wood`
  - If `blue` then `metallic`
  - If `square` then not `metallic`
  - If `red` then `square`
  - `square`

  One solution: `square`, not `metallic`, `red`, `wood`
- Does not logically follow, but is one possible assignment (or model).

Abduction: Inference to the Best Explanation

- In diagnosis tasks, we often have to find a good explanation for a given observation or symptom.
- Given a background theory, a set of explanations and an observation, find the most likely set of explanations.
  - `earthquake` implies `alarm`
  - `burglar` implies `alarm`
  - { `earthquake`, `burglar` } is the set of abducibles
  - `alarm` is observed
  - One explanation is `earthquake` ...
- There can be many possible explanations.
- Not a sound inference

Default Reasoning: Jumping to Conclusions

- Often we do not have enough information, but nevertheless want to reach a conclusion (that is likely to be true).
- In the absence of evidence to the contrary, we jump to a conclusion.
  - Birds are usually able to fly.
  - Tweety is a bird.
  - So, you would expect that Tweety is able to fly.
- Unsound conclusion
- It might be necessary to withdraw conclusions when evidence to the contrary becomes available $\rightsquigarrow$ nonmonotonic reasoning.

The Role of Complexity Theory (1)

- Intelligent behavior is based on a vast amount of knowledge: Reddy's (1988) estimate is 70000 knowledge "units".
- Because of the huge amount of knowledge we have represented, reasoning should be easy in the complexity theory sense.
- Reasoning should scale well: we need efficient reasoning algorithms.

The Role of Complexity Theory (2)

Use complexity theory and recursion theory to

- determine the complexity of reasoning problems,
- compare and classify different approaches based on complexity results,
- identify easy (polynomial-time) special cases,
- use heuristics/approximations for provably hard problems, and
- choose among different approaches.

Course Outline

1. Introduction
2. Reminder: Classical Logic
3. A New Logic: Boxes and Diamonds
4. Nonmonotonic Logics
5. Qualitative Spatial and Temporal Reasoning
6. Description Logics

Literature I

- R. J. Brachman and Hector J. Levesque, *Knowledge Representation and Reasoning*, unpublished manuscript.
- C. Beierle and G. Kern-Isberner, *Methoden wissensbasierter Systeme*, Vieweg, 2000.
- G. Brewka, ed., *Principles of Knowledge Representation*, CSLI Publications, 1996.
- G. Lakemeyer and B. Nebel (eds.), *Foundations of Knowledge Representation and Reasoning*, Springer-Verlag, 1994
- W. Bibel *Wissensrepräsentation und Inferenz*, Vieweg, 1993

Literature II

- R. J. Brachman and Hector J. Levesque (eds.), *Readings in Knowledge Representation*, Morgan Kaufmann, 1985.
- B. Nebel, "Logics for Knowledge Representation," in: N. J. Smelser and P. B. Baltes (eds.), *International Encyclopedia of the Social and Behavioral Sciences*, Kluwer, Dordrecht, 2001.
- B. Nebel, "Artificial Intelligence: A Computational Perspective" in G. Brewka, ed., *Principles of Knowledge Representation, Studies in Logic, Language and Information*, CSLI Publications, 1996, 237-266.
- *Proceedings of the International Conference on Principles of Knowledge Representation and reasoning*, (1989, 1991, 1992, . . . , 2002, 2004), Morgan Kaufmann Publishers.