

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

# Principles of Knowledge Representation and Reasoning

## Introduction

Bernhard Nebel, Malte Helmert and Stefan Wöfl

Albert-Ludwigs-Universität Freiburg

April 22, 2008

# Lectures: Where, When, Webpage

## Where

Lecture hall, Geb. 101, SR 00-010/14

## When

Tue: 14:15–16:00, Fri: 14:15–15:00 (+ exercises)

## Pentecost break

Last lecture before Pentecost: Fri, May 9

First lecture after Pentecost: Tue, May 20

## Web page

<http://www.informatik.uni-freiburg.de/~ki/teaching/ss08/krr/>

KRR

Nebel,  
Helmert,  
Wölfl

Organization  
Time, Location,  
Web Page  
Lecturers  
Exercises  
Examination  
Motivation

# Lecturers

## Prof. Dr. Bernhard Nebel

Room 52-00-028

**Consultation:** Mon 13:00-14:00 and by appointment

**Phone:** 0761/203-8221

**email:** [nebel@informatik.uni-freiburg.de](mailto:nebel@informatik.uni-freiburg.de)

## Dr. Malte Helmert

Room 52-00-044, **Consultation:** by appointment

**Phone:** 0761/203-8225

**email:** [helmert@informatik.uni-freiburg.de](mailto:helmert@informatik.uni-freiburg.de)

## Dr. Stefan Wölfel

Room 52-00-043, **Consultation:** by appointment

**Phone:** 0761/203-8228

**email:** [woelfl@informatik.uni-freiburg.de](mailto:woelfl@informatik.uni-freiburg.de)

KRR

Nebel,  
Helmert,  
Wölfel

Organization

Time, Location,  
Web Page

Lecturers

Exercises

Examination

Motivation

# Exercises I

## Where

Lecture hall, Geb. 101, SR 00-010/14

## When

Fri, 15:15-16:00

Exercise assistant: Gabi Röger

Room 52-00-030, [Phone](tel:07612038219): 0761/203-8219

[email](mailto:roeger@informatik.uni-freiburg.de): roeger@informatik.uni-freiburg.de

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Time, Location,  
Web Page

Lecturers

Exercises

Examination

Motivation

# Exercises II

- Exercises will be handed out and posted on the web page on Tuesdays.
- 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 Tuesday.

KRR

Nebel,  
Helmert,  
Wölfel

Organization

Time, Location,

Web Page

Lecturers

Exercises

Examination

Motivation

- An oral examination takes place in the semester break.
- The examination is obligatory for all Bachelor/Master/ACS Master students.

KRR

Nebel,  
Helmert,  
Wölfl

Organization

Time, Location,

Web Page

Lecturers

Exercises

**Examination**

Motivation

# 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

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

**Course Goals**

Knowledge

Representation

Reasoning

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline  
Literature

# 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.

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals

Knowledge

Representation

Reasoning

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature



# 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”.

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals

**Knowledge**

Representation

Reasoning

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

- 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”.

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals

**Knowledge**

Representation

Reasoning

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

# 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).

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals

Knowledge

Representation

Reasoning

Role of Formal

Logic

Role of

Complexity

Theory

Course Outline

Literature

# 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

KRR

Nebel,  
Helmert,  
Wölfel

Organization

Motivation

Course Goals

Knowledge

Representation

Reasoning

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

# 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.

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals  
Knowledge  
Representation

**Reasoning**

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline  
Literature

# 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).
```

KRR

Nebel,  
Helmert,  
Wölfl

Organization

Motivation

Course Goals

Knowledge

Representation

**Reasoning**

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

# Advantages of Knowledge-Based Systems

KRR

Nebel,  
Helmert,  
Wölfel

Organization

Motivation

Course Goals  
Knowledge  
Representation

**Reasoning**

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline  
Literature

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.

# Advantages of Knowledge-Based Systems

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals  
Knowledge  
Representation

**Reasoning**

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline  
Literature

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.



# Advantages of Knowledge-Based Systems

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals  
Knowledge  
Representation

Reasoning

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline  
Literature

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.

# Advantages of Knowledge-Based Systems

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals  
Knowledge  
Representation

**Reasoning**

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline  
Literature

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.

# 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.

KRR

Nebel,  
Helmert,  
Wölfel

Organization

Motivation

Course Goals

Knowledge

Representation

**Reasoning**

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

# 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.

KRR

Nebel,  
Helmert,  
Wölfel

Organization

Motivation

Course Goals

Knowledge

Representation

**Reasoning**

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

# 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.

KRR

Nebel,  
Helmert,  
Wölfel

Organization

Motivation

Course Goals

Knowledge

Representation

**Reasoning**

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

# 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.

KRR

Nebel,  
Helmert,  
Wölfel

Organization

Motivation

Course Goals

Knowledge

Representation

Reasoning

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

# 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).

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals

Knowledge

Representation

Reasoning

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

# 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).

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals

Knowledge

Representation

Reasoning

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature



# 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.

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals

Knowledge

Representation

Reasoning

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

# 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.

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals

Knowledge

Representation

Reasoning

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

# 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.

KRR

Nebel,  
Helmert,  
Wölfel

Organization

Motivation

Course Goals

Knowledge

Representation

Reasoning

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

# 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.

KRR

Nebel,  
Helmert,  
Wölfel

Organization

Motivation

Course Goals

Knowledge

Representation

Reasoning

Role of Formal

Logic

Role of

Complexity

Theory

Course Outline

Literature

# 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

KRR

Nebel,  
Helmert,  
Wölfel

Organization

Motivation

Course Goals

Knowledge

Representation

Reasoning






Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

# 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

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals

Knowledge

Representation

Reasoning

Role of Formal  
Logic

Role of  
Complexity  
Theory

Course Outline

Literature

# 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, . . . , 2004, 2006), Morgan Kaufmann Publishers.

KRR

Nebel,  
Helmert,  
Wöfl

Organization

Motivation

Course Goals  
Knowledge  
Representation  
Reasoning  
Role of Formal  
Logic  
Role of  
Complexity  
Theory  
Course Outline  
Literature