

# Principles of AI Planning

## 1. Introduction

Albert-Ludwigs-Universität Freiburg



**UNI  
FREIBURG**

Bernhard Nebel and Robert Mattmüller

October 21st, 2015



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# About the course



## Lecturers

Prof. Dr. Bernhard Nebel

- **email:** `nebel@informatik.uni-freiburg.de`
- **office:** room 052-00-029
- **consultation:** Wednesday, 12:15-13:00

Dr. Robert Mattmüller

- **email:** `mattmuel@informatik.uni-freiburg.de`
- **office:** room 052-00-030
- **consultation:** by appointment (email) or just come to my office

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## Exercises

Robert Mattmüller

David Speck

- **email:** `david.speck@pluto.uni-freiburg.de`
- **consultation:** by appointment (email)



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## Lectures

- **time:** Wednesday 14:15-16:00, Friday 11:15-12:00
- **place:** Building 051, lecture hall 03-026

## Exercises

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- **place:** Building 051, lecture hall 03-026



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## Course web site

<http://gki.informatik.uni-freiburg.de/teaching/ws1516/aip/>

- [main page](#): course description
- [lecture page](#): slides
- [exercise page](#): assignments, software
- [bibliography page](#): literature references and papers



- no script, no specifically recommended textbook
- however, two textbooks exist, but they are not necessary for this course:
  - Geffner and Bonet (2013), A Concise Introduction to Models and Methods for Automated Planning  
(comes closest to this course, includes relatively recent research results – a few copies available in the Faculty of Engineering library)
  - Nau, Ghallab, and Traverso (2004), Automated Planning: Theory and Practice  
(very different from this course, quite outdated)
- slides available on the web
- additional resources: bibliography page on web +  
ask us!

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## Acknowledgments:

- slides based on earlier courses by Jussi Rintanen, Bernhard Nebel and Malte Helmert
- many figures by Gabi Röger





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## Students of Computer Science:

- Master of Science, any year
- Bachelor of Science, ~3rd year

## Other students:

- advanced study period (~4th year)



## Course prerequisites:

- [propositional logic](#): syntax and semantics
- [foundations of AI](#): search, heuristic search
- [computational complexity theory](#): decision problems, reductions, NP-completeness



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- 6 ECTS points
- special lecture in specialization field  
[Cognitive Technical Systems](#)
- [oral exam](#) of about 30 minutes for B.Sc. students
- [written or oral exam](#) for M.Sc. students (likely written)



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## Exercises (written assignments):

- handed out once a week
- due one week later, before the lecture
- discussed in the next exercise session
- may be solved in groups of two students ( $2 \neq 3$ )
- successful participation prerequisite for exam admission



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- points can be earned for “reasonable” solutions to exercises.
- at least 50% of points prerequisite for admission to final exam.



## What is plagiarism?

- passing off solutions as your own that are not based on your ideas (work of other students, Internet, books, ...)
- <http://en.wikipedia.org/wiki/Plagiarism> is a good intro

**Consequence:** no admission to the final exam.

- We may (!) be generous on first offense.
- Don't tell us "We did the work together."
- Don't tell us "I did not know this was not allowed."

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- What is planning?
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- Dynamics
- Observability
- Objectives
- Planning vs. game theory
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## Planning

“Planning is the art and practice of thinking before acting.”

— Patrik Haslum

- intelligent decision making: What actions to take?
- general-purpose problem representation
- algorithms for solving any problem expressible in the representation
- application areas:
  - high-level planning for intelligent robots
  - autonomous systems: NASA Deep Space One, ...
  - problem solving (single-agent games like Rubik's cube)

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# Why is planning difficult?



- solutions to classical planning problems are **paths from an initial state to a goal state** in the **transition graph**
  - efficiently solvable by Dijkstra's algorithm in  $O(|V| \log |V| + |E|)$  time
  - Why don't we solve all planning problems this way?
- state spaces may be **huge**:  $10^{10}, 10^{100}, 10^{1000}, \dots$  states
  - constructing the transition graph is infeasible!
  - planning algorithms try to **avoid constructing whole graph**
- planning algorithms are often much more efficient than obvious solution methods constructing the transition graph and using e. g. Dijkstra's algorithm

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- **dynamics:** deterministic, nondeterministic or probabilistic
  - **observability:** full, partial or none
  - **horizon:** finite or infinite
  - ...
- 
- 1 classical planning
  - 2 conditional planning with full observability
  - 3 conditional planning with partial observability
  - 4 conformant planning
  - 5 Markov decision processes (MDP)
  - 6 partially observable MDPs (POMDP)

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## Deterministic dynamics

Action + current state **uniquely** determine successor state.

## Nondeterministic dynamics

For each action and current state there may be **several possible** successor states.

## Probabilistic dynamics

For each action and current state there is a **probability distribution** over possible successor states.

**Analogy:** deterministic versus nondeterministic automata

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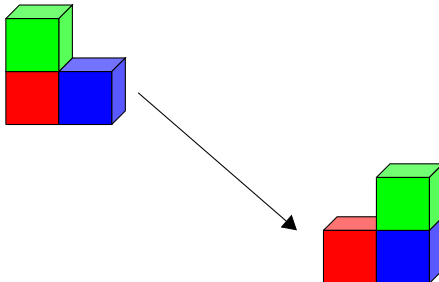
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# Deterministic dynamics example



Moving objects with a robotic hand:  
move the green block onto the blue block.



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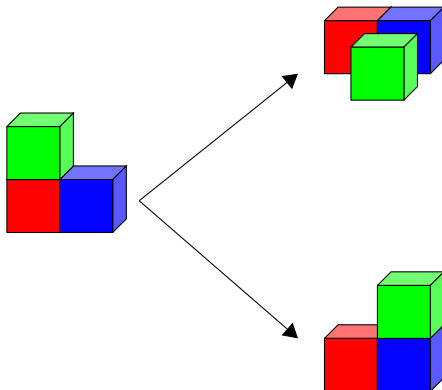
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# Nondeterministic dynamics example



Moving objects with an **unreliable** robotic hand:  
move the green block onto the blue block.



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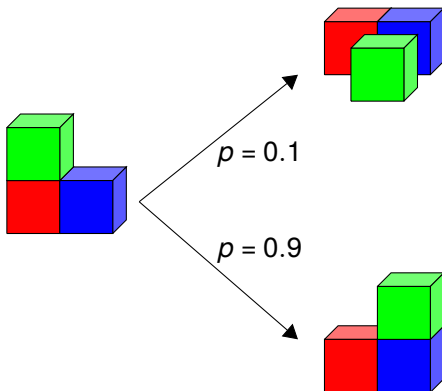
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# Probabilistic dynamics example



Moving objects with an **unreliable** robotic hand:  
move the green block onto the blue block.



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# Properties of the world: observability



## Full observability

Observations determine current world state **uniquely**.

## Partial observability

Observations determine current world state **only partially**: we only know that current state is one of several possible ones.

## No observability

There are **no observations** to narrow down possible current states. However, can use knowledge of **action dynamics** to deduce which states we might be in.

**Consequence**: If observability is not full, must represent the **knowledge** an agent has.

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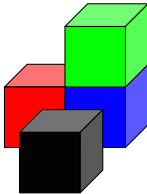
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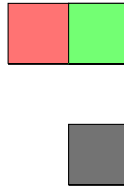
# What difference does observability make?



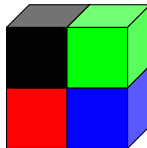
Camera A



Camera B



Goal



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- 1 Reach a goal state.
  - **Example:** Earn 500 Euros.
- 2 Stay in goal states indefinitely (infinite horizon).
  - **Example:** Never allow bank account balance to be negative.
- 3 Maximize the probability of reaching a goal state.
  - **Example:** To be able to finance buying a house by 2025 study hard and save money.
- 4 Collect the maximal **expected** rewards/minimal expected costs (infinite horizon).
  - **Example:** Maximize your future income.
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- Game theory addresses decision making in multi-agent setting: “Assuming that the other agents are rational, what do I have to do to achieve my goals?”
- Game theory is related to **multi-agent planning**.
- In this course we concentrate on **single-agent planning**.
- Some of the techniques are also applicable to special cases of multi-agent planning.
  - **Example:** Finding a **winning strategy** of a game like chess. In this case it is not necessary to distinguish between **an intelligent opponent** and **a randomly behaving opponent**.
- Game theory in general is about **optimal strategies** which do not necessarily guarantee winning. For example card games like poker do not have a winning strategy.

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# What do you learn in this course?



- emphasis on **classical** planning (“simplest” case)
  - brief digression to **nondeterministic** planning
  - **theoretical background** for planning
    - formal **problem definition**
    - basic **theoretical notions**  
(e. g., normal forms, progression, regression)
    - **computational complexity** of planning
  - **algorithms** for planning:
    - based on **heuristic search**
- Many of these techniques are applicable to problems outside AI as well.
- **hands-on experience** with a classical planner (probably)

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