

Principles of AI Planning

1. Introduction

Albert-Ludwigs-Universität Freiburg



UNI
FREIBURG

Bernhard Nebel and Robert Mattmüller

October 23rd, 2019



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About the course



Lecturers

Dr. Robert Mattmüller

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- **office:** room 052-00-042
- **consultation:** by appointment (email) or just come to my office

Prof. Dr. Bernhard Nebel

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- **consultation:** Tuesday, 12:00-13:00 and by appointment

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Exercises

David Speck

- **email:** `speckd@informatik.uni-freiburg.de`
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Tim Schulte

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- **consultation:** by appointment (email)

Mario Kantz

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Lectures

- **time:** Wednesday 16:15-18:00, Friday 16:15-17:00
- **place:** Building 101, seminar room 00-010/014

Exercises

- **time:** Friday 17:15-18:00
- **place:** Building 101, seminar room 00-010/014



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Course web site

<http://gki.informatik.uni-freiburg.de/teaching/ws1920/aip/>

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



- no script, but these slides available on the web
- three textbooks exist, but 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)
 - Ghallab, Nau, and Traverso (2004), Automated Planning: Theory and Practice
(very different from this course, quite outdated)
 - Ghallab, Nau, and Traverso (2016), Automated Planning and Acting
(heavily modified rewrite of the above, still quite different from this course)

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- other resources:
 - Muise, Haslum, Magazzeni, and Lipovetzky (2019), An Introduction to the Planning Domain Definition Language (about the modeling language, not so much about algorithms; pretty nice, though)
 - Website: <http://planning.domains/>
 - 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)



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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
- specialization lecture
- [oral exam](#) of about 30 minutes for computer science B.Sc. students
- [written or oral exam](#) for M.Sc. students and students in study programs other than computer science (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 to pass the “Studienleistung”

Exercises and “Studienleistung”



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- points can be earned for “reasonable” solutions to exercises.
- at least 50% of points needed to pass the “Studienleistung”.



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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Summary

Planning in the AI landscape

(hugely simplified ...)



Symbolic AI, e. g. ...

| | |
|--|-------------------------------------|
| Knowledge representation and reasoning | Logic AI planning, search |
|--|-------------------------------------|

Sub-symbolic AI, e. g. ...

| | |
|-----------------------------|------------------------|
| Perception (vision, ...) | Pattern Recognition |
| (Deep) Learning | |

- Knowledge and symbols
 - Often model-based
 - Explainability: ✓
-
- Data, no symbols
 - Often model-free
 - Explainability: ✗

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Symbolic AI, e. g. ...

Knowledge
representation
and reasoning

Logic

AI planning,
search

You are here!

Sub-symbolic AI, e. g. ...

Perception
(vision, ...)

Pattern
Recognition

(Deep) Learning

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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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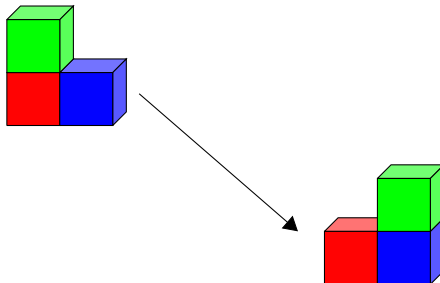
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Deterministic dynamics example



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



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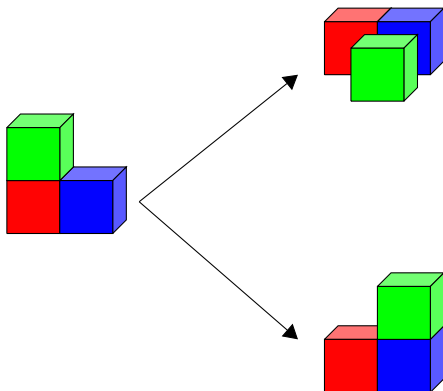
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Nondeterministic dynamics example



Moving objects with an **unreliable** robotic hand:
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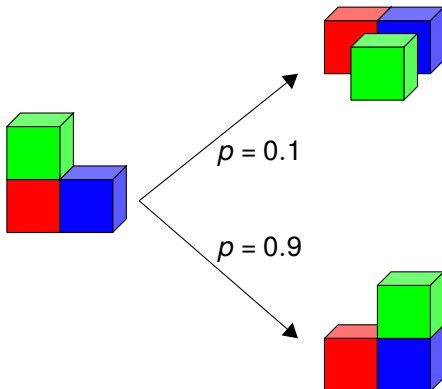
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Probabilistic dynamics example



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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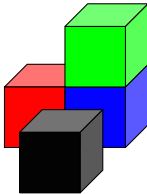
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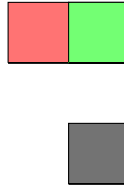
What difference does observability make?



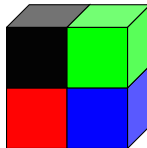
Camera A



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 2029 study hard and save money.
- 4 Collect the maximal **expected** rewards/minimal expected costs (infinite horizon).
 - **Example:** Maximize your future income.
- 5 ...

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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**
 - based on exhaustive search with logic-based data structures such as BDDs (if time permits)

Many of these techniques are applicable to problems outside AI as well.

- **hands-on experience** with a classical planner (probably)

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