Principles of AI Planning

1. Introduction

Bernhard Nebel and Robert Mattmüller

Albert-Ludwigs-Universität Freiburg

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About the course
# People

## Lecturers

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People

Assistant

Thomas Keller

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Tutor

Yusra Alkhazraji

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## Time & place

### Lectures
- **time:** Tuesday 16:15-18:00, Friday 14:15-15:00
- **place:** SR 101-01-018

### Exercises
- **time:** Friday 15:15-16:00
- **place:** SR 101-01-018
Web site

Course web site

http://gki.informatik.uni-freiburg.de/teaching/ws1112/aip/
- main page: course description
- lecture page: slides
- exercise page: assignments, model solutions, software
- bibliography page: literature references and papers
no textbook, no script
slides handed out during lectures and available on the web
additional resources: bibliography page on web + ask us!

Acknowledgments:
slides based on earlier courses by Jussi Rintanen, Bernhard Nebel and Malte Helmert
many figures by Gabi Röger
Target audience

Students of Computer Science:
- Master of Science, any year
- Bachelor of Science, \( \sim \) 3rd year

Students of Applied Computer Science:
- Master of Science, \( \sim \) 2nd year

Other students:
- advanced study period (\( \sim \) 4th year)
Prerequisites

Course prerequisites:

- **propositional logic**: syntax and semantics
- **foundations of AI**: search, heuristic search
- **computational complexity theory**: decision problems, reductions, NP-completeness
Credit points & exam

- 6 ECTS points
- special lecture in concentration subject
  Artificial Intelligence and Robotics
- oral exam of about 30 minutes B.Sc. students
- written or oral exam for M.Sc. students
  (depending on their number)
Exercises (written assignments):

- handed out on Tuesdays (exception: sheet 1 handed out this Friday instead of Tuesday next week because of All Saints’ Day)
- due Tuesday following week, before the lecture
- discussed Friday that week
- may be solved in groups of two students ($2 \neq 3$)
- successful participation prerequisite for exam admission
Projects (programming assignments):

- handed out every now and then
  (probably three times over the course of the semester)
- more time to work on than for exercises
- may be solved in groups of two students \((2 = 2)\)
- language: Python
- codebase: https://bitbucket.org/malte/pyperplan
- solutions that obviously do not work: 0 marks
  - may fix bugs uncovered by our testing
    if still within submission deadline
- successful participation prerequisite for exam admission
points can be earned for “reasonable” solutions to exercises and projects (one project counts like two exercise sheets).

at least 50% of points prerequisite for admission to final exam.
Plagiarism

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](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.”
Introduction
What is 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)
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: $10^{10}, 10^{100}, 10^{1000}, \ldots$ 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
Different classes of problems

- **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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## Properties of the world: dynamics

<table>
<thead>
<tr>
<th>Deterministic dynamics</th>
<th>Action + current state <strong>uniquely</strong> determine successor state.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nondeterministic dynamics</td>
<td>For each action and current state there may be <strong>several possible</strong> successor states.</td>
</tr>
<tr>
<td>Probabilistic dynamics</td>
<td>For each action and current state there is a <strong>probability distribution</strong> over possible successor states.</td>
</tr>
</tbody>
</table>

**Analogy:** deterministic versus nondeterministic automata
Deterministic dynamics example

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

Moving objects with an unreliable robotic hand: move the green block onto the blue block.
### Properties of the world: observability

<table>
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<tr>
<th>Full observability</th>
<th>Observations/sensing determine current world state <strong>uniquely</strong>.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial observability</td>
<td>Observations determine current world state <strong>only partially</strong>: we only know that current state is one of several possible ones.</td>
</tr>
<tr>
<td>No observability</td>
<td>There are <strong>no observations</strong> to narrow down possible current states. However, can use knowledge of <strong>action dynamics</strong> to deduce which states we might be in.</td>
</tr>
</tbody>
</table>

**Consequence:** If observability is not full, must represent the **knowledge** an agent has.
What difference does observability make?

Camera A

Camera B

Goal
Different objectives

1. Reach a goal state.
   - Example: Earn 500 Euro.

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 2022 study hard and save money.

4. Collect the maximal expected rewards/minimal expected costs (infinite horizon).
   - Example: Maximize your future income.

5. ...
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.
What do you learn in this course?

- emphasis on classical planning ("simplest" case)
- 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 satisfiability testing (SAT)
    (time permitting)

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

- hands-on experience with a classical planner