Principles of AI Planning

1. Introduction
About the course
People

Lecturers

Dr. Robert Mattmüller

- **email**: mattmuel@informatik.uni-freiburg.de
- **office**: room 052-00-042
- **consultation**: by appointment (email) or just come to my office

Prof. Dr. Bernhard Nebel

- **email**: nebel@informatik.uni-freiburg.de
- **office**: room 052-00-029
- **consultation**: Tuesday, 12:00-13:00 and by appointment
People

Exercises

Robert Mattmüller

Dominik Drexler

- **email**: drexlerd@informatik.uni-freiburg.de
- **consultation**: by appointment (email)
### Lectures

- **time:** Monday 16:15-18:00, Friday 16:15-17:00  
- **place:** Building 101, seminar room 00-010/14

### Exercises

- **time:** Friday 17:15-18:00  
- **place:** Building 101, seminar room 00-010/14
Course web site

http://gki.informatik.uni-freiburg.de/teaching/ws1718/aip/

- main page: course description
- lecture page: slides
- exercise page: assignments, software
- bibliography page: literature references and papers
Teaching materials

- 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)
    (very different from this course, quite outdated)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)
- additional resources: bibliography page on web + ask us!
Teaching materials

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, ~3rd year

Other students:
- advanced study period (~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 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)
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
Admission to exam

- 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](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

**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
Deterministic dynamics example

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

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.

$p = 0.9$

$p = 0.1$
Properties of the world: observability

<table>
<thead>
<tr>
<th>Full observability</th>
<th>Observations 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 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 2027 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)
- 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)