Seminar on Automated Planning

Bernhard Bliem & Matti Järvisalo

Practical arrangements, introduction, choosing topics
September 19, 2018

Practical Arrangements

Course Information

Instructors:	Dr. Bernhard Bliem, Prof. Matti Järvisalo

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Credit units:	5 ECTS
Language:	english
WWW:	https://courses.helsinki.fi/en/csm12113/124922697
Announcements:	seminar webpage, email
Reception:	Contact instructor(s) by email for an appointment. or during seminar meetings

Course Requirements

- Choose a topic (scientific chapter/article) to study
- Write a 10-15 page (plus references) report on the topic
- Give a 40-min presentation on the topic
- Peer-review of the reports of two other students (draft and final versions)
  - or hands-on project work
- Act as the opponent of another student's presentation
- Actively attend the seminar

Grading:

- On scale 0–5
- Report 40%, presentation 40%, peer-review/project work 20%
- Activity (incl. being an opponent) ± 1 grade

Deadlines

- All deadlines are strict you will fail the course if you do not meet a deadline
  - Need proof of illness to postpone deadlines
  - . . . or let us know well in advance to make rearrangements
- Today: choose topic and presentation date
- Presentations: during period II, Nov 14 – Dec 5
- One week before your presentation: preliminary report & slides
  (send to instructors by email)
- At presentation day:
  Presenters: arrive early to set up slides etc.
  Opponents: actively ask questions during & after presentation
- December 12: final reports
- December 18: final peer reviews

Choosing a Topic

Topic = 1-2 articles from the list on the course webpage

- Choose 1-2 articles from the list
- Can suggest a topic+articles outside the list!
- You will likely need to read additional articles for necessary background
- Reserve topic no later than Sep 26 (within one week)
  - <u>Preferably already TODAY!</u>

Note: more background material listed on the course webpage

Report

- A seminar report is a short review paper:
  you explain some interesting results in your own words.
- A typical seminar report will consist of the following parts:
  - an informal introduction,
  - a formally precise definition of the problem that is studied,
  - a brief overview of very closely related work: here you might cite approx. 10 papers and explain their main contributions,
  - a more detailed explanation of one or two interesting results, with examples
  - conclusions.
- Superficially, your report should look like a typical scientific article.
  - However, it will not contain any new scientific results, just a survey of previously published work.

Presentation

- The presentation is an overview of the report
  - You should understand what you are saying
  - Everyone should understand you
  - The abstraction level should be right
  - Examples are always good to communicate ideas

Templates

- Use of Latex especially for the seminar report is strongly encouraged
- Latex template for the report available via the seminar webpage
- For the presentation, use software of your choice
  - If you use latex, look into the beamer package

Some Words of Advice

- Start working on your topic early!
- Depending on your background, you will very likely need to read additional papers for background
- Aim at understanding the key aspects of your topic – do not get side-tracked
- You are responsible for figuring out the details
  - The instructors will not teach you all necessary background
  - In case you get completely stuck, contact the instructors
  - You will need to show that you have made a serious attempt to understand the topic by yourself

Introduction

Generic Solvers for Hard Problems

Solving hard problems

- Many practically relevant problems are NP-hard.
- There has been great progress in solving some of them.
- But domain-specific algorithms are only useful for one particular problem.
- Insights cannot easily be transferred to other problems.

Generic solvers

- Capable of solving **many problems**.
- Provide a **declarative language** for problem specification.
- Better solvers benefit **all** modeled problems.

Programming vs. Modeling + Solving

Planning

What is planning?

- “Planning is the reasoning side of acting.” [Ghallab et al., 2004]
- Which actions does an agent have to execute to reach certain goals?
- Which actions allow it to do so most efficiently?

Some Applications

- Robots
- Autonomous vehicles
- Controlling operations in spacecraft
- Scheduling of observations at the Hubble Space Telescope
- Controlling NPCs in computer games
- …

Automated/AI Planning

- Planning is concerned with finding a sequence of actions that lead from an initial state of a system to a goal state.
- Generally a very hard problem
- Many algorithms have been proposed.
- One of the core disciplines of AI
- In real systems (e.g., robots), there is usually an interplay between planning and acting.

Formalisms

We focus on classical planning.

Simplifying assumptions

- Finite number of states
- Fully observable system
  - We know which state we are in.
- Static system
  - Changes are only due to actions.
- No extended conditions on goals
  - No special conditions on, e.g., which trajectory we took.
- Sequential plans
- Implicit time
  - Actions have no duration.

Research on classical planning is important
to improve the techniques in more realistic settings.

Transition systems

We can formalize planning tasks with transition systems.

Definition

A transition system is a tuple (S, A, γ, i, g), where

- S is the set of **states**,
- A is the set of **actions**,
- $\gamma : S \times A \rightarrow S$ is a partial function, the **transition function**,
- $i \in S$ is the **initial state** and
- $g \in S$ is the **goal state.**

Many variants are in place – use depends on application.

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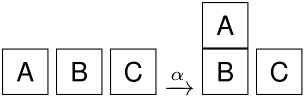
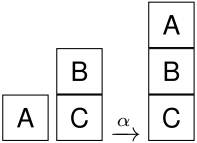
A sequence $\langle a_1, \ldots, a_n \rangle$ of actions is a plan if there are states $s_0, \ldots, s_n$ such that $s_0 = i$, $s_n = g$ and $s_0 \xrightarrow{a_1} \ldots \xrightarrow{a_n} s_n$.

Our domain

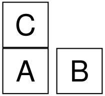
- We have a table and wooden blocks A, B, C.
- A block can be on another block or on the table.
  - Each possible configuration of blocks is a state.
- We can move single blocks that have no blocks on top.
  - E.g., possible transitions for an action α, which lifts A from the table onto B:

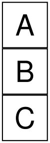


and



A possible planning task

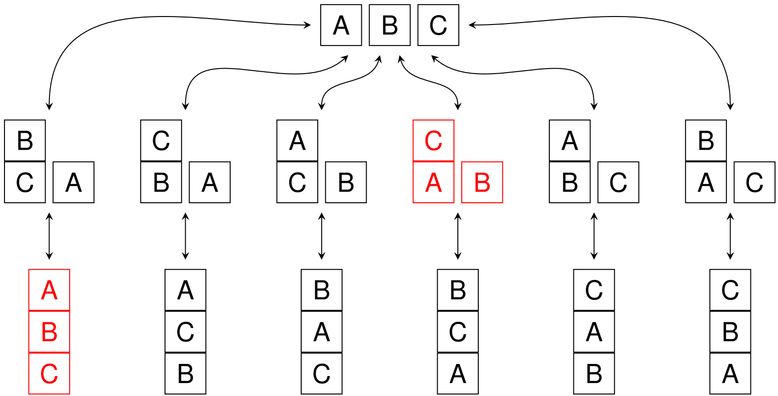
How to get from initial state 

to goal state 

?

Planning as Finding Paths in Transition Graphs

Why not use a path finding algorithm for finding plans?



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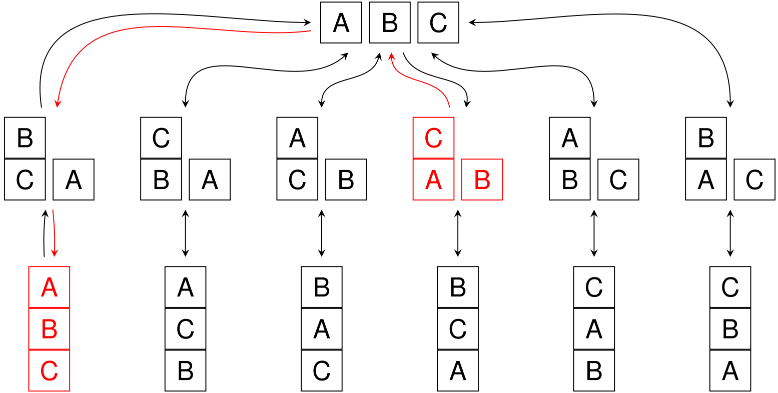

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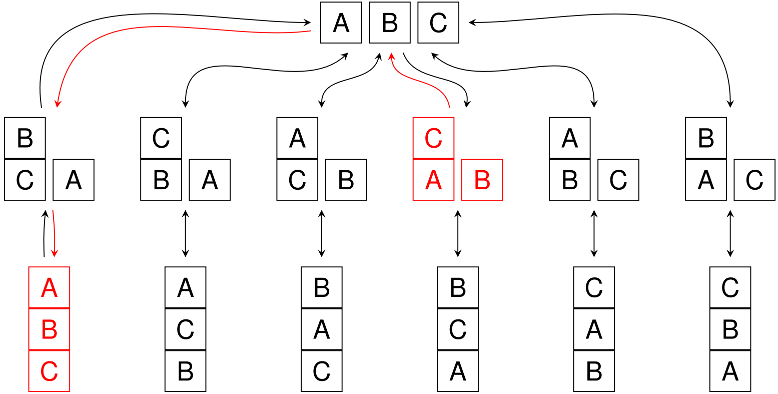

As the instance grows, the number of states explodes.

State Explosion

Why path finding algorithms are not feasible:

Blocks	States
1	1
2	3
3	13
4	73
⋮	
10	$\sim 6 \cdot 10^7$
⋮	
15	$\sim 7 \cdot 10^{13}$

We need to reason over a compact representation of the transition system.

STRIPS Planning

STRIPS: A formalism for classical planning

We can use it to represent planning tasks in a compact way:

- A state is represented as a set of ground atoms.
  - Example: $\{\text{on\_table}(A),\ \text{on\_block}(B, A),\ \text{clear}(B)\}$
- Actions are represented by means of operators.
  - An action is any ground instance of an operator.
  - An operator is defined by the following statements:

Precondition	When is the action applicable?
Delete list	Which atoms are no longer true afterwards?
Add list	Which atoms additionally become true?

- We just need to store the initial state.
- Other states can then be generated using operators.

STRIPS Example: Blocks World

One possible model:

- Atoms: on_table(x), on_block(x, y), clear(x), for blocks x
  - Initial state:
    $\{$on_table(A), clear(A), on_table(B), on_block(C, A), clear(C)$\}$
  - Goal state:
    $\{$on_table(C), on_block(B, C), on_block(A, B), clear(A)$\}$

STRIPS Example: Blocks World

One possible model:

- Atoms: on_table(x), on_block(x, y), clear(x), for blocks x
  - Initial state:
    {on_table(A), clear(A), on_table(B), on_block(C, A), clear(C)}
  - Goal state:
    {on_table(C), on_block(B, C), on_block(A, B), clear(A)}
- Operator down_from(x, y):

Precondition	on_block(x, y) $\wedge$ clear(x)
Delete list	on_block(x, y)
Add list	on_table(x), clear(y)

STRIPS Example: Blocks World

One possible model:

- Atoms: on_table(x), on_block(x, y), clear(x), for blocks x
  - Initial state:
    {on_table(A), clear(A), on_table(B), on_block(C, A), clear(C)}
  - Goal state:
    {on_table(C), on_block(B, C), on_block(A, B), clear(A)}
- Operator down_from(x, y):

Precondition	on_block(x, y) $\wedge$ clear(x)
Delete list	on_block(x, y)
Add list	on_table(x), clear(y)

- Operator up_to(x, y):

Precondition	on_table(x) $\wedge$ clear(x) $\wedge$ clear(y)
Delete list	on_table(x), clear(y)
Add list	on_block(x, y)

Variants of Classical Planning

We introduced classical planning, which is quite restrictive.

Sometimes one may want to use a more general formalism:

- not fully observable
- more than one initial state
- more than one goal state
- non-deterministic actions
- actions have costs / durations
- multiple actors
- parallel actions
- ...

Complexity of Planning

We can study the following decision problems for a specification language L (e.g., STRIPS):

Plan Existence	
Input:	A planning problem $P \in L$
Question:	Is there a plan for P?

Also interesting because we often want optimal plans:

Short Plan	
Input:	A planning problem $P \in L$ and an integer k
Question:	Is there a plan with at most k actions for P?

For STRIPS, both problems are PSPACE-complete.

Algorithms

- State-space planning
  - Try to reach goal state from initial state
  - State-of-the-art (but only with good heuristics)
  - Main techniques: Forward search and backward search
- Plan-space planning
  - Here, plans are not linear, only a partial order of actions.
  - Graph: Nodes are partial plans, edges are refinements.
  - Plans are easier to understand and check for humans.
- Planning by translation to SAT
- Planning by translation to constraint satisfaction
- Planning-graph techniques
- Situation calculus: Planning in first-order logic

Competitions

International Planning Competition (IPC)

- Purpose: Find benchmarks, determine state of the art
- Organized every few years since 1998
- Results presented at the International Conference on Planning and Scheduling (ICAPS)
- Planning Domain Definition Language (PDDL) introduced at first IPC
- 2018: Various tracks in three groups:
  - Classical: Optimal, bounded-cost, satisficing, agile
  - Probabilistic
  - Temporal

There are several related, more specialized competitions.

Choosing Topics & Dates

Algorithms — Heuristics — Representations — Complexity — Competitions — Applications

Or suggest your own topic.

Topic List

Algorithms

1. Comparison of forward-search planners: FF, Fast Downward, LAMA
2. Planning-graph based techniques
3. SAT-based planning and beyond (QBF-based planning)

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Heuristics

1. Heuristics for state-space planners
2. Choosing among different heuristics
3. Planning by refining solutions of relaxations

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Representations

1. Extensions of classical planning (e.g., time, uncertainties)
2. Transformation to a non-propositional representation (PDDL $\rightarrow$ FDR)

Topic List (contd.)

Complexity

1. Overview of complexity of planning
2. Expressive power of planning formalisms
3. Bounds on time and space
4. Parameterized complexity

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Competitions
Overview of a planning competition: PDDL language, benchmarks, results

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Competitions: Overview of a planning competition: PDDL language, benchmarks, results

Applications: Present some interesting applications