Planning and Optimization

A2. What is Planning?

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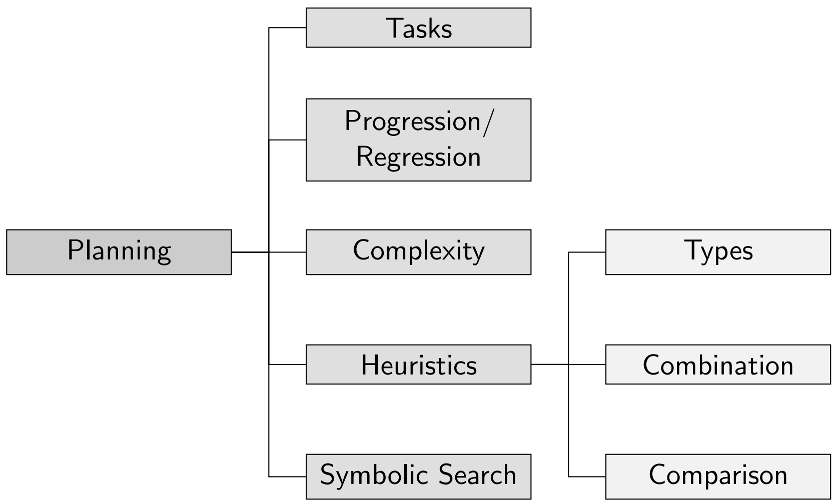
Content of this Course



Before We Start. . .

today: a very high-level introduction to planning

- our goal: give you a little feeling what planning is about
- preface to the actual course

⇝ "actual" content (beginning on October 2) will be mathematically formal and rigorous

- You can ignore this chapter when preparing for the exam.

A2.1 Planning

General Problem Solving

Wikipedia: General Problem Solver

General Problem Solver (GPS) was a computer program created in 1959 by Herbert Simon, J.C. Shaw, and Allen Newell intended to work as a universal problem solver machine.

Any formalized symbolic problem can be solved, in principle, by GPS. [. . .]

GPS was the first computer program which separated its knowledge of problems (rules represented as input data) from its strategy of how to solve problems (a generic solver engine).

⇝ these days called "domain-independent automated planning"
⇝ this is what the course is about

So What is Domain-Independent Automated Planning?

Automated Planning (Pithy Definition)

"Planning is the art and practice of thinking before acting."

— Patrik Haslum

Automated Planning (More Technical Definition)

"Selecting a goal-leading course of action based on a high-level description of the world."

— Jörg Hoffmann

Domain-Independence of Automated Planning

Create one planning algorithm that performs sufficiently well on many application domains (including future ones).

Planning Tasks

input to a planning algorithm: planning task

- initial state of the world
- actions that change the state
- goal to be achieved

output of a planning algorithm: plan

- sequence of actions that takes initial state to a goal state

⇝ formal definition later in the course

The Planning Research Landscape

- one of the major subfields of Artificial Intelligence (AI)
- represented at major AI conferences (IJCAI, AAAI, ECAI)
- annual specialized conference ICAPS ($\approx$ 200 participants)
- major journals: general AI journals (AIJ, JAIR)

Classical Planning

This course covers classical planning:

- offline (static)
- discrete
- deterministic
- fully observable
- single-agent
- sequential (plans are action sequences)
- domain-independent

This is just one facet of planning.

Many others are studied in AI. Algorithmic ideas often (but not always) translate well to more general problems.

More General Planning Topics

More general kinds of planning include:

- ~~offline~~: online planning; planning and execution
- ~~discrete~~: continuous planning (e.g., real-time/hybrid systems)
- ~~deterministic~~: FOND planning; probabilistic planning
- ~~single-agent~~: multi-agent planning; general game playing; game-theoretic planning
- ~~fully observable~~: POND planning; conformant planning
- ~~sequential~~: e.g., temporal planning

Domain-dependent planning problems in AI include:

- pathfinding, including grid-based and multi-agent (MAPF)
- continuous motion planning

A2.2 Planning Task Examples

Example: The Seven Bridges of Königsberg

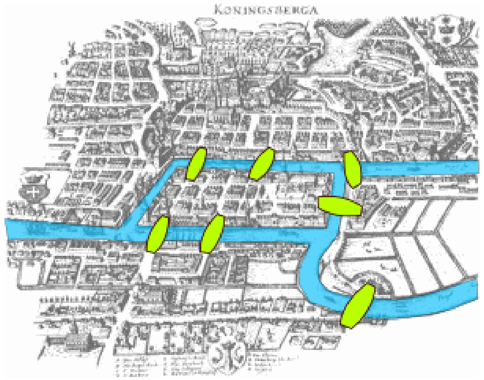


image credits: Bogdan Giuşcă (public domain)

Demo

```
$ ls demo/koenigsberg
```


Example: Intelligent Greenhouse

photo © LemnaTec GmbH

Demo

```
$ ls demo/ipc/scanalyzer-08-strips
```


Example: FreeCell

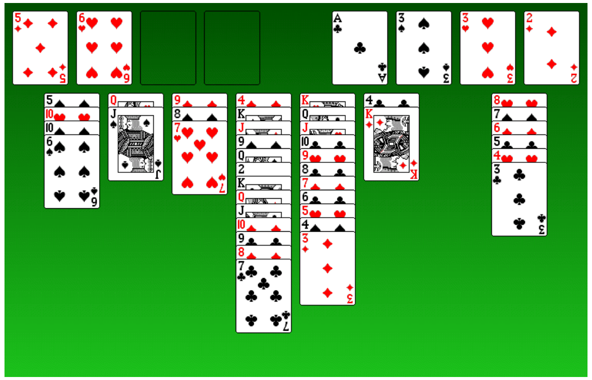


image credits: GNOME Project (GNU General Public License)

Demo Material

```
$ ls demo/ipc/freecell
```


Many More Examples

Demo

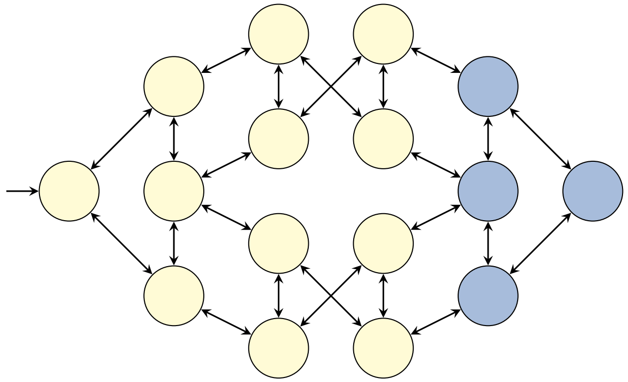
```
$ ls demo/ipc
airport
airport-adl
assembly
barman-mco14-strips
barman-opt11-strips
barman-opt14-strips
barman-sat11-strips
barman-sat14-strips
blocks
cavediving-14-adl
...
```

⇝ (most) benchmarks of planning competitions IPC 1998–2014

A2.3 How Hard is Planning?

Planning as State-Space Search

Planning as state-space search:



⇝ much more on this later in the course

Is Planning Difficult?

Classical planning is computationally challenging:

- number of states grows exponentially with description size when using (propositional) logic-based representations
- provably hard (PSPACE-complete)

⇝ we prove this later in the course

Problem sizes:

- Seven Bridges of Königsberg: 64 reachable states
- Rubik's Cube: $4.325 \cdot 10^{19}$ reachable states
  ⇝ consider 2 billion/second ⇝ 1 billion years
- standard benchmarks: some with $> 10^{200}$ reachable states

A2.4 Getting to Know a Planner

Getting to Know a Planner

We now play around a bit with a planner and its input:

- look at problem formulation
- run a planner (= planning system/planning algorithm)
- validate plans found by the planner

Planner: Fast Downward

Fast Downward

We use the Fast Downward planner in this course

- because we know it well (developed by our research group)
- because it implements many search algorithms and heuristics
- because it is the classical planner most commonly used as a basis for other planners these days

⇝ `http://www.fast-downward.org`

Validator: VAL

VAL

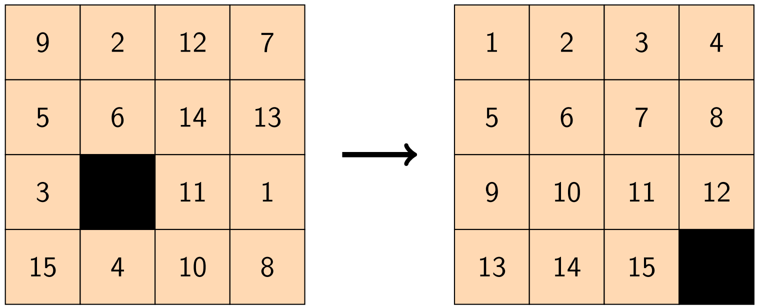
We use the VAL plan validation tool (Fox, Howey & Long) to independently verify that the plans we generate are correct.

- very useful debugging tool

⇝ `https://github.com/KCL-Planning/VAL`

Because of bugs/limitations of VAL, we will also occasionally use another validator called INVAL (by Patrik Haslum).

Illustrating Example: 15-Puzzle



Solving the 15-Puzzle

Demo

```
$ cd demo
$ less tile/puzzle.pddl
$ less tile/puzzle01.pddl
$ ./fast-downward.py \
      tile/puzzle.pddl tile/puzzle01.pddl \
      --heuristic "h=ff()" \
      --search "eager_greedy([h],preferred=[h])"
...
$ ./validate tile/puzzle.pddl tile/puzzle01.pddl \
      sas_plan
...
```


Variation: Weighted 15-Puzzle

Weighted 15-Puzzle:

- moving different tiles has different cost
- cost of moving tile x = number of prime factors of x

Demo

```
$ cd demo
$ meld tile/puzzle.pddl tile/weight.pddl
$ meld tile/puzzle01.pddl tile/weight01.pddl
$ ./fast-downward.py \
      tile/weight.pddl tile/weight01.pddl \
      --heuristic "h=ff()" \
      --search "eager_greedy([h],preferred=[h])"
...
```


Variation: Glued 15-Puzzle

Glued 15-Puzzle:

- some tiles are glued in place and cannot be moved

Demo

```
$ cd demo
$ meld tile/puzzle.pddl tile/glued.pddl
$ meld tile/puzzle01.pddl tile/glued01.pddl
$ ./fast-downward.py \
      tile/glued.pddl tile/glued01.pddl \
      --heuristic "h=cg()" \
      --search "eager_greedy([h],preferred=[h])"
...
```

Note: different heuristic used!

Variation: Cheating 15-Puzzle

Cheating 15-Puzzle:

- Can remove tiles from puzzle frame (creating more blanks) and reinsert tiles at any blank location.

Demo

```
$ cd demo
$ meld tile/puzzle.pddl tile/cheat.pddl
$ meld tile/puzzle01.pddl tile/cheat01.pddl
$ ./fast-downward.py \
      tile/cheat.pddl tile/cheat01.pddl \
      --heuristic "h=ff()" \
      --search "eager_greedy([h],preferred=[h])"
...
```

A2.5 Summary

Summary

- planning = thinking before acting
- major subarea of Artificial Intelligence
- domain-independent planning = general problem solving
- classical planning = the "easy case"
  (deterministic, fully observable etc.)
- still hard enough!
  $\rightsquigarrow$ PSPACE-complete because of huge number of states
- many examples of planning tasks ($\rightsquigarrow$ demo material)