Planning and Optimization

A2. What is Planning?

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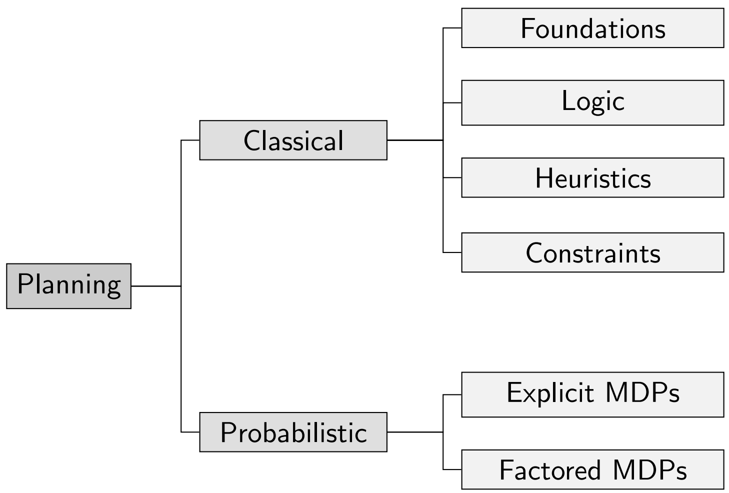
Content of this Course



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

$\rightsquigarrow$ main course content (beginning next week) 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)

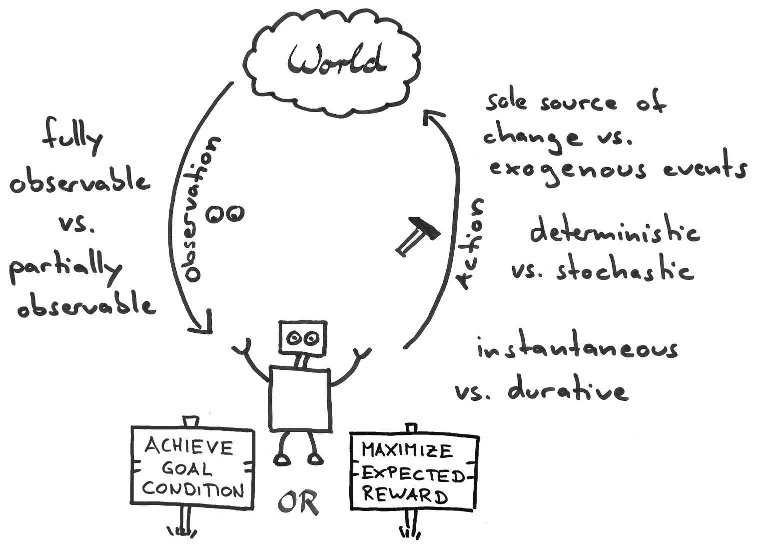
"Selecting a goal-leading course of action based on a high-level description of the world."

— Jörg Hoffmann

Domain-Independence of Automated Planning

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

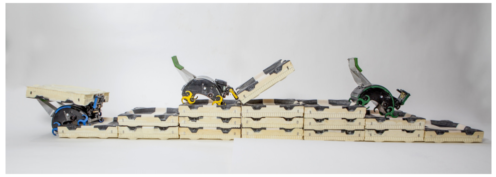
General Perspective on Planning



Example: Earth Observation

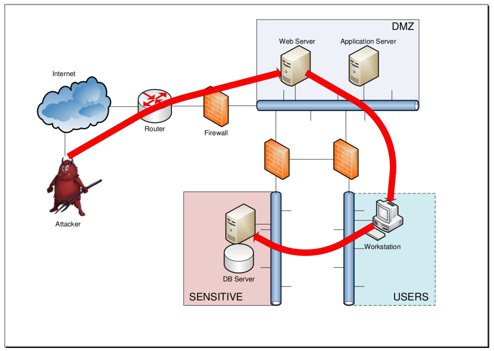
- satellite takes images of patches on Earth
- use weather forecast to optimize probability of high-quality images

Example: Termes



Harvard TERMES robots, based on termites

Example: Cybersecurity

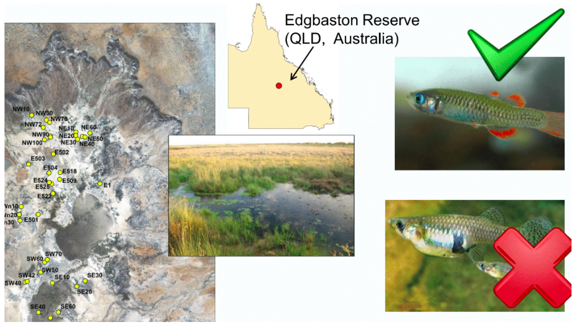


CALDERA automated adversary emulation system

Example: Intelligent Greenhouse

photo © LemnaTec GmbH

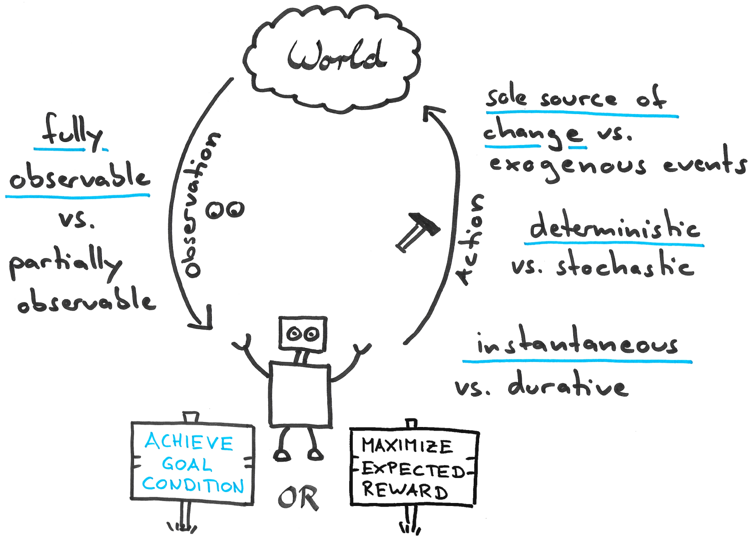
Example: Red-finned Blue-eye



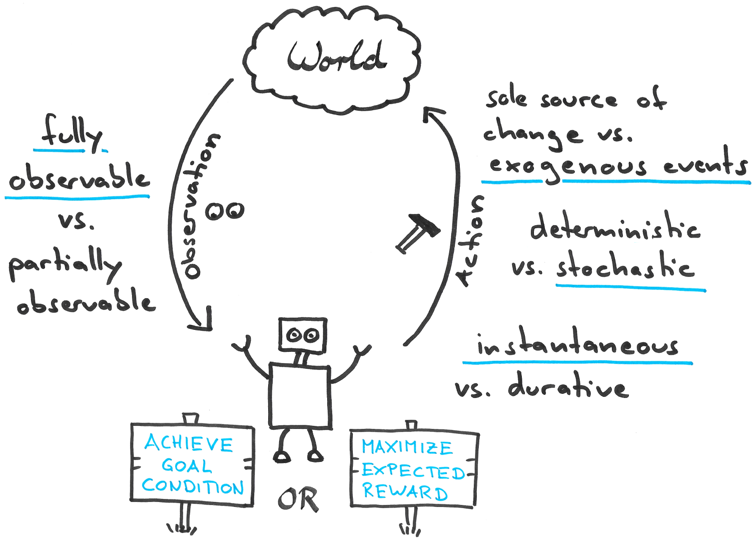
Picture by Iadine Chadès

- red-finned blue-eye population threatened by gambusia
- springs connected probabilistically during rain season
- find strategy to save red-finned blue-eye from extinction

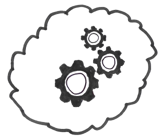
Classical Planning



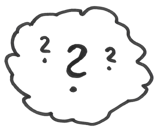
Probabilistic Planning



Model-based vs. Data-driven Approaches



Model-based approaches know the "inner workings" of the world
⇝ reasoning



Data-driven approaches rely only on collected data from a black-box world
⇝ learning

We focus on model-based approaches.

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 (classical setting)
  - sequence of actions that takes initial state to a goal state
- policy (probabilistic setting)
  - function that returns for each state the action to take
- Why different concepts?

$\rightsquigarrow$ formal definitions 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 ($\approx$ 250 participants)
- major journals: general AI journals (AIJ, JAIR)

A2.2 Planning Task Examples

Example: The Seven Bridges of Königsberg

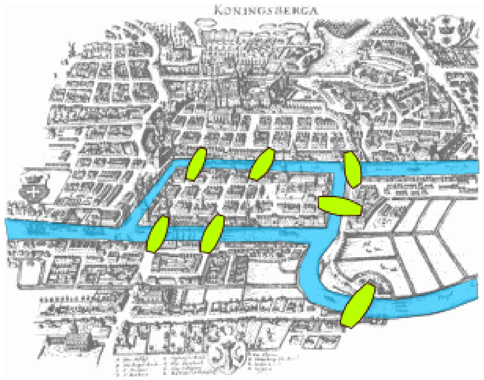


image credits: Bogdan Giușcă (public domain)

Demo

```
$ ls demo/koenigsberg
```

Example: Intelligent Greenhouse

photo © LemnaTec GmbH

Demo

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


Example: FreeCell

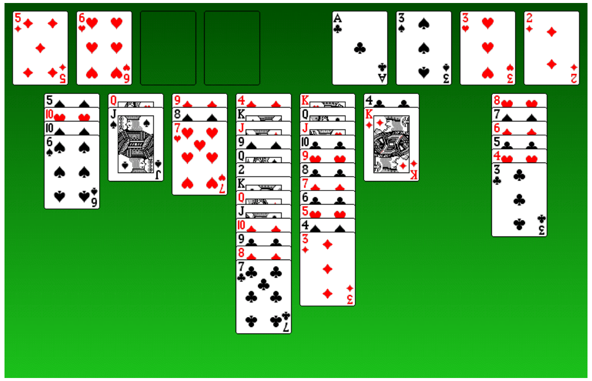


image credits: GNOME Project (GNU General Public License)

Demo Material

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


Many More Examples

Demo

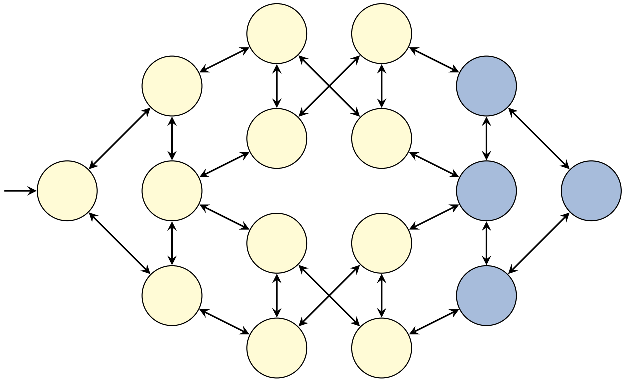
```
$ ls demo/ipc
agricola-opt18-strips
agricola-sat18-strips
airport
airport-adl
assembly
barman-mco14-strips
barman-opt11-strips
barman-opt14-strips
...
```

⇝ (most) benchmarks of planning competitions IPC 1998–2018

A2.3 How Hard is Planning?

Classical Planning as State-Space Search

classical 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 Classical 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

9	2	12	7
5	6	14	13
3		11	1
15	4	10	8

→

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	

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
- probabilistic planning considers stochastic action outcomes
  and exogenous events.