Planning and Optimization

A2. What is Planning?

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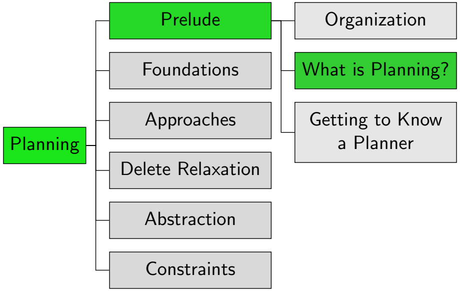
Content of the Course



Before We Start...

Prelude (Chapters A1–A3): very high-level intro to planning

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

$\rightsquigarrow$ main course content (beginning with Chapter B1) will be mathematically formal and rigorous

- You can ignore the prelude when preparing for the exam.

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).

$\leadsto$ these days called "domain-independent automated planning"
$\leadsto$ 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)

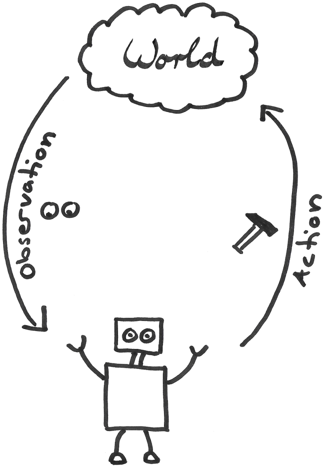
"Selecting a goal-leading course of action
based on a high-level description of the world."

— Jörg Hoffmann

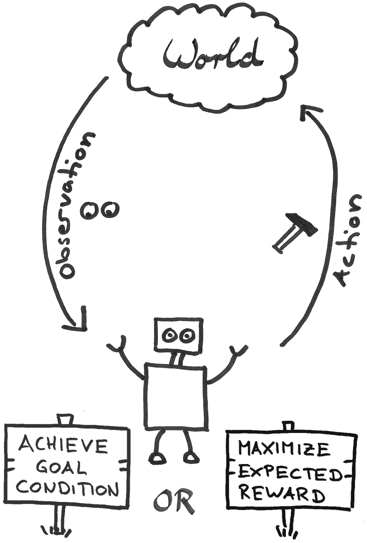
Domain-Independence of Automated Planning

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

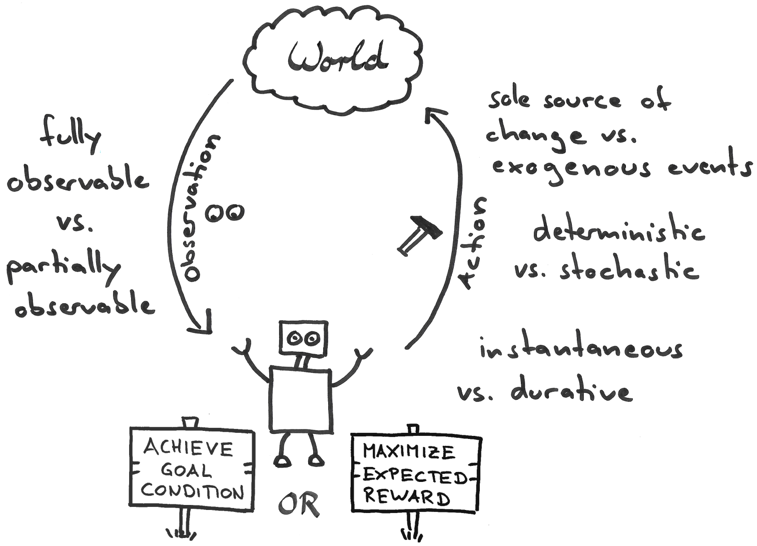
General Perspective on Planning



General Perspective on Planning



General Perspective on Planning


World
observation
action
fully observable vs. partially observable
sole source of change vs. exogenous events
deterministic vs. stochastic
instantaneous vs. durative
ACHIEVE GOAL CONDITION
OR
MAXIMIZE EXPECTED REWARD

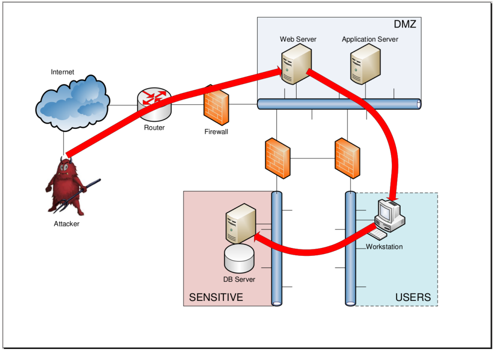
Example: Earth Observation

- 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

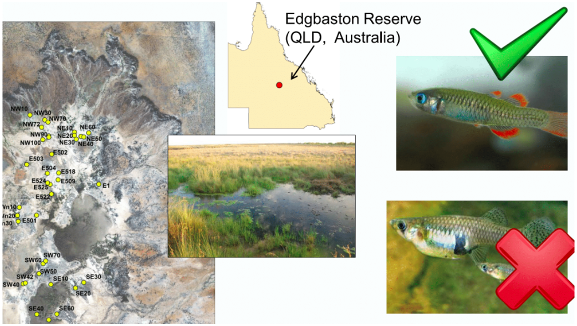


CALDERA automated adversary emulation system

Example: Intelligent Greenhouse

photo © LemnaTec GmbH

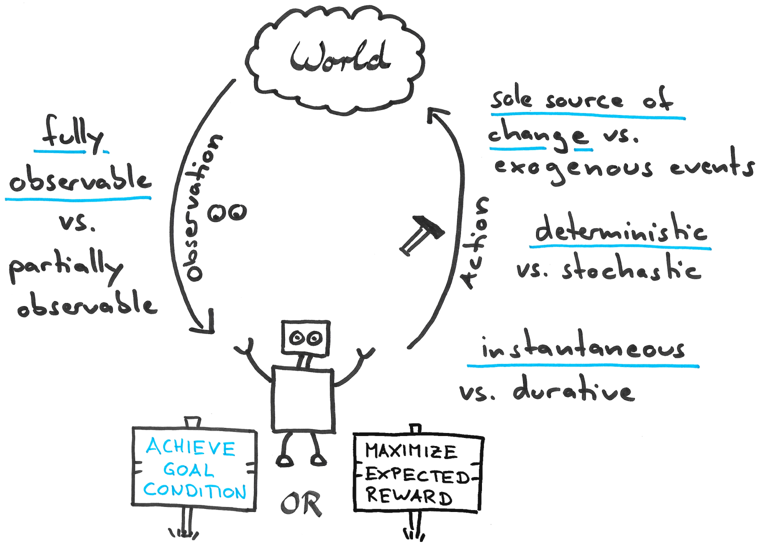
Example: Red-finned Blue-eye



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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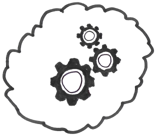
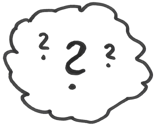
Model-based vs. Data-driven Approaches



Model-based approaches know
the "inner workings" of the world
$\rightsquigarrow$ reasoning



Data-driven approaches rely only
on collected data from a black-box world
$\rightsquigarrow$ 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: sequence of actions taking initial state to a goal state
- or confirmation that no plan exists

$\rightsquigarrow$ 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)

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

Planning Task Examples

Example: The Seven Bridges of Königsberg

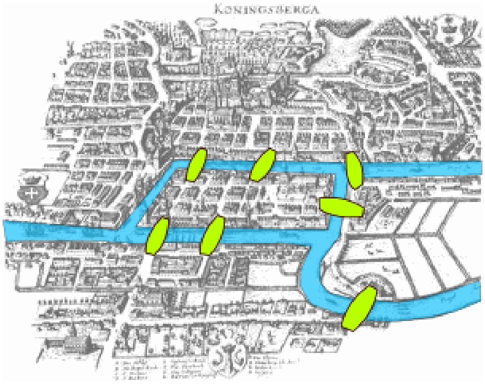


image credits: Bogdan Giușcă (public domain)

Demo

```
$ ls demo/koenigsberg
```

Example: Intelligent Greenhouse

photo © LemnaTec GmbH

Demo

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

Example: FreeCell

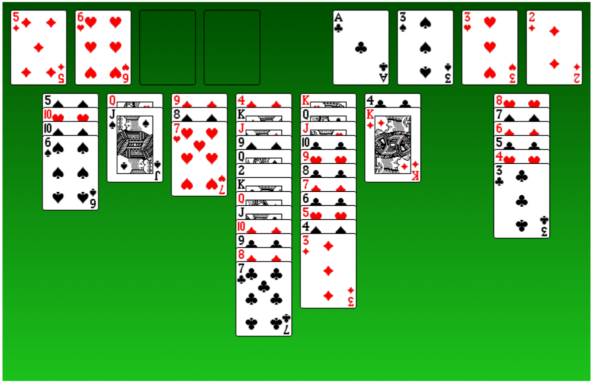


image credits: GNOME Project (GNU General Public License)

Demo Material

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

Many More Examples

Demo

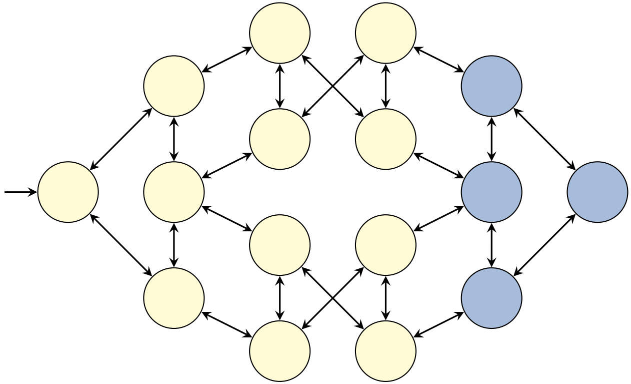
```
$ ls demo/ipc
agricola-opt18-strips
agricola-sat18-strips
airport
airport-adl
assembly
barman-mco14-strips
barman-opt11-strips
barman-opt14-strips
...
```

$\rightsquigarrow$ (most) benchmarks of planning competitions IPC since 1998

How Hard is Planning?

Classical Planning as State-Space Search

classical planning as state-space search:



$\rightsquigarrow$ 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)

$\rightsquigarrow$ 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
  $\rightsquigarrow$ consider 2 billion/second $\rightsquigarrow$ 1 billion years
- standard benchmarks: some with $> 10^{200}$ reachable states

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!
  $\leadsto$ PSPACE-complete because of huge number of states
- often solved by state-space search
- number of states grows exponentially with input size