Planning and Optimization

D1. Delete Relaxation: Relaxed Planning Tasks

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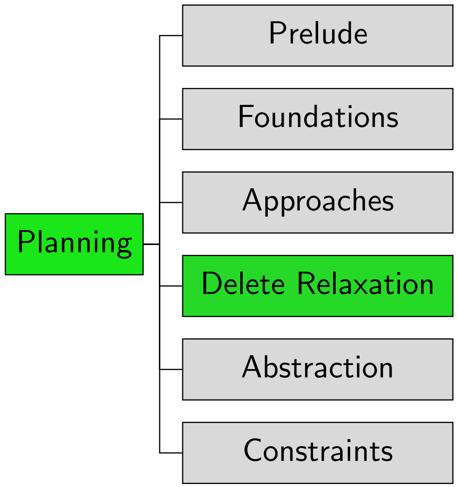
Content of the Course



D1.1 Heuristics

Planning as Heuristic Search

- Heuristic search is the most common approach to planning.
- ingredients: general search algorithm + heuristic
- heuristic estimates cost from a given state to a given goal
  - progression: from varying states s to fixed goal γ
  - regression: from fixed initial state I to varying subgoals φ
- Over the next weeks, we study the main ideas behind heuristics for planning tasks.

Reminder: Heuristics

Need to Catch Up?

- We assume familiarity with heuristics and their properties:
  - heuristic $h : S \to \mathbb{R}_0^+ \cup \{\infty\}$
  - perfect heuristic h^*: $h^*(s)$ cost of optimal solution from s (∞ if unsolvable)
  - properties of heuristics h:
    - safe: $(h(s) = \infty \Rightarrow h^*(s) = \infty)$ for all states s
    - goal-aware: $h(s) = 0$ for all goal states s
    - admissible: $h(s) \leq h^*(s)$ for all states s
    - consistent: $h(s) \leq cost(o) + h(s')$ for all transitions $s \xrightarrow{o} s'$
  - connections between these properties
- If you are not familiar with these, we recommend Ch. B9–B10 of the Foundations of Artificial Intelligence course: `https://dmi.unibas.ch/en/studies/computer-science/courses-in-spring-semester-2024/lecture-foundations-of-artificial-intelligence/`

D1.2 Coming Up with Heuristics

A Simple Heuristic for Propositional Planning Tasks

STRIPS (Fikes & Nilsson, 1971) used the number of state variables that differ in current state s and a STRIPS goal $v_1 \wedge \cdots \wedge v_n$:

$$h(s) := |\{i \in \{1, \ldots, n\} \mid s \not\models v_i\}|.$$

Intuition: more satisfied goal atoms $\leadsto$ closer to the goal

$\leadsto$ STRIPS heuristic (a.k.a. goal-count heuristic)

Criticism of the STRIPS Heuristic

What is wrong with the STRIPS heuristic?

- quite uninformative:
  the range of heuristic values in a given task is small;
  typically, most successors have the same estimate
- very sensitive to reformulation:
  can easily transform any planning task into an equivalent one
  where $h(s) = 1$ for all non-goal states (how?)
- ignores almost all problem structure:
  heuristic value does not depend on the set of operators!

⇝ need a better, principled way of coming up with heuristics

Coming Up with Heuristics in a Principled Way

General Procedure for Obtaining a Heuristic

- Simplify the problem, for example by removing problem constraints.
- Solve the simplified problem (ideally optimally).
- Use the solution cost for the simplified problem as a heuristic for the real problem.

As heuristic values are computed for every generated search state, it is important that they can be computed efficiently.

Relaxing a Problem: Example

Example (Route Planning in a Road Network)

The road network is formalized as a weighted graph over points in the Euclidean plane. The weight of an edge is the road distance between two locations.

Example (Relaxation for Route Planning)

Use the Euclidean distance $\sqrt{|x_1 - x_2|^2 + |y_1 - y_2|^2}$ as a heuristic for the road distance between $\langle x_1, y_1 \rangle$ and $\langle x_2, y_2 \rangle$
This is a lower bound on the road distance (⇝ admissible).

⇝ We drop the constraint of having to travel on roads.

Planning Heuristics: Main Concepts

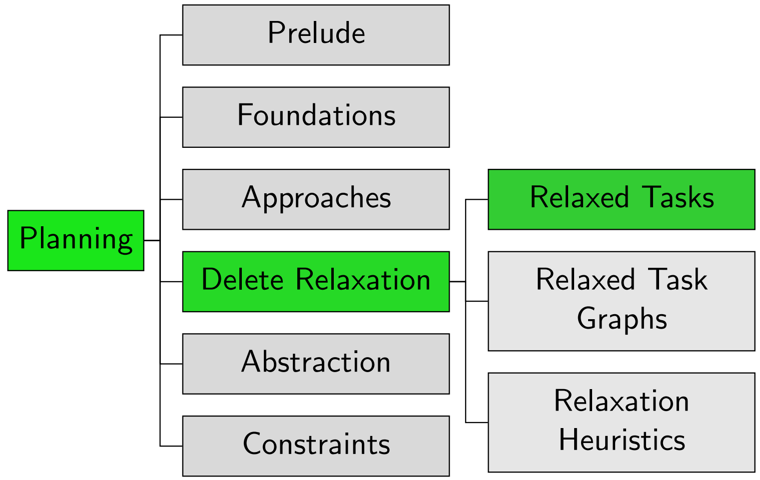
Major ideas for heuristics in the planning literature:

- delete relaxation ⇝ Part D
- abstraction ⇝ Part E
- critical paths ⇝ not considered in this course
- landmarks ⇝ Part F
- network flows ⇝ Part F
- potential heuristics ⇝ Part F

We will consider most of them in this course.

D1.3 Relaxed Planning Tasks

Content of the Course



Delete Relaxation: Idea

In positive normal form (Chapter B5, remember?), good and bad effects are easy to distinguish*:

- Effects that make state variables true are good (add effects).
- Effects that make state variables false are bad (delete effects).

Idea of delete relaxation heuristics: ignore all delete effects.

(*) with a small caveat regarding conditional effects

Delete-Relaxed Planning Tasks

Definition (Delete Relaxation of Operators)

The delete relaxation o^+ of an operator o in positive normal form is the operator obtained by replacing all negative effects $\neg a$ within $\mathit{eff}(o)$ by the do-nothing effect $\top$.

Definition (Delete Relaxation of Propositional Planning Tasks)

The delete relaxation Π^+ of a propositional planning task $\Pi = \langle V, I, O, \gamma\rangle$ in positive normal form is the planning task $\Pi^+ := \langle V, I, \{o^+ \mid o \in O\}, \gamma\rangle$.

Definition (Delete Relaxation of Operator Sequences)

The delete relaxation of an operator sequence $\pi = \langle o_1, \dots, o_n\rangle$ is the operator sequence $\pi^+ := \langle o_1^+, \dots, o_n^+\rangle$.

Note: "delete" is often omitted: relaxation, relaxed

Relaxed Planning Tasks: Terminology

- Planning tasks in positive normal form without delete effects are called relaxed planning tasks.
- Plans for relaxed planning tasks are called relaxed plans.
- If Π is a planning task in positive normal form and π^+ is a plan for Π^+, then π^+ is called a relaxed plan for Π.

D1.4 Summary

Summary

- A general way to come up with heuristics: solve a simplified version of the real problem, for example by removing problem constraints.
- delete relaxation: given a task in positive normal form, discard all delete effects