

# Planning and Optimization

## D1. Delete Relaxation: Relaxed Planning Tasks

Malte Helmert and Gabriele Röger

Universität Basel

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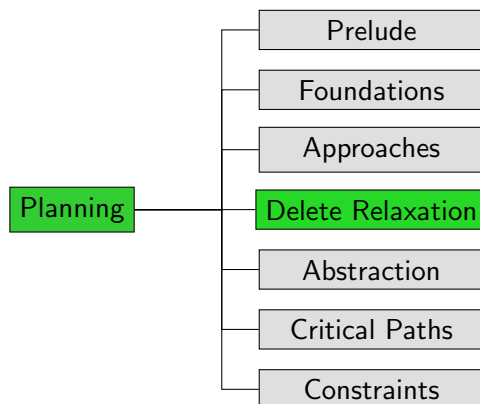
D1.1 Heuristics

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## Content of this 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  $\gamma$
  - ▶ **regression**: from fixed initial state  $l$  to varying subgoals  $\varphi$
- ▶ 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**  $h : S \rightarrow \mathbb{R}_0^+ \cup \{\infty\}$
  - ▶ **perfect heuristic**  $h^*$ :  $h^*(s)$  cost of optimal solution from  $s$  ( $\infty$  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**:  $h(s) \leq \text{cost}(o) + h(s')$  for all transitions  $s \xrightarrow{o} s'$
  - ▶ connections between these properties
- ▶ If you are not familiar with these, we recommend Ch. 13–14 of the [Foundations of Artificial Intelligence](https://dmi.unibas.ch/de/studium/computer-science-informatik/lehrangebot-fs23/lecture-foundations-of-artificial-intelligence-1/) course:  
<https://dmi.unibas.ch/de/studium/computer-science-informatik/lehrangebot-fs23/lecture-foundations-of-artificial-intelligence-1/>

## 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  $v_1 \wedge \dots \wedge v_n$ :

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

**Intuition**: more satisfied goal atoms  $\rightsquigarrow$  closer to the goal

$\rightsquigarrow$  **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

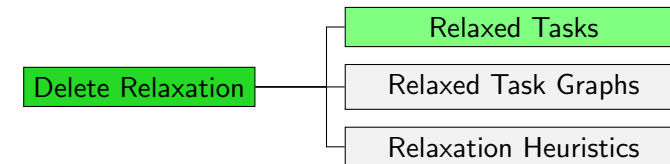
Major ideas for heuristics in the planning literature:

- ▶ delete relaxation ↪ Part D
- ▶ abstraction ↪ Part E
- ▶ critical paths ↪ Part F
- ▶ landmarks ↪ Part G
- ▶ network flows ↪ Part G
- ▶ potential heuristics ↪ Part G

We will consider all of them in this course.

## D1.3 Relaxed Planning Tasks

## Content of this Course: Delete Relaxation



## 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  $eff(o)$  by the do-nothing effect  $\top$ .

### Definition (Delete Relaxation of Propositional Planning Tasks)

The **delete relaxation**  $\Pi^+$  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  $\Pi$  is a planning task in positive normal form and  $\pi^+$  is a plan for  $\Pi^+$ , then  $\pi^+$  is called a **relaxed plan for  $\Pi$** .

## 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