

# Planning and Optimization

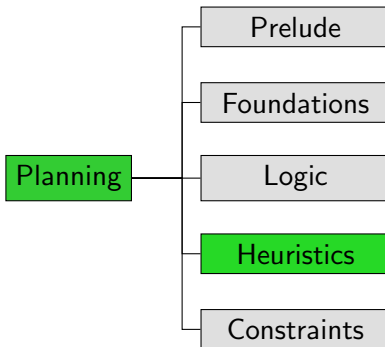
## D1. Delete Relaxation: Relaxed Planning Tasks

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# Content of this Course



# 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](#) course:  
<https://dmi.unibas.ch/en/studies/computer-science/courses-in-spring-semester-2022/lecture-foundations-of-artificial-intelligence/>

# 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 ( $\rightsquigarrow$  admissible).

$\rightsquigarrow$  We drop the constraint of having to travel on roads.

# Planning Heuristics: Main Concepts

Major ideas for heuristics in the planning literature:

- delete relaxation
- abstraction
- landmarks
- critical paths
- network flows
- potential heuristics

We will consider most of them in this course.

# Planning Heuristics: Main Concepts

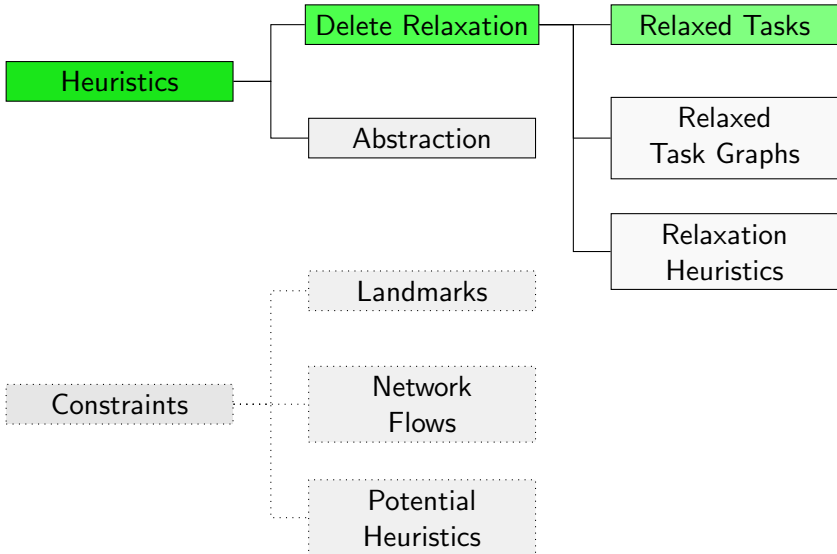
Major ideas for heuristics in the planning literature:

- delete relaxation      ⇨ Part D
- abstraction            ⇨ Part E
- landmarks             ⇨ Part F
- critical paths
- network flows        ⇨ Part F
- potential heuristics   ⇨ Part F

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# Relaxed Planning Tasks

# Content of this Course: Heuristics



## 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  $\text{eff}(o)$  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  $\Pi$** .

# Summary

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- 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