

Foundations of Artificial Intelligence

35. Automated Planning: Delete Relaxation

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How to Design Heuristics?

A Simple Planning Heuristic

The STRIPS planner (Fikes & Nilsson, 1971) uses the **number of goals not yet satisfied** in a STRIPS planning task as heuristic:

$$h(s) := |G \setminus s|.$$

intuition: fewer unsatisfied goals \rightsquigarrow closer to goal state

\rightsquigarrow **STRIPS heuristic** (properties?)

Problems of STRIPS Heuristic

drawback of STRIPS heuristic?

- rather **uninformed**:

For state s , if there is no applicable action a in s such that applying a in s satisfies strictly more (or fewer) goals, then all successor states have the same heuristic value as s .

- ignores almost the whole **task structure**:

The heuristic values do not depend on the actions.

⇒ we need better methods to design heuristics

Planning Heuristics

We consider **three basic ideas** for general heuristics:

- **delete relaxation** \rightsquigarrow this and next chapter
- abstraction \rightsquigarrow later
- landmarks \rightsquigarrow later

Planning Heuristics

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Delete Relaxation: Basic Idea

Estimate solution costs by considering a **simplified planning task**, where all **negative action effects** are ignored.

Automated Planning: Overview

Chapter overview: automated planning

- 33. Introduction
- 34. Planning Formalisms
- 35.–36. Planning Heuristics: Delete Relaxation
 - 35. Delete Relaxation
 - 36. Delete Relaxation Heuristics
- 37. Planning Heuristics: Abstraction
- 38.–39. Planning Heuristics: Landmarks

Delete Relaxation

Relaxed Planning Tasks: Idea

In STRIPS planning tasks,
good and bad effects are easy to distinguish:

- **Add effects** are always **useful**.
- **Delete effects** are always **harmful**.

Why?

Relaxed Planning Tasks: Idea

In STRIPS planning tasks,
good and bad effects are easy to distinguish:

- **Add effects** are always **useful**.
- **Delete effects** are always **harmful**.

Why?

idea for designing heuristics: **ignore all delete effects**

Relaxed Planning Tasks

Definition (relaxation of actions)

The **relaxation** a^+ of STRIPS action a is the action with $pre(a^+) = pre(a)$, $add(a^+) = add(a)$, $cost(a^+) = cost(a)$, and $del(a^+) = \emptyset$.

German: Relaxierung von Aktionen

Definition (relaxation of planning tasks)

The **relaxation** Π^+ of a STRIPS planning task $\Pi = \langle V, I, G, A \rangle$ is the task $\Pi^+ := \langle V, I, G, \{a^+ \mid a \in A\} \rangle$.

German: Relaxierung von Planungsaufgaben

Relaxed Planning Tasks

Definition (relaxation of action sequences)

The **relaxation** of action sequence $\pi = \langle a_1, \dots, a_n \rangle$ is the action sequence $\pi^+ := \langle a_1^+, \dots, a_n^+ \rangle$.

German: Relaxierung von Aktionsfolgen

Relaxed Planning Tasks: Terminology

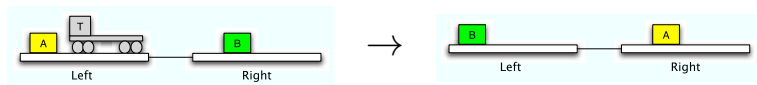
- STRIPS planning tasks without delete effects are called **relaxed planning tasks** or **delete-free planning tasks**.
- Plans for relaxed planning tasks are called **relaxed plans**.
- If Π is a STRIPS planning task and π^+ is a plan for Π^+ , then π^+ is called **relaxed plan for Π** .

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- If Π is a STRIPS planning task and π^+ is a plan for Π^+ , then π^+ is called **relaxed plan for Π** .
- $h^+(\Pi)$ denotes the cost of an **optimal plan** for Π^+ , i.e., of an **optimal relaxed plan**.
- analogously: $h^+(s)$ cost of optimal relaxed plan starting in state s (instead of initial state)
- h^+ is called **optimal relaxation heuristic**.

Examples

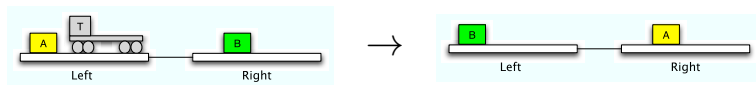
Example: Logistics



Example (Logistics Task)

- **variables:** $V = \{at_{AL}, at_{AR}, at_{BL}, at_{BR}, at_{TL}, at_{TR}, in_{AT}, in_{BT}\}$
- **initial state:** $I = \{at_{AL}, at_{BR}, at_{TL}\}$
- **goals:** $G = \{at_{AR}, at_{BL}\}$
- **actions:** $\{move_{LR}, move_{RL}, load_{AL}, load_{AR}, load_{BL}, load_{BR}, unload_{AL}, unload_{AR}, unload_{BL}, unload_{BR}\}$
- ...

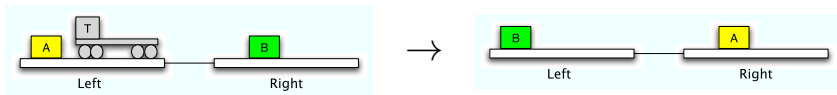
Example: Logistics



Example (Logistics Task)

- $pre(move_{LR}) = \{at_{TL}\}$, $add(move_{LR}) = \{at_{TR}\}$,
 $del(move_{LR}) = \{at_{TL}\}$, $cost(move_{LR}) = 1$
- $pre(load_{AL}) = \{at_{TL}, at_{AL}\}$, $add(load_{AL}) = \{in_{AT}\}$,
 $del(load_{AL}) = \{at_{AL}\}$, $cost(load_{AL}) = 1$
- $pre(unload_{AL}) = \{at_{TL}, in_{AT}\}$, $add(unload_{AL}) = \{at_{AL}\}$,
 $del(unload_{AL}) = \{in_{AT}\}$, $cost(unload_{AL}) = 1$
- ...

Example: Logistics



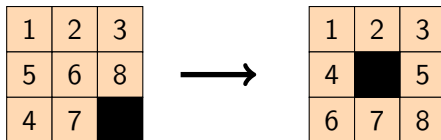
- optimal plan:

- ① $load_{AL}$
- ② $move_{LR}$
- ③ $unload_{AR}$
- ④ $load_{BR}$
- ⑤ $move_{RL}$
- ⑥ $unload_{BL}$

- optimal relaxed plan: ?

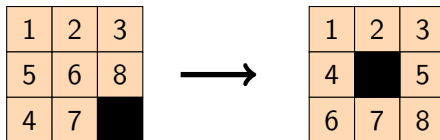
- $h^*(I) = 6$, $h^+(I) = ?$

Example: 8-Puzzle



- (original) task:
 - A tile can be moved from cell A to B if A and B are adjacent and B is free.
- simplification (basis for Manhattan distance):
 - A tile can be moved from cell A to B if A and B are adjacent.
- relaxed task:
 - A tile can be moved from cell A to B if A and B are adjacent and B is free.
 - ... where delete effects are ignored
(in particular: free cells at earlier time remain free)

Example: 8-Puzzle



- actual goal distance: $h^*(s) = 8$
- Manhattan distance: $h^{\text{MD}}(s) = 6$
- optimal delete relaxation: $h^+(s) = 7$

relationship:

h^+ **dominates** the Manhattan distance in the sliding tile puzzle
(i.e., $h^{\text{MD}}(s) \leq h^+(s) \leq h^*(s)$ for all states s)

Relaxed Solutions: Suboptimal or Optimal?

- For general STRIPS planning tasks, h^+ is an **admissible and consistent heuristic**.

Relaxed Solutions: Suboptimal or Optimal?

- For general STRIPS planning tasks, h^+ is an **admissible and consistent heuristic**.
- Can h^+ be computed efficiently?
 - It is **easy** to solve delete-free planning tasks **suboptimally**. (**How?**)
 - optimal solution (and hence the computation of h^+) is **NP-hard** (reduction from SET COVER)
- In practice, heuristics approximate h^+ from below or above.

Summary

Summary

delete relaxation:

- ignore **negative effects** (delete effects) of actions
- use **solution costs of relaxed planning task** as **heuristic** for solution costs of the original planning task
- computation of optimal relaxed solution costs h^+ is NP-hard, hence usually **approximated** from below or above