# Foundations of Artificial Intelligence

## 35. Automated Planning: Delete Relaxation

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# 35.1 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 ⇝ this and next chapter
- abstraction ⇝ later
- landmarks ⇝ later

**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







# 35.2 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?

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 $\Pi^+$ 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

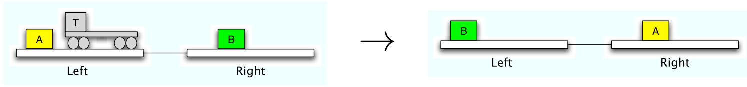
- STRIPS planning tasks without delete effects are called relaxed planning tasks or delete-free planning tasks.
- Plans for relaxed planning tasks are called relaxed plans.
- If $\Pi$ is a STRIPS planning task and $\pi^+$ is a plan for $\Pi^+$, then $\pi^+$ is called relaxed plan for $\Pi$.
- $h^+(\Pi)$ denotes the cost of an optimal plan for $\Pi^+$, 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.

# 35.3 Examples





## Example: Logistics



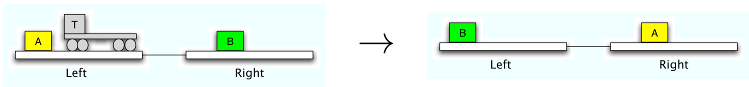

**Example (Logistics Task)**

- 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



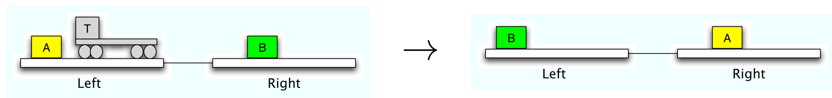

**Example (Logistics Task)**

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



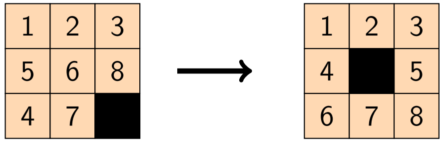


## Example: Logistics




- 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

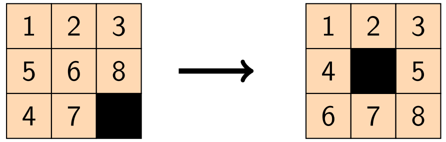



- (original) task:
  - A tile can be moved from cell A to B if A and B are adjacent and B is free.
- simplification (basis for Manhattan distance):
  - A tile can be moved from cell A to B if A and B are adjacent.
- relaxed task:
  - A tile can be moved from cell A to B if A and B are adjacent and B 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: $h^{\mathrm{MD}}(s) = 6$
- optimal delete relaxation: $h^+(s) = 7$

relationship (no proof):
$h^+$ dominates the Manhattan distance in the sliding tile puzzle (i.e., $h^{\mathrm{MD}}(s) \leq h^+(s) \leq h^*(s)$ for all states $s$)





## Relaxed Solutions: Suboptimal or Optimal?

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





# 35.4 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