# Foundations of Artificial Intelligence

## F3. Automated Planning: Delete Relaxation

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# Automated Planning: Overview

## Chapter overview: automated planning

- F1. Introduction
- F2. Planning Formalisms
- F3. Delete Relaxation
- F4. Delete Relaxation Heuristics
- F5. Abstraction
- F6. Abstraction Heuristics

# F3.1 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

# 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.

$\rightsquigarrow$ we need better methods to design heuristics

# Planning Heuristics

We consider two basic ideas for general heuristics:

- delete relaxation $\rightsquigarrow$ this and next chapter
- abstraction $\rightsquigarrow$ Chapters F5–F6

**Delete Relaxation: Basic Idea**

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

# F3.2 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: 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 $\Pi$.

# Optimal Relaxation Heuristic

**Definition (optimal relaxation heuristic $h^+$)**

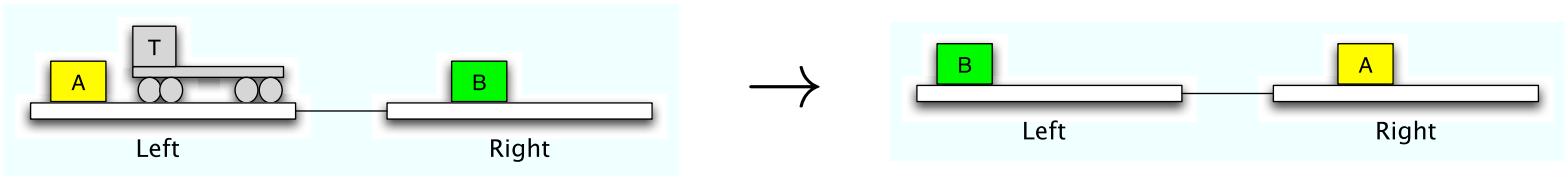
Let $\Pi$ be a STRIPS planning task with the relaxation $\Pi^+ = \langle V, I, G, A^+ \rangle$.

The optimal relaxation heuristic $h^+$ for $\Pi$ maps each state $s$ to the cost of an optimal plan for the planning task $\langle V, s, G, A^+ \rangle$.

In other words, the heuristic value for $s$ is the optimal solution cost in the relaxation of $\Pi$ with $s$ as the initial state.

# F3.3 Example & Discussion

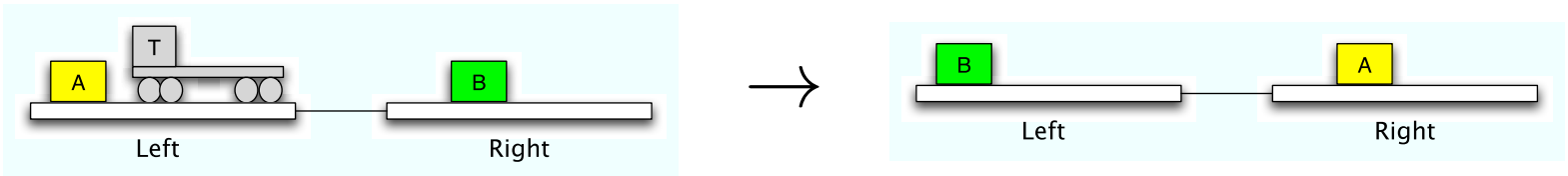
# Example: Logistics




**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: $\{move_{LR}, move_{RL}, load_{AL}, load_{AR}, load_{BL}, load_{BR}, unload_{AL}, unload_{AR}, unload_{BL}, unload_{BR}\}$
- ...

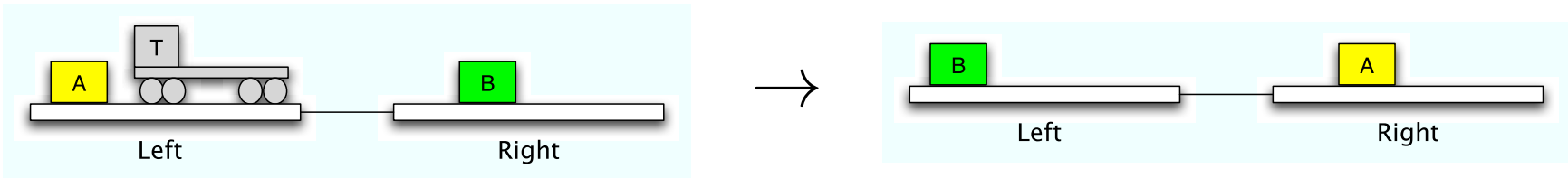
# Example: Logistics




## Example (Logistics Task)

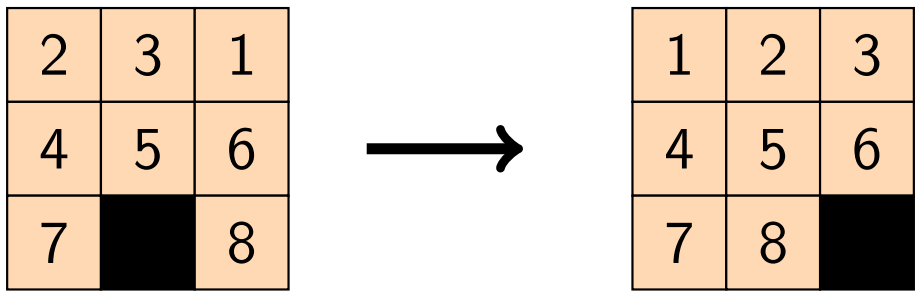
- $pre(move_{LR}) = \{at_{TL}\}$, $add(move_{LR}) = \{at_{TR}\}$, $del(move_{LR}) = \{at_{TL}\}$, $cost(move_{LR}) = 1$
- $pre(load_{AL}) = \{at_{TL}, at_{AL}\}$, $add(load_{AL}) = \{in_{AT}\}$, $del(load_{AL}) = \{at_{AL}\}$, $cost(load_{AL}) = 1$
- $pre(unload_{AL}) = \{at_{TL}, in_{AT}\}$, $add(unload_{AL})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

# 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




- actual goal distance: $h^*(s) = 17$
- Manhattan distance: $h^{\mathrm{MD}}(s) = 5$
- 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 (no proof).
- 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.

# F3.4 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