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

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.

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 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: 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.

Optimal Relaxation Heuristic

Definition (optimal relaxation heuristic h^+)

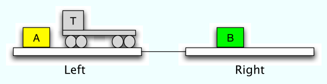
Let Π be a STRIPS planning task with the relaxation $\Pi^+ = \langle V, I, G, A^+ \rangle$.

The optimal relaxation heuristic h^+ for Π 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 Π with s as the initial state.

Examples

Example: Logistics



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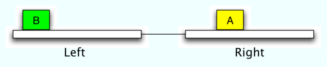
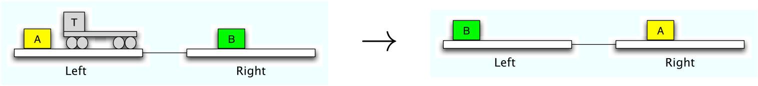


Example (Logistics Task)

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

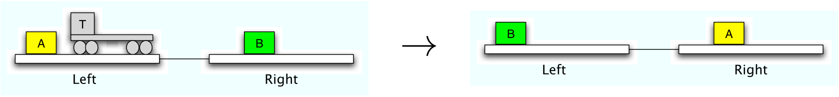
Example: Logistics



Example (Logistics Task)

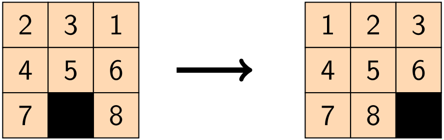
- $pre(move_{\mathrm{LR}}) = \{at_{\mathrm{TL}}\}$, $add(move_{\mathrm{LR}}) = \{at_{\mathrm{TR}}\}$, $del(move_{\mathrm{LR}}) = \{at_{\mathrm{TL}}\}$, $cost(move_{\mathrm{LR}}) = 1$
- $pre(load_{\mathrm{AL}}) = \{at_{\mathrm{TL}}, at_{\mathrm{AL}}\}$, $add(load_{\mathrm{AL}}) = \{in_{\mathrm{AT}}\}$,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

Example: Logistics



- optimal plan:
  1. $load_{\mathrm{AL}}$
  2. $move_{\mathrm{LR}}$
  3. $unload_{\mathrm{AR}}$
  4. $load_{\mathrm{BR}}$
  5. $move_{\mathrm{RL}}$
  6. $unload_{\mathrm{BL}}$
- 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.

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