Foundations of Artificial Intelligence

35. Automated Planning: Delete Relaxation

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35.1 How to Design Heuristics?

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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 ⇝ closer to goal state

⇝ 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

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 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 $\pi = \langle a_1, \ldots, a_n \rangle$
is the action sequence $\pi^+ := \langle a_1^+, \ldots, a_n^+ \rangle$.

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.
- ▶ $h^+(\Pi)$ 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)
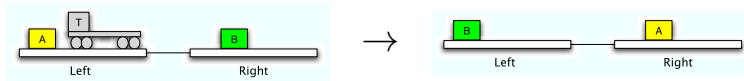- ▶ h^+ is called optimal relaxation heuristic.

35.3 Examples

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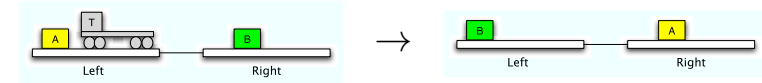
Example (Logistics Task)
- variables: $V = \{at_{AL}, at_{AR}, at_{BL}, at_{BR}, at_{TL}, at_{TR}, in_{AT}, in_{BT}\}$
- initial state: $I = \{at_{AL}, at_{BR}, at_{TL}\}$
- goals: $G = \{at_{AR}, at_{BL}\}$
- actions: $\{move_{LR}, move_{RL}, load_{AL}, load_{AR}, load_{BL}, load_{BR},$
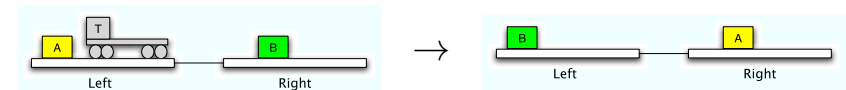 $unload_{AL}, unload_{AR}, unload_{BL}, unload_{BR}\}$
- . . .

Example: Logistics

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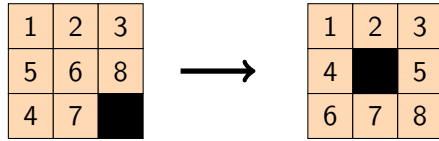

Example: Logistics

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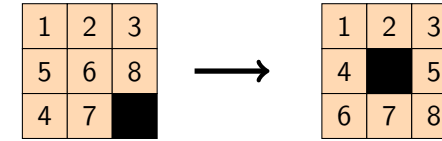
- ▶ actual goal distance: $h^*(s) = 8$
- ▶ Manhattan distance: $h^{MD}(s) = 6$
- ▶ optimal delete relaxation: $h^+(s) = 7$

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