Foundations of Artificial Intelligence

35. Automated Planning: Delete Relaxation

Martin Wehrle

Universität Basel

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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.

$\rightsquigarrow$ 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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- abstraction ⇝ later
- landmarks ⇝ later

Delete Relaxation: Basic Idea

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

Chapter Overview: Planning

Chapter overview: planning

- 33. Introduction
- 34. Planning Formalisms
- 35.–36. Planning Heuristics: Delete Relaxation
  - 35. Delete Relaxation
  - 36. Delete Relaxation Heuristics
- 37.–38. Planning Heuristics: Abstraction
- 39.–40. 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 $\pi = \langle a_1, \ldots, a_n \rangle$ 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.

Relaxed Planning Tasks: Terminology

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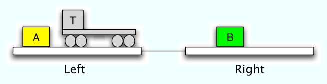
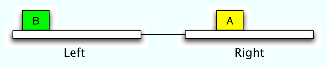
- Plans for relaxed planning tasks are called relaxed plans.
- If Π is a STRIPS planning task and π^+ is a plan for Π^+, then π^+ is called relaxed plan for Π.
- $h^+(\Pi)$ denotes the cost of an optimal plan for Π^+, i.e., of an optimal relaxed plan.
- analogously: $h^+(s)$ cost of optimal relaxed plan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

Examples

Example: Logistics



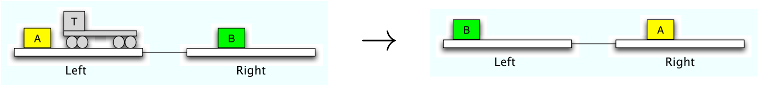
$\rightarrow$



Example (Logistics Task)

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

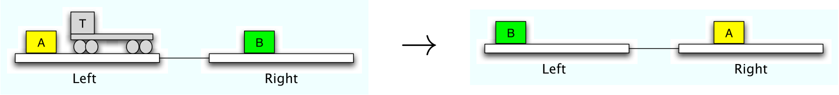
Example: Logistics



Example (Logistics Task)

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

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

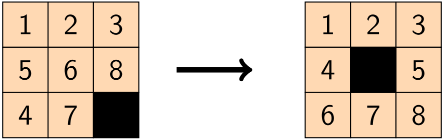
1	2	3
5	6	8
4	7	

$\longrightarrow$

1	2	3
4		5
6	7	8

- (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:
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.

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