Foundations of Artificial Intelligence

35. Automated Planning: Delete Relaxation

Thomas Keller and Florian Pommerening

University of Basel

May 8, 2023

Foundations of Artificial Intelligence

May 8, 2023 — 35. Automated Planning: Delete Relaxation

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

Chapter overview: automated planning

- 33. Introduction
- 34. Planning Formalisms
- 35.–36. Planning Heuristics: Delete Relaxation
  - 35. Delete Relaxation
  - 36. Delete Relaxation Heuristics
- 37. Planning Heuristics: Abstraction
- 38.–39. Planning Heuristics: Landmarks

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
- $del(a^+) = \emptyset$.

Definition (relaxation of planning tasks)

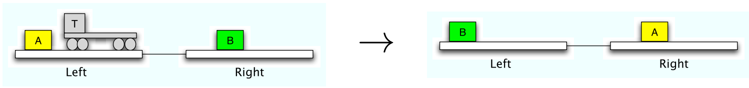
The relaxation Π^+ of a STRIPS planning task $\Pi = \langle V, I, G, A\rangle$ is the task $\Pi^+ := \langle V, I, G, \{a^+ \mid a \in A\}\rangle$.

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.
- An optimal plan for Π^+ is called optimal relaxed plan for Π.

35.3 Example

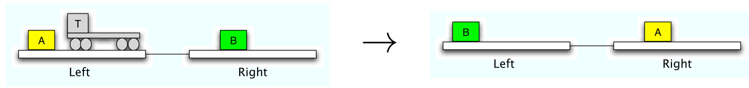
Example: Logistics



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

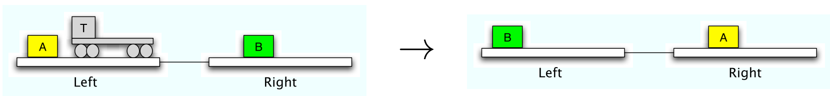
Example: Logistics



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: ?
- $h^*(I) = 6$, $h^+(I) = ?$

35.4 Optimal Relaxation Heuristic

Some Additional Notation

Definition (resulting states)

If action a is applicable in s with $s \xrightarrow{a} s' \in T$, we use $s[\![a]\!] := s'$.

If action sequence $\pi = \langle a_1, \dots, a_n \rangle$ is applicable in s, we use $s[\![\pi]\!] := s[\![a_1]\!] \cdots [\![a_n]\!]$.

Definition (relaxation of action sequences)

The relaxation of action sequence $\pi = \langle a_1, \dots, a_n \rangle$ is the action sequence $\pi^+ := \langle a_1^+, \dots, a_n^+ \rangle$.

Properties of Delete-Free Tasks

- Relaxed actions only add facts to states: $s \subseteq s'$ for any transition $s \xrightarrow{a^+} s'$
- Conditions remain satisfied in supersets: If $s \subseteq s'$ and $pre(a) \subseteq s$ then $pre(a) \subseteq s'$.
  $\rightsquigarrow$ Applicable actions cannot become inapplicable.
- If action a is applicable in s and $s \subseteq s'$, then a^+ is applicable in s' and $s[\![a]\!] \subseteq s'[\![a^+]\!]$.
- If action sequence π is applicable in s and $s \subseteq s'$, then π^+ is applicable in s' and $s[\![\pi]\!] \subseteq s'[\![\pi^+]\!]$.

$\rightsquigarrow$ If π is a plan, then π^+ is a relaxed plan.
$\rightsquigarrow$ The optimal plan is a relaxed plan.
$\rightsquigarrow$ The optimal relaxed plan cannot be more expensive than the optimal plan.

Optimal Relaxation Heuristic

Definition (h^+)

The optimal relaxation heuristic h^+ maps each state s to the cost of optimal relaxed plan starting in state s (instead of initial state).

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.

35.5 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