Foundations of Artificial Intelligence

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Exercise Sheet 11

Due: May 15, 2019

Exercise 11.1 (0.5+0.5+1+0.5+0.5+0.5 marks)

Consider the STRIPS planning task $\Pi = \langle V, I, G, A \rangle$ with $V = \{a, b, c, d, e, f\}$, $I = \{a, b\}$, $G = \{e, f\}$, and $A = \{a_1, a_2, a_3\}$ with $cost(a) = 1$ for all $a \in A$ and

$$\begin{array}{lll} pre(a_1) = \{a\} & add(a_1) = \{c\} & del(a_1) = \{e\} \\ pre(a_2) = \{b\} & add(a_2) = \{d\} & del(a_2) = \{c\} \\ pre(a_3) = \{c, d\} & add(a_3) = \{e, f\} & del(a_3) = \{\}. \end{array}$$

Compute the following and justify your answers:

(a) the cost of an optimal plan $h^\star(I)$

(b) the cost of an optimal relaxed plan $h^+(I)$

(c) the relaxed planning graph for Π up to depth 3 (i.e., the resulting graph should have four variable layers, three action layers and a goal vertex)

(d) the maximum heuristic $h^{\max}(I)$

(e) the additive heuristic $h^{\text{add}}(I)$

(f) the FF heuristic $h^{\text{FF}}(I)$

Exercise 11.2 (2 marks)

Prove that h^+ is admissible. For this, prove that if Π is a STRIPS planning task and π is a plan for Π, then π^+ is a plan for the relaxed planning task Π^+. Why does it follow from this that h^+ is admissible?

Exercise 11.3 (1.5+1+1 marks)

Consider a planning task where Bob aims to tighten the nuts of a gate. Initially, he is located at the shed. To be able to tighten the nuts, he needs to pick up a spanner, which is at the middle location between the shed and the gate. The problem is formalized in SAS^+ as follows. $\Pi = \langle V, I, G, A \rangle$, where

- $V = \{loc, spanner, tightened\}$ is the set of variables with $\text{dom}(loc) = \{S, M, G\}$, $\text{dom}(spanner) = \{\top, \bot\}$, and $\text{dom}(tightened) = \{\top, \bot\}$;
- $I = \{loc \mapsto S, spanner \mapsto \bot, tightened \mapsto \bot\}$ is the initial state;
- $G = \{tightened \mapsto \top\}$ is the goal description; and

- $A = \{move_{S,M}, move_{M,S}, move_{M,G}, move_{G,M}, pickup, tighten\}$ is the set of actions with

$$
\begin{array}{lll}
pre(move_{S,M}) = \{loc \mapsto S\} & eff(move_{S,M}) = \{loc \mapsto M\} & cost(move_{S,M}) = 3 \\
pre(move_{M,S}) = \{loc \mapsto M\} & eff(move_{M,S}) = \{loc \mapsto S\} & cost(move_{M,S}) = 3 \\
pre(move_{M,G}) = \{loc \mapsto M\} & eff(move_{M,G}) = \{loc \mapsto G\} & cost(move_{M,G}) = 3 \\
pre(move_{G,M}) = \{loc \mapsto G\} & eff(move_{G,M}) = \{loc \mapsto M\} & cost(move_{G,M}) = 3 \\
pre(pickup) = \{loc \mapsto M, & eff(pickup) = \{spanner \mapsto \top\} & cost(pickup) = 1 \\
\qquad spanner \mapsto \bot\} & & \\
pre(tighten) = \{loc \mapsto G, & eff(tighten) = \{tightened \mapsto \top\} & cost(tighten) = 2 \\
\qquad spanner \mapsto \top, & & \\
\qquad tightened \mapsto \bot\} & &
\end{array}
$$

(a) Provide the state space as a graph and mark the initial state and all goal states. The state space consists of 12 states, some of which are not reachable from the initial state. For each state, provide the values of all variables, e.g., in the form $S\bot\bot$ for the initial state and accordingly for other states.

(b) Compute the projection of Π to $P = \{loc, tightened\}$ (i.e., the variable *spanner* is ignored). Draw the abstract state space that is induced by P in the same way as in part (a).

(c) Use the abstraction from part (b) to derive a pattern database heuristic. Provide the database entries (i.e., the abstract distances for all states in the abstract state space) and use them to assign a heuristic value to each of the 12 concrete states.

Exercise 11.4 (3 marks)

Consider the delete-free STRIPS planning task $\Pi^+ = \langle V, I, G, A\rangle$, with

- set of variables $V = \{a, b, c, d, e, f, g\}$
- initial state $I = \{a\}$,
- goal description $G = \{g\}$, and
- set of actions $A = \{a_1, \dots, a_6\}$ with

$$
\begin{array}{lll}
pre(a_1) = \{a\} & add(a_1) = \{b, d\} & cost(a_1) = 1 \\
pre(a_2) = \{b\} & add(a_2) = \{d, e, f\} & cost(a_2) = 6 \\
pre(a_3) = \{a\} & add(a_3) = \{c, d\} & cost(a_3) = 2 \\
pre(a_4) = \{c, d\} & add(a_4) = \{e\} & cost(a_4) = 1 \\
pre(a_5) = \{e\} & add(a_5) = \{f\} & cost(a_5) = 2 \\
pre(a_6) = \{d, e, f\} & add(a_6) = \{g\} & cost(a_6) = 0.
\end{array}
$$

Compute $h^{\text{LM-cut}}(I)$ and provide all intermediate results in the same way they were given in the example of the lecture (including the justification graph with $h^{\max}$ annotations).

Exercise 11.5 (4 bonus marks)

Hint: This is a *bonus* exercise, so its marks are not considered when the amount of marks required for admission to the exam is computed. However, the marks you obtain in this exercise count for your achieved total marks.

You can find the AAAI 2007 paper "Domain-Independent Construction of Pattern Database Heuristics for Cost-Optimal Planning" from Haslum et al. on the website of the course. Download the paper, read it and provide a summary of 200 to 350 words that describes how the algorithm from the paper finds patterns and uses them to compute a heuristic.

Important: Solutions should be submitted in groups of two students. However, only one student should upload the solution. Please provide both student names on each file and each page you submit. We can only accept a single PDF or a ZIP file containing *.java or *.pddl files and a single PDF.