02285 AI and MAS, SP19
Exercises for week 3, 19/2-19

Exercise 1 (Blocks World)

Consider the Blocks World problem P described in PDDL in Figure 10.3 of R&N. Let s_0 denote the initial state of this problem, and let g denote the goal.

a) The blocks world P problem possesses the so-called **Sussman anomaly**. The problem was considered anomalous because the non-interleaved planners of the early 1970s could not solve it. A non-interleaved planner is a planner that, given two subgoals g_1 and g_2, produces either a plan for g_1 concatenated with a plan for g_2, or vice versa. Explain why a non-interleaved planner cannot solve this problem.

b) Determine $h^*_P(s_0)$.

c) Determine $h_{gc}(s_0)$ (the goal count heuristics).

d) Provide an example of a Blocks World problem where $h_{gc}(s_0) = 1$ and $h^*(s_0) \geq 1000$ (that is, a problem where h_{gc} heavily underestimates the optimal cost).

e) Provide an example of a Blocks World problem where $h_{gc}(s_0) > h^*(s_0)$ (that is, where h_{gc} **over**estimates the optimal cost).

f) Determine $h_{ip}(s_0)$ (the ignore preconditions and non-goal literal heuristics) for the original Blocks World problem of Figure 10.3.

g) Provide an example of a Blocks World problem where $h_{ip}(s_0) = 1$ and $h^*(s_0) \geq 1000$ (that is, a problem where h_{ip} heavily underestimates the optimal cost).

h) Is it possible to create a Blocks World problem where $h_{ip}(s_0) > h^*(s_0)$?

i) In the initial state of the Blocks World problem of Figure 10.3, the ground atoms of the form $C_1 = C_2$ that hold true are left implicit. Add the relevant atoms of this form to the initial state. In the rest of the exercise, we will assume that these atoms have been added.

j) The heuristics based on delete-relaxation requires that we have a planning problem where goals and preconditions only contain positive literals. This is not true of the Blocks World problem of Figure 10.3, as an inequality $x \neq y$ is short for $\neg(x = y)$. Rephrase the Blocks World problem so that there are no negative literals in goal and preconditions. In the rest of the exercise, we will work with these rephrased version of the problem.

k) Determine $h^+(s_0)$ (the delete-relaxation heuristics) for the rephrased Blocks World problem.

l) Provide an example of a Blocks World problem where $h^+(s_0) < h^*(s_0)$. Explain what it is that make h^+ underestimate the optimal cost in your example.

m) A **rigid atom** of a planning problem is one that can never change the truth value it has in the initial state. Find the rigid atoms in the rephrased Blocks World problem. Then show that for any rigid atom p in any planning problem we must have either $h_{add}(p, s) = 0$ or $h_{add}(p, s) = \infty$ for all states s, where h_{add} is the additive heuristics.

n) Determine $h_{add}(s_0)$ (the additive heuristics) for the rephrased Blocks World problem. Explain also the intuitive meaning of all the values $h_{add}(p, s_0)$ you calculate in order to compute $h_{add}(s_0)$. *Hint*: Make use of your answer to the previous question. You can simplify the calculations by not including all the calculations of the rigid atoms, but simply immediately replace by 0 or ∞ whenever appropriate.

o) Give an example of a Blocks World problem where $h_{add}(s_0) > h^*(s_0)$.

p) Determine $h_{max}(s_0)$ (the max heuristics) for the rephrased Blocks World problem. Explain also the intuitive meaning of all the values $h_{max}(p, s_0)$ you calculate in order to compute $h_{max}(s_0)$.

q) Find the admissible heuristics among the ones you have considered above (except h^*). Taking the maximum value of the value returned by all of these still gives an admissible heuristics (cf. the slides from today). What is this maximum value for the (rephrased) Blocks World problem considered in this exercise?

r) *Optional*: Draw the (relevant part of the) directed hypergraph for calculating $h_{add}(s_0)$, cf. the slides from today and Section 2.7 of Geffner & Bonet. Look up directed hypergraph on Google first, if you don't know what they or how to draw them. To make the graph smaller, you can omit all nodes representing rigid atoms, as well as omit any action a in which one of the preconditions is a rigid atom false in the initial state.

Exercise 2 (Relaxed problems in the hospital domain)

Optional: Try to come up with one or two relaxed problems for the hospital domain of the programming project. In which way do they relax the original problem? Consider the heuristics derived from the relaxed problems. How computationally demanding are they to calculate (tractable/intractable)? How well will the heuristics guide the search for a solution? Are the heuristics admissible?

A possible approach is also to try to come up with a number of distinct relaxed problems that are approximately independent, so that a good heuristics can be calculated as the sum of the individual heuristics (somewhat like the additive heuristics). It can also be valuable to think of the different *types* of relaxations, cf. the slides from the lecture (adding edges vs. reducing the number of nodes in the state space).