Note: This homework covers the entire planning material even though the last bit of it is only taught next week.

Assignment11 – Planning

Problem 11.1 (Admissible Heuristics in Gripper)

Consider a problem where we have two rooms, A and B, one robot initially located in room A, and n balls that are also initially located in room A. The *goal* demands that all balls be located in room B. The robot can move between the rooms, it can pick up balls provided its gripper hand is free (see below), and it can drop a ball it is currently holding.

Answer the following questions with yes/no. Justify your answer.

1. Say that the robot has only one gripper, so that it can only hold one ball at a time. Is the number of balls not yet in room B an *admissible heuristic*?

2. Say that the robot has only one gripper, so that it can only hold one ball at a time. Is the number of balls still in room A, multiplied by 4, an *admissible heuristic*?

3. Say now the robot has two grippers, and it takes only one action to pick up two balls, and only one action to drop two balls. Is the number of balls not yet in room B an *admissible heuristic*?

4. Say now the robot has two grippers, but picks up/drops each ball individually, so that it needs two actions to take two balls, and two actions to drop two balls. Is the number of balls not yet in room B an *admissible heuristic*?

Problem 11.2 (Partial Order Planning)

Consider the planning task (P, A, I, G) where

- facts $P = \{p, q, r, s\}$

- actions $A = \{X, Y, Z\}$ where the preconditions (above the box) and effects (below the box) of the actions are given by

$$\begin{array}{ccc} p & q & p \\ \boxed{X} & \boxed{Y} & \boxed{Z} \\ q & \neg p, r & \neg p, s \end{array}$$

- initial state $I = \{p\}$

- goal $G = \{r, s\}$

Our goal is to build a partially ordered plan. Recall that the steps consist of the actions plus the start and finish step; and that the effect of an action consists of the added facts and the negations of the deleted facts.

1. Give the start step and finish step.

2. Give all causal links between the steps.
3. Give an example where a step clobbers a link.
4. Give the temporal ordering that yields a partially ordered plan that solves the task.

Problem 11.3 (STRIPS)

Consider a set of objects $Obj = \{1, 2, 3, 4, 5, 6\}$ that can be at location A or B. Currently all objects are at location A and **unpainted**. Eventually all objects are needed in location A and **painted**. At location B, a painting station is available that can paint up to 3 objects at a time. A robot is available (currently at location A) that can move up to 2 objects at a time from one location to another.

We formalize this problem as a STRIPS task (P, A, I, G) where the set P of facts contains

- at(l, o) for $l \in \{A, B\}$ and $o \in (Obj \cup \{Robot\})$

- painted(o) for $o \in Obj$
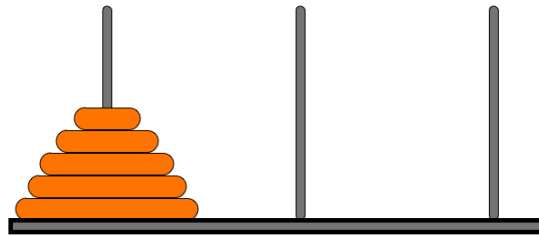
and the set A of actions contains

- move(l, m, O) for $l, m \in \{A, B\}$, $O \subseteq Obj$, $\#(O) \leq 2$ given by

    – precondition: at(l, o) for all $o \in (O \cup \{Robot\})$
    – add list: at(m, o) for all $o \in (O \cup \{Robot\})$
    – delete list: same as precondition

- paint(O) for $O \subseteq Obj$, $\#(O) \leq 3$ given by

    – precondition: at(B, o) for all $o \in O$
    – add list: painted(o) for all $o \in O$
    – delete list: nothing

1. Give the initial state I and the goal G.
2. After applying move($A, B, \{1, 2\}$) in I, multiple actions are applicable. Give two of them.
3. Give the value $h^*(I)$.
4. Give the value $h^+(I)$.
5. Let $U_s(l)$ and $P_s(l)$ be the numbers of unpainted and painted objects at location l in state s. For each of the following *heuristic $h(s)$*, say if it is *admissible*.

1. $2 \cdot U_s(A) + U_s(B)$

2. 0

3. $U_s(A)+\text{roundDown}((U_s(A)+U_s(B))/3)+\text{roundDown}((P_s(B)+U_s(B))/2)$

Problem 11.4

Encode the Tower of Hanoi task below into PDDL. There are five discs and the goal is to move them from left to right according to the rules of Tower of Hanoi. Solve the PDDL encoding using FF. As your solution, submit a print-out of the following 3 files: The PDDL domain file "towersofhanoi-domain.pddl"; the PDDL problem file "towersofhanoi-problem.pddl", as well as a file "towersofhanoi-output.txt" containing FF's output.

Problem 11.5 (STRIPS Planning)

Consider the road map of Australia given below. The task here is to visit Darwin, Brisbane and Perth, starting from Sydney.

The task is formalized in STRIPS as follows. Facts are $at(x)$ and $visited(x)$ where $x \in \{Adelaide, Brisbane, Darwin, Perth, Sydney\}$. The initial state is $\{at(Sydney), visited(Sydney)\}$, the goal is $\{visited(Brisbane), visited(Darwin), visited(Perth)\}$. The actions move along the roads, i.e., they are of the form

$$drive(x, y) : (\{at(x)\}, \{at(y), visited(y)\}, \{at(x)\})$$

where x and y have a direct connection according to the road map. **Each road can be driven in both directions, except for the road between Adelaide and Perth, which can only be driven from Adelaide to Perth, not in the opposite direction.** In your answers to the following questions, use the abbreviations "v" for "visited", and "Ad", "Br", "Da", "Pe", "Sy" for the cities.

1. Give an optimal (shortest) plan for the initial state, if one exists; if no plan exists, argue why that is the case. Give an optimal (shortest) relaxed plan for the initial state, if one exists; if no relaxed plan exists, argue why that is the case. What is the h^* value and the h^+ value of the initial state? (When writing up a plan or relaxed plan, it suffices to give the sequence of action names.)

2. Do the same in the modified task where the road between Sydney and Brisbane is also one-way, i.e., it can only be driven from Sydney to Brisbane, not in the opposite direction.

3. Write up, in STRIPS notation, all states reachable from the initial state in at most *two* steps. Start at the initial state, and insert successors. Indicate *successor states* by edges. Annotate the states with their h^* values as well as their h^+ values.

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4. Do the same in the modified task where the road between Sydney and Brisbane is one-way, i.e., it can only be driven from Sydney to Brisbane, not in the opposite direction.

Problem 11.6 (Relaxation)

We want to solve a *STRIPS planning task*.

1. Explain (in about 2 sentences) the purpose of *relaxed planning*.
2. Explain (in about 2 sentences) why it is bad to *relax* too much or too little.

Now consider a concrete task given by a *finite set B* of *size n* and

- *Facts*: $inA(b)$, $inB(b)$, $held(b)$ for $b \in B$, $Rfree$, $RinA$, $RinB$

- *Actions*

action	precondition	add list	delete list
$move_A$	$RinB$	$RinA$	$RinB$
$move_B$	$RinA$	$RinB$	$RinA$
$pickup(b)$	$RinA, Rfree, inA(b)$	$held(b)$	$Rfree, inA(b)$
$release(b)$	$RinB, held(b)$	$inB(b), Rfree$	$held(b)$

- *Initial state $\mathcal{I}$*: $inA(b)$ for $b \in B$, $Rfree$, $RinA$

- *Goal state*: $inB(b)$ for $b \in B$

3. Let h^+ be the *heuristic* obtained from the *delete relaxation*. Give the *value* of $h^+(\mathcal{I})$.

4. Let h^+ be the *heuristic* obtained from the *only-adds relaxation*. Give the *value* of $h^+(I)$.