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Exercise Sheet 8.

Solutions due Tuesday, **June 26**, 16:00 – 16:15, in the lecture hall.[1]

Exercise 29. (3.5 Points)

Consider a situation where you (*Marty*) need to travel back in time to fix the past to make the present better for everybody. Luckily, you are friends with Dr. Brown, who lets you use his *DeLorean* that can travel through time. To do so, however, you will need lots of energy which you can either obtain by stealing plutonium from terrorists or by being struck by lightning. This common problem can be described in STRIPS as tuple $\Pi = (P, A, I, G)$ with:

$$
\begin{aligned}
P =&\{\mathit{hasEnergy}, \mathit{everybodyHappy}\}\\
&\cup \{\mathit{year}(x) \mid x \in \{\mathit{1955}, \mathit{1985}, \mathit{2015}\}\}\\
&\cup \{\mathit{at}(x, y) \mid x \in \{\mathit{Marty}, \mathit{DeLorean}\}, y \in \{\mathit{School}, \mathit{ParkingLot}, \mathit{ClockTower}\}\}\\
I =&\{\mathit{year}(\mathit{1985}), \mathit{at}(\mathit{Marty}, \mathit{ParkingLot}), \mathit{at}(\mathit{DeLorean}, \mathit{ParkingLot})\}\\
G =&\{\mathit{year}(\mathit{1985}), \mathit{everybodyHappy}\}\\
A =&\{\mathit{knockOutBiff}, \mathit{beStruckByLightning}, \mathit{stealPlutonium}\}\\
&\cup \{\mathit{walk}(\mathit{from}, \mathit{to}) \mid \mathit{from}, \mathit{to} \in \{\mathit{School}, \mathit{ParkingLot}\}\}\\
&\cup \{\mathit{drive}(\mathit{from}, \mathit{to}) \mid \mathit{from}, \mathit{to} \in \{\mathit{ParkingLot}, \mathit{ClockTower}\}\}\\
&\cup \{\mathit{timeTravel}(\mathit{location}, \mathit{from}, \mathit{to})\\
&\mid \mathit{location} \in \{\mathit{ParkingLot}, \mathit{ClockTower}\}\}\\
&\mid \mathit{from}, \mathit{to} \in \{\mathit{1955}, \mathit{1985}, \mathit{2015}\}\}
\end{aligned}
$$

where

[1]Solutions in paper form only, and solution submission only at the stated time at the stated place. At most 3 authors per solution. All authors must be in the same tutorial group. All sheets of your solution must be stapled together. At the top of the first sheet, you must write the names of the authors and the name of your tutor. Your solution must be placed into the correct box for your tutorial group. Also, you should write the solutions of the exercises in order, in particular, do not interleave parts of different exercises otherwise we may oversee part of your solution. Please, don't use red ink, preferably use a black or blue pen instead. If you don't comply with these rules, 3 points will be subtracted from your score for this sheet.

- $knockOutBiff$
  - $pre : \{year(1955), at(Marty, School)\}$
  - $add : \{everybodyHappy\}$
  - $del : \{\}$
- $beStruckByLightning$
  - $pre : \{year(1955), at(DeLorean, ClockTower)\}$
  - $add : \{hasEnergy\}$
  - $del : \{\}$
- $stealPlutonium$
  - $pre : \{year(1985), at(Marty, ClockTower)\}$
  - $add : \{hasEnergy\}$
  - $del : \{\}$
- $walk(from, to)$ `for` $from, to \in \{School, ParkingLot\}$`,` $from \neq to$
  - $pre : \{at(Marty, from)\}$
  - $add : \{at(Marty, to)\}$
  - $del : \{at(Marty, from)\}$
- $drive(from, to)$ `for` $from, to \in \{ParkingLot, ClockTower\}$`,` $from \neq to$
  - $pre : \{at(Marty, from), at(DeLorean, from)\}$
  - $add : \{at(Marty, to), at(DeLorean, to)\}$
  - $del : \{at(Marty, from), at(DeLorean, from))\}$
- $timeTravel(location, from, to)$ `for` $location \in \{ParkingLot, ClockTower\}$`;` $from, to \in \{1955, 1985, 2015\}$`,` $from \neq to$
  - $pre : \{hasEnergy, year(from), at(DeLorean, location), at(Marty, location)\}$
  - $add : \{year(to)\}$
  - $del : \{hasEnergy, year(from)\}$

All actions have uniform cost of 1.

a) Compute the h^{FF} value for the initial state. Write down the action and fact sets for each iteration of the RPG algorithm. Then, iteratively compute the h^{FF} value. For each step t, write down which actions are selected and the resulting G_{t-1} you obtain. What is the final $h^{\mathrm{FF}}(I)$ value?

b) Run A^* search on the problem and use h^+ as heuristic. If several nodes have the same $g + h$ value, expand the node with largest g value. In each search node, mention the literals that are true (e.g. abbreviate the predicates, like "y('85)at(M,S)at(DL,PL)" for the initial state), the g and h values. Additionally, indicate the order in which states are selected for expansion. Stop after 9 expansions, indicating what node would be the 10th selected for expansion. Annotate transitions by the name of the according action.

Exercise 30. (3 points)

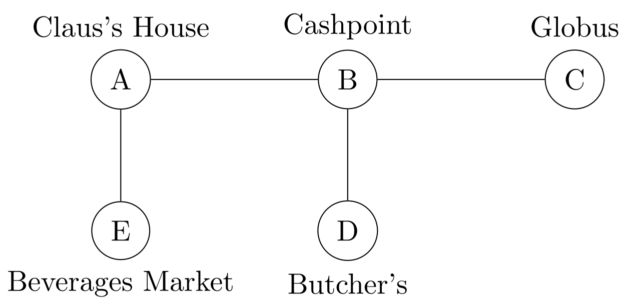

Figure 1: Illustration of the Map of Exercise 30

Dieter's party last week was a great success. Everybody laughed and danced. Rainer even said that this party was legendary and no party could ever be better than this evening. "Sounds like a challenge", said Claus and invited Dieter and Rainer to a second party on Saturday. The week goes by and finally it is Saturday morning. As Claus was born in Saarbrücken, he thinks that Fleischkäse and beer (of course nonalcoholic) are essential for the party. Of course, Claus could go to the Globus market in Güdingen to buy the Fleischkäse as well as the beer, but he does not like large crowds. Alternatively, he can visit two village shops to get both party-basics. Since there are many other things to prepare for the evening, Claus wants to save as many time as possible. Please help Claus to estimate the time of his purchase.
To do so, consider the map in Figure 1. Currently, Claus is at home at location A. The Globus is at location C, the butcher's is at location D and the beverages market is at location E. In the end, Claus wants to have Fleischkäse and beer and to be at home again.

Note that he first needs to withdraw money at the cashpoint at location B. The problem is formalized as the following STRIPS planning problem $\Pi = (P, A, I, G)$:

$$
\begin{aligned}
P =& \{atC(x) |\ x \in \{A, B, C, D, E\}\} \cup \{haveFleischk\ddot{a}se, haveBeer, have2Money, have1Money\} \\
I =& \{atC(A)\} \\
G =& \{atC(A), haveFleischk\ddot{a}se, haveBeer\} \\
A =& \{walk(x, y) \mid x, y \in \{A, B, C, D, E\} \wedge x, y \text{ are connected}\} \\
& \cup \{buyFleischk\ddot{a}se_2(x) \mid x \in \{C, D\}\} \cup \{buyFleischk\ddot{a}se_1(x) \mid x \in \{C, D\}\} \\
& \cup \{buyBeer_2(x) \mid x \in \{C, E\}\} \cup \{buyBeer_1(x) \mid x \in \{C, E\}\} \\
& \cup \{withdrawMoney()\}
\end{aligned}
$$

where

- $walk(x, y)$ for $x, y \in \{A, B, C, D, E\}$, x, y are connected in the map of Figure 1
  - $pre : \{atC(x)\}$
  - $add : \{atC(y)\}$
  - $del : \{atC(x)\}$
- $buyFleischk\ddot{a}se_2(x)$ for $x \in \{C, D\}$
  - $pre : \{atC(x), have2Money\}$
  - $add : \{haveFleischk\ddot{a}se, have1Money\}$
  - $del : \{have2Money\}$
- $buyFleischk\ddot{a}se_1(x)$ for $x \in \{C, D\}$
  - $pre : \{atC(x), have1Money\}$
  - $add : \{haveFleischk\ddot{a}se\}$
  - $del : \{have1Money\}$
- $buyBeer_2(x)$ for $x \in \{C, E\}$
  - $pre : \{atC(x), have2Money\}$
  - $add : \{haveBeer, have1Money\}$
  - $del : \{have2Money\}$
- $buyBeer_1(x)$ for $x \in \{C, E\}$
  - $pre : \{atC(x), have1Money\}$

  - $add : \{haveBeer\}$
  - $del : \{have1Money\}$

- $withdrawMoney()$
  - $pre : \{atC(B)\}$
  - $add : \{have2Money\}$
  - $del : \{have1Money\}$

All actions have uniform cost of 1.

a) Compute the h^{FF} value for the initial state. Write down the action and fact sets for each iteration of the RPG algorithm. Then, iteratively compute the h^{FF} value. For each step t, write down which actions are selected and the resulting G_{t-1} you obtain. What is the final $h^{\mathrm{FF}}(I)$ value?

b) Compute the h^{max} value for the initial state, using the relaxed planning graph that you computed in part (a), and filling up the table below. What is $h^{max}(I)$?.

g	$h^{\max}(I, g)$
$atC(A)$	0
$atC(B)$	
$atC(C)$	
$atC(D)$	
$atC(E)$	
$have2Money$	
$have1Money$	
$haveFleischkäse$	
$haveBeer$	

Table 1: Complete the table with the h^{max} values for every fact.

c) Compare $h^*(I)$ and $h^+(I)$ with $h^{\max}(I, G)$ and $h^{\mathrm{FF}}(I)$. To do so, give the value of $h^*(I)$ and $h^+(I)$, and use the values of $h^{\max}(I)$ and $h^{\mathrm{FF}}(I)$ from parts (a) and (b). Which of these heuristics are admissible heuristics?

Exercise 31. (2 Points)

Prove that, given an arbitrary planning task $\Pi = (P, A, I, G)$ and any state s, if $\langle a_1, \dots, a_n \rangle$ is a plan for (P, A, s, G), then $\langle a_1^+, \dots, a_n^+ \rangle$ is a plan for $(P, A, s, G)^+$.
Tip: Denote the state-action sequence traversed by $\langle a_1, \dots, a_n \rangle$ as $seq = s_0, a_1, s_1, \dots,$ a_n, s_n. Denote the state-action sequence traversed by $\langle a_1^+, \dots a_n^+ \rangle$ as $seq^+ = s_0^+, a_1^+, s_1^+,$ $\dots, a_n^+, s_n^+$. Then show that *(*) for* $1 \leq i \leq n$, a_i^+ *is applicable to* s_{i-1}^+; *and for* $0 \leq i \leq n$ *we have* $s_i \subseteq s_i^+$. Once (*) is proved, use it to prove that $\langle a_1^+, \dots, a_n^+ \rangle$ is a plan for $(P, A, s, G)^+$.

Exercise 32. (1.5 Points)

As specified in the lecture, PlanLen$^+$ is the problem of deciding, given a STRIPS planning task Π and an integer B, whether or not there exists a delete-relaxed plan for Π of length at most B. Prove that PlanLen$^+$ is a member of **NP**.
Tip: There is a simple upper bound on the length of a relaxed plan, if one exists.