

Exercise 1

Consider the following planning task, where a rover needs to take a picture of the surface of Mars.

- $P = \{at-A, at-B, at-C, cam-ready, pic-taken\}$
 - $A =$
 - $move-A-B = \langle pre : \{at-A\}, add : \{at-B\}, del : \{at-A\} \rangle$
 - $move-B-C = \langle pre : \{at-B\}, add : \{at-C\}, del : \{at-B\} \rangle$
 - $calibrate = \langle pre : \{\}, add : \{cam-ready\}, del : \{\} \rangle$
 - $take-pic = \langle pre : \{cam-ready, at-C\}, add : \{pic-taken\}, del : \{\} \rangle$
 - $I = \{at-A\}$.
 - $G = \{pic-taken\}$.
- i) Construct the formula $\phi_{\Pi,1}^{seq}$
 - ii) Which pairs of actions have interference in \forall -step semantics? Why?
 - iii) What is the minimum value of L for which the formula $\phi_{\Pi,L}^{seq}$ is satisfiable?
 - iv) What is the minimum value of L for which the formula $\phi_{\Pi,L}^{\forall-step}$ is satisfiable?

Exercise 2

Let Π be a planning task. For each of the following cases, indicate what can you infer about $h^*(I)$ (i.e., $h^*(I) < 5$, $h^*(I) \leq 5$, $h^*(I) > 5$, $h^*(I) \geq 5$, $h^*(I) = 5$, $h^*(I) \neq 5$, or other) and justify your answer.

- i) $\phi_{\Pi,5}^{seq}$ is unsatisfiable
- ii) $\phi_{\Pi,5}^{seq}$ is satisfiable
- iii) $\phi_{\Pi,5}^{\forall-step}$ is unsatisfiable
- iv) $\phi_{\Pi,5}^{\forall-step}$ is satisfiable

Exercise 3

Table 1 provides the number of BDD nodes in symbolic forward and backward search for a concrete planning task. Considering this data, and considering that symbolic bidirectional search chooses whether to do a forward or backward step by comparing the BDD nodes in the frontier, answer the following questions and justify your answer:

- i) How many steps will be required by symbolic bidirectional search to solve the problem?
- ii) How many of those steps will be in the forward and how many in the backward direction?
- iii) How much time will symbolic bidirectional search take to solve the problem?
- iv) What will be the maximum number of nodes in the frontier BDD?
- v) What is the length of the plan retrieved by symbolic bidirectional search?
- vi) What is the length of the plan retrieved by symbolic forward search?
- vii) What is the length of the plan retrieved by symbolic backward search?

Step	Forward		Backward	
	Nodes	Accumulated Time (s)	Nodes	Accumulated Time (s)
1	47	0.50	64	0.49
2	61	0.50	47	0.49
3	71	0.50	47	0.49
4	72	0.50	47	0.49
5	111	0.50	64	0.49
6	172	0.50	91	0.49
7	264	0.50	128	0.49
8	390	0.50	187	0.49
9	476	0.50	240	0.49
10	877	0.50	373	0.49
11	1314	0.50	569	0.49
12	2445	0.51	999	0.49
13	3606	0.52	1524	0.49
14	6698	0.53	2731	0.50
15	9633	0.55	4011	0.51
16	18265	0.58	7352	0.52
17	27102	0.64	11115	0.54
18	53583	0.77	21260	0.59
19	69305	1.00	33219	0.68
20	129679	1.39	62252	0.85
21	144626	2.00	90287	1.14
22	233384	2.85	155914	1.61
23	225292	4.04	194383	2.41
24	304373	5.35	292845	3.52
25	263044	6.90	315181	5.19
26	294367	8.33	398764	7.05
27	232805	9.79	375256	9.47
28	200063	10.8	388079	11.7
29	146009	11.6	327009	14.8
30	88664	12.1	254826	16.9

Table 1: Nodes and accumulated time of symbolic forward and backward search on a blocksworld task with 9 blocks.

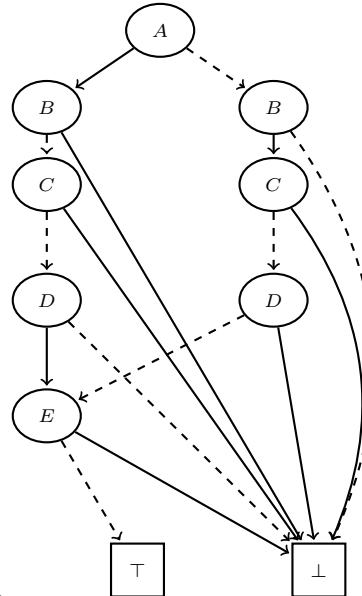
Exercise 4

Consider the following planning task, where a rover needs to take a picture of the surface of Mars.

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 - $calibrate = \langle pre : \{\}, add : \{cam-ready\}, del : \{\} \rangle$
 - $take-pic = \langle pre : \{cam-ready, at-C\}, add : \{pic-taken\}, del : \{\} \rangle$
- $I = \{at-A\}$.
- $G = \{pic-taken\}$.

Considering that the BDD variable ordering is $\langle at-A, at-B, at-C, cam-ready, pic-taken \rangle$, draw the following BDDs:

1. I
2. G
3. $TR_{take-pic}$
4. $image(I, TR)$ Hint: TR represents the disjunction of all actions; you don't need to do the operation step by step, simply think which set of states this operation will result in.

Exercise 5

Consider the following BDD representing the function f .

- i) Draw the BDD corresponding to $\exists_A f$.

- ii) Draw the BDD corresponding to $\exists_{A,B} f$.
- iii) Draw the BDD corresponding to $\exists_{D,E} f$.
- iv) In the worst case, if we have an arbitrary BDD and apply existential quantification with respect to k variables, is the size of the resulting BDD polynomial or exponential in the size of the original BDD. Explain why.