UNIVERSITY OF TORONTO
Faculty of Arts and Science

APRIL 2010 EXAMINATIONS

CSC384H1S
Introduction to Artificial Intelligence
Instructor: Sheila McIlraith

PLEASE HAND IN

Duration — 3 hours

Examination Aids: Calculator permitted, but not necessary.

Student Number: |_|_|_|_|_|_|_|_|_|_|

Last Name: _____

First Name: _____

---

*Do **not** turn this page until you have received the signal to start.*
(In the meantime, please fill out the identification section above, and read the instructions below *carefully*.)

This final examination consists of 8 questions on 20 pages (including this one). *When you receive the signal to start, please make sure that your copy of the examination is complete.* Answer each question directly on the examination paper, in the space provided, and *use the reverse side of the pages for rough work.* (If you need more space for one of your solutions, use the reverse side of the page and indicate **clearly** which part of your work should be marked.)

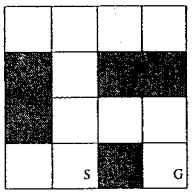
1: _____/ 15
2: _____/ 25
3: _____/ 18
4: _____/ 20
5: _____/ 23
6: _____/ 12
7: _____/ 25
8: _____/ 12

TOTAL: _____/150

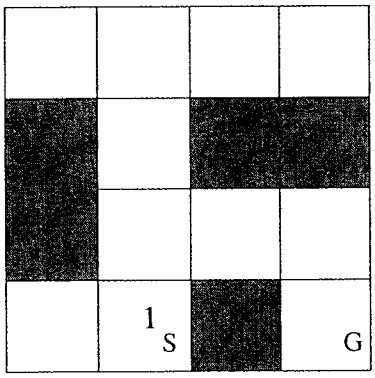
Good Luck!

Question 1. Search [15 MARKS]

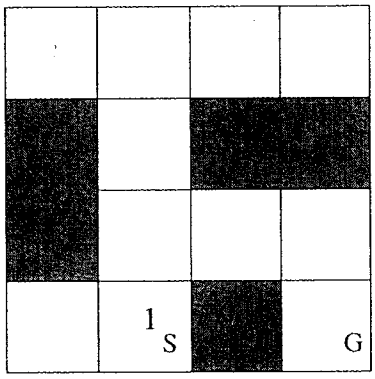
Consider the problem of finding a path in the grid shown below. The problem is to find a path from square S to square G, given that you can move only horizontally and vertically, one square at a time (each step has cost one). No step may be made into a blocked shaded square. Assume also that *cycle checking* is automatically being employed so that none of the searches visit the same square twice.



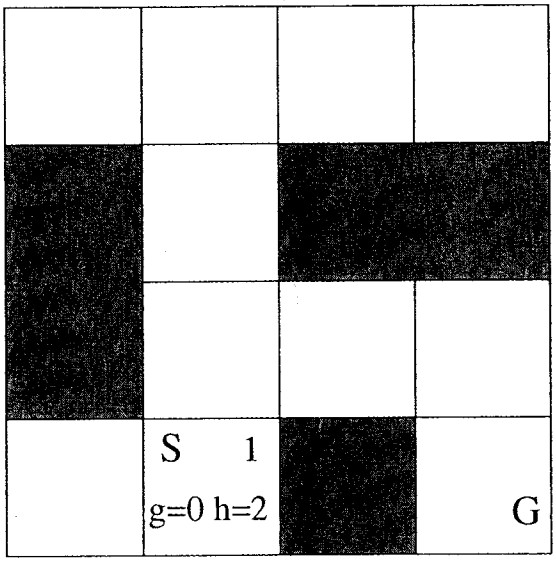
(a) [5 MARKS]
Say that we are doing a *depth-first search*, and that in the search the moves are always examined in the order, **up**, **left**, **right**, then **down**. Number the squares in the grid below in the order in which they are examined by the depth-first search.



(b) [5 MARKS] Repeat the problem (with a newly drawn grid) this time using *breadth-first search*.



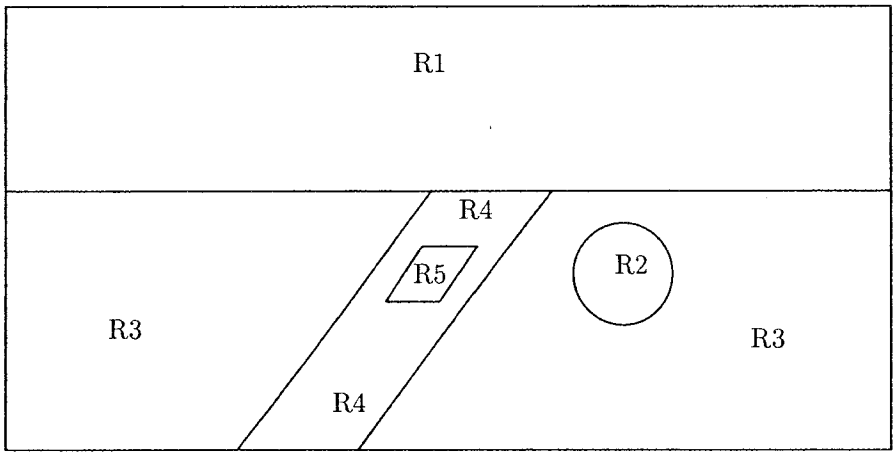
(c) [5 MARKS] Repeat the problem (with a newly drawn grid) this time using A* search with the manhattan distance as a heuristic function. For the A* search, put three numbers in each square visited. The number of the square (i.e., the order it was examined) at the top, and the square's g and h value at the bottom (as shown for the start square S). In the case of equal f values break ties using the same ordering **up, left, right**, then **down**.



Question 2. CSPs [25 MARKS]

Consider the figure shown below. There are five regions, and the following information is available about what they can represent.

1. R1 can only be the sky or grass,
2. R2 can only be trees or a road,
3. R3 can only be grass or trees,
4. R4 can only be road or grass,
5. R5 can only be a car.



Furthermore, we have the following knowledge about the real world, and the figure:

1. A car cannot be next to grass.
2. No two neighbouring regions can be the same.
3. Only one region is a road.

The problem is to find what each region in the figure represents.

(a) [10 MARKS] Represent the above problem as a CSP.

1. Variables:

2. Domain of each variable:

3. Constraints:

(b) [10 MARKS] Apply forward checking to solve the problem. Use the heuristic of always assigning next the variable with fewest remaining values (you can break ties as you choose). You *do not* need to show the updated current domains, only show the nodes of the search tree visited by forward checking and the assignments made at those nodes.

(c) [5 MARKS] How many solutions are there, and what are they?

Question 3. Logic [18 MARKS]

(a) [6 MARKS] Translate the following English sentences into logic:

1. Nobody likes taxes.

2. Some people like anchovies.

3. Emma is a poodle and a good dog.

(b) [6 MARKS] Consider a first-order language $\mathcal{L}$ containing the following basic symbols:

- Constants, A, B, C, D.
- The binary predicate R.
- The unary predicates P and Q.

Let $\mathcal{M}$ be a model for $\mathcal{L}$, with domain $D = \{a, b, c, d\}$, and interpretation function σ:

1. $A^\sigma = a$, $B^\sigma = b$, $C^\sigma = c$, $D^\sigma = d$.
2. $R^\sigma = \{(b, c), (a, d)\}$.
3. $P^\sigma = \{a, b\}$.
4. $Q^\sigma = \{c, d\}$.

Which of the following formulas are satisfied by $\mathcal{M}$.

1. $R(C, B) \vee R(B, A)$.

2. $\forall x.P(x) \vee Q(x)$.

3. $\forall x.P(x) \Rightarrow \neg\exists y.R(y, x)$.

4. $\forall x.Q(x) \Rightarrow \neg\exists y.R(y, x)$.

5. $\forall x.Q(x) \Rightarrow \exists y.R(y, x)$.

6. $\exists x, y.(P(x) \wedge Q(y)) \Rightarrow R(y, x)$.

(c) [6 MARKS] Give the most general unifier (MGU) for the following pairs of expressions, or say *why* it does not exist. In all of these expressions variables start with a "?".

1. $p(a, ?y, b)$, $p(?x, c, ?z)$

2. $older(?y, father(?y))$, $older(john, father(?x))$

3. $r(m(?y), ?y)$, $r(?z, ?z)$

Question 4. Resolution [20 MARKS]

Consider the following sentences:

- John likes all kinds of food.
- Apples are food.
- Chicken is food.
- Anything anyone eats and isn't killed by is food.
- Bill eats peanuts and is still alive.
- Sue eats everything Bill eats.

(a) [6 MARKS] Represent these sentences in first order logic.

(b) [4 MARKS] Convert the formulas to clausal form. (Recall that the 8 steps are: eliminate implication, move negation inward, standardize variables, skolemize, convert to prenix, distribute $\vee$ over $\wedge$, flatten conjunctions and disjunctions, convert to clauses.) **Clearly indicate any Skolem functions or constants used in the conversion.**

(c) [2 MARKS] Convert the negation of the statement "What food does Sue eat" to clausal form and augment it with an answer literal.

(d) [8 MARKS] Answer this question (i.e., "What food does Sue eat") using resolution and answer extraction. In the proof use *the notation employed in the lecture slides.* That is, every new clause must be labeled by the resolution step that was used to generate it. For example, a clause labeled $R[4c, 1d]\{x = a, y = f(b)\}$ means that it was generated by resolving literal c of clause 4 against literal d of clause 1, using the MGU $\{x = a, y = f(b)\}$.

Question 5. GraphPlan [23 MARKS]

Consider the following STRIPS actions:

Name	Pre	Adds	Del
A	q	r,o	q
B	r	o,q	r
C	o	r,q	

You are to use the GraphPlan algorithm to find a plan for the goal $\{o, q, r\}$ from the initial state $S_0 = \{q\}$. In particular,

(a) [7 MARKS] Show the levels of the GraphPlan graph grown from the initial state S_0. Grow the graph until the first time we can search it for a solution. For each level of graph indicate the pairs of actions/facts that are mutex in that level.

(b) [7 MARKS] Search backwards in the graph to find a plan. Show each step of the search by specifying the following:

- For each goal fact specify the action from the previous action layer that you have selected to achieve that goal.
- The new set of goal facts you obtain from these actions.

(c) [9 MARKS] Provide *short* answers to the following questions.

1. (3 marks) Can the set of mutexes in a GraphPlan graph ever increase as the level increases? Why?

2. (3 marks) The `CountActions` heuristic given in class is not admissible. Why?

3. (3 marks) Can this heuristic be made to be admissible? And if so what price do we pay?

Question 6. Planning [12 MARKS]

Consider the following ADL operator written in PDDL. drop drops object ?obj onto surface ?surf under the specified preconditions and with the specified effects.

```
(:action drop
 :parameters (?obj - object ?surf - surface)
 :precondition (and (holding ?obj)
                    (above ?obj ?surf))
 :effect (and (not (above ?obj ?surf))
              (not (holding ?obj))
              (on ?obj ?surf)
              (when (or (fragile ?obj)
                        (hard ?surf))
                    (broken ?obj))))
```

(a) [2 MARKS] Name two features of ADL that are not contained in STRIPS. Hint: one is illustrated in the drop operator above.

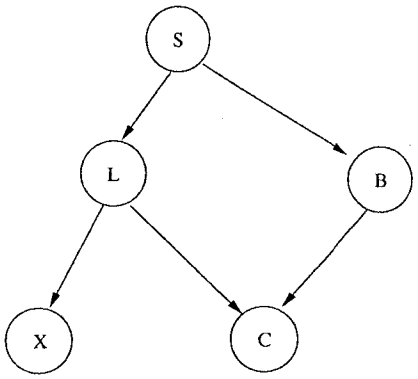
(b) [4 MARKS] Convert this ADL operator into STRIPS. You may create any new predicate symbols, action/operator symbols, or constants that you deem necessary.

(c) [4 MARKS] The FF planning system uses a Relaxed Planning Graph (RPG) heuristic. In order to use the RPG heuristic, the domain is *relaxed*. How is this done? Write a relaxed version of the `drop` operator above.

(d) [2 MARKS] In the situation calculus representation of dynamic domains, representing the non-effects of an action becomes difficult. What is this problem called?

Question 7. Bayes Nets [25 MARKS]

Consider the following Bayes Network:



In this network B = *Bronchitis*, S = *Smoker*, C = *Cough*, X = *positive X-ray*, and L = *lung cancer*.

(a) [1 MARK] Write down the product decomposition for $\Pr(S, L, X, C, B)$.

(b) [2 MARKS] Is this network a polytree? (Yes or No)

(c) [2 MARKS] If we use variable elimination on this network, what would be a better elimination order: (a) L, C, S, B, X, or (b) S, B, X, C, L? (Answer a or b)

(d) [6 MARKS] Using d-separation, list the pairs of individual nodes that are conditionally independent in this network

1. (2 marks) When there is no evidence.

2. (2 marks) When the patient has *lung cancer* and *Bronchitis*.

3. (2 marks) When the patient is a *smoker*.

(e) [14 MARKS] Let the variables B, L, C, and X be boolean (with values true/false), while S has 3 values (0 = non-smoker, 1 = light smoker, 2 = heavy smoker).
Let the conditional probability tables parameterizing this network be as follows (in these tables, e.g., c means that cough is true, while $-c$ means that cough is false).

$Pr(S=0) = 6/10$ $Pr(S=1) = 2/10$ $Pr(S=2) = 2/10$	$Pr(b\|S=0) = 0$ $Pr(-b\|S=0) = 1$ $Pr(b\|S=1) = 2/10$ $Pr(-b\|S=1) = 8/10$ $Pr(b\|S=2) = 1/2$ $Pr(-b\|S=2) = 1/2$	$Pr(l\|S=0) = 0$ $Pr(-l\|S=0) = 1$ $Pr(l\|S=1) = 2/10$ $Pr(-l\|S=1) = 8/10$ $Pr(l\|S=2) = 4/10$ $Pr(-l\|S=2) = 6/10$
$Pr(x\|l) = 1$ $Pr(-x\|l) = 0$ $Pr(x\|-l) = 0$ $Pr(-x\|-l) = 1$	$Pr(c\|l,b) = 1$ $Pr(-c\|l,b) = 0$ $Pr(c\|l,-b) = 8/10$ $Pr(-c\|l,-b) = 2/10$ $Pr(c\|-l,b) = 8/10$ $Pr(-c\|-l,b) = 2/10$ $Pr(c\|-l,-b) = 0$ $Pr(-c\|-l,-b) = 1$	

HINT. In the following questions first check if independence or relevance can make answering the question easier.

1. (3 marks) Given that the patient has Bronchitis and Lung Cancer give the 3 values of $Pr(S|b,l)$.

2. (4 marks) Give the two values of $Pr(X|S=1)$.

3. (4 marks) Give the two values of $Pr(C|S=1)$.

4. (3 marks) What is the relationship between the quantities $Pr(x|l,S=1,c,-b)$ and $Pr(-x|l,S=2,-c,-b)$.

This page was intentionally left blank.

Question 8. Misc - Short Answer [12 MARKS]

(a) [2 MARKS] In uniform cost search, as soon as a state satisfying the goal is added to the frontier the search is complete. (True/False)? Why?

(b) [2 MARKS] Arc-consistency is stronger than forward checking. (True/False)? Why?

(c) [2 MARKS] In first-order logic name three things that are "terms"?

(d) [3 MARKS] Explain in English what the following statement means:

$$KB \models f \rightarrow KB \vdash f$$

This concept is called *completeness.* (True/False)?

(e) [3 MARKS] The Variable Elimination algorithm has worst case complexity $2^{O(\omega)}$ where ω is the tree width of the initial Bayes net. (True/False)? Explain what the tree width of a Bayes net is.

Total Marks = 150