Table 1: For instructor's use

Question	Points Scored	Possible Points
1		12
2		12
3		12
4		12
5		12
6		12
7		12

EXTRA CREDIT

For every two questions worked correctly, you can receive 1 point of extra credit added to your final grade, for a maximum of 3 points of extra credit. In order to submit your answers for extra credit, bring them to class on Friday 4/24/15 and *turn them in at the beginning of class.*

Note: No late submissions for extra credit will be accepted!

Here is some extra space. **Show all of your work on the questions!** If you need more paper just ask. Good luck!!

Question 1. **Conjunctive Normal Form (CNF)**

Write each of the following expressions as a conjunction of clauses in order to put them in CNF.

(a) $A \Rightarrow (B \vee C)$

(b) $B \Leftrightarrow \neg C$

(c) $((A \Rightarrow B) \wedge C) \Rightarrow D$

(d) For each of the clauses you generated above, identify whether or not it is a Horn clause (e.g. write "HC" below each of the Horn clauses).

Question 2. **Resolution in Predicate Logic**

In the game *Minesweeper*, the objective is to uncover hidden mines in a board by probing board locations. Each time a square is probed, the player learns the number of mines which are adjacent to that square (adjacent horizontally, vertically, or diagonally). The objective is to locate all of the mines. The following figure shows the state of the game for a simple 3 by 2 board:

3		
2	$X_{1,2}$	$X_{2,2}$
1	2	$X_{2,1}$
	1	2

The presence of a 2 in location $(1,1)$ means that there are exactly two mines hidden in the adjacent squares $(1,2), (2,1)$, and $(2,2)$. Let $X_{i,j}$ be a boolean literal denoting the presence of a mine at location (i,j).

(a) For each of the following logical sentences, give the number of mines that could be adjacent to $(1,1)$ if the sentence is true. Explain your answer.

- $R_1 : \neg X_{1,2} \vee \neg X_{2,2} \vee \neg X_{2,1}$

- $R_2 : (X_{1,2} \vee X_{2,2}) \wedge (X_{1,2} \vee X_{2,1}) \wedge (X_{2,2} \vee X_{2,1})$

- $R_1 \wedge R_2$

(b) Using resolution, show that $\neg X_{2,2}$ entails $X_{1,2} \wedge X_{2,1}$. Note: KB $\equiv R_1 \wedge R_2 \wedge \neg X_{2,2}$

Question 3. **First Order Logic**

(a) Represent the following sentences in first order logic, using a consistent vocabulary (which you must define):

- Some students took Finnish in fall 2014
- Every student who takes Finnish passes it
- Only one student took Quenya in fall 2014
- The best score in Quenya is always higher than the best score in Finnish
- Everyone who lives on-campus buys a meal-plan
- No student buys an expensive meal-plan
- There is an office on-campus that sells meal-plans only to students
- If a faculty-member buys a meal-plan, then it must be expensive
- Bud Peterson's meal-plan is the most expensive

(b) Use unification to prove that Bud Peterson is not a student. What can we conclude about whether Bud Peterson lives on campus?

Question 4. **Bayes Nets**

A professor is heading back into the lab late at night and is trying to guess whether his student is working on their paper. He has noticed that whenever this student is working, their car is in the garage and there is music playing in the lab. Let W, C, M be three binary random variables corresponding to the events "student Working on paper", "Car in parking lot", and "Music playing". Through careful observation, the professor has determined the following conditional probabilities:

(1) $P(C|W, M) = P(C|W) =$

	$W = 1$	$W = 0$
$C = 1$	0.8	0.1
$C = 0$	0.2	0.9

(2) $P(M|W) = P(C|W)$

(3) $P(W = 1) = 0.8$

Note that equation (2) says that C and M have the same conditional distribution (e.g. $P(C = 1|W = 1) = P(M = 1|W = 1) = 0.8$.)

(a) Draw a Bayesian network model (i.e. a directed graphical model) for this problem.

(b) Compute the marginal distributions $P(C)$ and $P(M)$, before any evidence is availble

(c) Upon entering the garage, the professor notices that the student's car is parked there. Calculate $P(W|C = 1)$.

(d) Calculate the updated probability that music is playing in the lab

Question 5. **Decision Tree Learning**

Consider the following dataset for training a decision tree:

	A_1	A_2	A_3	A_4	Output
1	1	1	1	0	1
2	1	0	1	0	1
3	0	0	1	1	1
4	0	0	0	0	1
5	1	0	0	1	0
6	1	1	1	1	0
7	1	0	0	0	0
8	0	0	1	1	0

(a) The attribute A_4 is selected for the first (root) node of the decision tree. Calculate the information gain based on splitting on A_4.

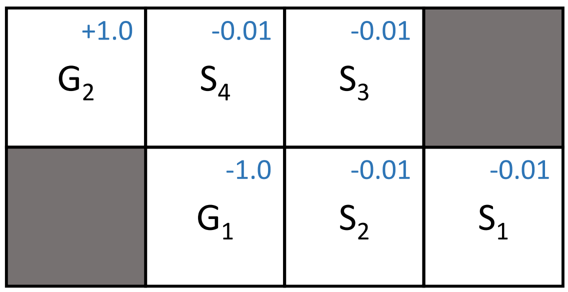
(b) Consider the **TRUE** branch of the A_4 split. Identify whether an additional split is needed, and if so which attribute to select next.

(c) Consider the **FALSE** branch of the A_4 split. Identify whether an additional split is needed, and if so which attribute to select next.

(d) Make the smallest possible change to the training dataset such that A_3 is selected as the first attribute instead of A_4. Indicate your answer by directly editing the values in the table on the previous page.

Question 6. **Markov Decision Processes**

Consider the grid world shown below. The agent starts in state S_1 and is trying to reach the positive goal G_2. There is also a negative terminal G_1 which the robot wants to avoid. The reward for each of the two goals and the four states is shown in the top right of each square. Assume that there are *three* action choices in each state: *Left*, *Up*, and *Down*. Use the standard noise model for actions in which the probability of moving in the desired direction is 0.8 and there is 0.1 chance to move in each of the orthogonal directions (this is the same action model we used in class and is used in your book). Assume that rewards are not being discounted (i.e. discount factor of 1.0).

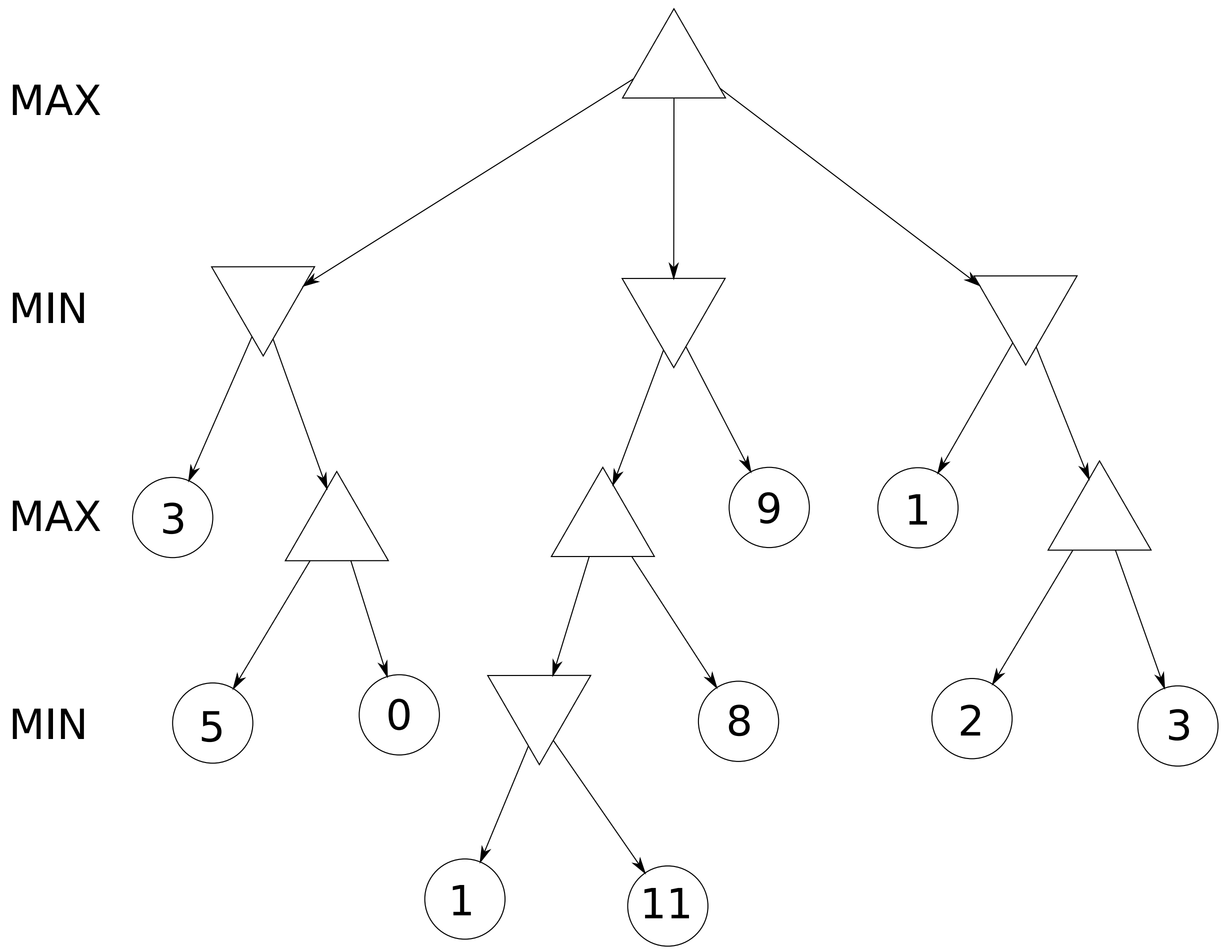


(a) Assume that the utilities for each of the states S_1 to S_4 are initialized to 0.1. Perform two rounds of value iteration, and show the utilties for each of the four states at each round.

(b) For each state in the figure above, draw an arrow indicating the optimal policy following the 2nd iteration of value iteration.

(c) Now assume that the robot is moving on an infinite plane with no obstacles or goals, and the reward at each state is 0.5. Using a discounting factor of 0.9, what is the expected utility of the optimal policy?

Question 7. Consider the following tree for a minimax game. Note: End utilities given are always with respect to MAX, even if they don't appear on a MAX layer.



Use the **Minimax algorithm with Alpha-Beta pruning** to identify the best strategy for MAX. Assume the algorithm always searches successors from left to right. Cross out all branches that are pruned. For each prune, write the value of v and α or β (whichever applies to the pruning decision). Fill in the value of every node, as the algorithm would determine.