

Table 1: For instructor's use

Question	Points Scored	Possible Points
1		12
2		12
3		6
4		12
5		12
6		6
7		12
8		2-4

The final exam is closed book. You are allowed 4 sheets of notes (8 pages front and back). You may use any format for your notes that you like. Please explain all of your answers fully in order to receive any partial credit.

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

Question 1. Naïve Duck

Your friend *Howard the Duck* has constructed a highly-biased probabilistic model of the animal kingdom, consisting of the joint probability distribution $P(W, Q, D)$, where W stands for “walks,” Q stands for “quacks,” and D stands for “is-a-duck.”

	$W = 0$		$W = 1$	
	$Q = 0$	$Q = 1$	$Q = 0$	$Q = 1$
$D = 0$	0.15	0.08	0.05	0.02
$D = 1$	0.05	0.10	0.10	0.45

(a) (1 pt) Suppose that you are drawing random samples from this probabilistic model. What is the likelihood that a randomly-sampled animal will *walk*, *quack*, and *be a duck*?

(a) (4 pt) Calculate the following joint probability tables through marginalization (i.e. “summing out”): $P(W, Q)$, $P(D, Q)$, and $P(D)$. Note: we have provided the table $P(D, W)$ as an example.

	$W = 0$	$W = 1$
$D = 0$	0.23	0.07
$D = 1$	0.15	0.55

	$Q = 0$	$Q = 1$
$W = 0$		
$W = 1$		

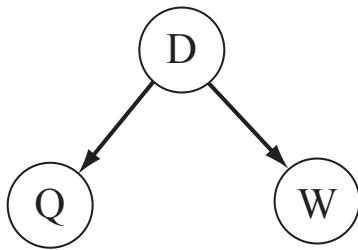
	$Q = 0$	$Q = 1$
$D = 0$		
$D = 1$		

$D = 0$	
$D = 1$	

(b) (3 pt) If you are observing a duck, what is the probability that it can quack (i.e. $P(Q = 1|D = 1)$)? What is the probability that it can both quack and walk?

(c) (2 pt) You observe that a particular animal walks and quacks. What is the probability that it is a duck? Compare this answer to your answer in part (a). Are the probabilities the same or different? Explain why.

(d) (2 pt) Howard claims that Bayesian networks can provide a more compact and elegant model of the animal kingdom, and proposes the model below. Demonstrate that his model is incorrect. (Hint: Consider the case where all attributes are true, since a single counter-example is sufficient to disprove an assertion).



Question 2. Markov Decision Process

Consider the following grid world for an MDP, where the states are $\{S_1, S_2, S_3\}$ and there are four goal terminals $\{G_1, G_2, G_3, G_4\}$. The reward for being in each state is -0.1 . The reward for reaching G_1 is 10, while the reward for reaching each of the other goals is 1. The agent starts in S_1 and has *two* possible actions: *Right* and *Up*. The probabilistic transition model is as follows:

- When moving *Right*, the agent will go *Up* by accident with probability 0.2
- When moving *Up*, the agent will go *Right* by accident with probability 0.2.

1	1	1	
G_2	G_3	G_4	
-0.1	-0.1	-0.1	10
S_1	S_2	S_3	G_1

(a) Assume that all of the *utilities are initialized to 0.1* and there is *no discounting* (i.e. $\gamma = 1$). Calculate the updated utilities for states S_1 , S_2 , and S_3 over *three rounds* of value iteration, by filling in the missing elements below. (Note that $U^i(S_j)$ denotes the utility for state j in iteration number i .)

$$U^1(S_3) = \max_{R,U}\{$$

$$U^2(S_2) = \max_{R,U}\{$$

$$U^3(S_1) = \max_{R,U}\{$$

(b) When value iteration has converged, indicate on the grid world figure from the previous page what you believe the final (optimal) policy will be. How many iterations will be required for policy iteration to converge (in the sense that the policy no longer changes)? Explain your answer.

(c) Demonstrate that your policy in part (b) is optimal using *policy iteration*. Policy iteration has converged when we compute the expected utility $U(\pi^*)$ for a policy π^* , and then demonstrate that π^* is optimal under $U(\pi^*)$.

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. Decision Tree Learning

Sarah organizes a local science fiction book club. She plans to build an agent that will decide whether to buy a book for the club. It will eventually search the internet. But first, she has to learn a decision tree classifier based on books the club has already read. The classifier will learn to identify good books by their attributes:

- Space - the story is not set on Earth
- Time - the story involves someone traveling through time
- Heroine - the protagonist is a female

	Space	Time	Heroine	Good?
1	1	1	0	0
2	1	1	1	1
3	1	0	1	1
4	0	1	1	1
5	1	1	0	0
6	0	0	0	0
7	0	0	1	0
8	0	1	1	1

When determining the root for her decision tree, Susan calculates that $\text{Gain}(\text{Heroine})=0.54$, $\text{Gain}(\text{Space})=0.00$, and $\text{Gain}(\text{Time})=0.05$. She picks **heroine** to be the root.

The questions start on the next page, break any ties between attributes alphabetically.

You may want to use the following table of logarithms:

$$\begin{aligned}
 \log_2(1/3) &= -1.585 \\
 \log_2(2/3) &= -0.585 \\
 \log_2(1/5) &= -2.322 \\
 \log_2(2/5) &= -1.322 \\
 \log_2(3/5) &= -0.737 \\
 \log_2(4/5) &= -0.322 \\
 \log_2(3/8) &= -1.415 \\
 \log_2(5/8) &= -0.678
 \end{aligned}$$

4(a) Consider the **TRUE** branch of the heroine node.

Is another attribute necessary for this branch?

If so, calculate $\text{Gain}(\text{Space})$ and $\text{Gain}(\text{Time})$. Which attribute should go next?

Show your calculations to be eligible for partial credit.

4(b) Consider the **FALSE** branch of the heroine node.

Is another attribute necessary for this branch?

If so, calculate $\text{Gain}(\text{Space})$ and $\text{Gain}(\text{Time})$. Which attribute should go next?

Show your calculations to be eligible for partial credit.

Question 5. Dynamic Bayesian Networks

The AI faculty decide to build an agent to guess the mood of Dean Zvi Galil from hour to hour (so visits to the Dean's office can be carefully timed). After detailed observation, they determine that when the Dean is in a good mood, there is a 75% chance he will be in a good mood an hour later. But when he is in a bad mood, there is a 50% chance he will be in a bad mood an hour later. Unfortunately the Dean's mood can't be observed directly. However, through careful study the faculty have determined that when the Dean is in a good mode, the likelihood that he will send a reminder email about CIOS is 80%, but there is only a 60% chance of sending a CIOS email when he is in a bad mood.

(a) Draw a dynamic Bayesian network model for this problem. Be sure to show at least two time slices. Label the nodes in your graph. Use the random variable M to indicate the Dean's mood. M can take on the values "good" or "bad." Use the random variable C to indicate whether a CIOS email was sent. C can take on the values "true" or "false." Use subscripts on M and C to indicate time slices.

(b) Fill in the conditional probability tables for the transition model and sensor model elements of the DBN. Be sure the columns and rows are labeled properly in the spaces provided.

Transition Model:

Sensor Model:

(c) The faculty have no knowledge of the Dean's mood prior to the first day of Finals Week. Give the distribution for the Dean's mood.

$$P(M_0) =$$

(d) On the first day of Finals Week, the Dean sends a CIOs reminder email. Compute the normalized probability distribution for the Dean's mood on the first day of Finals Week, given that $C = 1$. Show your work to be eligible for partial credit.

$$P(M_1|C_1 = 1) =$$

Question 6. Knowledge Representation

Some people define AI as knowledge representation plus efficient algorithms. In each of the AI techniques below, very briefly describe how knowledge is represented. [Hint: you should just need a couple words or terms each.]

- Informed Search:

- Markov decision processes:

- Dynamic Bayesian network:

- Propositional logic:

- Neural network:

- Constraint satisfaction:

Question 7. Horn Clauses

Consider the following set of Horn clauses which define a knowledge base:

$$A \wedge B \Rightarrow F$$

$$C \Rightarrow F$$

$$C \wedge D \Rightarrow G$$

$$G \wedge H \Rightarrow I$$

$$E \wedge F \Rightarrow I$$

(a) Draw the AND-OR tree associated with this set of clauses.

(b) Suppose that E and C are true (ie asserted in our knowledge base KB). Use backward chaining in the above AND-OR graph to demonstrate that $KB \models I$. Show your work by indicating the order in which nodes are visited and by indicating the nodes that are instantiated.

Question 8. Extra Credit: *This problem is worth 4 points * the CLOS response rate for the class.*

Suppose your AI for controlling a Roomba (robot vacuum cleaner) has become sentient. Further suppose that it tries to pass the Turing Test by composing a Haiku poem. Write that Haiku poem below. To receive credit, your poem must reference the type of environment (from an AI perspective) that Roomba's inhabit.

Haiku is a very short form of Japanese poetry typically characterized by:

- Having 17 syllables on three lines: 5, 7, and 5 syllables per line.
- A seasonal reference (although for the purposes of this question, the seasonal reference will be replaced by a reference to the AI environment type).
- A juxtaposition of ideas (feel free to ignore this requirement).