

# Sp22-CS-221-01 Final Exam

Jason Alexander Chan

TOTAL POINTS

**81.3 / 121**

QUESTION 1

**1 Honor Code 0 / 0**

- ✓ - **0 pts** Correct
- **0 pts** Missing

QUESTION 2

**2 1a(i) 4 / 4**

- ✓ - **0 pts** Correct
- **1 pts** Right idea with math errors
- **3 pts** Some work
- **4 pts** No/insufficient answer

QUESTION 3

**3 1a(ii) 2 / 2**

- ✓ - **0 pts** Correct, k=6
- **0 pts** Incorrect/no answer

QUESTION 4

**4 1b(i) 1 / 2**

- **0 pts** Correct
- ✓ - **1 pts** Partially correct
- **2 pts** Incorrect/no answer
- 💬 All (a) (b) (c) are correct.

QUESTION 5

**5 1b(ii) 2 / 2**

- ✓ - **0 pts** Correct
- **2 pts** Incorrect
- **1 pts** Partially correct/not clear.

QUESTION 6

**6 1b(iii) 2 / 2**

- ✓ - **0 pts** Correct
- **2 pts** Incorrect
- **1 pts** Partially correct/not clear

QUESTION 7

**7 1b(iv) 2 / 3**

- **0 pts** Correct
- **3 pts** Incorrect
- ✓ - **1 pts** Partially correct / not clear

💬  $\delta L/\delta w_2 = (x_2 \cdot 83 + x_3 \cdot 64) \cdot 82 \cdot 81 \cdot 80$

QUESTION 8

**8 1c 1 / 2**

- **0 pts** Correct
- ✓ - **1 pts** 2, 4 and one extra answer selected or only one of 2 and 4 is picked (one choice differ from the correct answer)
- **2 pts** More than one choice differ from than correct answer/ incorrect/ missing

QUESTION 9

**9 2a(i) 2 / 2**

- ✓ - **0 pts** Correct
- **0.4 pts** One overall incorrect (Did not pick one of (B, C, D, E), or picked A)
- **0.8 pts** Two overall incorrect
- **1.2 pts** Three overall incorrect
- **1.6 pts** Four overall incorrect
- **2 pts** Five overall incorrect

QUESTION 10

**10 2a(ii) 0.8 / 2**

- **0 pts** Correct
- **0.4 pts** One incorrect choice (picked (A, B, C) or didn't pick (D, E))
- **0.8 pts** Two incorrect choices
- ✓ - **1.2 pts** Three incorrect choices
- **1.6 pts** Four incorrect choices
- **2 pts** Five incorrect choices

#### QUESTION 11

##### 11 2a(iii) 2 / 2

✓ - 0 pts Correct

- 0.4 pts One choice incorrect (Selected one of (A, B, C, E) or didn't select D)

- 0.8 pts Two choices incorrect

- 1.2 pts Three choices incorrect

- 1.6 pts Four choices incorrect

- 2 pts Five choices incorrect

- 2 pts No answer :(

#### QUESTION 12

##### 12 2b(i) 2 / 3

- 0 pts Correct

- 1.5 pts Does not represent the previous action and the number of times it was taken minimally.

✓ - 1 pts Missing descriptor for the previous action taken.

- 1 pts Missing descriptor for the number of times the previous action has been taken consecutively.

- 1 pts Missing descriptor for the location on the grid.

- 0.5 pts Position, previous action, and number of times previous action has been taken consecutively are stated, but extra terms are included in state description (eg: cost).

- 3 pts Incorrect or missing

#### QUESTION 13

##### 13 2b(ii) 1 / 3

- 0 pts Correct

- 1 pts Correct state in 2b(i) but minor errors

✓ - 2 pts If 2b(i) state was incorrect but transition is reasonable for the state as defined.

- 3 pts Incorrect or missing

#### QUESTION 14

##### 14 2b(iii) 3.5 / 4

+ 4 pts Correct. Mentions that  $\$h(s_{\text{end}}) = 0\$$ .

1) Mentions that  $\$h(\text{succ}(s,a)) - h(s) \geq -1\$$  since

neighbouring states have a difference in L1 distance of at most 1. Since the cost of any action is at least 1, and therefore  $\$cost(s,a) + h(\text{succ}(s,a)) - h(s) \geq 0\$$ .

OR

2) uses the theorem "consistency of relaxed heuristics", shows that  $\$cost_{\text{rel}}(s,a) \leq cost(s,a)\$$  (using the argument above) and that L1 is the future cost in the relaxed problem because it is the shortest path between locations on the grid such that each location on the path is also on the grid.

✓ + 3.5 pts Correct, but doesn't mention that

$\$h(s_{\text{end}}) = 0\$$

+ 0.5 pts Mentions heuristic is consistent.

+ 0.5 pts States that  $\$h(s_{\text{end}}) = 0\$$

Triangle inequality proof

+ 0.5 pts States the triangle inequality definition of consistency, i.e.  $\$cost(s,a) + h(\text{succ}(s,a)) - h(s) \geq 0\$$

+ 1.5 pts Demonstrates admissibility (i.e. mentions that the L1 distance will underestimate future costs of paths), but doesn't prove consistency.

+ 1.5 pts States the definition of consistency and considers heuristic values of neighbouring states, but doesn't correctly justify that the difference is bounded by 1.

+ 0 pts Click here to replace this description.

Theorem of consistency of relaxed heuristics

+ 0.5 pts States that  $\$cost_{\text{rel}}(s,a) \leq cost(s,a)\$$  but doesn't justify this.

+ 1.5 pts Mentions  $\$cost_{\text{rel}}(s,a) \leq cost(s,a)\$$  because cost between neighbouring states is bounded by 1.

+ 1.5 pts States that the  $\$h(s) = FutureCost_{\text{rel}}(s)\$$  without mountains and limits on actions.

+ 0 pts Incorrect or missing.

#### QUESTION 15

##### 15 2b(iv) 1 / 1

**✓ - 0 pts Correct**

**- 0.5 pts** Stated that heuristic is not consistent, but incorrect/insufficient justification.

**- 1 pts** Incorrect or missing.

QUESTION 16

**16 3a(i) 2 / 2**

**✓ - 0 pts Correct**

**- 2 pts** Incorrect

QUESTION 17

**17 3a(ii) 2 / 2**

**✓ - 0 pts Correct**

**- 2 pts** Incorrect

**- 1 pts** partial correct

QUESTION 18

**18 3a(iii) 0 / 2**

**- 0 pts** Correct

**- 1 pts** Incorrect/blank explanation

**✓ - 2 pts Incorrect choice and explanation**

**- 1 pts** correctly explain C but not select B

QUESTION 19

**19 3a(iv) 0 / 2**

**- 0 pts** Correct

**- 1 pts** Incorrect/blank explanation

**✓ - 2 pts Incorrect choice and explanation**

QUESTION 20

**20 3b(i) 1 / 5**

**- 0 pts** Correct

**- 5 pts** Answer missing/ incorrect

**✓ - 4 pts Made an incorrect/very incomplete attempt**

**- 3 pts** A couple of correct steps

**- 1 pts** Almost correct

QUESTION 21

**21 3b(ii) 2 / 2**

**✓ - 0 pts Correct**

**- 1 pts** Correct answer, wrong/missing explanation

**- 2 pts** Incorrect

**- 0.5 pts** Almost correct

QUESTION 22

**22 3b(iii) 3 / 3**

**✓ - 0 pts Correct**

**- 3 pts** Incorrect answer

**- 1.5 pts** Incorrect explanation

**- 1.5 pts** Partially correct answer

**- 2 pts** No explanation

QUESTION 23

**23 4a(i) 1 / 2**

**+ 2 pts** Correct

**✓ + 1 pts Answering "Yes"**

**+ 1 pts** Correct justification: Your earnings are your opponent's losses, and your opponent's earnings are your losses. Hence, the sum of the utilities between you and your opponent will always be 0. Insufficient justifications usually do not mention one of the keywords "constant utility" or "you win what your opponent loses"

**+ 0 pts** Incorrect

QUESTION 24

**24 4a(ii) 1 / 2**

**+ 2 pts** Correct

**✓ + 1 pts Answering "No"**

**+ 1 pts** Correct justification: "Again, this scenario has an aspect of cooperation since both cars must avoid crashing into one another. Specifically, if both cars merge, then the sum of the utilities is not 0, violating the conditions for a 0-sum game." Common mistakes: (1) describes the scenario as prisoner's dilemma without further explanation (2) vague statements that don't explain why it is not zero sum

**+ 0 pts** Incorrect

QUESTION 25

**25 4b 6 / 6**

**✓ - 0 pts Correct**

**- 1 pts** One incorrect node (given nodes below)

**- 2 pts** 2 incorrect nodes (given nodes below)

- **3 pts** 3 incorrect nodes (given nodes below)
- **4 pts** 4 incorrect nodes (given nodes below)
- **5 pts** 5 incorrect nodes (given nodes below)
- **6 pts** Incorrect

QUESTION 26

**26 4c 3 / 6**

- **0 pts** Correct
- ✓ - **3 pts** 1 of lower or upper bound correct
- **6 pts** Incorrect

QUESTION 27

**27 4d 2 / 2**

- ✓ - **0 pts** Correct
- **2 pts** Incorrect

QUESTION 28

**28 5a(i) 0 / 2**

- **0 pts** Correct (Power set of students)
- **0.5 pts** Mostly Correct (i.e. size-limited power set or stating that the domain is the the particular assignment of students)
- **1 pts** Only size K subsets
- ✓ - **2 pts** Incorrect

QUESTION 29

**29 5a(ii) 8 / 8**

- ✓ - **0 pts** Correct
- **1 pts** Incorrect/No factor encoding constraint 1
- **0.5 pts** Partially correct constraint 1
- **1 pts** Incorrect/No factor encoding constraint 2
- **0.5 pts** Partially correct constraint 2
- **3 pts** Incorrect/No factor encoding constraint 3
- **1.5 pts** Partially correct constraint 3
- **1 pts** Incorrect/No factor encoding constraint 4
- **0.5 pts** Partially correct constraint 4
- **2 pts** Incorrect/No factor encoding constraint 5
- **1 pts** Partially correct constraint 5
- **8 pts** Incorrect (Blank, Using students as variables, not expressed mathematically)

QUESTION 30

**30 6a(i) 2 / 2**

- ✓ - **0 pts** Correct
- **2 pts** Incorrect/Missing Answer

QUESTION 31

**31 6a(ii) 2 / 2**

- ✓ - **0 pts** Correct
- **2 pts** Incorrect Answer

QUESTION 32

**32 6a(iii) 2 / 2**

- ✓ - **0 pts** Correct
- **2 pts** Incorrect Answer

QUESTION 33

**33 6a(iv) 0 / 2**

- **0 pts** Correct
- ✓ - **2 pts** Incorrect Answer
- **1 pts** partially incorrect

QUESTION 34

**34 6b(i) 2 / 2**

- ✓ - **0 pts** Correct
- **2 pts** Incorrect

QUESTION 35

**35 6b(ii) 3 / 3**

- ✓ - **0 pts** Correct ("no" to the word problem and/or "yes" to conditional independence of W and R)
- **1 pts** Correct but no explanation given
- **3 pts** Incorrect

QUESTION 36

**36 6b(iii) {Mislabeled as ii} 2 / 4**

- **0 pts** Fully Correct
- **1 pts** Minor error in final result (e.g. single missing/incorrect coefficient in term in denominator)
- ✓ - **2 pts** Partially correct reasoning or intermediate result
- **4 pts** Incorrect/Blank

QUESTION 37

**37 6b(iv) {Mislabeled as iii} 0 / 4**

- **0 pts** Correct
  - **1 pts** Denominator not fully simplified
  - **2 pts** Partially correct reasoning or intermediate result
- ✓ - **4 pts** Incorrect/Blank

QUESTION 38

**38 6c 2 / 2**

- ✓ + **1 pts** Correctly identifying "ethics dumping"
- ✓ + **1 pts** Justification conveys understanding of ethical dumping
- **2 pts** No concept named
- **2 pts** Incorrect/skipped

QUESTION 39

**39 7a(i) 3 / 3**

- ✓ + **3 pts** Correct (True)
- **3 pts** Incorrect/Skipped

QUESTION 40

**40 7a(ii) 2 / 2**

- ✓ + **2 pts** Correct (c)
- **2 pts** Incorrect/Skipped

QUESTION 41

**41 7a(iii) 0 / 3**

- + **3 pts** Correct (a)
- ✓ - **3 pts** Incorrect/Skipped

QUESTION 42

**42 7b(i) 2 / 2**

- ✓ - **0 pts** Correct (d) only
- **2 pts** Incorrect

QUESTION 43

**43 7b(ii) 0 / 2**

- **0 pts** Correct:  $(\neg A \vee \neg B \vee C) \wedge (\neg A \vee \neg B \vee D)$
- ✓ - **2 pts** Incorrect

QUESTION 44

**44 7b(iii) 0 / 4**

- **0 pts** Correct (i.e. correct CNF and correct application of MP)
- **2 pts** Partially correct (i.e. correct CNF)
- ✓ - **4 pts** Incorrect

QUESTION 45

**45 7c 2 / 2**

- ✓ - **0 pts** Correct
- **0.5 pts** fail to identify one of civilian or military use.
- **1 pts** fail to identify usages of technology
- **1 pts** fail to identify specific algorithm or technology
- **2 pts** missing/incorrect

# CS221 Final Exam

Spring 2022

Please read all of the following information before starting the exam:

- This test has 7 questions, each with multiple subparts.
- You will have 180 minutes to complete and submit the exam.
- Note that different questions are worth different amounts of points. Budget your time accordingly!
- Keep your answers precise and concise. We may award partial credit so show all your work clearly and in order.
- Don't spend too much time on one problem. Read through all the problems carefully and do the easier ones first.
- If you are unsure about a problem statement when taking the exam, state your assumptions in your answer. We will take all reasonable assumptions into account when grading.
- You are only allowed a 1-page cheatsheet (front and back) to refer to during this exam.
- Being subject to the provisions of the Honor Code means in part that you must observe the rules established for this exam, which are: you may consult only inanimate sources. You may not consult or collaborate with anyone about the questions. Such collaboration is a violation of the Honor Code.
- Good luck!

Problem	Part	Max Score	Score
1	a	6	
	b	9	
	c	2	
	<b>Total</b>	17	
2	a	6	
	b	11	
	<b>Total</b>	17	
	a	8	
3	b	10	
	<b>Total</b>	18	
	a	4	
	b	6	
4	c	6	
	e	2	
	<b>Total</b>	18	
	a	10	
5	<b>Total</b>	10	
	a	8	
	b	13	
	c	2	
6	<b>Total</b>	23	
	a	8	
	b	8	
	c	2	
7	<b>Total</b>	18	

30m/second

bii

→ 90mins mark

→ 2h 45'

-

**Honor Code (0 points)** Please sign your name underneath the honor code below. By signing, you agree to abide by the honor code statement as well as the rules stated on Page 1.

Your exam will **not** be graded if this question is not completed.

*"I will not consult or collaborate with anyone about the questions. Such collaboration is a violation of the Honor Code."*

Jaron Chan  
8 June 2021  
10:12 AM AEST

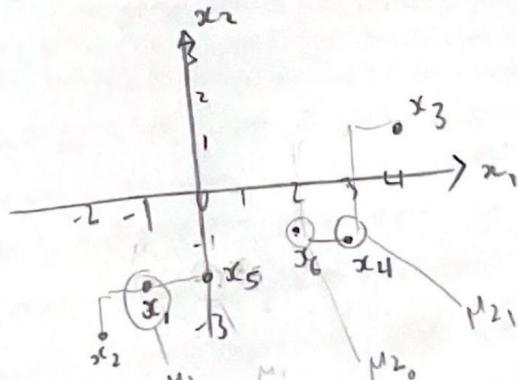
## 1. Machine Learning (17 points)

a. (6 points) K-Means Clustering You are given the following six points:  $x_1 = [-1, -2], x_2 = [-2, -2], x_3 = [4, -1], x_4 = [3, -1], x_5 = [0, -2], x_6 = [2, -1]$ . Answer the following questions.

- (i) [4 points] In class we saw the use of the L-2 distance for the computation of the K-means objective. Now, we will instead be using the L-1 distance. Recall that the L-1 distance between two points  $x = [x_1, x_2]$  and  $y = [y_1, y_2]$  is  $|x_1 - y_1| + |x_2 - y_2|$ . Furthermore, recall that for a group of points, the point that minimizes the sum of the L-1 distance to all of the points is the element-wise median of the points.

If we select  $x_1$  and  $x_6$  as the initial centroids, write down the simulation of the 2-means clustering process until convergence. Include the new positions of the centroids  $\mu_1$  and  $\mu_2$ , the new cluster assignments  $z$  and the cost (i.e. K-means objective) at every step of the simulation. Note: you may not need all the rows.

Iteration	$\mu_1$	$\mu_2$	Cluster Assignments $z$	Cost
0	$[-1, -2]$	$[2, -1]$	$z_{\mu_1} = \{x_1, x_2, x_5\}, z_{\mu_2} = \{x_3, x_4, x_6\}$	$1+4+1+2=8$
1	$[-1, -2]$	$[2, -1]$	$z_{\mu_1} = \{x_1, x_2, x_5\}, z_{\mu_2} = \{x_3, x_4, x_6\}$	$1+3+1+2=7$
2				
3				
4				



- (ii) [2 points] If we can arbitrarily set the value of  $K$  (i.e. the number of clusters) and randomly select  $K$  points (without replacement) from the set as initial centroids for each of the clusters, is it possible to achieve the global minimum of the K-means objective cost function? If yes, what is the minimum value of  $K$  that achieves the global minimum for this problem? If no, what is the minimum cost achieved?

There exists a case where  $K = \text{number of all data points}$ , such that at convergence the location of each centroid coincides uniquely to each datapoint, which would result in a cost of 0 for the K-means objective cost function.

Hence min. value of  $K$  for this case must be equal to 6 for this problem.

b. (9 points) **Neural Networks and Backpropagation** You are trying to classify images to determine whether or not a dog is present (1) or absent (0) using a 2-layer neural network with sigmoid activations.

- (i) [2 points] You think that your model is overfitting because your test error is much higher than your train error. Which of the following methods can you use to reduce overfitting? Select all that apply.
- (a) Collect more data and increase the size of your dataset  $m$
  - (b) Use some form of regularization
  - (c) Reduce the size (number of parameters) in the network

(b), (c)

- (ii) [2 points] Suppose you have access to a large training and test set. You do not know what values to use for the hyperparameters of your network (such as the learning rate). What would be an acceptable strategy regarding the dataset splits that you can use to go about choosing the suitable hyperparameters for your network?

An acceptable strategy is to create 3 splits: training, validation & test sets. Training is of course to train models, Validation set is used to tweak hyperparameters & compare the effects, finally test is the 'hidden' data set against which a model's performance can be evaluated against. Typical percentage splits are 70% training, 20% validation, 10% test, or 70% training, 10% validation, 20% test.

You somehow reduce our image down to three scalar features  $x_1, x_2, x_3$ , and design a neural network (defined by the following equations) to perform the binary classification: The architecture of your network (in the form of the feed-forward, loss, and cost equations) is given below:

$$a_1 = w_1 x_1 + w_2 x_2$$

$$a_2 = w_1 x_2 + w_2 x_3$$

$$z = \max(a_1, a_2)$$

$$a_3 = w_3 z$$

$$\hat{y} = \sigma(a_3)$$

$$L = y \log(\hat{y}) + (1-y) \log(1-\hat{y})$$

w<sub>1</sub>, w<sub>2</sub>, w<sub>3</sub>, w<sub>4</sub> are the trainable parameters of the network, and L denotes the binary cross-entropy loss function applied on the model's prediction ŷ and the true label y.

We will now determine some of the equations required to update the w<sub>i</sub>s via backpropagation. Suppose that we have already computed the following derivatives:

$$\delta_0 = \partial L / \partial \hat{y}$$

$$\delta_1 = \partial \hat{y} / \partial a_3$$

$$\delta_2 = \partial a_3 / \partial z$$

$$\delta_3 = \partial z / \partial a_1$$

$$\delta_4 = \partial z / \partial a_2$$

$$\frac{\partial \hat{y}}{\partial a_3} \times \frac{\partial a_3}{\partial z} \times \frac{\partial z}{\partial a_2}$$

$$\delta_1 \times \delta_2 \times \delta_3$$

(iii) [2 points] What is  $\partial L / \partial w_3$ ? You may use the  $\delta_i$ s in your answer.

$$L = y \log \hat{y} + (1-y) \log(1-\hat{y})$$

$$= y \log \sigma(a_3) + (1-y) \log(1-\sigma(a_3))$$

$$\frac{\partial L}{\partial w_3} = y \frac{\sigma'(a_3) a_3^1}{\sigma(a_3)} + (1-y) \frac{(-\sigma'(a_3)) \cdot a_3^1}{1-\sigma(a_3)}$$

$$= \frac{y \delta_1 \lambda}{\sigma(a_3)} - \frac{(1-y) \delta_1 \lambda}{1-\sigma(a_3)}$$

(iv) [3 points] What is  $\partial L / \partial w_2$ ? You may use the  $\delta_i$ s in your answer.

$$L = y \log \sigma(w_3 \cdot \max(a_1, a_2)) + (1-y) \log(1 - \sigma(w_3 \cdot \max(a_1, a_2)))$$

$$\frac{\partial L}{\partial w_2} = y \frac{\sigma'(w_3 \cdot \max(a_1, a_2)) \frac{\partial (w_3 \cdot \max(a_1, a_2))}{\partial w_2}}{\sigma(w_3 \cdot \max(a_1, a_2))} + (1-y) \frac{(-\sigma'(w_3 \cdot \max(a_1, a_2)))}{1 - \sigma(w_3 \cdot \max(a_1, a_2))}$$

where:

$$\frac{\partial}{\partial w_2} w_3 \max(a_1, a_2) = \begin{cases} w_3 x_2 & \text{if } a_1 > a_2 \\ w_3 w_3 & \text{if } a_2 > a_1 \end{cases}$$

$$\therefore \frac{\partial L}{\partial w_2} = y \frac{\delta_1 \delta_2 \delta_3 \frac{\partial}{\partial w_2} (w_3 \max(a_1, a_2))}{\sigma(w_3 \cdot \max(a_1, a_2))} + (1-y) \frac{\delta_1 \delta_2 \delta_3 \frac{\partial}{\partial w_2} (w_3 \max(a_1, a_2))}{1 - \sigma(w_3 \cdot \max(a_1, a_2))}$$

c. (2 points) **Identifying ethical concerns** Consider a deep learning model trained on public GitHub repositories that can convert natural language instructions into code. On testing, it was discovered that it was possible to make the model output sensitive user information like SSH keys, database passwords, etc. Recall the NeurIPS Ethical Guidelines. Which of the following is the model likely in violation of? Select all that apply. No explanation required.

1. Directly facilitate injury to living beings
2. Contain any personally identifiable information or sensitive personally identifiable information
3. The dataset used has been discredited by the creators
4. Contain information that could be deduced about individuals that they have not consented to share

(2) (4) (1)

↑

∴ injury = financial or physical, both possible

↑  
bank accounts

↑  
powerstation

## 2. Search (17 points)

a. (6 points)

**Warm-up** Consider the following search algorithms as they were presented in this course:

A: DFS

B: BFS

C: DFS with iterative deepening

D: Dynamic Programming

E: UCS

For each of the following problems, you may assume that the state graph is acyclic.

- (i) [2 points] Suppose you would like to find the minimum cost path between two states  $s_1, s_2$ . You know that the cost function is a positive constant  $\alpha$  for every edge in the state-graph. Which algorithms can you use to find the optimal path? Select all that apply or None from A, B, C, D, E. No explanation is necessary.

(B) (C) (D) (E)

- (ii) [2 points] Now you know that the cost is a non-negative function. Which algorithms can you use to find the optimal path? Select all that apply or None from A, B, C, D, E. No explanation is necessary.

(A) (B) (C) (D) (E)

(iii) [2 points] You now know nothing about the cost, e.g. the cost is an arbitrary function that is bounded. Which algorithms can you use to find the optimal path? Select all that apply or None from A, B, C, D, E. No explanation is necessary.

(D)

b. (11 points)

**Encroaching the enemy territory** Samar is at the start position on a  $5 \times 5$  grid and wants to reach the goal position by avoiding the mountains along the way (see figure below). To make things harder for himself, he decides that he will never take the same action more than 3 times in a row. Samar decides to model this as a search problem where the actions are {left, right, down, up}. The cost for every legal step he takes is +1. If he tries to run into a wall or a mountain or repeats an action for a fourth time in a row, he incurs a cost of  $+\infty$  and the episode ends. Help Samar model the rest of the search problem and reach the enemy camp with the least cost path!

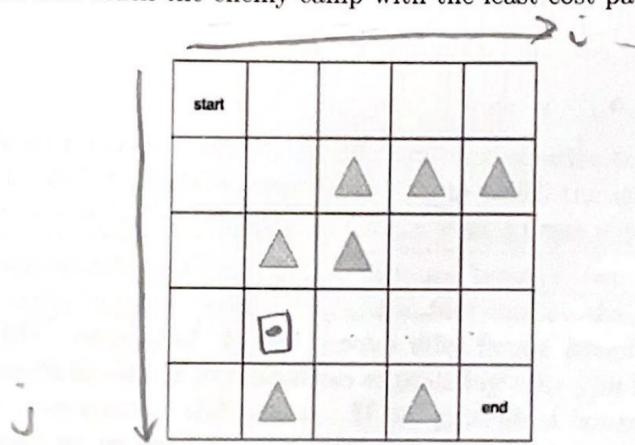


Figure 1: Samar's mission

- (i) [3 points] Clearly define a minimal necessary state representation for this problem as a tuple.

S: (position, numRepeatedSameAction)

where position = coordinate in the  $5 \times 5$  grid.

$$= (i, j)$$

numRepeatedSameAction = count of repeated same action

reset if current action  $\neq$  previous

- (ii) [3 points] Clearly define a successor function  $T(s'|s, a)$  (where  $s'$  is the next state,  $s$  is the current state, and  $a$  is the action taken) in the form of a piece-wise function. To simplify things, you can ignore the illegal actions (cases where Samar would run into a wall or a mountain or take an action for the fourth consecutive time).  
**Hint:** To simplify notation, assume the actions left, right, up and down can be encoded as tuples  $a = (a_1, a_2)$  as  $(-1, 0), (1, 0), (0, -1), (0, 1)$  respectively.

$$T(s'|s, a) = \begin{cases} (i+1, j) & \text{if } a = (1, 0) \text{ & numRepeteSameAction} < 3 \\ (i-1, j) & \text{if } a = (-1, 0) \text{ & "} \\ (i, j+1) & \text{if } a = (0, 1) \text{ & "} \\ (i, j-1) & \text{if } a = (0, -1) \text{ & "} \end{cases}$$

- (iii) [4 points] We wish to run  $A^*$  search to find an optimal solution to this problem. To find a heuristic, we define a relaxed search problem in which the mountains are removed and the infinite cost on repeating actions more than 3 times is removed.

In this relaxed search problem, the L1 distance between two points is the cost of the optimal path and is a potential heuristic function for the original problem. Is this heuristic consistent? If yes, prove why (your proof should be a clear written or mathematical explanation explaining why you think this heuristic satisfies the consistency definition). If no, provide a counter-example. Your answer should fit in the space provided below.

consist if  $\text{cost}'(s, a) = \text{cost}(s, a) + h(\text{succ}(s, a)) - h(s) \geq 0$

The optimal cost can never be less than L1 distance of the obstacles.

- $h(\text{succ}(s, a)) + h(s) = 0$  in relaxed condition & L1 distance
- Therefore  $\text{cost}(s, a) \geq h(\text{succ}(s, a)) - h(s)$
- ∴  $\text{cost}'(s, a) \geq 0 \therefore \text{consistent}$

- (iv) [1 point] Suppose you change the cost such that the cost for every legal step taken by Samar is  $c$ , where  $0 < c < 1$ . Is the L1 heuristic consistent in this setting? Provide a brief explanation as to why or why not.

No ∵ you can have very low cost such that  
not consistent  $\text{cost}'(s, a) \leq h(\text{succ}(s, a)) - h(s)$

suppose  $c = 0.00001 \times 100 \text{ steps} \Rightarrow \text{total cost} = 0.00$

$0.00 \leq L_1 \text{ distance}$

∴ inconsistent

### 3. MDPs and Reinforcement Learning (18 points)

a. (8 points) Debugging Q-learning Sharon wants to train a Q-learning model for her CS221 project but doesn't quite remember the algorithm. Assume an MDP with finite number of states and actions. **Sharon initializes her Q-value table with all 0s.** She remembers that the update rule is as given below but does not remember how to vary  $\epsilon$  and  $\eta$ . Remember  $\epsilon$  is from  $\epsilon$ -greedy and  $\eta$  is the learning rate. The exploratory policy/data-generating policy is  $\epsilon$ -greedy as we have seen in the lectures.

$$\hat{Q}_{opt}(s, a) \leftarrow (1 - \eta)\hat{Q}_{opt}(s, a) + \eta(r + \gamma \max_{a'} \hat{Q}_{opt}(s', a'))$$

She tries the following variations of the algorithm:

A: initialize  $\epsilon = 1$  and never decrease it during training.

B: initialize  $\epsilon = 0$  and never increase it during training.

C:  $\epsilon$  is initialized to 1 is decayed to 0 during training.

For each of parts i-iv, provide a brief (one-sentence) explanation.

- (i) [2 points] Sharon finds that **A** converges very slowly to  $Q_{opt}$ . What could be the cause of this slow convergence?

Because  $\epsilon=1$  means always try a random action which leads to very slow convergence.

- (ii) [2 points] Sharon finds that **B** does not converge to  $Q_{opt}$ . Why could this be?

Because  $\epsilon=0$  means that she never 'exploits' hence  $Q_{opt}$  doesn't converge to an optimal solution because she's not on an optimal trajectory/path that takes her to  $Q_{opt}$

(iii) [2 points] In which variations is the data-generating policy changing during the course of training? Select all that apply or **None** from **A, B, C**.

(C)

(iv) [2 points] For some MDP, say we know that  $Q^\pi(s, a_1) > V^\pi(s)$ . Which of the following is true? Select all that apply. Note: this part is unrelated to Sharon's experiments.

- (a) action  $a_1$  is the best action that can be taken in state A
- (b)  $\pi$  may be an optimal policy
- (c)  $\pi$  is not an optimal policy
- (d) None of the above

(D)

(iii) [2 points] In which variations is the data-generating policy changing during the course of training? Select all that apply or **None** from **A, B, C**.

(C)

(iv) [2 points] For some MDP, say we know that  $Q^\pi(s, a_1) > V^\pi(s)$ . Which of the following is true? Select all that apply. Note: this part is unrelated to Sharon's experiments.

- action  $a_1$  is the best action that can be taken in state A  
(a)  $\pi$  may be an optimal policy  
(b)  $\pi$  is not an optimal policy  
(c) None of the above

(D)

b. (10 points) **Constantly changing reward functions** Amrita lives in an MDP and wants to find the optimal policy. She uses value-iteration and finds an optimal policy  $\pi_{old}$  with a corresponding value function  $V_{old}$ . She wants to determine what happens if she adds a constant scalar  $C$  to all rewards in the MDP; to do this, she constructs a new MDP with the new reward function, and computes the optimal policy and value function  $\pi_{new}$  and  $V_{new}$ .

- (i) [5 points] Suppose that her MDP is infinite horizon, with a discount factor of  $\gamma$ . Find  $\max_{s \in \mathcal{S}} (V_{new}(s) - V_{old}(s))$  where  $\mathcal{S}$  is the set of all the states in the MDP. Show your work. We expect a mathematical derivation or an explanation.

**Hint:** The utility of a infinite horizon trajectory  $\tau = (s_1, a_1, r_1), (s_2, a_2, r_2), (s_3, a_3, r_3) \dots$  is  $r_1 + \gamma r_2 + \gamma^2 r_3 + \dots$

Value Iteration:  $V_{\text{on}}^t(s) \leftarrow \max_{\text{of Actions}} \sum T(s, a, s') \left[ \underbrace{\text{Reward}(s, a, s') + \gamma V_{\text{off}}^{t-1}(s')}_{Q_{\text{on}}^{t-1}(s, a)} \right]$  converges if  $\gamma < 1$

- (ii) [2 points] Is  $\pi_{new}$  the same as  $\pi_{old}$ ? Explain why or why not. Assume both policies are deterministic and we break ties in the same way in the new and old MDPs.

Yes, the polg is the same : adding a scalar to all actions doesn't change the relative reward between each action, so the polg still chooses the same actions in  $\pi_{old}$  &  $\pi_{new}$

(iii) [3 points] Would your answers to the previous parts change if the MDP was of *finite horizon*? Explain why or why not.

**Hint:** Recall that a finite horizon MDP is one in which trajectories are no longer than some length  $T \in \mathbb{Z}^+$ . You also do not need to re-derive your answer from part (i).

Yes because of the discount factor,  
we then add more weight to present  
actions which may change the policy  
vs. an infinite horizon problem.

#### 4. Games (18 points)

a. (4 points)

**Zero-sum or not?** For each of the following scenarios, state whether it can be represented as a zero-sum game. Answer "yes" or "no", and give a brief (1-2 lines) explanation.

- (i) [2 points] **Heads up Holdem:** You are playing a game of poker against an opponent. If you win the current round, you win the money in the pot, but if you lose, your opponent gets the money in the pot. Both players want to maximize their earnings.

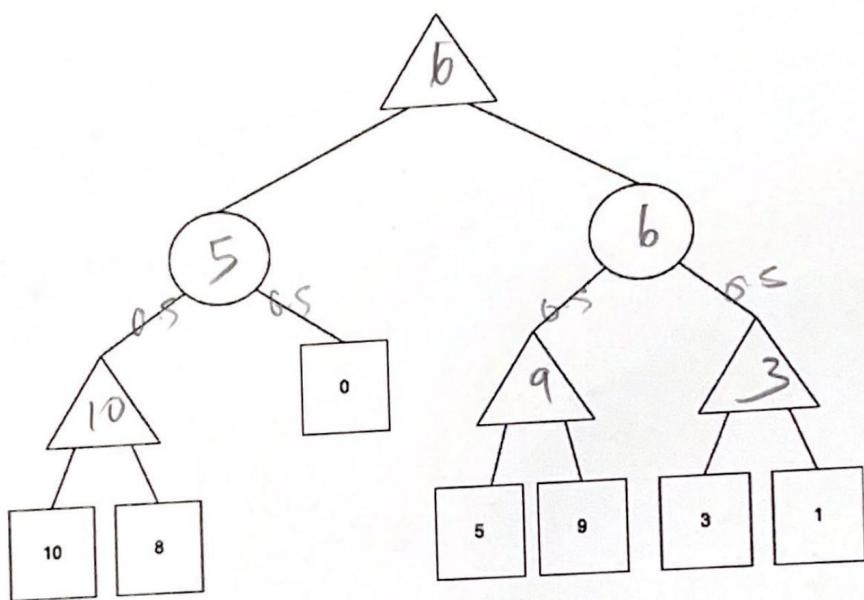
Yes : the pot is shared rewards between each player. If my opponent wins = corresponding loss of the same amount of reward for me.

- (ii) [2 points] **Autonomous Driving:** Two cars are driving next to one another, and are each trying to merge into the lane ahead of the other (without crashing into one another). Each car has two available actions: merge, or wait. If both cars merge, a crash occurs (resulting in a large negative utility). If one car merges and the other waits, the merged car gets a utility of 10 and the waiting car gets a utility of -10. If both cars wait, they both get a utility of 0.

Prisoner dilemma equivalent

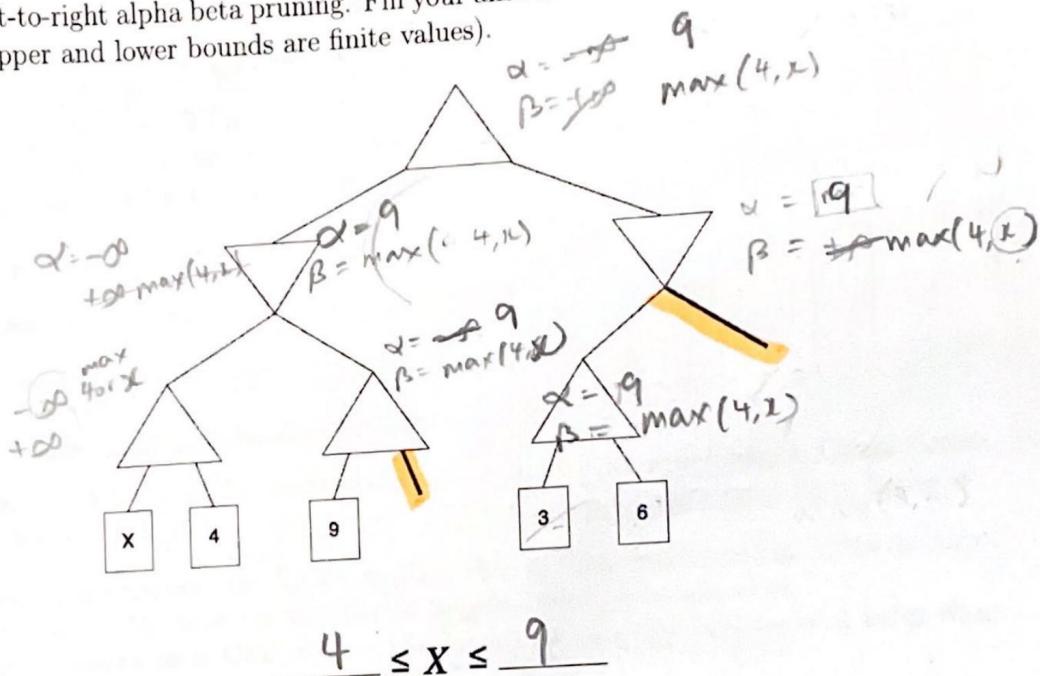
∴ No not zero sum

b. (6 points) Expectimax Consider the following Expectimax game. Suppose that the chance nodes (circle) play the left and right actions with 0.5 probability each. Fill in the values of the maximizer (triangle) and chance (circle) nodes in the figure below.



c. (6 points) Alpha-beta pruning

• (6 points) Alpha-beta pruning  
Consider the following minimax game tree, in which the top node is a maximizer. Determine the range of values for X which could result in the red edges being pruned by left-to-right alpha beta pruning. Fill your answer in the provided blanks (hint: both the upper and lower bounds are finite values). 9



d. (2 points) **Wicked Problems** Recall that problems that have multiple, potentially conflicting objectives, a high degree of uncertainty and risk, and stakeholder disagreement about what would count as a solution to the problem are sometimes called "wicked problems." Another characteristic of wicked problems is that each attempt to solve them has consequences for people at the time it is made, even if another choice is made later. Which of the following are wicked problems? (1)(3)  
Select all that apply. No explanation required.

1. Mitigating homelessness in California
  2. Developing an agent to play Pac-Man
  3. Assigning vaccine priority for Covid-19
  4. Creating an optimal chip layout for a circuit board using a simulator

## 5. Constraint Satisfaction Problems (10 points)

a. (10 points) **Sam and his Sorting CSP** Sam is the new headmaster at Hogwarts and is in charge of splitting the students into houses. However, Hogwarts has expanded and now there are more than just the 4 traditional houses – there are now  $H$  houses  $X_1, X_2, \dots, X_H$  and  $N$  students at Hogwarts. Alice (A), Bob (B), Candice (C), David (D) and Ed (E) are a part of the new cohort of  $N$  students at Hogwarts and must be sorted into houses. To add to the problem, Sam needs to adhere to some constraints specified by the school and some students as given below:

1. Every house must have at-least one student. ✓
2. No house can have more than  $K$  students. ✓
3. Every student must be assigned exactly one house. ✓
4. Bob and David must be in the same house.
5. Candice must be in the house right-after Alice i.e. if Alice is in house  $h$ , Candice must be in house  $h + 1$ . If Alice is in the last house  $H$ , then Candice must be in house 1. *wap*

This problem seems too complex for the Sorting Hat, so Sam decides to model the problem as a CSP and assign the students to different houses.  
**Model the problem as a CSP where the variables are the houses and help Sam find the optimal assignment in the CSP.**

- (i) [2 points] What is the domain of each variable in the CSP? Write it in English or as a set.

*Hint: Don't worry about enforcing any constraints here, we will do that when we define factors.*

$$\text{Domain} = \{s_1, s_2, \dots, s_N\}$$

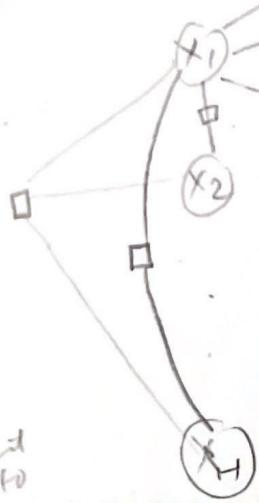
*where  $s$  is a student*

(ii) [8 points] Express the constraints as factors on the variables. You are allowed to use only one n-ary factor. All your other factors must be unary / binary.

Hint: There may be several correct answers.

let  $i = 1 \dots H$

every student assigned to 1 house



$$f_1(x_i) = 1[x_i \geq 1]$$

$$f_2(x_i) = 1[x_i \leq K]$$

$$f_4(x_i) = 1[\exists [B \in X_i \wedge D \in X_i] \vee \exists [B \in X_i \vee D \in X_i]]$$

every house must have  
at least 1 student

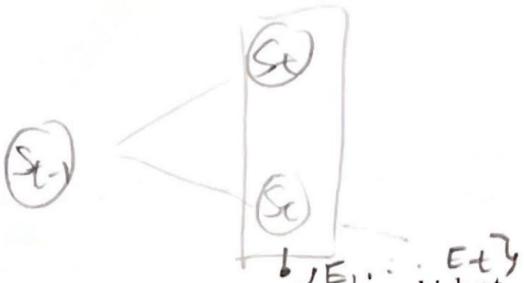
no house can have  
more than K students

Bob & David in same  
house or not

$$f_5(x_i, x_{i+1}) = 1[1[c \in X_i \wedge A \in X_i] \vee 1[A \in X_i \wedge C \in X_{i+1}] \vee 1[C \in X_i \vee A \in X_{i+1} \vee C \in X_{i+1} \vee A \in X_i]]$$

$$f_3(x_1, x_2, \dots, x_H) = 1[1[s_1 \in X_1 \oplus s_2 \in X_2 \oplus \dots \oplus s_N \in X_H] \wedge 1[s_2 \in X_1 \oplus s_3 \in X_2 \oplus \dots \oplus s_2 \in X_H] \wedge \dots \wedge 1[s_N \in X_1 \oplus s_N \in X_2 \oplus \dots \oplus s_N \in X_H]]$$

## 6. Bayes Nets (23 points)



### a. (8 points) Bayes' Casino

Suppose you are in a casino and have been observing the behavior of a slot machine, which at timestep  $t$  has a true state of  $S_t$ , whose distribution only depends on  $S_{t-1}$ . Your observations have resulted in a set of evidence variables  $E_1, \dots, E_t$ . You know the distribution  $P(E_i|S_i)$ .

For each of the following questions, **No explanation is required.**

- (i) [2 points] **True or false?** This situation can be modeled as a Hidden Markov Model (HMM).

True.

- (ii) [2 points] Suppose you wish to answer the query  $P(S_t | E_1, \dots, E_t)$ . What type of query does this correspond to?  
*up to current timestep*

- (A) Smoothing  
(B) Filtering  
(C) None of the above

(B)

- (iii) [2 points] Suppose you wish to answer the query from the previous question. Which of the following algorithms will guarantee you to answer the query **exactly**?

- (A) Gibbs sampling with finite number of iterations. *approx*  
(B) Forward-backward algorithm *exact*  
(C) Particle filtering with finite number of iterations. *approx*  
(D) None of the above

(B)

(iv) [2 points] Your friend has a crystal ball and tells you what  $E_{t+5}$  will be. Suppose you wish to again find the distribution of  $S_t$  given this new piece of information, and your observations up till time  $t$ . What type of query does this correspond to?

- (A) Smoothing
- (B) Filtering
- (C) None of the above

(A)

: incorp future evidence.

b. (13 points) **Bayesian Sports** You and your friend are fans of the Golden State Warriors and wish to predict the outcome of playoff games. In order to achieve this, you decide to model a Warriors game's outcome with a Bayesian Network with the following variables:

- $H \in \{0, 1\}$ : whether the game is being played at home ( $H = 1$ ) or away ( $H = 0$ ).
- $C \in \{0, 1\}$ : whether Steph Curry scores more than 30 points.
- $R \in \{0, 1\}$ : whether refs are helping the Warriors ( $R = 1$ ) or their opponents ( $R = 0$ ). *haha*
- $O \in \{0, 1\}$ : whether the Warrior's offense plays well or not.
- $D \in \{0, 1\}$ : whether the Warrior's defense plays well or not.
- $W \in \{0, 1\}$ : whether the Warriors win the game or not.

With these variables, you model this situation with the following Bayesian Network:

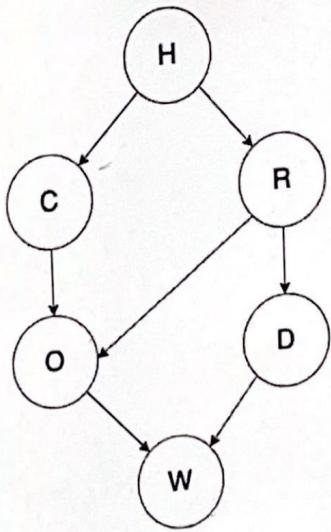
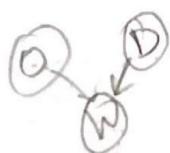


Figure 2: Bayes Net used to model the outcome of a GSW Playoff Game

Assume that offense and defense both positively impact winning (e.g.,  $P(W = 1|O = 1) \geq P(W = 1|O = 0)$  and  $P(W = 1|D = 1) \geq P(W = 1|D = 0)$ ).

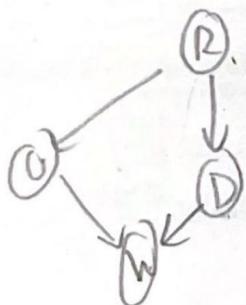
- (i) [2 points] True or false?  $P(O = 1|W = 1) \geq P(O = 1|W = 1, D = 1)$ . Explain your answer briefly (one sentence).



True :: explaining answer

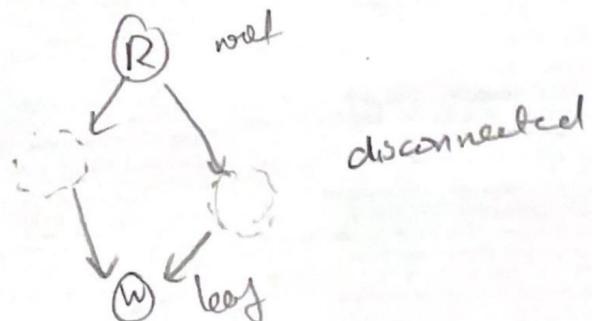
- (ii) [3 points] You now want to examine the impact the ref can have by siding with the Warriors. Suppose you know that both the offense and defense play well (e.g., you know  $O = 1$  and  $D = 1$ ). Given this evidence, will knowledge of  $R$  (whether the ref will help the Warriors) affect the distribution over whether the Warriors win the game? State yes or no, and explain your answer briefly.

Hint: this question is asking whether  $(W \perp\!\!\!\perp R)|O, D$ .



condition on  $O, D \Rightarrow$

does knowing  $O, D$   
tell me something about  
 $R, W$ ?



True that  $(W \perp\!\!\!\perp R) \parallel O, D$ ,  
ie knowing  $R$  won't affect  
whether warriors win  
-; disconnected graph when  
conditioned on  $O \& D$

Suppose now you do not care about whether the Warriors win and only want to analyze the performance of the Warrior's offense and defense. You remove the  $W$  variable and define a new Bayes Net:

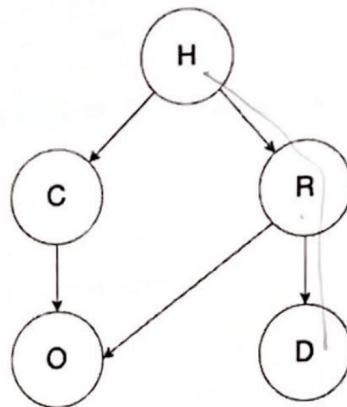


Figure 3: New Bayes Net to model the performance of the offense and defense.

The defense is playing well and you want to determine if the refs have been favoring the Warriors and if the Warriors are playing at home, e.g. you wish to compute  $P(R, H | D = 1)$ . To do this, you define the following Markov Network. The tables denotes the values of the factors in terms of  $\alpha, \beta, \theta$  which are known to you.

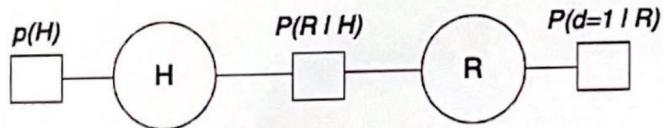


Figure 4: Markov Net for parts (ii) and (iii).

$P(H)$	$P(R   H)$	$P(D   R)$
$h \quad p(h)$		
0 $1 - \alpha$	$r \quad 0 \quad 1$	$d \quad 0 \quad 1$
1 $\alpha$	0 $\beta \quad 1 - \beta$	r 0 $\theta \quad 1 - \theta$
	1 $1 - \beta \quad \beta$	1 $1 - \theta \quad \theta$

Table 1: The parameters of the Markov Network in Fig. 4.

You realize that you have no idea what values for  $\alpha, \beta, \theta$  are, and decide to collect data to estimate them. However, your data collection assistant is careless and forgets to record values for whether the games were played at home or not. However, you have learned the EM algorithm from CS221 and decide to use that the EM algorithm to estimate the parameters. The table below shows your dataset.

$i$	$h_i$	$r_i$	$d_i$
1	?	1	1
2	?	1	0
...	...	...	...
100	?	0	1

Table 2: The dataset  $\mathcal{D}$  containing 100 sample dishes.

- (ii) [4 points] **E-Step:** In our situation, the E-step will compute the posterior probability  $q_i(h) = \mathbb{P}(H = h | R = r_i, D = d_i)$  for each  $i \in \{1, 2, \dots, 100\}, s \in \{0, 1\}$ . Compute  $q_1(1)$ , expressing your answer in terms of  $\alpha, \beta, \theta$  (i.e., your current estimates). Show your work.

$q_1(1)$

$h$	$r$	$d$	$P$
0	1	1	$\alpha(\beta)(\theta)$
1	1	1	$(1-\alpha)(1-\beta)(\theta)$

$$q_1(1) = \frac{\alpha(\beta)(\theta)}{(1-\alpha)(\beta)(\theta) + \alpha(1-\beta)(\theta)}$$

$$\therefore q_1(1) = \frac{\alpha\beta}{(1-\alpha)\beta + \alpha(1-\beta)}$$

- (iii) [4 points] M-Step: Having computed the values of  $q_i(h)$ ,  $i \in \{1, 2, \dots, 100\}$ ,  $s \in \{0, 1\}$  from the E-step, what is the value of  $\alpha$  after the M-step, expressing your answer in terms of  $q_i(h)$ ? Show your work.

M step = count & normalize

$$\alpha = \frac{q_i(h) \times \# \text{times } (r_i=1 \wedge d_i=1) \text{ occurs in evidence}}{q_i(h) \times \# \text{times } (r_i=1 \wedge d_i=1) \text{ occurs} + (1 - q_i(h)) \times \# \text{number of times } (r_i=1 \wedge d_i=1) \text{ occurs}}$$

- c. (2 points) **Household Robotics** A robotics company has created a new household robot that can help people with chores at home like washing dishes and cleaning, cooking, etc. However, the company doesn't get approval to test their robot in California. To test their robot, they decide to test it in another country where fire safety laws are not as strict. What ethics concept that you learned in this course would this choice be in violation of, and why?  
What we expect: Your answer should be 1-2 sentences and should clearly name the relevant concept, explain why it is in violation in a way that makes it clear that you understand what the concept is.

Ethics Dumping: the company deliberately & knowingly chose to get approval in a state whose regulation are less strict to evade the fact that their approval was rejected.  
If there were just cause for that rejection eg. beach safety standards, privacy standards etc  
then this is unethical.

## 7. Logic (18 points)

- a. (8 points) **Knowledge Bases** Consider a setting with four propositional symbols: Healthy, Fatigue, Flu, and Fever. Let your current knowledge base be:

$$KB = \{\text{Fatigue} \rightarrow \neg\text{Flu}, \text{Fever} \wedge \text{Flu}\}$$

You are asked by the CDC to update the knowledge base with some new formulas, but the CDC would like to know how the new formulas will change the set of models representing the knowledge base. For each of the following questions, **no explanation is required**.

- (i) [3 points] First the CDC would like to know if the knowledge base is satisfiable. True or false: The knowledge base is satisfiable.

Satisfiable if  $M(KB) \neq \emptyset$

True.

- (ii) [2 points] CDC researcher Sharan gives you the following new formula to compare with your knowledge base:  $f_1 = \text{Fatigue} \vee \text{Healthy}$ . Which of the following are true? Circle all that apply.

- (a) KB entails  $f_1$  ✗
- (b) KB contradicts  $f_1$  ✗
- (c)  $f_1$  is consistent
- (d) None of the above

③ adds new info

$$\neg \text{Fatigue} \vee (\neg \text{Flu}, \text{Fever} \wedge \text{Flu})$$

- (iii) [3 points] The CDC now gives you a new knowledge base:

KB = {Headache,

Headache  $\wedge$  Fatigue,

Headache  $\wedge$  Fatigue  $\rightarrow$  Fever,

Fever  $\wedge$  Headache  $\wedge$  Fatigue  $\rightarrow$  Flu

Flu  $\rightarrow$  False}. Which of the following statements are true? Circle the correct answer.

(a) Modus ponens is sound on the given KB, but not necessarily complete.

(b) Modus ponens is complete on the given KB, but not necessarily sound.

(c) Modus ponens is sound and complete on the given KB.

(d) Modus ponens is neither sound nor complete on the given KB.

(D)

sound  $\sqsubseteq$   
complete  $\supseteq$

H	Fat	Fever	Flu
1	0	1	0
1	1	1	1
0	1	1	1

Flu  
0  
1  
0  
contradict

b. (8 points) **Conjunctive Normal Form (CNF)** Modus ponens asserts that if we have two formulas,  $AB$  and  $A$  in our knowledge base, then we can derive  $B$ . Resolution asserts that if we have two formulas,  $A \vee B$  and  $\neg B \vee C$  in our knowledge base, then we can derive  $A \vee C$ . If  $A \wedge B$  is in the knowledge base, then we can derive both  $A$  and  $B$ .

**Hint:** For some of the questions, consider expressing  $A \rightarrow B$  in other ways.

- (i) [2 points] Your friend Skanda can only read first order logic and needs your help to convert an English sentence into first order logic. Let us consider the following formulas:  $Student(x)$  means  $x$  is a student,  $Classroom(x)$  means  $x$  is a classroom,  $Safe(x)$  means  $x$  is safe, and  $Wears(x, mask)$  means  $x$  wears a mask. Select the correct conversion(s) of the following English sentence into a first order logic formula. Circle all that apply.

"None of the classrooms are safe if not all students wear masks."

- (a)  $(\forall s Student(s) \wedge \neg Wears(s, mask)) \rightarrow (\forall c Classroom(c) \rightarrow \neg Safe(c))$
- (b)  $(\exists s Student(s) \wedge \neg Wears(s, mask)) \rightarrow (\exists c Classroom(c) \wedge \neg Safe(c))$
- (c)  $(\exists s Student(s) \rightarrow \neg Wears(s, mask)) \rightarrow (\forall c Classroom(c) \wedge \neg Safe(c))$
- (d)  $(\exists s Student(s) \wedge \neg Wears(s, mask)) \rightarrow (\forall c Classroom(c) \rightarrow \neg Safe(c))$

(D)

- (ii) [2 points] You are given the symbols  $A, B, C, D$ . Convert the following formula to conjunctive normal form (CNF):  $(A \wedge B) \rightarrow (C \wedge D)$ .

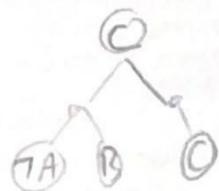
$$\begin{aligned} & \neg(A \wedge B) \vee (C \wedge D) \\ &= (\neg A \vee \neg B) \vee (C \wedge D) \end{aligned}$$

- (iii) [4 points] Suppose the knowledge base contains the following two formulas:  $\text{KB} = \{(A \vee B) \rightarrow C, A\}$ . Convert the KB into CNF and then apply modus ponens to derive  $C$ . Show how the KB changes as you apply the derivation rules.

$$A \vee B \rightarrow C$$

$$\begin{aligned} & A \\ &= \neg(A \vee B) \vee C \quad \text{so } \text{KB} = \{\neg A \wedge B \vee C, A\} \\ &= \neg A \wedge B \vee C \end{aligned}$$

modus ponens .  $\frac{A, \neg A \wedge B \vee C}{C}$



c. (2 points) **Dual-use technologies** Recall that dual-use technologies are technologies that serve two purposes, typically a military and a civilian purpose. In the car-tracking assignment, we saw how a Bayes Net-based tracking system could be used for lethal secondary uses. Give an example of another dual-use AI-based technology related to what we learned in this course (e.g. a technology that includes AI or machine learning). Clearly specify how this technology could be used for both civilian and military purposes. **What we expect:** Your answer should be 2-3 sentences and should (a) clearly describe a specific algorithm or AI-based technology related to what we learned in this course and (b) mention one civilian use and one (actual or plausible) military use of this technology.

The Search & MDP techniques can be considered dual use. In civilian application they can be used for guidance i.e. navigation from starting point A → desired end point B e.g. Google Maps. Simultaneously, such techniques are already used in military application for path planning & guidance of autonomous/semi-autonomous vehicles in air, land, sea - to move the vehicle to an 'enemy' location to conduct offensive capabilities e.g. 'suicide' loitering drones, or UGVs with remote weapon systems.