Queen Mary
University of London

January Examination Period 2024

ECS759P Main ARTIFICIAL INTELLIGENCE Duration: 2 hours (+1 for uploads)

Answer FOUR questions

You MUST adhere to the word limits, where specified in the questions. Answer text beyond the word limit will not be marked.

This paper requires **two hours work**. There is an extra hour allowance for downloading the paper and uploading your answers.

You MUST submit your answers before the exam end time.

You must follow the online exam guidelines and instructions on the EECS exam access and submission page.

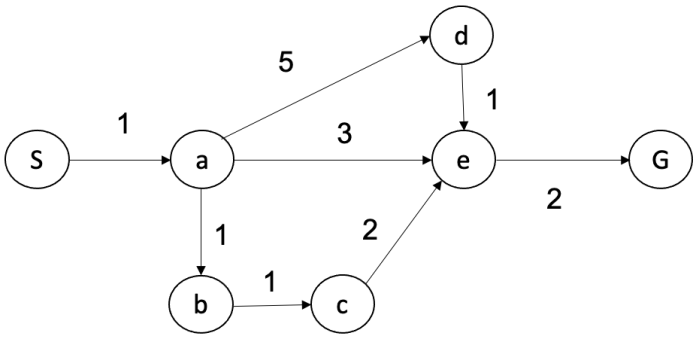
This is an open-book exam. You may use lecture notes and any module materials made available to you (online or physical). You must not use other online resources.

YOU MUST COMPLETE THE EXAM ON YOUR OWN, WITHOUT CONSULTING OTHERS.

Examiners:
Dr. Julia Ive and Dr. Paulo Rauber

Question 1

You are given the state space as shown below.



S is the Initial State, G is the Goal State. The number associated with an edge represents the path cost from one state to another of that edge.

(a) Using Depth-First Search to find a path from S to G, what are the first 3 states expanded? (There is more than one correct answer. Just give one possible answer).

[3 marks — word limit 3]

(b) Using Breadth-First Search to find a path from S to G, what are the first 4 states expanded? (There is more than one correct answer. Just give one possible answer).

[3 marks — word limit 4]

(c) (i) Execute A* search to find a path from S to G. Show your work including the order of state expansion and the agenda at each step using the **admissible** heuristic h_1 from the table below. Write exactly one expansion step per line in your answer, indicating each state and the costs at that state in the agenda as *StateName*(g, h, f), for example, C(2,5,7). *StateName* is the name of the state; (g, h, f) denotes the "past" cost, the "future" cost (i.e. the heuristic value), and the total cost, respectively.

(ii) What are the path and its cost found by the A* search algorithm?

node	h_1	h_2
S	6	6
a	5	5
b	5	4
c	4	2
d	2	1
e	2	1
G	0	0

[8 marks — word limit 50]

(d) Consider heuristic h_2 from the table above. It indicates the "future" cost to goal (h value) for each node in the search graph above.

Is heuristic h_2 admissible? Show all work by computing the actual least path costs from each node to the goal G (h^*) and comparing each of those costs to the respective heuristic values at each node.

[7 marks — word limit 50]

(e) Explain why A* search always finds the optimal path from S to G for this search problem using heuristic h_1.

[4 marks — word limit 50]

Question 2

Consider an iterated Prisoner's Dilemma. Two players are arrested and isolated from each other. There is no sufficient evidence for a conviction. The players are proposed the following options:

1. If both refuse to testify, they both receive a moderate sentence.
2. If one prisoner testifies against another, the betrayer goes free and the other one receives a severe sentence.
3. If both prisoners testify against each other, they both receive a moderately severe sentence.

The payoff matrix is provided as follows:

	P1: Testify	P1: Refuse
P2: Testify	P1: 1, P2: 1	P1: 0, P2: 5
P2: Refuse	P1: 5, P2: 0	P1: 3, P2: 3

The game is played over 6 rounds.

The sequence of actions for Player 1 is fixed (always the same): Refuse, Testify, Refuse, Testify, Refuse, Testify.

The goal is to find an optimal sequence of actions for Player 2 which will optimise the player's profit.

(a) You want to use a Genetic Algorithm to solve the problem. As the fitness function, you use the average payoff across six rounds for Player 2 (the higher the better).

(i) Give a state representation for this problem.

(ii) Give the chromosome and fitness value for Player 2 assuming that Player 2 plays the Hawk strategy (a player who always testifies).

[4 marks — word limit 70]

(b) Give the chromosome and fitness value for Player 2 assuming that Player 2 plays the Tit-For-Tat strategy (a player initially refuses to testify and subsequently mirrors the opponent's previous move).

[4 marks — word limit 50]

(c) Two parents from Part (a) and (b) above are chosen for crossover to produce two offsprings (c-i) and (c-ii). Apply 2-point crossover at the two following crossover points:

- between bits 1 and 2;
- between bits 4 and 5.

Note that bits start at index 0.

Give the chromosomes and the fitness scores of (c-i) and (c-ii).

[6 marks — word limit 50]

(d) Given the chromosomes from Part (a) and Part (b) above, explain why crossover could be not enough to explore the entire search space described by this representation. Give a detailed explanation of how this problem can be solved.

[5 marks — word limit 100]

(e) To produce the next generation of population, you decide to carry out fitness proportional selection from the pool of individuals, including: (c-i) and (c-ii) (from Part c).

As part of the selection process, you generate a set of random numbers in the range $[0, 1]$. In this case, two following numbers $(0.30, 0.85)$ are generated in order for (c-i, c-ii), respectively.

(i) Calculate the selection probabilities for each individual in the pool.

(ii) Describe how you will use the generated random numbers to select individuals for the next generation.

(iii) Report the selected individuals.

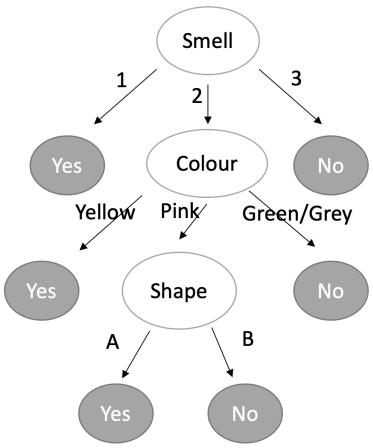
[6 marks — word limit 100]

Question 3

You are given the following training data.

Shape	Colour	Smell	Poisonous
A	Pink	1	Y
B	Pink	1	Y
B	Yellow	1	Y
B	Yellow	2	Y
A	Pink	2	Y
B	Pink	2	N
B	Green	2	N
A	Grey	2	N
A	Pink	3	N
A	Yellow	3	N
B	Yellow	3	N

They are used to learn a decision tree shown below for predicting whether a berry is poisonous or not based on its shape, colour and smell.



(a) (i) Which attribute is at the root of the tree?

(ii) Provide a test set of two examples which the tree above will classify with the accuracy of 50%.

[7 marks — word limit 50]

(b) Compute the initial entropy of the training set and the information gain after partitioning this training set according to the attribute Smell.

[6 marks — word limit 150]

(c) The table below contains some observations of BMI and whether the person has diabetes or not.

BMI	Diabetes
27	no
28	no
29	no
31	yes
35	yes
39	no
40	yes

(i) Which thresholds of BMI will be chosen by ID3 algorithm as possible split points for a classifier to predict diabetes?

(ii) Compute the information gain for the lowest threshold of BMI. Show all work.

[6 marks — word limit 150]

(d) Convert the two logical sentences below into conjunctive normal form (CNF), showing all work. Report all the steps (state "nothing to do" for the steps where this is the case).

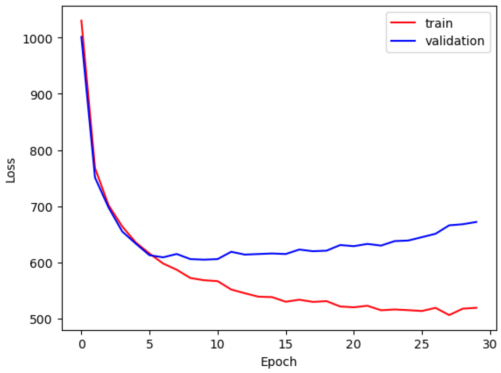
(i) $\exists x.\forall y.\exists z.P(x, y, z)$

(ii) $\forall x.(\forall y.P(x, y) \rightarrow \exists z.R(x, z))$

[6 marks — word limit 100]

Question 4

(a) Consider the plot below showing the curves of the training and validation losses for a classification problem. Consider the case when we will re-train exactly the same network but with ten times as much training data.



(i) Do you expect the training curve to be different?

(ii) Do you expect the validation curve to be different and if so how?

[3 marks — word limit 30]

(b) Explain how the backpropagation algorithm computes the following given a training example:

(i) Observed error.

(ii) Partial derivatives with respect to the output layer weights.

(iii) Partial derivatives with respect to the hidden layer weights.

In (ii) and (iii) use the notion of delta values. Use no more than five sentences and describe formulas with words.

[5 marks — word limit 150]

(c) Given a single perceptron with inputs x_i for $1 \leq i < 3$, where $x_3 = 1$ is the bias, initial weights $w_1 = w_2 = w_3 = 1$, learning rate $\alpha = 0.25$ and the step activation function:

$$g(s) = \begin{cases} 1, & s > 0.5 \\ 0, & s \leq 0.5, \end{cases}$$

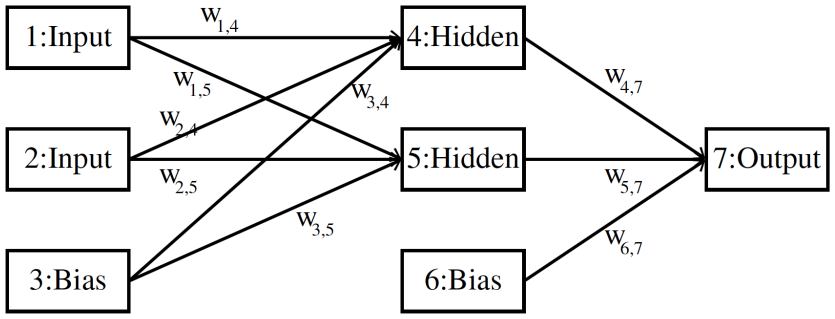
use the perceptron training algorithm for the following table of training examples.

x_1	x_2	Output
-1	2	1
3	-1	0
1	2	0
3	1	1

What will be the values of weights w_1, w_2 and w_3 after the first update (which is performed after the first incorrect output)?

[5 marks — word limit 50]

(d) You are given the following neural network with 3 inputs (1 of which is bias), 2 hidden units, 1 additional bias unit and 1 output unit. All the hidden and output units use the sigmoid activation function.



Initial weights are shown below:

$w_{1,4}$	$w_{1,5}$	$w_{2,4}$	$w_{2,5}$	$w_{3,4}$	$w_{3,5}$	$w_{4,7}$	$w_{5,7}$	$w_{6,7}$
0.2	0.1	0.4	0.3	0.8	-0.4	0.1	-0.1	0.1

The formulas for the sigmoid function and its derivative:
$g(x) = \frac{1}{(1+e^{-x})}$
$g'(x) = g(x)(1 - g(x))$
Given a training example with $\text{Input}_1 = \text{Input}_2 = 1$, $\text{Bias}_3 = \text{Bias}_6 = 1$ and Output = 1, calculate the activations of nodes 4, 5 and 7.

[6 marks — word limit 100]

(e) Given the outputs from (d), calculate the delta values Δ_7 and Δ_4 for backpropagation. Using these delta values and a learning rate of $\alpha = 1$, calculate the updated value of the weight $w_{1,4}$.

Update function for individual weights:

$$w_{i,j} = w_{i,j} - \alpha a_i \Delta_j$$

where:

$$\Delta_j = (y' - y)g'(\sum_k w_{k,j}a_k) \quad \text{for output layer}$$

$$\Delta_j = g'(\sum_k w_{k,j}a_k)\sum_i w_{j,i}\Delta_i \quad \text{for other layers}$$

where j indicates the current node, y' – is the network output for the training example, y – is the target output for the training example, k – indices of the incoming connections, i – indices of the outgoing connections.

[6 marks — word limit 60]

End of questions