HERIOT WATT UNIVERSITY

SCHOOL OF MATHEMATICAL AND COMPUTER SCIENCES

Department of Computer Science

F21BC

Biologically-Inspired Computation

Semester 1 2022/23

Duration: Two Hours

ANSWER THREE OUT OF FOUR QUESTIONS

Total of 60 marks

Q1

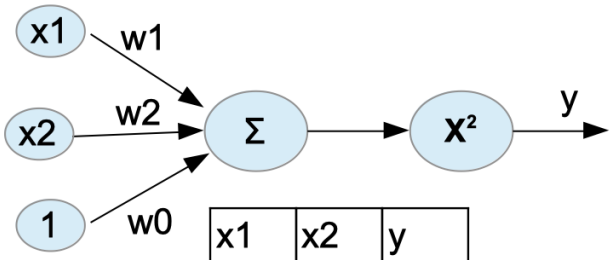
(a) Please explain the role of forward pass and backward pass when training a neural network. (4 marks)

(b) Consider the single perceptron. If we modify the activation function to be $f(x)=x^2$, as shown in the below figure, we can model the XOR problem with this perceptron.

(i) What is the role of w0? (2 marks)

(ii) Please give the values of w1, w2, and w0. (3 marks)

(iii) What would be the issue of this activation function if we use gradient descent to train this perceptron? (3 marks)



x1	x2	y
0	0	0
0	1	1
1	1	0
1	0	1

(c) Explain when sigmoid function will suffer from gradient vanishing problem when it is used as an activation function in neural networks. Please also use figures or mathematical analysis to support your explanation.

(4 marks)

(d) You are training a multilayer perceptron using backpropagation for a binary classification problem.

You first set the learning rate to be 0.0005. During the first 10 epochs you find that the loss curve (the value of the loss function along with the epochs) is decreasing, but it is decreasing very slowly. At the same time, the classification accuracy is around 60%.

You then change the learning rate to be 0.001 and retrain the network. This time you find that during the first 10 epochs the loss curve is decreasing faster compared to the previous case. At the same time, you find that the classification accuracy is still not high (around 65%).

Finally, you change the learning rate to be 0.1, and this time you find that the loss curve goes up and down dramatically with the accuracy changing from 40% to 60%). Please explain all the above phenomena and propose how you would adjust the learning rate to further improve the accuracy. (2 marks for explaining the phenomena and 2 marks for possible solutions).

(4 marks)

Q2

(a) Are the following statements true or false? **Give your explanations**.

(i) Deep Neural Networks are the only deep learning architecture. (2 marks)

(ii) Deep Learning can perform both supervised and unsupervised learning tasks. (2 marks)

(iii) Back Propagation can be used to train Recurrent Neural Networks. (2 marks)

(b) In a convolutional neural network, suppose there are 6 filters of size 3 x 3 and stride 2 (the step size of the filter) in the first layer. If an input of dimension 15 x 15 x 3 is passed through this layer, what are the dimensions of the data which the next layer will receive? Please present the details of your calculation. (2 marks for the result, and 4 marks for the details of calculation)

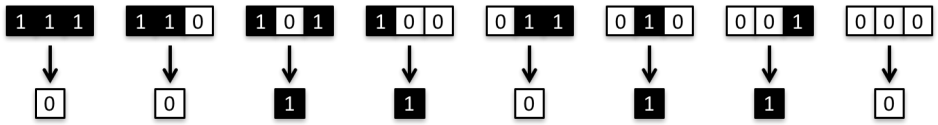
Note: the input dimension 15 x 15 x 3 means the input images have three channels (RGB), and the convolution operation needs to be adapted to the three channel situation. (6 marks)

(c) The use of a population has been central to the success of Evolutionary Algorithms and other bio-inspired optimisation methods. Explain why the population based approaches as used in evolutionary algorithms can normally outperform running multiple local search processes in parallel. Please draw fitness landscapes to help your explanation. (3 marks)

(d) You are asked to design a neural network to solve a non-linear problem (the data cannot be classified by a linear classifier properly). You are only allowed to use linear activiation function (i.e. y=c*x, where c is a non zero constant, x is the input to the linear function, and y is the output of the linear function). However, you are allowed to have up to 10 hidden layers, and for each layer you are allowed to choose different values of “c” for the linear activation function. Please explain if you can design such a neural network to solve the non-inear problem. Please use mathematical analysis to support your explaination. (5 marks)

Q3

(a) Rule 54 is an elementary cellular automata rule, defined as follows:



(i) Why is it called “Rule 54”?

(2 marks)

(ii) In what sense is it “elementary”?

(2 marks)

(iii) Using Rule 54, complete the space-time diagram shown below by giving the sequence of 0s and 1s that should appear in each of the rows shaded in grey. Note that this cellular automata has periodic boundary conditions.

0	0	0	0	0	0	1	0	0	0	0	0	0
0	0	0	0	0	1	1	1	0	0	0	0	0
?	?	?	?	?	?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?	?	?	?	?	?

(4 marks)

(b) In terms of their ability to express computational behaviours, would you say that elementary CAs are more expressive, less expressive, or equally expressive as the Game of Life? Explain why. (4 marks)

(c) CAs are one example of a computational system with the kind of emergent behaviour seen within biological systems. Explain what is meant by *emergent*, and also give an example of emergence within another biologically-inspired computing model. (4 marks)

(d) Another example of a biological phenomenon seen within biologically-inspired computation is stigmergy. Indicate what is meant by *stigmergy*, and explain how it is used within the Ant Colony Optimisation algorithm. (4 marks)

Q4 Genetic Programming (GP) is a kind of evolutionary algorithm that is used to automatically generate computer programs, or other executable structures.

(a) Why is *representation* an important topic in GP? (4 marks)

(b) How does the solution representation used in Koza-style GP differ from the solution representation used in Grammatical Evolution (GE)? What advantages, if any, does the solution representation used in GE have over that used by Koza-style GP? (4 marks)

(c) What is Genetic Improvement? In what ways does it differ from other forms of GP? (4 marks)

(d) What are the main ways in which a multi-objective evolutionary algorithm (MOEA) differs from a standard evolutionary algorithm? Do you think it would be useful to use an MOEA for GP? Explain why. (4 marks)

(e) Many of the representations used in GP are not particularly biologically-inspired. What might be the potential advantages and disadvantages of using representations that are more biologically-inspired, such as cellular automata and gene regulatory models, to express computational behaviours within a GP context? (4 marks)

END OF PAPER