UNIVERSITY OF BRISTOL

SAMPLE PAPER Examination Period

FACULTY OF ENGINEERING

M Level Examination for the Degree of Master of Engineering / Masters of Science

COMSM0094-A
Learning, Computation and the Brain

TIME ALLOWED:
2 hours

This paper contains *two* parts.
The first section contains *15* short questions.
Each question is worth *two marks* and all should be attempted.
The second section contains *three* long questions.
Each long question is worth *20 marks*.
The best *two* long question answers will be used for assessment.
The maximum for this paper is *70 marks*.
If you attempt a question and do not wish it to be marked, delete it clearly.

Other Instructions:

SAMPLE: Only non-programmable calculators may be used. Please note that you should ensure that any calculations are clearly shown. You may use a single two-sided A4 sheet of written notes for this exam. SAMPLE.

TURN OVER ONLY WHEN TOLD TO START WRITING

Section A: short questions - answer all questions

Q1. Hebb's rule is often paraphrased as 'neurons that fire together wire together'; why is this no longer considered accurate?

Q2. The two principal forms of aphasia are expressive aphasia and fluent aphasia, one is distinguished by the inability to find words, the other by the inability to understand language. Expressive aphasia is associated with lesions in which brain areas.

Q3. What is the equilibrium value of h in the equation $dh/dt = 4 - 2h$? How do we know this value is stable?

Q4. What are the advantages and disadvantages of Electroencephalography (EEG) as a tool to study neuroscience.

Q5. What caused the damage to patient HM's hippocampus and what did it cause?

Q6. Give a typical value of the resting potential inside a neuron.

Q7. What are dopaminergic cells believed to fire in response to.

Q8. Define Shannon's capacity $C(B, S)$.

Q9. What was Dennards scaling law?

Q10. Approximately how many neurons are in the human brain?

Q11. Consider the following fully connected, multilayer neural network, where all of the layers use the same activation function. A:(50 nodes) $->$ (40 nodes) $->$ (10 nodes)$->$ (40 nodes) $->$ (50 nodes)
What would you call this type of neural network architecture?

Q12. In neural networks, what is an convolutional neural network and why does it need pooling layers?

Q13. Give two features of natural language that make it hard for neural networks to process?

Q14. What, in the field of generative AI, is latent space?

Q15. Why do neural network activation functions need to be non-linear?

Section B: long questions - answer two questions

Q1. This question is about integrate-and-fire neurons.

(a) In the leaky integrate-and-fire neuron the voltage, v, satisfies

$$\tau_m \frac{dv}{dt} = E_l - v + R_m I_e$$

with the rule that if $v > V_t$ the voltage is reset to V_r. What is the term E_l and where does it come from? *[5 marks]*

(b) In an experiment a constant current input I_e is applied with successively larger values. What value of I_e will make the neuron spike? *[5 marks]*

(c) Draw the f-I curve for the integrate and fire neuron. *[3 marks]*

(d) Derive a formula for the interspike interval for this neuron when there is a constant current large enough to cause spiking. *[7 marks]*

Q2. This question is about Shannon's capacity theorem and its application to the energy efficiency of communication.

(a) Define Shannon's capacity $C(B, S)$. *[4 marks]*

(b) Calculate the channel capacity for two cases $S = 3N$ and $S = 15N$. *[5 marks]*

(c) Given the energy efficiency is $F = C/(S + N)$, where S is defined in terms of a constant times N, Compare the energy efficiency of the two cases from the previous part of the question, given $B = 1/2$. What can you say about the difference between the two cases? *[3 marks]*

(d) Explain, with reference to Shannon's capacity theorem, why the channel capacity cannot become unboundedly large even as we increase the bandwidth without bound? *[3 marks]*

(e) How can we show that the channel capacity has a bound? You do not have to calculate the limit. *[5 marks]*

Q3. This question is about the neural network model in Figure [1]. The network has two input nodes with fixed values, one hidden layer and an output layer.

(a) Calculate the outputs of the neural network as described with activation function $f(x) = \frac{1}{1+e^{-x}}$. *[6 marks]*

(b) Prove that this activation function is non-linear? *[3 marks]*

(c) Given the following back formula:

$$\partial C/\partial w_{j,k}^{(L)} = \partial C/\partial a_j^{(L)} \times \partial a_j^{(L)}/\partial z_j^{(L)} \times \partial z_j^{(L)}/\partial w_{j,k}^{(L)} \quad \text{Partial Derivative}$$

$$C = \sum (output - y)^2 \quad \text{Cost function}$$

$$z_j^{(L)} = w_{j,k}^{(L)} a_k^{(L-1)} + b^{(L)} \quad \text{Summation of weights plus bias}$$

$$a_j^{(L)} = f\left(z_j^{(L)}\right) \quad \text{Activation function}$$

where L is the layer, $_j$ is the node index, $_k$ is the weight index and $f(x) = \frac{1}{1+e^{-x}}$, the logistic function. Calculate the formula for adjusting the weights from layer $L = 1$ to $L = 2$, by back propagation, using the above formula. *[2 marks]*

(cont.)

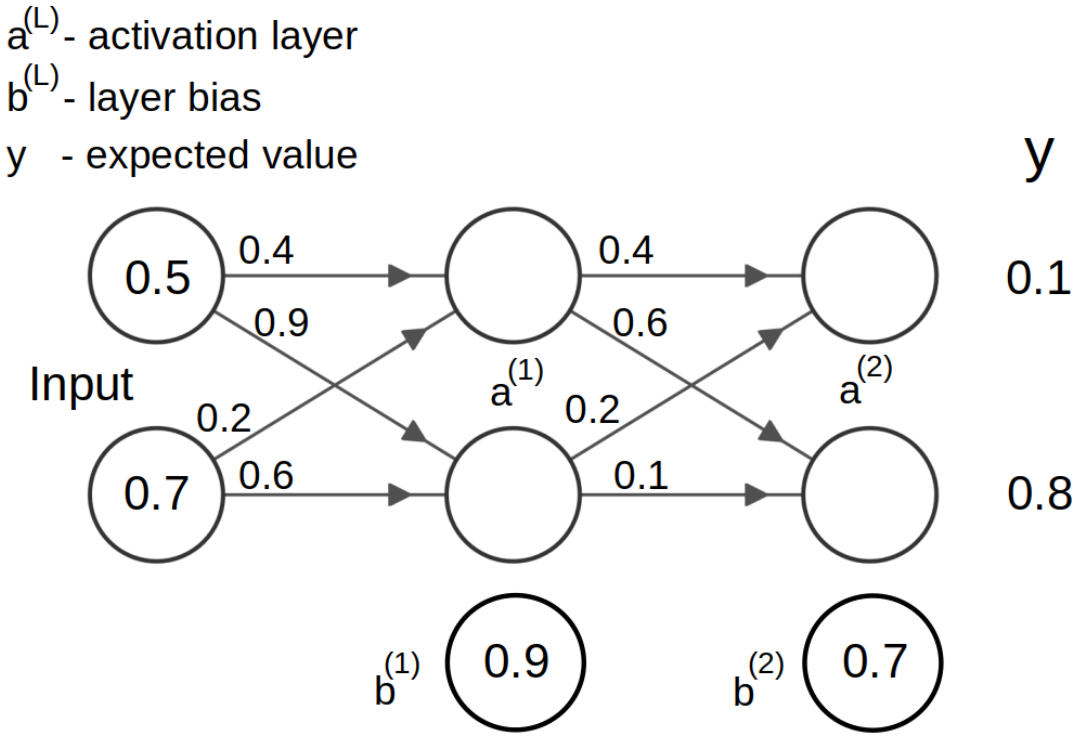

Figure 1: **Neural network for question 3.**

(d) Calculate the change to the weights 1, 0 and 1, 1, the bottom two weights, between layer 1 and layer 2, which have values 0.2 and 0.1, using standard back propagation. *[4 marks]*

(e) What is the learning rate of a neural network and how can it affect learning? *[5 marks]*

END OF PAPER