UNIVERSITY OF BRISTOL

August / September 2019 Examination Period

FACULTY OF ENGINEERING

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

COMS 30127-R / COMSM 2127-R
Computational Neuroscience

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*.

Other Instructions:

Calculators must have the Faculty of Engineering Seal of Approval.

TURN OVER ONLY WHEN TOLD TO START WRITING

Section A: short questions - answer all questions

Q1. This is a picture of Tan's brain showing a lesion to Broca's area. What were the consequences of this lesion to Tan.

A very old looking photograph of a brain, it has a rough hole about where your temple is.

Q2. What are the advantages and disadvantages of Electroencephalography (EEG) as a tool to study neuroscience.

Q3. The Euler approximation used to solve differential equations has errors of order $O(\delta t^2)$, where δt is the time step; why is that?

Q4. The differential equation

$$\tau \frac{df}{dt} = c - f$$

with c a constant is in equilibrium at $f = c$; without solving the differential equation describe how we know the equilibrium is stable.

Q5. Some models of single neurons are simpler than others (for example McCulloch-Pitts versus Hodgkin-Huxley). Name two benefits that simple neuron models have compared with more detailed neuron models.

Q6. Which subregion of the hippocampus is thought to perform pattern completion? And which other subregion of the hippocampus is thought to be crucial for pattern separation?

Q7. Give the expression for the energy of a Hopfield network as a function of its activity state and synaptic weights. How does the energy relate to pattern completion?

Q8. What is an attractor network?

Q9. The receptive field of neurons in primary visual cortex can often be approximated by a Gabor function (see picture). What feature of visual scenes would a neuron with this receptive field be sensitive to?

A bright oval, running from SW to NE, is flanked by two darker ovals

Q10. Draw the typical f-I curve for a leaky integrate-and-fire neuron model.

Q11. What are the two main timescales of synaptic plasticity? Give the respective timescales at which each type of plasticity operates.

Q12. Draw the basic pair-wise STDP learning curve, with the respective axes.

Q13. Briefly describe the phenomenon of memory savings and its synaptic theory.

Q14. Name an ion which is found in greater concentration outside a neuron than inside.

Q15. According to the Hodgkin-Huxley equation the conductance of the potassium gate is proportional to n^4. Give the differential equation that describes how n evolves.

Section B: long questions - answer two questions

Q1. This question is about mathematics.

(a) Show that the solution to the differential equation

$$\tau \frac{df}{dt} = g(t) - f$$

is

$$f(t) = \frac{1}{\tau} e^{-t/\tau} \int_0^t e^{s/\tau} g(s) ds + f(0) e^{-t/\tau}$$

[4 marks]

(b) Explain how this solution can be described as a filter of the input $g(t)$ and what this tells us about $f(t)$. *[4 marks]*

(c) If

$$g(t) = e^{-t/\tau}$$

what is the solution? *[4 marks]*

(d) Solve the differential equation for $g(t) = c$ a constant. *[4 marks]*

(e) If $c = 1$ and $f(0) = -1$ write an expression for the time until $f = 0$. *[4 marks]*

Q2. This question is about Perceptrons.

(a) The Perceptron can be considered as a linear classifier. Describe what this means. *[3 marks]*

(b) Draw some example datapoints on a 2D plot in a way that makes it impossible for a Perceptron to separate. *[4 marks]*

(c) Is Perceptron learning supervised or unsupervised? *[2 marks]*

(d) What is the Perceptron learning rule? Give the mathematical rule for updating the weights. *[5 marks]*

(e) Assume a Perceptron initially has thee input weights: $\mathbf{w} = (-1, 1, 2)$. There are also two training input patterns $p_1 = (0, 1, 1)$, $p_2 = (1, 0, 1)$ with associated target labels $d_1 = 1$ and $d_2 = -1$. Perform the weight update rule sequentially for each input pattern, and report the weight vector at each step. Assume the learning rate $\eta = 0.1$. *[6 marks]*

Q3. This question is part about Oja's rule and part about sparse coding.

(a) Give Oja's learning rule. *[3 marks]*

(b) Give the expression to which the weight converges for the above rule and explain its meaning. *[5 marks]*

(c) What does sparse coding mean? *[2 marks]*

(d) Name a potential benefit of a sparse coding scheme for the brain. *[3 marks]*

(e) Sparse code features are typically learned in a supervised setting by minimising a loss or error function. Write down an example loss function that could lead to sparse features. *[3 marks]*

(f) Draw an example of a typical 2D basis function learned from a sparse coding rule trained on natural images, as in Olshausen and Field, 1996. *[4 marks]*

END OF PAPER