UNIVERSITY OF BRISTOL

SAMPLE PAPER Examination Period

FACULTY OF ENGINEERING

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

COMSM0094
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*.

Other Instructions:

You may use a single two-sided A4 sheet of notes for this exam, you can use a calculator. Calculators must have the faculty seal of approval.
Do not turn over until told to start

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. In the Hodgkin-Huxley model of the squid giant axon, which ion is responsible for the initial rise in the voltage during a spike?

Q4. What are the advantages and disadvantages of *in vivo* electrode recordings as a tool to study neuroscience.

Q5. Draw the typical f-I curve for a leaky integrate-and-fire neuron model.

Q6. Solve the equation

$$3\frac{dv}{dt} = -v$$

with $v(0) = 1$.

Q7. Define Shannon's capacity $C(B, S)$.

Q8. What was Dennards scaling law?

Q9. Approximately how many neurons are in the human brain?

Q10. Draw the experimental stimuli and timing of the Wisconsin General Test Apparatus task used by Fuster and colleagues that is used to probe working memory.

Q11. Draw the bifurcation diagram for the simple recurrent model that was studied in this unit.

Q12. If the fraction of open channels due to AMPA receptors, s_AMPA = 0.5 at the current time, calculate s_AMPA 0.1ms later when there is one presynaptic spike, with tau_AMPA = 2ms, dt = 0.1ms and s_AMPA = 0.5. using the Euler method.

Q13. What is meant by 'activity-silent working memory'?

Q14. How can an 'activity-silent' memory trace be detected? What is the logic behind this method?

Q15. What time constants are typically used for synaptic facilitation and depression in models of activity-silent working memory?

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 is about large-scale models of the cortex.

(a) Explain why is it valuable to build large-scale cortical models of cognitive functions? *[2 marks]*

(b) List and describe three major steps in building a modern large-scale model of the cortex. *[3 marks]*

(c) What is a dendritic spine? *[2 marks]*

(d) In this equation

$$\tau \frac{dr_{x,E}}{dt} = -r_{x,E} + \beta_E \left[w_{E,E} r_{x,E} + G \sum y \in Y C_{y \to x} r_{y,E} - w_{E,I} r_{x,I} \right]_+$$

How can the spine count of area x be implemented? *[3 marks]*

(cont.)

(e) What are the potential dynamical consequences of a gradient of spines, and what may be the functional implications of this? *[3 marks]*

(f) In some of the large-scale models we studied, some brain areas showed persistent activity, while others did not. Why? Illustrate your answer. *[4 marks]*

(g) In the lectures we focused on a working memory attractor state in the large-scale models. What other attractor states could exist in the brain? If so, how could the real brain shift between attractor states? *[3 marks]*

END OF PAPER