UNIVERSITY OF BRISTOL

May / June 2018 Examination Period

FACULTY OF ENGINEERING

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

COMS30127 / COMSM2127
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. Many synapses exhibit short-term plasticity: they temporarily change their efficacy when stimulated repeatedly, on a tens of milliseconds timescale. Some synapses tend to increase their strength while others tend to decrease their strength. What are the names given to these two forms of short-term plasticity, respectively?

Q2. What glutamate receptor is crucial for Hebbian forms of long-term synaptic plasticity?

Q3. What is the difference between metabotropic and ionotropic neurotransmitter receptors?

Q4. Sketch the nullclines for the Fitzhugh-Nagumo model.

Q5. What is the typical timescale of opening and closing of ion channels: nanoseconds, microsecond, milliseconds, seconds, minutes, hours or days?

Q6. What does the term 'rate coding' mean?

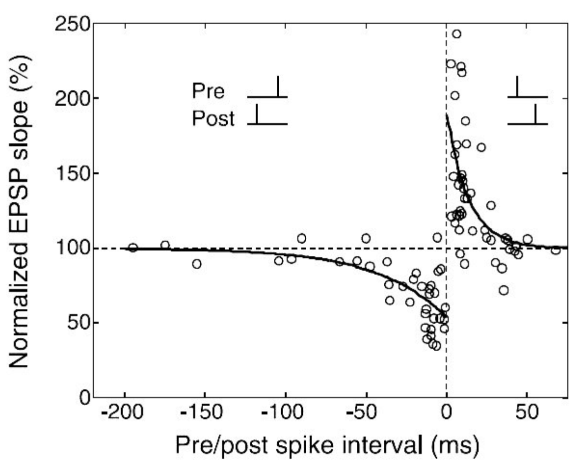
Q7. Solve the equation

$$2\frac{dv}{dt} = -v$$

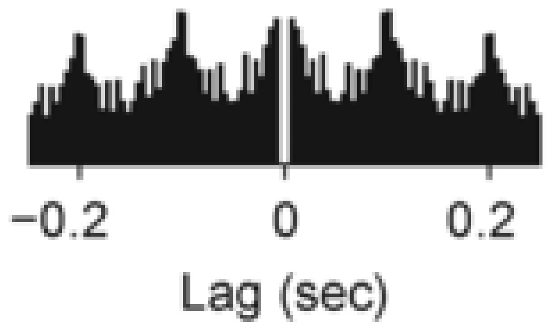
with $v(0) = 5$.

Q8. The left and right hemispheres of the brain respond to different aspects of the visual field. What part of the visual field does the brain's right hemisphere respond to?

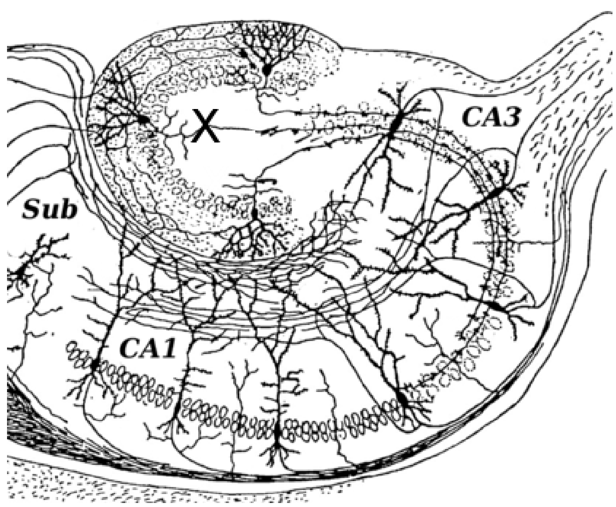
Q9. Classic spike-timing dependent plasticity learning rules such as that shown below, and taken from Dan, Yang, and Mu-ming Poo. "Spike timing-dependent plasticity of neural circuits." Neuron 44 (2004): 23-30, are typically unstable, meaning that they lead to synaptic strengths growing infinitely large. Explain how this can happen.



Q10. This image, taken from Newman, Jonathan P., et al. "Optogenetic feedback control of neural activity." eLife 4 (2015) shows the auto-correllogram for a cell in rat brain that responds to stimulation of a whisker. Speculate on the frequency the whisker is being stimulated at.



Q11. Name the region of the hippocampus marked as X.



Q12. In the Hodgkin-Huxley squid axon model, which two membrane conductances from the following list are responsible for the rise and fall of the voltage during the action potential: chloride channels, potassium channels, calcium channels, or sodium channels? Be explicit about which channels drive the rising phase and which channels drive the falling phase.

Q13. In a Hopfield network with three neurons there are two patterns to store: $(-1, -1, -1)$ and $(1, -1, 1)$; use the single-step approach to calculate the weights.

Q14. Describe briefly how varying the constant current input in the Fitzhugh-Nagumo model

$$\begin{aligned}\frac{dv}{dt} &= v - \frac{1}{3}v^3 - w + I \\ \frac{dw}{dt} &= 0.08(v + 0.7 - 0.8w)\end{aligned}$$

changes the behaviour from resting to spiking.

Q15. What is meant by spike rate adaptation?

Section B: long questions - answer two questions

Q1. This question is about McCulloch-Pitts neurons.

(a) Consider two McCulloch-Pitts neurons with zero thresholds; initially $x_1 = -1$ and $x_2 = 1$. $w_{12} = w_{21} = 2$ and $w_{11} = w_{22} = 0$. The neurons are updated synchronously, what are their values after the update. *[5 marks]*

(b) Describe a perceptron; what is its update rule? *[5 marks]*

(c) Explain carefully why a perceptron is only capable of learning the classification of groups of data which can be separated using a line? *[5 marks]*

(d) It was proposed by David Marr that the cerebellum acts like a perceptron, explain this. *[5 marks]*

Q2. This question is about rate models. Consider a neuron that varies its mean firing rate $\bar{r}(s)$ as a logarithmic function of the scalar intensity of stimulus s: $\bar{r}(s) = \ln(s)$. Imagine we are trying to detect changes in the stimulus intensity from the neuron's firing rate alone. Due to the noisiness of the firing, assume our detector can only reliably detect firing rate changes of σ or larger, $\Delta r_{min} = \sigma$.

(a) Using the identity $\frac{d}{dx}\ln(x) = \frac{1}{x}$, calculate the smallest detectable change in stimulus intensity Δs_{min}. *[5 marks]*

(b) Sketch a plot with s on the x-axis and $\frac{\Delta s_{min}}{s}$ on the y-axis. *[5 marks]*

(c) This result is related to a psychophysical phenomenon known as Weber's law. Does Weber's law state that humans perceive relative or absolute changes in the intensity of sensory stimuli? Explain how Weber's law follows from the previous result in parts (a) and (b). *[5 marks]*

(d) A more realistic scenario would be where the firing rate noise scales with the square root of r, so that smallest firing rate change our detector can resolve is $\Delta r_{min} = \eta r^{1/2}$. What would the smallest detectable change in stimulus intensity be now? *[5 marks]*

Q3. 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? Describe two significant approximations that are made in this model. *[7 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) Derive a formula for the interspike interval for this neuron when there is a constant current large enough to cause spiking. *[8 marks]*

END OF PAPER