COMS30127 / COMSM2127 sample paper - DRAFT

Rubrik

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*.
This is a two hour exam.

Section A: short questions - answer all questions

1. Neurophysiologists typically distinguish between two cell types in primary visual cortex: simple cells and complex cells. What is the key characteristic that distinguishes these two cell types?

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

3. Visual neurons receptive fields can often be modelled as a 2D sine wave multiplied by a 2D Gaussian. What is the common name for this compound function?

4. Neurons cannot fire at arbitrarily high rates because after a spike there is typically a short period of time, usually several milliseconds, where they are resistant to spiking again. What is this time period called?

5. Which channel is typically responsible for spike rate adaptation?

6. 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. These are associated with lesions in which brain areas.

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

8. What is the typical scale of voltage differences in the brain: microvolts, millivolts or volts?

9. For a spike train with spike times $\{t_1, t_2, \ldots, t_n\}$ evoked by stimulus $s(t)$ define the spike triggered average.

10. What is d' used for in describing a neuronal response?

11. Which part of the hippocampus is thought to act as a Hopfield network?

12. Sketch the hippocampus and labelling CA3, CA1 and dentate gyrus.

13. Solve the equation
$$3\frac{dv}{dt} = -v$$
with $v(0) = 1$.

14. What is meant by a central pattern generator?

15. Define the energy of a pattern in the Hopfield network and briefly describe how this is related to pattern storage and completion.

Section B: long questions - answer two questions

1. This question is about numerical methods.

   (a) Explain how the Euler method for integrating the differential equation
   $$\frac{dv}{dt} = F(v)$$
   is derived from the Taylor expansion. [7 marks]

   (b) Although the error in the Euler method is $O(\delta t^2)$ and therefore small, there is a problem with it accumalating: if the error is always positive, for example, it grows as t increases. Explain why this might be less of a problem when integrating the leaky integrate-and-fire neuron? [5 marks]

   (c) In the second order Runge-Kutta algorithm we define

   $$\begin{aligned} k_1 &= F(v)\delta t \\ k_2 &= F(v + k_1/2)\delta t \end{aligned}$$

   and approximate
   $$v(t + \delta_t) = v(t) + k_2$$

   Show using the Taylor expansion that this is accurate to $O(\delta t^3)$. [8 marks]

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2. This question is about synaptic plasticity.

   (a) Let each synapse's weight w_i be plastic, and change according to a Hebbian rule: $w(t+1) = w(t) + 0.1 \times x_i y$. Is this plasticity rule stable or unstable? Explain your answer. [4 marks]

   (b) Now consider a case where there are just two input neurons with firing rates $x_1 = 2$ and $x_2 = 4$, and respective synaptic weights initially both equal to one, $w_1 = w_2 = 0.5$. Compute the synaptic weights after one update. [4 marks]

   (c) Let's assume that we always want the sum of the weights to remain $w_1 + w_2 = 1$. This can be achieved by renormalising the synaptic strengths after each update, either by subtracting some fixed amount from each weight, or by dividing both weights by some fixed amount. Compute the normalised synaptic weights after one weight update for each case. Which method (additive scaling or multiplicative scaling) leads to a greater difference between synaptic strengths? [4 marks]

   (d) Now consider a new plasticity rule (similar to the "BCM" rule), where $\frac{dw_i}{dt} = x_i(y - \theta)$ where θ is a threshold that determines whether the synapse increases or decreases in strength. The threshold itself changes on a slow timescale, according to $\frac{d\theta}{dt} = y^2 - \theta$. What is the steady state value of the threshold in terms of y? [4 marks]

   (e) Now consider there are just two input neurons with firing rates $x_1 = 3$ and $x_2 = 5$. If the synaptic weights change according to the BCM-like plasticity rule from the previous question, what is the eventual steady-state value of w_1 as a function of the steady-state value of w_2? [4 marks]

3. This question is about the Hodgkin-Huxley equation.

   (a) Sketch a spike; label the up swing and down swing and indicate what aspect of the current dynamics are responsible for each. [4 marks]

   (b) Write down the Hodgkin-Huxley equation; include the sodium and potassium channels. [4 marks]

   (c) Which axon is this an equation for? [2 marks]

   (d) Write down the equation for n, m and h both in terms of the transition probabilities and in terms of the time constant and asymptotic values. [5 marks]

(e) Sketch the asymptotic values for n, m and h indicating what role these play in the spike. [5 marks]