Version GH/3

EGT2
ENGINEERING TRIPOS PART IIA

Monday 23 April 2018 14:00 to 15:40

Module 3G3

INTRODUCTION TO NEUROSCIENCE

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 (a) Describe the method of extracellular action potential recordings. Give one advantage and one disadvantage over intracellular recordings. [20%]

(b) In the standard Hodgkin-Huxley model, the dynamics of the membrane potential V are given by:

$$C_{\mathrm{m}}\frac{\mathrm{d}V}{\mathrm{d}t} = -\bar{g}_{\mathrm{Na}}m^3h(V-E_{\mathrm{Na}}) - \bar{g}_{\mathrm{K}}n^4(V-E_{\mathrm{K}}) - \bar{g}_L(V-E_{\mathrm{L}}) + I_{\mathrm{ext}}$$

where C_{m} is the specific membrane capacitance and I_{ext} is an externally applied current.

(i) Explain the meaning of the variables $\{m,h,n\}$ as well as $\{\bar{g}_{\mathrm{Na}},\bar{g}_{\mathrm{K}}\}$. [20%]

(ii) Sketch the steady-state dependence of m, h, and n on voltage. [20%]

(iii) Figure 1 shows the time evolution of the state variables V, m, n and h in the Hodgkin-Huxley model. Unfortunately the y-axes of the plots have not been labelled. Identify which plot (a, b, c, or d) corresponds to each state variable and give the approximate range used on the y-axes, giving a brief justification for each choice. [30%]

(iv) Is there a maximum achievable firing rate for the Hodgkin-Huxley model subjected to constant current input? Justify your answer briefly. [10%]

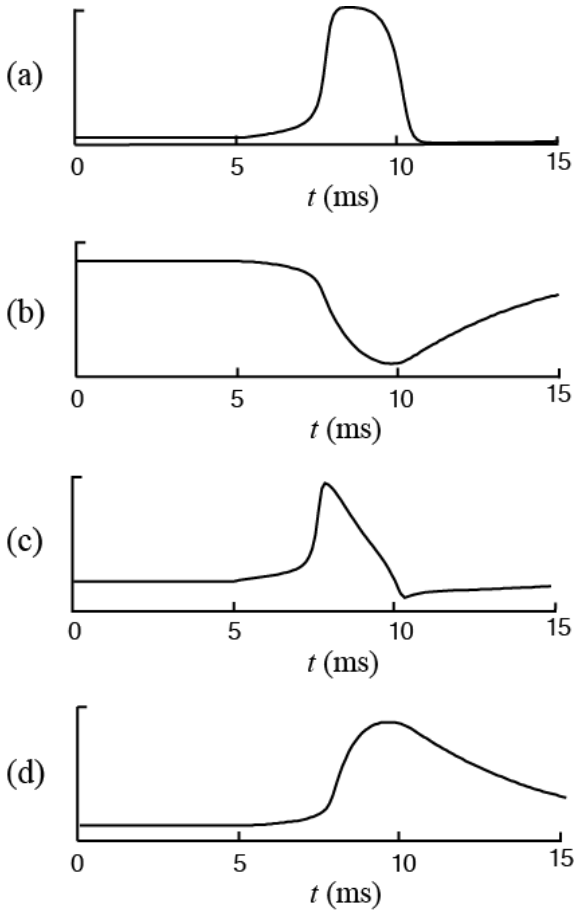

Fig. 1

2 (a) Write short notes on the following:

(i) the four dimensions that characterize any sensory input to the brain;

(ii) coarse ensemble (or population) coding in the context of sensation.

[30%]

(b) A scientist sets out to test the hypothesis that the brain optimally combines sensory evidence with prior expectations, in a task involving visual perception. In this task, a subject sits in front of a large display (Fig. 2), and initiates a trial by fixating their gaze on a small cross, centred horizontally on the display. A dot is presented briefly at some horizontal position x chosen randomly (and independently in each trial) from some distribution $p(x)$ within the grey-shaded ruler. After the dot disappears, the subject is asked to report an estimate $\hat{x}$ of the dot's position.

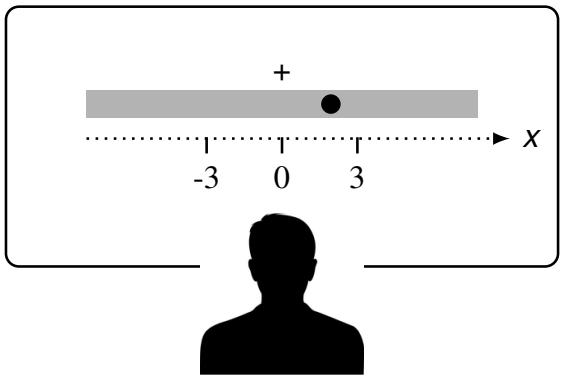

Fig. 2

(i) Optimal inference of the dot's position requires computing the posterior distribution $p(x|s) \propto p(s|x)p(x)$, where s denotes sensory evidence. Explain what the two terms on the right of this equation represent, and in particular how they relate to the task design. [20%]

(ii) Assume $p(x)$ is Gaussian with zero mean and unit standard deviation. Make a reasonable assumption for the form of the likelihood function, and sketch the prior distribution, likelihood function, and posterior distribution (on a single graph), when the *true* position of the dot is $x = 3$. [20%]

(iii) Assuming Bayesian estimation, how would the subject's estimate of x depend on the visual contrast of the black dot against the grey ruler? Based on your observation, explain how you would extend this experiment to directly test the implications of Bayesian inference in this task. [30%]

3 (a) In the *Aplysia* gill withdrawal reflex, describe the sequence of cellular-molecular events during normal synaptic transmission between a sensory and a motor neuron, before and after sensitisation. [30%]

(b) In an *in vitro* experiment about LTP, extracellular electrodes are used both for stimulation and recording. Assume the recording electrode is in the same layer where axons of the stimulated pathway form synapses with the postsynaptic cells. Sketch the extracellular potential signals that can be recorded following a stimulation, before and after the induction of potentiation. Describe in words the main differences between the "before" and "after" signals. [30%]

(c) In a classical conditioning experiment, three different conditioned stimuli, CS_1 (a light), CS_2 (a tone), and CS_3 (a click), are used to signal the same unconditioned stimulus (US; delivery of food). Before training, none of the CSs evoked a response. Describe how strong a response (if any) you expect for each of the CSs presented in separation after the following training protocols:

(i) phase 1: (CS_1, CS_2) + US; phase 2: CS_3 + CS_1

(ii) phase 1: (CS_1, CS_2) + US; phase 2: (CS_3, CS_1) + US

(iii) phase 1: (CS_1, CS_2) + US; phase 2: (CS_3, CS_1, CS_2) + US

In these expressions, the shorthand notation X+Y stands for sequential presentation of the stimuli X and Y, while (X,Y) denotes their simultaneous presentation. [40%]

4 (a) Explain what determines whether a synapse is excitatory or inhibitory. [15%]

(b) Describe the sequence of events during the expression of late LTP in the hippocampus. [25%]

(c) You are to design an experiment making use of a neurotransmitter antagonist to distinguish between the contributions of hippocampal and striatal LTP to the learning of different navigational strategies. You may assume that striatal LTP is based on the same mechanism as hippocampal LTP.

(i) What kind of behavioural task would you use to assess the performance of animals, and how would you measure their performance? [20%]

(ii) What receptor would you block with your antagonist? At what point(s) during the course of the experiment would you apply your antagonist? [15%]

(iii) What results do you expect from your experiment? [15%]

(iv) If you had the opportunity to do *in vivo* electrophysiological recordings, how would you do them to give further support to your results? [10%]

In all cases, explain your choices.

END OF PAPER