Version GH/2

EGT2
ENGINEERING TRIPOS PART IIA

Monday 24 April 2017 14:00 to 15:30

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.

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

1 (a) Write short notes on the following:

(i) David Marr's three levels of understanding.

(ii) The two-alternative forced choice detection task-design and the associated psychometric function. [30%]

(b) This question is about the action potential.

(i) Explain why, in the Hodgkin-Huxley model, voltage-gated ion channels are necessary for the generation of an action potential by injection of a step current. [20%]

(ii) Describe the key stages responsible for the action potential upstroke. [25%]

(iii) Figure 1 below shows the membrane potential of a neuron modelled with Hodgkin & Huxley's equations, in response to a pair of consecutive, 2 ms-long pulses of input current, separated by either 3 ms (CASE A, top), or 1 ms (CASE B, bottom; the membrane potential shown in A is reproduced in B as a dashed line to allow comparison). Explain why only one action potential is elicited in CASE B, and why the membrane potential eventually decays more slowly towards rest in CASE B compared to CASE A, in spite of the fact that the input is withdrawn earlier. [25%]

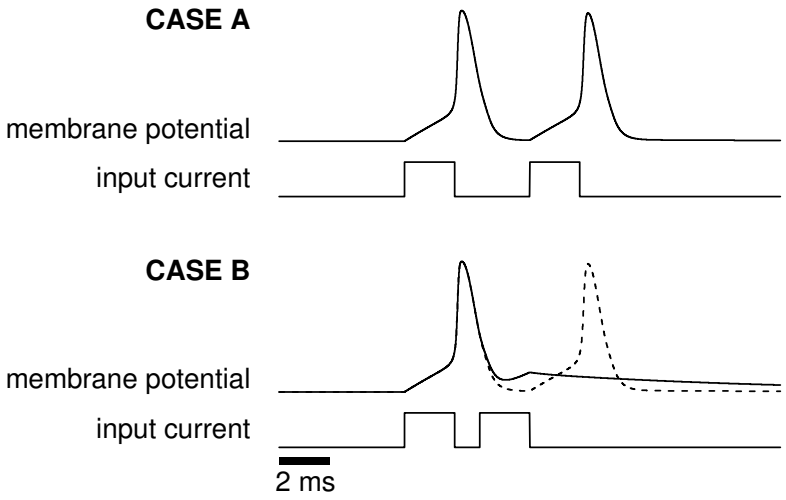

Fig. 1

2 (a) Explain why perception is fundamentally different from sensation and support your argument with one example. [20%]

(b) Outline the formalisation of perception as probabilistic inference, carefully explaining the various mathematical quantities involved. [20%]

(c) Look at Fig. 2 below. Although the drawing is entirely flat, the first three disks are commonly perceived as bulging outwards, and the last three disks look as if they have been carved. Explain why we perceive depth where there really is none, and why the perception of depth is different in the two cases. [20%]

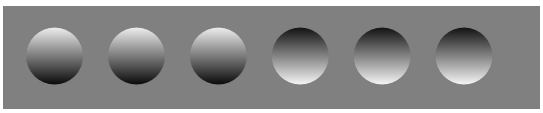

Fig. 2

(d) An experimenter discovers a new type of sensory neuron under the skin. They record its membrane potential $V(t)$ in a variety of conditions, and find that its temporal average $\overline{V} = \langle V(t) \rangle_t$ exactly encodes the room temperature θ according to

$$\theta = k \times (\overline{V} + 80\,\mathrm{mV})$$

with a gain $k = 2\ ^\circ\mathrm{C/mV}$. Here, the notation $\langle x(t) \rangle_t$ denotes temporal averaging, i.e.

$$\langle x(t) \rangle_t = \lim_{T \to \infty} \frac{1}{T} \int_0^T x(t)\, dt.$$

(i) What recording technique do you think the experimenter may have used? [10%]

(ii) The experimenter records $V(t)$ over a very long time period, at constant room temperature. They compute its autocovariance function $A(\tau)$ defined as

$$A(\tau) = \langle (V(t) - \overline{V})(V(t+\tau) - \overline{V}) \rangle_t$$

This is plotted in Fig. 3 as a function of the time lag τ. Did this sensory neuron fire action potentials in this recording? Explain your reasoning. [5%]

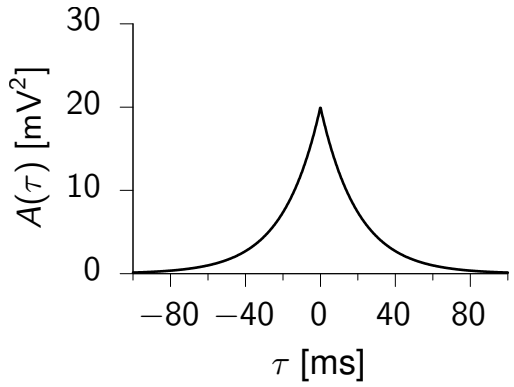

Fig. 3

(iii) Based on Figure 3, derive an approximation of the duration over which you would need to observe the membrane potential of this neuron to be able to estimate the room temperature with an expected squared error less than 0.25 °C^2.

Hint: you may start by approximating the time lag τ at which successive values $V(t)$ and $V(t+\tau)$ are effectively uncorrelated, and approximate the fluctuations of V by a staircase-like signal with steps of duration τ. [25%]

3 (a) Explain, with the help of one concrete example, why optimal decision-making often requires taking into account one's uncertainty. In particular, what kinds of uncertainty must be considered? [20%]

(b) Describe the Receiver Operating Characteristic (ROC) curve. [20%]

(c) A monkey engages in the classical random dot motion discrimination task. A circular field of moving dots is presented on the display, with a fraction c of the dots moving coherently either to the left or to the right (this direction is set randomly with equal probability at the beginning of each trial). The remaining $(1-c)$ fraction of the dots move in random, incoherent directions. The monkey must decide whether coherent motion occurs to the left or to the right, and report its decision whenever ready.

(i) Sketch the percentage of correct answers, as well as the mean reaction time, both as a function of c, for a typical monkey in this task. [20%]

(ii) What behavioural evidence exists in support of monkeys temporally accumulating and integrating evidence about motion direction? [20%]

(iii) Explain the drift-diffusion formalism typically employed to model the behaviour of monkeys in this task. Your answer should include:

- an equation describing the dynamics of the decision variable, with a description of each term and other model parameters,
- how this equation is used to model decision making,
- a description of the behavioural quantities that this model can predict.

[20%]

4 (a) Using an evolutionary argument, explain why learning and adaptation are important for an animal species. [20%]

(b) Explain how calcium ions are involved in the process of synaptic transmission. [20%]

(c) Figure 4 below shows the current-voltage (I-V) relationships in two types of ion channels, one bearing NMDA ionotropic glutamate receptors, the other bearing non-NMDA receptors.

(i) Which of the two curves corresponds to NMDA receptors? What are the reversal potentials of these two ion channels? [10%]

(ii) The dashed curve is strongly nonlinear for negative membrane potentials. Explain the molecular mechanism that gives rise to such a nonlinearity. [10%]

(iii) Explain how NMDA receptors can be used as pre- and postsynaptic coincidence detectors. [20%]

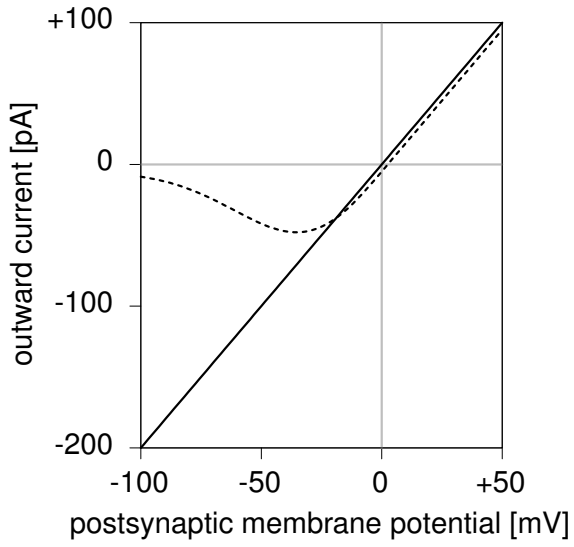

Fig. 4

(d) List three types of preparations that can be used to study synaptic plasticity in the hippocampus. For each, give one of the main limitations. [10%]

(e) List one pre-synaptic and one post-synaptic biophysical properties of a synapse that determine its transmission efficacy and are altered by long-term potentiation. [10%]

END OF PAPER