ENGINEERING TRIPOS PART IIA

Friday, 26th April 2013 9.30 to 11am

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.*

There are no attachments.

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

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

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1 (a) Write short notes on:

(i) Coarse coding;

(ii) Labelled line codes;

(iii) The benefits of multisensory integration. [20%]

(b) The following questions are about the action potential.

(i) Explain the mechanisms that give rise to, and sustain, the resting potential of a neuron.

(ii) Explain the channel mechanisms that give rise to the absolute and relative refractory periods.

(iii) Explain how the voltage clamp technique works and why it is useful for studying the mechanisms underlying the action potential. [30%]

(c) The following questions are about hearing.

(i) Low frequency sounds are used by many species to communicate over long distances because they are less likely to be degraded by the environment. Explain why small animals that use low frequency communication sounds may find it hard to localise one another. Take care to describe the different localisation cues in your answer.

(ii) What is auditory scene analysis? Describe the cues which are utilised by the auditory system to perform auditory scene analysis. [50%]

2 (a) There are an infinite number of arm movements which could move the hand from one point in space to another, yet such movements in humans are stereotypical.

(i) What are the stereotypical features of these arm movements?

(ii) Describe a computational principle that can account for the stereotypical features of arm movements.

(iii) Given this computational principle, why might one person be more skilled in their actions than another? [50%]

(b) Humans can adapt their reaching movements to a wide variety of externally imposed dynamic perturbations (e.g. tools or force fields).

(i) Briefly describe the difference between forward and inverse model learning under such perturbations.

(ii) Describe the two different strategies people can employ when adapting to predictable dynamic perturbations (such as reaching while holding a tool) and unpredictable dynamic perturbations (such as when holding the string of a kite on a gusty day).

(iii) A robot is used to perturb a person's arm and after adaptation their arm movements become similar to the movements they made prior to the perturbation. How could you experimentally assess which of the two strategies in (b)(ii) the person has used? [50%]

3 This question is about the interplay of dendritic signal propagation and LTP induction in glutamatergic synapses.

(a) Just as axons, dendrites can have voltage-gated conductances, such as sodium and potassium channels, that allow the active propagation of electrical signals. Describe, for the cases when dendritic propagation is either active or passive, how the voltage spreads in time in the three main parts of a neuron (cell body, axon, and dendrite) following the generation of an action potential at the cell body. Assume the axon is unmyelinated. [10%]

(b) An experiment is performed in which a single presynaptic cell is stimulated so that it fires an action potential. No other presynaptic cells fire at the same time. The experimenter controls whether the postsynaptic cell fires or not and whether signal propagation in the dendrite is passive or active (by blocking or unblocking sodium channels). When the postsynaptic cell fires, it happens at around the same time as when the presynaptic cell fires. The synapse between the pre- and postsynaptic cell is close to the tip of the dendrite (far from the soma). In each of the cases in Table 1 explain why LTP did or did not occur. Support your answer by describing the sequence of cellular-molecular events that happen at the stimulated synapse, and how the membrane potential changes in the postsynaptic cell at the synapse. [30%]

	presynaptic cell fires	**postsynaptic cell fires**	**dendritic signal propagation**	**LTP induced**
case 1	yes	no	passive	no
case 2	yes	yes	passive	no
case 3	yes	yes	active	yes

Table 1

(c) In a different experiment, dendritic propagation is active in the postsynaptic cell, the cell's firing is not controlled by the experimenter but by the synaptic inputs it receives, and we record whether it fired or not. Two groups of presynaptic cells, A and B, that have synapses at two distinct dendritic sites on the postsynaptic cell, are stimulated. The locations of group A and B synapses are shown in Fig. 1. Group B synapses are stimulated shortly after group A synapses (if at all). No other presynaptic cells fire.

Fig. 1

In each of the cases in Table 2 explain why LTP did or did not occur. Support your answer by describing the sequence of cellular-molecular events at group A and B synapses, and how the membrane potential changes in the postsynaptic cell at each dendritic site. [60%]

	% of cells in group A stimulated	**% of cells in group B stimulated**	**post-synaptic cell fires**	**LTP induced for group A**	**LTP induced for group B**
case 1	10	0	no	no	no
case 2	50	0	no	yes	no
case 3	100	0	yes	yes	no
case 4	10	10	no	no	no
case 5	50	10	no	yes	no
case 6	100	10	yes	yes	yes

Table 2

4 This question refers to a modified secondary conditioning experiment in an animal. In this experiment, training involves two conditional stimuli (CS1 and CS2) and one unconditional stimulus (US). In phase 1, CS1 is paired with the US such that in each trial CS1 is followed by the US, after a short delay. In phase 2, CS2 is paired with CS1 such that in each trial CS2 is followed by CS1, after a short delay, which in turn is followed by the US, after another short delay.

(a) How is this paradigm different from a standard secondary conditioning paradigm? [5%]

(b) Describe how the animal responds to CS1 and CS2 presented separately, before phase 1, after phase 1, and after phase 2. [10%]

(c) Describe the time course of the activation of dopamine cells within a trial, according to the temporal difference learning rule, before phase 1, during phase 1, after phase 1, during phase 2, and after phase 2. [25%]

(d) A new type of "value" neuron is discovered in the brain, that fires proportionally to the predicted total future reward within a trial, as computed by the temporal difference learning rule. Describe the time course of the activation of such a neuron within a trial before phase 1, during phase 1, after phase 1, during phase 2, and after phase 2. [30%]

(e) In simple classical conditioning experiments, catch trials can be used after training is finished, to demonstrate negative prediction errors in neural signals. Using catch trials, how would you demonstrate negative prediction errors in this modified secondary conditioning experiment, and what is the time course of the activity of dopamine and value-representing neurons in these trials? [30%]

END OF PAPER

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