Version ML/4

EGT2
ENGINEERING TRIPOS PART IIA

Monday 18 April 2016 9.30 to 11.00

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) differences between the brain and the central processing units (CPUs) commonly found in modern-day computers;

(ii) the components and properties of the neuronal membrane that contribute to establishing the resting potential;

(iii) the two-alternative forced choice discrimination task-design and the associated psychometric function.

[30%]

(b) In the auditory system, it is widely believed that the inner ear carries out active amplification of incoming sounds.

(i) Describe two pieces of evidence that support this hypothesis. [25%]

(ii) Describe what is believed to be the physiological mechanism responsible for active amplification in the inner ear. [30%]

(iii) How might an audiologist determine whether the inner ear's active amplification mechanism is damaged? [15%]

2 This question is about vision.

Consider performing the following experiment shown in Figure 1. A subject sits in front of a large display, and initiates a trial by fixating their gaze on a small cross, centred horizontally on the display. A dot is then presented briefly at some horizontal position x chosen randomly from some distribution $p(x)$ within the grey-shaded ruler of width w. After the dot disappears, the subject is asked to provide an estimate $\hat{x}$ of the dot's position.

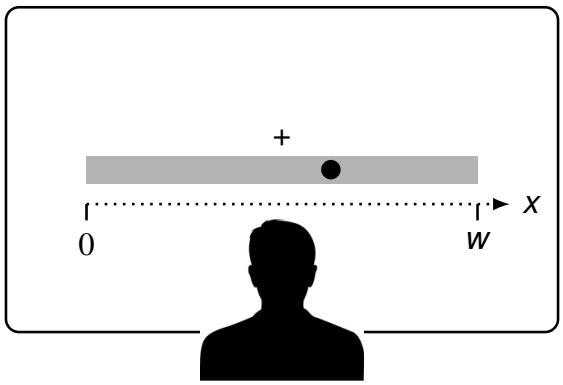


Figure 1

(a) Describe the algorithm that a "Bayesian observer" would use to report the most probable dot position. [30%]

(b) Consider the case when the distribution $p(x)$ from which dot positions are drawn is uniform across the ruler. Following intensive training on this task, we present the subject repeatedly with a dot in the centre of the ruler, and construct a histogram of the subject's estimates $\hat{x}$. Draw a sketch of this histogram, and explain your reasoning. In your answer, consider two scenarios: when the dot is high-contrast (black), and when it is low contrast (only slightly darker than the grey ruler). [30%]

(c) Repeat question (b) with the following prior distribution over dot positions: $p(x) = 2x/w^2$ for $x \in [0, w]$, and $p(x) = 0$ otherwise. [40%]

3 (a) Describe the experimental procedure for habituating the gill-withdrawal reflex in the Aplysia. State for each of the following quantities whether they increase / decrease / or do not change in response to stimulating the siphon over the course of habituation:

(i) activity of sensory neurons;

(ii) amount of transmitter released by sensory neurons;

(iii) activity of interneurons;

(iv) amount of transmitter released by interneurons;

(v) activity of motor neurons;

(vi) amount of transmitter released by motor neurons. [10%]

(b) Describe four different kinds of neural preparations used for electrophysiological experiments, together with their advantages and disadvantages. [30%]

(c) In a classical conditioning experiment, two different conditional stimuli (CS), CS_1 (a light), and CS_2 (a tone) are used to signal the same unconditional stimulus (US, delivery of food). Before training, neither CS evokes a response. During training, three kinds of trials are intermixed:

- CS_1 followed by US;
- CS_2 followed by US;
- CS_1 and CS_2 presented simultaneously, without US following.

After training, the following responses (salivation) are observed in response to the CSs:

- $CS_1 \longrightarrow$ response
- $CS_2 \longrightarrow$ response
- $CS_1 + CS_2 \longrightarrow$ no response

(i) Explain whether the Rescorla-Wagner rule can account for these results. [20%]

(ii) Someone proposes a new theory to describe animal learning in this experiment. The new theory starts from assuming that an animal's response to a combination of CSs reflects how much it predicts the occurrence of a US, and that in the case of two CSs this prediction, r, is given by the following equation:

$$r = w_1 s_1 + w_2 s_2 + w_3 s_1 s_2$$

where s_1 and s_2 are the presence ($= 1$) or absence ($= 0$) of CS_1 and CS_2 in a trial, respectively, and w_1, w_2, and w_3 are prediction strength parameters. Just like the Rescorla-Wagner theory, the new theory also assumes that, during learning,

the prediction strength parameters are gradually changed over trials such that the average squared prediction error $E = (u - r)^2$ is minimised (where u is the presence ($= 1$) or absence ($= 0$) of the US in a trial).

A. Write down the equations describing how each of the prediction strength parameters should change in a trial, based on u, s_1, s_2, and r, according to this new theory. [20%]

B. Explain if this new theory can account for the experimental results described above. [20%]

4 (a) Sketch the amount of postsynaptic current as a function of the postsynaptic membrane potential for an AMPA and an NMDA receptor. For both receptors, sketch the current under four different conditions:

(i) when only glutamate is present in the synaptic cleft; [10%]

(ii) when glutamate and AP5 are present in the synaptic cleft; [10%]

(iii) when only AP5 is present in the synaptic cleft; [10%]

(iv) when only NMDA is present in the synaptic cleft. [10%]

(b) Describe how the Morris water maze is used in learning experiments. Include the following in your answer:

- what is the apparatus like;
- what is the animals' task;
- what aspects of behavioural performance are measured to quantify learning;
- what variants of the Morris water maze can be used to show that some treatment specifically impairs spatial learning as opposed to other factors contributing to performance in the task?

[40%]

(c) Describe the sequence of cellular-molecular events at the synapse, including the main steps of synaptic transmission that leads to the induction of LTP. [20%]

END OF PAPER

Answers

1(a)(i)

speed, reliability, robustness to damage, memory, areas of excellence

1(a)(ii)

ion channels (conductances), lipid bilayer (capacitance), ion pumps

1(a)(iii)

vary difference in stimuli, Δ, plot probability of one option vs. Δ – usually sigmoid so that 0 at -∞, 1 and +∞, and 0.5 at 0

1(b)(i)

gain of the basilar membrane motion is level dependent, spontaneous acoustical emissions (or otoacoustic emissions), distortion products

1(b)(ii)

outer hair cells, outer hair cells exhibit electromotility, positive feedback

1(b)(iii)

suppression of spontaneous acoustical emissions, audiogram insufficient

2(a)

compute $p(x|s) \propto p(s|x)p(x)$, for signal s received from the eyes, then choose the x that maximises $p(x|s)$

2(b)

$\hat{x} = s$, it has a bell-shaped distribution centred around $w/2$ and with width σ, where σ controls the quality of the evidence

2(c)

$\hat{x} = (\sqrt{s^2 + 4\sigma^2} + s)/2$

3(a)

activity of sensory neurons does not change, everything else decreases

3(b)

in vitro slice, *in vitro* tissue culture, *in vivo* anaesthetised, *in vivo* awake

3(c)(i)

RW cannot account for this.

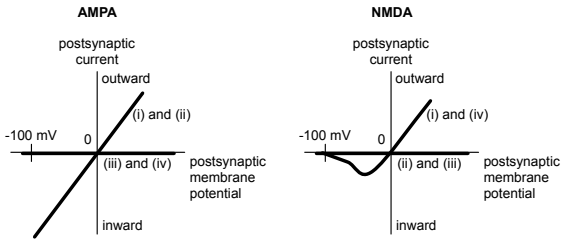
3(c)(ii)

$w_1 \to w_1 + \varepsilon\,(u - r)\,s_1, \quad w_2 \to w_2 + \varepsilon\,(u - r)\,s_2, \quad w_3 \to w_3 + \varepsilon\,(u - r)\,s_1\,s_2$

3(c)(ii)

Yes, it can: $w_1 = w_2 = +1, w_3 = -2$.

4(a)



M. L.