Version GH/3

EGT2
ENGINEERING TRIPOS PART IIA

Monday 4 May 2026 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
Supplementary page: one extra copy of Fig. 1 (Question 1)

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.

You may not remove any stationery from the Examination Room.

1 (a) Write short notes on the following:

(i) Why perception is fundamentally different from sensation. Support your answer with one example; [15%]

(ii) Why optimal decision-making often requires taking into account one's uncertainty. In particular, what kinds of uncertainty must be considered? Support your answer with one example. [15%]

(b) This question is about the drift-diffusion model studied in lectures, whereby a decision variable x evolves according to the following stochastic differential equation:

$$\mathrm{d}x = \mu \mathrm{d}t + \sigma \mathrm{d}W$$

(i) State the meaning of μ, σ and $\mathrm{d}W$ in this equation. [10%]

(ii) How is this equation typically used to model animal behaviour in the classic Shadlen-Newsome visual motion discrimination task discussed in lectures? Are there any other parameters not explicitly present in the equation? [20%]

(iii) For a 2AFC task involving accumulation of sensory evidence, Fig. 1 shows the probability of choosing one of the two alternatives ('A'; left panel) and the average reaction time (right panel) as a function of some task parameter c describing stimulus difficulty. Three different parameter sets (P, Q, and R) were used, corresponding (in arbitrary order) to the three different line types (solid, dashed, dotted) in Fig. 1. These parameter sets are:

$$\text{set P}: \quad \mu = 0.2c \quad \sigma = 1.0 \tag{1}$$

$$\text{set Q}: \quad \mu = 0.6c \quad \sigma = 1.0 \tag{2}$$

$$\text{set R}: \quad \mu = 0.2c \quad \sigma = 0.8 \tag{3}$$

Note that one parameter set is deliberately missing from each graph. On the *additional copy of Fig. 1* provided at the end of this paper, complete the legend by entering the correct set ('P', 'Q', or 'R') next to each line style. In addition, draw a *qualitative* sketch of the missing curve in each panel. Provide a justification for your choices. Remember to hand in your completed copy of Fig. 1 with your answer to this question. [40%]

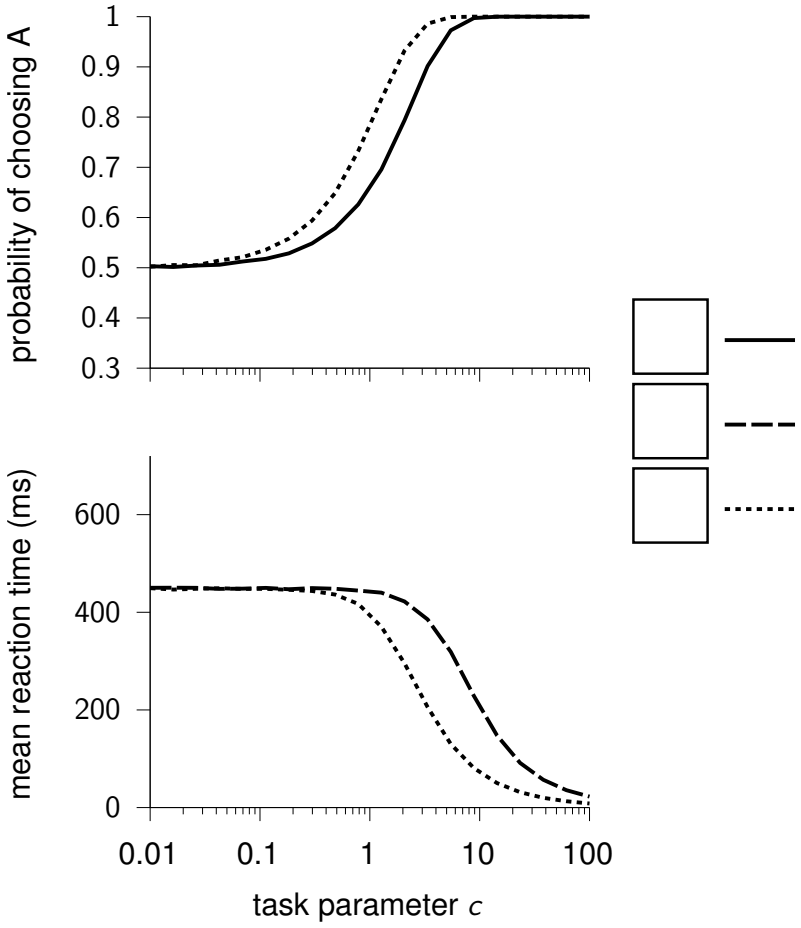
probability of choosing A
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
mean reaction time (ms)
600
400
200
0
0.01
0.1
1
10
100
task parameter c

Fig. 1

2 (a) Write short notes on the following:

(i) David Marr's three levels of understanding; [15%]

(ii) The action potential – in particular, what triggers it, and what terminates it. [15%]

(b) This part is about Bayesian inference in sensory perception. A subject is shown a brief flash of light at a random location x along a horizontal line. The location x is drawn from a Gaussian prior $p(x) = \mathcal{N}(x; 0, \sigma_p^2)$. The subject's sensory likelihood function is $p(s|x) \propto \mathcal{N}(x; s, \sigma_s^2)$.

(i) Give two biophysical reasons why σ_s cannot be zero. [10%]

(ii) Derive the posterior distribution $p(x|s)$. Explain how the subject should estimate x to minimize the expected squared error. [20%]

(iii) Assume that the subject's perception of the stimulus location conforms to Bayesian principles. Sketch the likelihood, prior distribution and posterior distribution on the same axes for $\sigma_p = 2$ cm and $\sigma_s = 1$ cm, for a trial for which the subject's perceived location turns out to be $\mu = 2$ cm. [10%]

(iv) What would the subject's estimate of x have been, in the same trial as in (iii), if the prior variance σ_p^2 had been halved? Justify your answer. [10%]

(v) A naive subject performs 100 consecutive trials of this task. The stimulus position x is drawn independently from $p(x)$ in each trial, and the subject is asked to report their estimate of it. It is found that the subject's mean squared error is lower in the second half of the trials, compared to the first half. How would the Bayesian perception hypothesis explain this? [20%]

3 (a) This part is about synaptic transmission. For each of the following manipulations, explain how pre- and postsynaptic signalling, with special regard to the PSP, changes in a glutamatergic synapse. All manipulations below keep the system in the physiological range to avoid depolarisation block or damage to cells.

(i) Increase in intracellular Na^+ concentration in the presynaptic cell. [10%]

(ii) Increase in intracellular Na^+ concentration in the postsynaptic cell. [10%]

(iii) Increase in extracellular Na^+ concentration. [10%]

(iv) Increase in intracellular K^+ concentration in the presynaptic cell. [10%]

(v) Increase in intracellular K^+ concentration in the postsynaptic cell. [10%]

(vi) Increase in extracellular K^+ concentration. [10%]

(b) This part is about conditioning in the Aplysia. For each of the pharmacological manipulations below, explain with reasons the effects it has on the gill withdrawal reflex, and its cellular mechanisms, before and after conditioning. Each pharmacological agent is applied throughout the experiment, CS+ is siphon touch, CS- is mantle shelf touch, and US is tail shock.

(i) Application of a selective serotonin re-uptake inhibitor in the synapse that connects the facilitating interneuron (of the tail pathway) to the sensory neuron (of the siphon pathway). [10%]

(ii) Application of AP5 in the (siphon) sensory neuron-motor neuron synapse. [10%]

(iii) Application of activated Ca^{2+} / calmodulin kinase in the motor neuron. (You can assume that the Ca^{2+} / calmodulin kinase plays a similar role as in hippocampal neurons.) [10%]

(iv) Application of lidocaine in the (siphon) sensory neuron. [10%]

4 (a) The following questions are about LTP.

(i) Describe the effect of an adenylyl cyclase blocker on LTP. [10%]

(ii) Describe the synaptic tagging problem. [10%]

(iii) Explain with reasons if the amplitude and latency of presynaptic stimulation-induced action potentials change following LTP. [10%]

(iv) Explain what LTD is. [10%]

(b) The following questions are about signals in a classical conditioning experiment with partial reinforcement in a rat. Explain with reasons what is expected for each of the signals below, in the given context, following the times of CS and US delivery.

(i) Reward prediction errors according to the Rescorla–Wagner rule after extensive training, when the learning rate is small or large, respectively. [15%]

(ii) Temporal difference prediction errors (their peak value) according to the temporal difference learning rule, when the learning rate is small or large, respectively. [15%]

(iii) The maximum of the across-trial average (peak) dopamine signal as a function of the reinforcement rate, r, in a modified version of the temporal difference prediction error model of dopamine signalling. In this version, dopamine (DA) is a piecewise linear function of the temporal difference prediction error (δ) with a non-zero baseline ($\alpha > 0$) and a larger sensitivity for positive than for negative prediction errors:

$$\mathrm{DA} = \begin{cases} 5\alpha\delta + \alpha & \text{if } \delta \geq 0 \\ \alpha\delta + \alpha & \text{otherwise.} \end{cases}$$

Express your answers in mathematical form as a function of α. [30%]

END OF PAPER

Version GH/3 Candidate Number:

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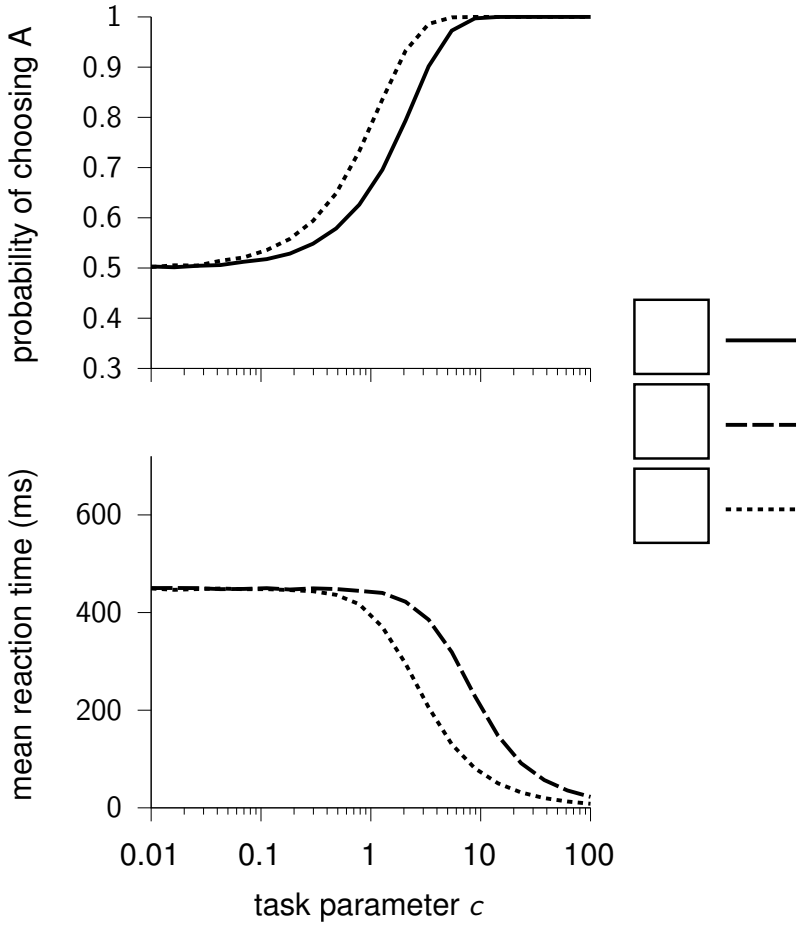
Monday 4 May 2026, Module 3G3, Question 1.



Additional copy of Fig. 1. This should be annotated as specified in Question 1, and handed in with your answers to that question.