Computational Neuroscience Exam
COMS30016

January 2022

Instructions to students

The exam has seven sections, corresponding to the seven weeks of teaching material. All questions are compulsory. You should consider it open-book in the sense that you can refer to the lecture notes.

Section 1: Brain basics (14 marks)

Q1. Roughly how many neurons does the human brain have? [3 marks]
a) 100 thousand
b) 100 million
c) 100 billion
d) 100 trillion
Ans: c (100 billion)

Q2. A person who is unable to experience fear might have damage to: [3 marks]
a) cortex
b) amygdala
c) hippocampus
d) cerebellum
Ans: b (amygdala)

Q3. When modelling neurons, where does the most important nonlinearity arise?[4 marks]
a) somatic spikes
b) synaptic transmission
c) axonal transmission
d) dendritic spikes
Ans: a (somatic spikes)

Q4. What are the advantages and disadvantages of patch clamp? [4 marks]
Ans: Advantage: get the membrane potential, which is much more informative than just spikes that we get from other methods [2 marks]. Disadvantage: only for one cell / fragile connection / difficult to do in vitro [2 marks].

Section 2: Differential equations, leaky integrate-and-fire neurons (14 marks)

Q1. Give the analytical solution to the following differential equation: $dy/dt = y/3 + 3$ with $y(t = 0) = 6$. What value will y converge to after a long time, $t \to \infty$? [4 marks]
Ans: Solution: $y = 15e^{t/3} - 9$ [3 marks] Converges to: ∞ [1 mark]

Q2. What are the steady-states of the differential equation $dy/dt = -(y+2)(y-2)(y-4)$? [4 marks]
Ans: $y = -2$, $y = 2$, $y = 4$ [4 marks]

Q3. A third order taylor series expansion has what approximation errors? [3 marks]
a) second order
b) third order
c) fourth order
d) fifth order
Ans: c (fourth order)

Q4. If the membrane timescale is 30 ms, what would be a sensible choice of timestep size for numerical integration? [3 marks]
a) 100 ms
b) 30 ms
c) 15 ms
d) 1 ms
Ans: d (1 ms)

Section 3: Hodgkin Huxley, modelling neurons, analysing spiking data (16 marks)

Q1. Which of these is NOT a potential advantage of an abstract model: [3 marks]
a) few parameters
b) fast simulation
c) analytic tractability
d) straightforward link to biology
Ans: d (straightforward link to biology)

Q2. Which ions depolarise the neural membrane potential? [3 marks]
a) sodium and calcium

b) sodium and potassium
c) sodium and chloride
d) calcium and potassium
Ans: a (sodium and calcium)

Q3. In the Hodgekin Huxley model, describe n, m and h [5 marks]?
Ans: n is potassium channel [1 mark], m is sodium activation [1 mark] and h is sodium inactivation [1 mark]. They range from 0 to 1 [1 mark], and obey their own voltage-dependent differential equations [1 mark].

Q4. The coefficient of variation (CV) and Fano Factor (FF) are two different measures of spike train variability. Define each measure and then comment on differences in which aspects of spike trains they are sensitive to. [5 marks]
Ans: The CV is the standard deviation of the interspike-interval divided by the mean, whereas the Fano Factor is the variance of the spike count divided by the mean [3 mark]. Since the CV operates on spike pair intervals, but the FF acts on spike counts over longer intervals, the CV is more sensitive to fine-timescale variability inherent in the data, whereas the FF can be sensitive to temporal correlations on experimentally-defined timescales [2 mark].

Section 4: Synapses, synaptic plasticity (7 marks)

Q1. Describe the mechanism of short term of short-term facilitation. [3 marks]
Ans: Multiple spikes causes calcium to build up on the pre-synaptic side, which encourages vesicle release.

Q2. Where is the dominant contribution to variability in the post synaptic potential? [3 marks]
a) presynaptic
b) postsynaptic
c) both
Ans: a (presynaptic)

Q3. Which ion flowing through which ion channel is believed to trigger plasticity? [4 marks]
a) Sodium flowing through AMPA receptors
b) Calcium flowing through AMPA receptors
c) Sodium flowing through NMDA receptors
d) Calcium flowing through NMDA receptors
Ans: d (Calcium flowing through NMDA receptors)

Q4. Give the standard equation for the change in weights under Hebbian plasticity. Describe why this rule is typically unstable [4 marks]. Ans: $\Delta w = \eta xy$ [2 marks]. Unstable because a small increase in w causes bigger y, and hence even bigger Δw [2 marks].

Section 5: Hippocampus, Hopfield networks (14 marks)

Q1. Why is pattern separation important? [3 marks]. Ans: to separate superficially similar but really distinct memories/experiences [3 marks].

Q2. What are the weights for a 2 state Hopfield network with 2 input patterns $x_1 = (-1, 1)$, $x_2 = (1, -1)$? [4 marks]
a) (0 1; 1 0)
b) (0 0; 0 0)
c) (0 -1; -1 0)
d) (0 -0.5; -0.5 0)
Ans: c (0 -1; -1 0) [4 marks]

Q3. In the Hopfield network from the previous question, if we start at $x = (1, 1)$ and asynchronously update the first neuron, then the second neuron, what is the output pattern? [4 marks]
a) (1, 1)
b) (-1, 1)
c) (1, -1)
d) (-1, -1)
Ans: b (-1, 1) [4 marks]

Q4. Which region within hippocampus contains recurrent excitatory activity, and therefore might contain attractors? [3 marks]
a) Dentate Gyrus
b) CA1
c) CA3
d) Subiculum
Ans: c (CA3) [3 marks]

Section 6: Visual system, rate coding (14 marks)

Q1. Which of these firing rate curves accounts for Weber's law? [3 marks]
a) $r(x) = \alpha e^{(x-x_0)^2/(2\ell^2)}$
b) $r(x) = \alpha \log(x)$
c) $r(x) = \alpha x + b$
d) $r(x) = \alpha x^2 + bx + c$
Ans: b ($r(x) = \alpha \log(x)$)

Q2. Which cell type might we describe using difference-of-Gaussians tuning curve [4 marks]
a) retinal ganglion cell
b) V1 simple cell
c) V1 complex cell

d) V4 cell
Ans: a (retinal ganlion cell)

Q3: V1 complex cells differ from simple cells in that they display more: [3 marks]
a) frequency invariance
b) orientation invariance
c) phase invariance
d) amplitude invariance
Ans: c (phase invariance)

Q4: Which experimental stimulus might a V1 simple cell respond most strongly to? [4 marks]
a) a circular spot of light surrounded by darkness
b) an oriented "edge"
c) a person's face
d) a random checkerboard
Ans: b (an oriented "edge")

Section 7: Supervised learning, Cerebellum, temporal difference learning (7 marks)

Q1. Consider the delta rule, where we initially have $w = (-1, 1)$. We then do TWO delta-rule updates, with $x = (1, 1)$, a target of $y^* = 2$, and a learning rate of $\nu = 0.2$. What are the final weights? [4 marks]
a) $w = (-0.6, 1.6)$
b) $w = (0.3, 1.3)$
c) $w = (0.32, 1.32)$
d) $w = (0.4, 1.4)$
Ans: c (First update: $\hat{y} = 0$, $\delta = 2$, $\delta \times \nu = 0.4$, $w = (-0.6, 1.4)$. Second update: $\hat{y} = 0.8$, $\delta = 1.2$, $\delta \times \nu = 0.24$, $w = (-0.36, 1.64)$)

Q2. Which type of learning is the cerebellum thought to perform? [3 marks]
a) Supervised learning
b) Unsupervised learning
c) Reinforcement learning
d) All of the above
Ans: a (supervised learning)

Q3. Dopaminergic cells are believed to fire in response to: [4 marks]
a) all rewards
b) unexpected rewards
c) all punishments
d) unexpected punishments
Ans: b (unexpected rewards)

Q4. Which of these isn't an unusual feature of cerebellar Purkinje cells: [3 marks]
a) Unusually large number of inputs ($\sim 100,000$).
b) Unusually large firing rate (~ 50 Hz).
c) Unusual spiking.
d) Unusual synapses.
Ans: d (Unusual synapses; we spiking is unusual due to simple + complex spikes)