Study guide for Midterm 1

9.40 Introduction to Neural Computation

Spring 2018

Useful formulas and constants:

T(Kelvin)=T(Celsius)+273
$k=1.38\times10^{-23}$ J/K Boltzmann constant
$e=1.6\times10^{-19}$ C Elementary charge
1 mol= 6.02×10^{23} Avogadro's number

Notes:

1. You will need a calculator for the exam.
2. There are no programming nor MATLAB based questions on the exam.
3. For all the plots, it is important to label the axes with units and numbers where relevant.

Important note:
On the exam, the sections 1 to 4 inclusive will be based on the biophysics of the alga *Chara sp.* This alga is capable of producing action potentials that are mainly driven by a voltage and time dependent chloride conductance. In these algae the sodium, potassium and chloride intracellular concentrations are much higher that their extracellular counterparts.

1. *Basic neuronal biophysics*

For a neuron with surface area A, specific membrane capacitance c_m, and a single ionic conductance with specific membrane conductance g_m, we expect you to know how to:

- Compute the total membrane capacitance.
- Compute the total membrane conductance and resistance.
- Compute the membrane time constant.
- Quantitatively compute how much current is required to hold the cell at a given membrane potential.
- Calculate how long it takes for the membrane potential to relax from V_0 to a given membrane potential, under a constant current injection.

2. *Equivalent circuit model*

We will consider cell models with one or more ionic channels of the type discussed in class. For these models, we expect you to know how to:

- Draw the equivalent cell circuit including an external current source and a membrane potential measuring device.
- Use Kirchoff's law to write an equation that relates all of the different sources of current flow in a given circuit.
- Use Ohm's law and the I-V relation for s capacitor to Write the differential equation that relates the membrane potential to the different sources of current.
- Derive equations for the steady state membrane potential, and the time constant.

3. *Nernst potential*

Given intra- and extra-cellular concentrations of different monovalent and bivalent ions, we want you to know how to:

- Compute the Nernst potential of the given ions at different temperatures.
- Compute the time constant with which V_m approaches the Nernst potential from any other holding membrane potential.
- Compute the number of ions that move across the membrane during the above process.
- Determine if these ions move into or out of the cell.

4. *Ion channels: conductance and currents*

For different ion channels, we expect you to know how to:

- Write the equation that relates membrane ionic current to the membrane potential.
- Qualitatively plot the sigmoidal activation function (total conductance as a function of membrane potential) for a given channel.
- Qualitatively plot the I-V (current-membrane potential) relationship for a specific ion channel.

5. *Hodgkin-Huxley model of the action potential*

We expect you to know how to:

- Draw the equivalent electric circuit for the Hodgkin-Huxley model.
- Write down the differential equations for the time evolution of the gating variables n and m in terms of rate constants α & β for the potassium and sodium channels.
- Derive and write down expressions for the steady state value and the time constants for n and m in terms of the rate constants α & β.
- Write down the probability that a sodium or potassium channel is in the open state in terms of their gating variables.
- Explain the difference between: activation, disactivation, inactivation and disinactivation.
- Qualitatively plot m_∞, h_∞, and n_∞ as a function of membrane potential.
- Qualitatively plot or interpret plots involving ionic currents and gating variables during a voltage step in a voltage clamp experiment.

6. *Integrate-and-Fire Neuron*

For the integrate –and-fire model with and without leak, we expect you to know how to:

- Plot the membrane potential as a function of time when the cell is stimulated with a square pulse of current.
- Compute the steady-state firing rate of the cell (for the no leak case).
- Compute the rheobase.

7. *Dendrites*

Consider an infinitely long dendrite of uniform diameter (D). A constant positive current is injected at a point at the center of this dendrite. For this dendrite, we expect you to know how to:

- Plot the steady-state membrane potential as a function of position, along the dendrite.
- State the functional form of this membrane potential profile.

Additionally, you should be able to estimate:

- The electrotonic length of a dendrite from a plot of membrane potential as a function of distance from the current injection point.

- The diffusion coefficient of a dye, given the time it takes to diffuse down the dendrite.

8. *Synapses*

- Draw the circuit model of a synapse and write the equation for the synaptic current as a function of the membrane potential and the values of the circuit components.
- Plot the synaptic conductance as a function of time after release of neurotransmitter.
- Qualitatively plot the postsynaptic current for excitatory (glutamate) or inhibitory (GABA) synapses while the membrane potential is held at different fixed values (voltage clamp).