Computational Neuroscience EC60007

Mid-semester Examination Autumn 2015

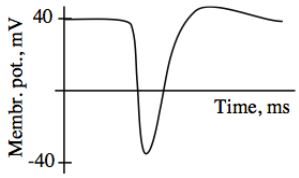
Exam Date: 13/9/2015, 10am-12:30 pm

Examination is open book, notes and printed/written materials. No electronic devices allowed. Question paper has 2 pages. You can bring external memory storage devices that you can look into in laptops provided.
Try to answer as many questions as you can.
Marks for each question given in [ ] before question number

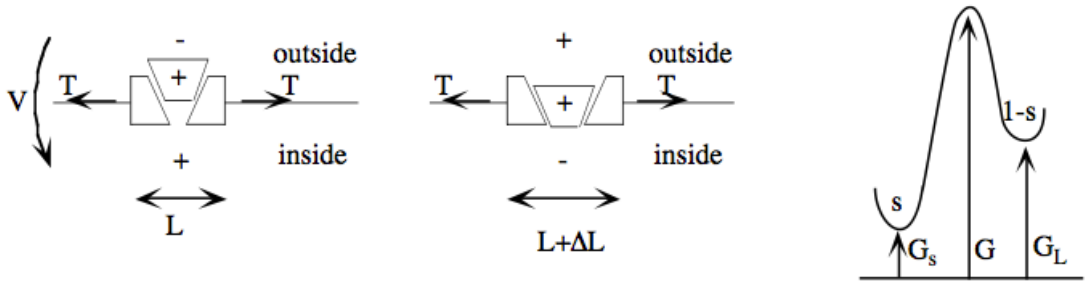
[6] 1) Consider a cell with ion concentrations inside and outside given in the table (in mM).

Ion	Inside	Outside
Sodium	15	140
Potassium	135	5
Calcium	10^{-4}	2
Chloride	22	135

Draw an electrical circuit for ion flow through the membrane of the cell, assuming all ions are permeant. (Label the batteries)
Suppose the Cl^- conductivity of this membrane is very small (ordinarily) and the resting potential is -60 mV. What will be the effect of opening of Cl^- channels on the membrane potential? Which direction would the ions flow?
Now consider a cell from an alien species (you have a PPO from ISRO) with the same ions (at same concentrations) inside and outside the cell. It is found that the resting potential is +40 mV and action potentials are as sketched in the figure. Assuming that the basic mechanisms and gating of ion channels are similar to those that we are familiar with, explain with equations clearly how such action potentials could be generated (there are many ways). If you are given added information that the extracellular Ca^{2+} and K^+ concentrations have no effect, what is the most likely mechanism?



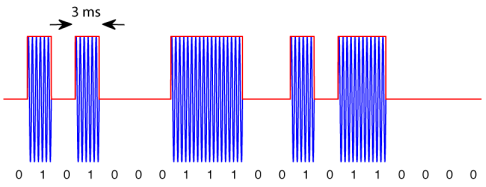
[8] 2) A particular cell membrane has a special protein called *Pullein* which serves to transduce membrane potential into movement. When the cell is depolarized *Pullien* changes its cross-sectional area – many proteins together cause the cell to change its length (and surface area). An approximate representation of the changes in 1-dimension is shown in the plot below. The protein has a plug with a positive charge



and that acts as voltage sensor and moves in or out of the membrane based on the membrane potential V (positive V repels and negative V attracts the plug. In the repelled state the cross-section length is L (short) and in the other state it is increased (long). Assume that there is a constant tension T with which the membrane pulls the protein (as indicated). Assume that the movement of the plug is characterized by the barrier diagram on the right [from the short state (fraction s) to the long state (fraction

(1-*s*)]. This does not include the mechanical energy change for *T* or electrical energy change for charge movement.
Show how *s* is like an Hodgkin Huxley gating variable (write equivalent equations).
When a step in *T* (and also separately *V*) is applied to the cell, while you are recording membrane currents (assume no ion channels are present), derive what currents will be observed.

[7] 3. Consider a discrete stimulus $x[n]$ (red line) as shown below (the blue carrier and bin size 3 ms, is irrelevant for the problem), where at each n, x takes on a value +1 or 0 (like the sequence given below the trace) with equal probability. The response rate of a neuron to such a stimulus is measured in each time bin (n) as $r[n]$. If the response of the neuron in each bin is modeled by $r_e[n]$ a random variable that is distributed Poisson with rate $\mathbf{w}^T\mathbf{s}[n]+r_0$, where $\mathbf{w}^T$ is the spike triggered average (obtained for the same neuron) and $\mathbf{s}[n]=[x[n\text{-}1]\ x[n\text{-}2]\ x[n\text{-}3]\ \ldots\ x[n\text{-}N]]^T$, what is the mutual information between the response and the stimulus **s** captured by the model?



[9] 4. The pre-synaptic neurons (E and I) of an excitatory synapse and an inhibitory synapse of a post-synaptic neuron (O) produce action potentials given by $\sum_{k=1}^{M_E}\delta(t-t_k^E)$ and $\sum_{j=1}^{M_I}\delta(t-t_j^I)$ over a long period of time. These spike trains have a cross-correlation function $R_{EI}[\tau]$, which is known. For each spike in the pre-synapse there is a membrane potential change in time given by $v_e(t)$ and $-v_i(t)$ in EX and IN synapse respectively, that you need to be determine. Assume that the O spike train is given by $\sum_{m=1}^{M_O}\delta(t-t_m^O)$ in the same time interval. First write out the membrane potential change for each of the input spike trains. Assume that the linear sum of the membrane potential changes is produced (with each synapse acting independently). This final expression is passed through a static nonlinearity that drives the point process output of the O neuron. How will you find $v_e(t)$ and $-v_i(t)$ given all the 3 spike trains (if possible).
It may help to start with just the E pre-synaptic input.