CNS 221, Spring 2006, Homework set III – 30% of total grade

(Due: May, 30th; noon in mailbox in front of 200BBB)

Question 1 Trace rule (50%) – (Földiak, 1991)

In the present question, you will deal with the trace-rule as presented in Földiak's 1991 paper. You can answer the questions by paper and pencil (not recommended), by using your own code or by downloading the matlab code from the class-homepage http://www.klab.caltech.edu/~wet/cns221/traceRule.m . It will also help if you read the original paper (Földiak, 1991) again and maybe refresh your knowledge of Hubel and Wiesel's classical experiments. If you have trouble getting the paper, send us an email.

a) Define appropriate measures for the specificity (as compared to invariance) of your simulated cells to orientation and position of a stimulus. Using Földiak's original parameters, how do these measures develop over "sweeps"? Use your measures to argue in what respect the resulting cells resemble complex cells?

b) Change delta (the parameter for the trace) to 1. What type of learning rule do you have now? Do you still get complex cells? Use your measures of a) to characterize the cells. Does this mean they are simple cells now? Provide an intuition why complex cells require time dependent learning? Plot your measures as function of sweep number for different values of delta {0.1,0.2,0.5,1}.

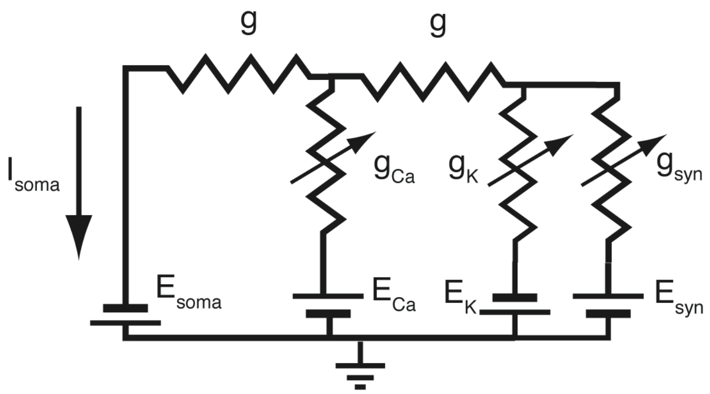
c) What would you need to do the input, to achieve the same devastating effect on complex cells as setting delta = 1? Based on this result, how would you test experimentally (e.g. in the cat or the ferret) whether input structure plays a role in the development of complex cells? What are possible problems to this approach?

d) Back at delta=0.2, what happens if you increase the number of complex cells, what if you decrease them? Why?

e) On a first glance, it seems as if there were no lateral coupling between the complex cells. However, if you have as many complex cells as orientations, every cell will pick exactly one orientation and each orientation will be picked exactly once. Which part of the learning rule guarantees this (You can test whether this is true by switching this part of in the simulation)? What alternative can you think of to guarantee such a behavior? How would approximate such a rule in (neuronal) hardware?

Question 2 Amplification / Linearization by active channels (25%)

Consider the following "compartemental" model (Bernander et al., 1994) for distal synaptic input to a pyramidal cell. Your model has just 3 compartments: To the right of the plot you have the "apical tuft" of your cell with your synapse and potassium conductance. The apical trunk includes an active calcium conductance and your soma is represented to the left.



E_{soma} = -50 mV is your average somatic potential (this includes spikes), you assume steady state and negligible leak conductance (compared to the axial conductance). For your calculations, assume further the reversal potential of Calcium to be 115mV, of potassium –95mV and your synaptic reversal potential is 0mV. Your axial conductances are g = 40nS.

a) First consider the purely passive case. Plot $I_{soma,passive}$ as a function of g_{syn}. What is the asymptotic value for $I_{soma,passive}$ for large g_{syn}?

b) Now we use the potassium conductance to "linearize" I_{soma} as function of g_{syn}. This means we want to arrive at an expression $I_{soma,linearized} = \kappa\, g_{syn}$ by choosing an appropriate $g_K(V)$. Derive this function analytically and plot it for some different values of κ, including $\kappa = 5\,mV$. To increase realism we first set $g_{K,rectified}(V) = \max(g_K(V),0)$ to avoid negative conductances and $g_{K,monoton}(V) = \max(g_K(V))$ for $V > \operatorname{argmax}(g_K(V))$. Plot I_{soma} as function of g_{syn} for $g_K(V)$, $g_{K,rectified}(V)$, and $g_{K,monoton}(V)$ for κ= 5mV.

c) Now we use the Calcium conductance to amplify the linearized relation $I_{soma,amplified}=\kappa_2 I_{soma,linearized}$. Use all of the three versions $g_{K,.}(V)$ you derived in b) and assume $\kappa_2=2$ (and again κ= 5mV) to the respective curves for $g_{Ca}(V)$.

Question 3 GHK equation (25%)

In class, we have spoken about the conditions that allow us to use the Ohmic approximation of current flux rather than the more accurate Goldman-Hodgkin-Katz equation.

$$
\begin{aligned}
V_s &= z_s \frac{E_m F}{RT} \\
\overrightarrow{I} &= P_s z_s F V_s \frac{[ion]_i}{1-\exp(-V_s)} \\
\overleftarrow{I} &= P_s z_s F V_s \frac{[ion]_o}{1-\exp(V_s)} \\
I_{total} &= \overrightarrow{I} + \overleftarrow{I}
\end{aligned}
$$

Where:
F=Faradays Constant
R=the Gas Constant
T= the absolute temperature

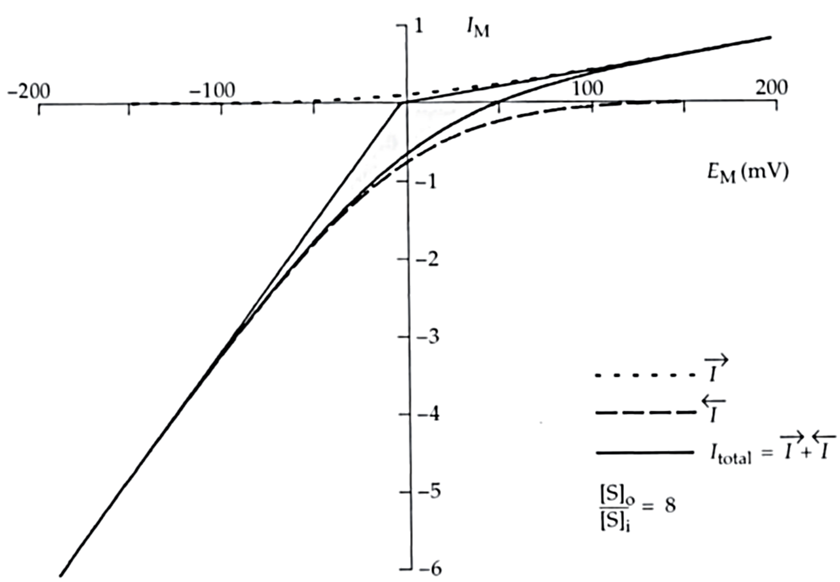


Figure from *Ion Channels of Excitable Membranes* Hille '92

a. Produce a plot similar to figure 2 for Ca^{2+} at the CNS spine. Use the ionic concentrations given during the lecture on Monday. State what you are seeing in this plot, what is happening?

b. What would a plot of the Ohmic approximation look like? Feel free to include a rough sketch of it on your plot.

c. What would you expect if you were to consider Na^{+} for the above parts of this question rather than Ca^{2+}?