

Homework 3: Due Oct 19 2011

1. The Connor-Stevens model is the first model to incorporate the A-type potassium channel. The equations for it are in Dayan & Abbott, but they are slightly different than the version that I have as the delayed rectifier is not multiplied by the temperature factor. I will put my version of them online so you can use them. Simulate the CS model for 200 msec, starting from rest and at $t=60$ inject a square wave of current for the remaining 140 msec. Plot $V(t)$ as you inject 5, 10, 15 $\mu A/cm^2$ of current. Plot the time from the stimulus to the first spike as you vary the current from 8 to 10 in steps of 0.2 $\mu A/cm^2$. Now multiply the db/dt equation by 0.25 to make the inactivation of the A-current slower. Inject $I = 15\mu A/cm^2$ current and plot the voltage response. Note the very long delay to spike, but that the interspike interval after the first spike is quite short. Explain what is going on. What type of axon is the CS: Class I, Class II, or Class II?
2. The Destexhe-Pare model (`dp.ode`) is a model for a cortical pyramidal neuron has a transient sodium, leak, delayed rectifier, and a slow potassium current that acts near rest. I have posted the model online with all the gating variables and the currents and conductances. Inject a constant current of 5 $\mu A/cm^2$ and plot the ISI's over a period of 1000 seconds. As there is spike frequency adaptation, you will get about 60 spikes ranging from 9-20 msec ISI. What is the minimum steady-state frequency that you can get (the current needed to get repetitive firing at the minimal rate is between 3 and 4 $\mu A/cm^2$.) Set $g_{km} = 0$ which removes the adaptation. What is the minimum frequency possible in this case (it happens between 0 and 1 $\mu A/cm^2$. The M -current changes the neuron from Class II to Class I.
3. Using the currents for the above Destexhe-Pare model without the M-type potassium current, add an L-type calcium current, some calcium dynamics, and an calcium-dependent potassium current. Choose $g_{ca} = 1$ and $g_{ahp} = 2$ and repeat the first part of the previous exercise. (This current is part of the model)
4. Build a 4 compartment model that consists of a three compartment apical dendrite and a soma. The soma compartment is a cylinder that is 10 microns long with a radius of 4 microns. The three dendrite compartments are 10 microns long with a radius of 2 microns. The dendrites are passive with $i_m(V) = g_L(V - E_L)$ and $g_L = .05mS/cm^2$ and $E_L = -65$ mV. The soma uses the same parameters as the Hodgkin-Huxley model. The capacitance is $c_m = 1\mu F/cm^2$. Inject current directly. Use $r_L = 100\Omega - cm$. (Part of this exercise is to compute the coupling coefficients between the soma and the dendrites; recall that you need to compute the area of the cylinders and the longitudinal resistance). Simulate this system for 100 msec starting at the resting state (about -65 mV) for each compartment

as follows. Find the minimal current needed to elicit a somatic spike when injecting a 10 msec current pulse at $t = 50\text{msec}$ into the soma, and each of the three dendritic compartments. Plot the voltages of all 4 compartments. Now, add a high-threshold calcium current to the dendrites:

$$I_{ca} = 0.25/(1 + \exp(-(V + 25)/5))(V - 120)$$

Inject a 10 msec pulse of current into the soma that is enough to elicit a spike. Simulate this for 200 msec. What happens? You have made the system bistable, the calcium currents in the dendrites turn on and this then produces repetitive firing in the soma. Can you turn the system on with a stimulus to the last compartment?

5. Here is a simplified model for a T-type calcium current `tcurrent.ode`

```
# T-current model
init v=-94,ht=.95
par I=0,c=.29
par ip=0,t_on=50,t_off=150
v'=(I -ileak-it+istep(t))/c
istep(t)=ip*heav(t-t_on)*heav(t_off-t)
# the current is a step function with amplitude ip
# passive leaks
par ena=45,ek=-105,eca=145
par gkleak=.007,gnaleak=.0005
Ileak=gkleak*(v-ek)+gnaleak*(v-ena)
#
aux i_leak=ileak
#
# IT and calcium dynamics -- transient low threshold
# permeabilites in 10-6 cm3/sec
#
par gt=2
mt=1/(1+exp(-(v+52)/7.4))
IT=gt*ht*mt2*(v-eca)
htinf=1/(1+exp((v+80)/5))
tauht=22.7+.27/(exp((v+48)/4)+exp(-(v+407)/50))
ht'=(htinf-ht)/tauht
@ dt=.25,total=500,xp=v,yp=ht,xlo=-100,xhi=40,ylo=-.1,yhi=1
@ nmesh=100,bounds=1000
done
```

In XPP this is set up for a phaseplane. You can also do this in MatLab, probably using PPLANE. The axes should be $-100 < V < 40$ and $-0.1 < h < 1$. Answer the following questions. Also, when asked to draw the phaseplane, please include a picture of the phaseplane in your answers.

- (a) How many fixed points are there? Which are stable? (In XPP, you can check stability by clicking on Sing Pts, Mouse, and then touching the intersection of two nullclines.) Or, you can just start near one and integrate forward in time.
- (b) Starting at rest, would a depolarizing or hyperpolarizing stimulus elicit a spike? Try using i_p small positive and negative to verify your answer. (This produces a 100 msec pulse of current)
- (c) Change $g_{NaLeak} = .001$ and redraw the nullclines. How many fixed points are there and what is their stability?
- (d) Integrate the equations. What behavior do you find? (Don't forget to set $i_p=0$.)
- (e) Increase the sodium leak to 0.003. Draw the nullclines. It might help to change the y-axis to $-.05$ to $.1$. How could one elicit a spike in this case? (Hint, what does changing the current, I do to the nullclines. Try $I=-.25, .25$ to see what happens to the fixed point.)
- (f) Set $I=0$ and try different values for the current pulse, i_p say $-.25$ and $.25$. You should be able to see a rebound calcium spike.