Introduction to Computational Neuroscience (Spring 2018)

The Hodgkin-Huxley model

In this exercise we will explore the Hodgkin-Huxley model for electrical impulses. There are 4 differential equations:

$$
\begin{aligned}
\frac{dV}{dt} &= [I_{ap} - I_{Na} - I_K - I_L]/c \\
\frac{dm}{dt} &= \frac{m_\infty(V) - m}{\tau_m(V)} \\
\frac{dn}{dt} &= \frac{n_\infty(V) - n}{\tau_n(V)} \\
\frac{dh}{dt} &= \frac{h_\infty(V) - h}{\tau_h(V)}
\end{aligned}
$$

where m is an activation variable for $\mathrm{I_{Na}}$, n is an activation variable for $\mathrm{I_K}$, and h is an inactivation variable for $\mathrm{I_{Na}}$.

An XPP file for the Hodgkin-Huxley model

The computer code for this model, **HH.ode**, can be downloaded from my website (www.math.fsu.edu/∼bertram/course_software). In this program, a pulse of applied current is given and the 4 variables respond to it. Note that there are some additional auxiliary variables so that you can view them.

Exploration

(1) Run the program and you should see an action potential. This is because of the applied current. In a separate window view the applied current. Is this a depolarizing or hyperpolarizing current?

(2) In a separate window plot m. Why does it increase during the beginning of a spike? This is called **activation**. Why does it decrease after that? This is called **deactivation**. When m is elevated what happens to the Na^+ conductance? To check, open a new window and plot gNa.

(3) Superimpose a plot of h in your m vs. t window. Why does h go down during a spike? (This is called **inactivation**.) Why does it rise at the end of a spike? Does h change faster or slower than m? What is the effect of the declining h on the Na^+ conductance?

(4) Now superimpose n onto the same window. Why does it rise during a spike? What is its activation time scale relative to that of m (i.e., is it faster or slower)? In the same window as gNa plot the K^+ conductance gK. Which conductance rises faster? What would happen if it were the other way around?

(5) In a separate window plot the superimposed Na^+ and K^+ driving forces, $Kdrive$ and $Nadrive$. Why is one positive and the other negative? What effect would the time-dependent changes in $Kdrive$ have on the K^+ current? What effect would changes in $Nadrive$ have on Na^+ current?

(6) In a separate window plot the Na^+ current, I_{Na}. Why is it negative? You should see a shoulder as I_{Na} is declining, what causes this? To answer this, it will probably help to reset your xmin and xmax values in appropriate windows to zoom in on the action. **XPP trick:** if you set the cursor at a point on the active window and click with the middle button on the mouse or do a two-finger click on the track pad then the x- and y-coordinates of that point will show up on the bottom of the window. Using this trick, you can determine when different things reach their peaks.

(7) In the same window as I_{Na} now superimpose the K^+ and leak currents, I_K and I_L. Why is the K^+ current positive? Why is the leak current sometimes positive and sometimes negative?

(8) If you now increase the total integration time from 50 ms to 70 ms you should see another spike. Why does voltage continue to depolarize after the first spike, leading to a second spike? Looking at the total current, I_{tot}, will help you answer this. If you look at the activation variables, you'll see that m goes to almost 0 between spikes, but n never gets that low. What does this mean in terms of the ion channels? Likewise, h never really gets to a value of 1. What does this mean in terms of the ion channels?