Circuits and Computational Neuroscience
Neurosci 613 Fall 2014
Computer Lab 1

Due: Friday, November 14 by 5pm

1. In numerical simulations of the Hodgkin-Huxley equations, investigate the voltage and current thresholds for action potential generation. Begin your simulations with the neuron at resting potential, then at time=100 ms, apply current pulses of varying amplitudes that last until t=1100 ms. Determine values for your answers to at least 2 decimal places and provide example voltage time trace plots.
    a. The rheobase is the minimal current of infinite duration that results in at least one action potential. What is the rheobase current for the Hodgkin-Huxley model (where we are assuming that 1s is infinite duration for the neuron)?
    b. As the applied current level is increased from rheobase, several action potentials may be fired but membrane potential will eventually equilibrate and remain steady at a level above resting potential by the end of the current pulse. Find the maximum steady state voltage level that the model neuron can maintain at the end of a current pulse which does not induce continuous repetitive firing of action potentials. What is the applied current value to reach that voltage?
    c. What is the minimum applied current value that induces continuous repetitive firing of action potentials to the end of the current pulse?
2. Numerically compute the frequency-current relation for the Hodgkin-Huxley model. Begin your simulations with the neuron at rest and at time t=100 ms, apply 1000 ms long current pulses of varying amplitudes to generate repetitively firing action potentials. Provide example voltage time trace plots.
    a. For applied current density levels up to 60 $\mu A/cm^2$, determine the frequency of the repetitive action potentials and plot the frequency versus the applied current density. Plot frequency in Hz.
    b. What happens to the action potential firing for applied current densities above 60 $\mu A/cm^2$?
    c. At what applied current density does the phenomenon known as "depolarization block" (when the membrane is too depolarized to support any sustained spiking or oscillatory activity) occur?
    d. Discuss any limitations of the Hodgkin-Huxley model in replicating neuron firing and any constraints on its use to ensure the model accurately reflects the behavior of real neurons.
3. In numerical simulations of the Hodgkin-Huxley model, illustrate that generation of subsequent action potentials is somewhat inhibited during the afterhyperpolarization following an action potential or the "relative refractory period". For example, identify a small amplitude, short duration current pulse that can induce an action potential from resting membrane potential, but does not induce a spike if it is delivered during the refractory period. Provide voltage time trace plots of your illustration.
4. Consider the leaky integrate-and-fire (LIF) model: $c_M \frac{dV}{dt} = -g_L(V - E_L) + I_{app}$ with E_L = -65 mV, V_{th} = -55 mV, V_{reset} = -70mV, c_M = 1 $\mu F/cm^2$, and g_L = 0.01 mS/cm^2.
    a. Numerically determine the current and voltage thresholds for firing up to 2 decimal

places. Provide example voltage time trace plots.

b. Numerically compute the frequency-current plot of the LIF model for I_{app} values between 0 and 2 $\mu A/cm^2$. Plot the frequency in Hz.

c. Discuss qualitative similarities and differences between the f-I curves for the LIF and H-H models. Compare the frequencies at current threshold for firing.