Exam 2: Information coding, plus review

Answer all **4** questions

Due: Thursday, March 13th, 2007

1. Spiking neuron models: In this question you will modify the integrate-and-fire neuron you simulated for Homework 4 (question 2):

$$\tau_m \frac{dV(t)}{dt} = E_{leak} - V(t) + R_m I(t)$$

Part A:

Add an additional current to the model to provide spike-rate adaptation:

$$\tau_m \frac{dV(t)}{dt} = E_{leak} - V(t) - r_m g_{rsa}(V - E_K) + R_m I(t)$$

where

$$\tau_{rsa} \frac{dg_{rsa}}{dt} = -g_{rsa}$$

Use parameters from your original model plus appropriate values for τ_{rsa} and r_m to demonstrate the spike-rate adaptation. Experiment with these values to learn about the behavior of your neuron. Provide plots of the change in conductance over time and of the membrane voltage as a function of time. Why does this neuron adapt its firing rate?

Part B:

How could you use a conductance like this to model absolute and relative refractory periods? Demonstrate with your model.

2. Population decoding: Simulate the responses of four inter-neurons in the cercal system of the cricket and check the accuracy of a vector decoding scheme:

Part A:

For a true wind direction θ_i the average firing rates of the four inter-neurons should be generated as: $\langle r_i \rangle = [50\cos(\theta - \theta_i]_+$ where $[\ ]_+$ is half-wave rectification, and $\theta_i = \pi/4,\ 3\pi/4,\ 5\pi/4,$ and $7\pi/4$ for each of the *i* neurons (1, 2, 3, 4). The actual rates r_i should then be obtained by adding Gaussian noise with zero mean and 5 Hz standard deviation. (Set any negative values to 0.) From these rates, construct the x and y components of a population vector:

$$x = \sum_{i=1}^{4} r_i \cos(\theta_i) \quad \text{and} \quad y = \sum_{i=1}^{4} r_i \sin(\theta_i)$$

From the direction of this vector, compute an estimate θ_{est} of the true wind direction.

A. Plot the estimated wind direction against the true wind direction.

B. Average the error $\sqrt{(\theta - \theta_{est})^2}$ over 1000 trials with different actual wind directions, and plot the error as a function of θ over the range $-\pi/2 \le \theta \le \pi/2$.

Part B:

What is the source of the error? How could the model be changed to reduce the error?

3. Phase Plane analysis: The Fitzhugh-Nagumo equations provide an intentionally simple model of action potential generation that describes the interaction between voltage V across the axon membrane (which is driven by an input current I_{input}) and a recovery variable R (that can be thought of as reflecting the outward K^+ current resulting in the hyper-polarization after a spike). One formulation of these equations is:

$$\frac{dV}{dt} = \frac{1}{\tau}\left(V - \frac{V^3}{3} - R + I_{input}\right)$$

$$\frac{dR}{dt} = \frac{1}{\tau_R}\left(-R + 1.25V + 1.5\right)$$

with τ=0.1 and τ_R=1.25. These are the versions of the Fitzhugh-Nagumo equations we discussed in class.

Part A:

Determine the nature of the equilibrium points for I_{input}=1.0mA, and for I_{input}=1.1mA. For each of these points, determine their stability and predict the trajectories around the points. What behavior would you expect the neuron to exhibit with each of these input currents? Why?

Part B:

Confirm your predictions of part A using the Matlab program **FH_run.m**. Save the figures to demonstrate the membrane potential and the phase plane results.

What is the minimum current (in 0.1mA resolution) needed to generate an action potential? Explain why this is true (in terms of what happens to the equilibrium point at this current level).

4. Course review: Provide short (1 paragraph) answers to each of the following questions. We are looking for an ***explanation*** that demonstrates your understanding (not a simulation). Please keep your answers concise. Answer all parts.
   - **A.** We know that channels for the L (high-threshold calcium) current are located primarily near the cells bodies and proximal dendrites of cells, whereas the T (low-threshold calcium) current is primarily located in distal dendrites. Based on the biophysical properties of these currents, why does this make sense?
   - **B.** Explain (in terms of their dynamical system or their biophysical properties) how mutually inhibitory neurons could exhibit phase locking.
   - **C.** What happens when an inhibitory synapse has a reversal potential very close to the resting potential of the cell? How does its effect on the membrane potential interact with that of nearby excitatory inputs? What location should such a synapse have to have its maximal effect?
   - **D.** Explain what might account for the stochastic nature of neuronal firing. Why is the simple Poisson neuron a reasonable model for this stochastic nature? What are two things that it fails to account for?