CAAM/NEUR 415: EXAMINATION #2

December 1, 2010

1 Answer the following questions (total 26 points):

1. What are the two main assumptions made by the quantal model of synaptic release about the release of neurotransmitter at a chemical synapse? At a typical synapse in the central nervous system, would you expect the binomial or the Poisson version of the model to better describe synaptic release? Briefly justify your answer. (4 points)

2. Assume an AMPA synapse is activated in a neuron at rest (-70 mV) or at a depolarized membrane potential (40 mV above rest). Do you expect more current to flow through the channel at rest or in the depolarized state? Briefly explain why. (2 points)

3. State one biophysical mechanism responsible for the generation of bursts in neurons and briefly explain how it works. Which short-term synaptic plasticity mechanism would make a postsynaptic cell more likely to fire an action potential in response to a pre-synaptic burst of action potentials? (4 points)

4. Explain the difference between a separable and inseparable receptive field for a neuron in the visual system. Give an example of a neuron with an inseparable receptive field. (3 points)

5. Your friend the neurophysiologist McAdrian has discovered a new neuron type in visual cortex and claims that its receptive field can be described by a linear weighting function. How would you test whether the claim is valid? (3 points)

6. What is the typical value of the coefficient of variation of a visual cortical neuron? Assuming that the spike trains of such a neuron are a renewal process, which value do you expect for the Fano factor over long time intervals (e.g., longer than 1 second)? Briefly justify your answer. (3 points)

7. How does the temporal power spectrum of natural scenes decay as a function of frequency and how does that decay compare with that of white Gaussian noise? Briefly explain what time-varying property of natural scenes gives rise to this type of power spectrum decay. (3 points)

8. You discovered a neuron in the visual system of a martian worm that responds with either 2 or with 3 spikes when no light flash is presented to the retina of the animal. The probabilities are 1/4 and 3/4, respectively, for 2 or 3 spikes under this condition. When a weak light flash is presented, the number of spikes is either 3 or 4 with probabilities 1/4 and 3/4, respectively. What is the treshold number of spikes

that you should use (either 2, 3 or 4 spikes) to call the stimulus present if you are to minimize the error rate in a task where the flash is presented at random in half of the trials? Briefly justify your answer. (4 points).

2 Theory and practice of Fourier transforms (total 25 points)

The function

$$f(t) = \exp(-|t|/\tau) \tag{1}$$

is (up to a constant factor) the autocovariance of two important stochastic processes used to describe: *i)* the random opening and closing of single ion channels and, *ii)* spontaneous fluctuations of the membrane potential of neurons *in vivo*. Its Fourier transform is given by:

$$\hat{f}(\omega) = \frac{2\tau}{1 + (2\pi\tau\omega)^2}. \tag{2}$$

In the following exercise, we will assume that $\tau = 20$ ms.

1. Compute analytically $\hat{f}(\omega)$. In other words use eq. 1 and the definition of the Fourier transform to derive eq. 2. (4 points)

2. Plot the function $f(t)$ (eq. 1) between -2.56 and 2.56 sec in an interval centered at zero using 1024 points and a time step of 5 ms. (2 points)

3. What is the range of frequencies (i.e., the Nyquist frequency, $\omega_{Nyquist}$) that you will obtain and what is the resolution $\Delta\omega$ that this data will give after a fast Fourier transform in the frequency domain? Briefly explain how you arrive at the results. (4 points)

4. Plot the predicted Fourier transform $\hat{f}(\omega)$, eq. 2, for the same range of frequencies between $-\omega_{Nyquist}$ and $\omega_{Nyquist}$ as in 3. (2 points)

5. What do you need to take into account to compare the numerical fast Fourier transform of the discretized function plotted in 2 with the theoretical formula for $\hat{f}(\omega)$ (eq. 2)? Briefly explain. (4 points)

6. Plot the real part of the fast Fourier transform as a function of frequency between $-\omega_{Nyquist}$ and $\omega_{Nyquist}$ taking into account 5 so as to compare it directly with the plot of 4. (4 points)

7. What is the maximal value of the imaginary part of the fast Fourier transform? Is it justified to neglect it? Explain why. (3 points)

8. Explain in your own words what an autocovariance function is (2 points).

3 Receptive field of retinal ganglion cells under low light conditions (total 25 points)

The spatial receptive field of retinal ganglion cells is usually well described by a difference of Gaussians:

$$u(x) = k_c r_c \sqrt{\pi} \exp(-(x/r_c)^2) - k_s r_s \sqrt{\pi} \exp(-(x/r_s)^2)$$

In light adapted conditions, we use the parameters $r_c = 0.24$ deg, $r_s = 0.96$ deg, $k_s/k_c = 0.06$, $k_c = 1$.

1. Plot the Fourier transform of this receptive field scaled so as to have a peak value of 50 (also called the contrast sensitivity of the retinal ganglion cell). (3 points)
2. Under low light conditions, the peak contrast sensitivity decreases to 30 and $r_c \to 1.5 r_c$, $r_s \to 1.5 r_s$, $k_c \to k_c/1.5$, and $k_s \to k_s/1.53$. Plot the resulting contrast sensitivity. (3 points)
3. Plot the corresponding spatial receptive fields for both light level conditions. (4 points)
4. A stationary contrast edge with high contrast to the left ($c = 1$ for $x \leq x_0$) and low contrast to the right ($c = 0$ for $x > x_0$) is flashed in the cell's receptive field. Compute numerically and plot the change in firing rate of the retinal ganglion cell model as a function of the position x_0 of the edge in the cell's receptive field both at high and at low light levels. In other words use the weighting function $u(x)$ above to derive the cell's response under the assumption of linearity. (10 points)
5. Explain in your own words the significance of the receptive field parameter changes from high to low light level. (5 points)

4 Detection of weak light flashes by retinal ganglion cells (total 24 points)

A model used to describe the discharge of retinal ganglion cells in response to weak light flashes assumes that the spike train representing the time at which photons are absorbed by photoreceptors is an homogeneous Poisson process. This spike train is convolved with an exponential low-pass filter,

$$f(t) = \begin{cases} Ce^{-t/\tau}, & t \geq 0, \\ 0, & t < 0, \end{cases}$$

with a time constant $\tau = 30$ ms. The resulting continous waveform is then used to drive an inhomogeneous Poisson process that represents the ganglion cell spike train. The constant C is chosen such that

$$\int_0^\infty f(t)\, dt = 2.$$

This implies that, on average, 2 spikes are generated per absorbed photon.

1. Generate a 500 ms long homogeneous Poisson train (each event represents the absorption of one photon) with a mean value of 10 absorbed photons per second. Convolve this sequence with $f(t)$. Plot five examples of such homogeneous Poisson trains toghether with the resulting continuous waveforms obtained by convolving with f. (6 points)
2. Use the waveform obtained in 1 to drive an inhomogeneous Poisson process. Repeat the whole procedure 100 times. Compute and plot from these 100 sample spike trains the corresponding distribution of spike number over the 500 ms period. (7 points)
3. Compute the mean spike number and the Fano factor of the spike count distribution. (6 points)
4. Briefly explain how the distribution compares to that of an homogeneous Poisson distribution with the same mean number of spikes. (5 points)

Note. Use a time step of 0.1 msec for 1 and 2.