

## CAAM/NEUR 415: EXAMINATION #2

April 24, 2006

### 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 from the presynaptic terminal at a chemical synapse? At a 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? What about an NMDA synapse? Briefly explain why. (3 points)
3. Explain what is meant by "silent" inhibition. (2 points)
4. An optimally oriented, stationary oscillating sinusoidal grating is presented in the receptive field of a simple and complex cell at various phases with respect to the receptive field center. Briefly describe the two main differences expected between their responses. (3 points)
5. Briefly explain how the spatial receptive field of a complex cell is obtained from that of simple cells in Hubel and Wiesel's model and why their idea is plausible. (2 points)
6. Why is the Fourier transform an important tool to describe the spatial receptive fields of the visual neurons studied in class? (2 points)
7. Sketch the spatio-temporal  $(x, t)$  receptive field of a simple cell sensitive to motion from left to right. Based on the sketch, briefly explain why the cell responds to one direction of motion and not the other. (2 points)
8. Give two common measures of variability used to describe the spike trains of neurons. Briefly explain the difference between the two. What is for each of these measures the expected range of values that you expect from cortical neurons in vivo? (3 points)
9. Briefly explain in words how the Tsodyks-Markram model of synaptic release extends the classical quantal model. How does in this model short term synaptic depression affect the transformation between pre- and postsynaptic rate? (2 points)
10. Briefly explain how a temporal weighting function is obtained using reverse-correlation. Give two assumptions that need to be satisfied by the stimulus and/or neuronal system under consideration for the method to work. (3 points).

## 2 Theory and practice of Fourier transforms (total 24 points)

1. You need to sample a time-varying signal whose frequency content does not exceed 100 Hz. What is the smallest sampling frequency that you can use without distorting the signal? Briefly justify your answer. (3 points)
2. Compute the sampling time step corresponding to the sampling frequency in 1. (2 points)
3. After acquiring 2048 samples of the signal, you decide to compute its discrete fast Fourier transform. What is the range of frequencies that you will obtain and what is the resolution  $\Delta f$  that the acquired data will give in the frequency domain? (3 points)
4. How many components will your fast Fourier transform vector have? Explain how each of the components relates to the frequency range of 3. (4 points)
5. If the signal consists of a linear superposition of two sine waves at frequencies  $f_1 = 10$  Hz and  $f_2 = 25$  Hz, how do you expect the individual coefficients of the discrete Fourier transform to look like? Briefly explain your answer. (4 points)
6. What is the relation between the mathematical definition of the Fourier transform and the numerical Fourier coefficients obtained by the fast Fourier transform algorithm? Briefly explain how this relation arises. (2 points)
7. You need to compute, with pencil and paper, the exact formula for the 2-dimensional Fourier transform of the following function,

$$f(x, t) = e^{-x^2 - t^2} \cos(\alpha x + \beta t).$$

Briefly explain in words how you would proceed about carrying out this task. (6 points)

## 3 Retinal ganglion cell receptive field properties (total 22 points)

According to the lecture notes, the 1-dimensional, spatial receptive field of a retinal ganglion cell at high light levels is given by,

$$v(x) = k_c r_c \sqrt{\pi} e^{-(x/r_c)^2} - k_s r_s \sqrt{\pi} e^{-(x/r_s)^2},$$

with parameters  $k_c = 1$ ,  $k_s = 0.06$ ,  $r_c = 0.24$  deg and  $r_s = 0.96$  deg.

1. Plot the spatial receptive field between  $\pm 6$  deg (approx.) with a spatial sampling step  $dx = 0.006$  deg. (3 points)
2. At low light levels, the parameters characterizing the weighting function  $v(x)$  of the cell are observed to change as follow:  $r_c \rightarrow 2 \cdot r_c$ ,  $r_s \rightarrow 2 \cdot r_s$ ,  $k_c \rightarrow k_c/5$ ,  $k_s \rightarrow k_s/5$ . Plot the spatial receptive field at low light levels. (3 points)

3. Use a fast Fourier transform to plot the frequency response both at high and at low light levels. Use semilogarithmic coordinates along the frequency axis. (6 points)
4. How do you interpret the change in receptive field properties between high and low light levels ? (4 points)
5. 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 and plot the change in firing rate of the neuron 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. (6 points).

#### 4 Detection of weak light flashes by retinal ganglion cells (total 28 points)

A model used to describe the discharge of retinal ganglion cells in response to weak light flashes assumes that photons are absorbed according to a Poisson process and filtered through 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 continuous wave form 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 Poisson train (each event represents the absorption of one photon) with a mean value of 10 absorbed photons per second. Filter this sequence with  $f(t)$  and plot five samples of the resulting continuous waveform. (5 points)
2. Use the waveform obtained in 1 to drive an inhomogeneous Poisson process. Compute and plot from 100 sample spike trains the corresponding distribution of spike number over the 500 ms period. (6 points)
3. Compute the mean spike number and the Fano factor of the spike count distribution. (5 points)
4. How does the distribution compare to a Poisson distribution with the same mean number of spikes? Justify your answer. (5 points)
5. Assume that spontaneous activity is described by the same model but with a mean number of absorbed photons equal to 6 per second. Compute and plot the corresponding spike count distribution as in 2. Plot the ROC curve based on a spike count

threshold. Compute the minimum error of an observer based on a spike threshold.  
(7 points)

**Notes.** *a.* Use a time step of 0.1 msec for 1 and 2. *b.* For 5 use 10 equally sized bins between 0 and 20 spikes to compute the ROC curve.