580.422 SBE 2 (Spring 2015)

Prof. Wang Questions [30 points total]
Questions 1 [9 points]

(1) What is a “psychometric function”? Why do we want to use the psychometric function to describe behaviors? **[3 points]**

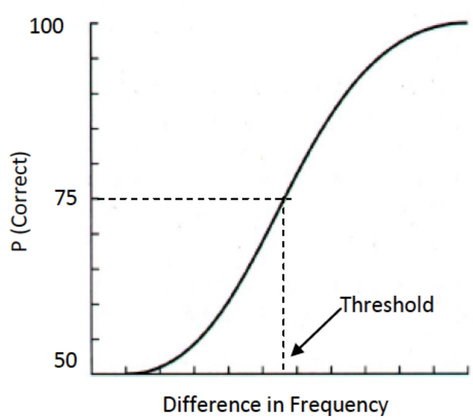
- In class definition:

- A psychometric function provides the fundamental data for psychophysics, the scientific discipline that explores the connection between physical stimuli and subjective responses.
- A psychometric function relates the subject’s response to a physical stimulus and is used to quantitatively measure behaviors.
- The x-axis (abscissa) represents the physical parameter of a stimulus, and the y-axis (ordinate) plots the observer’s response as a percentage

2 points, pulled potentially from:
+1 physical stimulus/subject’s response, probability
+1 for threshold

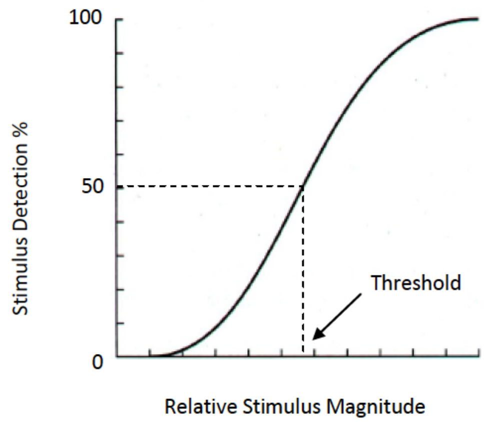
1 point maximum:
+1 mention of psychophysics or mentions “quantitative”

(2) Sketch the psychometric function of the following task, clearly mark all axes.
You are shown on a computer screen two squares side-by-side. We refer to these two squares as “left square” and “right square”, respectively. You are asked to indicate which one is darker. This is so-called “two-alternative forced choice (2AFC)” paradigm, i.e., you must choose from one of two possibilities (“left square” or “right square”). The grey levels of the two squares are chosen randomly from 0 to 255 (0-white, 255-dark). **[3 points]**



+1 x-axis (Difference in Stimulus (Intensity, Saturation, Brightness, etc.))
+1 y-axis (Percent Correct, from 50-100%)
+1 threshold marked and at 75%

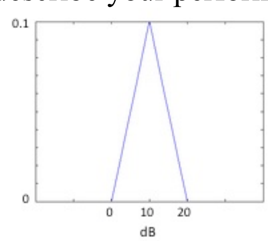
(3) Sketch another psychometric function if you are asked instead to indicate whether you see a difference between the two squares. **[3 points]**



+1 x-axis (Relative Stimulus Magnitude (Intensity, Saturation, Brightness, etc.))
+1 y-axis (Stimulus Detection Percentage, from 0-100%)
+1 threshold marked and at 50%

Question 2 [12 points]

You are asked to detect the presence of a tone in background noise. Each time you hear a brief sound that could be noise alone or tone plus noise. Your task is to determine if you hear a tone or not. The background noise has a randomly fluctuating sound level, with its probability density function as a triangular function centered at 10 dB and ranged from 0 to 20 dB (shown below). The sound level of the tone is 10 dB. Assume you act as an ideal observer, use the detection theory to quantitatively describe your performance in this behavioral task.



(1) Calculate probabilities of hit and false alarm if the decision criterion is set to 0, 5, 10, 15, 20, 25, 30 dB, respectively. **[4 points]**

Beta	P(HIT)	P(FA)
0	1	1
5	1	0.875
10	1	0.5
15	0.875	0.125
20	0.5	0
25	0.125	0
30	0	0

Choose one of the following:
+4: If the entire table is filled out and correct

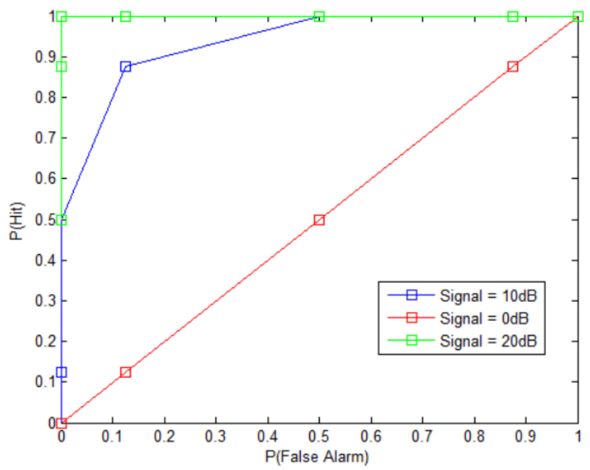
+3: If there is evidence they understood the problem correctly (i.e. they understood that a signal strength of 10 dB shifted the noise profile plotted above to the right, centering it at 20 dB) but had some small math errors.
+1: The student misunderstood the problem, but attempted to solve it.
0: No work.

(2) Sketch an ROC curve based on above conditions, mark all axes clearly. **[4 points]**

The plot should reflect the variables above, irregardless if they are the correct answers.

+1: Correctly labeled the axes
+1: Plot has general ROC Curve shape

(3) Sketch on the same plot two more ROC curves if the sound level of the tone is 0 and 20 dB, respectively. **[4 points]**



+4: Both additional plots are correct
+2: The plot for <u>either</u> Signal = 20 dB or 0 dB is incorrect
-1 if 20dB plot is not a right angle
0: Assign no credit if both plots are incorrect or if there is no answer. This question is asking a fundamental question about ROC curves and signal detection theory.

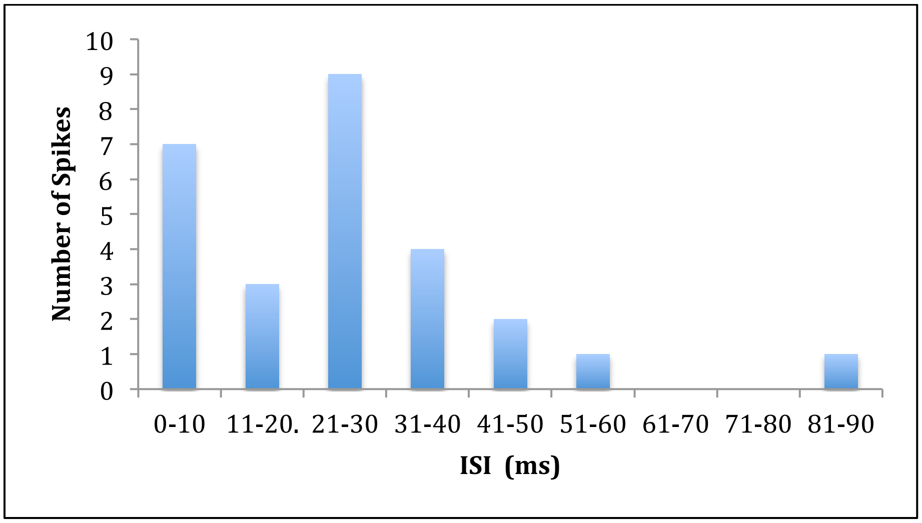
Question 3 **[9 points]**

Below are the spike times (in msec) recorded from one neuron in 3 trials.

Trial-1: [32	57	73	156	193	230	232	235	236	247]
Trial-2: [8	22	59	69	106	156	166	188	211	240]
Trial-3: [36	65	115	173	198	219	242	248	276	277]

(1) Calculate inter-spike-intervals and sketch the inter-spike-interval histogram (use binwidth of 10 ms). **[7 points]**

0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90
7	3	9	4	2	1	0	0	1



+7 points for correct graph – Starting bins at 0 is also okay (5, 5, 9, 4, 0, 3, 0, 0, 1)

Partial credit:

+/- 1 point x-axis (ISI in milliseconds)

+/- 1 point y-axis (number of spikes)

+/- 1 for correct bin width

-/+0.5 point for incorrect summation for each bin

(2) Calculate the mean firing rate for the time window [0, 300] msec. Explain how you arrive at your answer step by step. **[2 points]**

Mean Firing Rate

Total Number of Spikes / (# of Trials * Duration in seconds)

30 / (3 * 0.3 seconds)

33.3 spikes/second

+1 for correct equation

+1 for correct answer

-0.5 for no or incorrect

Prof. Young Questions [36 points total]

Question 1 [12 points]

Suppose that a cell membrane contains the following channels:

1. Ca++ channel that is voltage-activated and inactivated by Ca++ concentration
2. K+ channel activated both Ca++ and voltage, no inactivation
3. Cl- channel that is activated only by Ca++, no inactivation

Part a) Write a set of differential equations for this membrane. Make sure you indicate what variables the functions in the Hodgkin-Huxley equations depend on. Obviously you will not be able to write out explicit functions for things like $m_\infty(V,Ca)$, but you should indicate that they are functions of V or Ca or whatever (Hint: you should end up with 6 differential equations). **[8 points]**

There are many answers differing in details, but some features must be present. The following six equations must be present; they'll have to explain why they need any additional equations. The powers below indicate places where the answers can vary. I_{ext} and the leak channel are optional, no points off for leaving them out. The presence of V and Ca in the HH differential equations for m and h must be given correctly. The Ca equation can have various constants (instead of A and B).

$$C\frac{dV}{dt} = I_{ext} - \bar{G}_{Ca} m_{Ca}^{??} h_{Ca}(V - E_{Ca}) - \bar{G}_K m_K^{??}(V - E_K) - \bar{G}_{Cl} m_{Cl}^{??}(V - E_{Cl}) - \bar{G}_{leak}(V - E_{leak})$$

$$\frac{dm_{Ca}}{dt} = \frac{m_{Ca\infty}(V) - m_{Ca}}{\tau_{mCa}} \qquad \frac{dh_{Ca}}{dt} = \frac{h_{Ca\infty}(Ca) - h_{Ca}}{\tau_{hCa}}$$

$$\frac{dm_K}{dt} = \frac{m_{K\infty}(V,Ca) - m_K}{\tau_{mK}} \qquad \frac{dm_{Cl}}{dt} = \frac{m_{Cl\infty}(Ca) - m_{Cl}}{\tau l}$$

$$\frac{dCa}{dt} = A(-BI_{Ca} - Ca) \quad \text{where} \quad I_{Ca} = \bar{G}_{Ca} m_{Ca}^{??} h_{Ca}(V - E_{Ca})$$

It is also OK if they use the alternate HH form in terms of *alpha* and *beta* rate functions.

+8 if all 6 equations are correct
-1 for each equation that is not correct.

0 points total if not attempted.

Part b) Suppose the cell of part a) has an additional synaptic channel present, which passes a mixed cation current (Na, K, and Ca). It is observed that when the synapse is activated, there is a significant current through the chloride channel, but when the cell is depolarized, there is no current through the chloride channel, even though there is calcium entry, as judged by activation of the calcium-dependent potassium channel. Explain how this could happen based on our understanding of calcium pools. How would you have to change your equations above to account for this situation? **[4 points]**

The synaptic channel also admits Ca++ and there are two segregated Ca++ pools, as shown in an example in class, one associated with the voltage-gated calcium and potassium channels and another associated with the synaptic channel and the calcium-gated chloride channel.
The synaptic channel should be added to the dV/dt equation, as

$$C\frac{dV}{dt} = I_{ext} - \bar{G}_{Ca} m_{Ca}^{??} h_{Ca}(V - E_{Ca}) - \bar{G}_K m_K^{??}(V - E_K) - \bar{G}_{Cl} m_{Cl}^{??}(V - E_{Cl}) - \bar{G}_{leak}(V - E_{leak}) - \bar{G}_{synapse}(V - E_{synapse})$$

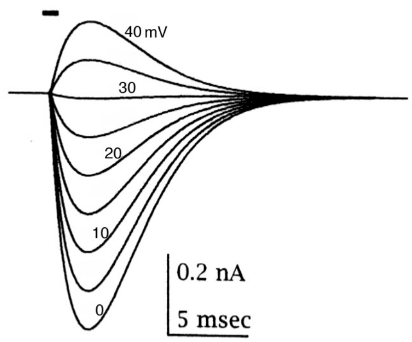
and a second calcium pool equation should be added. That is, there are now two Ca++ pools, called Ca1 and Ca2, each with its own equation. hca and mk depend on Ca1, whereas mcl depends on Ca2.

$$\frac{dCa_1}{dt} = A_1(-B_1 I_{Ca1} - Ca_1) \quad \text{where} \quad I_{Ca_1} = \bar{G}_{Ca} m_{Ca}^{??} h_{Ca}(V - E_{Ca})$$

$$\frac{dCa_2}{dt} = A_2(-B_2 I_{Ca2} - Ca_2) \quad \text{where} \quad I_{Ca2} = \bar{G}_{SynapseCa}(t)(V - E_{Synapse})$$

+2 points for proper explanation
+2 points for correct equations/explanation

Problem 2 [12 points]



A neuron is voltage clamped to the potentials shown in the figure (expressed as mV relative to rest, so that 0 means resting potential and 40 means 40 mV depolarized from rest). A synapse on the neuron is activated by stimulating a spike in the cell presynaptic to the synapse at time 0. The figure shows the postsynaptic currents in the neuron, measured as the current necessary to maintain the membrane voltage at the desired clamp potential. Note the current changes amplitude and sign as the clamp voltage changes.

Part a) Draw a circuit model for the synapse, label the components of the circuit and explain the behavior of the currents in the figure, i.e. the peak amplitude of the current and its sign as the membrane potential changes. **[6 points]**

A battery with potential ~30 mV re rest (which they could specify as -35 = -65+30 mV or equiv.) in series with a resistance. The resistance varies in time as an alpha wave (defined in lecture) *G(t) = const*t*exp(-t/tau)*. The current is given by $I_{synapse} = G(t)*(V-E_{synapse})$. The peak current is zero when $V = E_{synapse}$ and changes sign there. It would also be correct to specify *G(t)* as the solution to the differential equation for receptor binding given in lecture.

+4 points for correct circuit diagram

-2 point for leaving out resistor

-2 point for leaving out battery

(Or -1 for other circuit inadequacies: e.g. from circuits, just drawing all ion channels, and not synapse!)

+2 points for correct explanation

Part b) Is the synapse activated in part a) excitatory or inhibitory? Why? **[3 points]**

The synapse is excitatory because its reversal potential ($E_{synapse}$) is positive to the resting potential and therefore depolarizes the cell when activated.

+2 points for correctly identifying that the synapse is excitatory

+1 point for proper explanation

Part c) If you wanted to do the same experiment with the other type of synapse (i.e. inhibitory if the synapse in a) is excitatory or excitatory if it's inhibitory), what range of membrane potentials would you use? **[3 points]**

$E_{synapse}$ is -70 mV, or -5 mV re resting potential for an inhibitory synapse, so the range should include that potential, for example -80 mV to -50 mv (or -20 to +30 mV relative to the rest potential).

+3 points for correct range of membrane potentials: if excitatory: depolarizing ranges, if inhibitory, hyperpolarizing ranges.

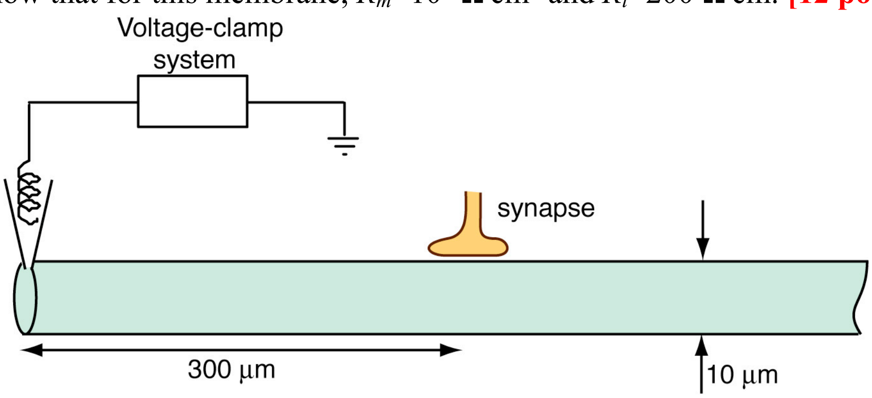
But, to give these marks, explanation need to include flipping sides.

-0.5 for no units.

-1 if no numbers, but qualitative.

Problem 3

Suppose the synapse of problem 2 is 300 μm away from the point of voltage-clamp (and current recording) along a dendrite, as in the drawing below. Assume the dendritic tree of the neuron is very long (i.e. for all practical purposes, infinitely long). What is the reversal potential of the synapse in this situation, given the same data at the recording site as in the figure above? It may help to know that for this membrane, $R_m=10^4\ \Omega\cdot cm^2$ and $R_i=200\ \Omega\cdot cm$. **[12 points]**



Now the clamp potential at the synapse is reduced by exp(-300μm/λ), where λ is the length constant of the cylinder. In this case,

$\lambda = [aR_m/2R_i]^{1/2} = [5\text{x}10^{-4}\text{cm} * 10^4\ \Omega\text{cm}^2 / 2 * 200\ \Omega\ \text{cm}]^{1/2}$ =0.112 cm, so the actual potential at the synapse, when the potential at the electrode is 30 mV is 30*exp(-0.03 cm/0.112 cm) = 23 mV.

+6 points for correctly calculating the length constant

- +3 points for correctly identifying the length constant equation
- -1 point for a math error
- -1 point for determining that a=10μm

+6 points for correctly calculating the reversal potential

- -1 point for a math error

Prof. Kirkwood Questions [14 points total]

1. Two important properties of long-term potentiation are its input specificity and its associativity. Describe these properties and also explain how the features of the NMDA receptor activation account for these properties. **[7 points]**

Input specificity: only activated synapses undergo LTP **+2 points**

Associativity: a strong input can help a weak input to undergo LTP. **+2 points**

NMDAR needs glutamate binding and postsynaptic depolarization **+1 point**

(Input specificity) only stimulated synapses (with glutamate) can undergo LTP **+1 point**

(Associativity) the strong input provides the postsynaptic depolarization to fully activate NMDARs in the weak pathway. **+1 point**

2. The "sliding threshold" and the "synaptic scaling" are two homeostatic mechanisms. How do they provide stability to neural networks? What do they have in common (at least two features)? **[7 points]**

Sliding Threshold: by adjusting the LTP/D threshold according to the history of activity in the cell **+2.5 points**

Synaptic Scaling: by adjusting the magnitude of synaptic responses according to the history of activity in the cell **+2.5 points**

Similarities
Global effect on all synapses **+1 points**
Does not affect stored memories **+1 points**

Prof. Connor's Questions **[14 points]**

1. Describe how the receptive field structures and/or tuning properties in the following 3 visual processing stages help to compress image information. **[7 points]**

a) Retinal ganglion cells **[3 points]**
Due to the center-surround structure of retinal ganglion cell receptive fields, these cells respond mainly to brightness (or color) borders, which contain important visual information, and not to regions of constant brightness (or color) (which contain a lot of redundant information).

b) Primary visual cortex (V1) **[2 points]**
V1 neurons exhibit (edge) orientation tuning (due to their elongated positive and negative receptive field regions). Because boundaries in the natural world tend to be straight on the (larger) scale of V1 receptive fields, orientation signals compress the information in those receptive fields (by providing a single signal for the oriented boundary, in place of a number of retinal ganglion cell signals along the boundary).

c) Area V4 (an intermediate stage in the ventral pathway) **[2 points]**
V4 neurons are tuned for curvature fragments (defined by their convex/concave curvature and by their object-centered position). Because boundaries in the natural world tend to exhibit curvature (orientation change) on the (even larger) scale of V4 receptive fields, V4 neurons compress information in their receptive fields (by providing a single signal that represents changing orientations signaled by multiple V1 neurons).

2. Describe how motion and color information are separately channeled through:
[7 points]

a) Retinal ganglion cells **[2 points]**
Motion (or luminance change in general) is carried by M retinal ganglion cells **+1 point**
Color is carried by P retinal ganglion cells **+1 point**

b) Layers in the lateral geniculate nucleus of the thalamus **[3 points]**
Motion is carried by the magnocellular layers **+1.5 points**
Color is carried by the parvocellular and koniocellular layers (give credit for either)
+1.5 points

c) Stripes in V2 **[2 points]**
Motion is channeled through thick (cytochrome oxidase or dark) stripes **+1 point**
Color is channeled through thin stripes **+1 point**

Prof. Chib Question [6 points total]

Consider a case in which you will be deciding if you would like to flip a coin to make a gamble or forgo any risk and choose not to flip a coin. The structure of the gamble will be as follows: Side 1 of the coin corresponds with winning an amount of money, while side 2 corresponds to losing (or having to pay) an amount.

Calculate the expected value of the following gambles. [2 points]

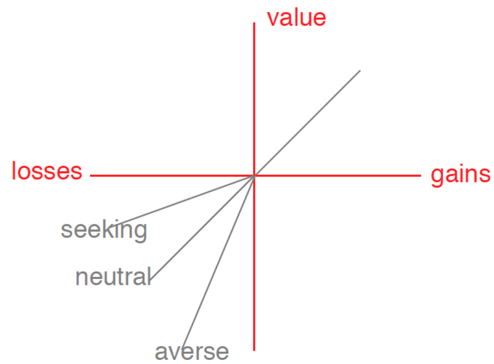
A) Side 1: Win $20 EV = (0.5*20)+(0.5*-10) = $5
Side 2: Lose $10

B) Side 1: Win $10 EV = (0.5*10)+(0.5*-15) = -$2.50
Side 2: Lose $15

C) Side 1: Win $15 EV = (0.5*15)+(0.5*-10) = $2.50
Side 2: Lose $10

D) Side 1: Win $20 EV = (0.5*20)+(0.5*-20) = $0
Side 2: Lose $20

Draw representative value functions for individuals who are loss averse, loss seeking, and loss neutral. [2 points]



-0.5 incorrect axis

Considering the gambles above:
If you chose to reject gamble A (i.e., not flip the coin) would this be considered loss averse, loss seeking, or loss neutral behavior? Explain why? [1 point]

This would be considered loss averse behavior. The expected value of the gamble is positive so the rational choice is to take the gamble. However, because of your subjective preferences the amount of gain does not outweigh the potential loss.

Given what you saw in lecture about the relationship between loss aversion and performance how would you expect loss averse, loss seeking, or loss neutral individuals to perform for large monetary incentives? Explain why? [1 point]

The more loss averse an individual the more likely they are to 'choke' under the pressure of large monetary incentives. From the data presented in class it seems that incentives associated with successful task performance are initially encoded as a potential gain; however, when actually performing a task, individuals encode the potential loss that would arise from failure. The extent to which individuals' encode this loss (loss aversion) is related to the degree to which they exhibit performance decrements.