Name: ______________________________

Week 5 Question Set
Variability of spikes trains & Depth

Summer 2023

1 CNS5.2 - Sources of Variability?

1. What are some sources of variability in a neuron's activity? (Select all that apply)

   (a) Stochastic opening and closing of ion channels
   (b) Unpredictable incoming spikes from other neurons
   (c) Variability in the amounts and timing of neurotransmitter release
   (d) Stochastic nature of biochemical reactions within the neuron

2. Why does a neuron's firing pattern become more predictable when given a fluctuating input current?

   (a) Fluctuating input current amplifies the neuron's intrinsic noise
   (b) Fluctuating input current can entrain the neuron's firing to its own rhythm
   (c) Fluctuating input current decreases the neuron's sensitivity to external stimuli
   (d) Fluctuating input current increases the amount of neurotransmitter release

3. Which of the following sources of noise contributes more significantly to the variability of a neuron's activity?

   (a) Intrinsic noise (e.g., due to ion channels)
   (b) Network noise (e.g., due to unpredictable incoming spikes from other neurons)

4. Please select the correct options: In the video, it is demonstrated that (deterministic/stochastic) leaky integrate-and-fire neurons with (random/nonrandom) connectivity can reproduce both the variability of membrane potentials and the broad interspike interval (ISI) distribution that are observed *in vivo*.

2 CNS5.3A - Three Definitions of Rate Code

1. The term ”firing rate” is not uniformly defined and may have three different interpretations. Match the corresponding definition with the correct description and feasibility in real-time conditions:

   (a) Definitions

   i. Temporal averaging

   ii. Averaging across repetitions

   iii. Population averaging ('spatial' averaging)

   (b) Examples

   - ________ Average taken across a population of neurons.
   - ________ Peristimulus time histogram (PSTH).
   - ________ Firing rate derived from a single neuron's spikes, calculated by counting the number of spikes and dividing by the stimulus duration. The interspike interval (ISI) can be used to measure its regularity, and the Fano factor can be used to assess the variability of spike count across trials.

   (c) Real-time feasibility

   - ________ Naturally occurring in animals, as postsynaptic neurons often receive input from pools of presynaptic neurons with similar properties.
   - ________ Might be too slow for an animal, as the calculation requires waiting for a stimulus duration. Given the sparse nature of firing, certain neurons might need to wait too long, potentially missing vital survival cues.
   - ________ Unlikely to be feasible in real-time animal conditions, as animals cannot afford to wait for multiple trials of stimulus presentation (e.g., prey or predator cues).

3 CNS5.3B - Poisson Model

1. **Poisson Process - Definition**: Select all conditions that accurately define a Poisson process:
   (a) The number of events in non-overlapping intervals is independent.
   (b) The probability of an event occurring in a small interval of length Δt is $\lambda * \Delta t$, for small Δt.
   (c) The probability of more than one event in an interval of length Δt goes to zero as Δt goes to zero.
   (d) The number of events in overlapping intervals is independent.
   (e) The probability of an event occurring in a small interval of length Δt is $\lambda / \Delta t$, for small Δt.
   (f) The probability of no event in an interval of length Δt goes to zero as Δt goes to zero.

2. **Poisson Process - Probability of Firing**: We learned that the probability of firing is

$$P_F = \rho_0 \, \Delta t \tag{1}$$

   What is P_F in this case?
   (a) The average rate of firing per unit time, i.e., instantaneous firing rate, which is in Hz and can be greater than 1.
   (b) The probability of an event (neuron firing) occurring in a small interval Δt
   (c) The number of firing events that occur in time Δt
   (d) The standard deviation of the firing rate

   What is ρ_0?
   (a) The average firing rate per unit time, i.e., instantaneous firing rate, which is in Hz and can be greater than 1.
   (b) The standard deviation of the firing rate
   (c) The duration of the interval in which we are interested
   (d) The number of firing events that occur in unit time

3. **Poisson Process - Interval Distribution**: Select the correct option about the interval distribution (for homogeneous Poisson porcess):
   (a) We use the survivor function of the exponential distribution to model the inter-spike intervals as a function of time.
   (b) The term "survive" here refers to the proportion of the neurons that have not fired yet.
   (c) We assume that, at each time step, the probability of survival given that the neuron has not fired, $P(S_t|S_{t-1})$, is the complement of the probability of firing in this time step, $1 - P_F$. This "memoryless property" occurs because we assume that the probability of a firing occurring in the future is independent of the past, given the present state.
   (d) All of the above.

4. **Poisson Process - Homogeneity**: Select the correct option about the inhomogeneous Poisson process:
   (a) An inhomogeneous Poisson process is characterized by an instantaneous firing rate $\rho(t)$ that is a function of time rather than a constant.

(b) The three definitions of ”firing rate” introduced in CSN5.3A can all be used to estimate $\rho(t)$.

(c) The interval distribution $P(t|\hat{t})$ can be obtained by multiplying the survival function $S(t|\hat{t})$ by $\rho(t)$. This is because, given survival up to time $\hat{t}$, the neuron fires at time t if it survives the period $(\hat{t}, t)$ and fires at time t. The survival function $S(t|\hat{t})$ captures the survival probability and $\rho(t)$ corresponds to the firing probability at time t.

(d) All of the above.

5. **Survivor function vs. interval distribution**: Given the scenario of waiting for a bus, determine which term applies:

   (a) You are wondering about the probability that the bus hasn't arrived by a certain time. (Survival function / Interval distribution)

   (b) You want to know the probability that the bus arrives at a specific time given it hasn't arrived yet. (Survival function / Interval distribution)

4 CNS5.4A - Stochastic Spike Arrival

1. **Linear Time-Invariant System**: The total spike train of K presynaptic neurons will result in a presynaptic current:
$$I(t) = \frac{1}{R}\sum_{k=1}^{K} w_k \sum_{f} \alpha(t - t_k^f)\,, \tag{2}$$
where α is the impulse response to a single spike, f represents the spike times, k is the index of the neuron, and w_k is the weight of k-th neuron. In this equation, we are approximating the system as a linear time-invariant (LTI) system. Why might this be the case?
   (a) Because LTI systems simplify the analysis and are often a good approximation for many real-world systems.
   (b) Because we are assuming that the total presynaptic current is equal to the weighted sum of all the responses to each spike (given by α). This is the superposition (a.k.a. additive property) and the scaling (a.k.a. homogeneity property) of the linear systems.
   (c) Because the response to each spike does not depend on the time at which the spike occurs, which is characteristic of a time-invariant system.
   (d) All of the above are correct.

2. **Mean Firing Rate**: In the video, it was stated that the expected value of the sum of the delta functions over time for the k-th neuron, denoted as $\langle \sum_f \delta(t - t_k^f) \rangle$, can be replaced by the mean firing rate $\rho_k(t')$ of that neuron. Why is this the case?
   (a) Because the mean firing rate does not accurately reflect the neuron's activity.
   (b) Because the mean firing rate $\rho_k(t')$ represents the average number of spikes that neuron k emits per unit time, which is equivalent to the expected value of the sum of the delta functions.
   (c) Because the delta functions are irrelevant in determining the neuron's activity.
   (d) Because the neuron's activity is entirely random and cannot be quantified.

5 CNS5.4B - Membrane Potential Fluctuations

1. **Applications of Autocorrelation**: Which of the following statements accurately describes a way in which autocorrelation is used in neuroscience?
   (a) Autocorrelation can help reveal whether a neuron has a tendency to fire at regular intervals.
   (b) Autocorrelation can reveal burst firing patterns due to the high correlation at short time lags.
   (c) Autocorrelation can be used to test whether a neuron's firing is consistent with a Poisson process.
   (d) Cross-correlation, a related concept, can be used to examine the degree to which two neurons are firing synchronously.
   (e) All of the above are correct.

2. **Testing Poisson with Autocorrelation**: How can we use autocorrelation to test whether a process is Poisson?
   (a) We use autocorrelation to look for periodic patterns in the process, as a Poisson process should not show any such patterns.
   (b) Autocorrelation can be used to test the randomness of the inter-event times in the process; for a Poisson process, the inter-event times should be independent and exponentially distributed.
   (c) All of the above are correct.

3. **Variance Formula**: In the video, the fluctuations of potential are expressed as:

$$\langle [\Delta u(t)]^2 \rangle = \langle [u(t)]^2 \rangle - \langle u(t) \rangle^2 \tag{3}$$

   . We can rewrite this using notation more conventional in probability theory:

$$Var[U] = E[U^2] - E[U]^2, \tag{4}$$

   where $Var[U]$ is the variance of the distribution U, and E is the expected value operator. Derive this equation by following these steps:
   (a) The variance of a random variable U is defined as $Var[U] = E[(U - \mu)^2]$, where μ is the expected value of U. Expand the square in this equation.
   (b) Next, note that the expected value operator E is a linear operator, meaning that $E[aX + bY] = aE[X] + bE[Y]$ for any random variables X and Y and any constants a and b. Use this property to simplify the right-hand side of the equation.
   (c) Lastly, recall that the expected value $E[U]$ of a random variable U is represented by μ in the variance formula. Substitute this into your equation to arrive at the final formula for the variance.

6 CNS5.5 - Stochastic Spike Firing in Integrate and Fire Models

1. What is the difference between the interspike interval (ISI) distributions in the superthreshold and subthreshold regimes of the Leaky Integrate-and-Fire (LIF) model with diffusive noise? Select the **incorrect** choice:

   (a) In the superthreshold regime, the ISI distribution often has a sharp peak because the mean input current, which is higher, primarily drives spike generation.

   (b) In the subthreshold regime, the ISI distribution is typically broader because the spikes are primarily driven by fluctuations in the current.

   (c) In both regimes, there is often a lower cut-off in the distribution because the neuron cannot physically fire at a rate beyond a certain limit.

   (d) The ISI distributions for the superthreshold and subthreshold regimes are identical because both are influenced by the same noise distribution.

7 V&B Chapter 5 - Depth: The Rogue Dimension

1. **Pictorial Cues for Distance Perception**: Which of the following are pictorial cues that the brain uses to estimate the relative distance of objects in a visual scene? Select all that apply.
   (a) **Size and height in the visual field**: Larger objects and objects lower in the visual field are typically perceived as closer.
   (b) **Overlap or interposition**: When one object occludes part of another, the occluded object is perceived as farther away.
   (c) **Linear perspective**: Parallel lines appear to converge as they recede into the distance, providing a sense of depth.
   (d) **Texture gradient**: The detail of texture decreases as distance increases, providing a cue to distance.
   (e) **Aerial (atmospheric) perspective**: Distant objects appear less sharp and more bluish due to light scattering by the atmosphere.
   (f) **Shadows and shading**: These provide information about the three-dimensional shape of an object and its distance from others.
   (g) **Accommodation**: The ciliary muscles in the eye change the shape of the lens to focus on objects at different distances, providing a cue to distance.
   (h) **Convergence**: The eyes rotate towards each other to focus on close objects, and this muscular effort provides a cue to the distance of the object.
   (i) **Binocular disparity (or stereopsis)**: Because our eyes are spaced apart, each eye gets a slightly different view of the world. The brain uses these differences to estimate distance.
   (j) **Motion parallax**: When you move your head side-to-side, objects at different distances move at different speeds. Closer objects appear to move more than distant objects.

2. **Neural Adaptation**: The book suggests that the phenomenon of neural adaptation - specifically the decrease in neuronal firing rate in response to a continuously present stimulus - can be better explained by information optimization rather than neuronal fatigue. Consider the research conducted on fly neurons which showed that the reduced firing rate following adaptation to motion increases the neuron's total information about that motion (Brenner, Bialek, & de Ruyter van Steveninck, 2000). How might this be possible?
   (a) Adaptation enhances a neuron's sensitivity to changes or variations in stimuli, thereby maximizing the information it can encode and transmit.
   (b) After adapting to a stimulus, neurons are fatigued and therefore fire less frequently.
   (c) Neurons have a fixed firing rate, unaffected by adaptation or the presence of stimuli.
   (d) All of the above.

3. **Motion Blur**: The author notes that in photography, motion blur results from scene points being spread across multiple pixel elements during the brief interval that the camera shutter is open. This concept can be applied analogously to the visual perception in animals. What represents the "shutter interval" in this context for animal eyes? Please elaborate on this analogy.

4. **Comparative Stereopsis Strategies:** In biological vision, evidence suggests that our brains approach the correspondence problem in stereopsis by matching coarse elements before fine details. This strategy seems to even apply to the interpretation of random-dot stereograms. How does this biological coarse-to-fine approach differ from feature-based matching commonly used in computer vision?

   (a) What are the main components of the biological coarse-to-fine strategy, and how might it function with random-dot stereograms?

   (b) How does feature-based matching in computer vision typically operate, and what advantages or disadvantages might it have in comparison to the biological approach?

5. **Cues for Shape**: Match the following visual cues with their correct examples:

   (a) Shape from Motion

   (b) Shape from Texture

   (c) Shape from Shading

   Match the above visual cues with these examples:

   - ________ A two-dimensional image of a gravel road appears to have depth due to changes in the size and density of gravel pebbles as they stretch into the distance.
   - ________ A crumpled piece of paper appears to have a three-dimensional structure due to the play of light and shadow across its surface.
   - ________ A wireframe cube appears three-dimensional when it is rotating.