

STA 4103/5107: Final Project

(Monday, 04/09)

Due: noon, Wednesday, 04/25

Topic: Neural Decoding using an Inhomogeneous Poisson Model

1. **Goal:** Using observed neural activity from brain cortex in research animals, we will perform a statistical modeling on this data to understand the brain mechanism and make inferences about the external behaviors.
2. **Inhomogeneous Poisson Process Model:** Let $x_k = [p_{x,k}, p_{y,k}, v_{x,k}, v_{y,k}]^T$ in \mathbf{R}^4 denote (x-position, y-position, x-velocity, y-velocity) of a 2-d hand movement at time t_k , and $y_k = \{y_{k,c}\}$ in \mathbf{R}^C denote the spiking rate of C neurons in the primary motor cortex at the same time.
 - a. For $y_{k,c}$, $c = 1, \dots, C$, we assume a generalized linear model (GLM) with an inhomogeneous Poisson process condition on x_k . That is,
$$y_{k,c} \sim \text{Poisson}(\lambda_{k,c})$$
where $\lambda_{k,c} = \exp(\mu_c + \alpha_{1,c} p_{x,k} + \alpha_{2,c} p_{y,k} + \alpha_{3,c} v_{x,k} + \alpha_{4,c} v_{y,k})$.
 - b. For x_k , we assume a simple linear Gaussian model over time. That is,
$$x_k = A x_{k-1} + w_k,$$
where $w_k \sim N(0, W)$.
3. **Model Identification:** In the training set (final_train.mat), both hand state and neural activity are known. Use the close-form formula to estimate the model parameters A , W (as in a Kalman filter model). Note that the kinematic data needs to be centralized before the model is fit. Use the MLE method to estimate parameters $\{\mu_c, \alpha_{1,c}, \alpha_{2,c}, \alpha_{3,c}, \alpha_{4,c}\}$, $c = 1, \dots, C$.
4. **Neural Decoding:** Once the parameters are identified, we can perform neural decoding on the testing data (final_test.mat). That is, we will use neural activity to infer the movement behaviors of the hand. Two inference methods need to be used here:
 - a. **Point Process Filter:** Use a point process filter to estimate the hand movement. Plot the true and estimated hand position and velocity (one subplot for each component in x_k). Compute the estimation accuracy for each component using R^2 Error.
 - b. **Sequential Monte Carlo Method:** Based on the same model, estimate the hand positions using a sequential Monte-Carlo method. Let the number of samples n be 20, 50, 100, and 500. For each n , plot the true and estimated states. Compute

the estimation accuracy in each component using R^2 Error. Plot the accuracy as a function of n and compare it with the accuracy in the point process filter.

- 5. Experiment:** Download the datasets (final_train.mat and final_test.mat) from the class website. Each set has two variables: *kin* and *rate*. *kin* is the kinematic state of the hand which includes *x-position*, *y-position*, *x-velocity*, and *y-velocity*. *rate* is the spiking rates of 42 neurons, where the rate at each time is the number of spikes within 70ms. Use the *kin* and *rate* in the training data to identify the model. In the test data, use the identified model and *rate* to infer *kin*, and compare the estimate with the true *kin*.

Your final report should include descriptions of:

- (a) The Problem Statement,
- (b) Methodology or Approach,
- (c) Matlab programs,
- (d) Main Results (using Tables or Figures),
- (e) Summary.

Points are allocated towards presentation of results and clarity of your report.