JOHNS HOPKINS
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Computational Models of Hippocampal Cells

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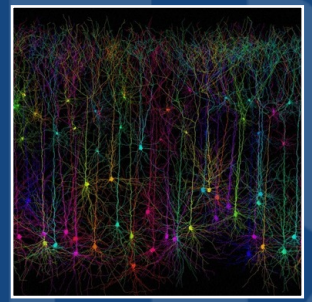


Models of the Neuron (EN.580.639.01.FA17)

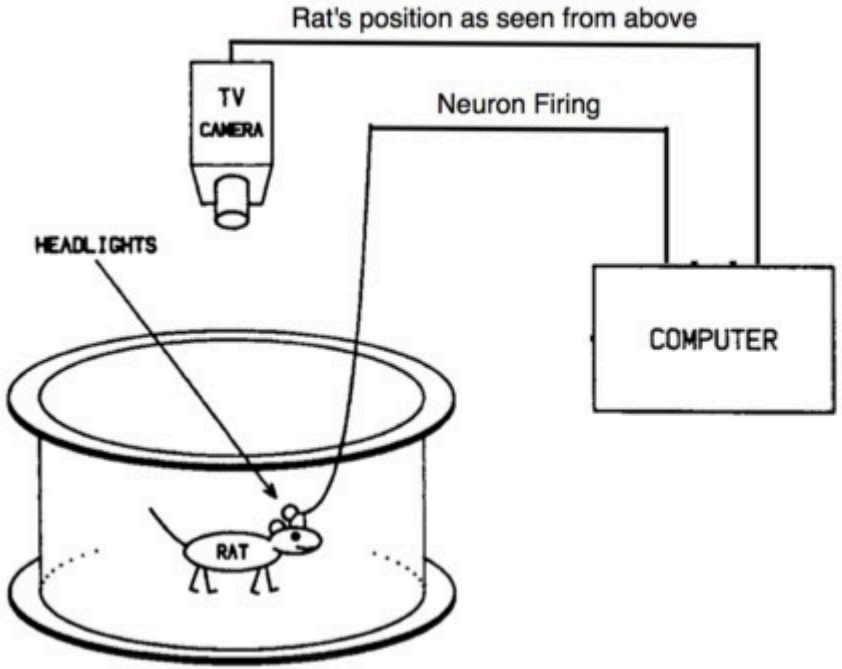
Introduction

- **Problem Statement:**

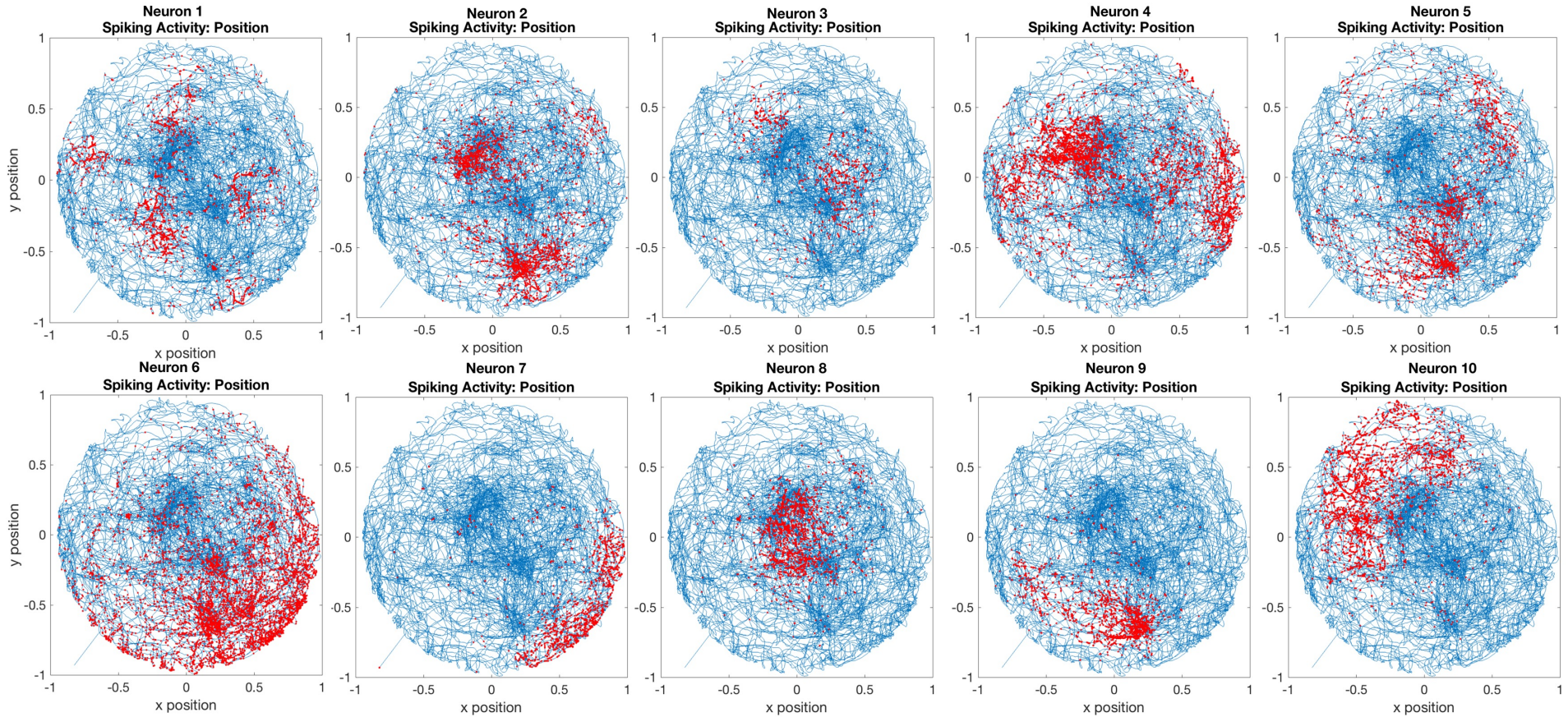
1. Building mathematical models to understand how a single neuron or multiple neurons encode spatial position or the spiking history.
2. Comparing models against each other to test how different covariates affect each neuron
3. Find the best model for the neurons we are testing

Experimental Protocol

- Long-Evans rat was freely foraging in an open field arena (~1 m radius) for a period of 36.36 minutes
- Custom micro-electrode drives with variable numbers of tetrodes were implanted in the rat's medial entorhinal cortex and dorsal hippocampal CA1 area.
- Spikes were acquired with a sampling rate of 31.25 kHz and filter settings of 300 Hz-6 kHz.
- Two infra-red diodes alternating at 60 Hz were attached to the micro-electrode array drive of the animal for position tracking



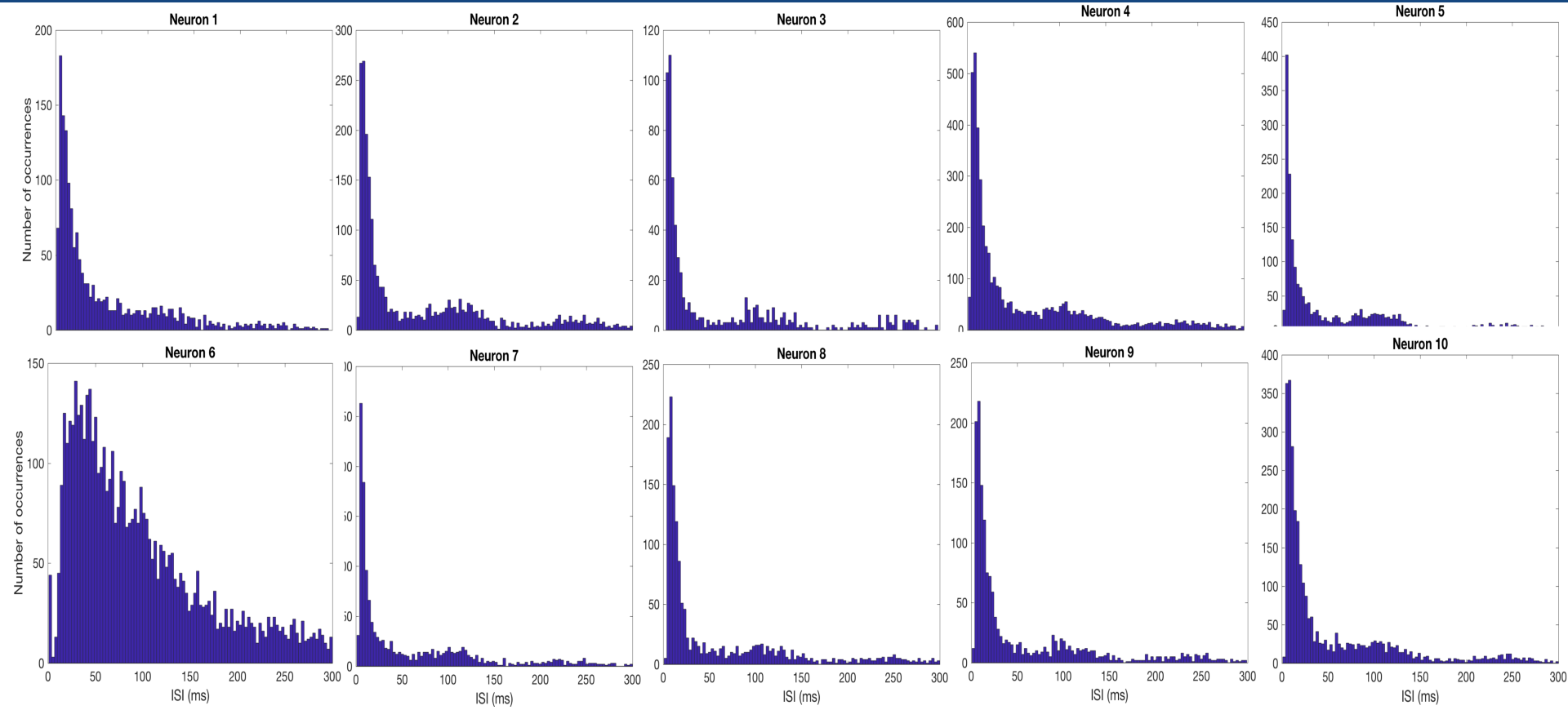
Visualizing the Raw Data - Spike Activities and Position



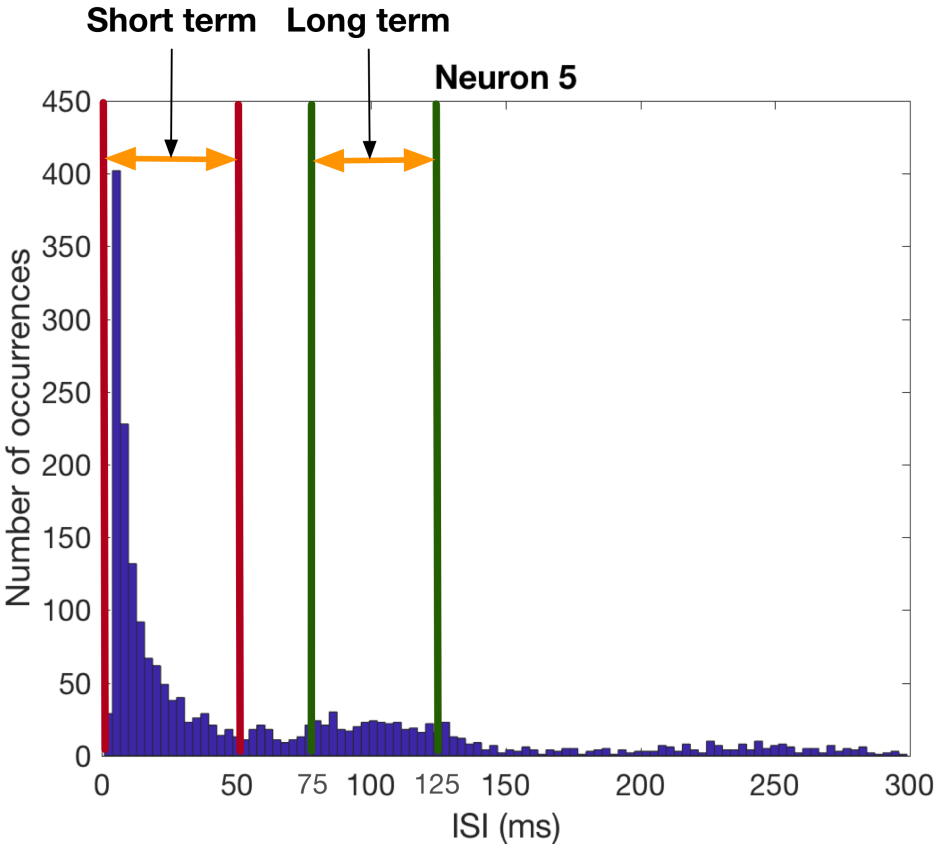
The Choice of the Covariates - Position

- *Linear (X, Y): Simplest way to depict position and starting point taken from HW5*
- *Quadratic (X, Y, X^2, Y^2, XY): Proven as an effective model in the past and since the log of the conditional intensity function (CIF) is modeled as a quadratic function, the CIF has a Gaussian shape. (R. Agarwal et al, 2016)*

The Choice of the Covariates - History



The Choice of the Covariates - History



Short term history: 0 - 50 ms

Long term history: 75 - 125 ms

Methods

Model definition

- Model 1: Linear position + Short term history

$$\log \lambda_c(t|x_t, y_t, h_c(t)) = \beta_0 + \beta_1 x_t + \beta_2 y_t + \sum_{n=0}^{49} \beta_{n+3} h_{nc}$$

- Model 2: Quadratic position + Short term history

$$\log \lambda_c(t|x_t, y_t, h_c(t)) = \beta_0 + \beta_1 x_t + \beta_2 y_t + \beta_3 x_t^2 + \beta_4 y_t^2 + \beta_5 x_t y_t + \sum_{n=0}^{49} \beta_{n+6} h_{nc}$$

- Model 3: Linear position + Short term history + Long term history

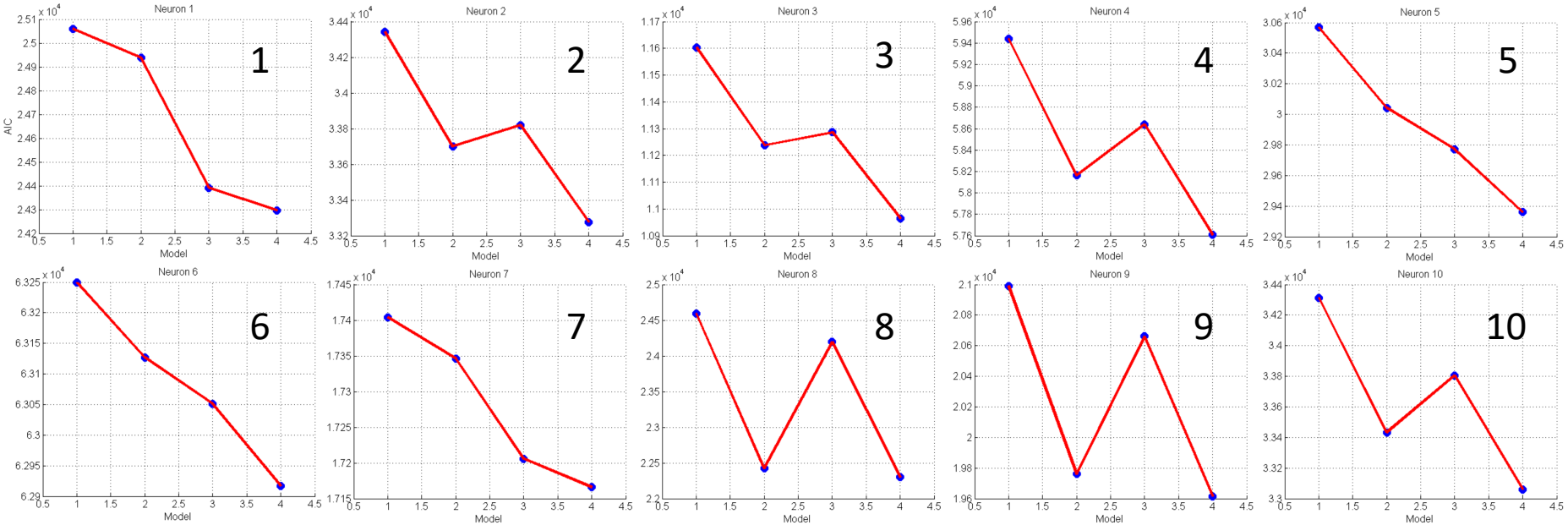
$$\log \lambda_c(t|x_t, y_t, h_c(t)) = \beta_0 + \beta_1 x_t + \beta_2 y_t + \sum_{n=0}^{49} \beta_{n+3} h_{nc} + \sum_{n=0}^{49} \beta_{n+53} h_{nc+74}$$

- Model 4: Quadratic position + Short term history + Long term history

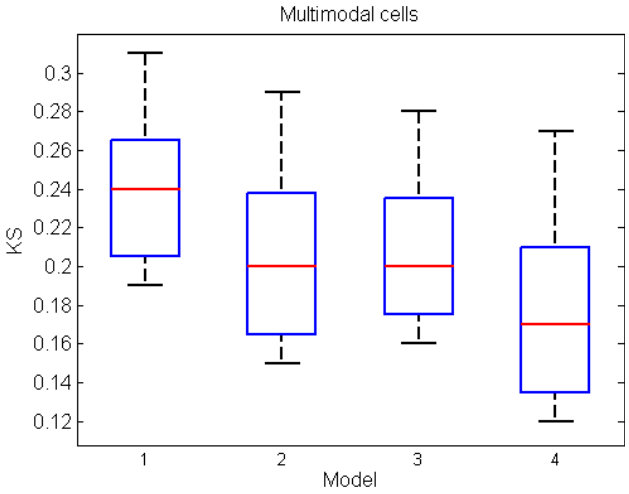
$$\log \lambda_c(t|x_t, y_t, h_c(t)) = \beta_0 + \beta_1 x_t + \beta_2 y_t + \beta_3 x_t^2 + \beta_4 y_t^2 + \beta_5 x_t y_t + \sum_{n=0}^{49} \beta_{n+6} h_{nc} + \sum_{n=0}^{49} \beta_{n+56} h_{nc+74}$$

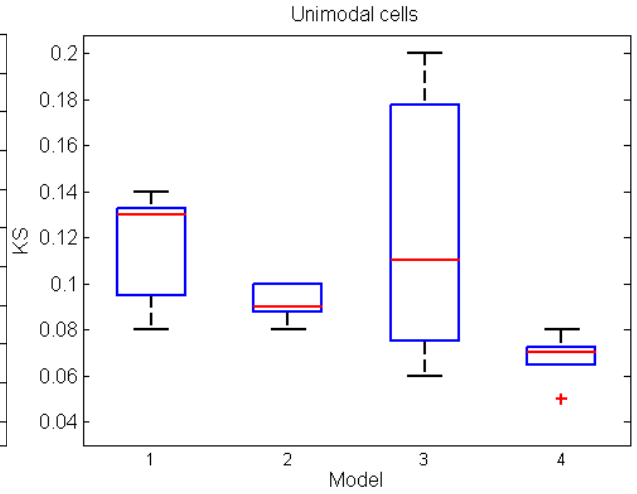
Justification 1 : AIC Analysis

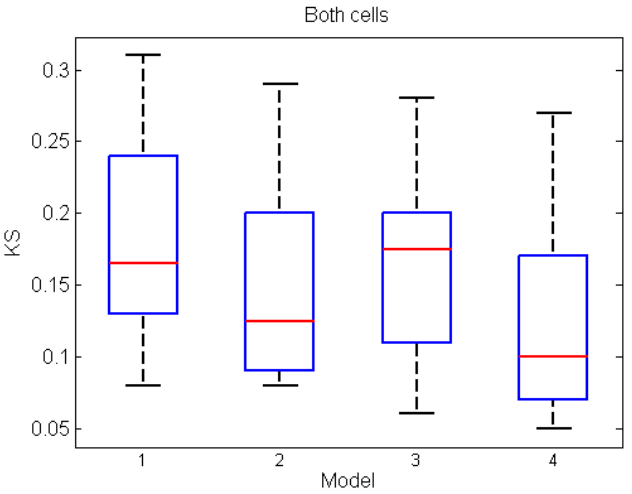
Neurons



Justification 2 : KS statistics (Box plot analysis)

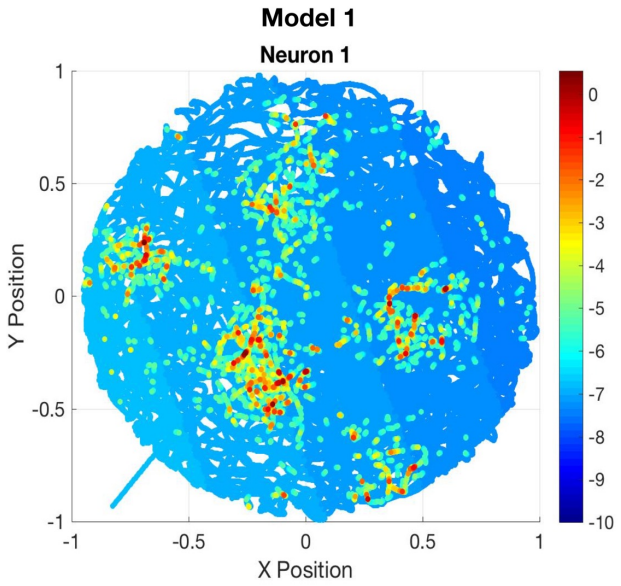


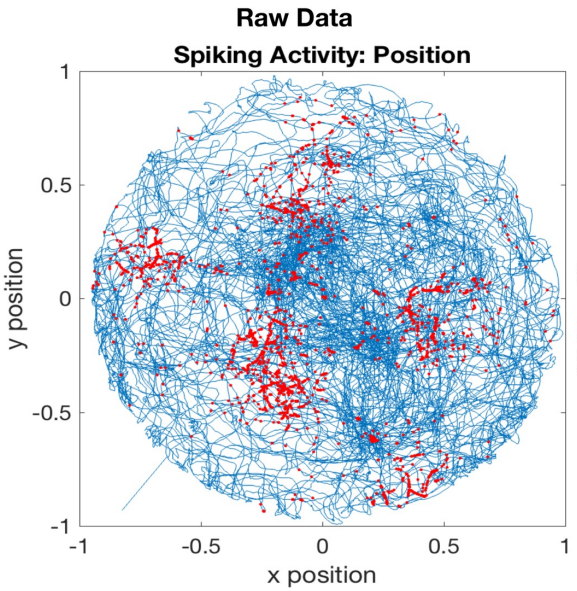


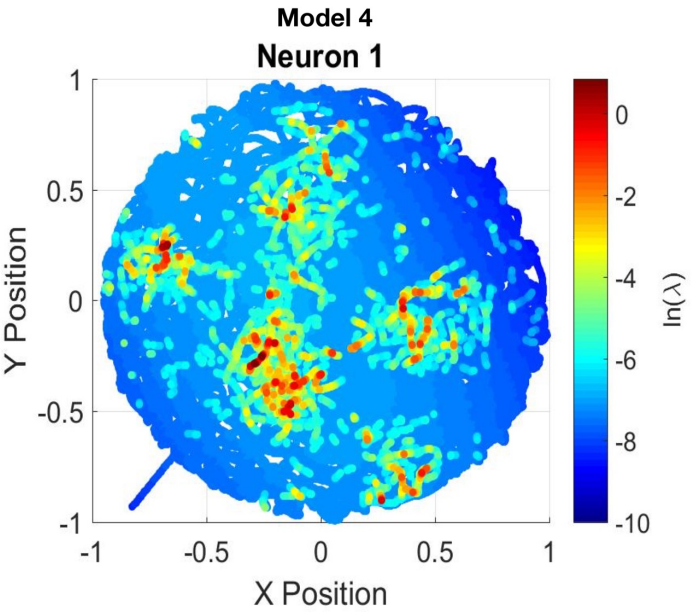


Absolute comparison to the ground truth data → Smallest KS found in Model 4

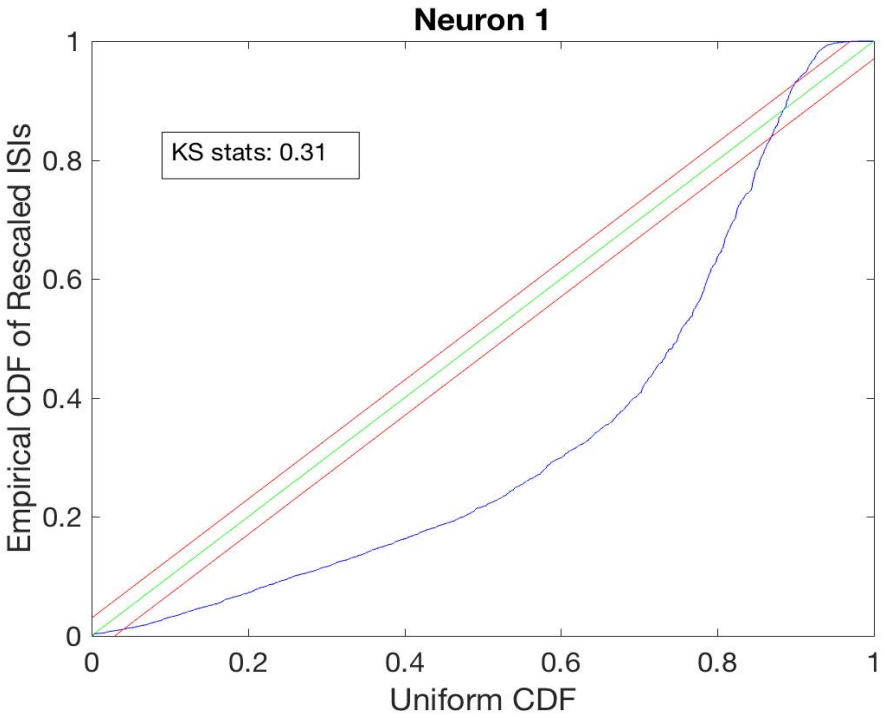
Justification 3 : Model Example comparison to raw data



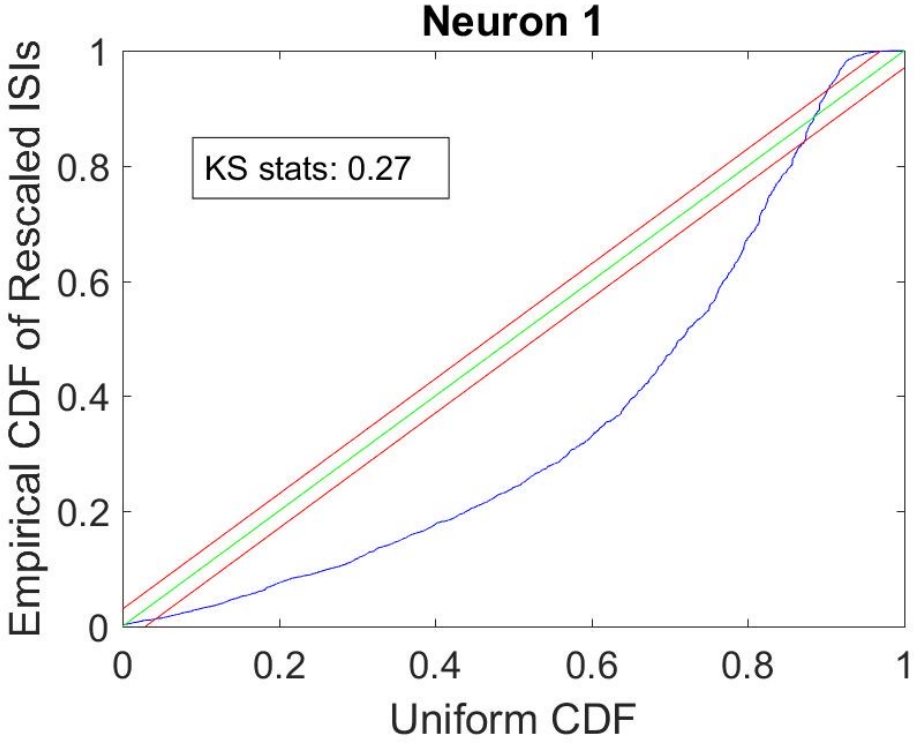




Justification 4 : KS Plot Comparison



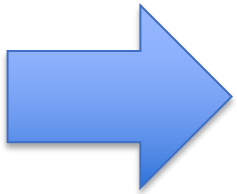
Model 1



Model 4

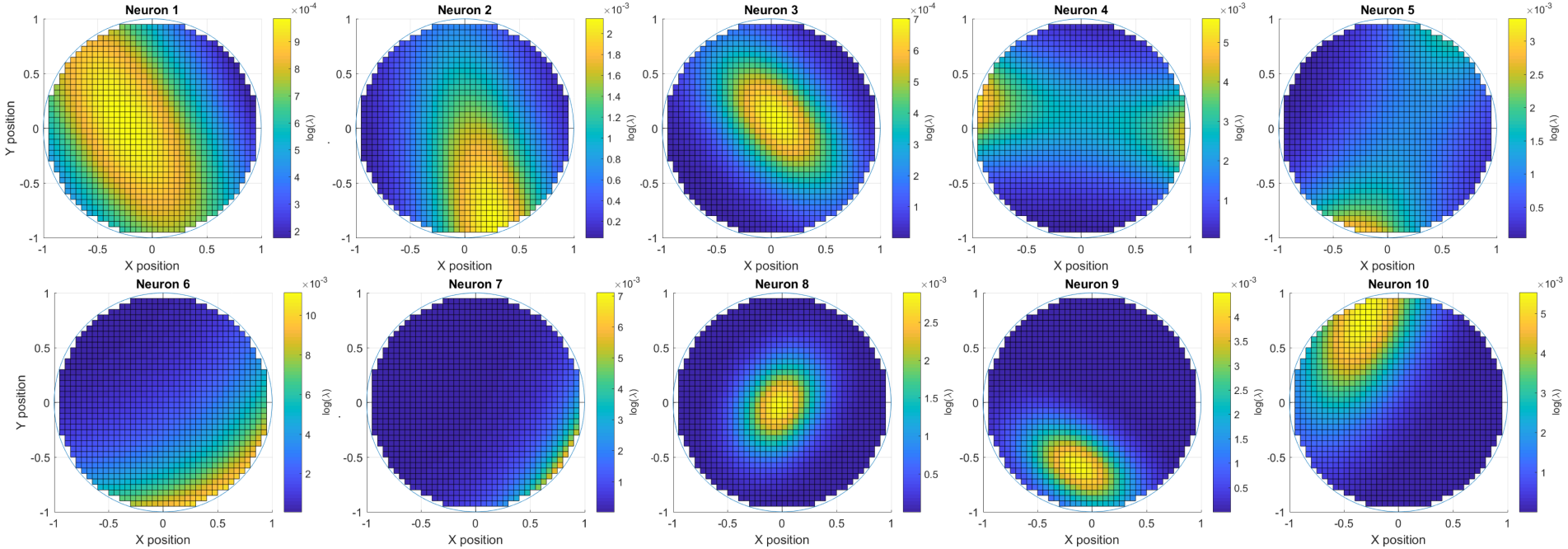
Model 4: Subgroup covariates

$$\log \lambda_c(t|x_t, y_t, h_c(t)) = \underbrace{\beta_0 + \beta_1 x_t + \beta_2 y_t + \beta_3 x_t^2 + \beta_4 y_t^2 + \beta_5 x_t y_t}_{\text{Spatial domain}} + \underbrace{\sum_{n=0}^{49} \beta_{n+6} h_{nc}}_{\text{Short term History}} + \underbrace{\sum_{n=0}^{49} \beta_{n+56} h_{nc+74}}_{\text{Long term History}}$$

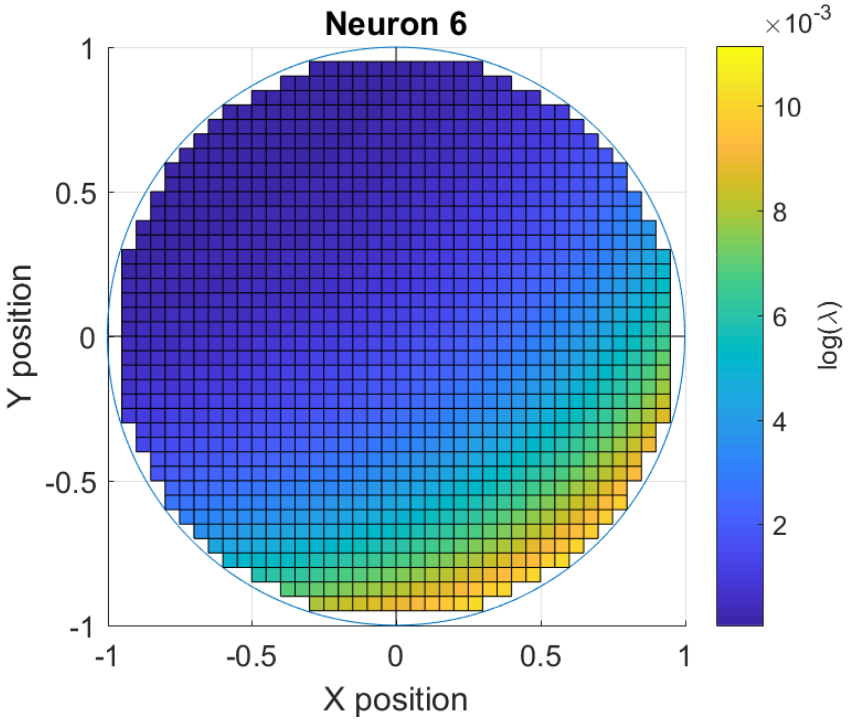


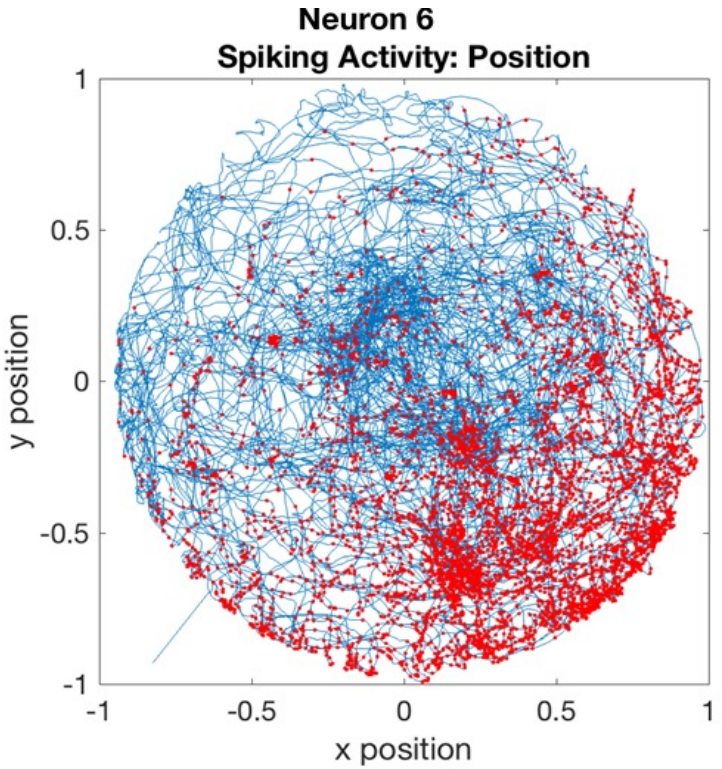
- Individual contribution of each subgroup of covaraties
- Better understanding of how they affects each neuron

Results: Model 4 - Spatial covariates

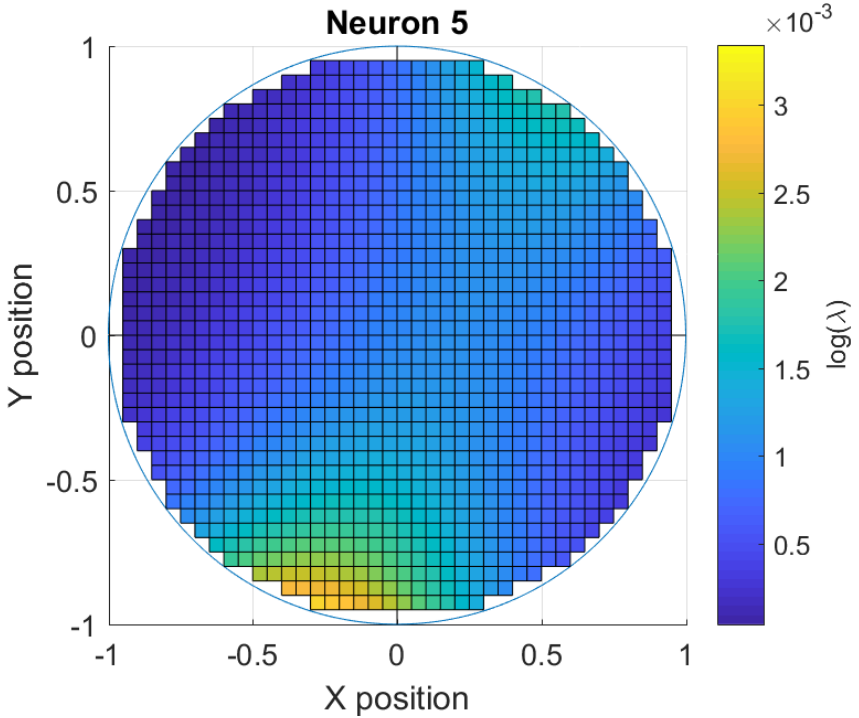


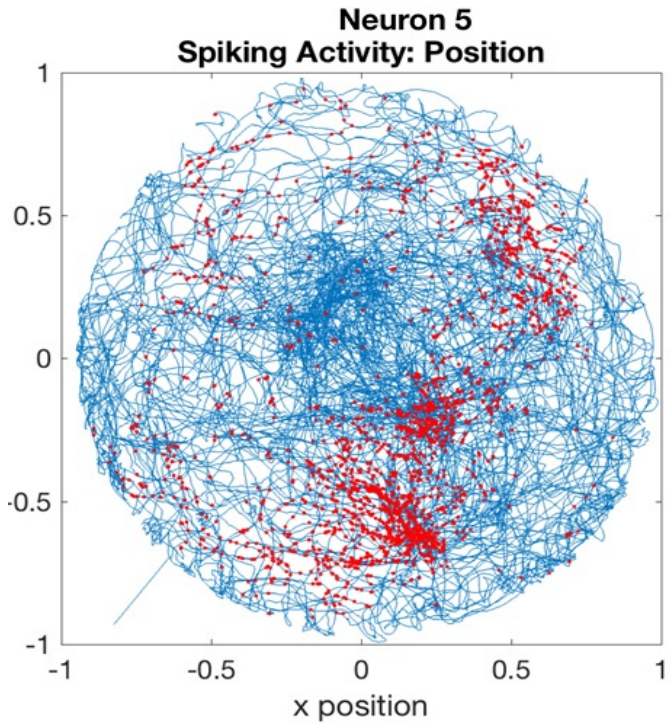
Results: Model 4 - Spatial covariates (Examples for good correlation)





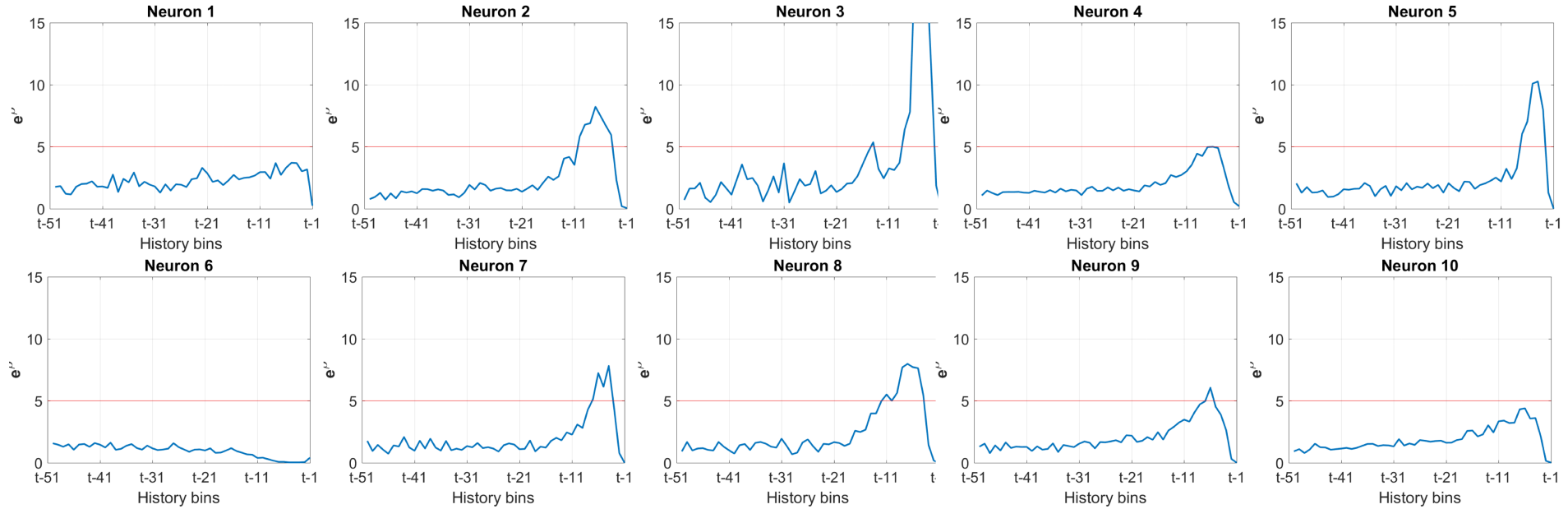
Results: Model 4 - Spatial covariates (Examples for poor correlation)





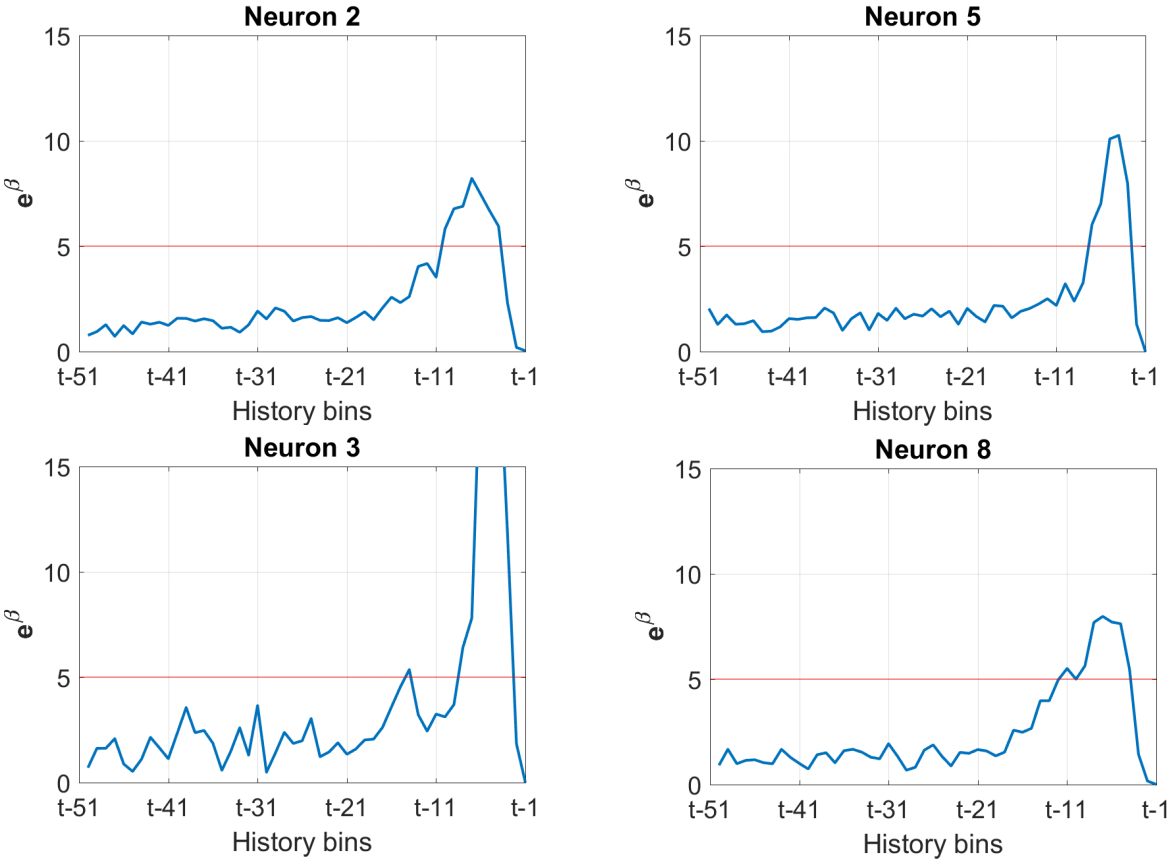
Poor: [1 2 3 5 8] Good: [4 6 7 9 10]

Results: Model 4 – Short term covariates

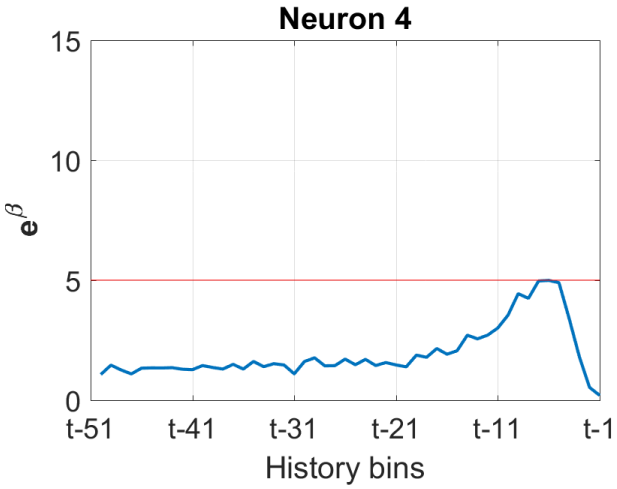


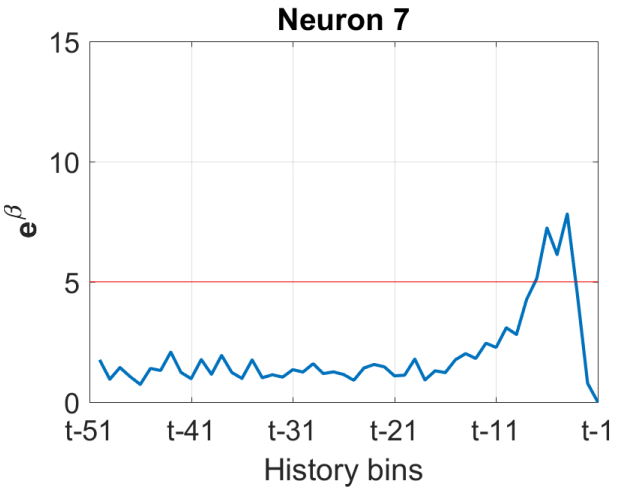
Arbitrary threshold = 5

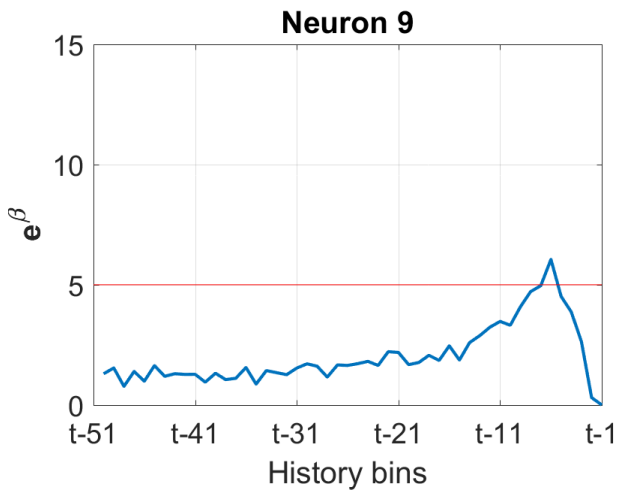
Results: Model 4 – Short term covariates (Strongly correlated)



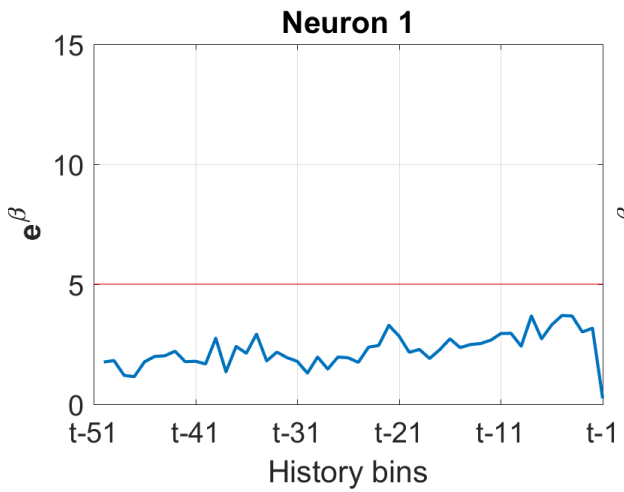
Results: Model 4 – Short term covariates (Moderately correlated)

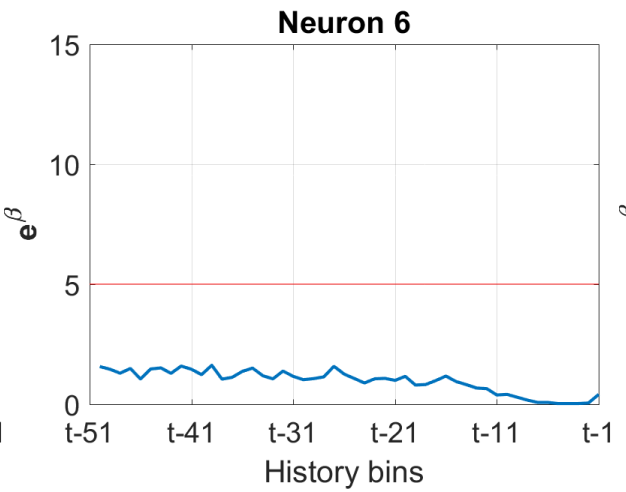


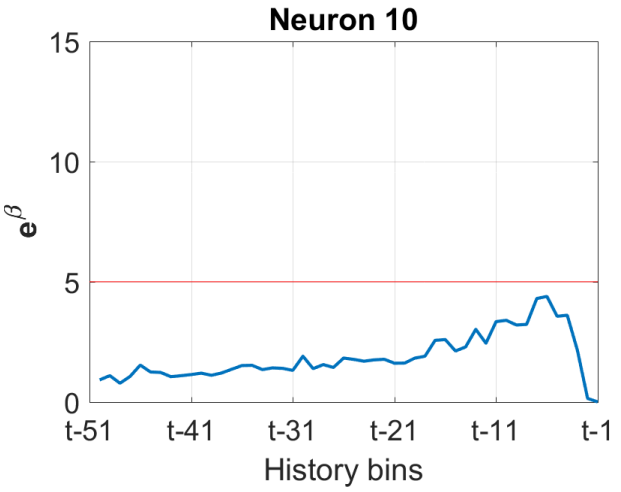




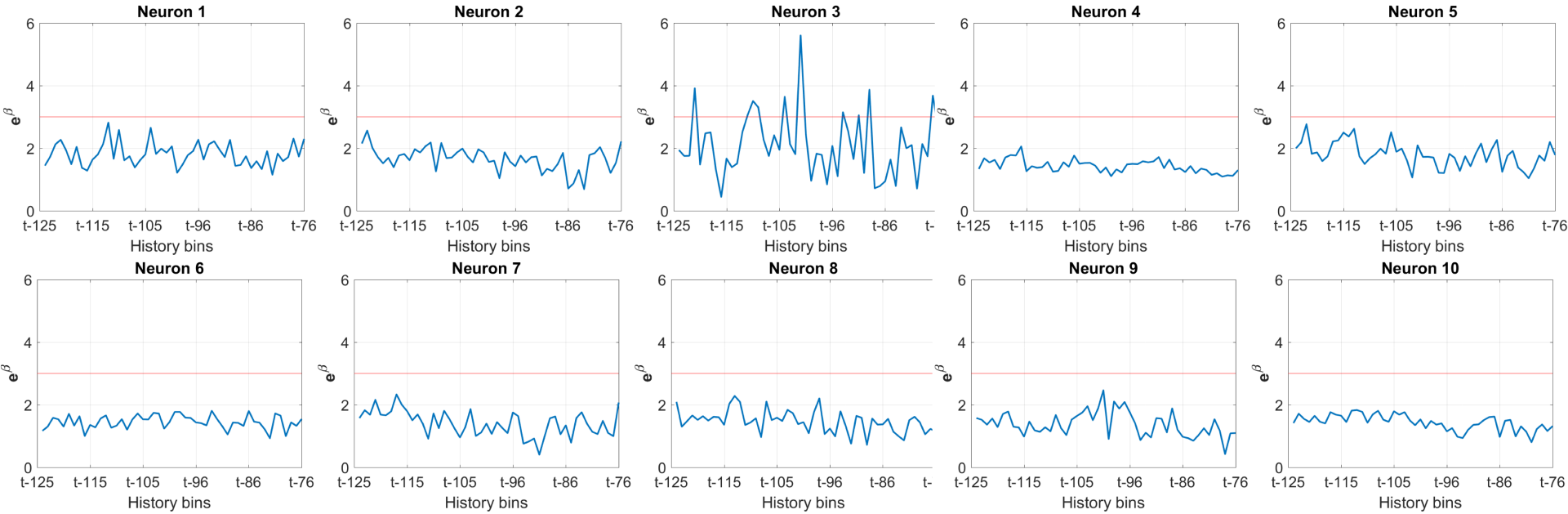
Results: Model 4 – Short term covariates (Poorly correlated)





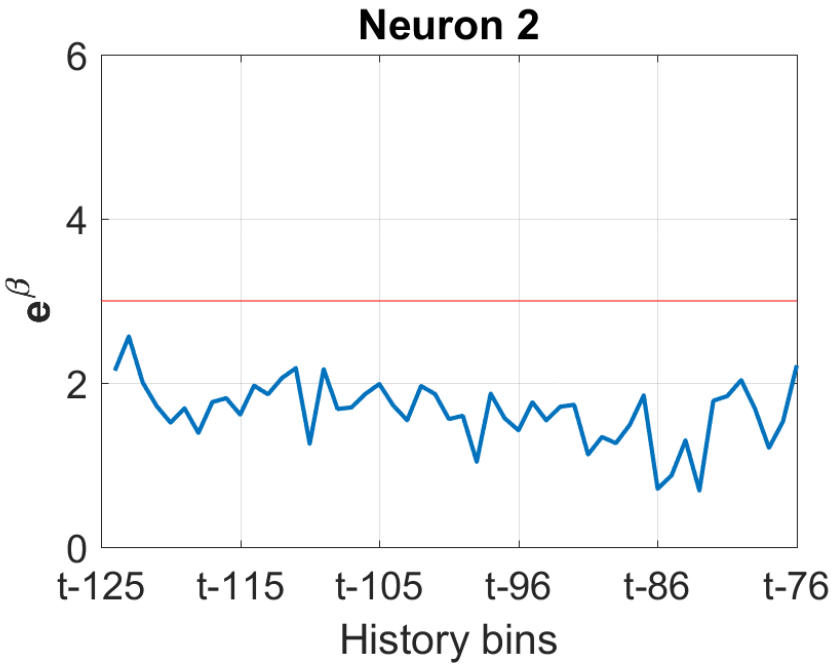


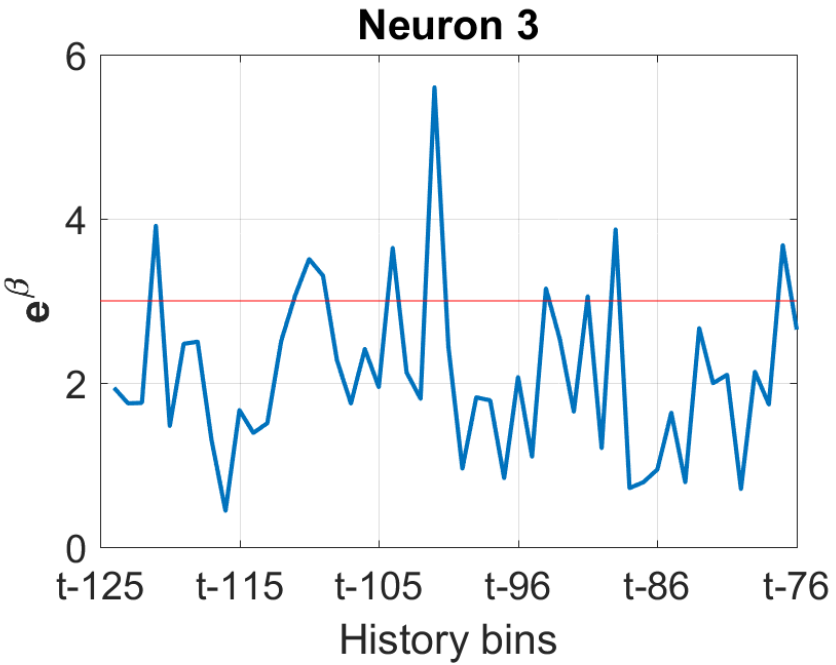
Results: Model 4 – Long term covariates



Arbitrary threshold = 3

Results: Model 4 – Long term covariates (No significant conclusion)





Results: Relation beetween spatial and short term temporal analysis

	1	2	3	4	5	6	7	8	9	10
Quad (good)				X		X	X		X	X
Quad (poor)	X	X	X		X			X		
Short Term (good)		X	X		X			X		
Short Term (normal)				X			X		X	
Short Term (poor)	X					X				X

Conclusions

- Quadratic position + Short term history + Long term history (Model 4) outperforms the other tested models due to the reduced KS and AIC
- While long term memory benefits the fit of the model, further studies are required to compare the impact between neurons.
- Evidence show that each neuron tends to more effectively encode either spatial or short term history