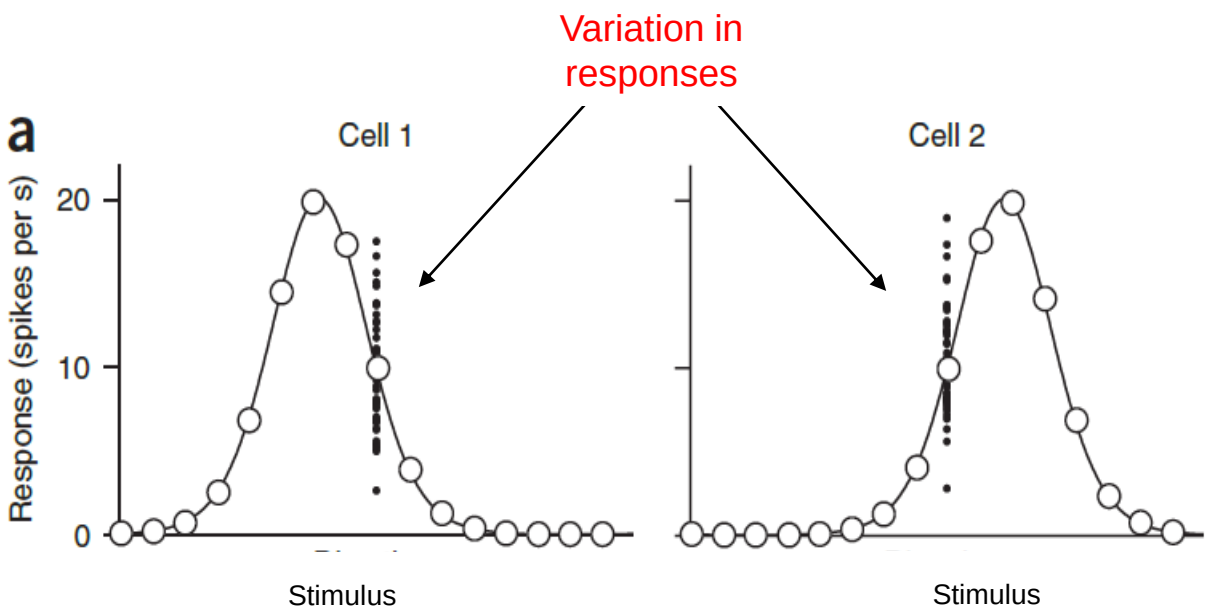
Analyzing the Effect of Noise Correlations on Decoding Neuronal Recording

Phenomenon

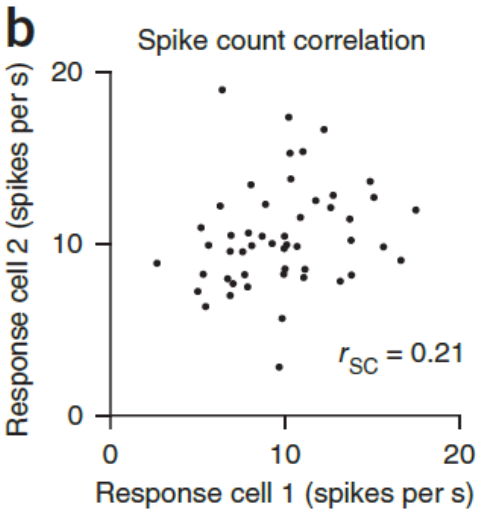
Trial-to-trial variability in neuronal response to the same stimulus



Cohen and Kohn, 2011

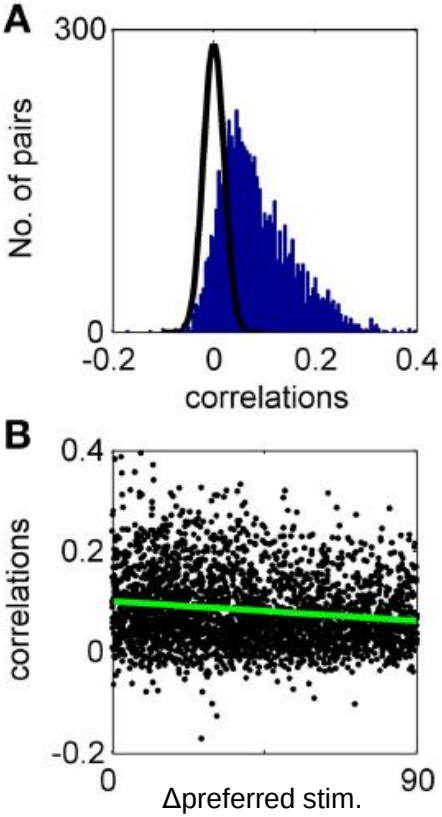
Phenomenon

Pair-wise noise correlation to the same stimulus



Cohen and Kohn, 2011

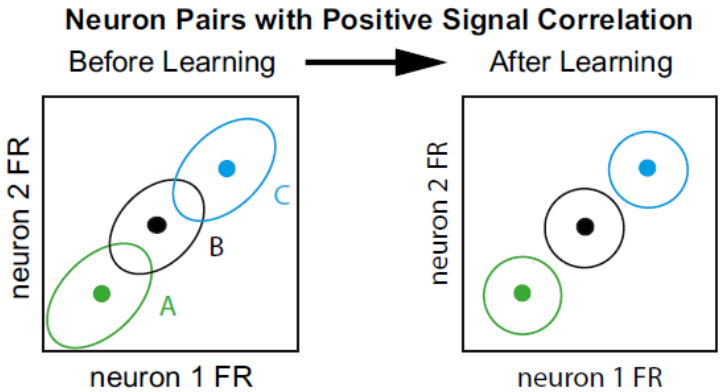
Distribution of pair-wise noise correlations



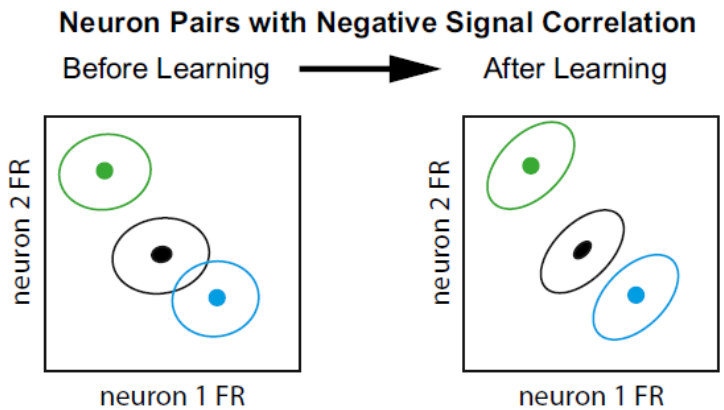
Mendels and Shamir, 2018

Background

Extracting information from noise correlations in auditory cortex in songbirds



- Discriminability increase
- Noise correlation decrease

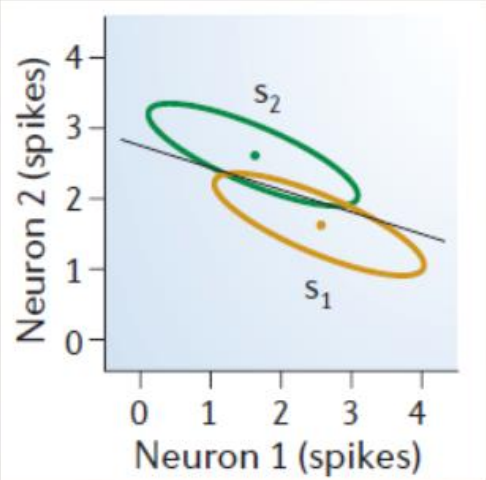


- Discriminability decrease
- Noise correlation increase

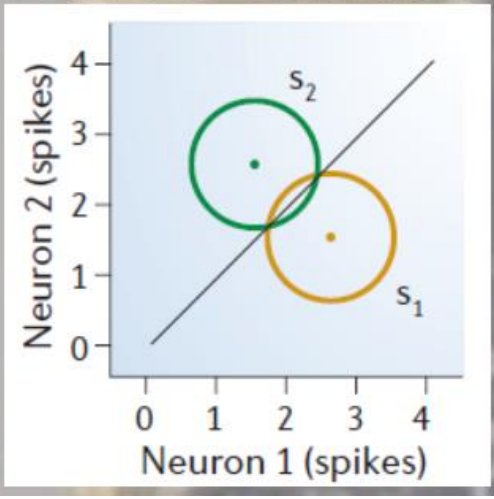
Theunissen & Elie, 2013

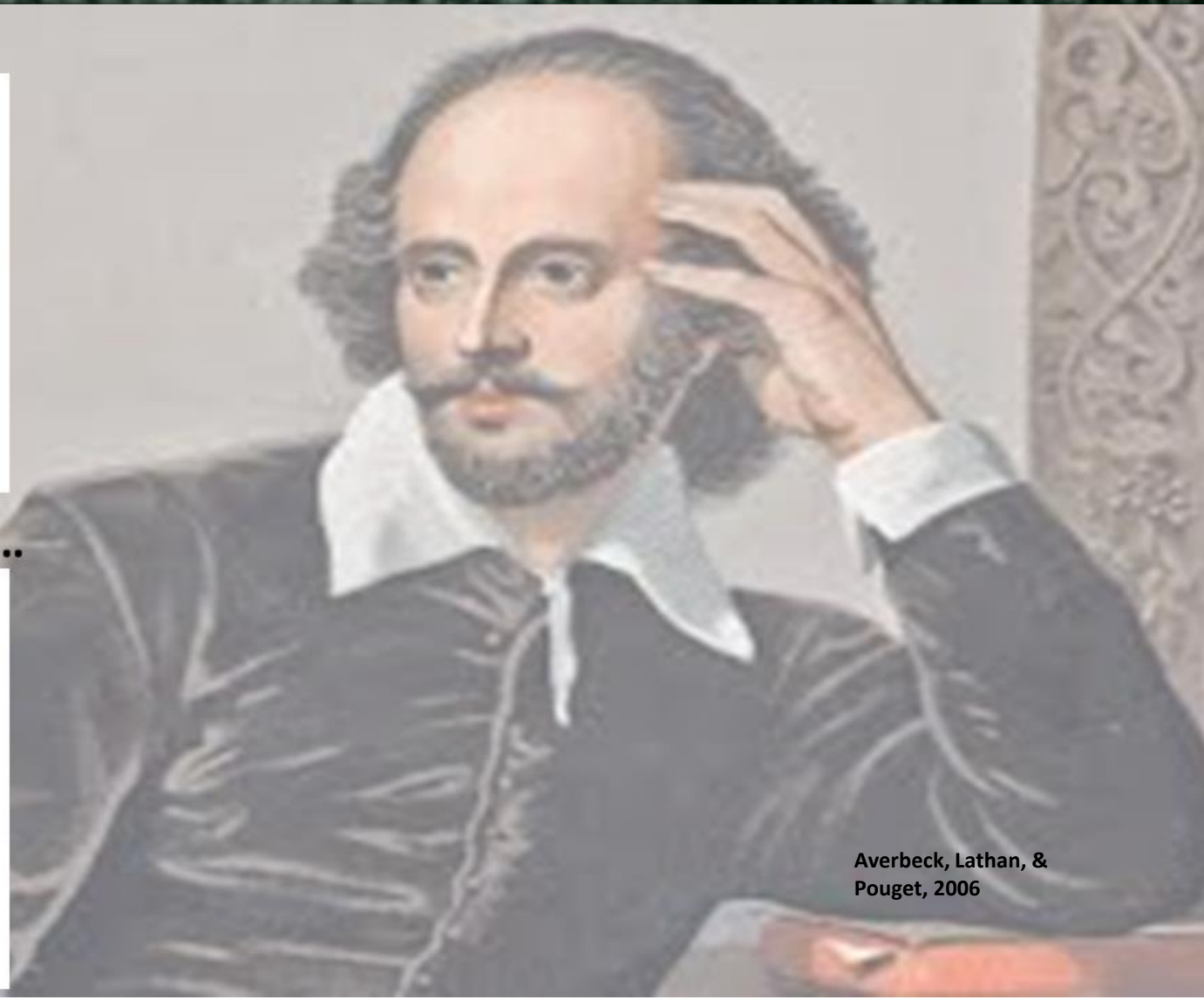
Objective / goal / question

To Correlate…



Or Not To Correlate…





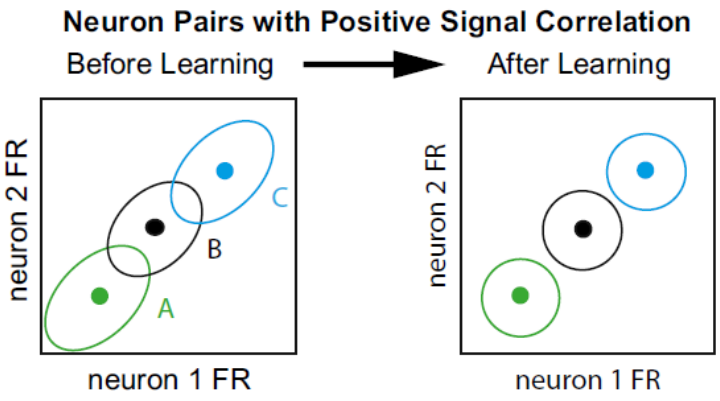
Averbeck, Lathan, & Pouget, 2006

Objective / goal / question

How do changes in the structure of noise correlation of a neural population affect the efficiency of sensory encoding?

Hypotheses

- Predictions:
  - Subpopulations with more negative noise correlations will have more precise stimulus encoding
  - Fewer neurons needed to reach same level encoding precision (fisher information) [decoding]



Selected Toolkit: Leaky Integrate and Fire (LIF) Neurons

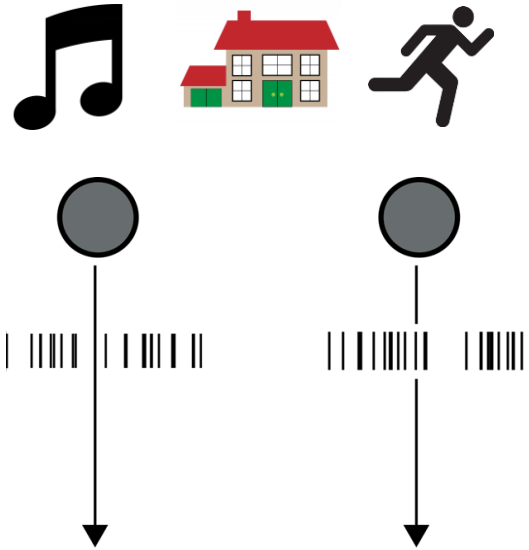
- Why is this the appropriate toolkit?
  - Biologically plausible spike count generator
  - Ability to modulate sources of noise individually
  - Easy link between tuning & noise

Parameters and variables

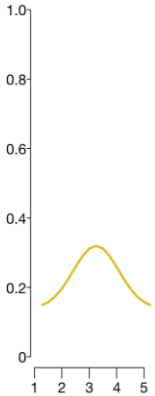
- Leaky Integrate and Fire (LIF) Neurons
  - τ = .02 seconds
  - V_{thresh} = - 0.05 V
  - V_{RMP} = - 0.07 V
  - V_{AHP} = - 0.08 V
  - …

  Biophysical Parameters
  Wang and Wang, 2006
- Two gains for individual noise distributions
- Excitability of neuronal population
- Number of Neurons (250 -1000)
- Number of Stimuli (17)

Model schematic / equations

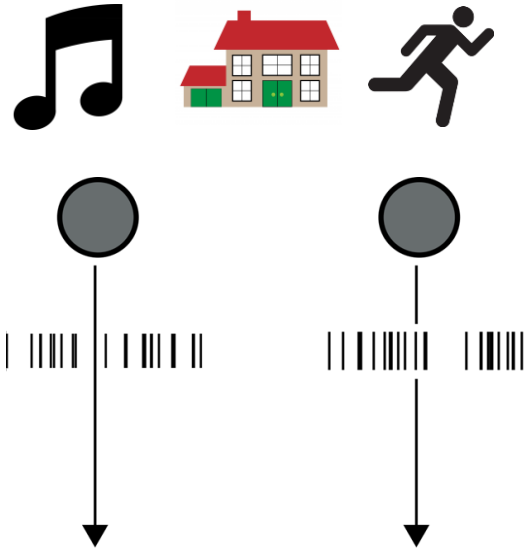


$$f_{tun}(s) = a * exp\left(-\frac{(s-\mu)^2}{b}\right) + c$$



Sensory Input

Model schematic / equations



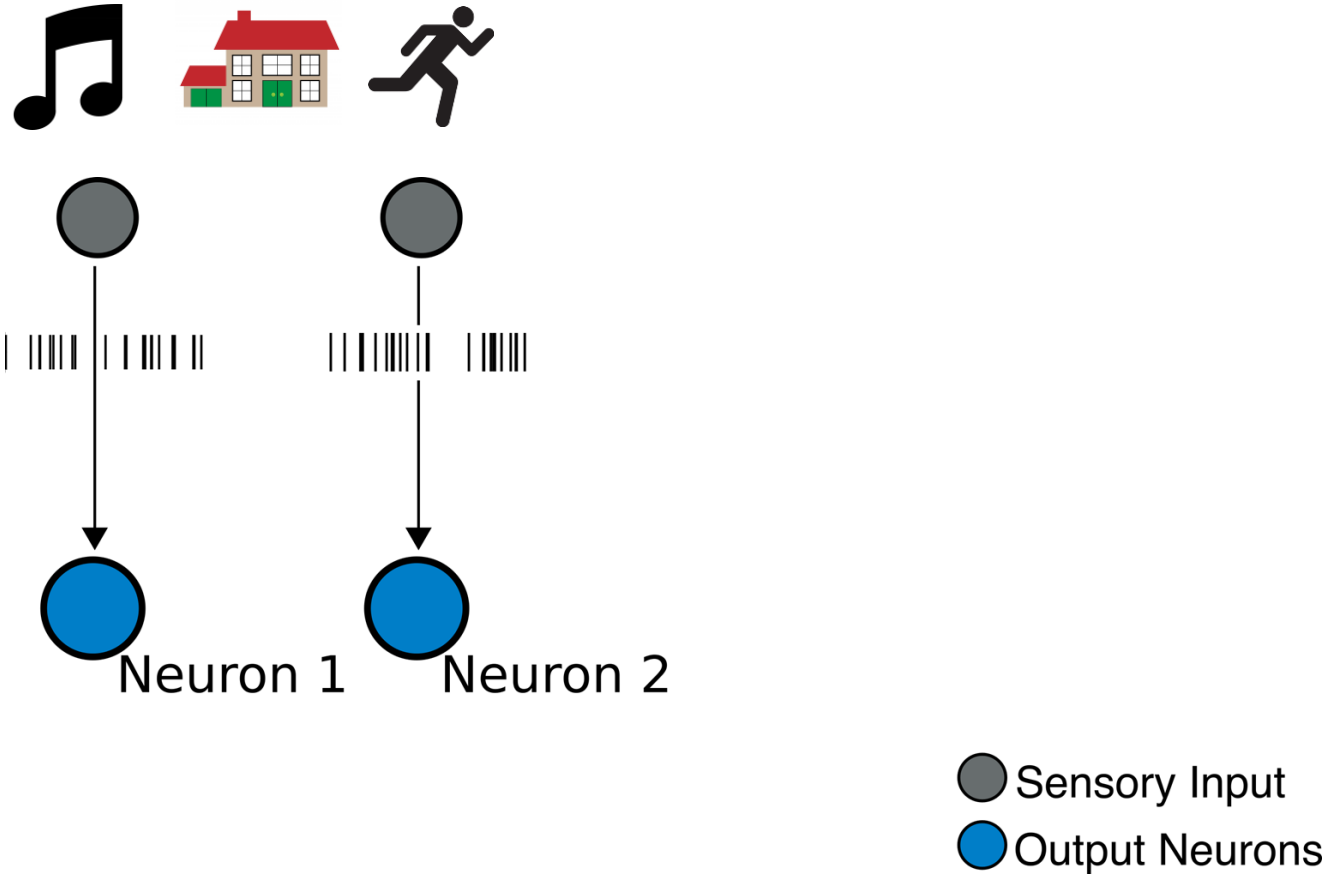
$$f_{tun}(s) = a * exp\left(-\frac{(s-\mu)^2}{b}\right) + c$$

$$p(k|s) = \frac{(g_{fr} * f_{tun}(s))^k * exp(-g_{fr} * f_{tun}(s))}{k!}$$

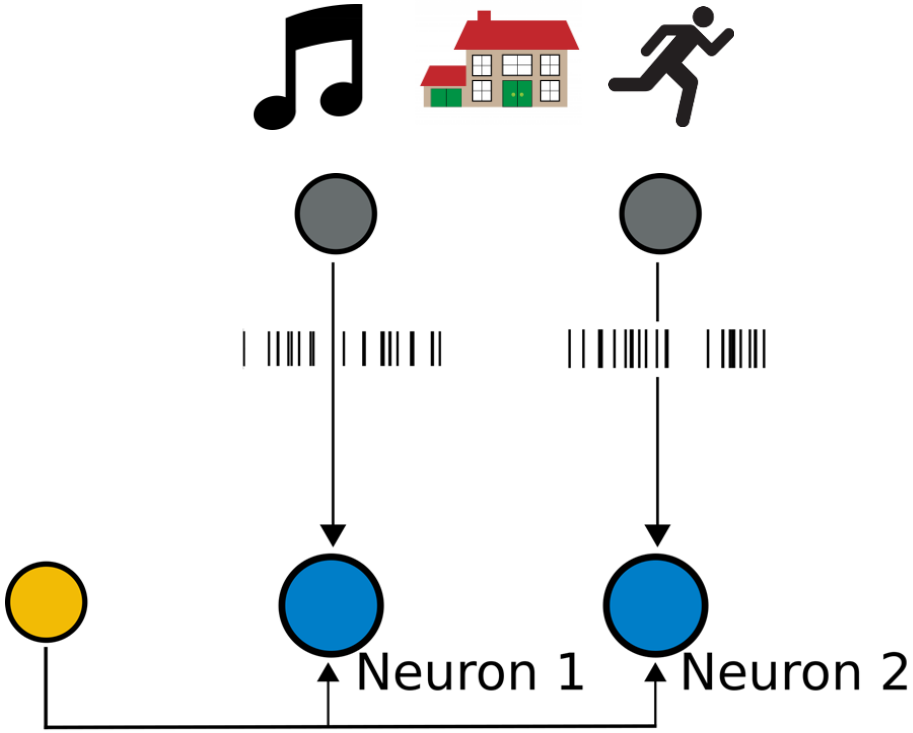
$$S(t) = \sum_k \delta(t - \tau_j^k)$$

Sensory Input

Model schematic / equations



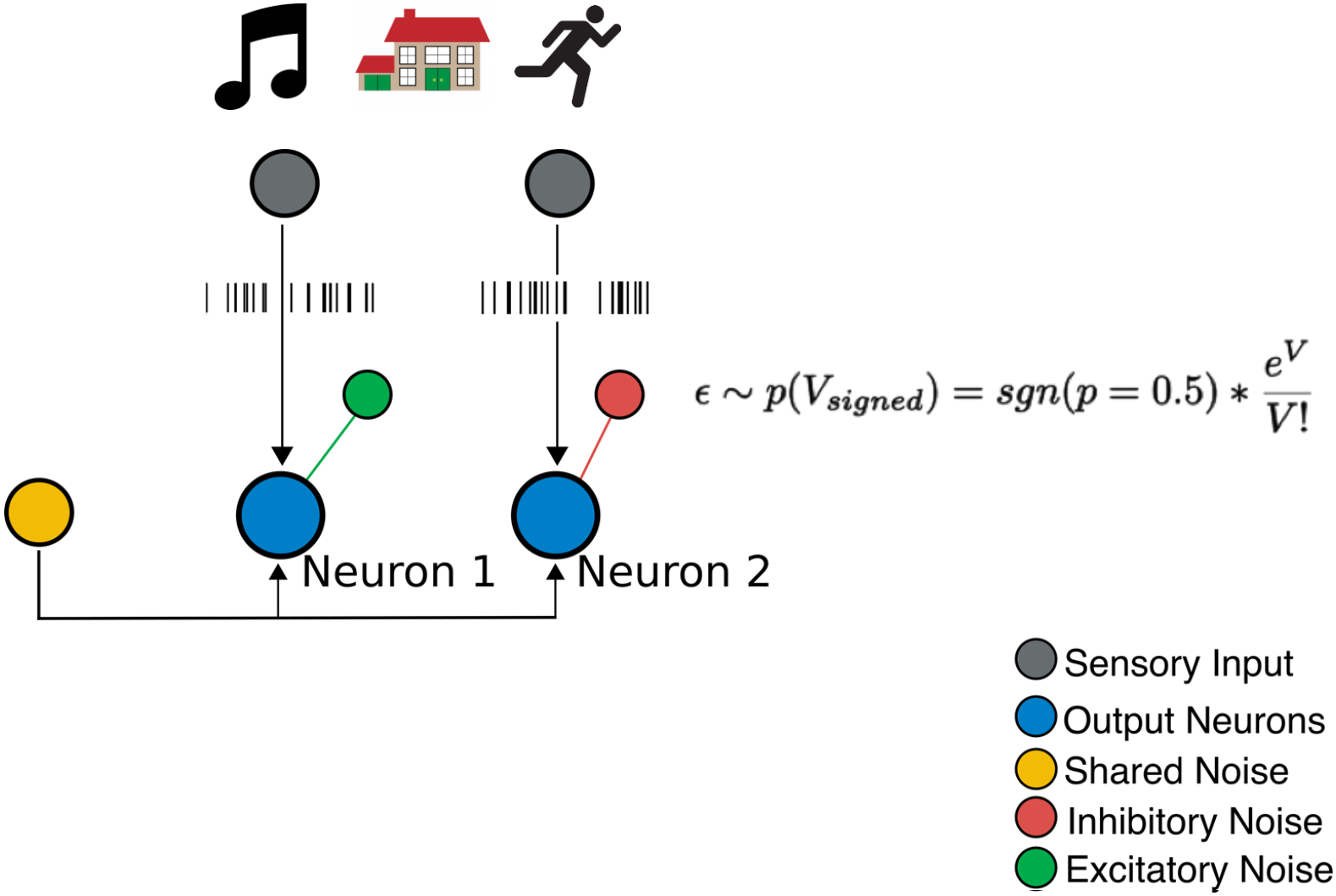
Model schematic / equations



$$\eta \sim p(V_{shared}) = \frac{1}{\sqrt{2\pi}} exp\left(-\frac{2}{2\pi}\right)$$

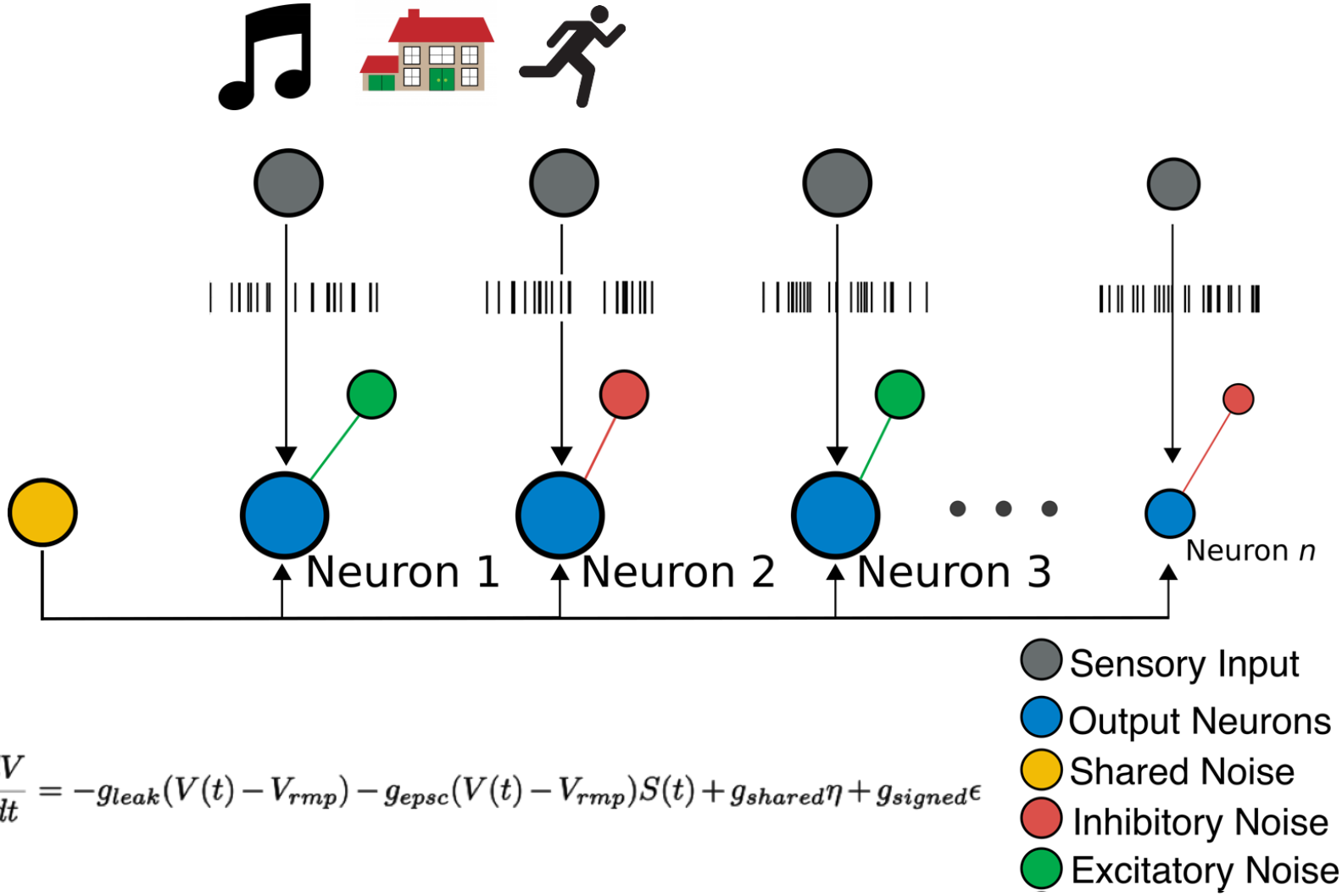
Sensory Input
Output Neurons
Shared Noise

Model schematic / equations



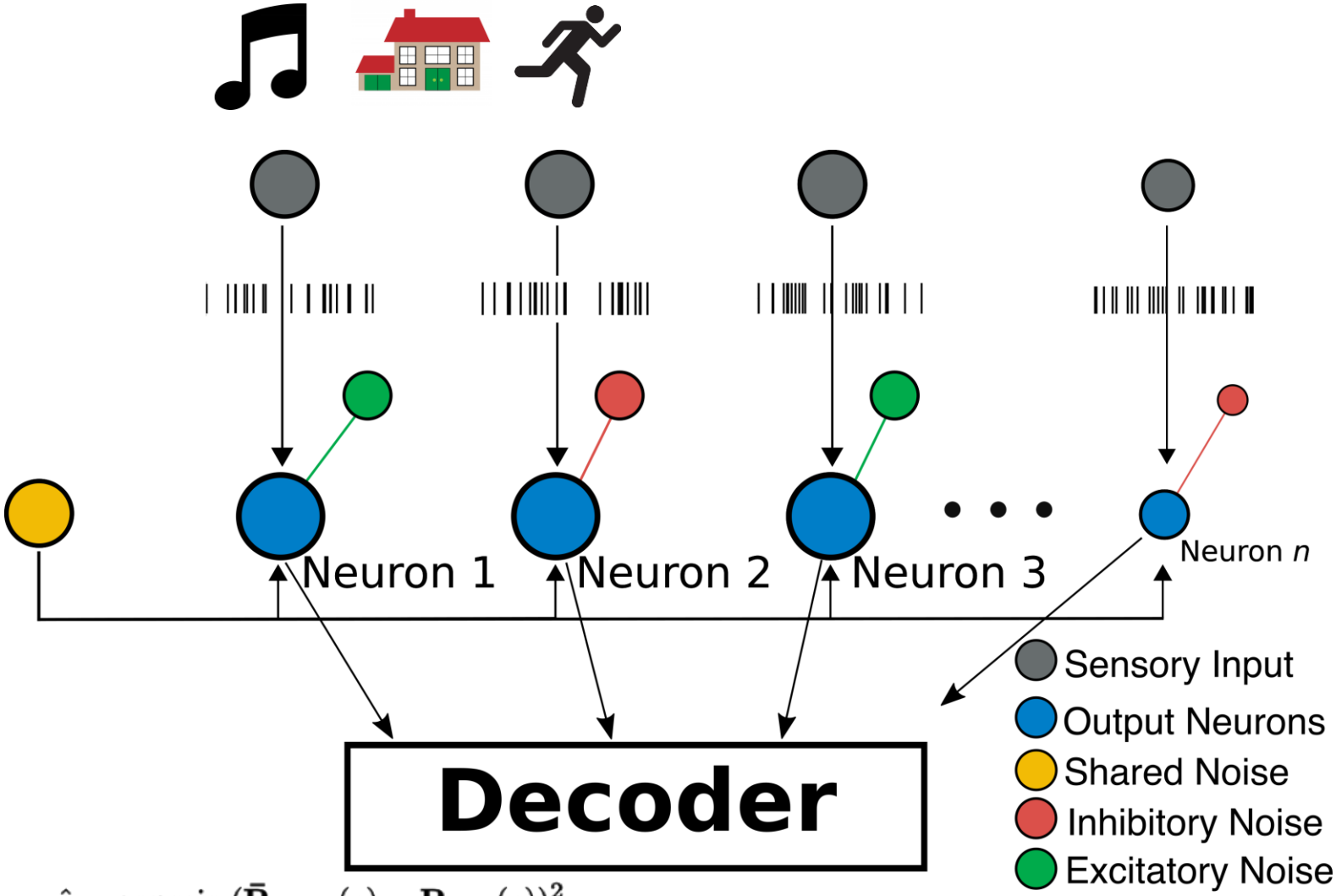
$$\epsilon \sim p(V_{signed}) = sgn(p = 0.5) * \frac{e^V}{V!}$$

Model schematic / equations



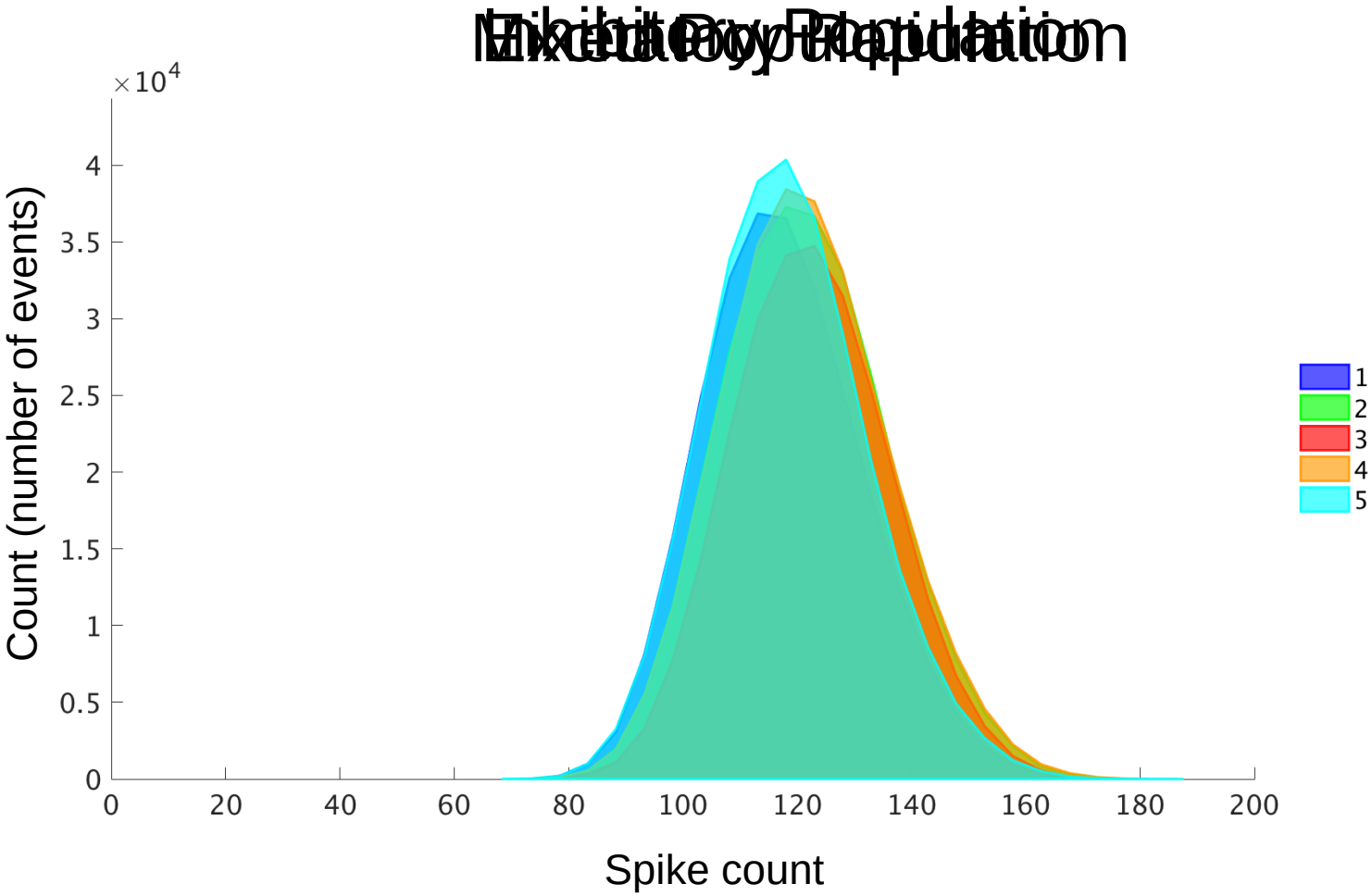
$$C\frac{dV}{dt} = -g_{leak}(V(t) - V_{rmp}) - g_{epsc}(V(t) - V_{rmp})S(t) + g_{shared}\eta + g_{signed}\epsilon$$

Model schematic / equations

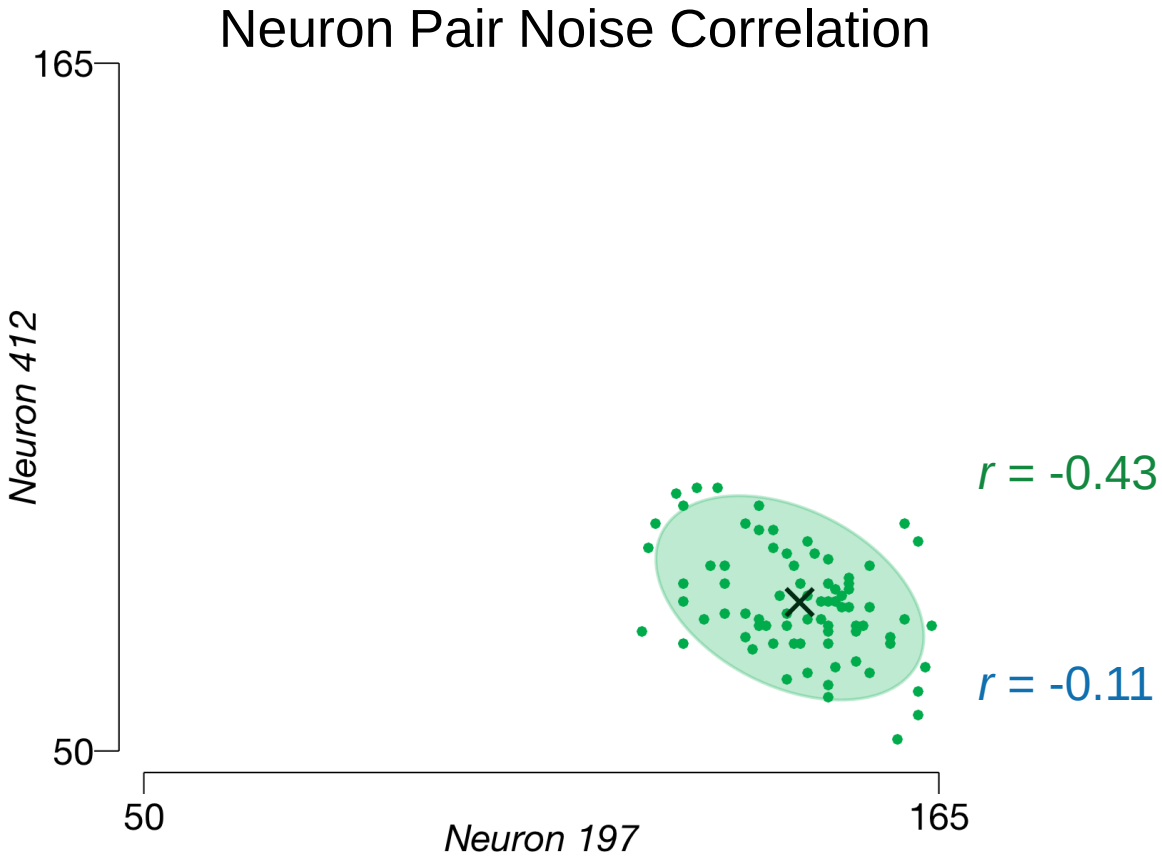


$$\hat{s} = \arg\min_{s} \left(\bar{\mathbf{R}}_{train}(s) - \mathbf{R}_{test}(s)\right)^2$$

Model schematic / equations



Simulations / results



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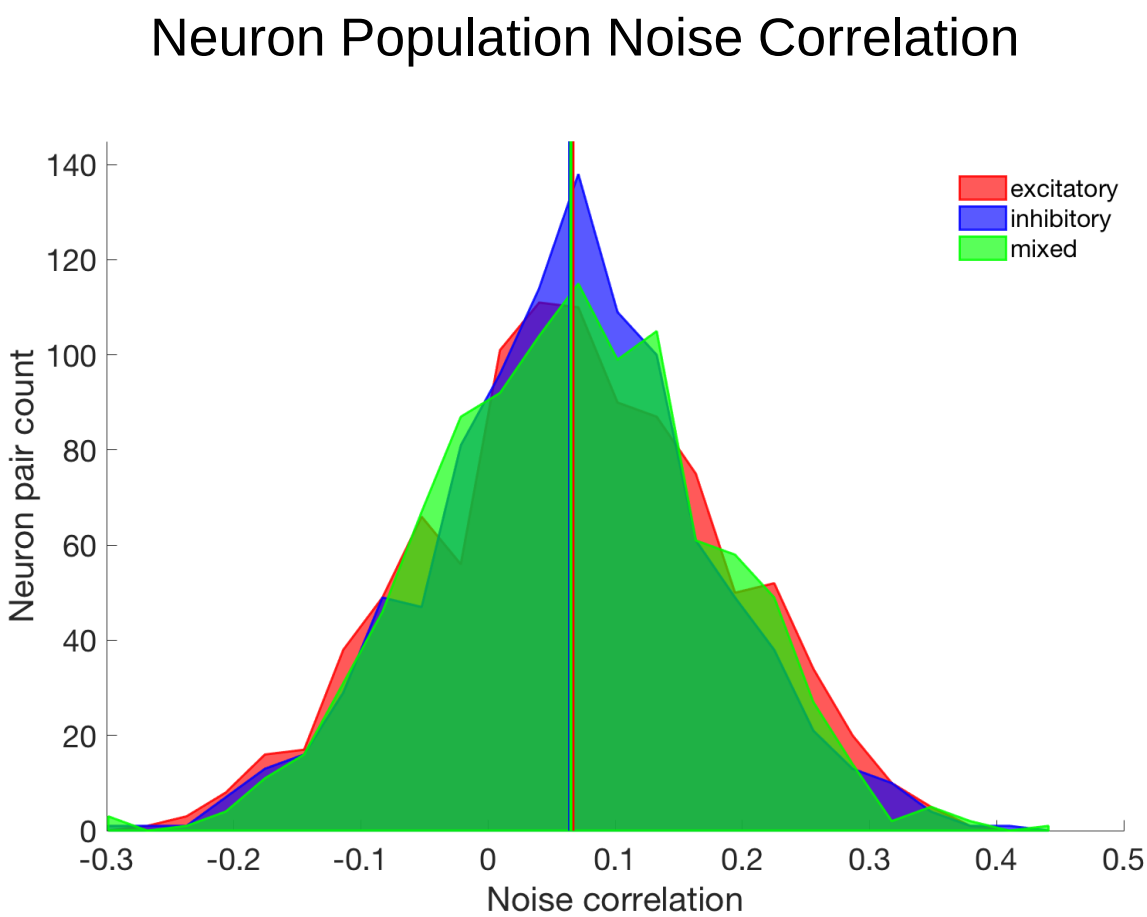
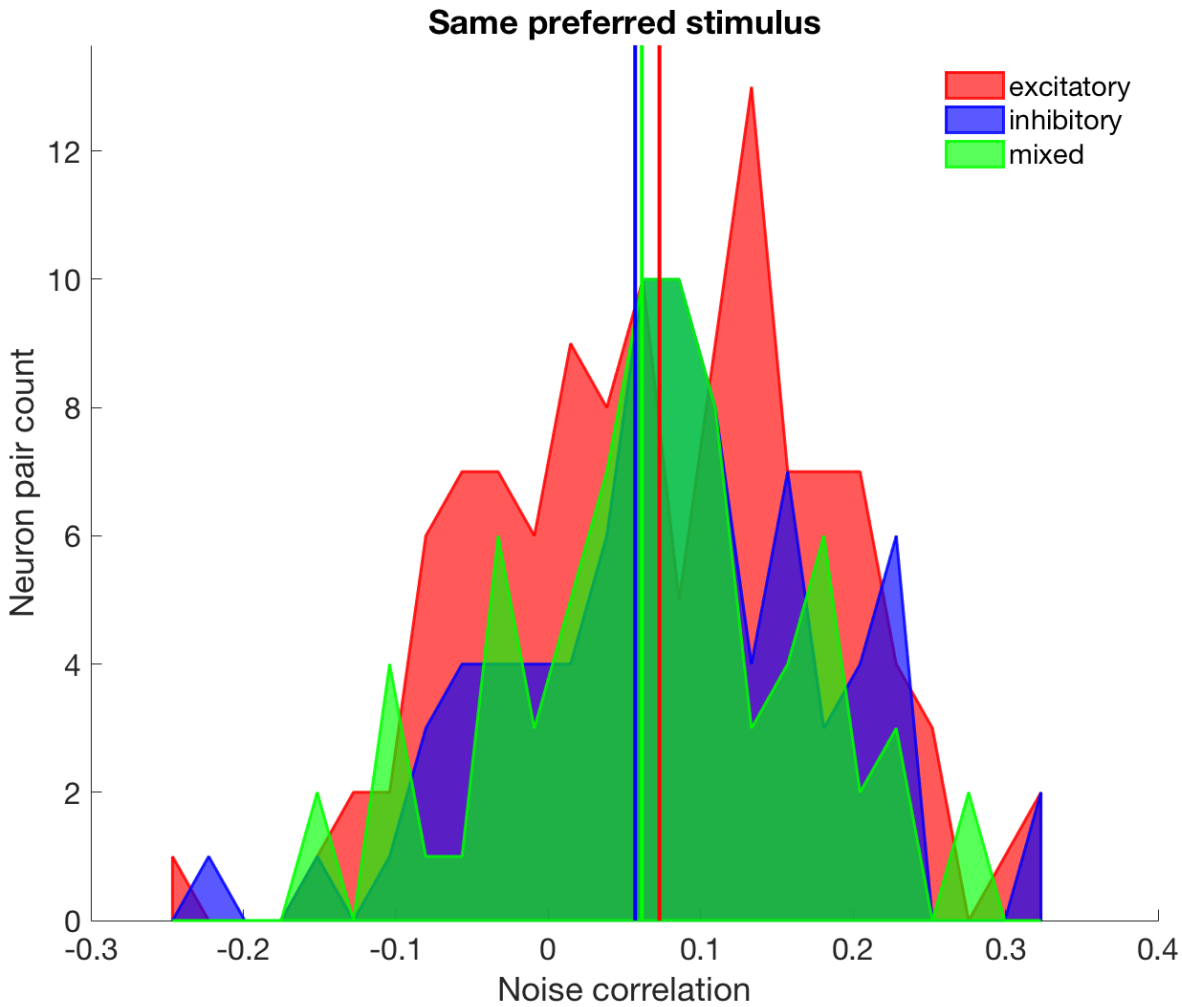
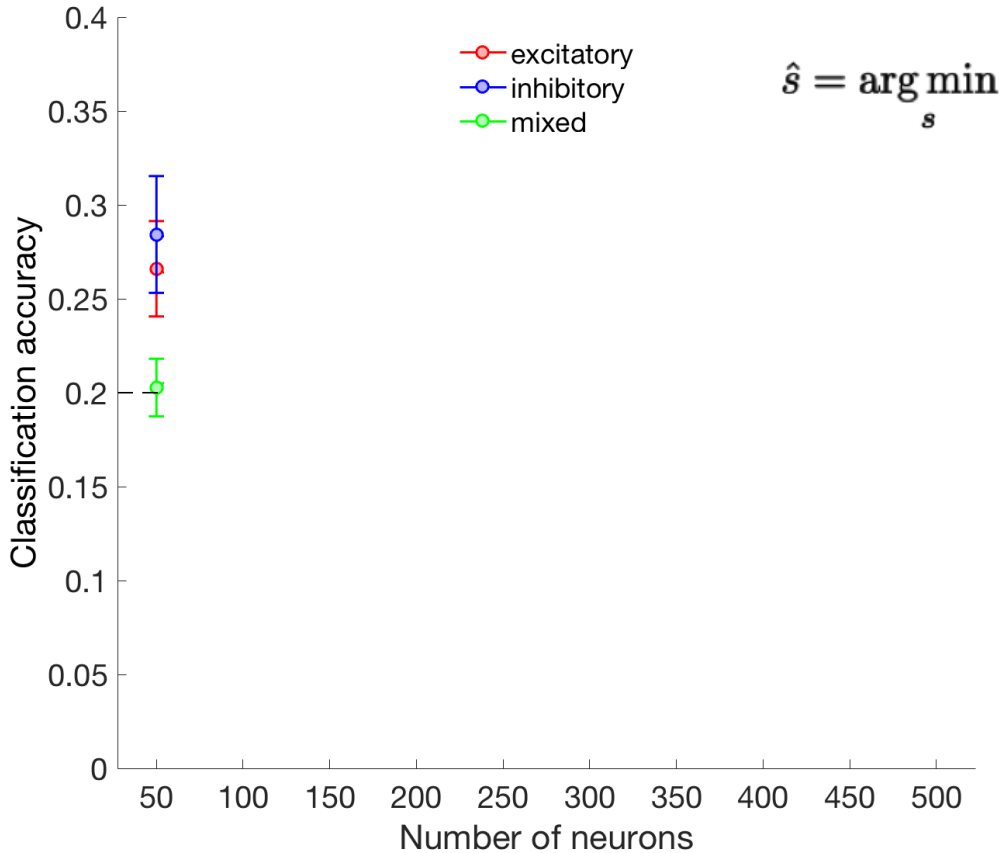


Simulations / results



Model testing re. hypotheses

Decoding Accuracy Isn't Better in Mixed Population



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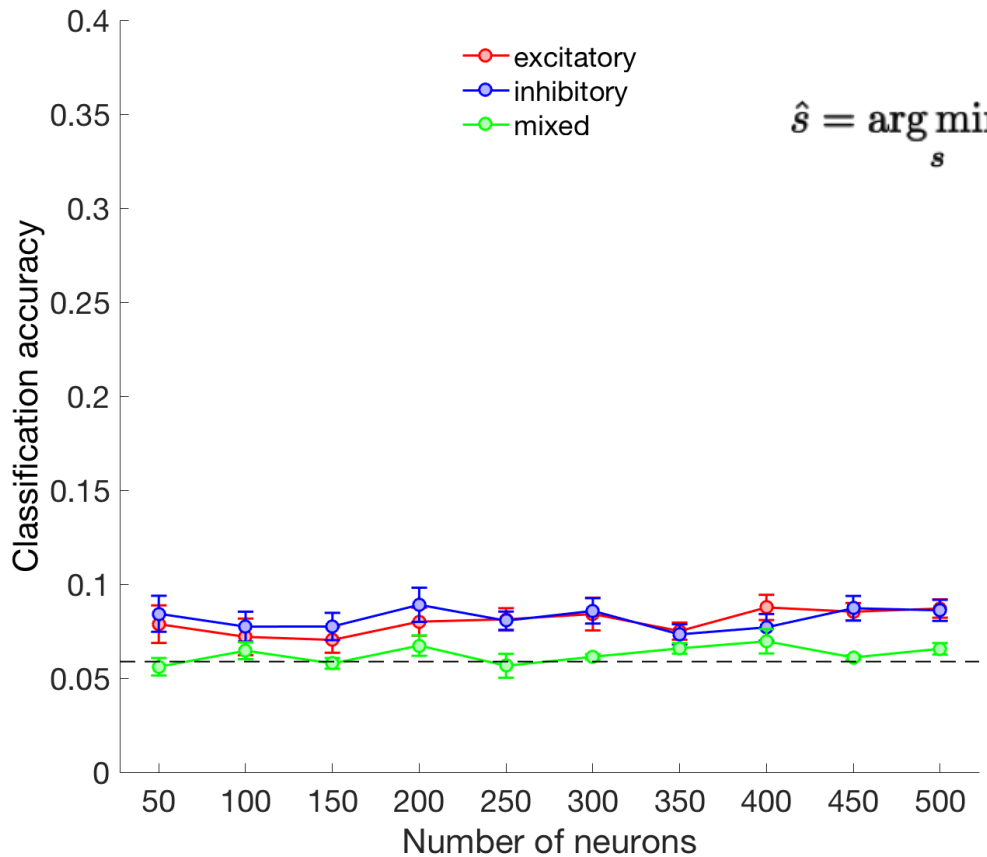
Model testing re. hypotheses

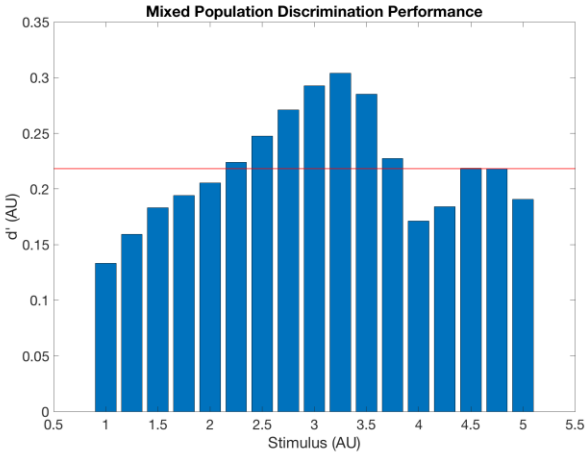
Decoding accuracy Isn't Better in Mixed Population

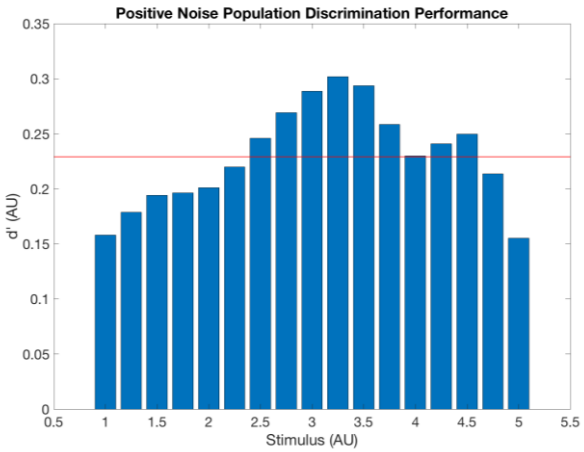


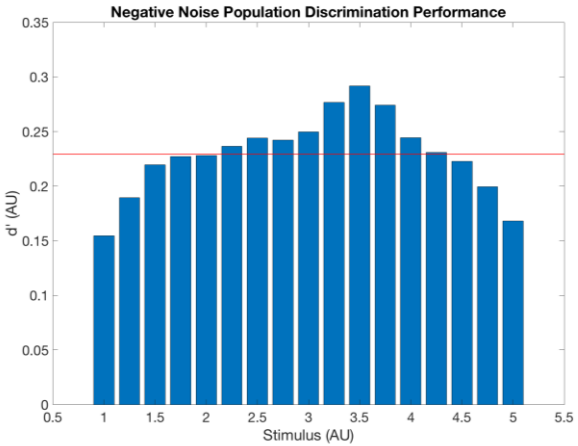
$$\hat{s} = \arg\min_{s} \left(\bar{\mathbf{R}}_{train}(s) - \mathbf{R}_{test}(s)\right)^2$$

Model testing re. hypotheses

- Fisher information -> d’







$$d'_{pop}(s) = \Delta s \sqrt{FI(s)}$$

$$Fisher\ Information = FI(s) = \frac{d\mathbf{f}(s)}{ds}^T \mathbf{\Sigma}(s)^{-1} \frac{d\mathbf{f}(s)}{ds}$$

Critical model evaluation

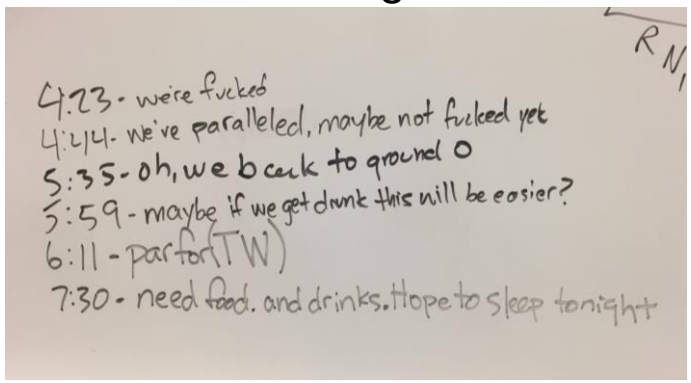
- Is this a good model?

Criteria	Our Model
Explains the data?	?
Generalizable?	✓
Provides new insight?	X
Usefulness?	?
Elegance?	✓

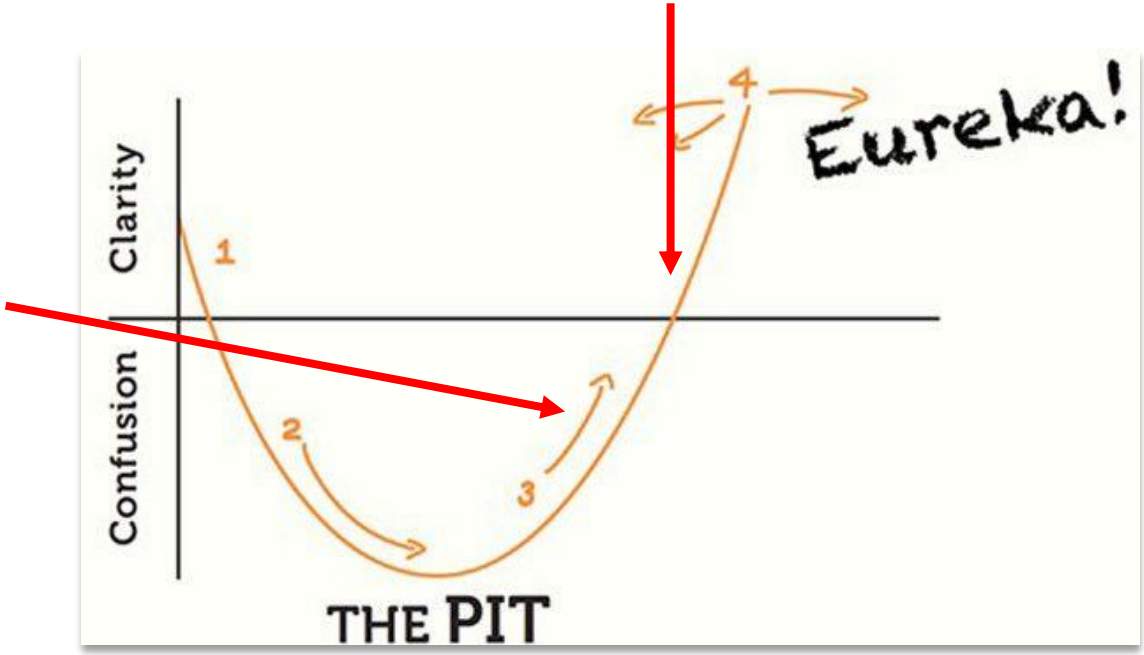
Limitations

- Steep learning curve
  - Unable to inject structured noise in a LIF population
  - No time to systematically vary signal:noise relationship

Last Night



Today



Summary & conclusions

- What have we learned?
  - Initial foray into modeling realistic neural networks
  - The ~~significance~~ difficulty of noise sources in neural modeling
  - Generating useful correlation structure de novo is challenging
  - Hofstadter's Law: A task always takes longer than you expect, even when you take into account Hofstadter's law

References

- Averbeck, Bruno B., Peter E. Latham, and Alexandre Pouget. “Neural Correlations, Population Coding and Computation.” *Nature Reviews Neuroscience* 7, no. 5 (May 2006): 358–66. https://doi.org/10.1038/nrn1888.
- Cohen, Marlene R, and Adam Kohn. “Measuring and Interpreting Neuronal Correlations.” *Nature Neuroscience* 14, no. 7 (July 2011): 811–19. https://doi.org/10.1038/nn.2842.
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- Theunissen, Frédéric E., and Julie E. Elie. “Population Code, Noise Correlations, and Memory.” *Neuron* 78, no. 2 (April 2013): 209–10. https://doi.org/10.1016/j.neuron.2013.04.012.