Does structure in neural activity match anatomical structure?

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Introduction

Information in the brain is carried in correlated network activity. Until recently, it has been difficult to record responses from multiple brain regions simultaneously. This meant that studies on network behaviour were restricted to studying only one region at a time. The development of 'Neuropixels' probes have allowed extracellular voltage measurements to be collected from multiple brain regions simultaneously. In this project, we used data collected from five different brain regions to compare distributions of correlated activity within these regions, and between these regions.

We then used these measurements to create networks between the neurons in these five regions. We used a cutting edge community detection algorithm to find communities in these networks. We are currently in the process of comparing these communities to the anatomical distribution of their constituents.

Main Objectives

1. To compare the distributions of spike count correlations (r_{SC}) and mutual information ($I(X;Y)$) in different regions.
2. To detect any communities in the networks created by these measurements, either within or between the anatomical regions.
3. To compare the communities detected in the spike count correlation networks to those detected in the mutual information networks.
4. To compare the network communities to their anatomical distribution.

Data

Using two probes, spiking activity was simultaneously collected from over 800 neurons in an awake mouse brain for a period of 84 minutes. During this period, the mouse and was shown various visual stimuli. The 800 neurons were distributed across 5 different brain regions: **V1, hippocampus, thalamus, motor cortex**, and **striatum** [1].

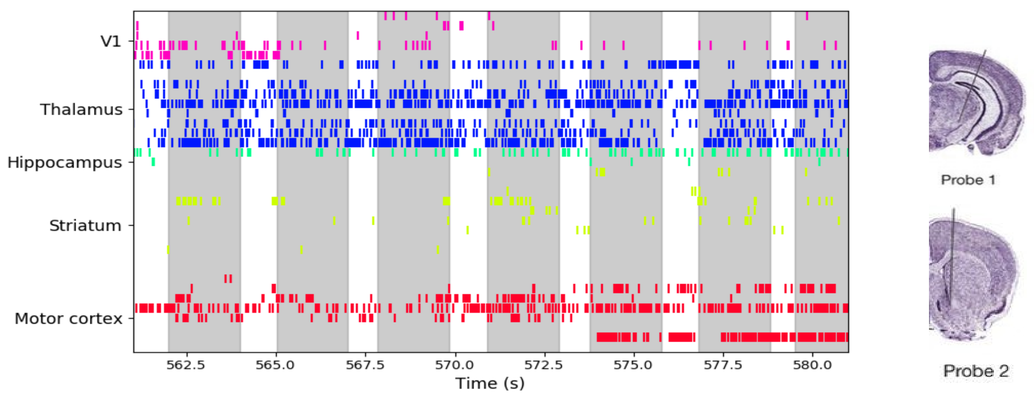

Figure 1: (Left) a Raster plot showing a the firing times of a subset of the cells, during a subset of the experiment time. Shaded areas indicate times when a visual stimulus was present, and (Right) positions of the two probes. Probe 1 intersects V1, the hippocampus, and the thalamus. Probe 2 intersects the motor cortex and the striatum.

Materials and Methods

Spike Count Correlation, r_{SC} We measured Pearson's correlation between the spike counts of neurons in pairs.

Mutual Information, $I(X;Y)$ We measured the mutual information between the spike counts of neurons in pairs.

Network Noise Rejection We used a recently developed method to split the networks created by these measures into signal and noise [2].

Consensus Clustering We used consensus clustering on the signal network to investigate any communities within these networks.

Results

Correlation & Information Distributions

We used statistical tests to find out if the distributions of pairwise correlation were different between regions. We found that correlations in the hippocampus and thalamus were statistically different those in the other three regions ($p < 0.05$). The other three regions were statistically similar.

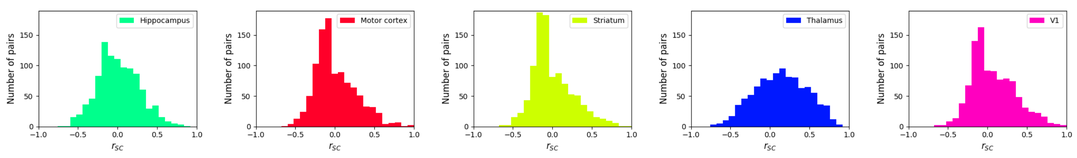

Figure 2: Histograms of the spike count correlations of 1000 randomly chosen pairs of neurons from within each region.

We did the same for mutual information distributions. Comparing all pairwise combinations of regions, we found that all regional distributions of mutual information were statistically different ($p < 0.001$).

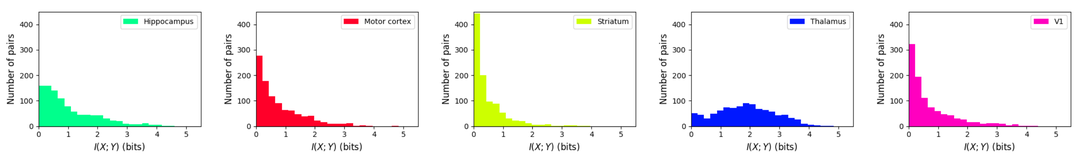

Figure 3: Histograms of the mutual information between the neuron spike counts of 1000 randomly chosen pairs from within each region.

Pairwise Geomtric Mean, Correlation & Information

We compared the spike count correlations for pairs of neurons to the geometric means of their firing rates. Surprisingly, we found very little correlation between the two quantities.

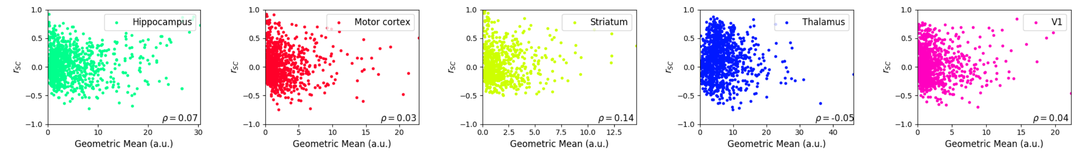

Figure 4: Spike count correlations of pairs of neurons plotted against geometric means of the firing rate of those pairs for each region.

We found a strong positive correlation between the pairwise geometric mean and the mutual information.

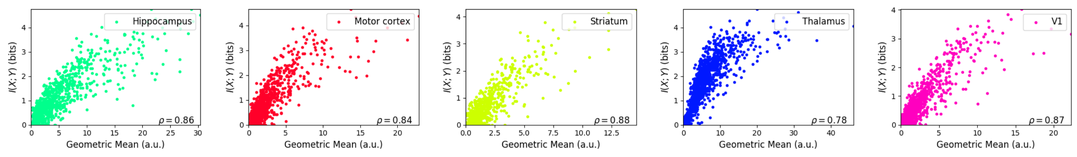

Figure 5: Mutual information of pairs of neurons plotted against geometric means of the firing rate of those pairs for each region.

We expected strong spike count correlations to correspond to relatively large values for the mutual information. So we scattered one quantity against the other and fit a quadratic curve to the data. Whatever correlation we found between the two quantities was not as strong as we expected.

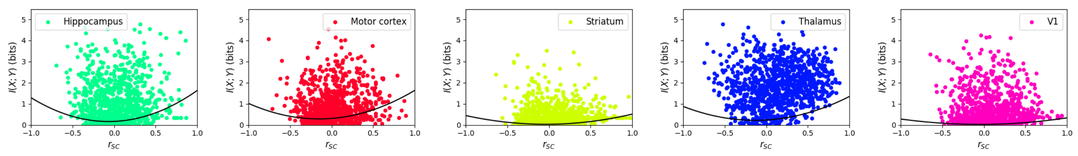

Figure 6: Mutual information of pairs of neurons plotted against geometric means of the firing rate of those pairs for each region.

Community Detection

Using Network Noise Rejection and Consensus Clustering, we isolated a network

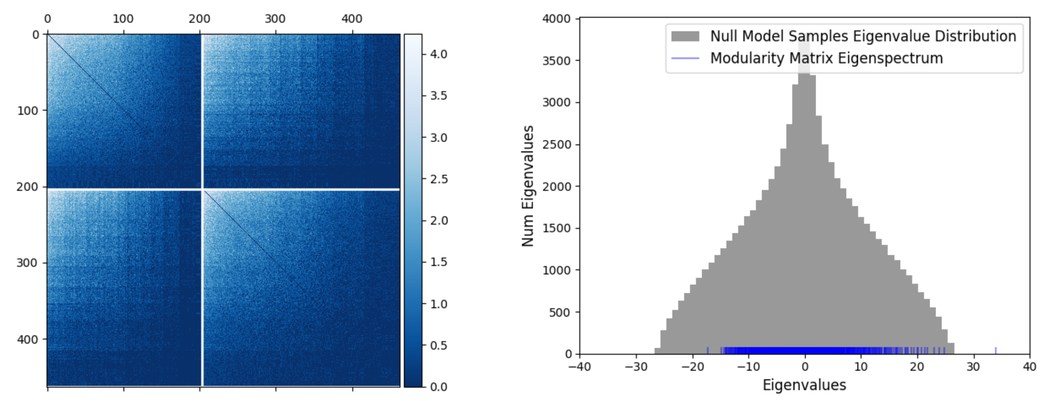

Figure 7: (Left) Mutual information matrix of the signal network, with communities shown. Main diagonal entries set to zero. (Right) A histogram of the eigenvalues of the samples from the null model, with the eigenvalues of the modularity matrix of the network shown in blue.

Conclusions

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Forthcoming Research

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Acknowledgements

I would like to thank Dr. Nick Steinmetz (University of Washington, Seattle) for making the dataset used in this project publicly available.

References

[1] James J. Jun, Nicholas A. Steinmetz, Timothy D. Harris, *Fully integrated silicon probes for high-density recording of neural activity*. Nature 551, 232236, (2017)

[2] Mark D. Humphries, Javier A. Caballero, Mat Evans, Silvia Maggi, Abhinav Singh, *Spectral rejection for testing hypotheses of structure in networks*. arXiv:1901.04747v1 [cs.SI], (2019)