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 bias corrected mutual information ($I(X;Y)$) in different regions.
2. To examine the relationship between these measurements and firing rates across all regions.
3. To detect any communities in the networks created by these measurements, either within or between the anatomical regions.
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].

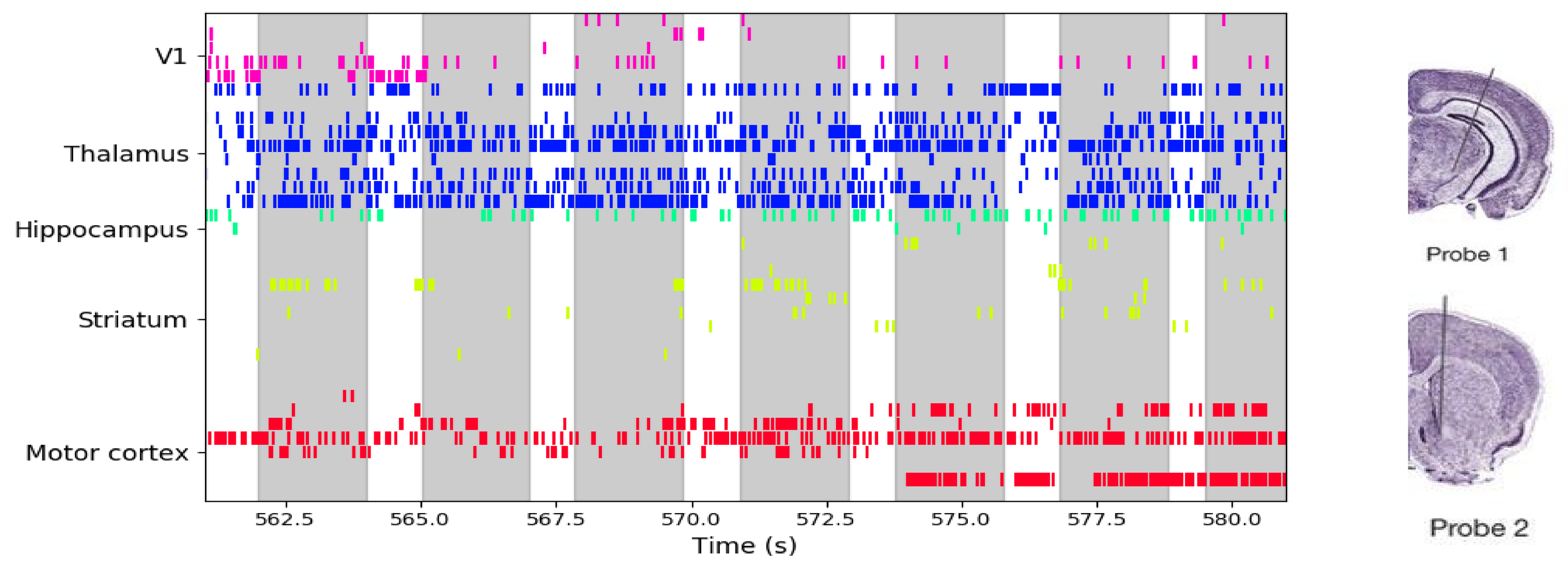

Figure 1: (Left) A raster plot showing the firing times of a subset of the cells, during a subset of the experiment time. Shaded areas indicate times when a visual stimulus was present, and (Right) Positions of the two probes. Probe 1 intersects V1, the hippocampus, and the thalamus. Probe 2 intersects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

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 networks [2].

Consensus Clustering We used consensus clustering on the signal network to investigate any communities within this network [2].

Results

Correlation & Information Distributions

We used the Kolmogorov-Smirnov statistical test to find out if the distributions of pairwise correlations were different between regions. We found that the distribution of correlations in the hippocampus and thalamus were statistically different to those in the other regions ($p < 0.05$).

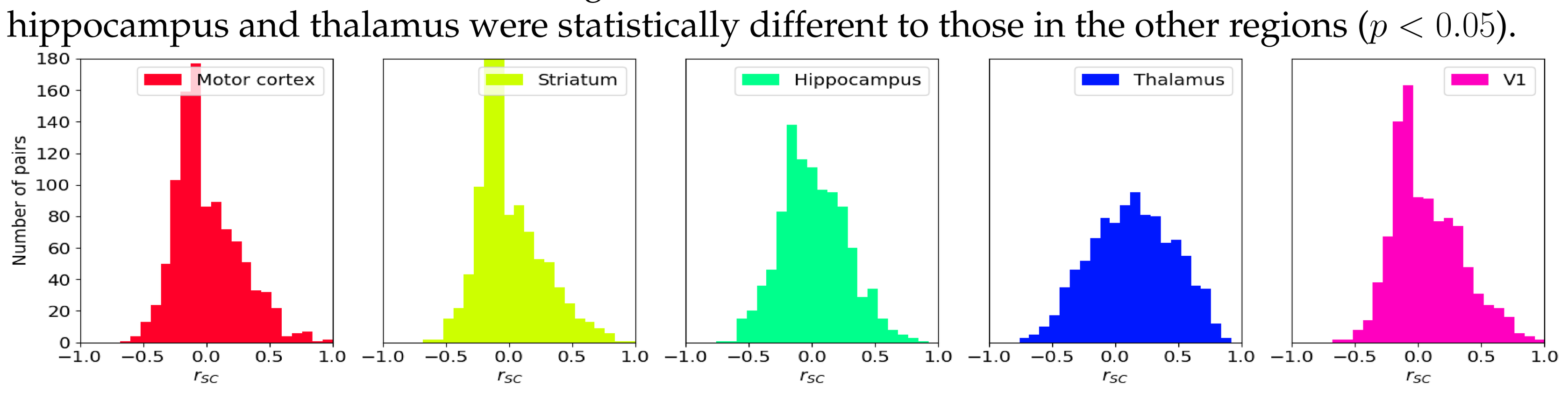

Figure 2: Histograms of the spike count correlations of 1000 randomly chosen pairs of neurons from within each region.

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 ($p < 0.001$).

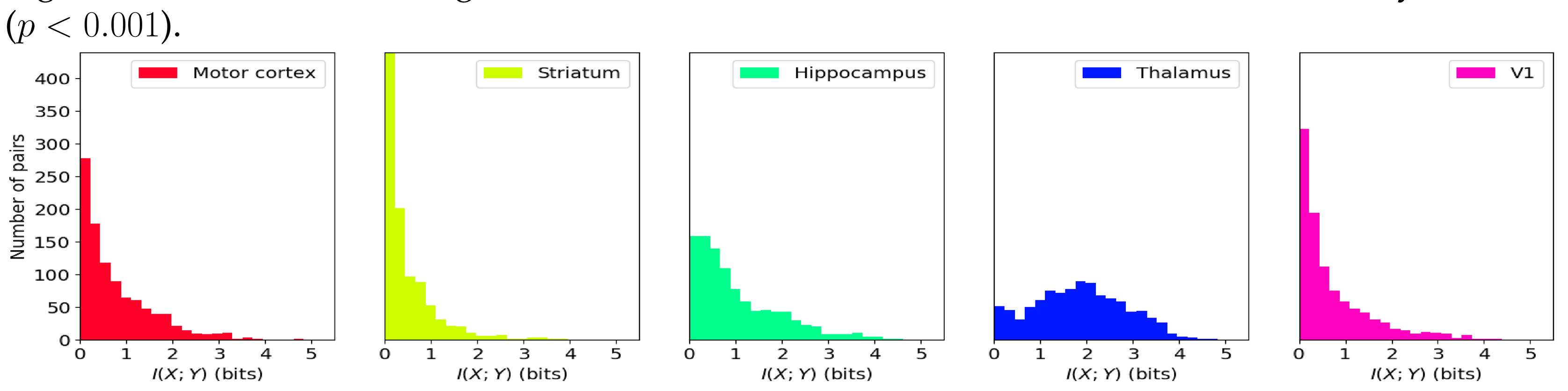

Figure 3: Histograms of the mutual information between the spike counts of 1000 randomly chosen pairs of neurons from within each region.

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.

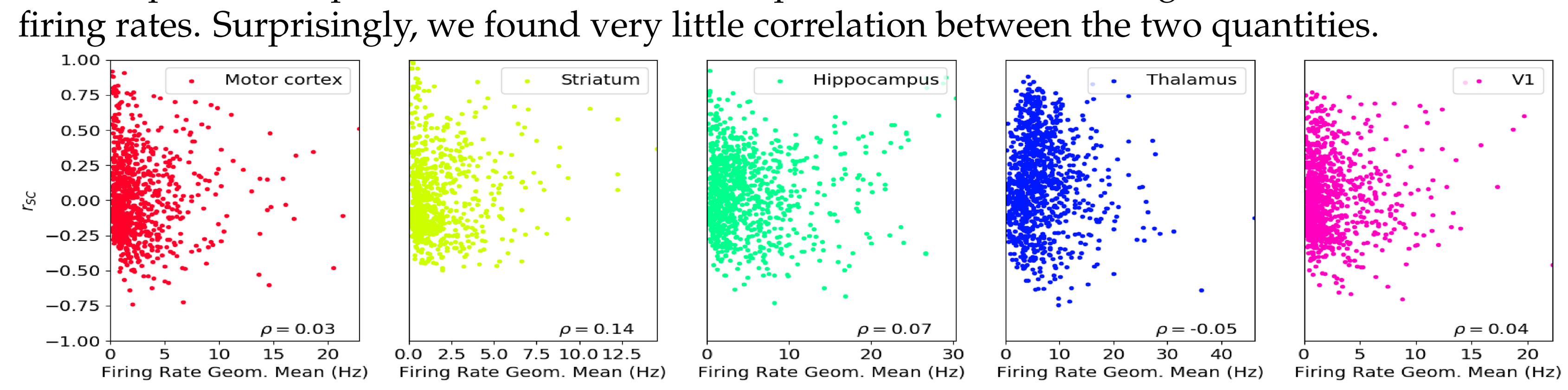

Figure 4: Spike count correlations of pairs of neurons plotted against geometric means of the firing rate of those pairs for each region.

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

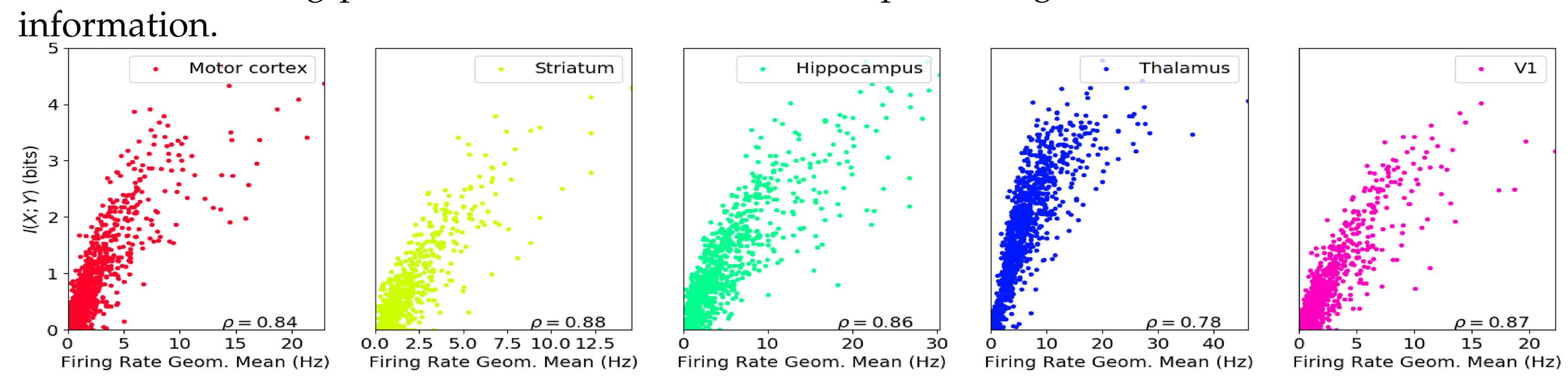

Figure 5: Mutual information of pairs of neurons plotted against geometric means of the firing rate of those pairs for each region.

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 fitted a quadratic curve to the data. Whatever correlation we found between the two quantities was not as strong as we expected.

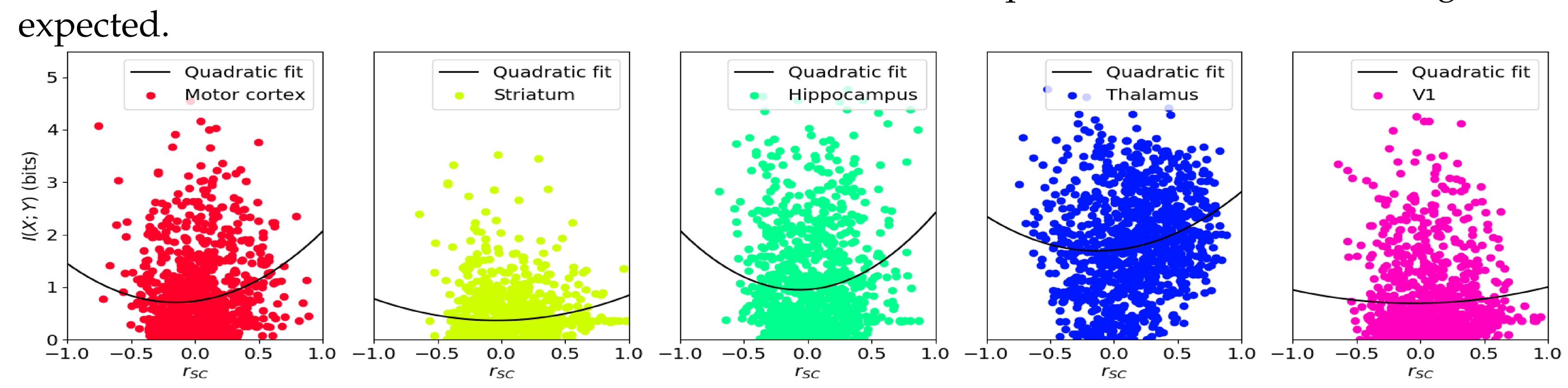

Figure 6: Mutual information of pairs of neurons plotted against the spike count correlations of those pairs for each region.

Community Detection

Using Network Noise Rejection and Consensus Clustering, we detected two communities in the network created by the mutual information measurements. It appears that one community is dominated by the thalamus, and the other community is dominated by the motor cortex and striatum. But each cluster contains cells from all of the available regions.

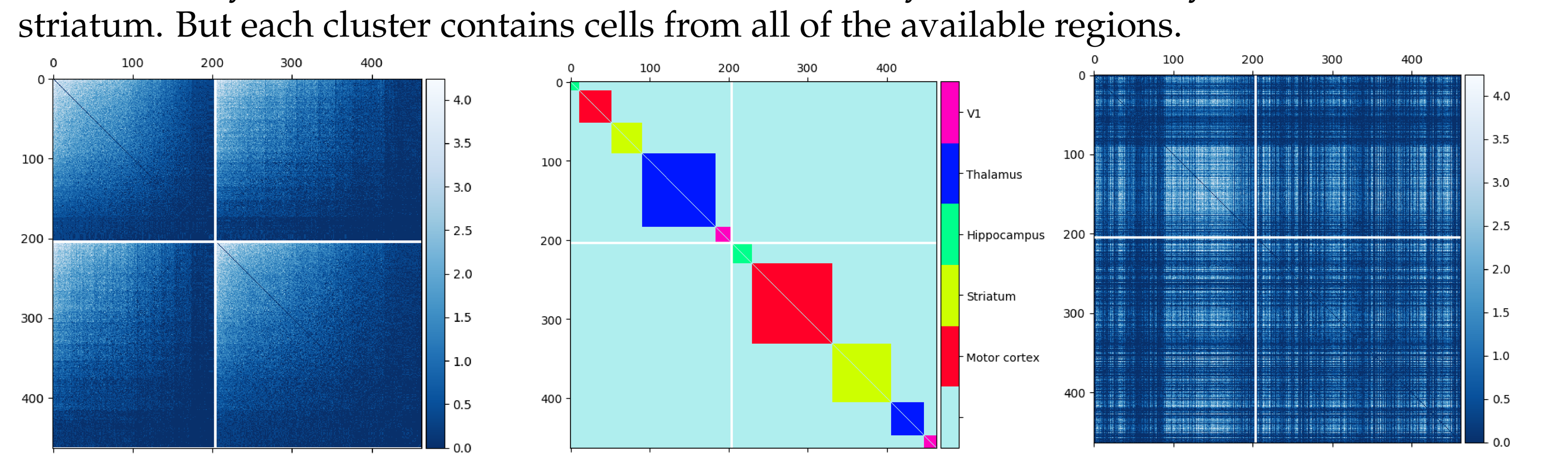

Figure 7: (Left) Mutual information matrix of the signal network, with communities shown. Main diagonal entries set to zero. (Middle) A matrix showing the regional membership of each cell within their clusters. (Right) The mutual info matrix sorted first by cluster, and second by region. Both the middle and right panels are sorted in the same way.

Conclusions

- The pairwise measurements we took were distributed differently in different brain regions.
- The mutual information between two cells is strongly correlated with the geometric mean of their firing rates. Conversely, the spike count correlation between two cells is not correlated with the geometric mean of their firing rate.
- Functional communities exist across anatomical regions.
- It appears the thalamus may be more isolated functionally than the other anatomical regions.

Forthcoming Research

Different pairwise measurements, such as a spike train metric, could be used along with the community detection. Alternatively, higher order correlation measures, such as population coupling could be examined. Changes in community structure in response to different stimuli could be examined.

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] Jun et al. *Fully integrated silicon probes for high-density recording of neural activity.* Nature 551, 232-236, (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)