

Network Inference from Neural Activation Time Series

A comparative review

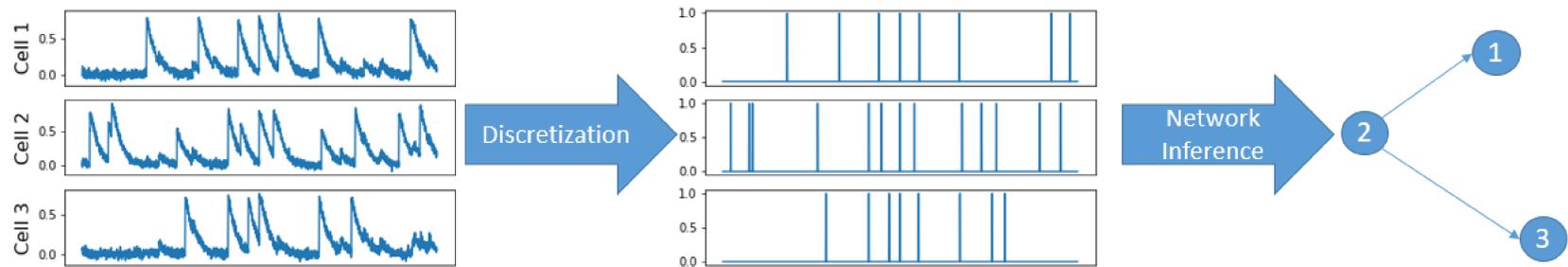
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Introduction

Problem: Infer the underlying connectivity of a neural circuit given the time series of neural activations

Motivation: Understand functional connectivity mechanisms in neural populations and study neural circuits without acute neuroimaging experiments



Unsupervised

Model-free

The connectivity between two neurons is defined based on a similarity metric on their spike trains

- Cross Correlation: Correlation with 1 sample lag $\sum_t [(v_t - \bar{v})(u_{t+1} - \bar{u})]$
- PCA: Compute partial correlation Σ^{-1} with 80% of variance retained
- Graphical Lasso: Compute partial correlation with: $\text{argmin}_{\Theta \geq 0} (\text{tr}(\Sigma\Theta) - \log \det(\Theta) + \lambda |\Theta|_1)$

Hawkes Process [2]

The set of spike trains is modeled as a Hawkes process with variables capturing their interactions

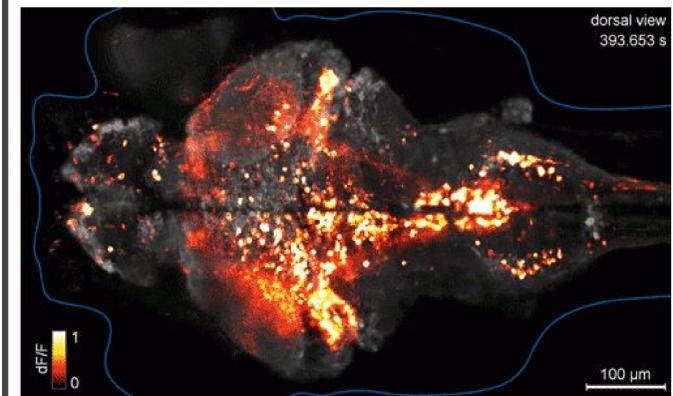
$$p(s_{v,\tau}) = p(s_{v,\tau} | \lambda_v) \times \prod_{t < \tau} \prod_{u \in N} p(s_{t,n} | A_{v,u} W_{v,u} G_{\theta_{v,u}}(t - \tau))$$

Connectivity parameters A & W are estimated using stochastic variational inference

Data

Chalearn Connectomics Challenge ^a

- Simulated fluorescence signals based on larval zebrafish calcium imaging
- 6 networks of 100 neurons
- One hour of recordings in 50Hz
- Ground truth connections



Preprocessing

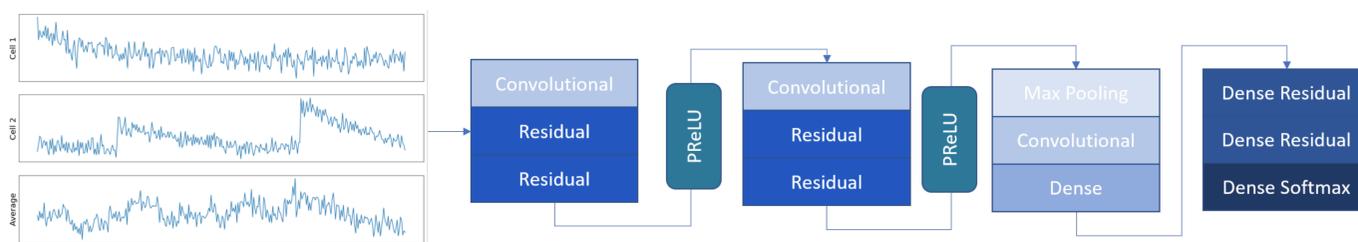
1. Removal of light scattering
2. Deconvolution using OASIS [1]
3. Discretization with threshold at 0.12

^a<https://www.kaggle.com/c/connectomics>

Supervised

Residual Convolutional Neural Network (RCNN)[3]

For each neuron pair, a subset of neural activations is extracted from a random point to serve as input sample to the RCNN. Connected pairs are sampled more to account for class imbalance.



Computing Impulse Responses Using Social Influence Model (CIRUSIM)

1. Define the impulse responses of a spike as the immediate spikes of all other neurons
2. Remove impulse responses that are less than 1 sec away from a spike preceding the current one
3. For each directed neuron pair calculate the time spans of all impulse responses (e.g. copying time) and transform the time span series into scores using $e^{1.0/(x)} - 1$
4. Compute the number of impulses, mean, variance and 95th percentile of the time span series
5. SVM with RBF kernel and adjusted class weights using the features from step 4

Discussion

- Partial correlation approaches outperform the rest because it accounts for confounding effects from the whole network
- Supervised methods perform worse largely due to the leave one network out validation method. CIRUSIM achieves 81% AUC with classic 5-fold cross validation
- RCNN architecture is built for networks of 1000 neurons, so it fails with 100

Results

Network Inference Method	AUC %	PRC %	Time (Sec)
Graphical Lasso	83.1	44.2	40
Cross Correlation	77.7	34.9	432
PCA	76.1	30.7	33
Hawkes	72.8	35.5	5588
CIRUSIM	68.1	18.9	3276
RCNN	66	18.4	97 ^b

^bRun in an Amazon g2.2 instance with deep learning Ubuntu AMI

References

- [1] Friedrich, Johannes, and Liam Paninski. "Fast active set methods for online spike inference from calcium imaging." *Advances In Neural Information Processing Systems*. 2016.
- [2] Linderman, Scott, and Ryan Adams. "Discovering latent network structure in point process data." *International Conference on Machine Learning*. 2014.
- [3] Dunn, Timothy, and Peter K. Koo. "Inferring Functional Neural Connectivity With Deep Residual Convolutional Networks." *bioRxiv* 2017: 141010.

Code

<https://github.com/GiorgosPanagopoulos/Network-Inference-From-Neural-Activations>