Network Inference from Neural Activation Time Series: A comparative review

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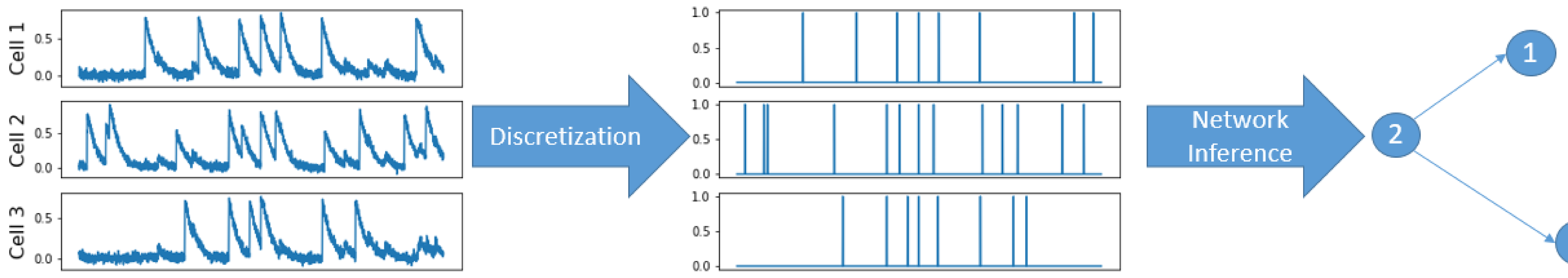
Introduction

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

Hawkes Process [2]
The set of spike trains is modeled as a Hawkes process with variables capturing their interactions

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

Connectivity parameters A, W $\&\theta$ are estimated using stochastic variational inference

Data

Chalearn Connectomics Challenge [a]

- Simulated fluorescence signals
- 6 networks of 100 neurons
- One hour of recordings in 50Hz
- Ground truth connections

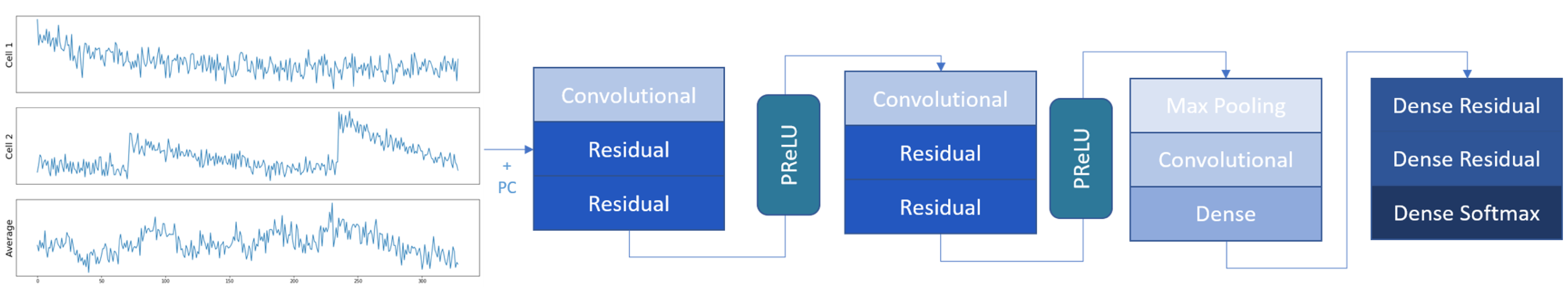
Preprocessing

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

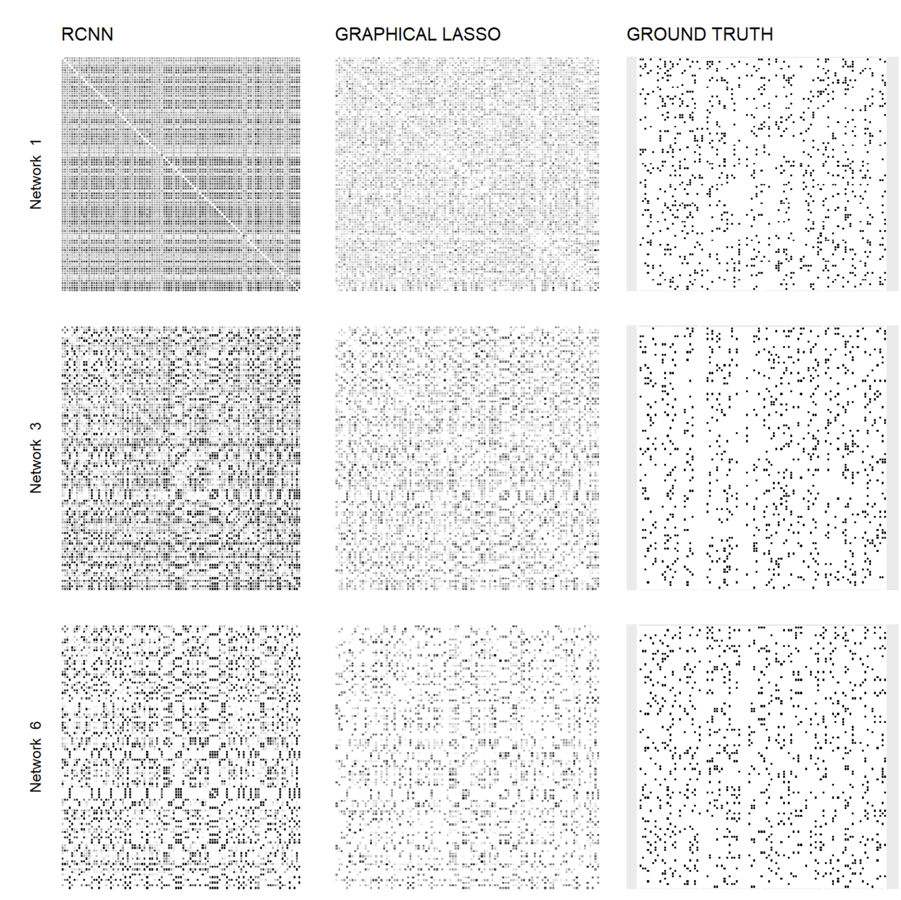
Residual Convolutional Neural Network (RCNN)[3]
For each neuron pair, a subset of neural activations and the average activation of the network are extracted from a random point to serve as input sample to the RCNN, together with the pair's partial correlation repeated. Connected pairs are sampled more 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. Count the durations of all impulse responses between a pair and transform them with $e^{1.0/(x)} - 1$
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

Predictions



Evaluation

Network Inference Method	AUC %	PRC %	Time (Sec)
Graphical Lasso	83.1	44.2	40
RCNN	83	44.9	6082
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

Conclusions

- Partial correlation is more efficient, but neural networks could surpass it
- Sparse solutions are preferred
- Leave-one-network-out validation is adverse. Maybe a semi-supervised approach could be promising

Paper & Code

https://arxiv.org/abs/1806.08212
https://github.com/GiorgosPanagopoulos/Network-Inference-From-Neural-Activations

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.