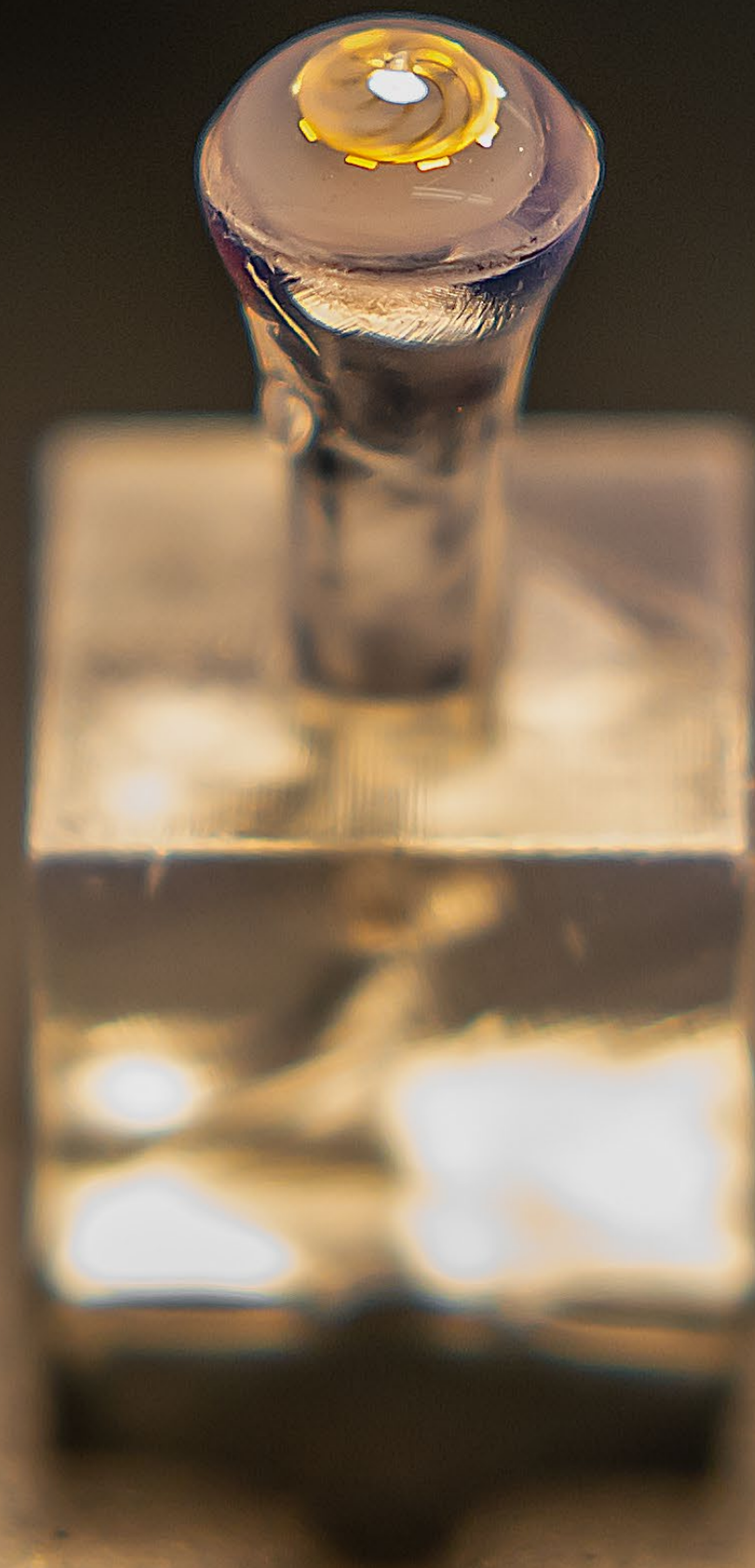


# Modular High-throughput Computing Pipelines for Scalable **Neuronal Electrophysiology** Research

*Engineering In Vitro computing platforms with Frontera*



**Seung Hyun Kim**

*Ivan Raikov*

*Frithjof Gressman*

*Pls:*

*Mattia Gazzola, UIUC*

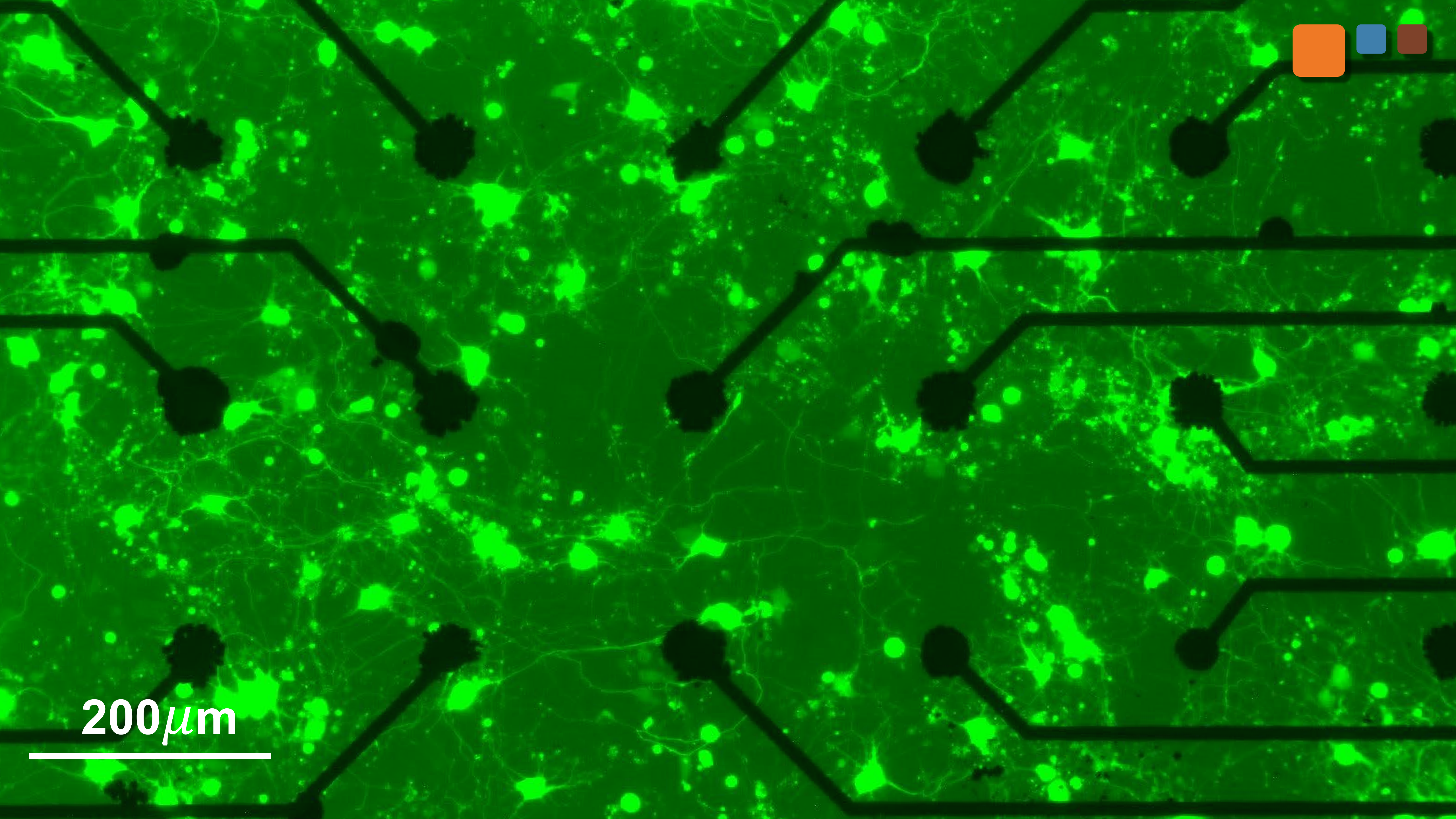
*Ivan Soltesz, Stanford*

*Lawrence Rauchwerger, UIUC*

- Project Overview — Mind In Vitro
- Biophysical Neural Network Simulator
- Modular and Scalable Analysis Pipeline



# Computing with cellular substrates



200  $\mu\text{m}$



## Neurons:

- Embryonic Stem cells derived
  - Motoneuron
  - Cortical neuron
- ChannelRhodopsin (ChR2)

## Recording Interface:

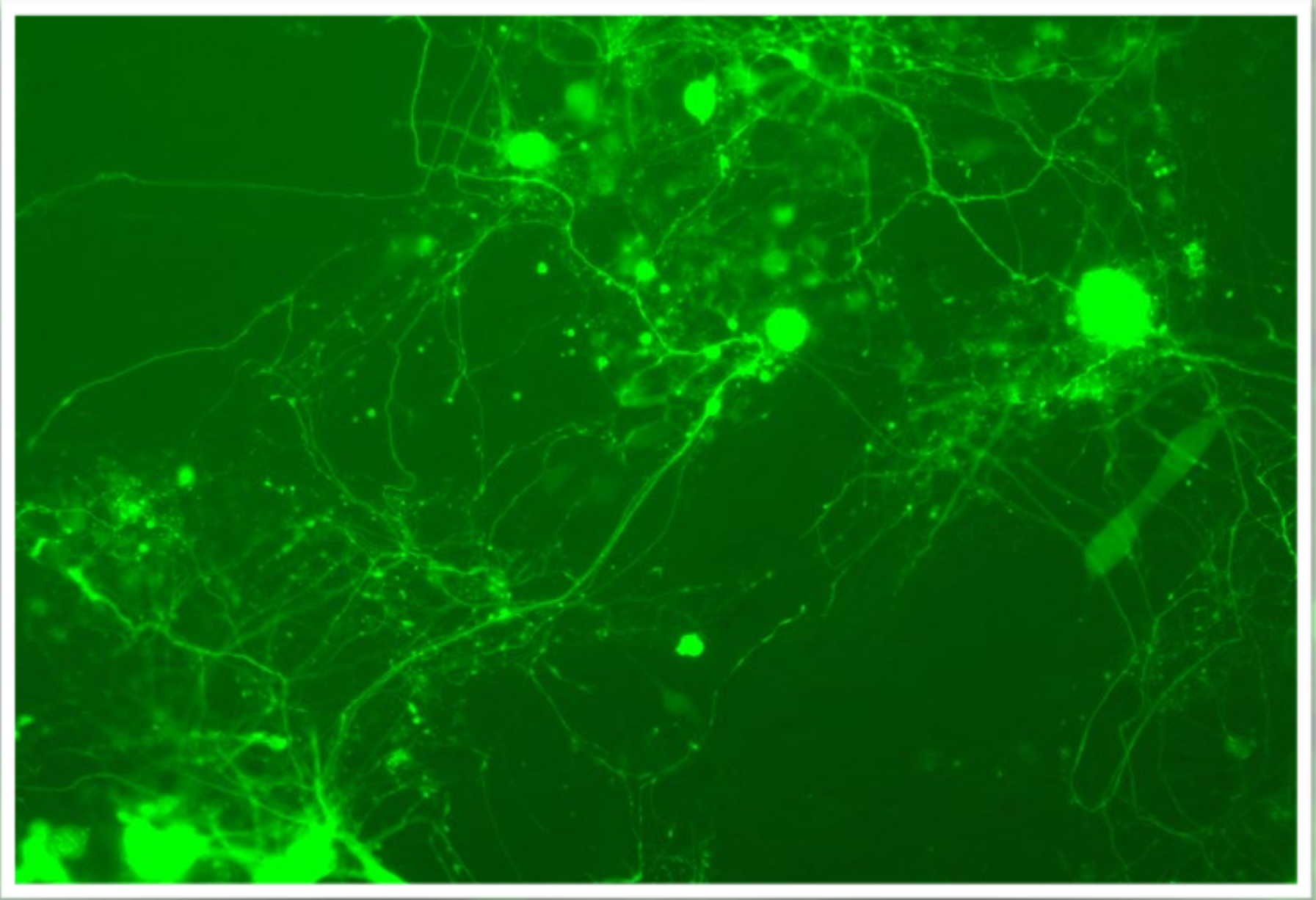
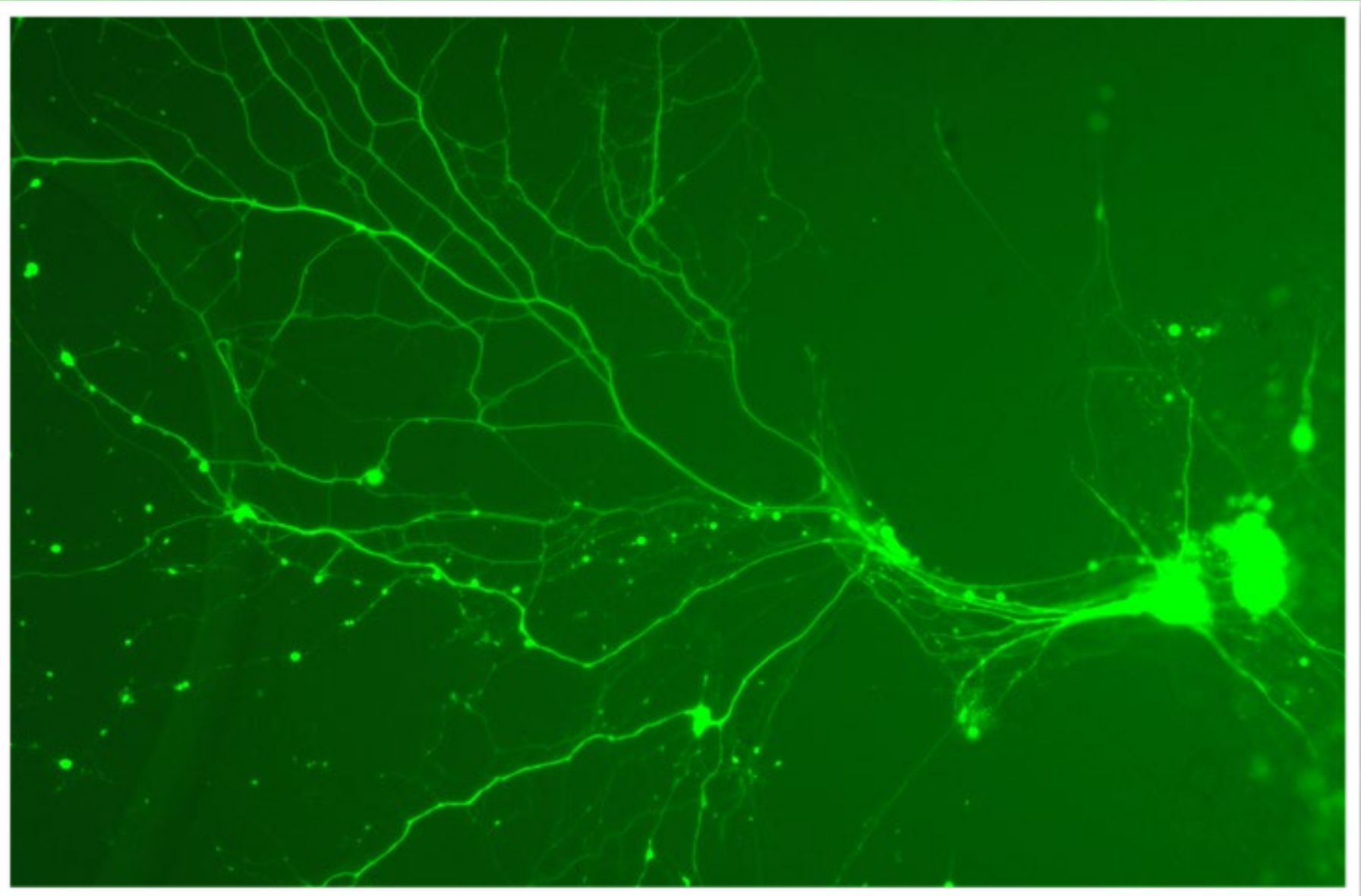
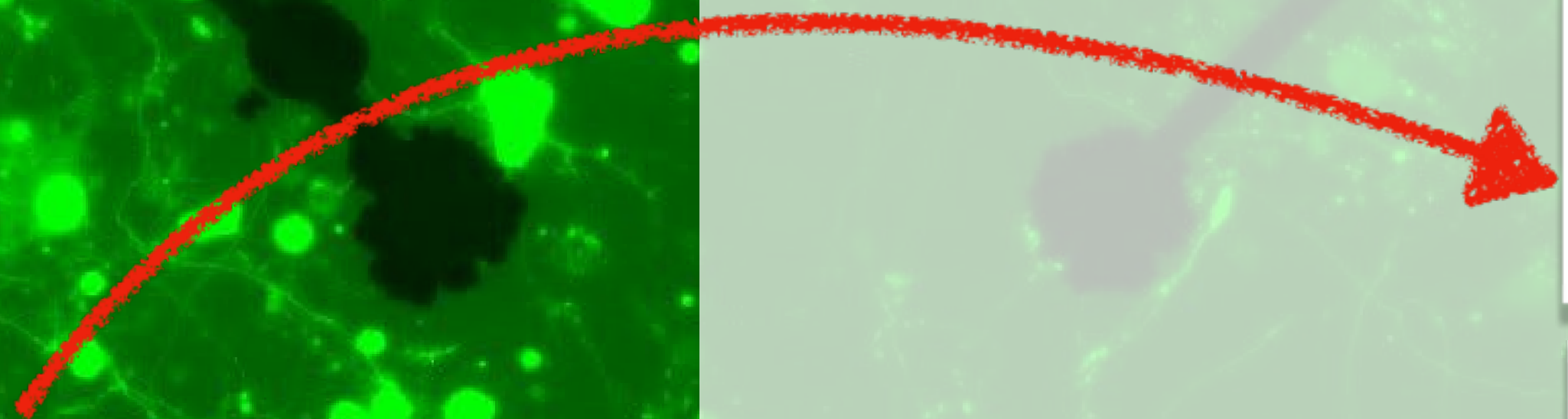
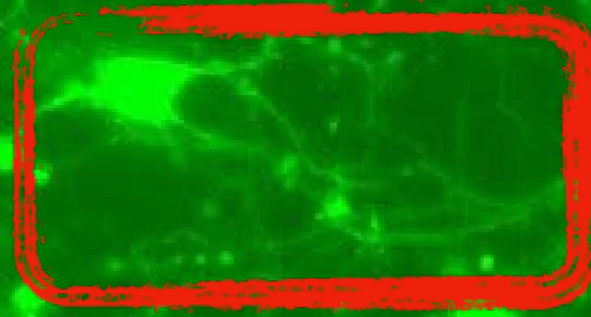
- Multi-electrode array: 512 Electrodes (30  $\mu\text{m}$ )
- Sampling Rate: 30 kHz

200  $\mu\text{m}$



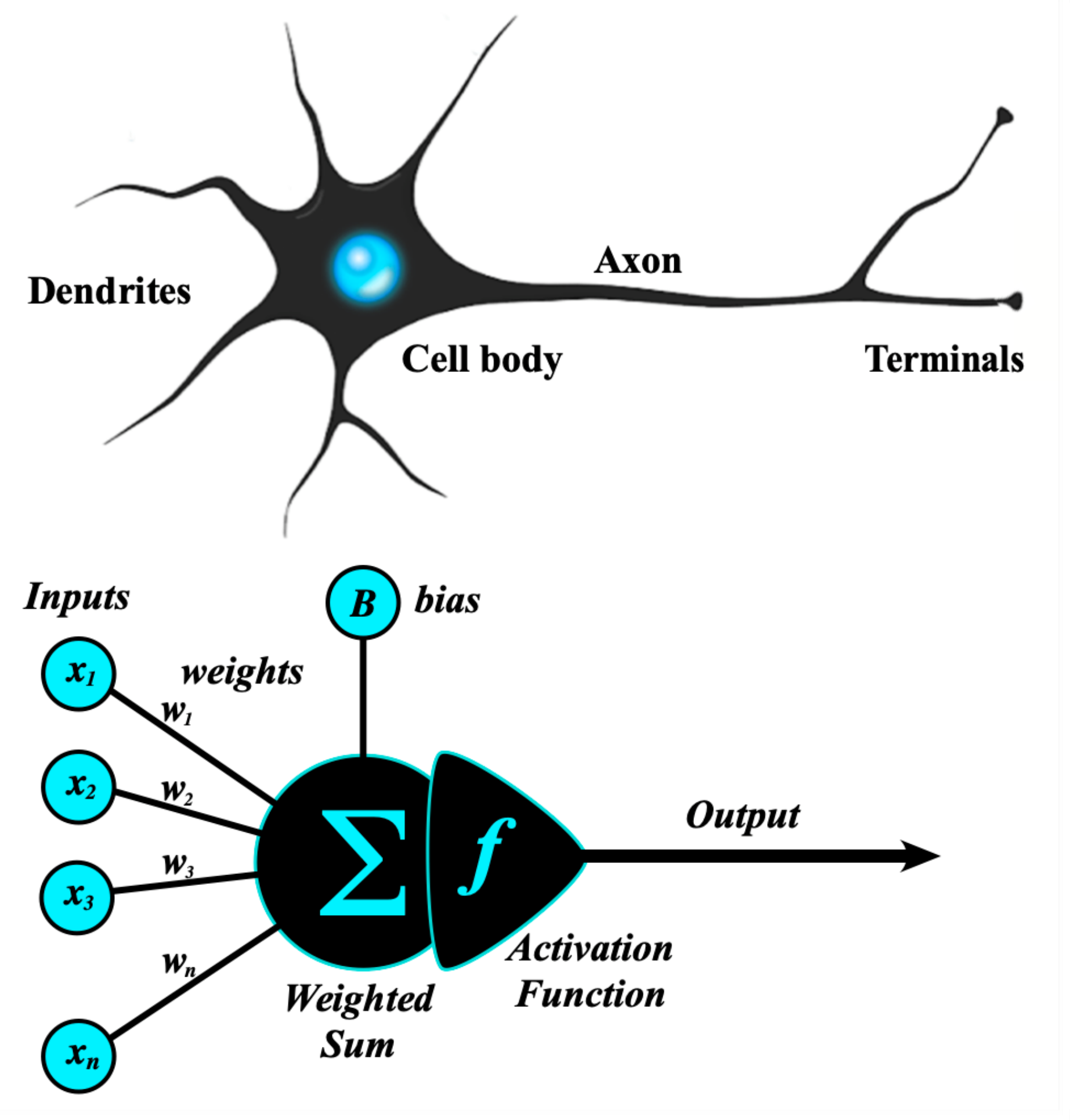
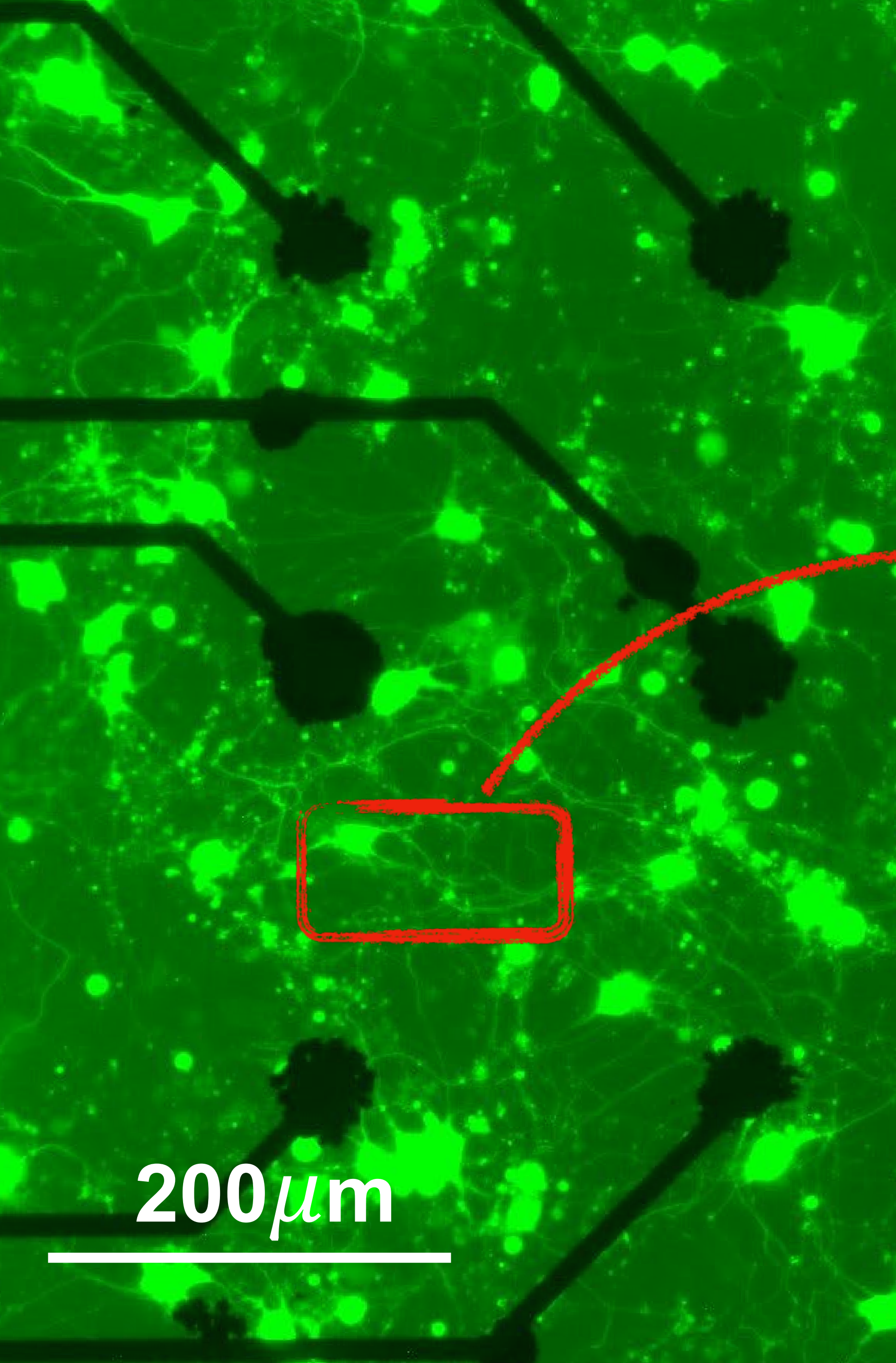


- 80~100k neurons
- X100 synapses per neuron



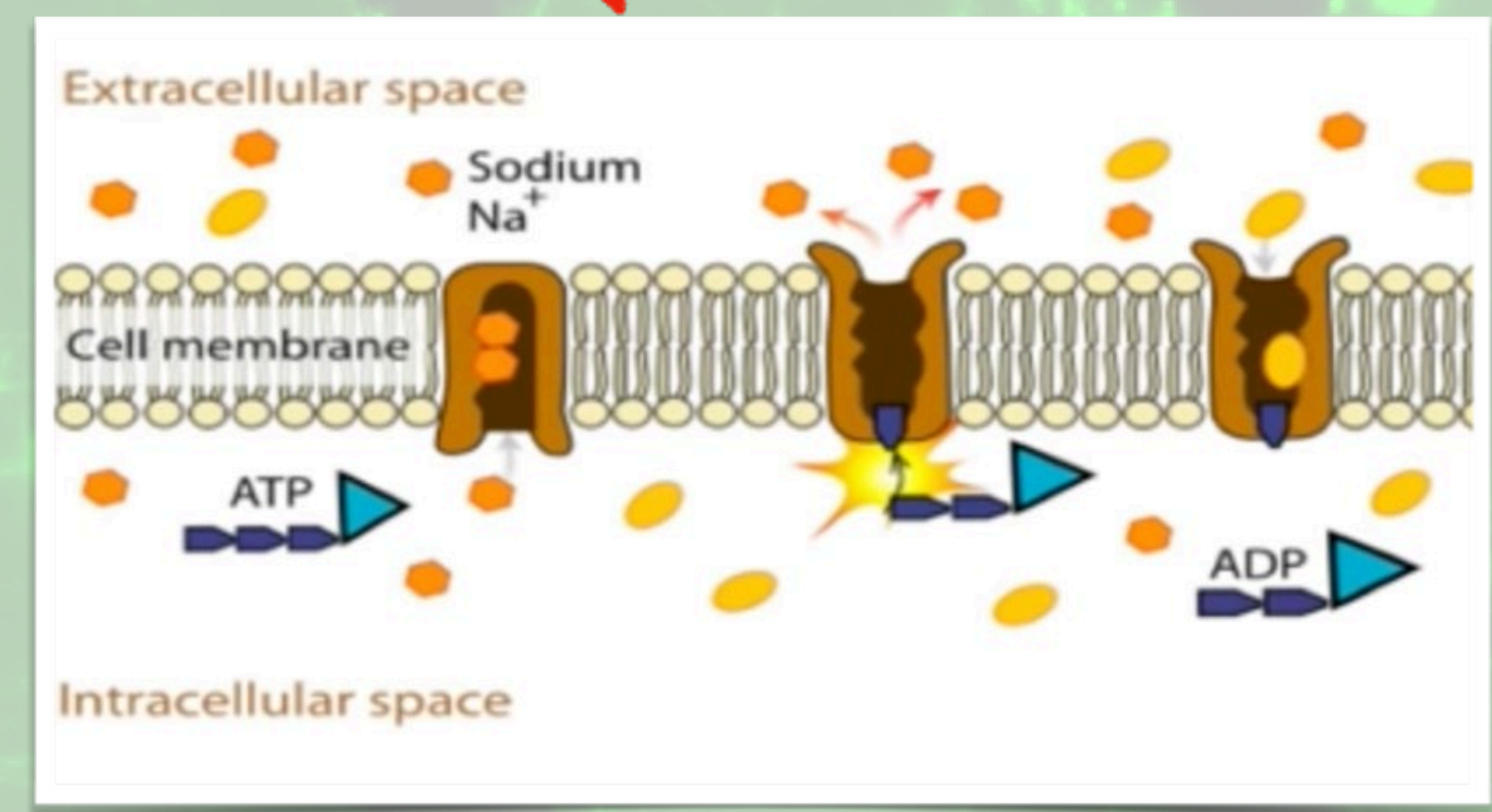
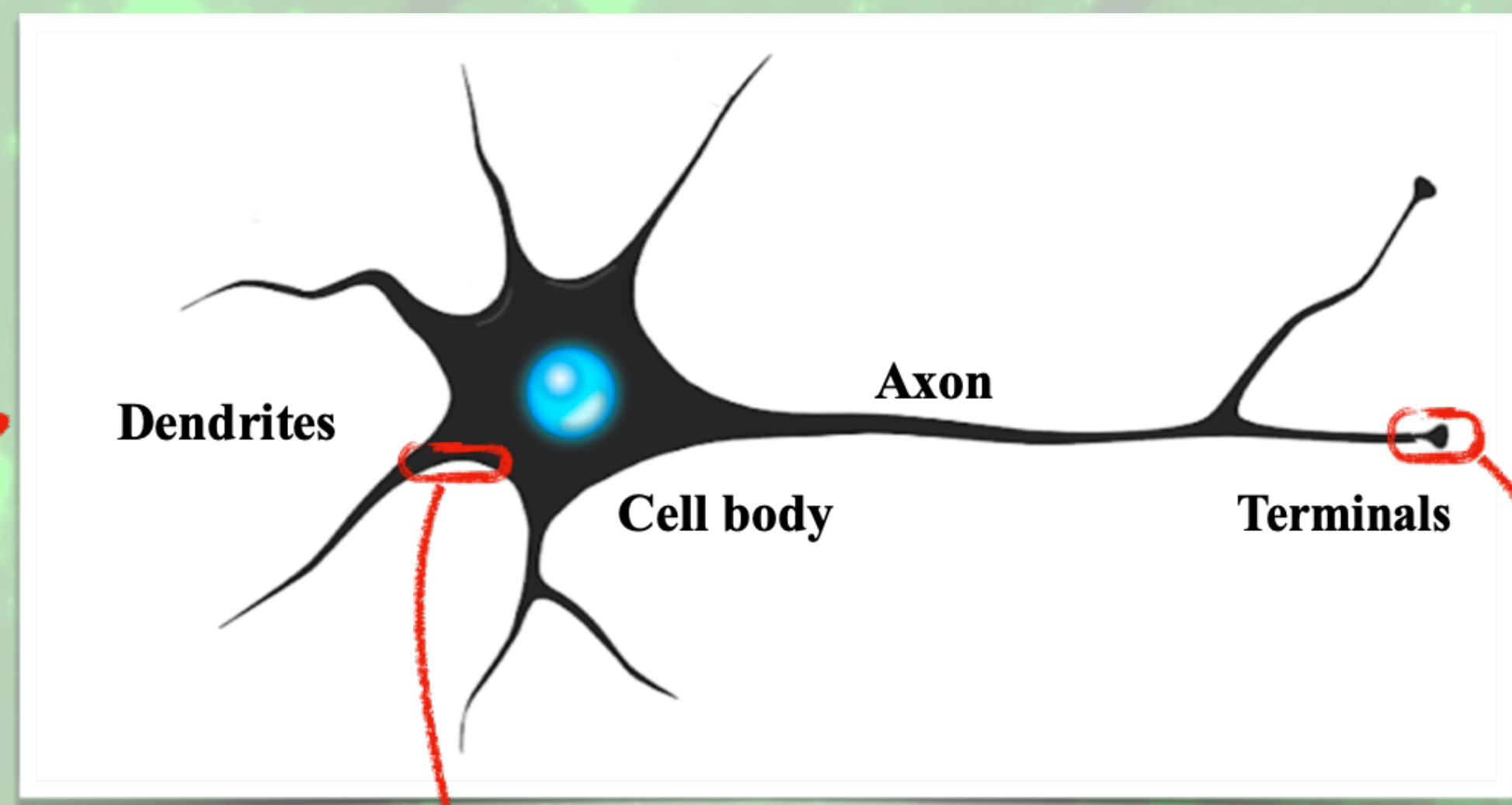
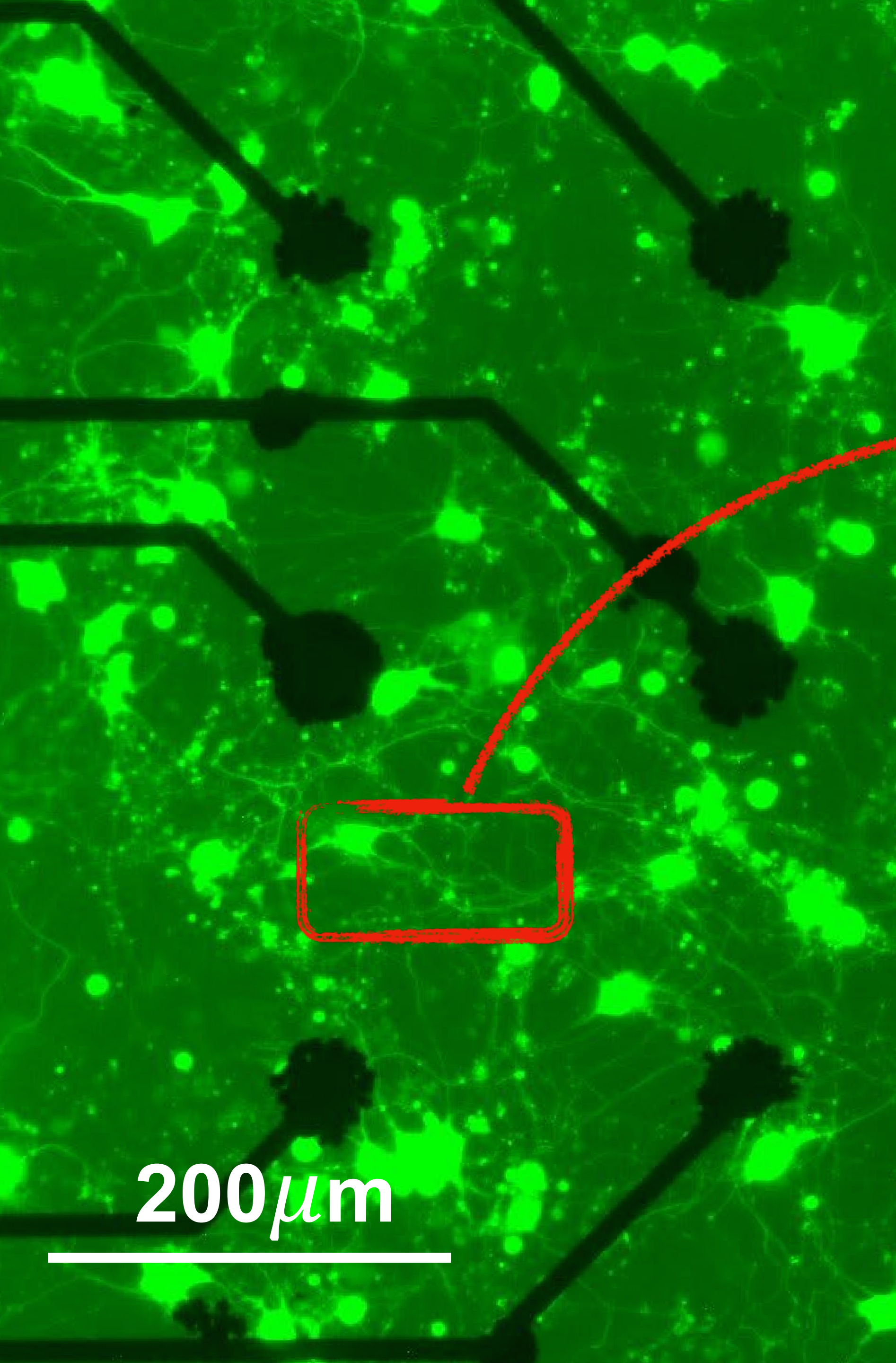
200  $\mu\text{m}$



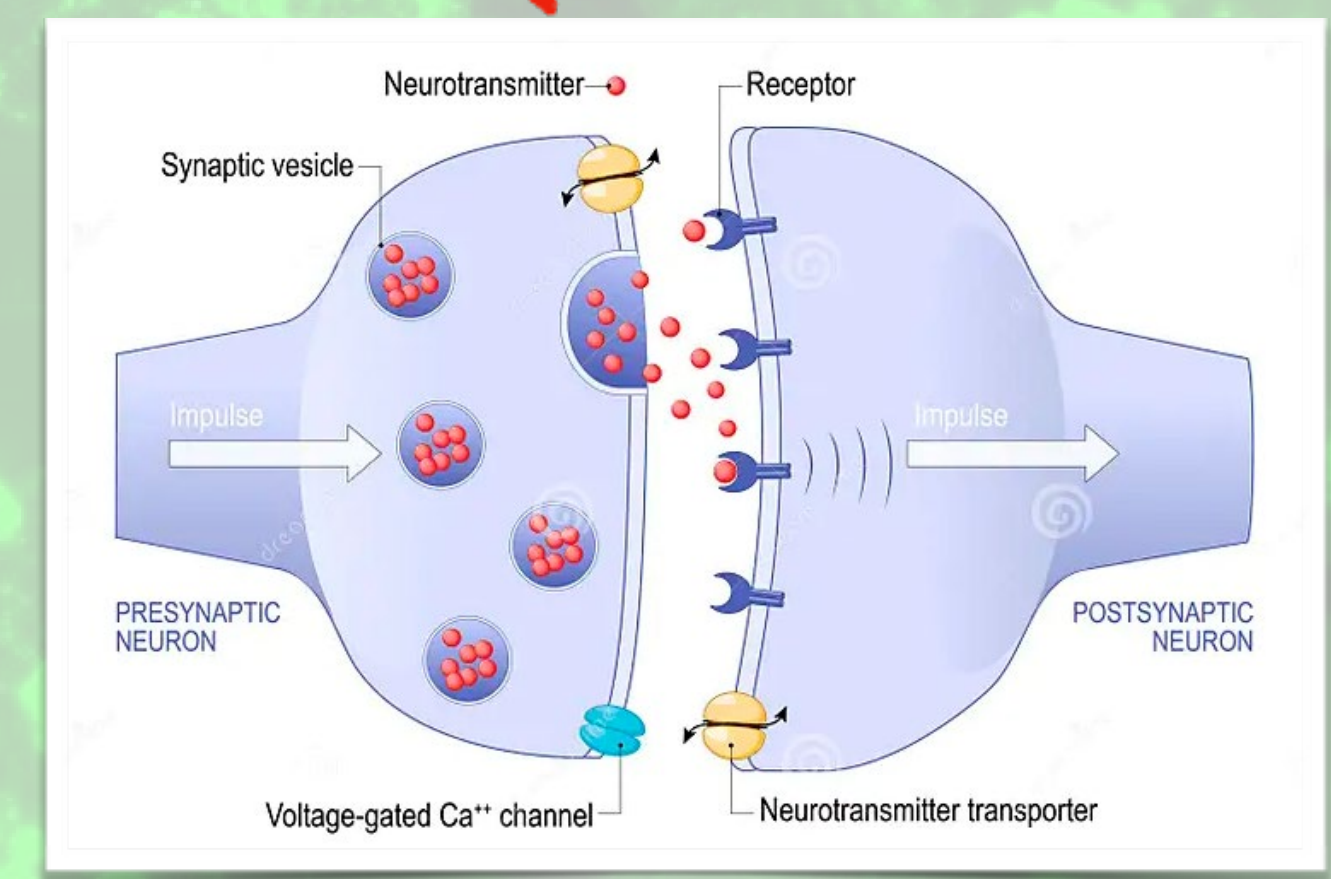


200  $\mu\text{m}$





Cell Membrane



Synapses

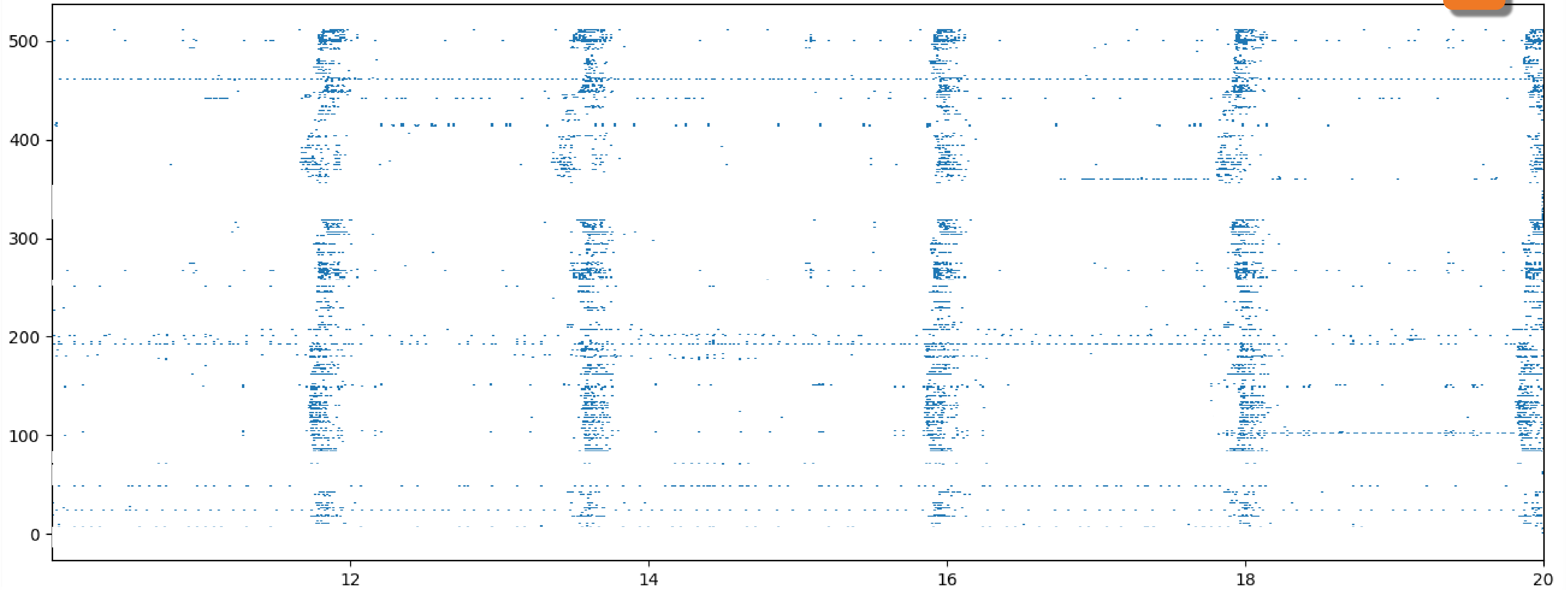
200  $\mu$ m





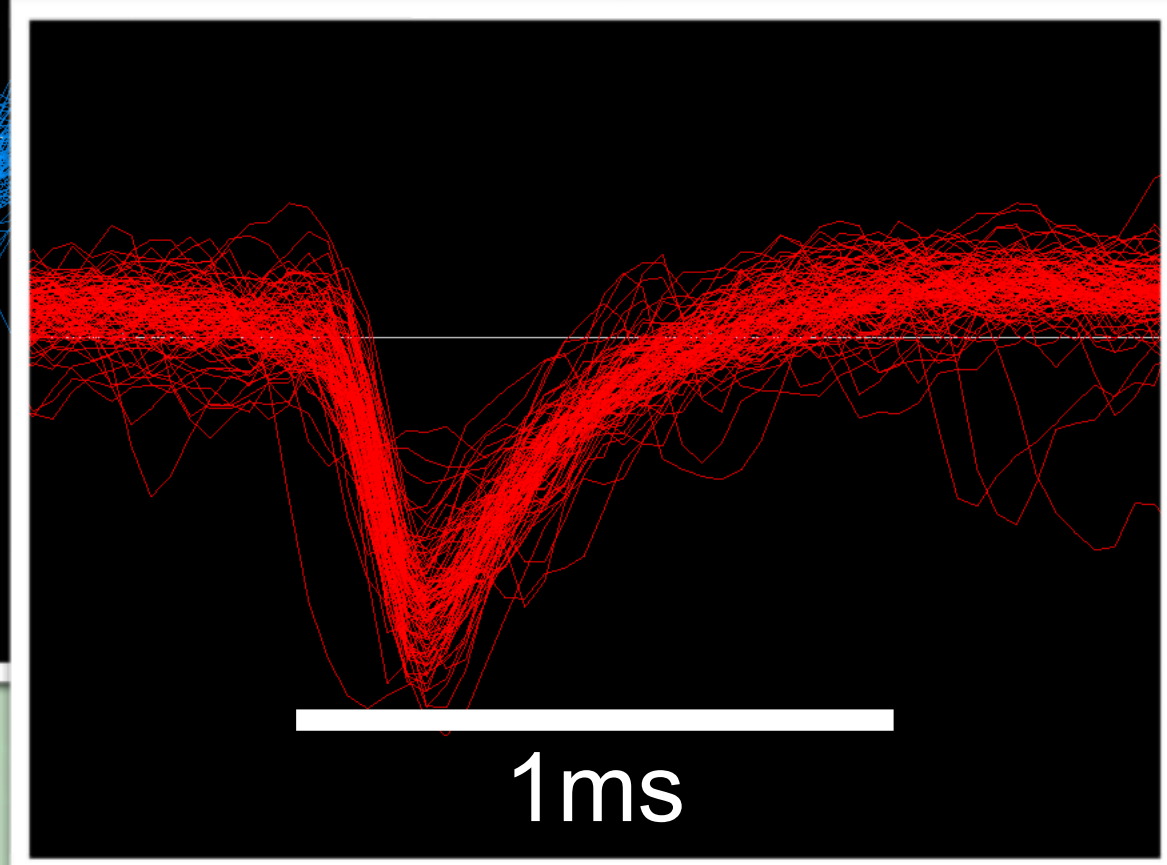
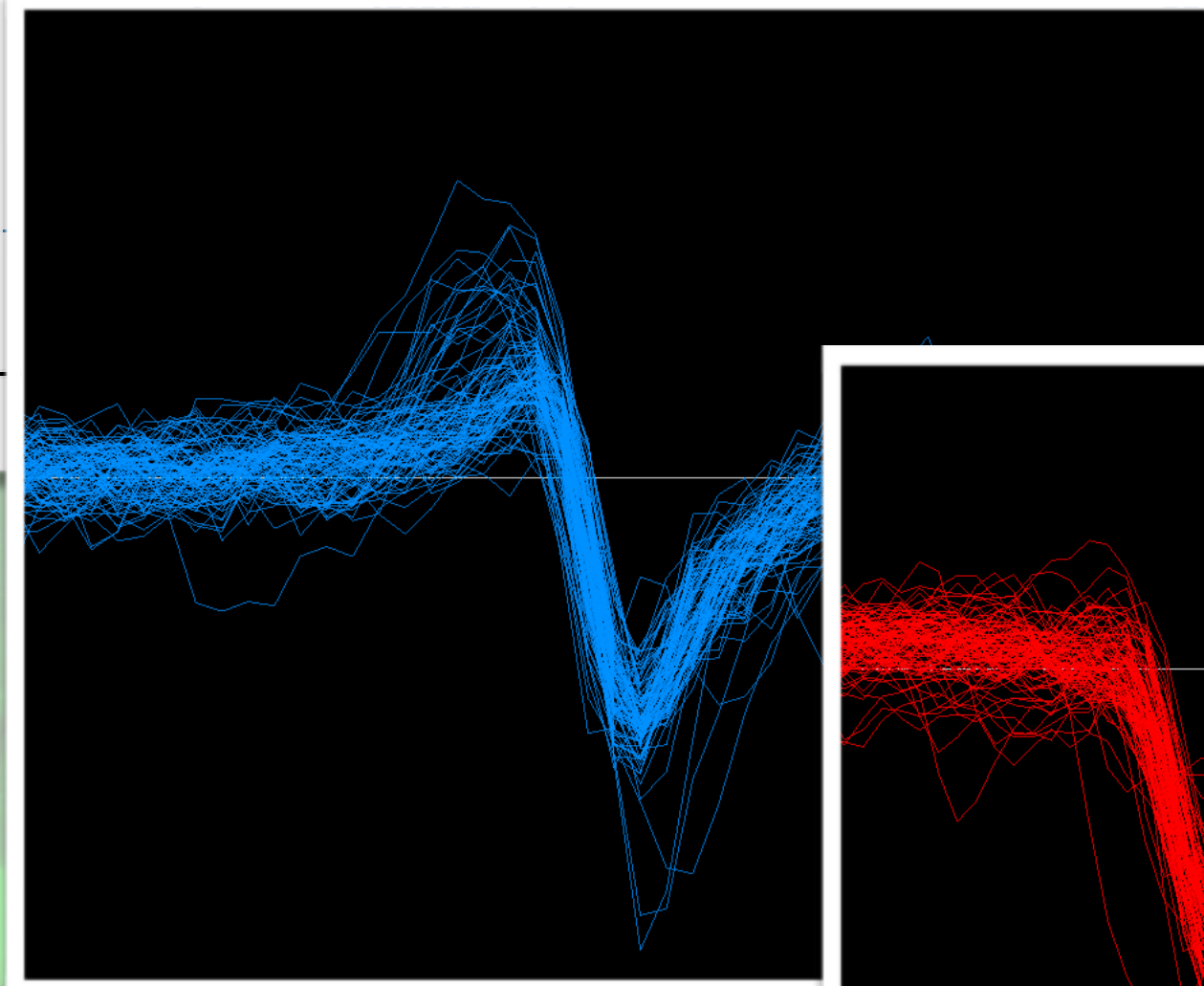
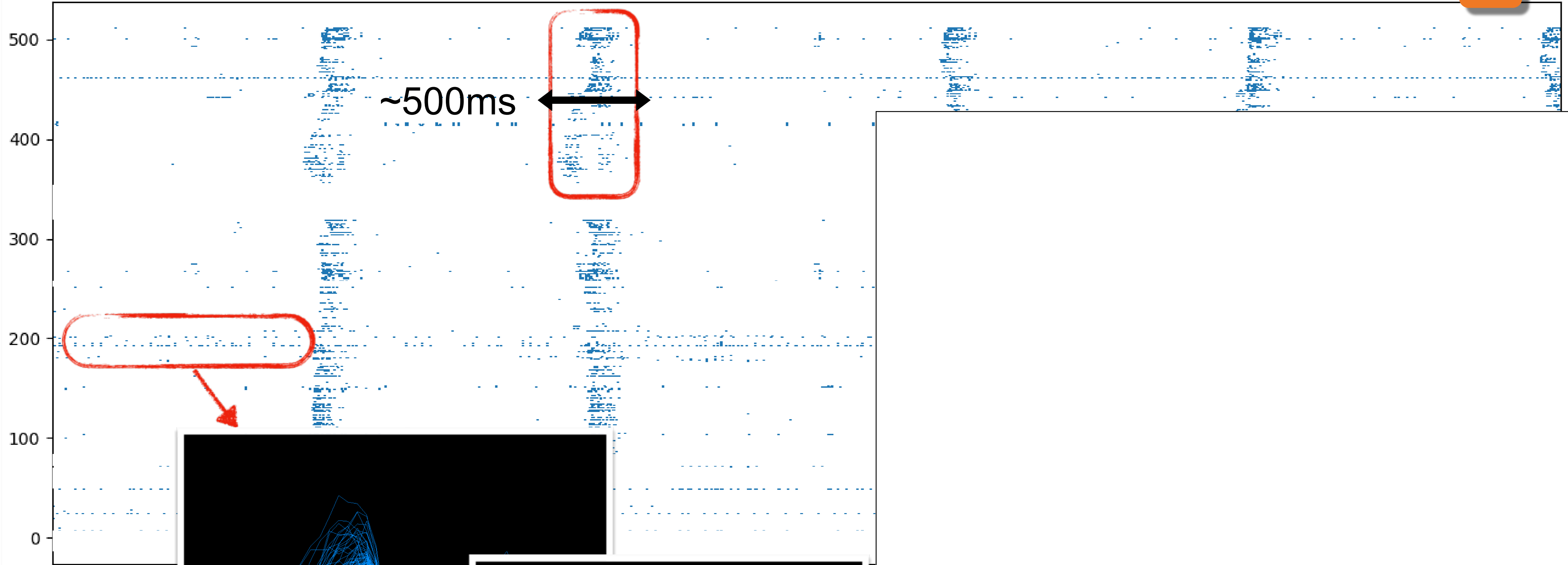
Spontaneous

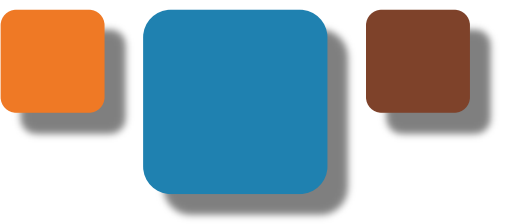
Raster plot (from 10.0002 to 20.0002)



# Spontaneous

Raster plot (from 10.0002 to 20.0002)

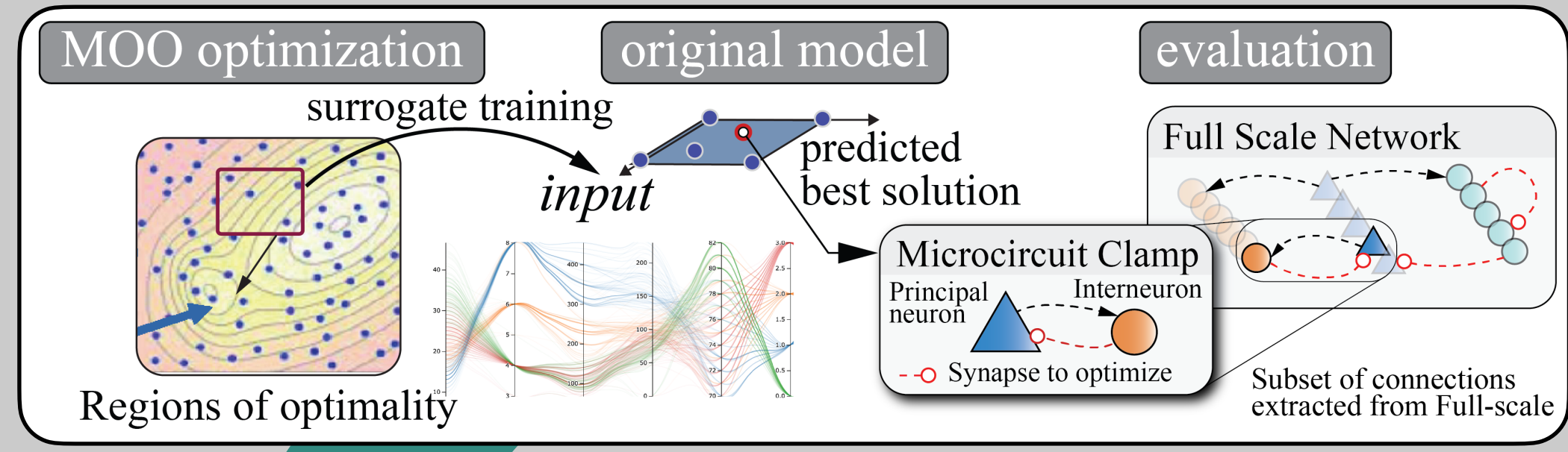
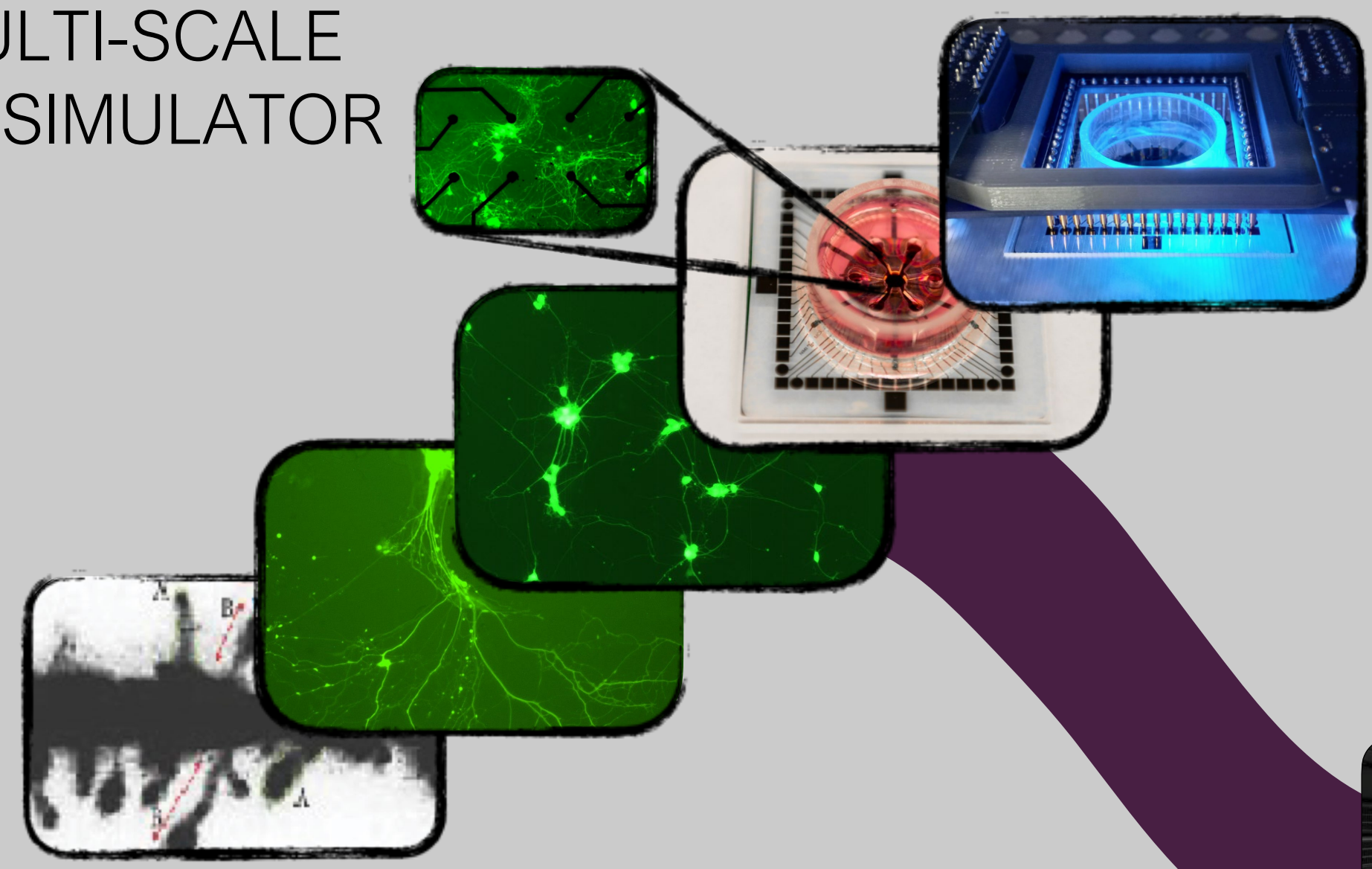




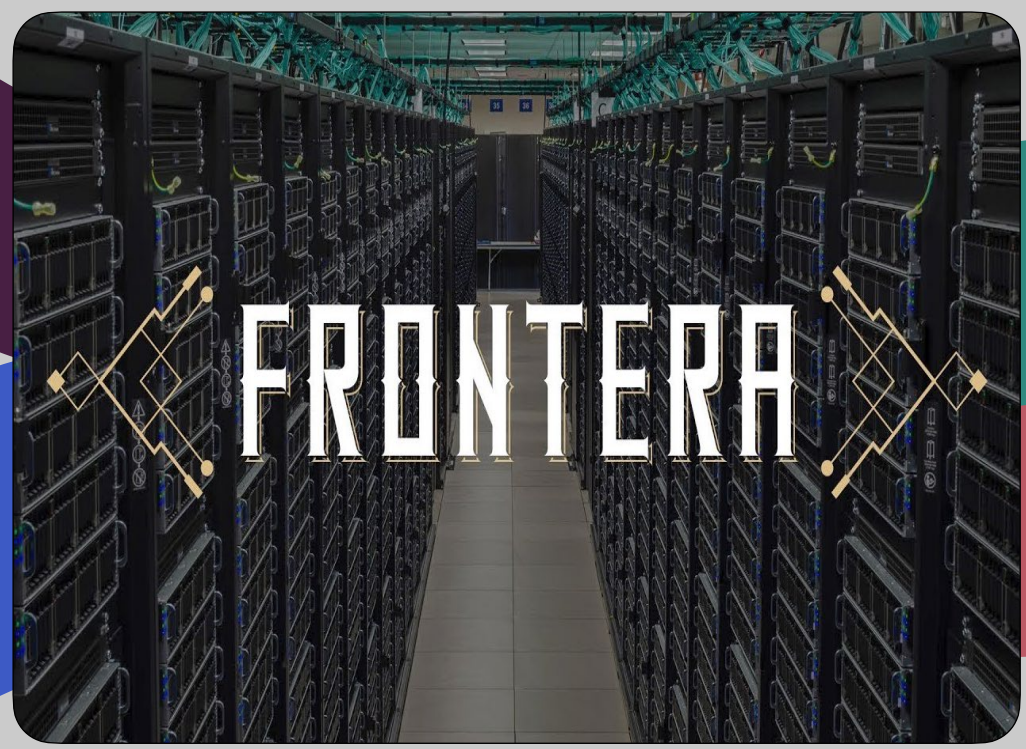
# Computational Problem

Need for a systematic framework to engineer these systems

# MULTI-SCALE MiV SIMULATOR

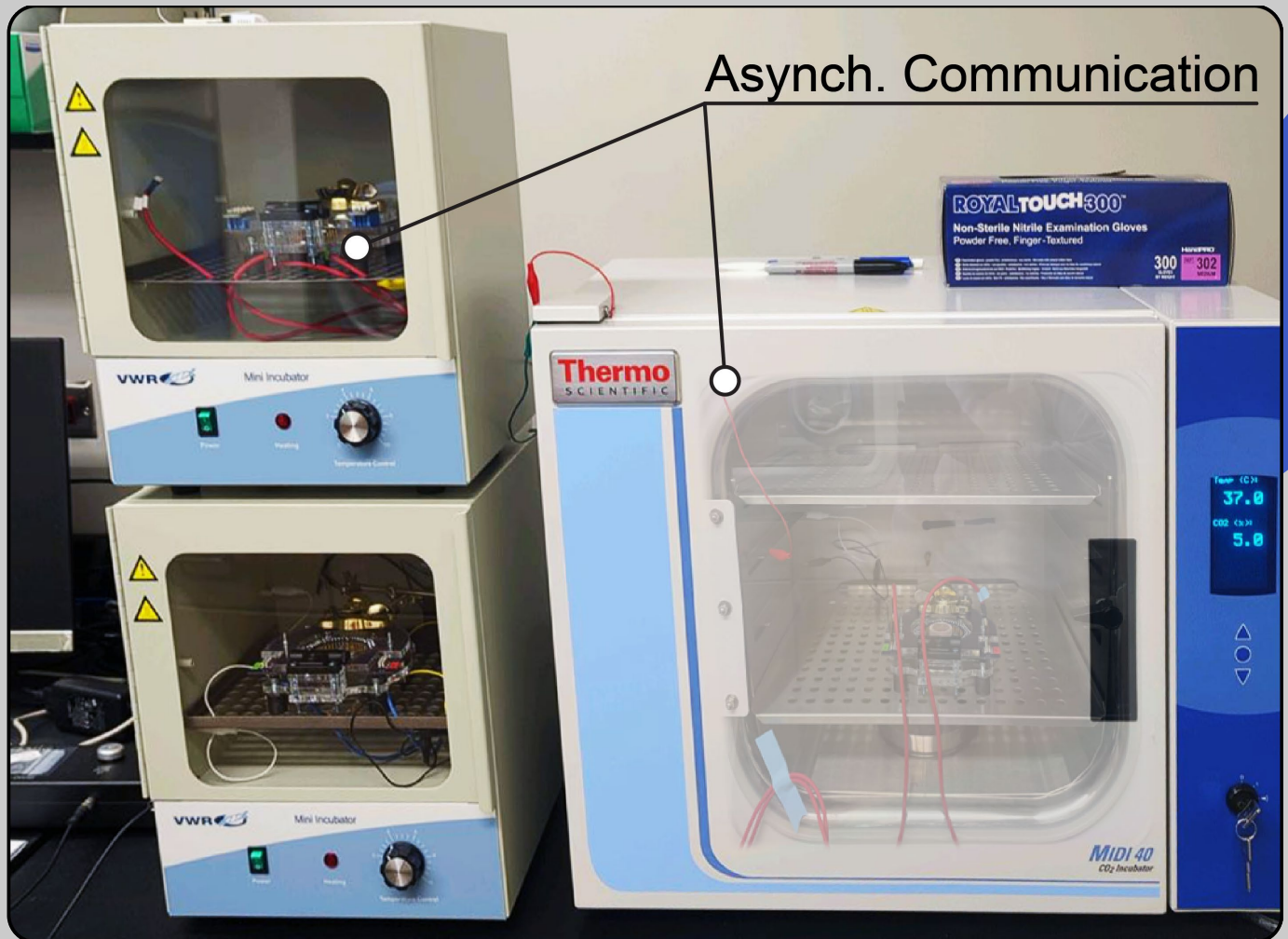


# SURROGATE OPTIMIZATION

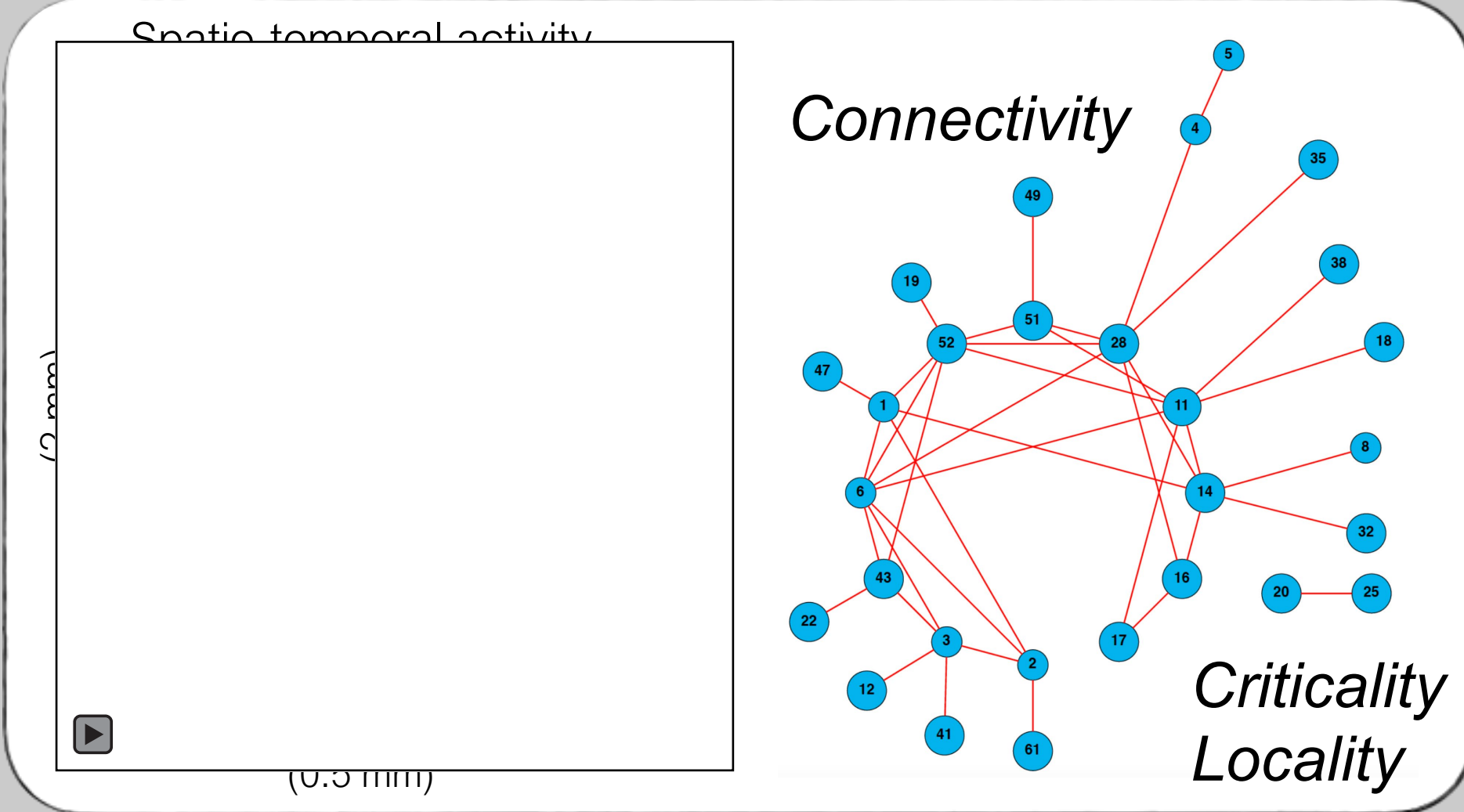


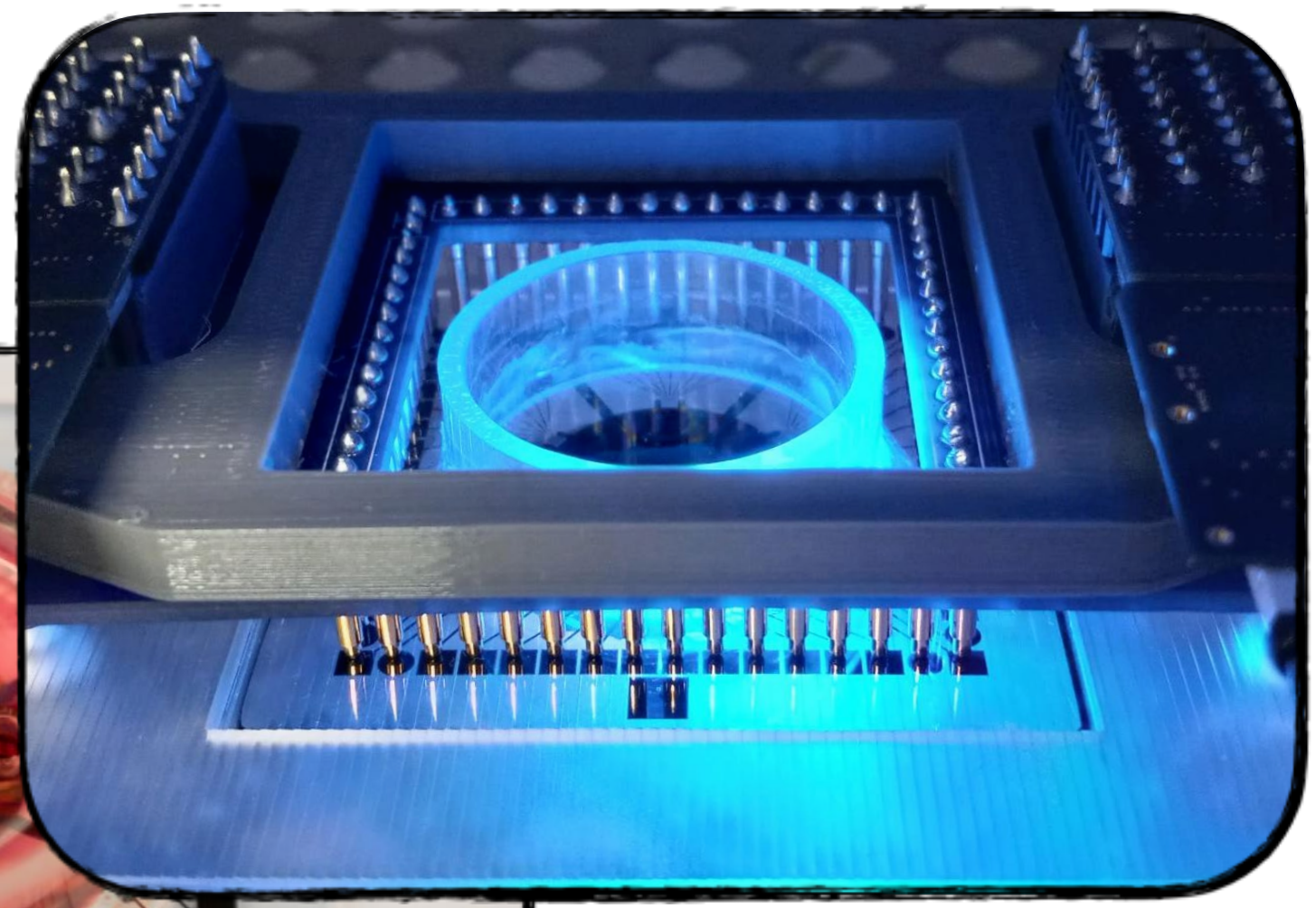
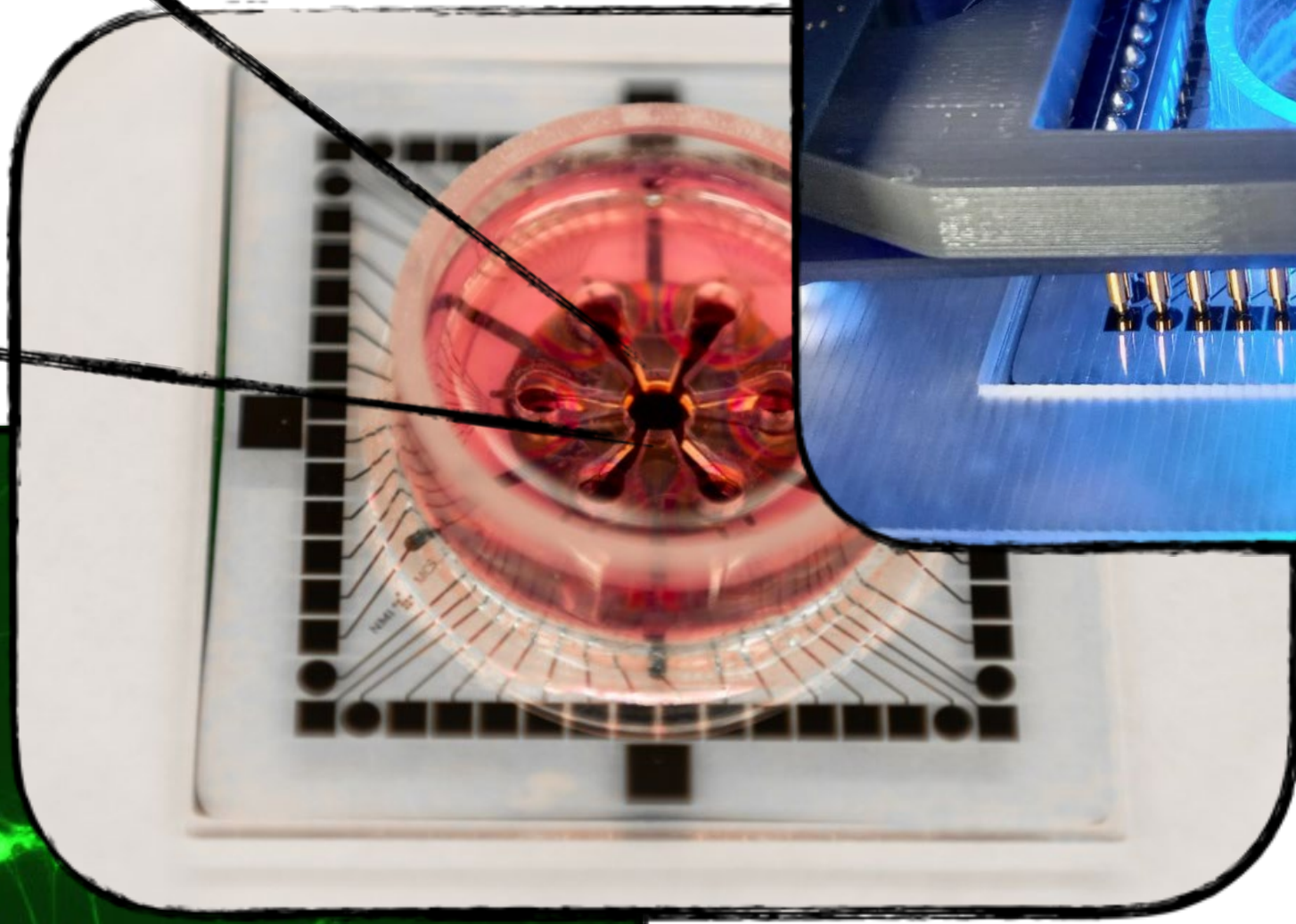
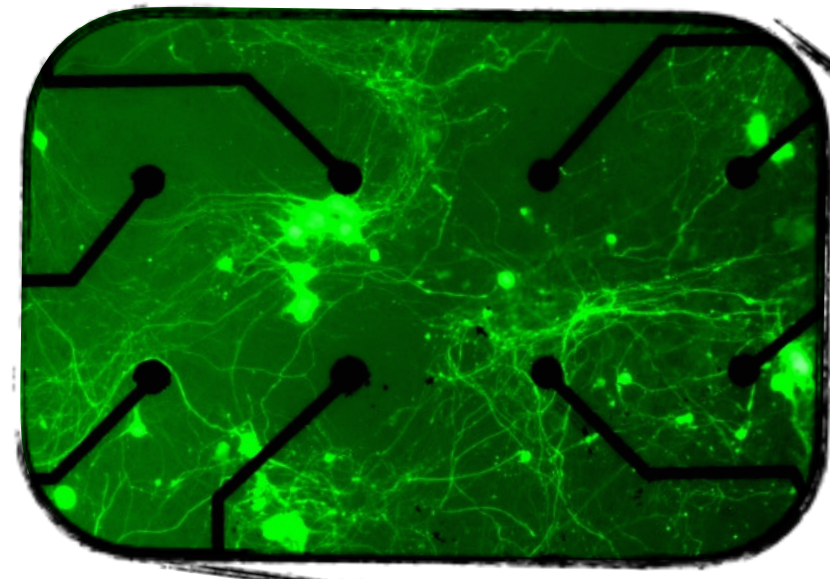
# HPC Framework

# IN VITRO EXPERIMENT



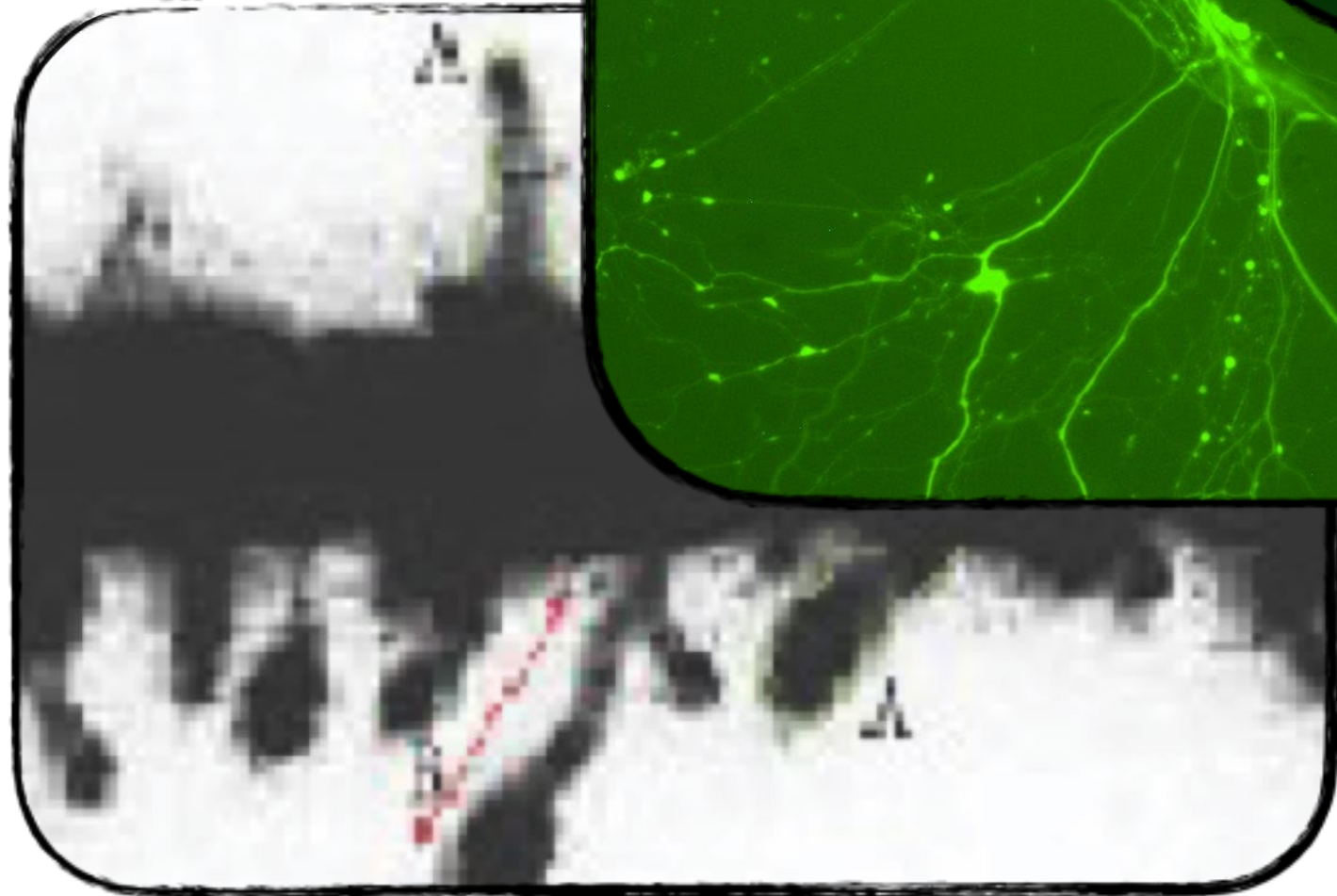
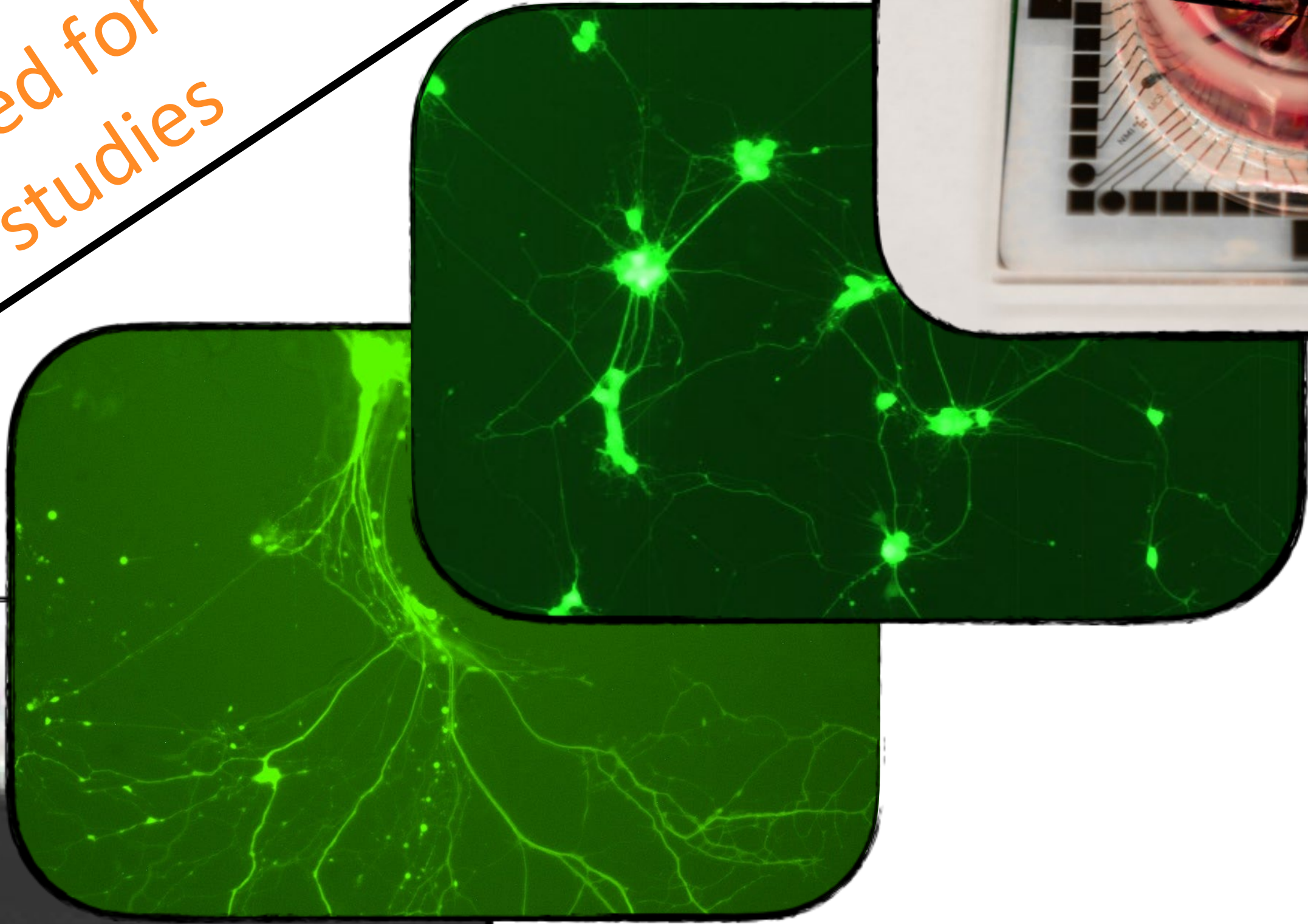
# ADVANCED ANALYSIS





*In Vitro*  
experiment

Developed for  
in vivo studies

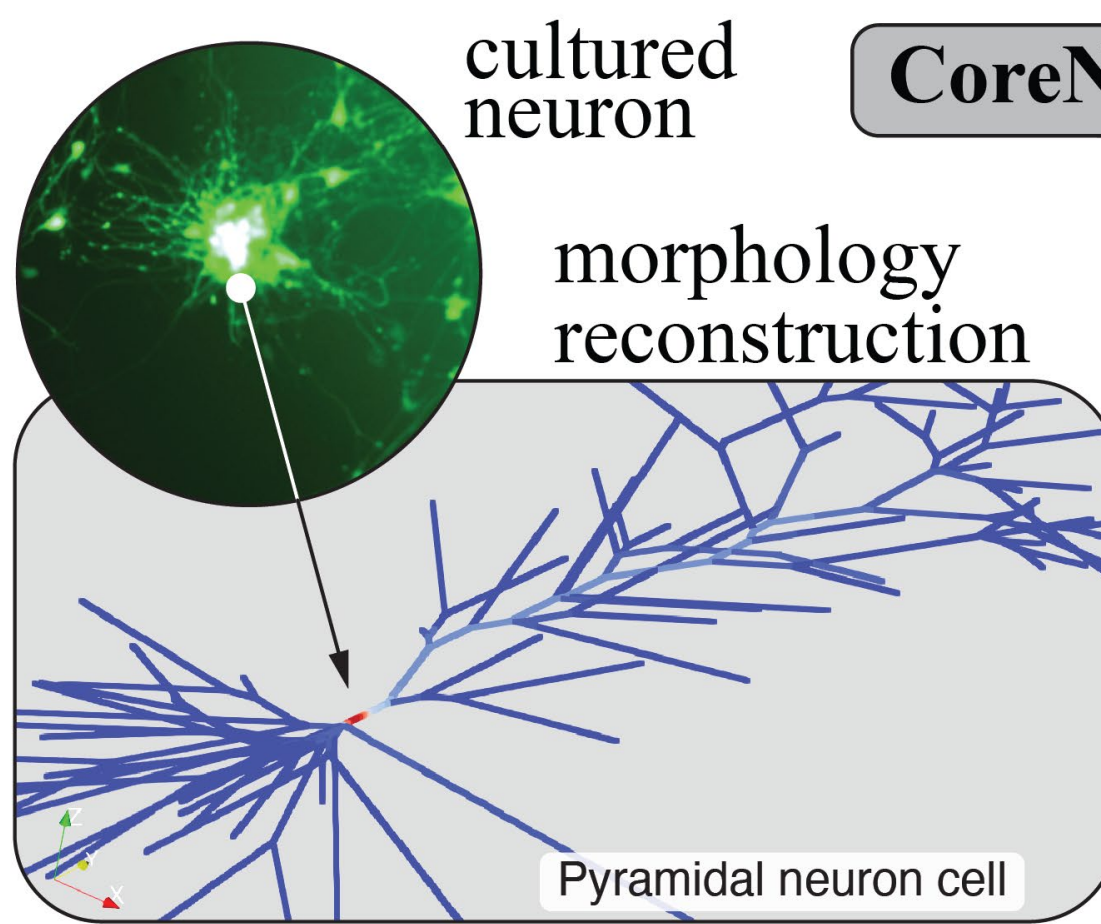


Synaptic Activity

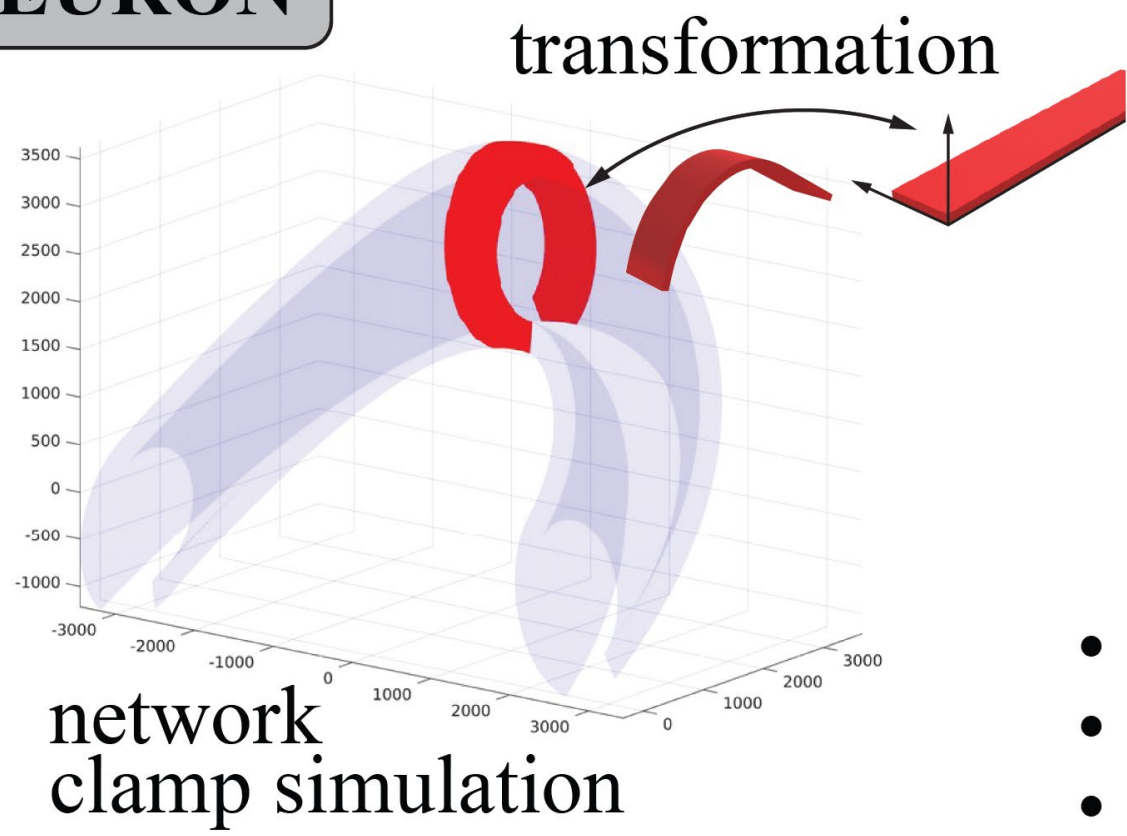
Modular  
HPC Framework

# Biophysical HPC Simulator

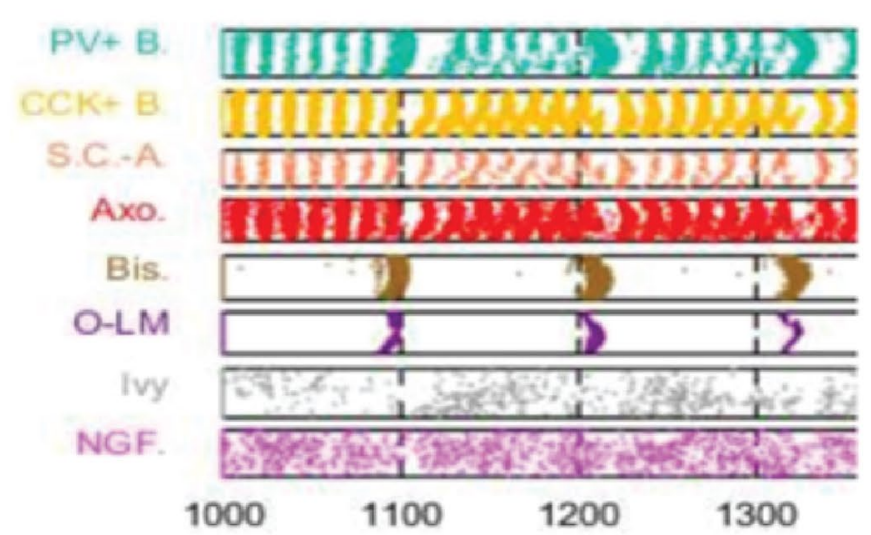
HPC Framework  
optimized for Frontera!



**CoreNEURON**



**MiV-Simulator**

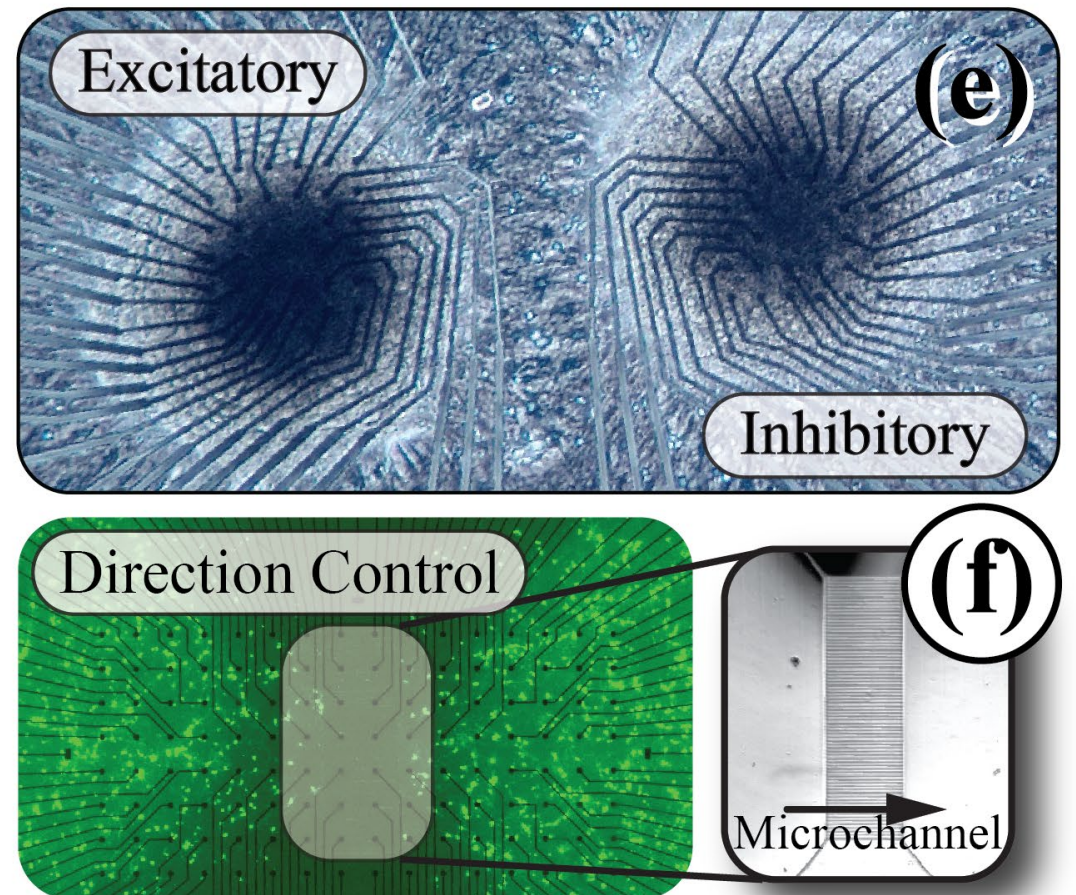
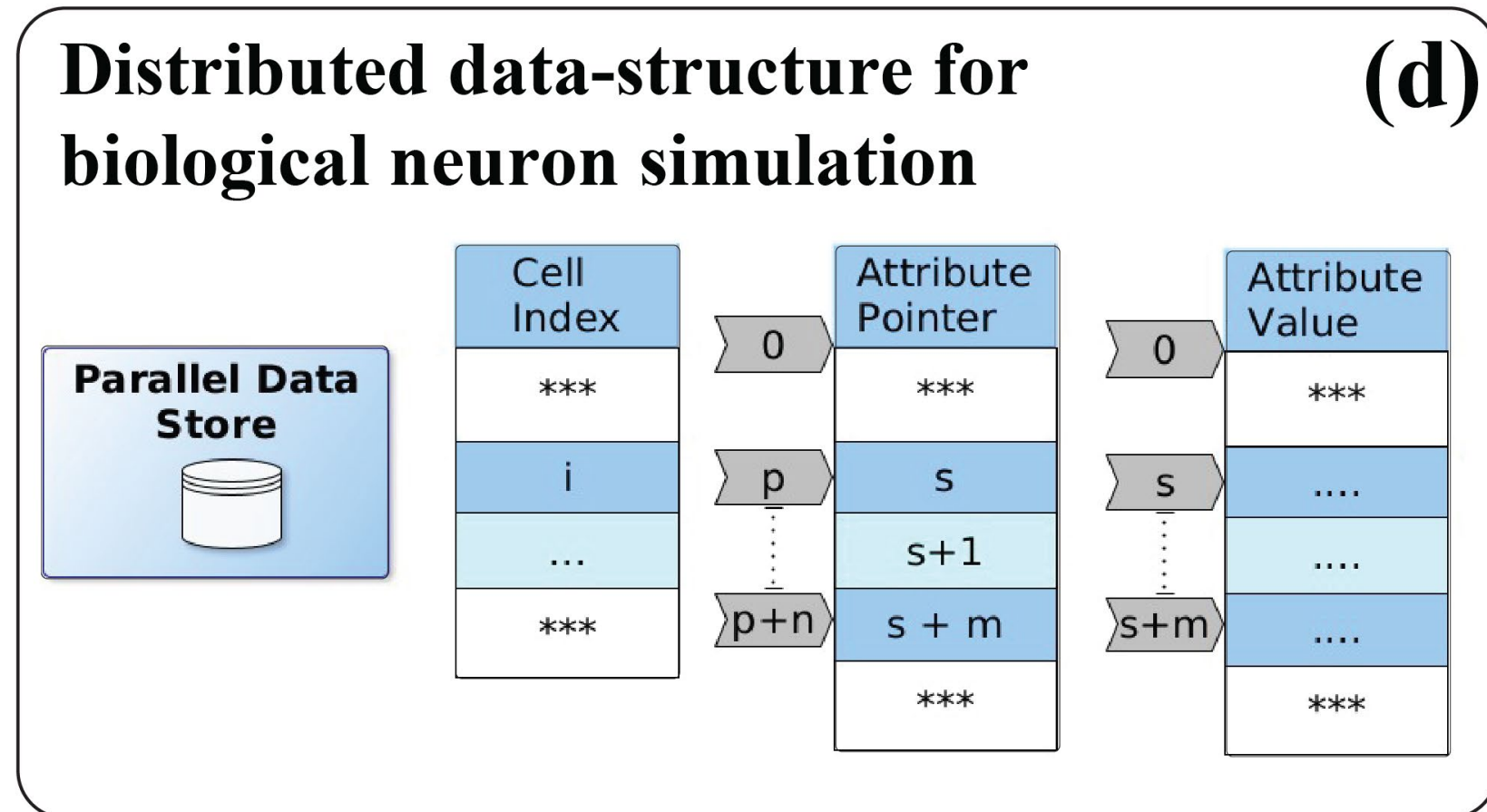
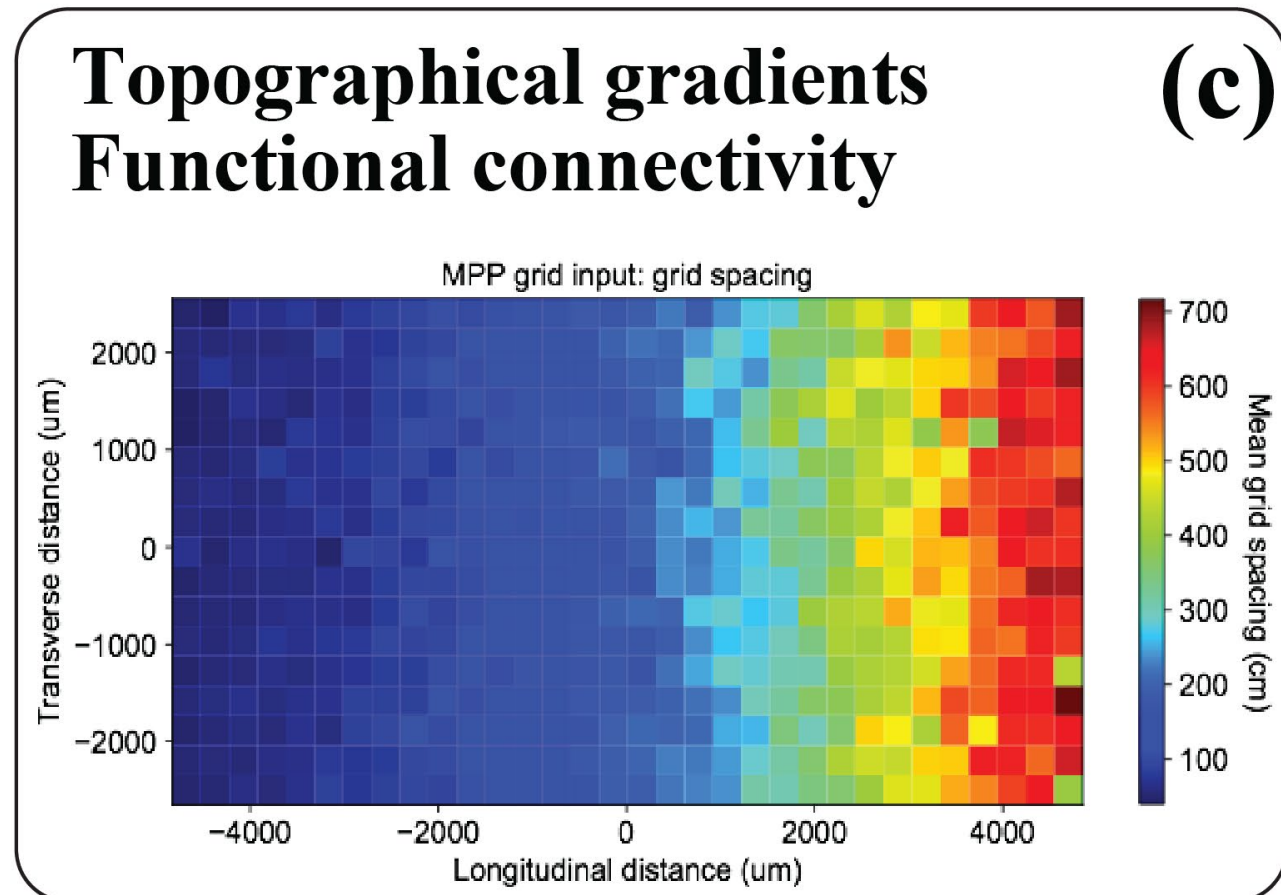
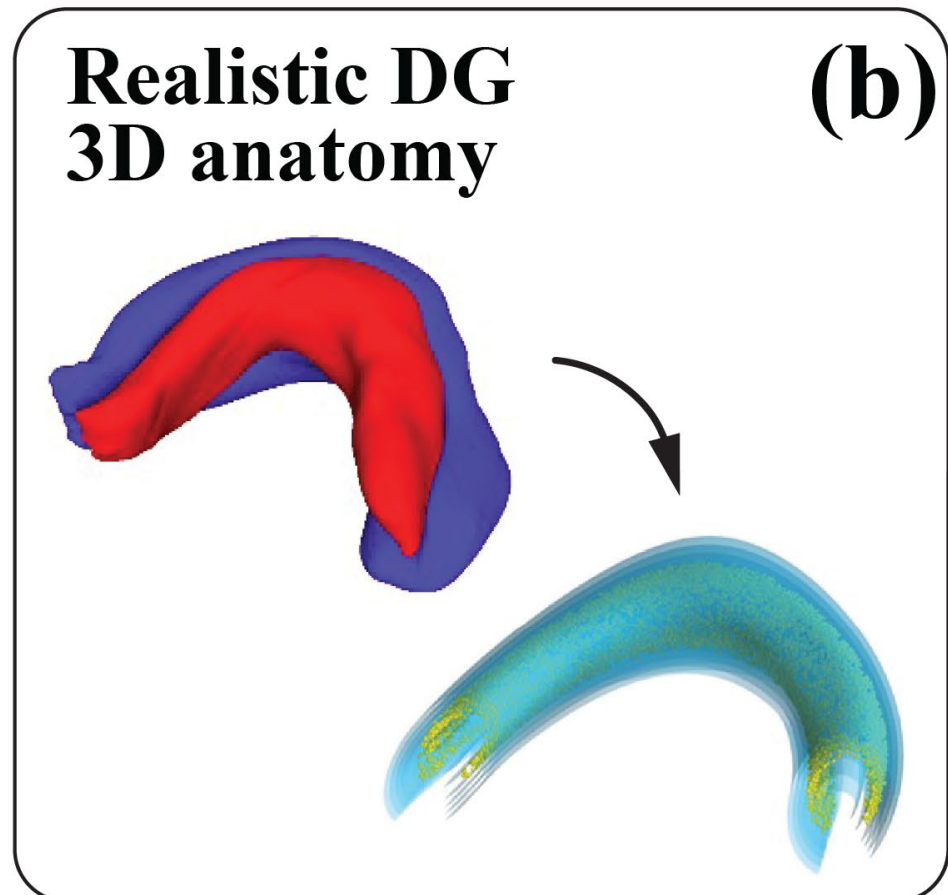
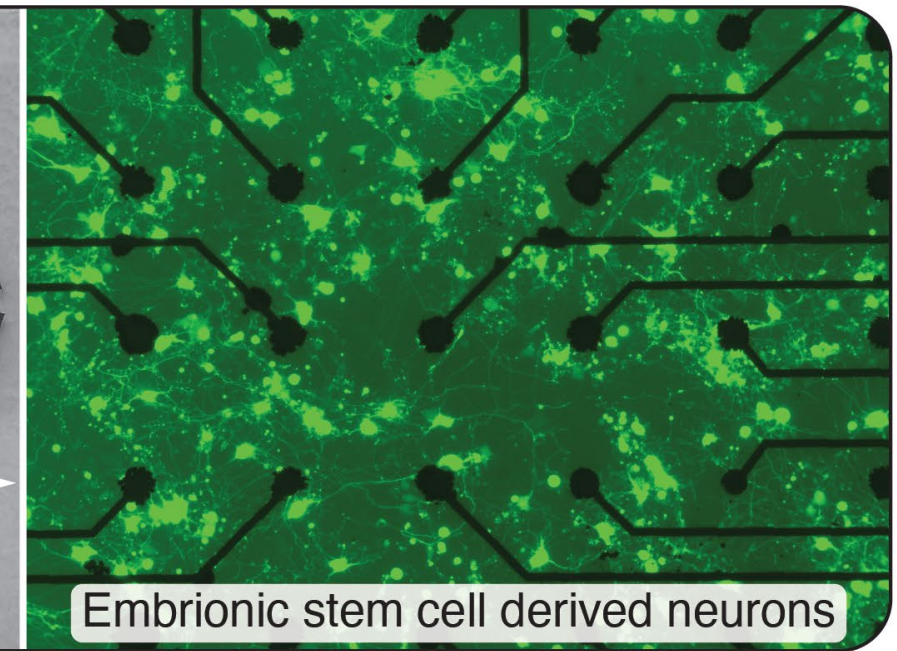
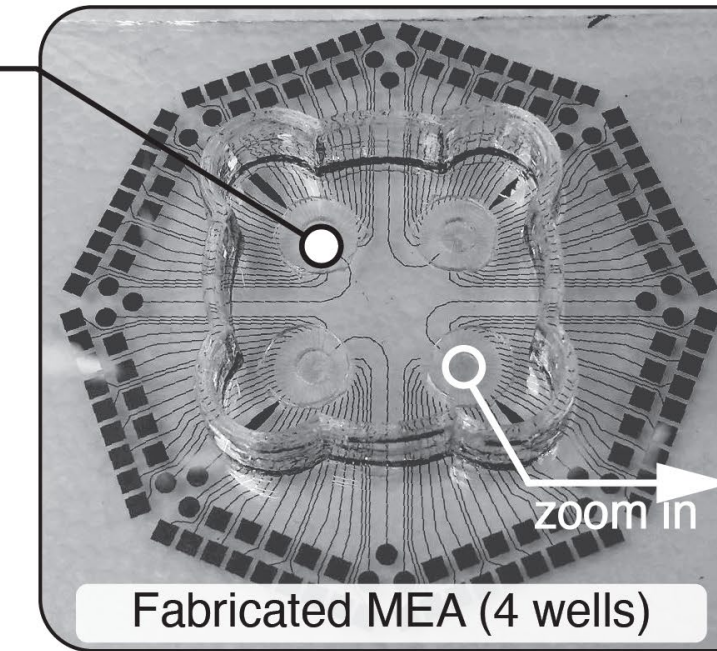


- resting membrane potential
- intrinsic conductances
- firing intensity and rate

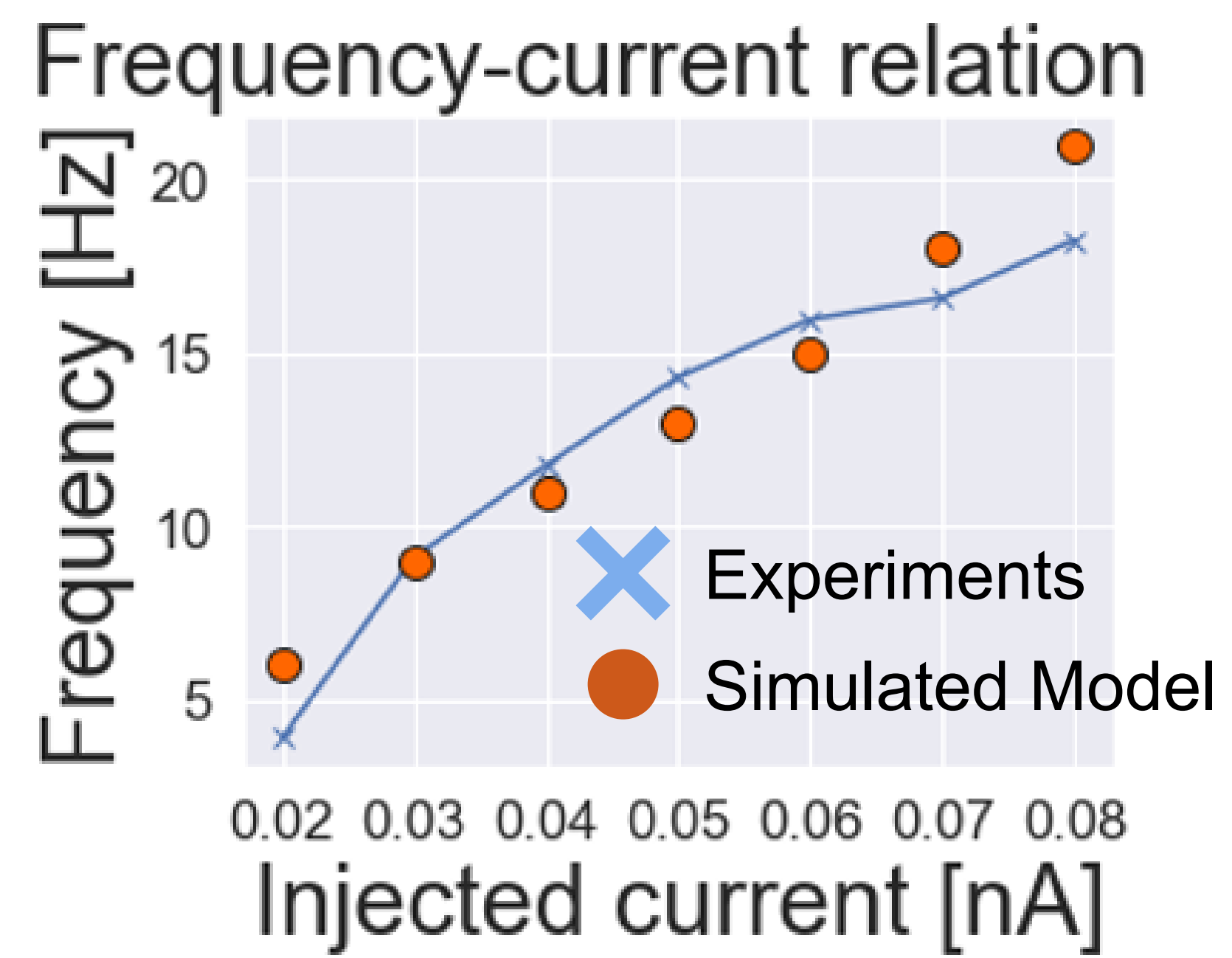
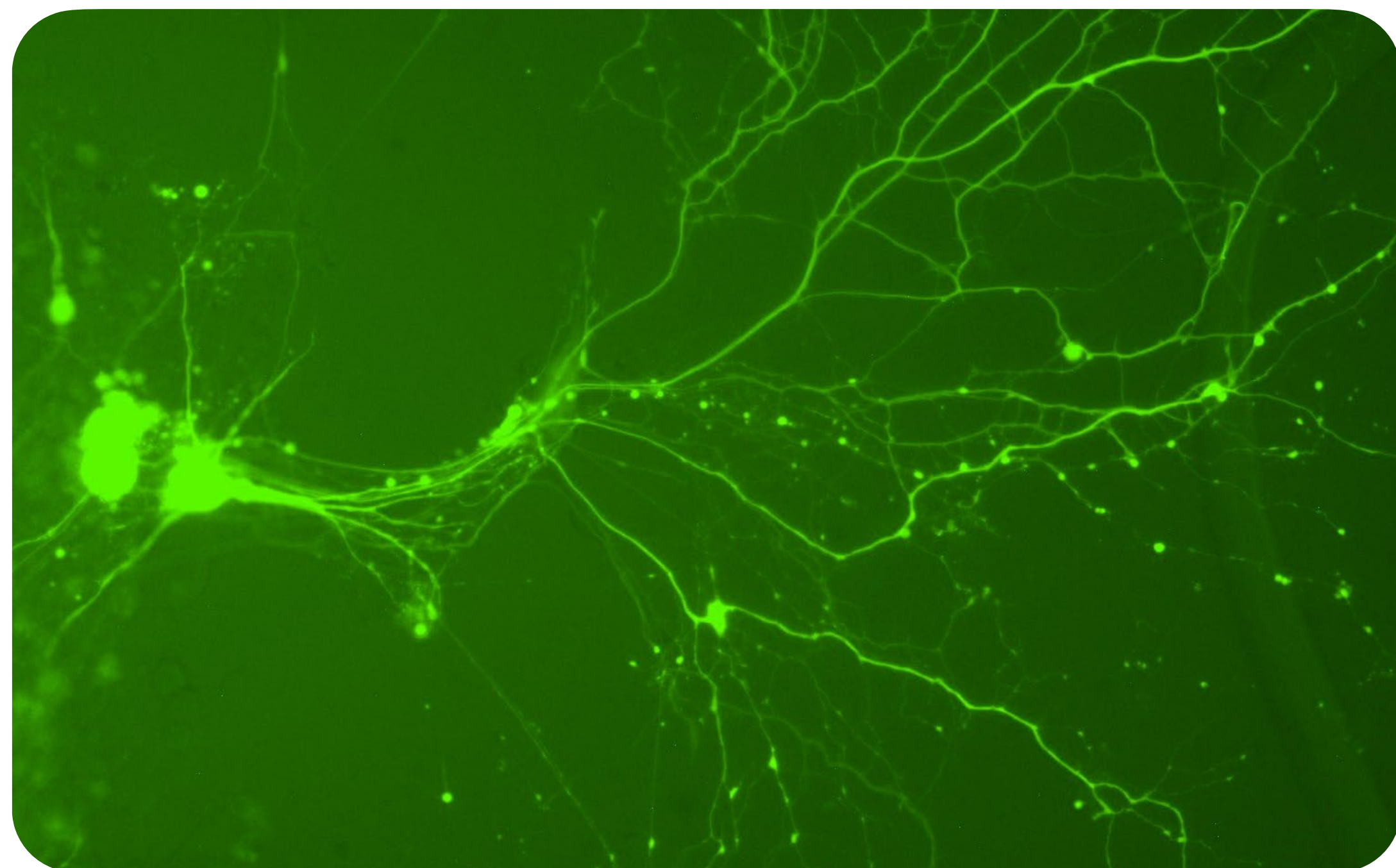
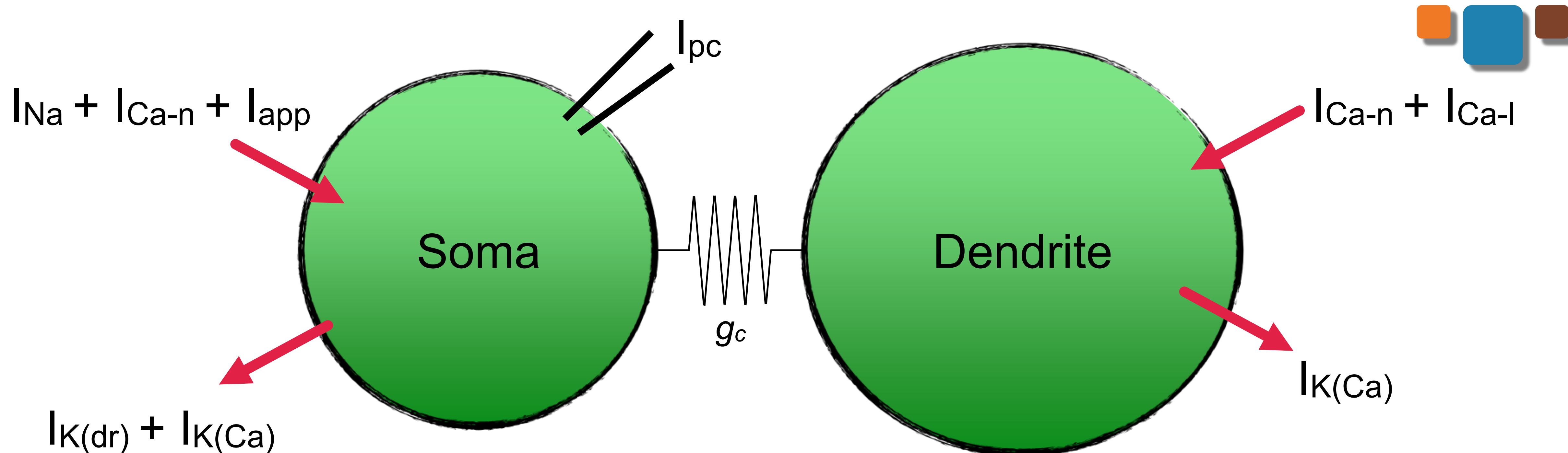
- optical
- electrical
- chemical

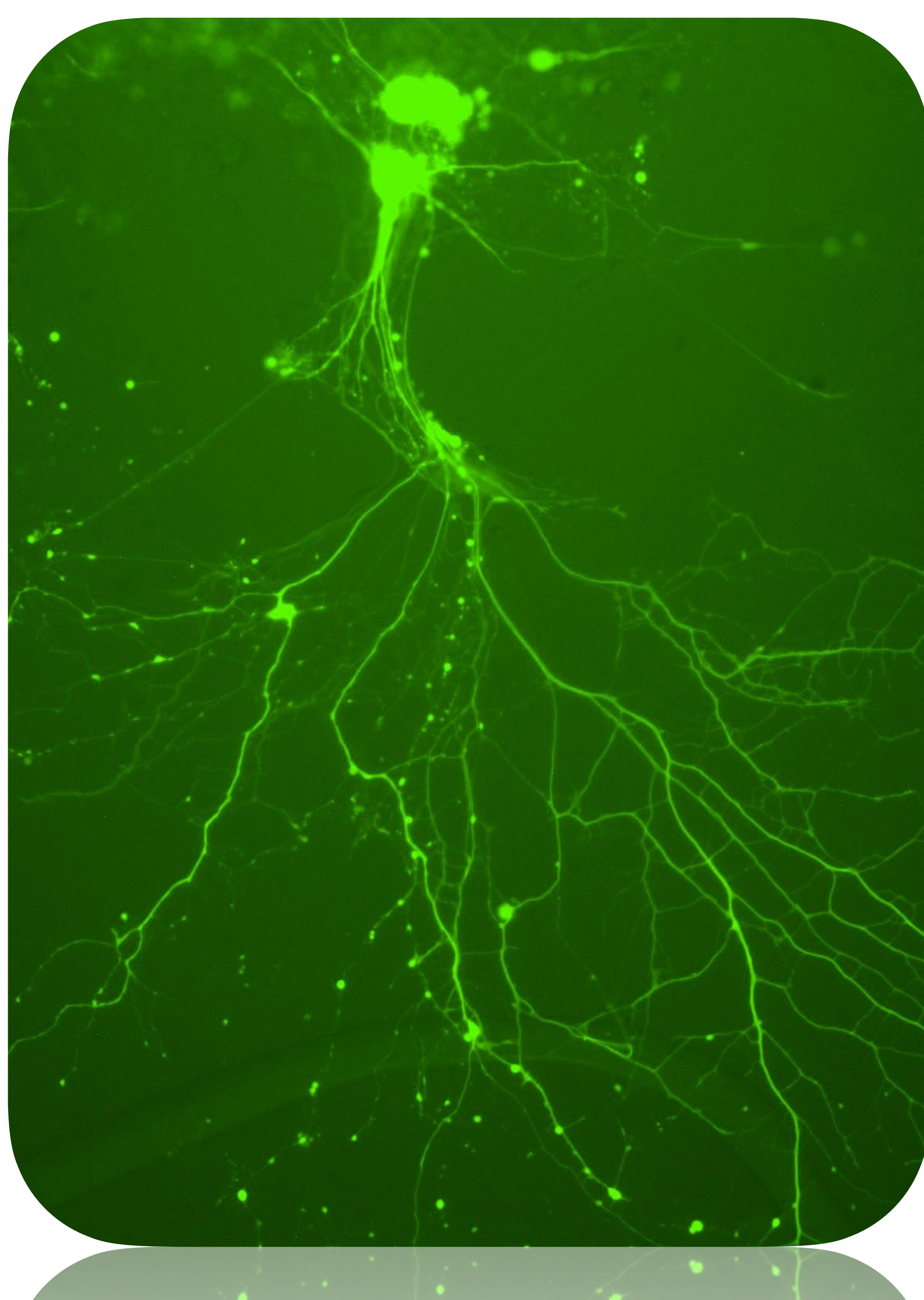
- selectivity
- sparsity
- structure

• LFP

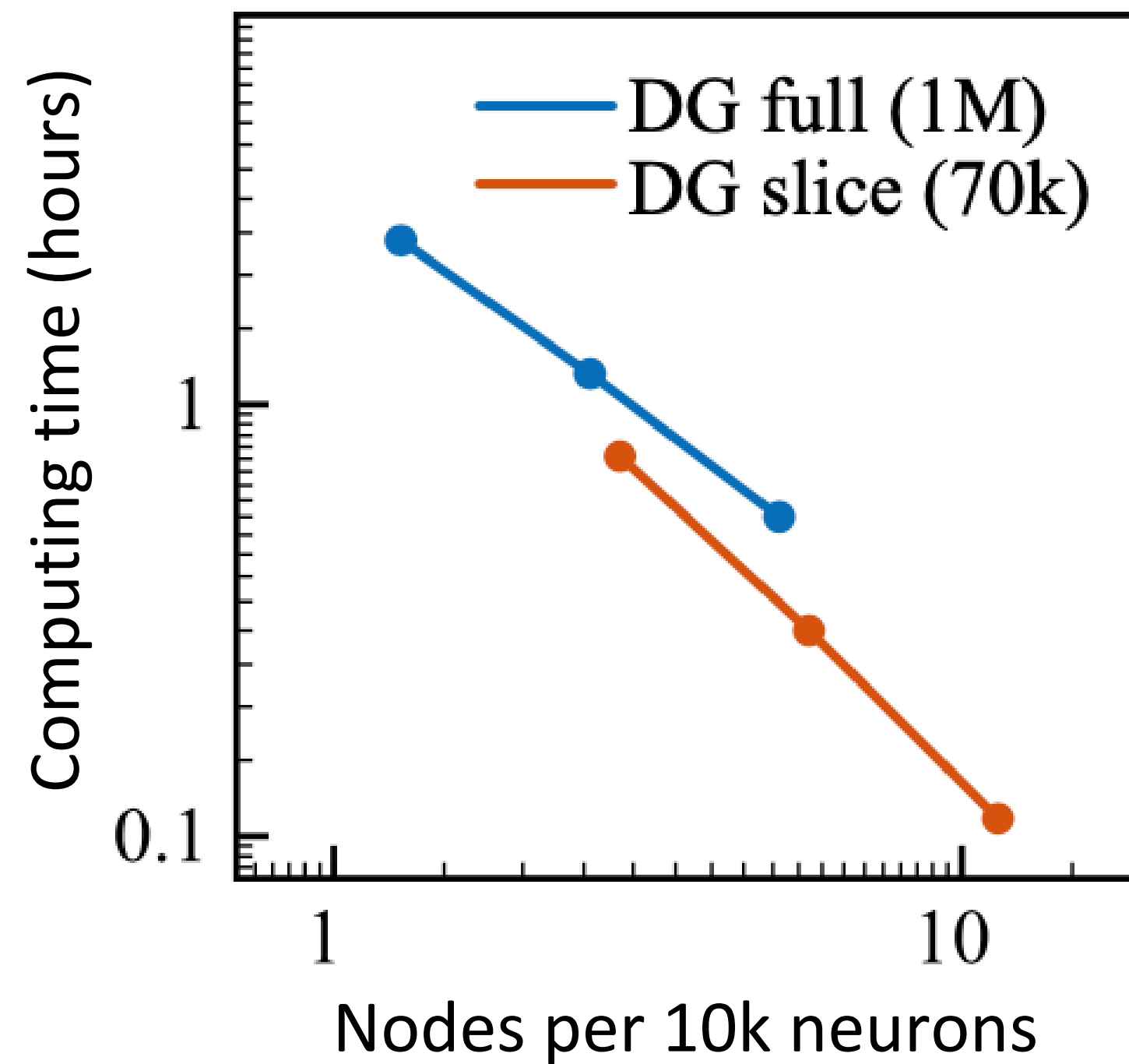
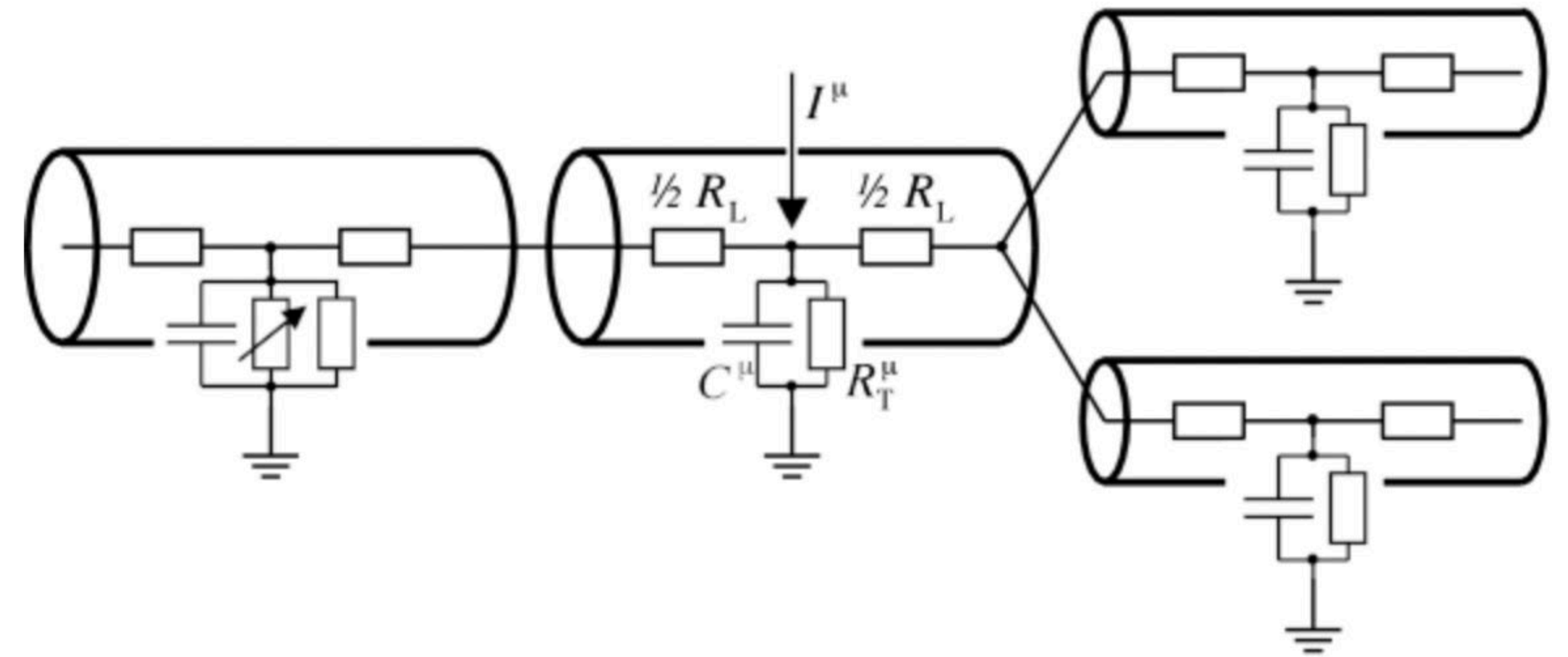


Ivan Raikov  
Ivan Soltesz, Stanford





# Neuron Morphology :

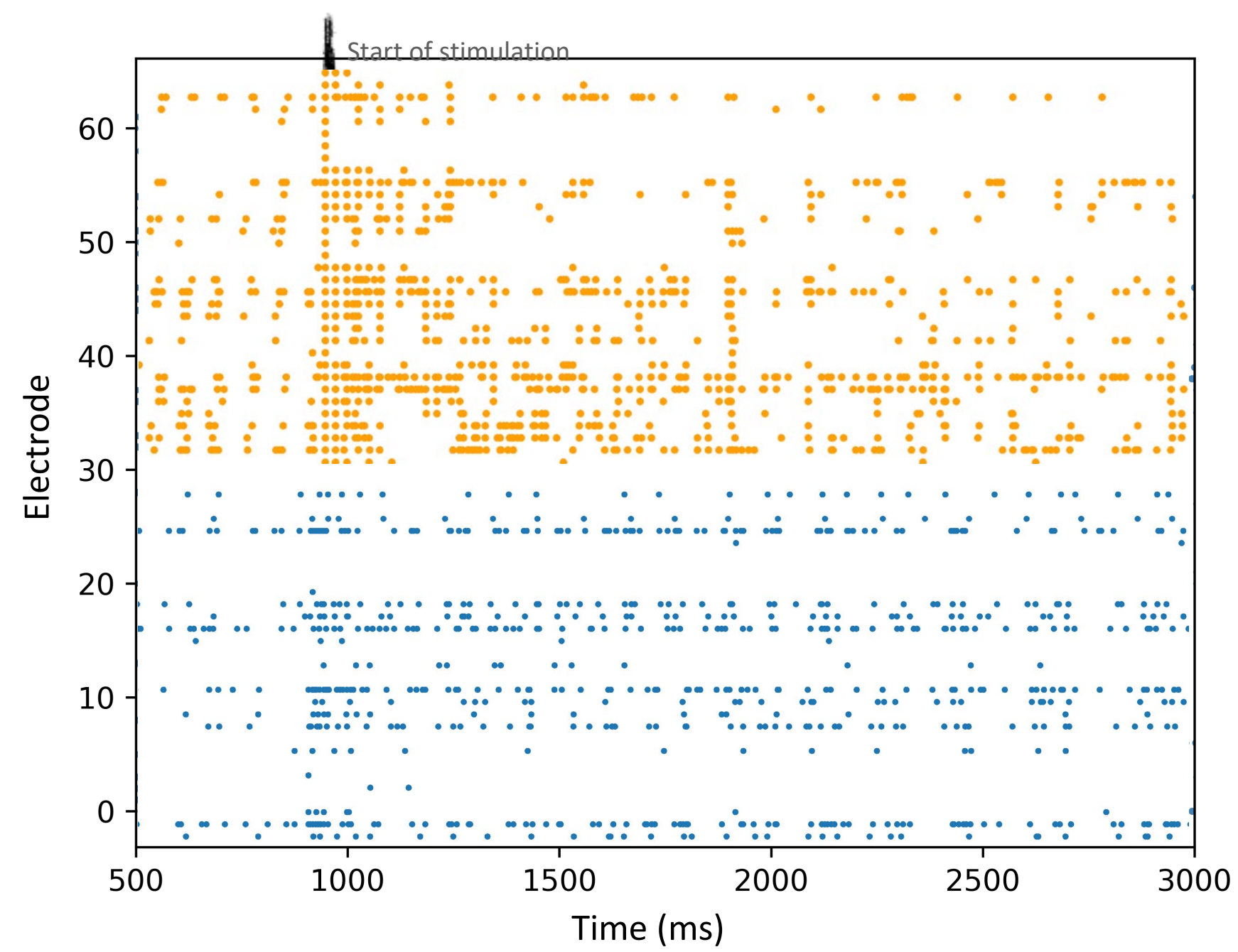
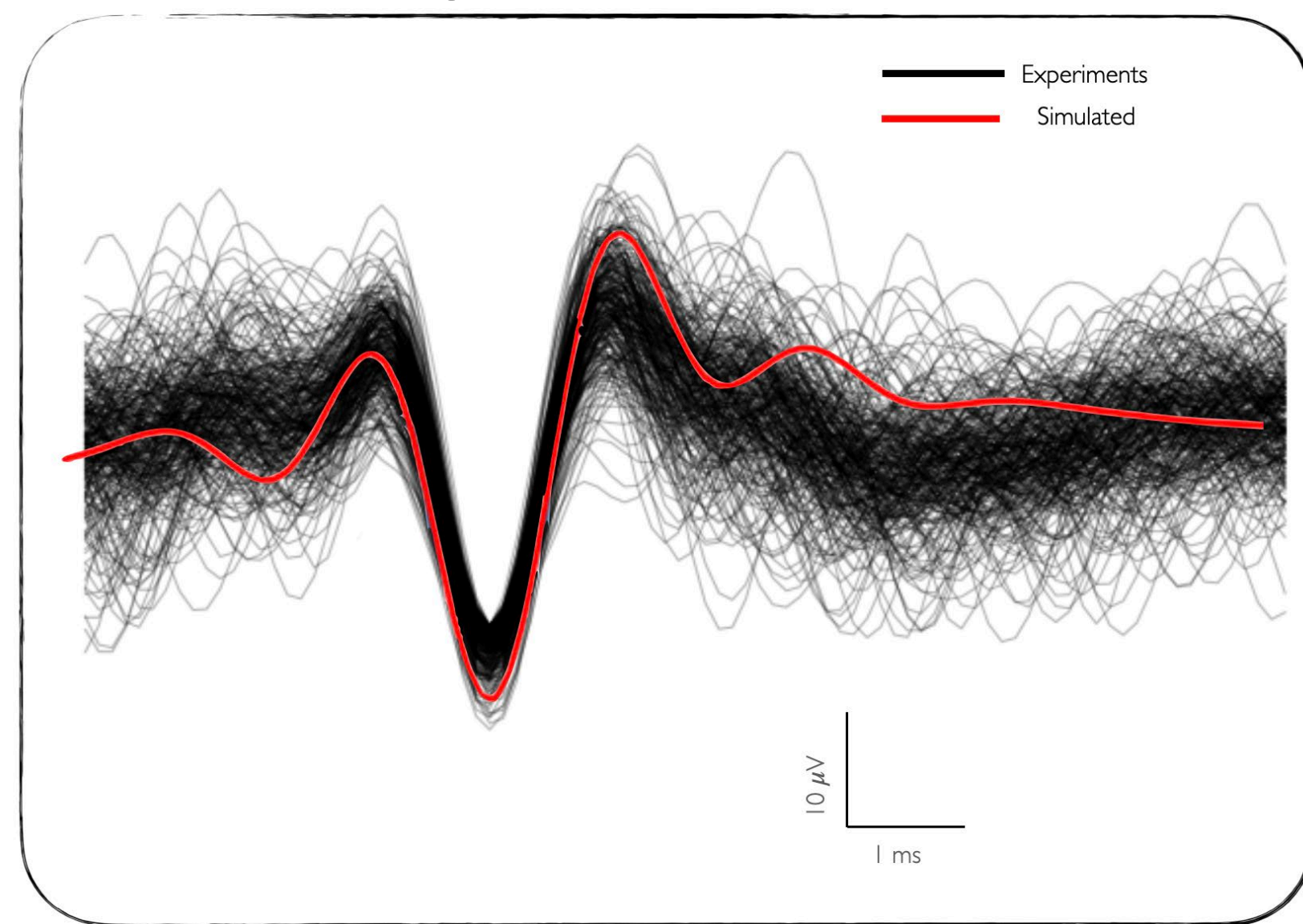


**1 million** neurons  
 ~**20 billion** synapses!

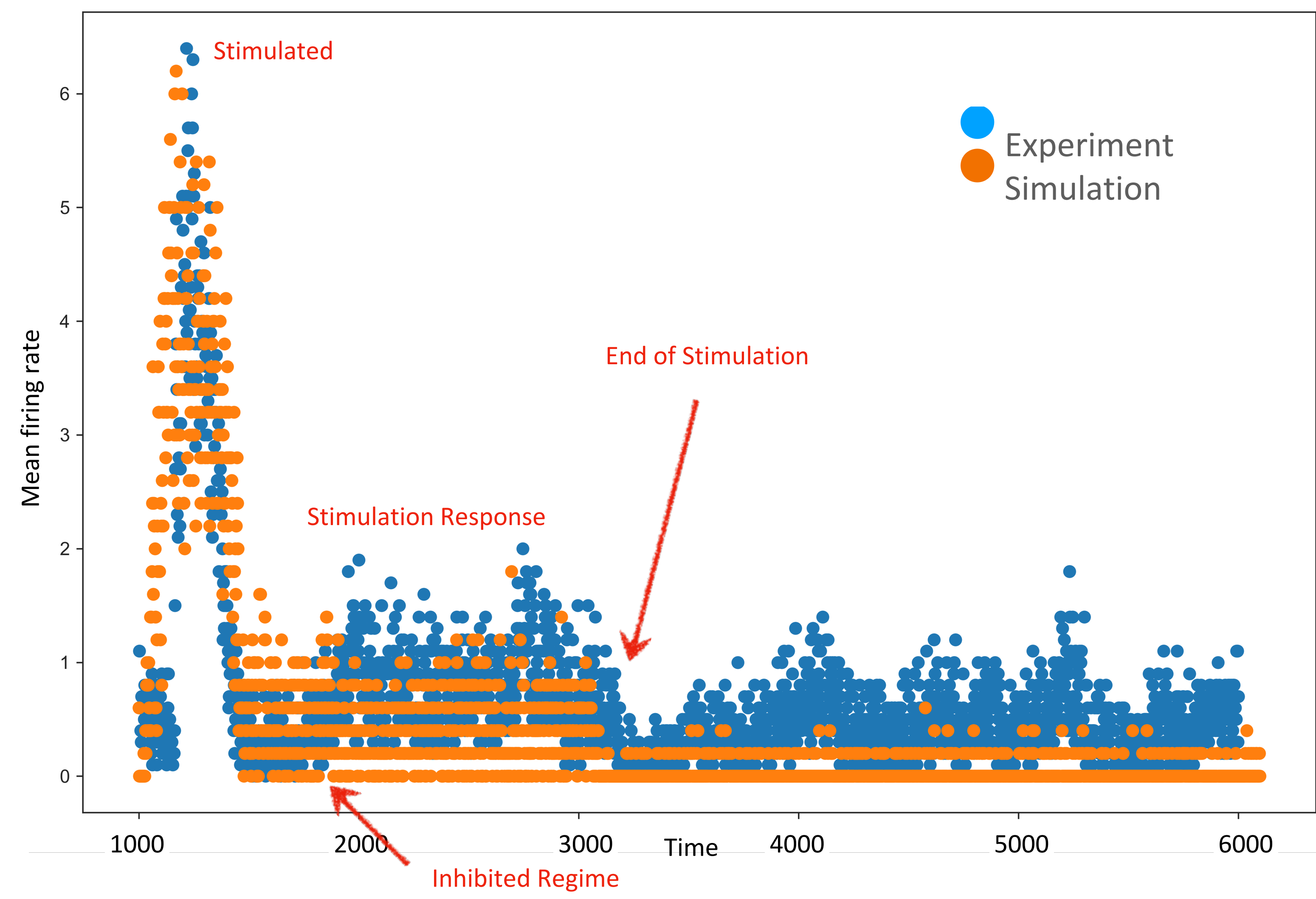


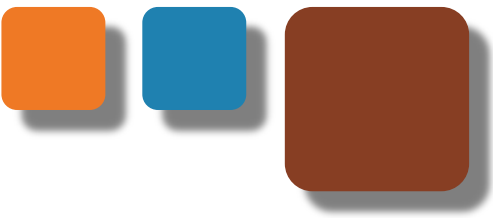


# Spike Profile

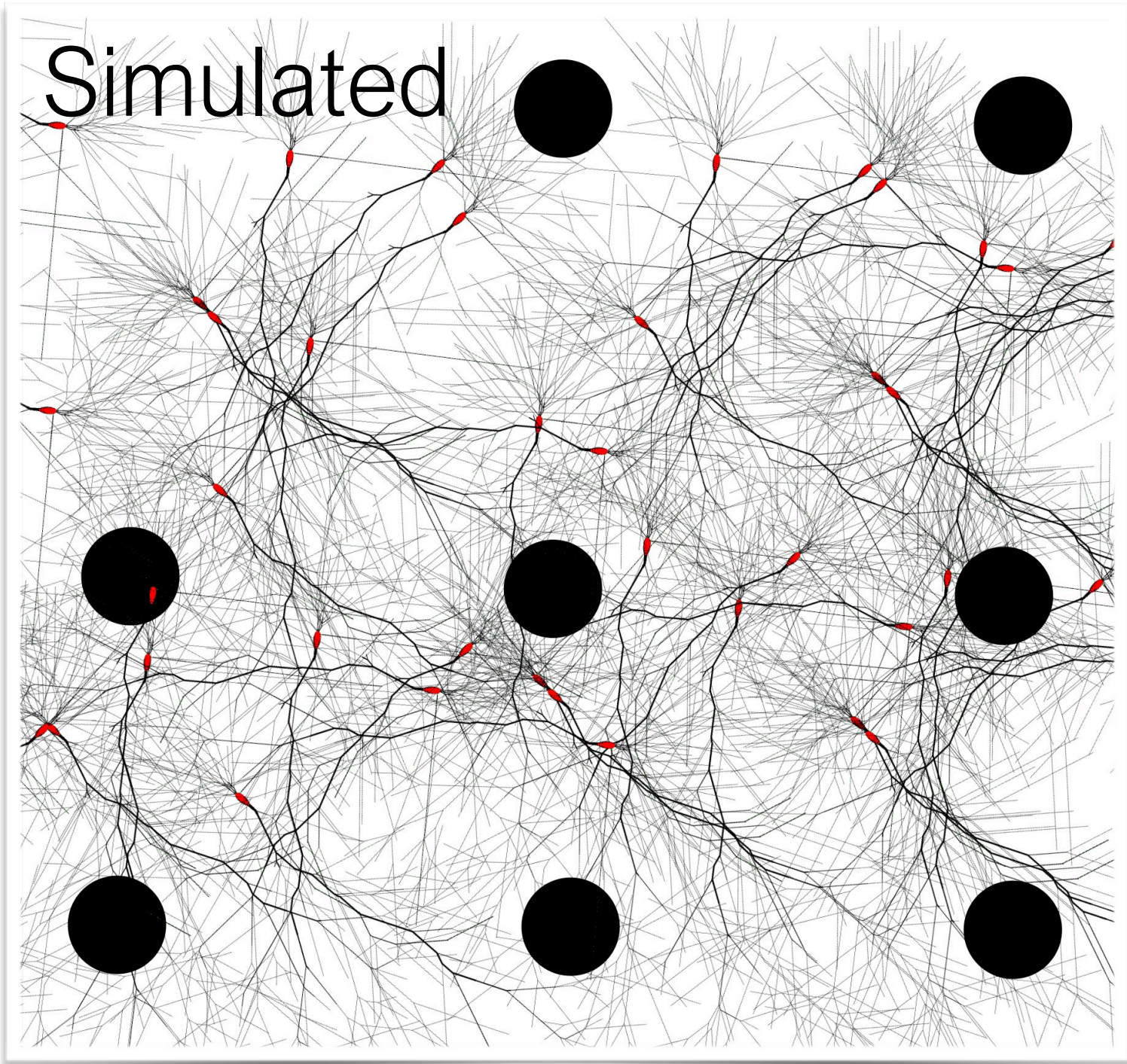
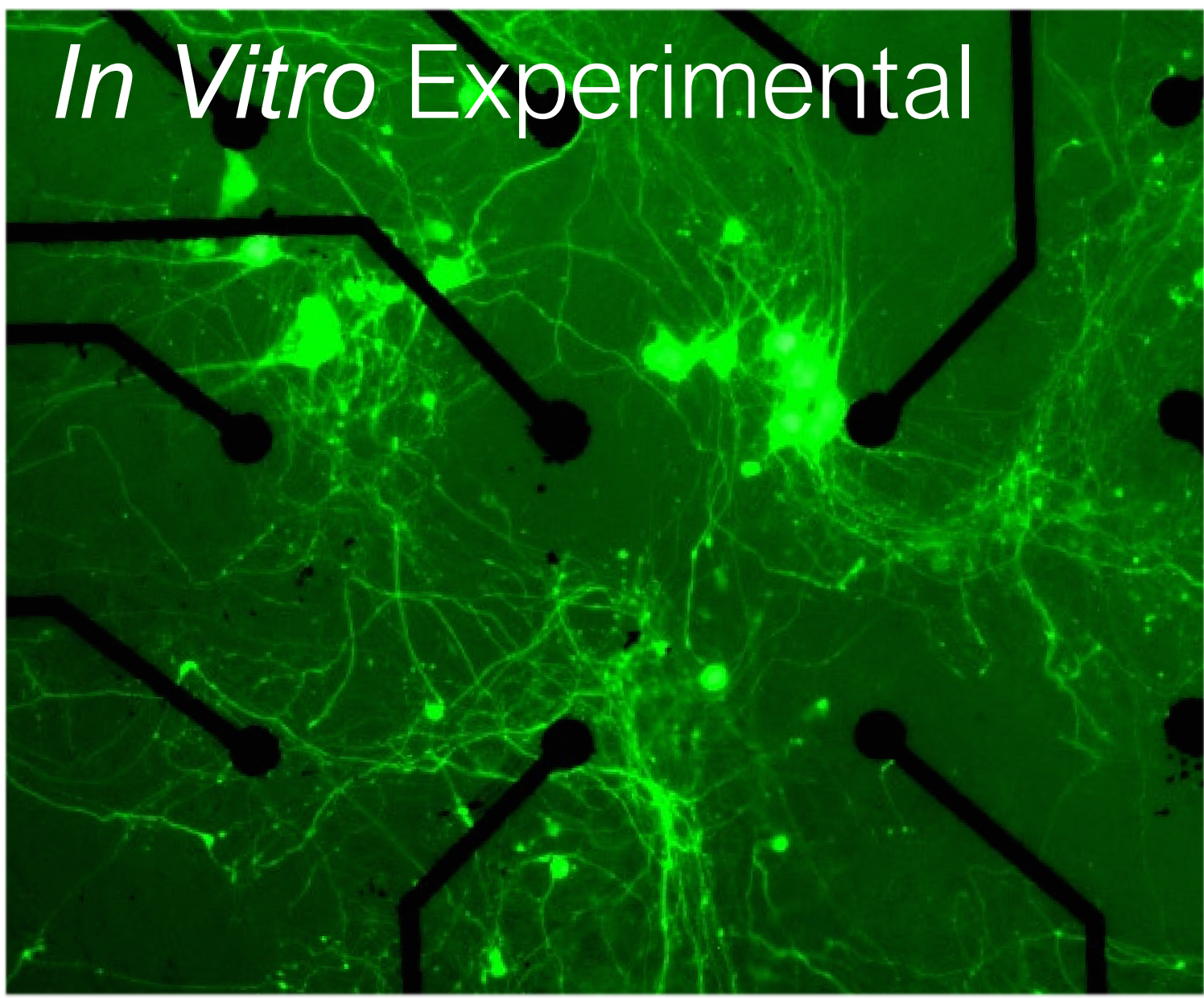
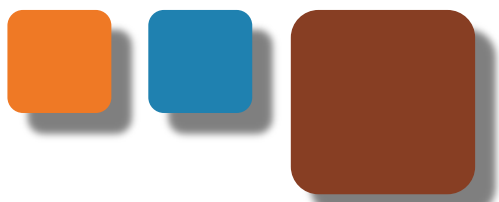


# Mean firing rate

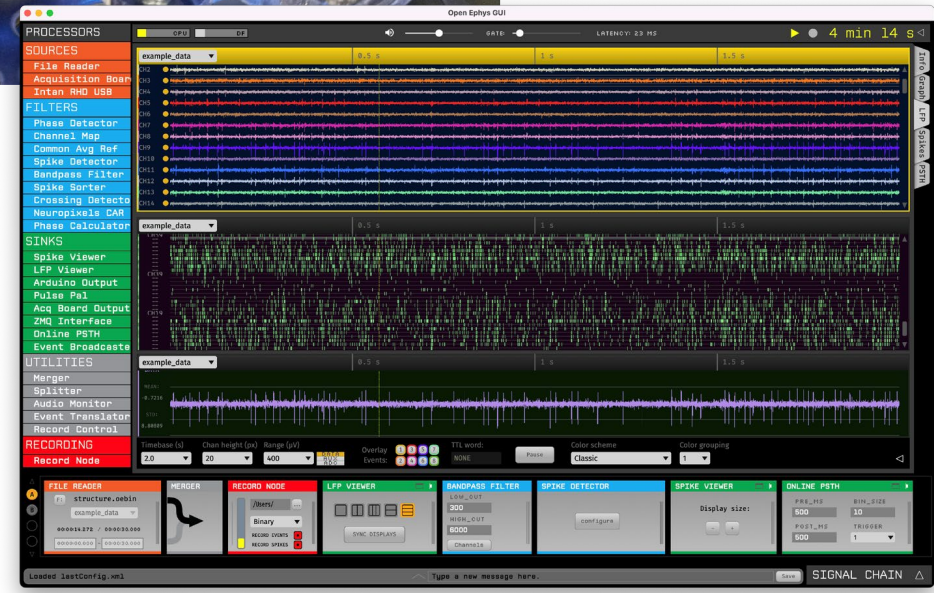
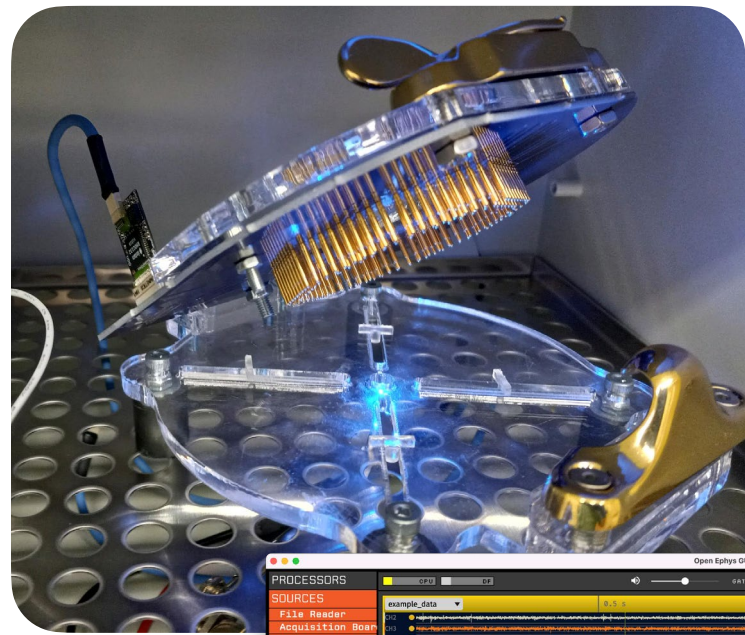




# MiV Software Stack in Frontera



### Electrophysiology



Other Spike Data Library

MiV-Interface (Frontend)

- Interactive Analysis

MiV Open Source

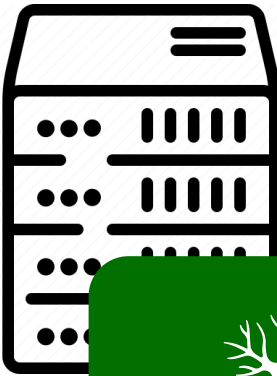
### Data Storage

- Data Archives
- Cloud

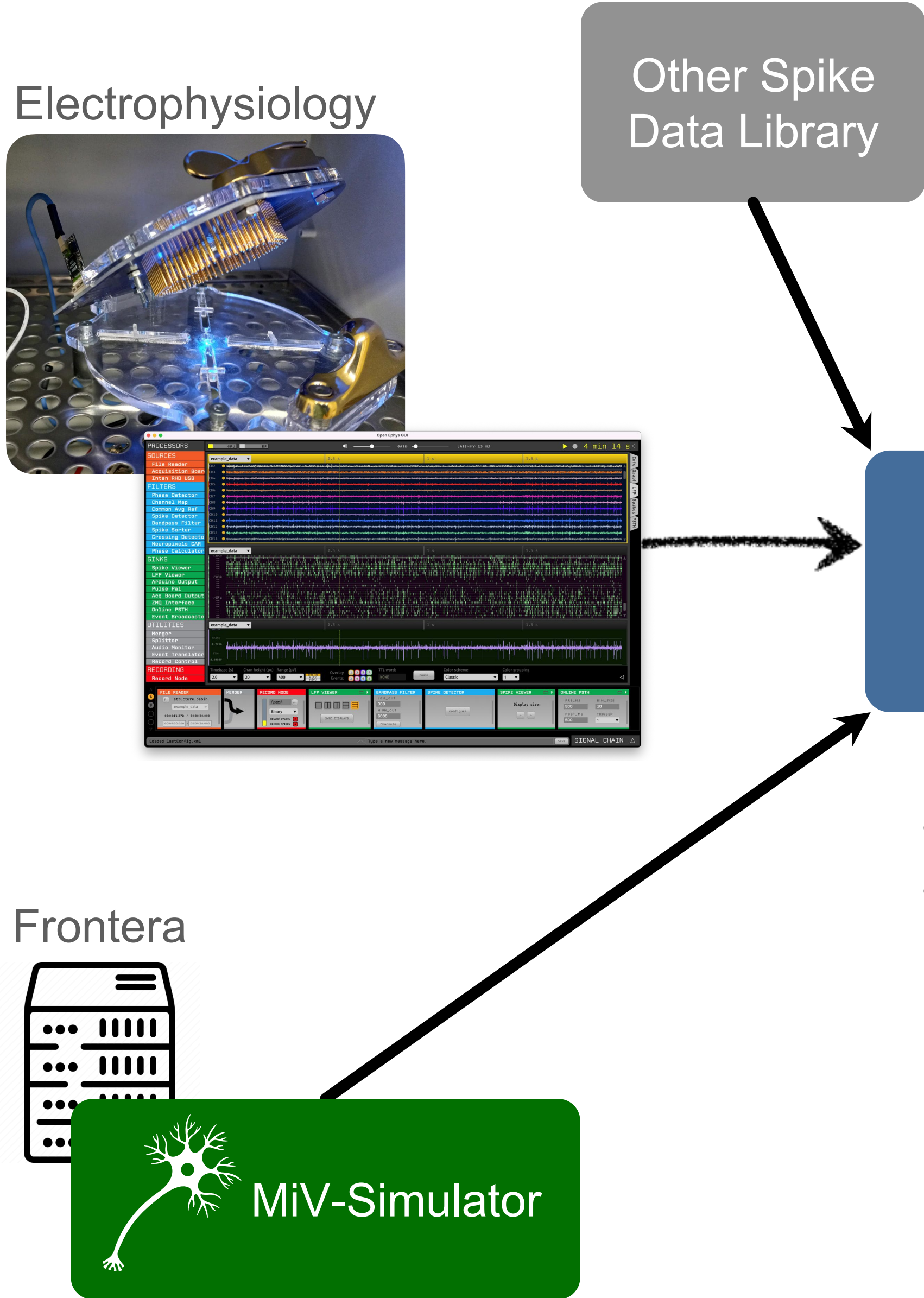
### HPC Tools

- Analysis
- Statistics
- Optimization
- Parameter search

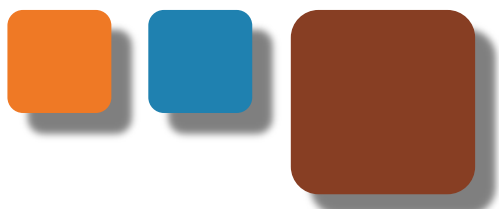
### Frontera



MiV-Simulator

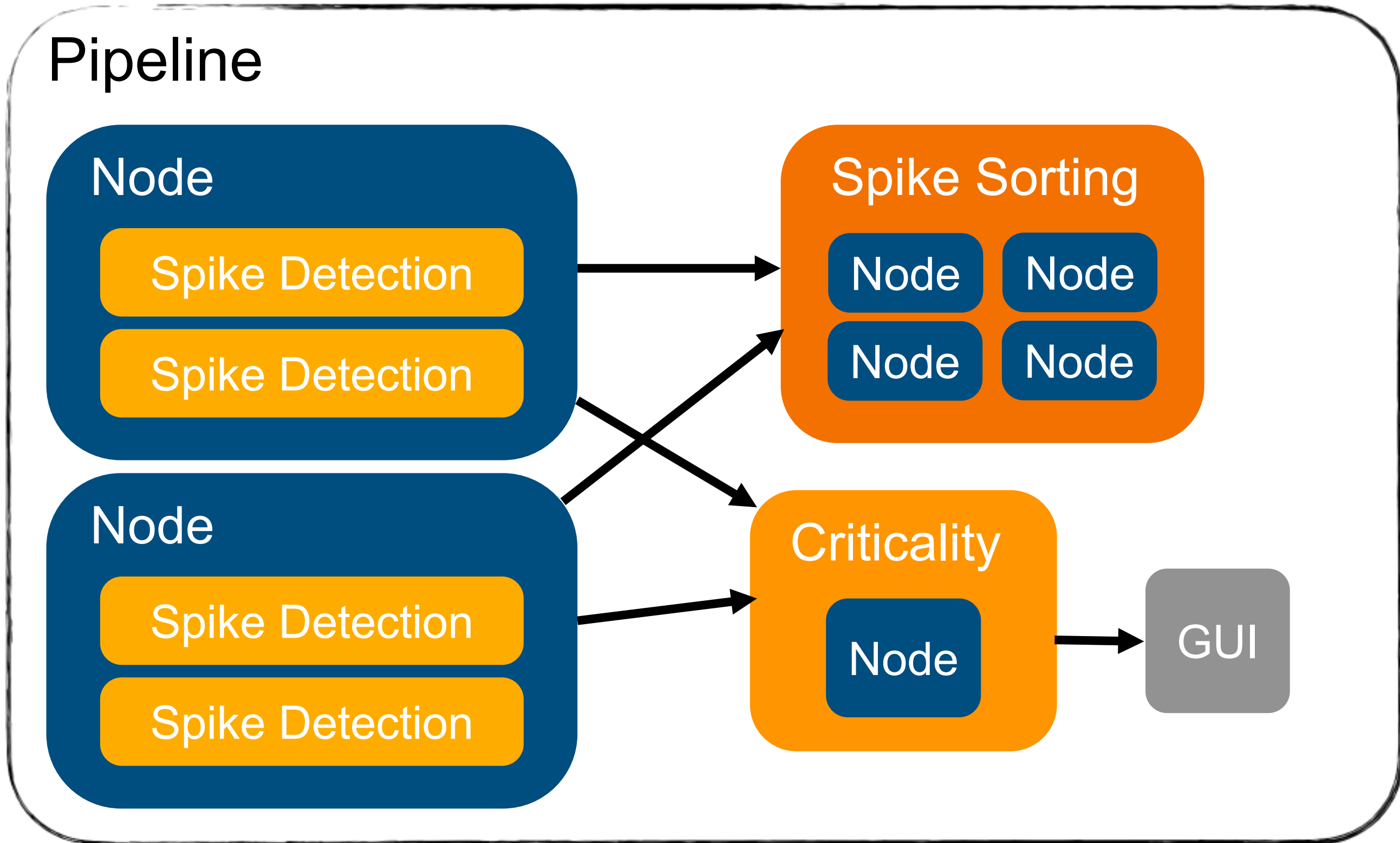


# HPC Data Post Processing

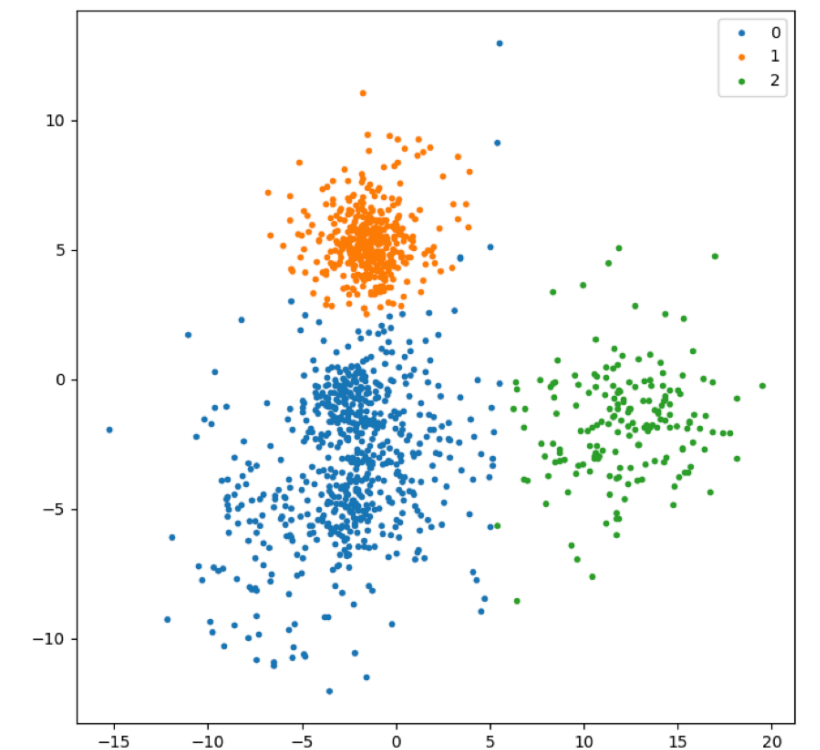
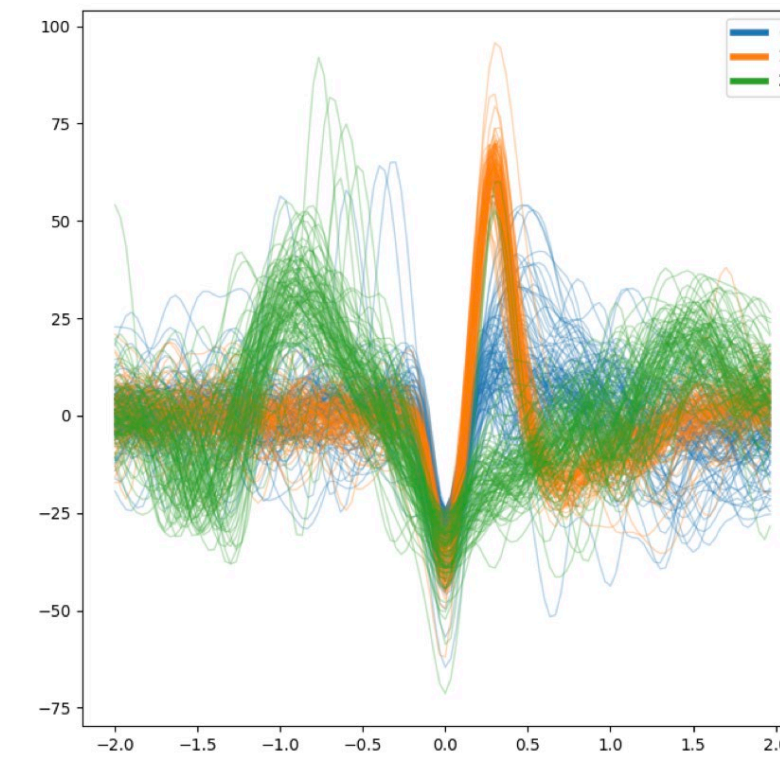


- Partition data block
- Manage I/O per nodes+cores
- Caching
- High Throughput Execution
- Dependency

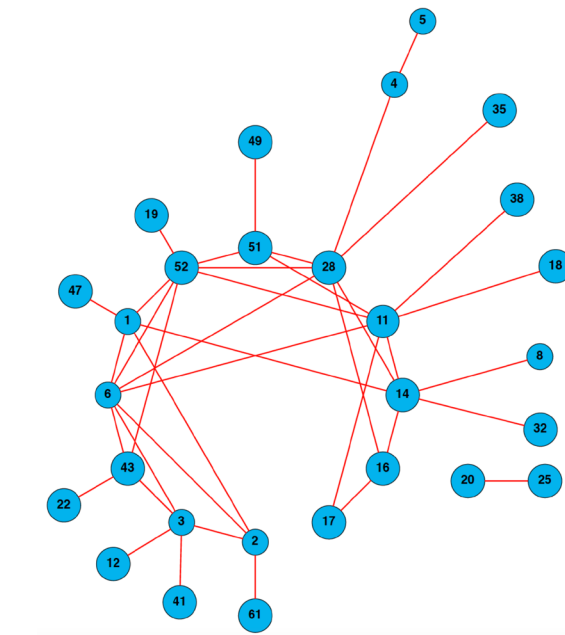
Multi-channel  
Time-series data



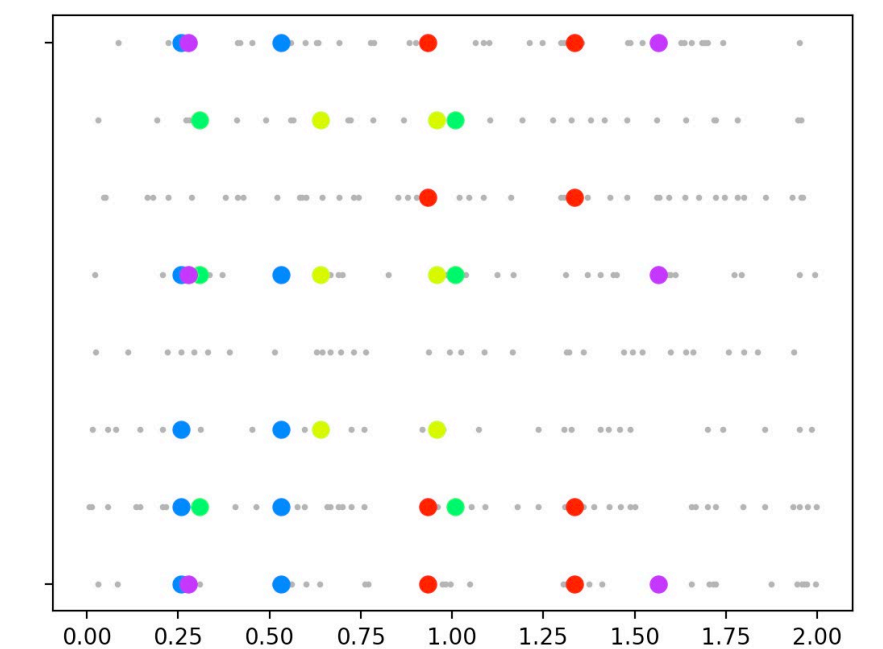
Spike Sorting (spyking-circus)<sup>[1]</sup>



Information Causality<sup>[2]</sup>



Cell Assembly<sup>[3]</sup>

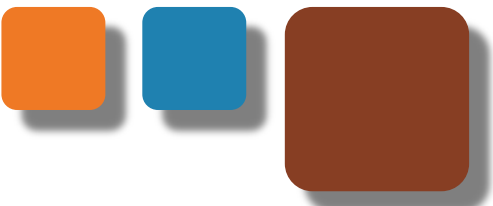


[1] Iger P., 2018

[2] Wollstadt P., 2018

[3] Russo E., 2017

# HPC Interactive Data Processing



- Pilot launch — Interactive hyperparameter search

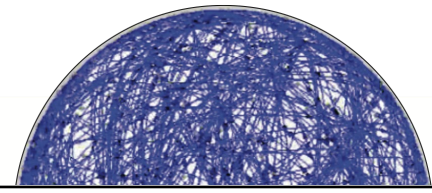
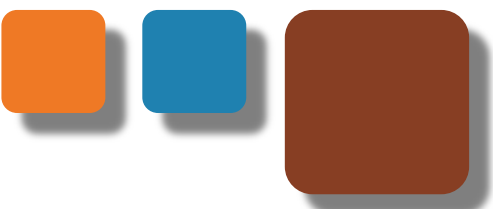
Hyperparameters from Pipeline

The dashboard is titled "MiV-Interface 0.24.2.dashboard" and features a "Criticality analysis configuration" section on the left. This section includes several sliders and checkboxes for adjusting parameters: "Bin Size" (1ms to 46ms), "Threshold percentage" (0.1 to 4.6), "Time Difference" (0s to 4s), "Allow multiple spike per bin" (Yes/No), "Minimum bins in avalanche" (0 to 25), "Minimum interburst interval bound" (0.01s to 0.50s), "Pre burst extension" (0.06s to 0.50s), and "Post burst extension" (0.06s to 0.50s). A "Configurations:" box at the bottom left lists the current settings: bin\_size: 0.002, threshold\_percentage: 2, time\_difference: 0.46, allow\_multiple\_spike\_per\_bin: False, minimum\_bins\_in\_avalanche: 10, min\_interburst\_interval\_bound: 0.1, pre\_burst\_extension: 0, post\_burst\_extension: 0.

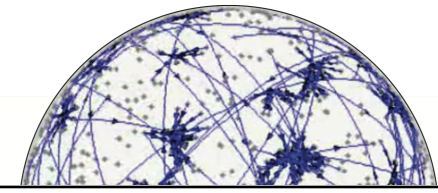
The main area displays "Analysis Plots" for a specific tag "Ideal" and ID "014c0f210490949a\_03". The plots include: a histogram of "Branching ratio" with a mean of 0.676; a scatter plot of "Avalanche size (# of channels)" vs "Avalanche duration (s)" with  $\tau = -2.641$ ; a scatter plot of "Avalanche duration (s)" vs "Duration (s)" with  $\alpha = -0.227$ ; and a scatter plot of "Average size (# of channels)" vs "Duration (s)" with  $1/svz = 0.18$  and  $(\alpha-1)/(\tau-1) = 0.34$ . A "Raster" plot shows "Channel" activity over "Time (s)". A summary box at the bottom center repeats the values:  $1/svz = 0.18$  and  $(\alpha-1)/(\tau-1) = 0.34$ . A "Hyperparameters from Pipeline" label on the left points to the configuration section, and an "Analysis Plots" label on the right points to the main plot area.



# Optimizing Cellular Substrate



Supercritical

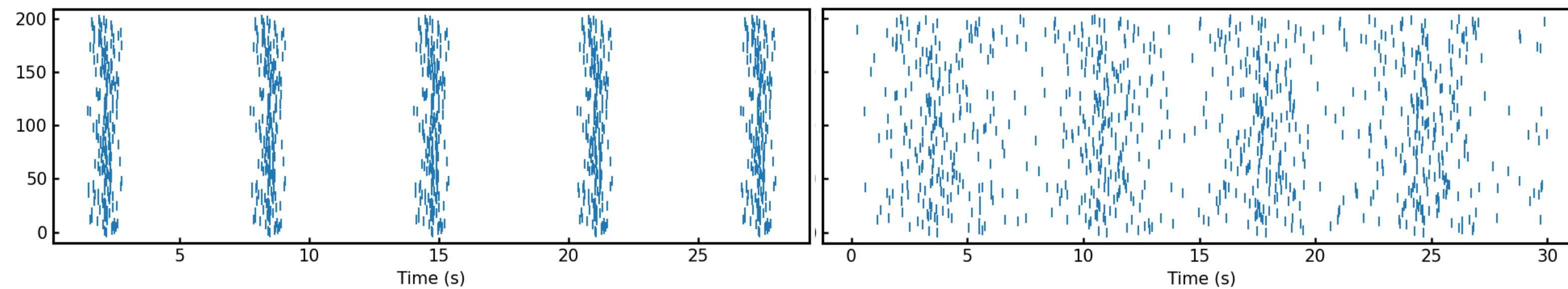


Critical

## Experiment

Information Theory

Simulation

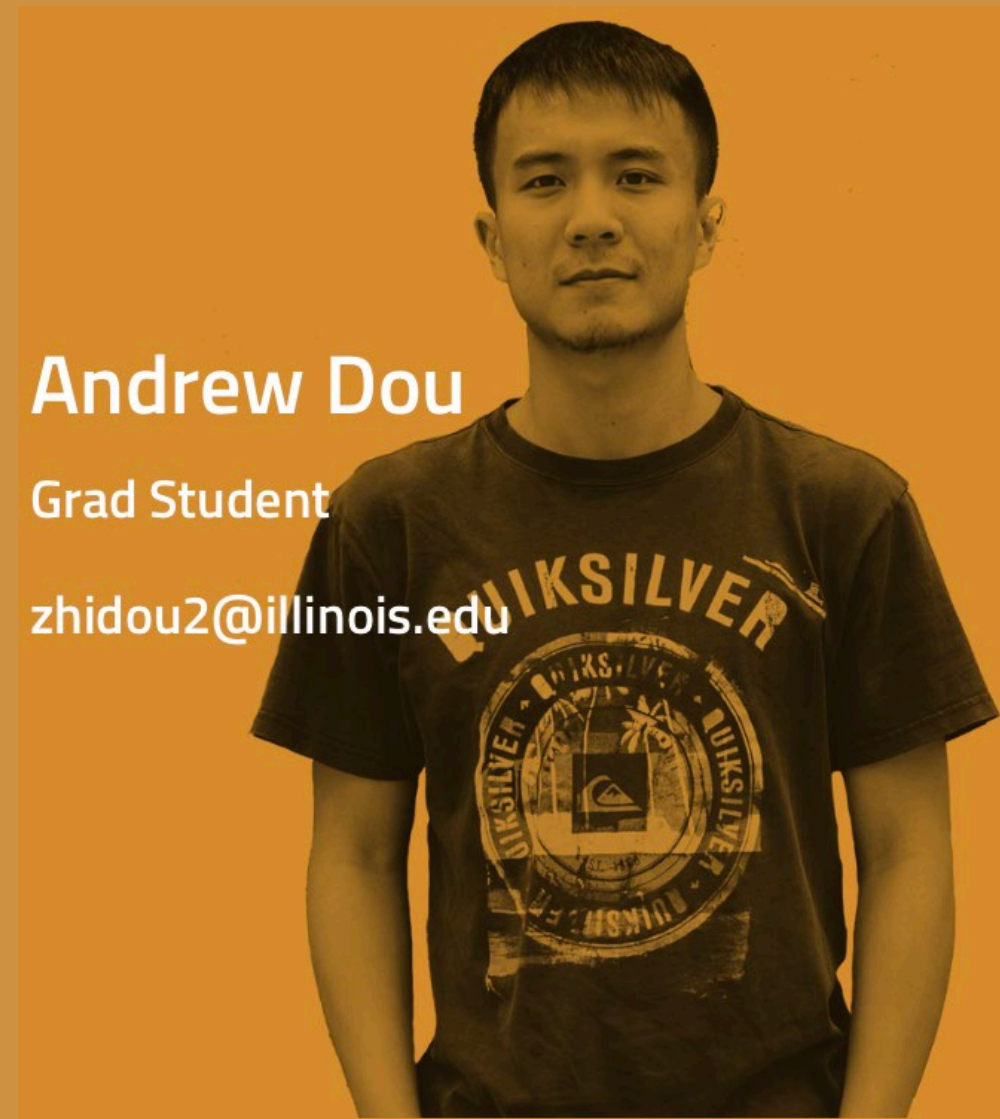




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Postdoc

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**Frithjof  
Gressmann  
UIUC**



**Lawrence  
Rauchwerger  
UIUC**



**Ivan Raikov  
Stanford**



**Ivan Soltesz  
Stanford**

