Integrated Systems & NeuroImaging Lab

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Predicting Behavior from Cortical Activity Recorded through Widefield Transcranial Imaging

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Outline

- **Introduction**
  - Background
  - Motivation
  - Overview
- **Experiment**
  - Setup
  - Data Collection
- **Analysis**
  - Visibility Graph
  - Feature Selection
  - Classification
- **Results and Conclusions**

Background

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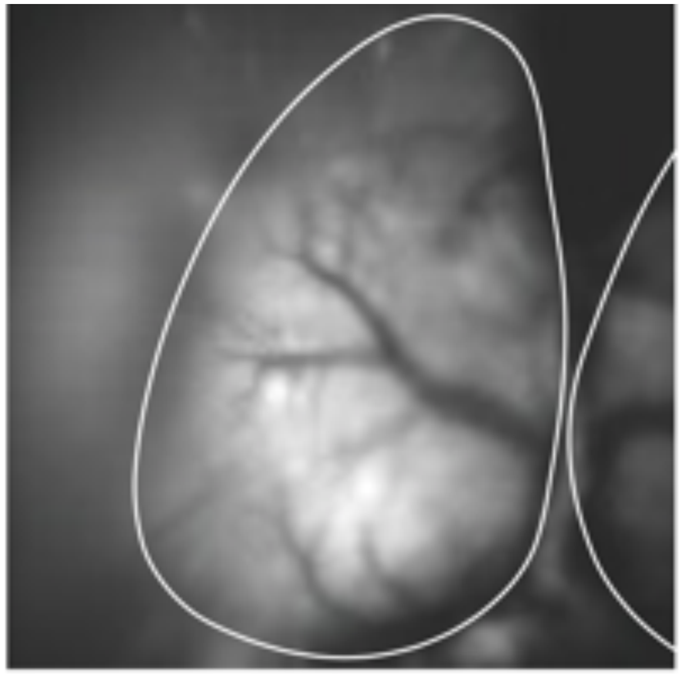
- **Widefield Calcium Imaging**
  - using GCaMP6f mice
  - capable of imaging neural populations over large portions of the cerebral cortex
  - enables longitudinal recording of neural activity
  - offers high temporal resolution
  - a powerful tool for studying the relationship between brain activity and behavior



Minderer, Matthias, et al. "Chronic imaging of cortical sensory map dynamics using a genetically encoded calcium indicator." *The Journal of physiology* 590.1 (2012): 99-107.

Madisen, Linda, et al. "Transgenic mice for intersectional targeting of neural sensors and effectors with high specificity and performance." *Neuron* 85.5 (2015): 942-958.

Motivation

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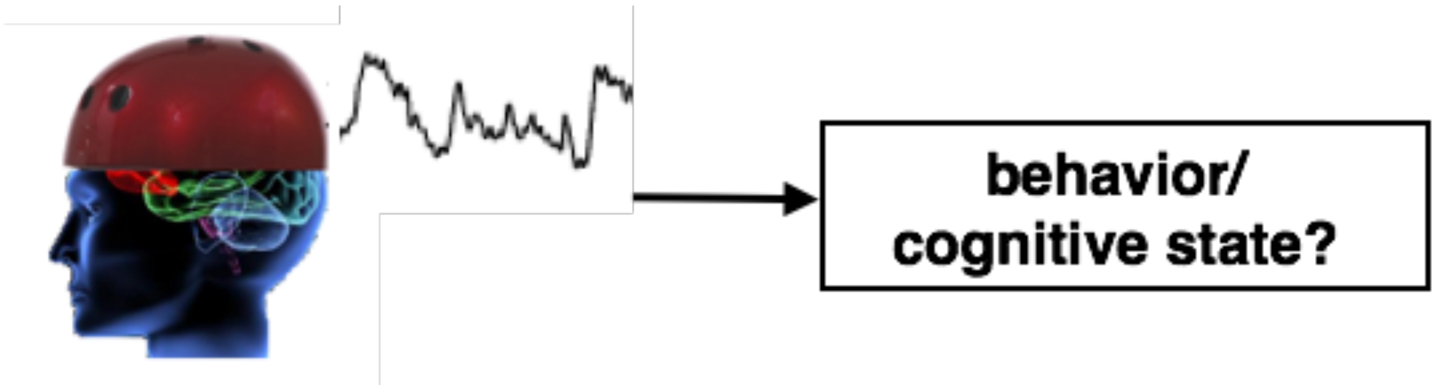
- **Decoding Behavior**
  - *goal:* inferring brain states/behavior from neuroimaging data



  - many applications
    - helps in understanding the brain function and relationship to behavior
    - helps in developing predictive models of brain function
    - helps in identifying biomarkers of brain-related disorders
  - several challenges
    - most existing work have looked at functional specificity
    - spatial information will aid only to decode few “distinct” cognitive processes
    - brain is dynamic and time variant

Motivation

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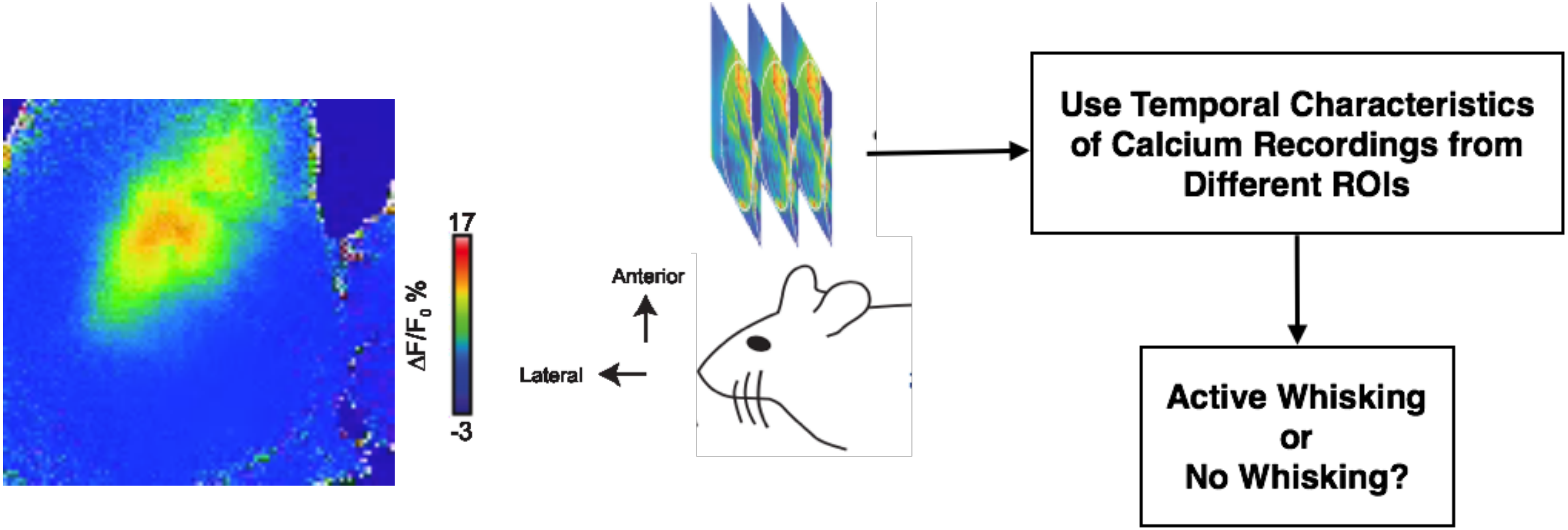
- **Decoding Behavior from Calcium Recordings**
  - can *temporal* characteristics of calcium recordings be used to predict behavior?
  - behavior
    - active whisking (AW)
    - no whisking (NW)



Overview

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Data Collection

Data acquisition (calcium & whisker)

Calcium signal preprocessing

Whisker movement labeling

Overview

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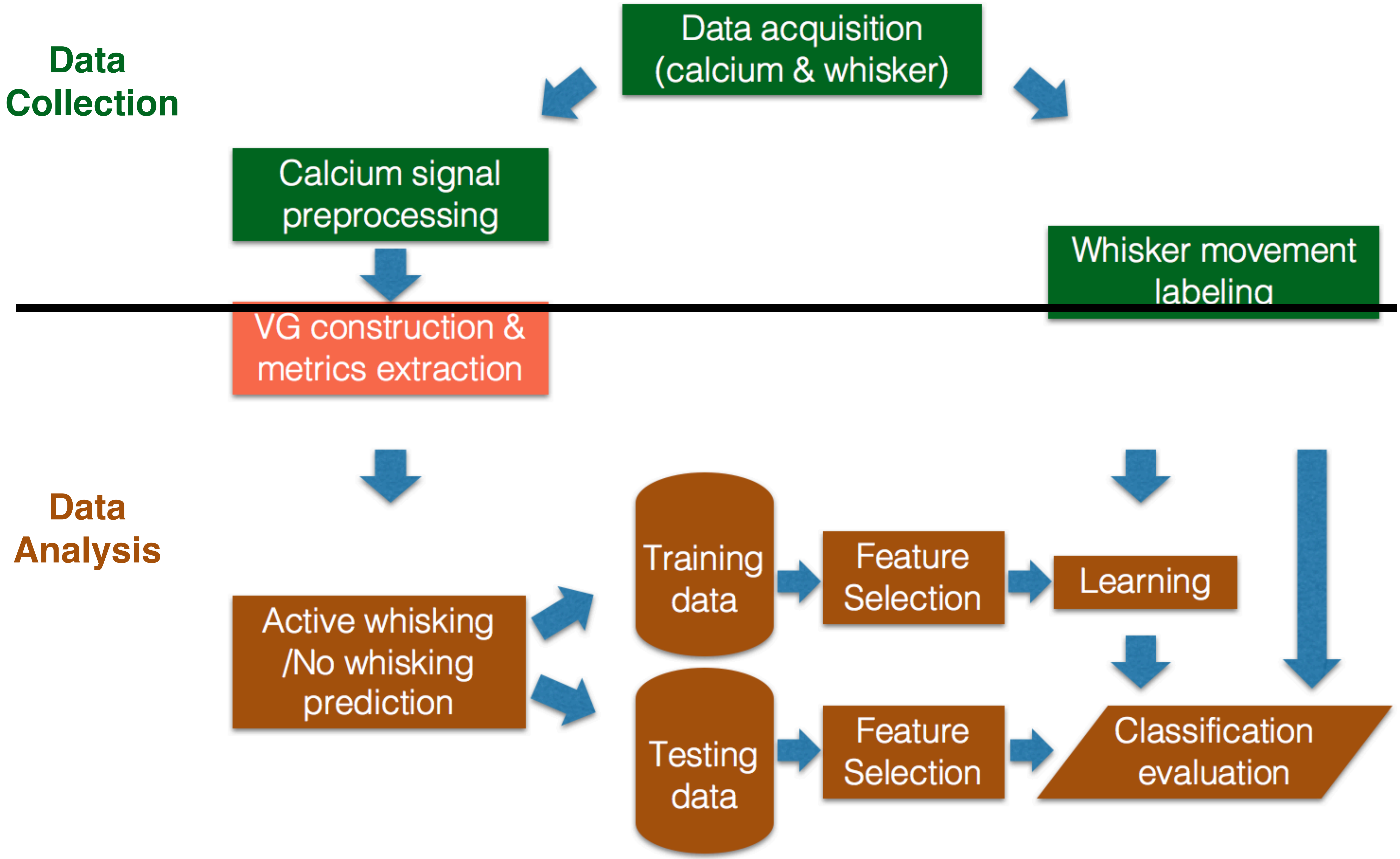

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Experimental Setup

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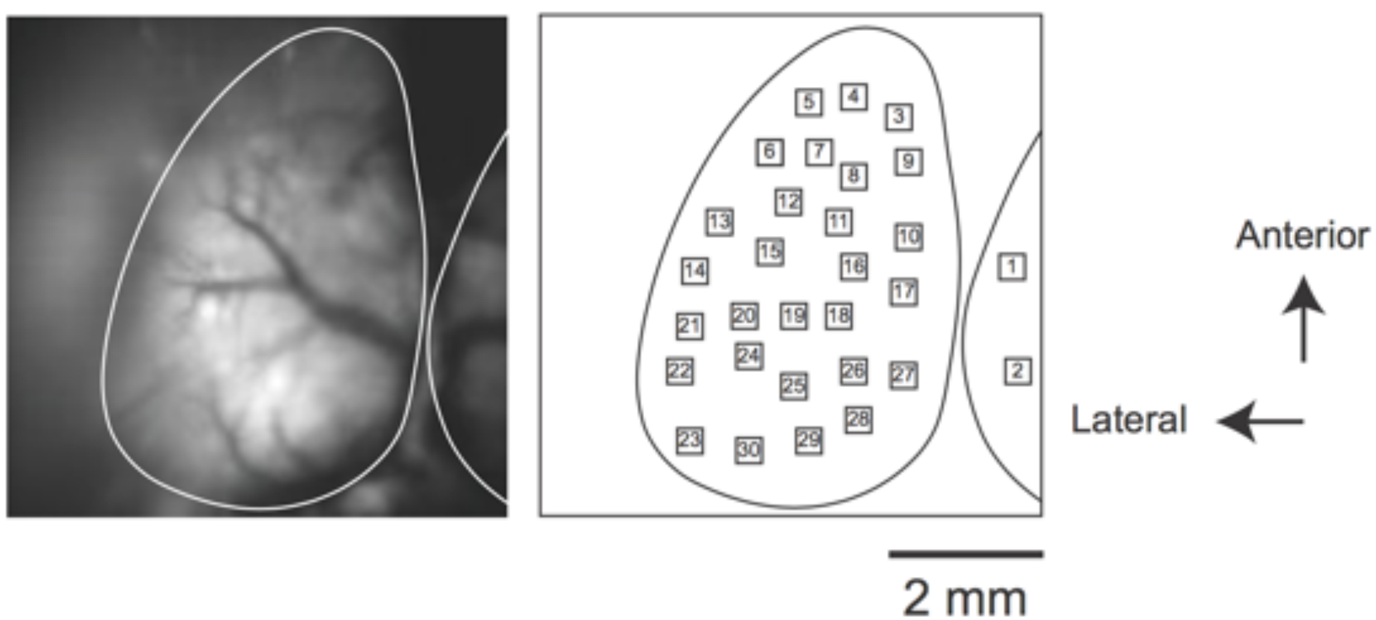
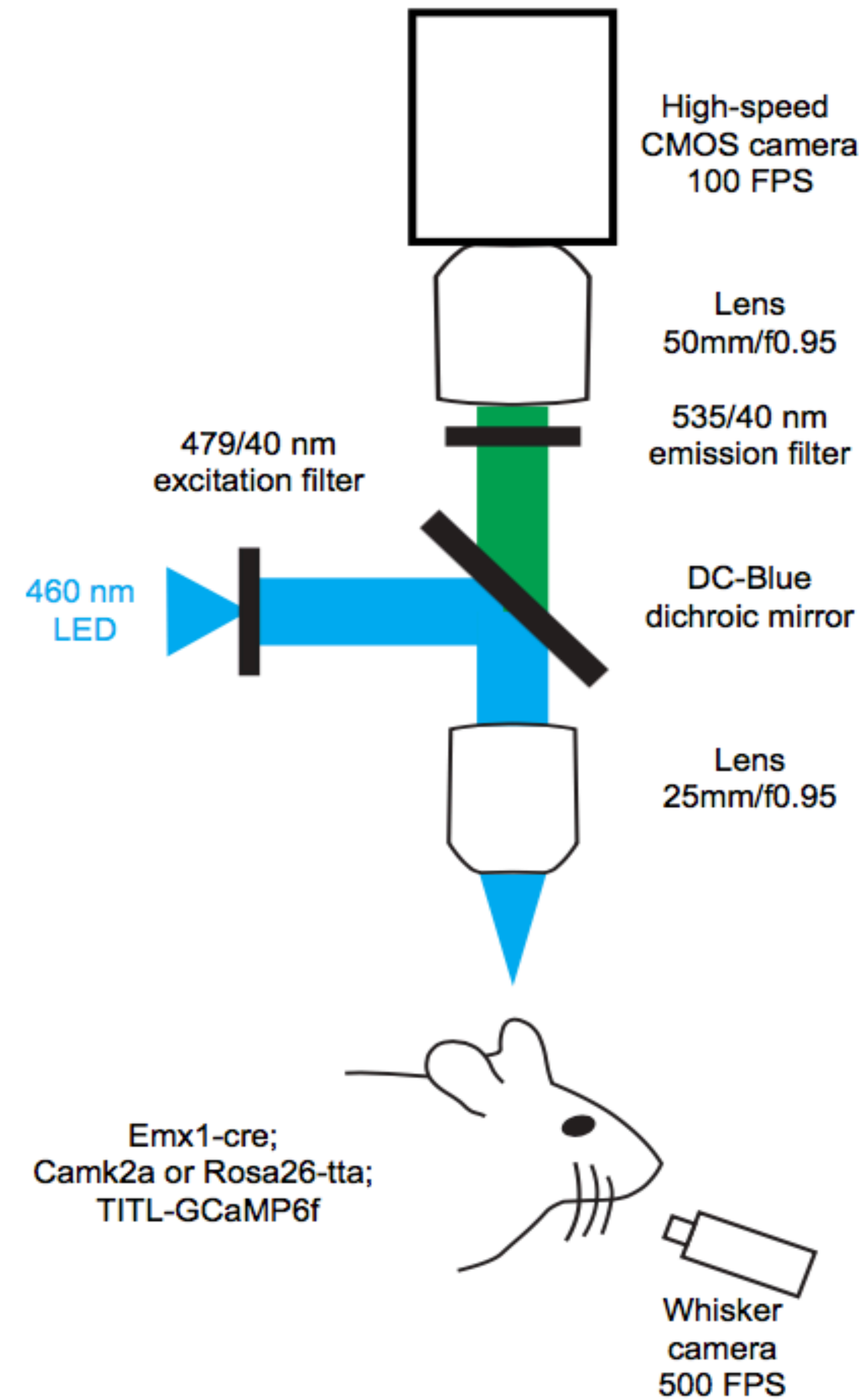
- **Widefield Calcium Imaging**
  - head-fixed GCaMP6f mice
  - entire left and mediate right hemisphere
  - 100 x 100 pixels per frame
  - sampling rate at 100 frames per second
  - 30 ROI locations (5x5 pixels) were selected





- **Whisker Movement Recoding**
  - simultaneously recorded at 500 frames per second

Data Collection

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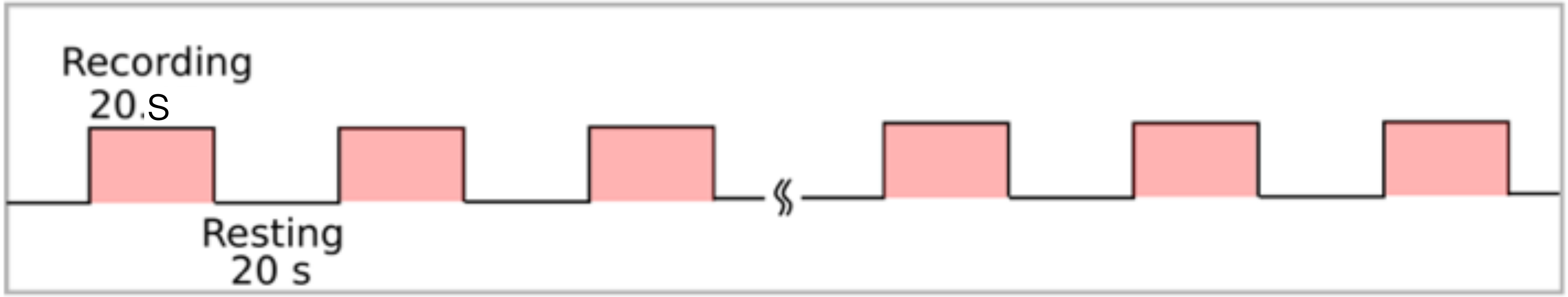
- **Paradigm**
  - 32 blocks with 20 second rest in between
  - 6 mice participated



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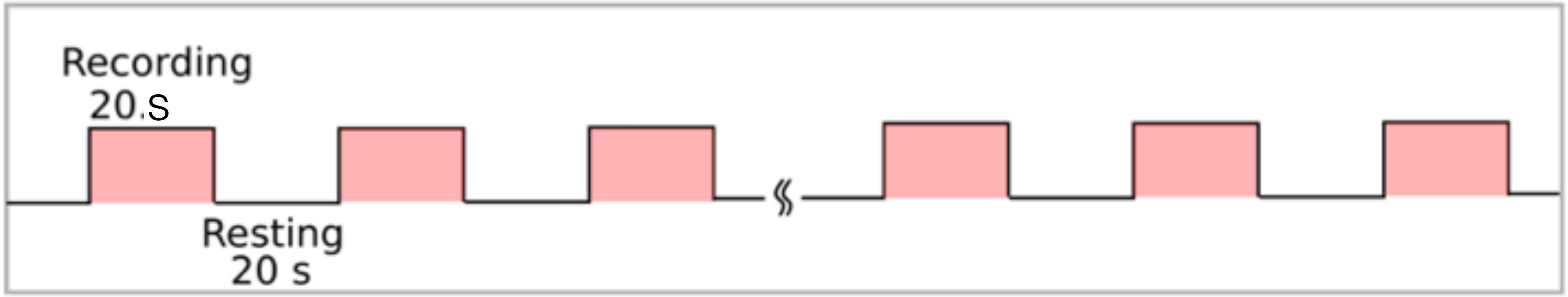
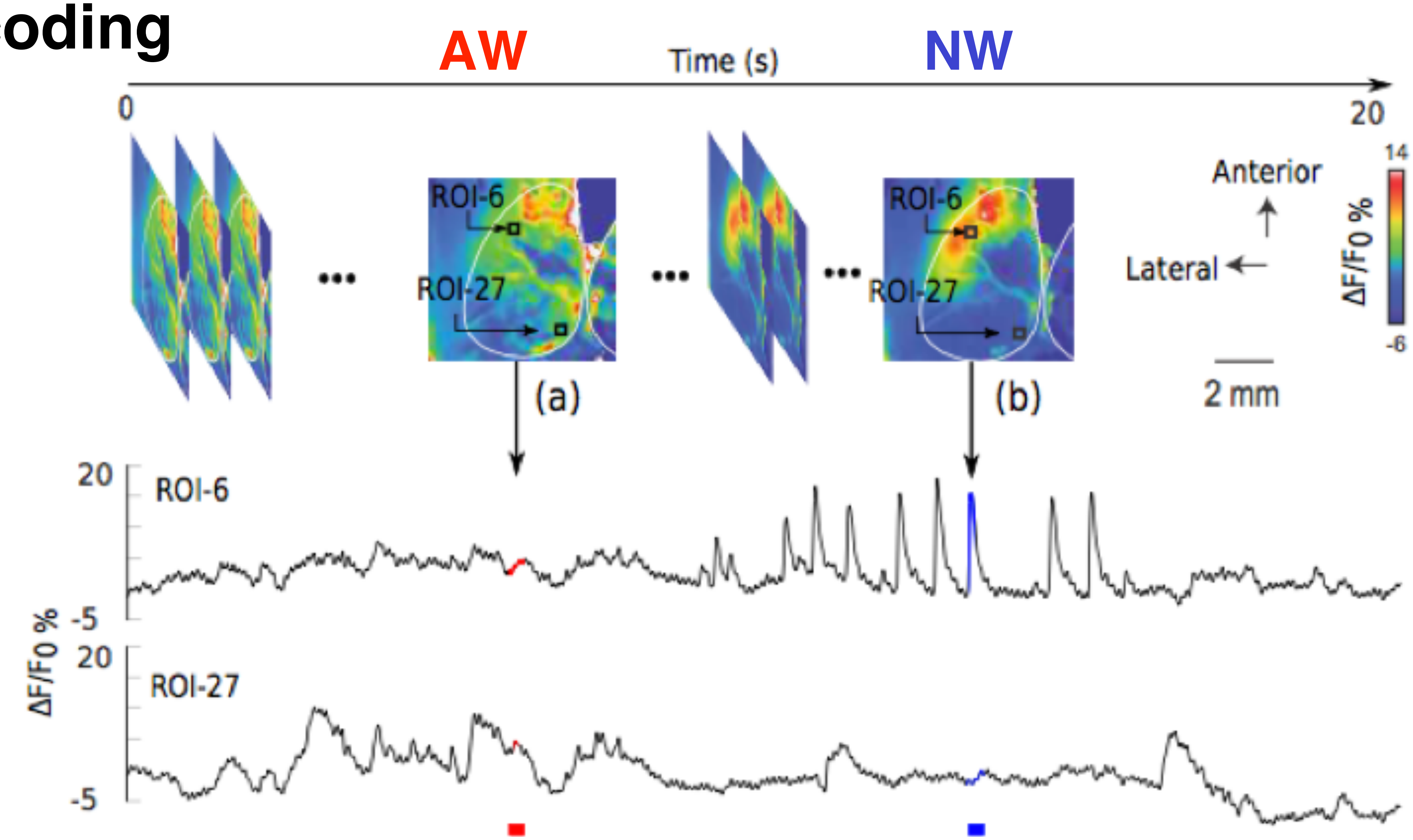


- **Sample Recoding**



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Visibility Graph

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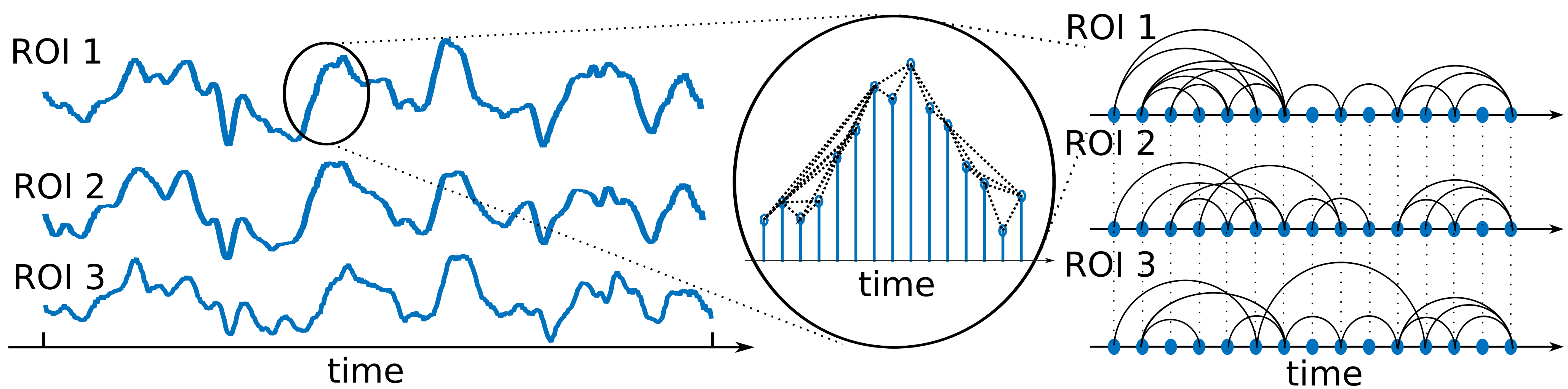
- **Maps a Time Series into a Graph**
  - each point in time serves as a node in the graph
  - nodes h and l are connected if for any point p ($h < p < l$), we have

$$x(p) < x(l) + [x(h) - x(l)][\frac{t_l - t_p}{t_l - t_h}]$$

- **Reveals Dynamic Properties of Time Series**
  - periodic signals result in regular graphs
  - fractal time series result in scale-free networks

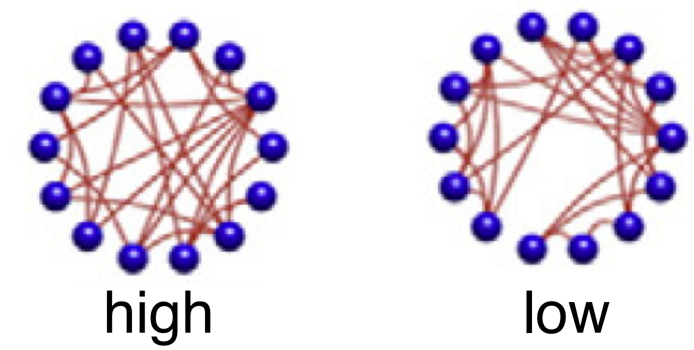


Lacasa, Lucas, et al. "From time series to complex networks: The visibility graph." *Proceedings of the National Academy of Sciences* 105.13 (2008): 4972-4975.

Graph Metrics

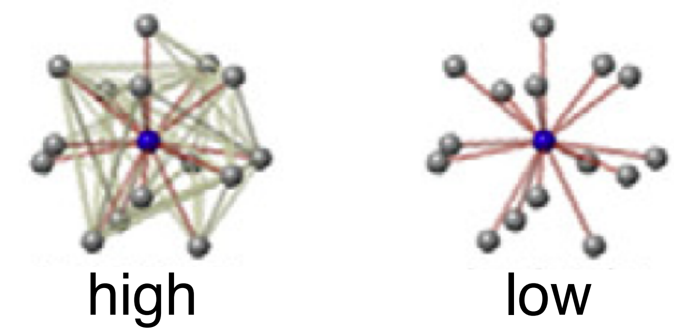
- **Topological Metrics of VG Quantify Characteristics of Time Series**
  - edge density (K):
    - related to number of existing edges in the graph

$$K = \frac{1}{N(N-1)} \sum_{i,j} a_{i,j}$$



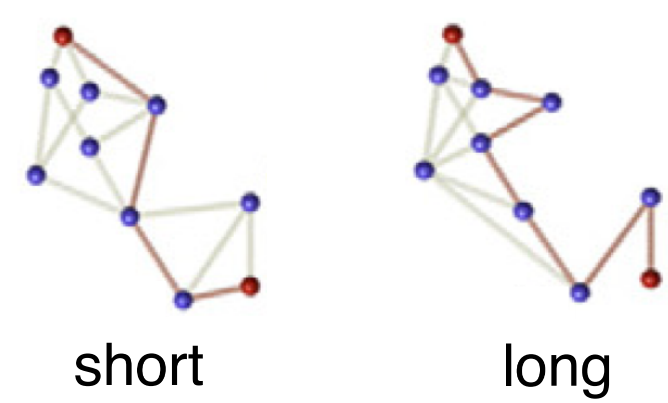
  - averaged clustering coefficient (C):
    - average of local clustering coefficients

$$C = \frac{1}{N} \sum_{i=1}^{N} C_i = \frac{1}{N} \sum_{i,j,l} \frac{a_{ij} a_{il} a_{jl}}{K_i (K_i - 1)}$$



  - characteristic pathlength (L):
    - averaged shortest pathlength between all node pairs

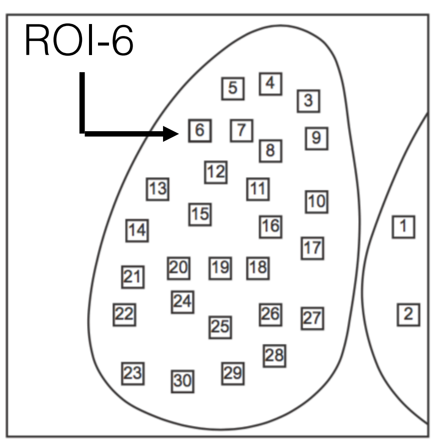
$$L = \frac{1}{N(N-1)} \sum_{i,j} l_{i,j}$$

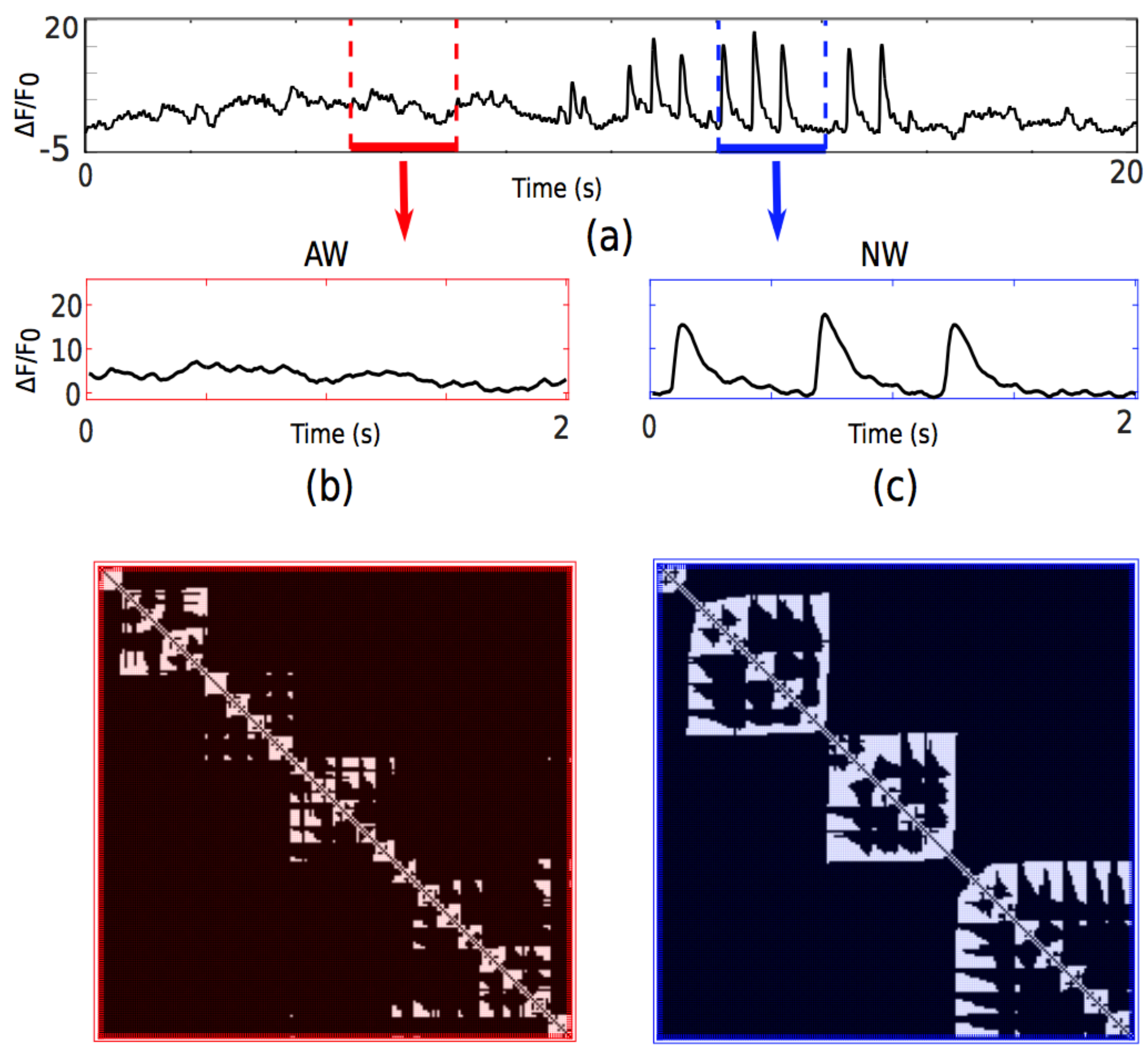


Kim, Dae-Jin, et al. "Longer gestation is associated with more efficient brain networks in preadolescent children." *Neuroimage* 100 (2014): 619-627.

Feature Selection

- **Procedure**
  - calcium recordings were first segmented using sliding windows
    - window length: 2 s
    - window step: 0.5 s
  - VG was constructed for each segment and each ROI
  - graph metrics were extracted from each VG





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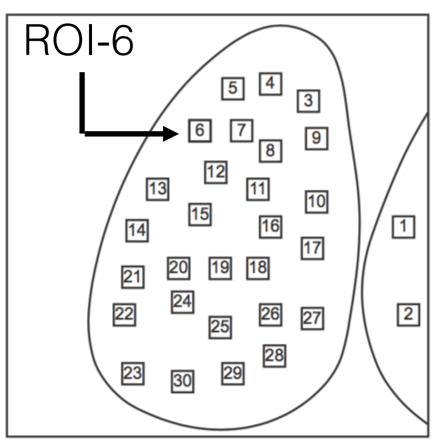

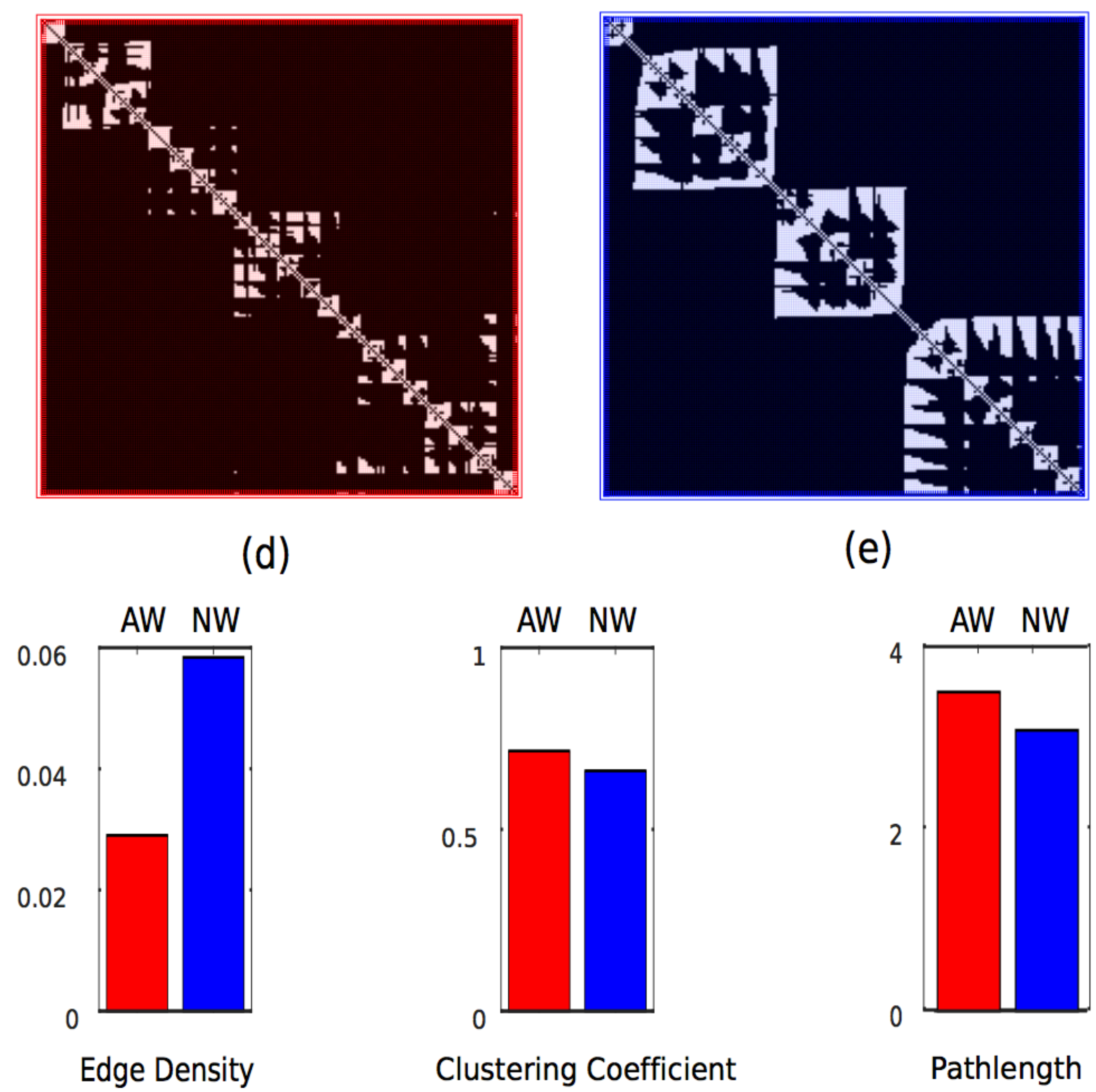

Feature Selection

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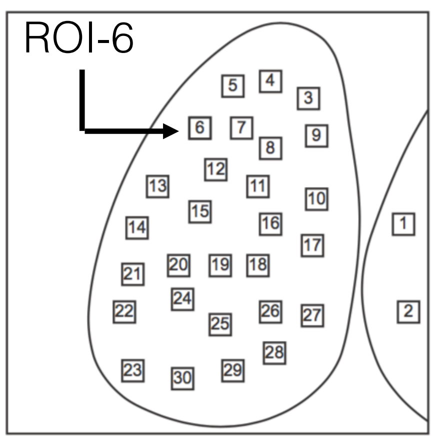
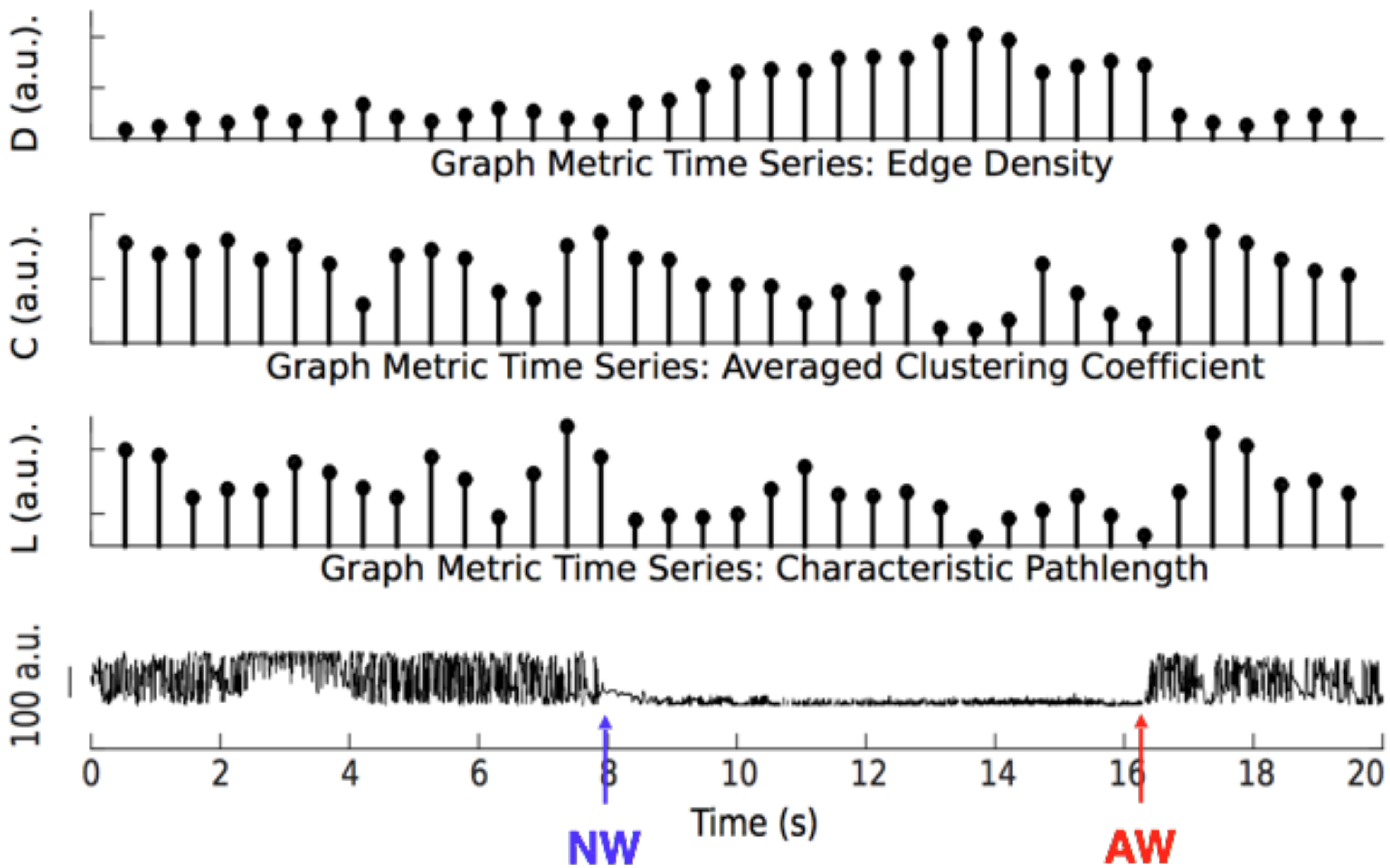
- **Procedure**
  - for each block, and each ROI, three new time series are obtained
  - at each point, for each ROI, seven types of features are extracted
    - *individual metrics:* K or C or L
    - *joint metrics:* K&C or K&L or C&L or K&C&L
  - feature vectors were formed by stacking selected graph metrics across ROIs





Classification

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- **Classifier**
  - logistic regression with l_2 regularization

- **Classification Experiments**
  - 10-fold cross validation: data were randomly partitioned into ten subsamples
  - nine subsamples were used to estimate the model parameters
  - remaining subsample was used to evaluate the performance
  - this procedure was repeated ten times

- **Evaluation Measures**
  - Accuracy
    - measure of correctly identified samples
  - Sensitivity
    - measure of correctly identified AW samples
  - Specificity
    - measure of correctly identified NW samples

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Results

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- **Overall**
  - classification experiments delivered better-than-naive-classifier results
- **Features**
  - edge density delivered the best performance
  - results suggest that edge density carries the strongest discriminatory information among the three metrics

	Subject						Mean	SD
	1	2	3	4	5	6		
Accuracy (%)	89.66	88.75	88.14	84.70	88.39	91.83	**88.59**	2.33
Sensitivity (%)	72.36	89.54	67.53	75.89	68.30	55.58	**71.53**	11.18
Specificity (%)	94.02	88.37	93.64	89.43	93.89	97.49	**92.81**	3.36
Feature	K	K&C	K&C&L	K&C	K&C	K&C		

Conclusions

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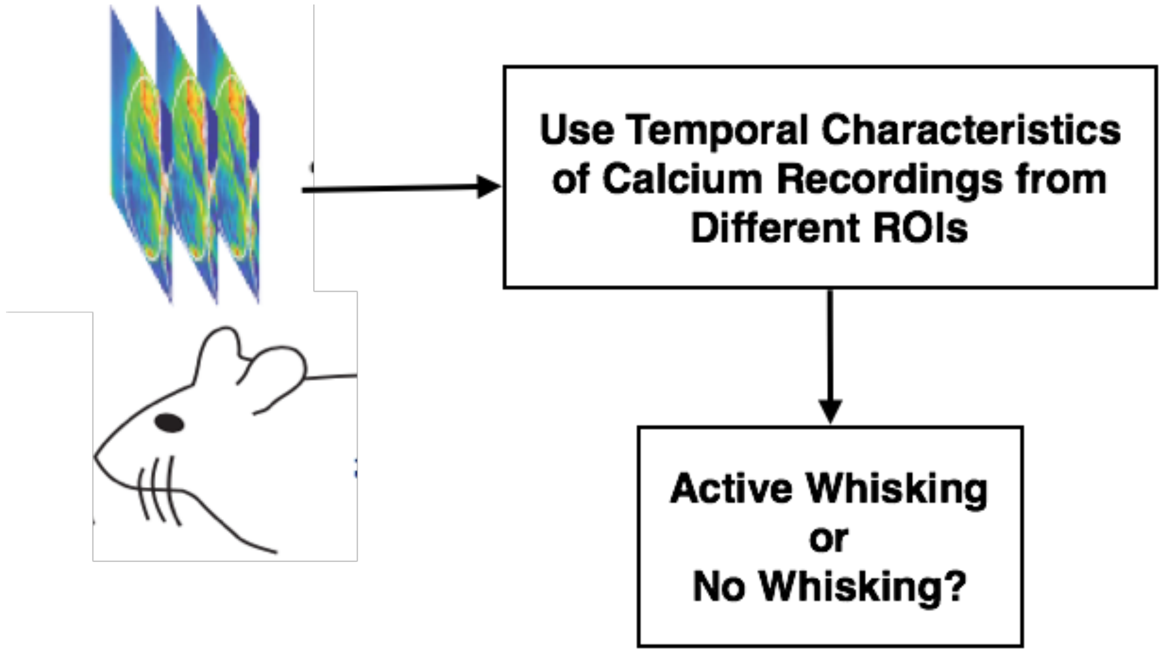
- Widefield Imaging Was Used to Record Cortical Activity in GCaMP6f Mice during Active Whisking and No Whisking
- A VG-based Approach Was Proposed for Predicting the Behavior from Recorded Calcium Signals
- We Demonstrated that Temporal Characteristics of Calcium Recordings can be Utilized to Predict Behavior
- Future Work Include Considering a More Diverse Range of Behavior



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Thank You!