

SIMONS COMPUTATIONAL THEORIES OF THE BRAIN  
APRIL 18, 2018

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**DECODING THE FUNCTIONAL  
NETWORKS OF CEREBRAL CORTEX**

# VISUAL CORTEX DISPLAYS ACTIVITY NOT DIRECTLY TIED TO VISUAL STIMULI

J. Physiol. (1959) 147, 226–238

## SINGLE UNIT ACTIVITY IN STRIATE CORTEX OF UNRESTRAINED CATS

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### *Background activity*

In the unrestrained preparation most units showed activity in the absence of intentional stimulation on the part of the observer. As the cat looked about, spurts and pauses in firing were seen to accompany eye movements. When the eyes were closed either passively by the observer or by the cat, firing usually persisted, although it was generally less active. Even when the room was made completely dark most units continued to fire.

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# GOALS

- ▶ Extend theories of cortical computation from the average case to single trials using network based analytical tools
- ▶ Incorporate a more comprehensive sampling of the network to include unbiased sample of neurons

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# OUTLINE

- ▶ Mouse V1 & high speed two-photon imaging
- ▶ What are functional networks?
- ▶ Functional networks accurately predict neuronal activity
- ▶ Higher order structure in functional networks
- ▶ Assemblies

# OUR EXPERIMENTAL SET-UP

- ▶ Awake behaving (ambulating) animals



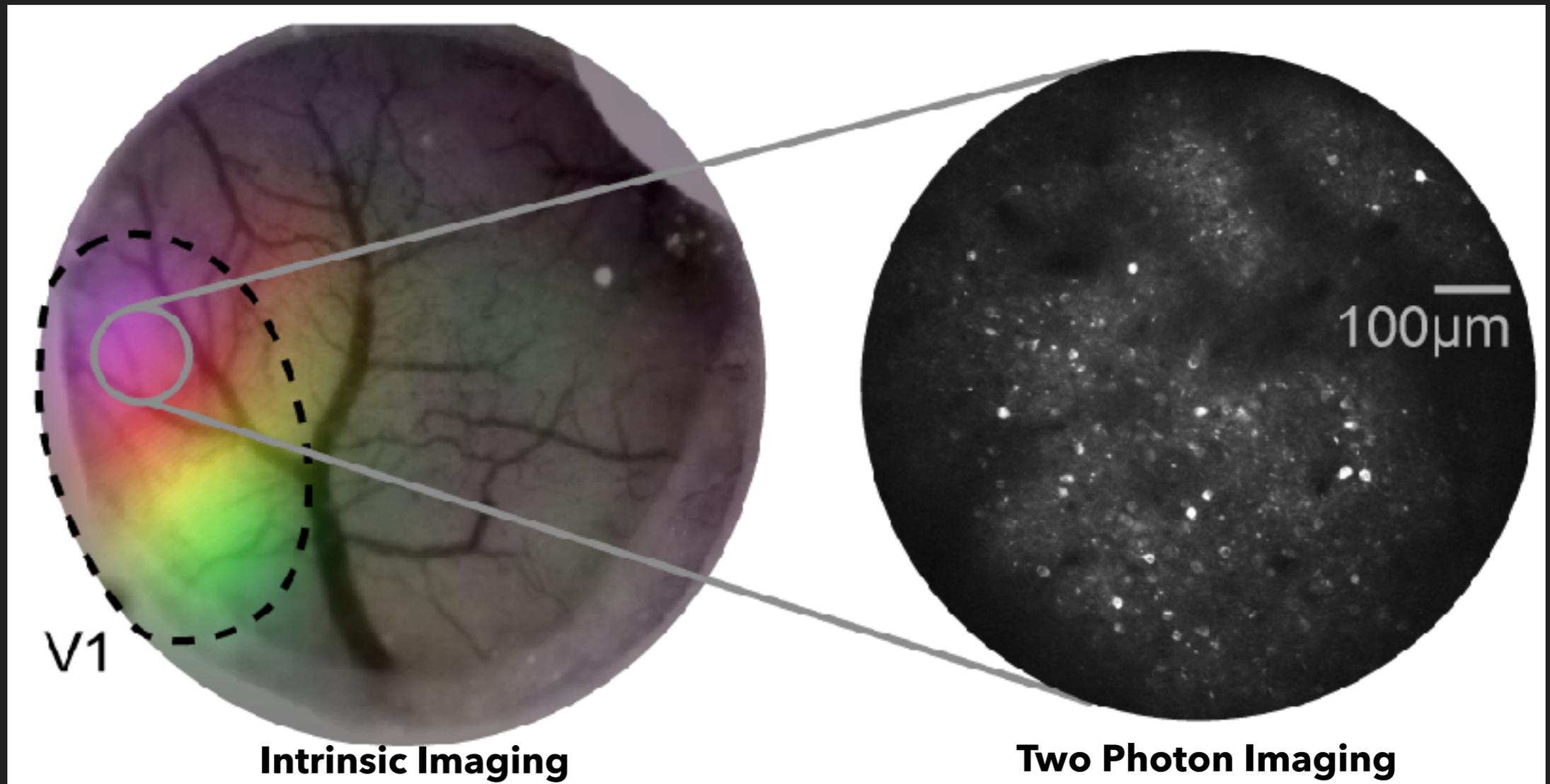
Window over V1



Head bar

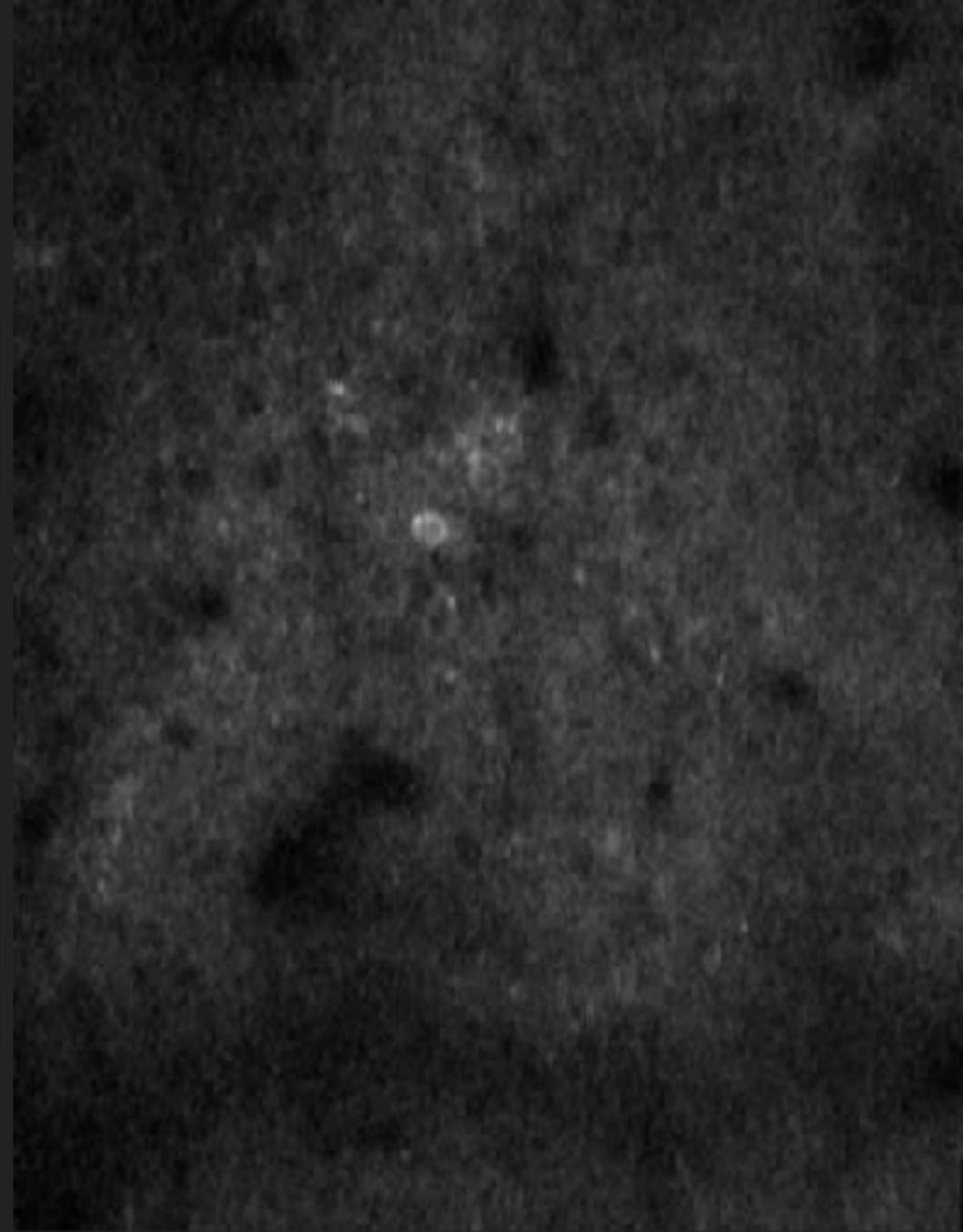
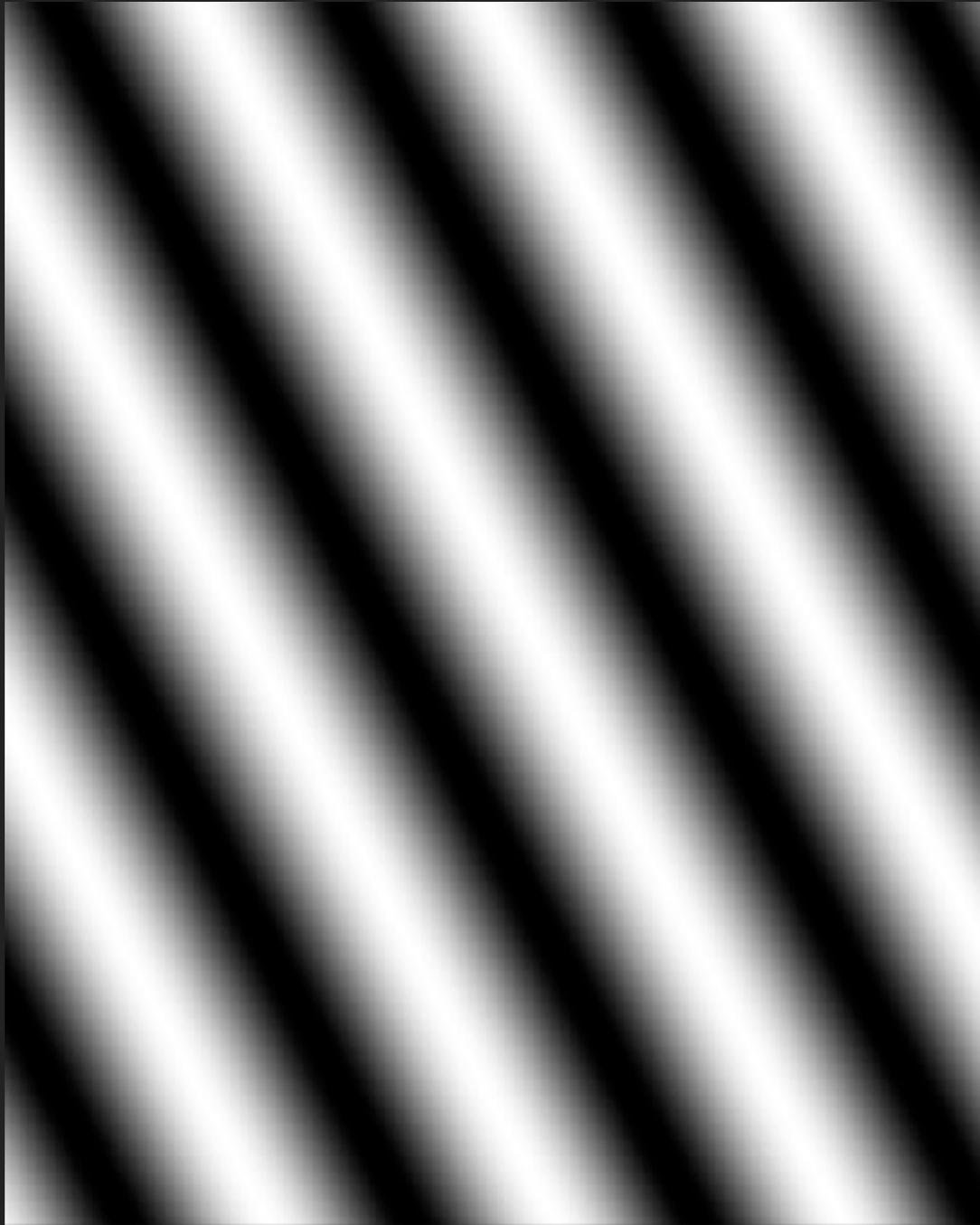
Top down view

# RETINOTOPY TO CONFIRM VISUAL CORTEX

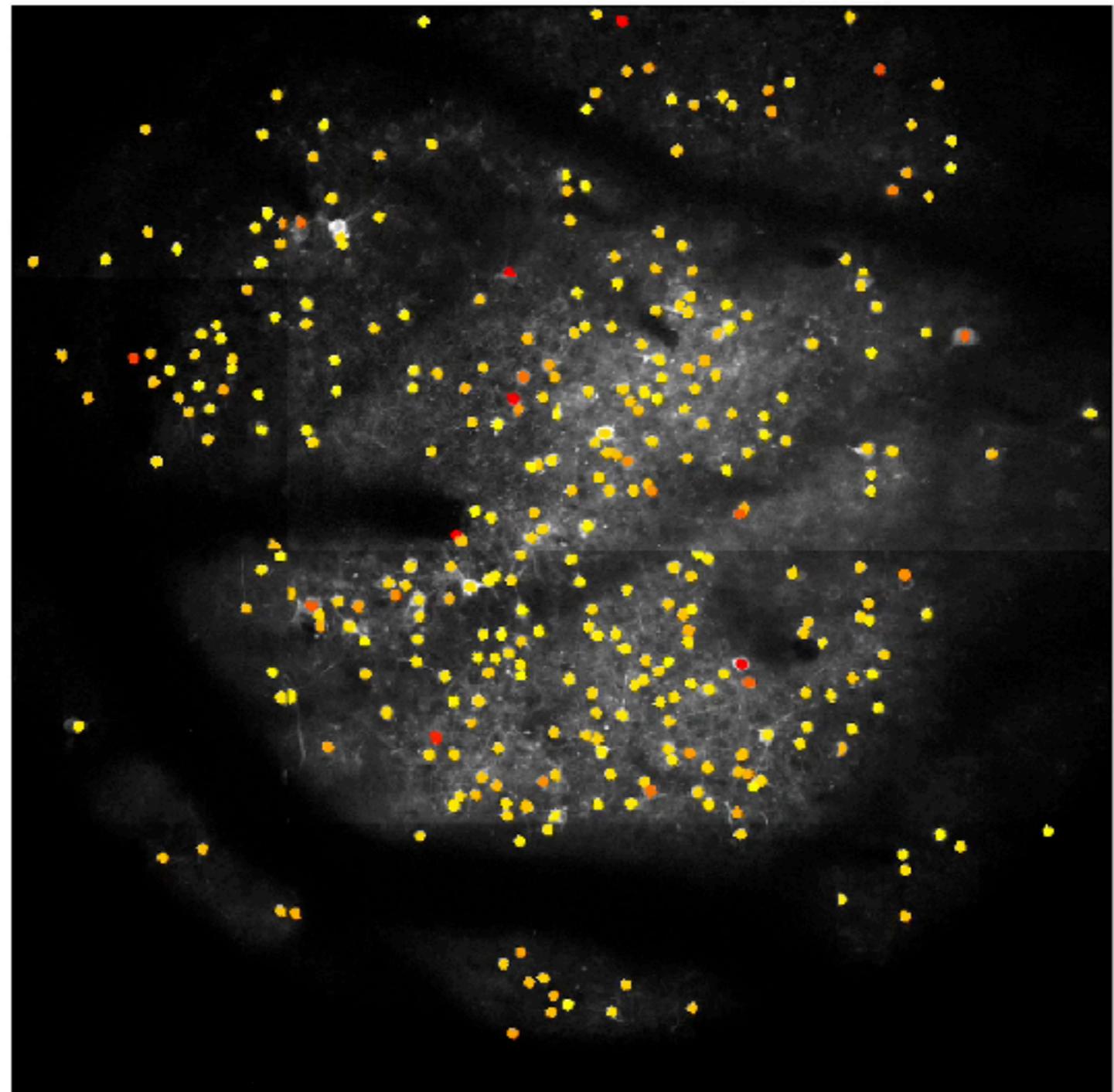
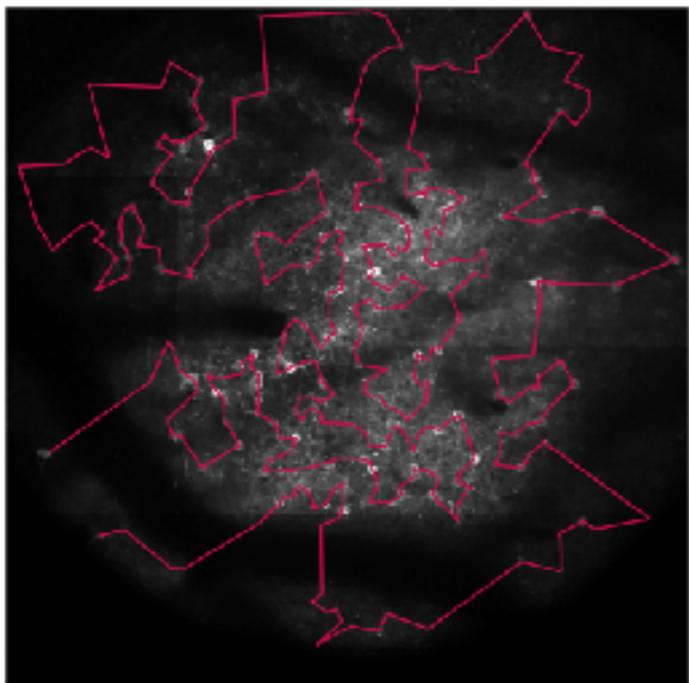
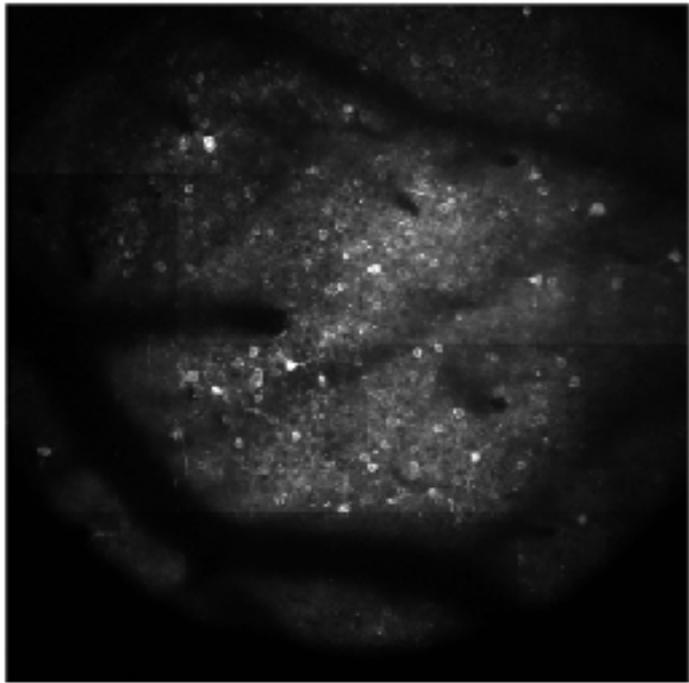


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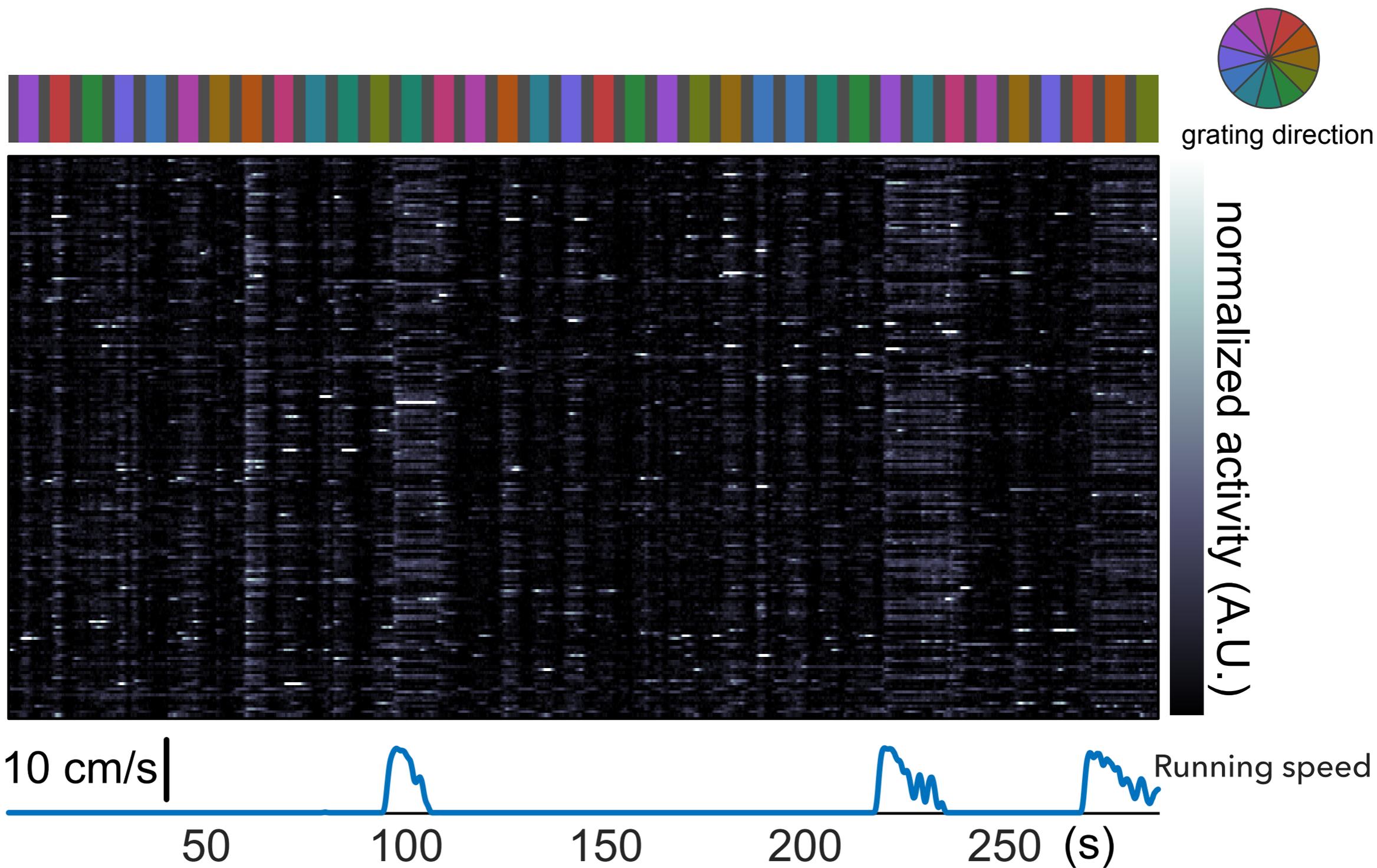
# IN VIVO 2P SOMATIC IMAGING OF VISUALLY EVOKED ACTIVITY



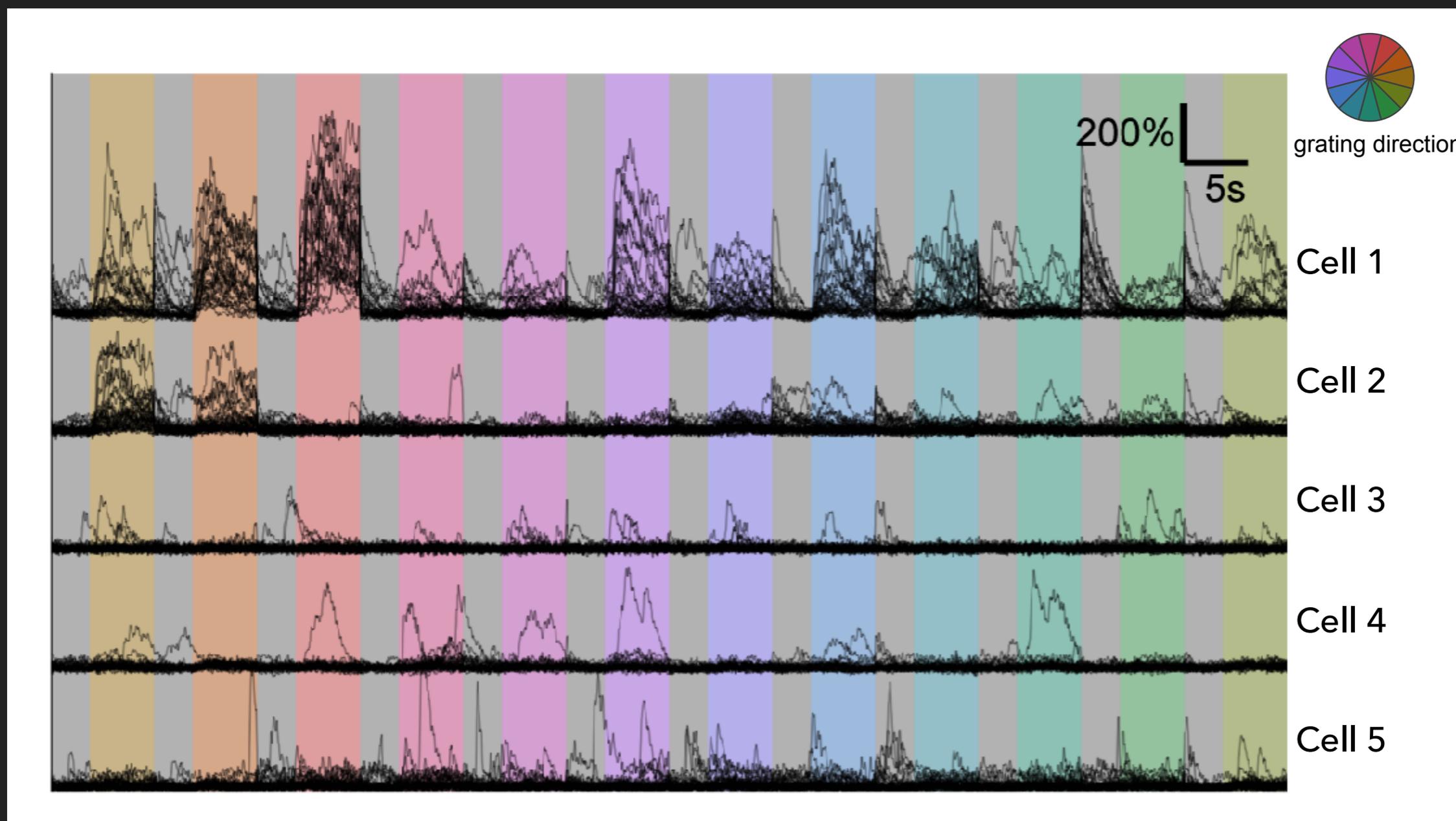
# CORTICAL V1 MICROCIRCUIT DYNAMICS IMAGED WITH HOPS



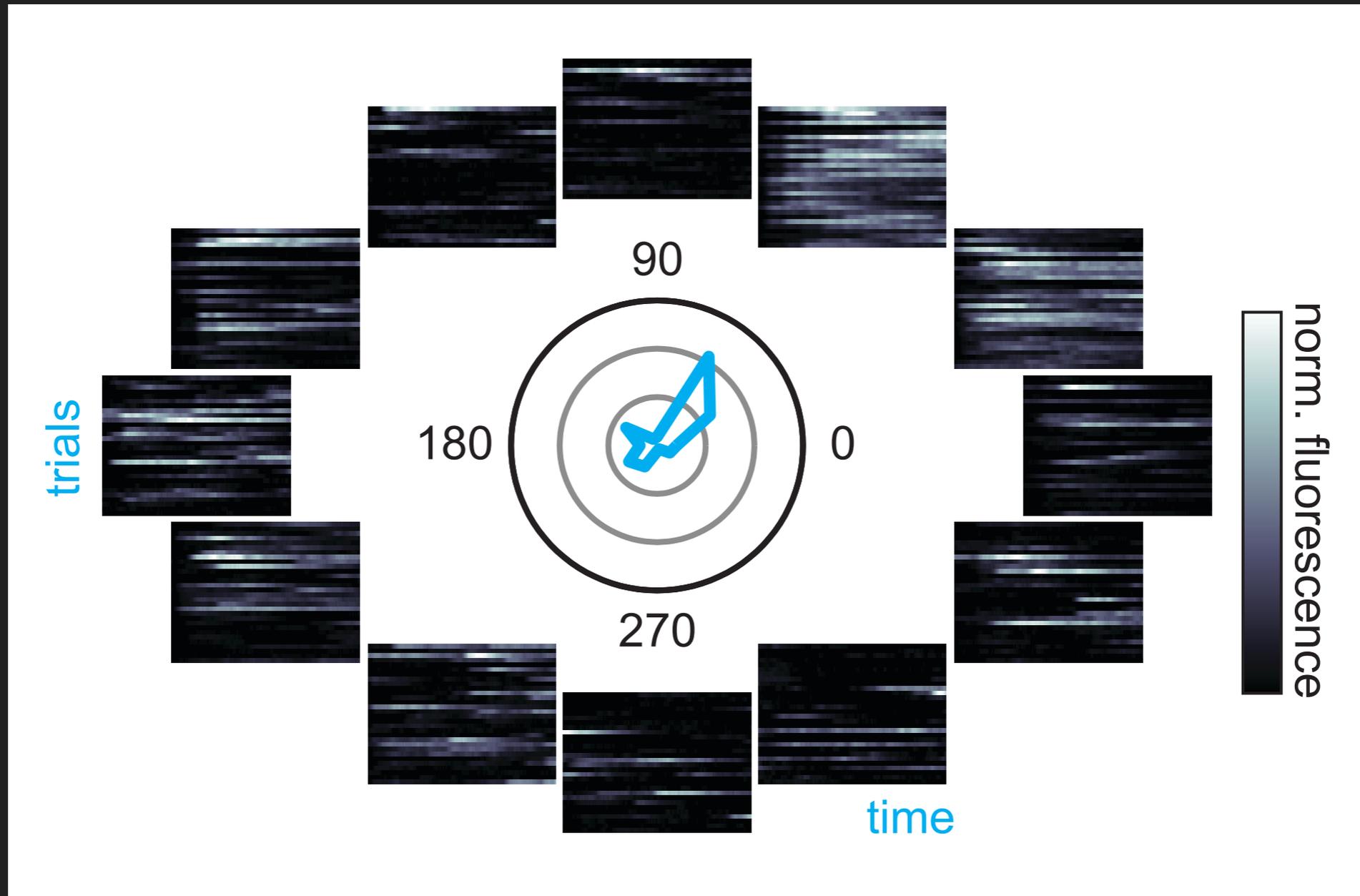
# MULTINEURONAL RESPONSES TO DRIFTING GRATINGS



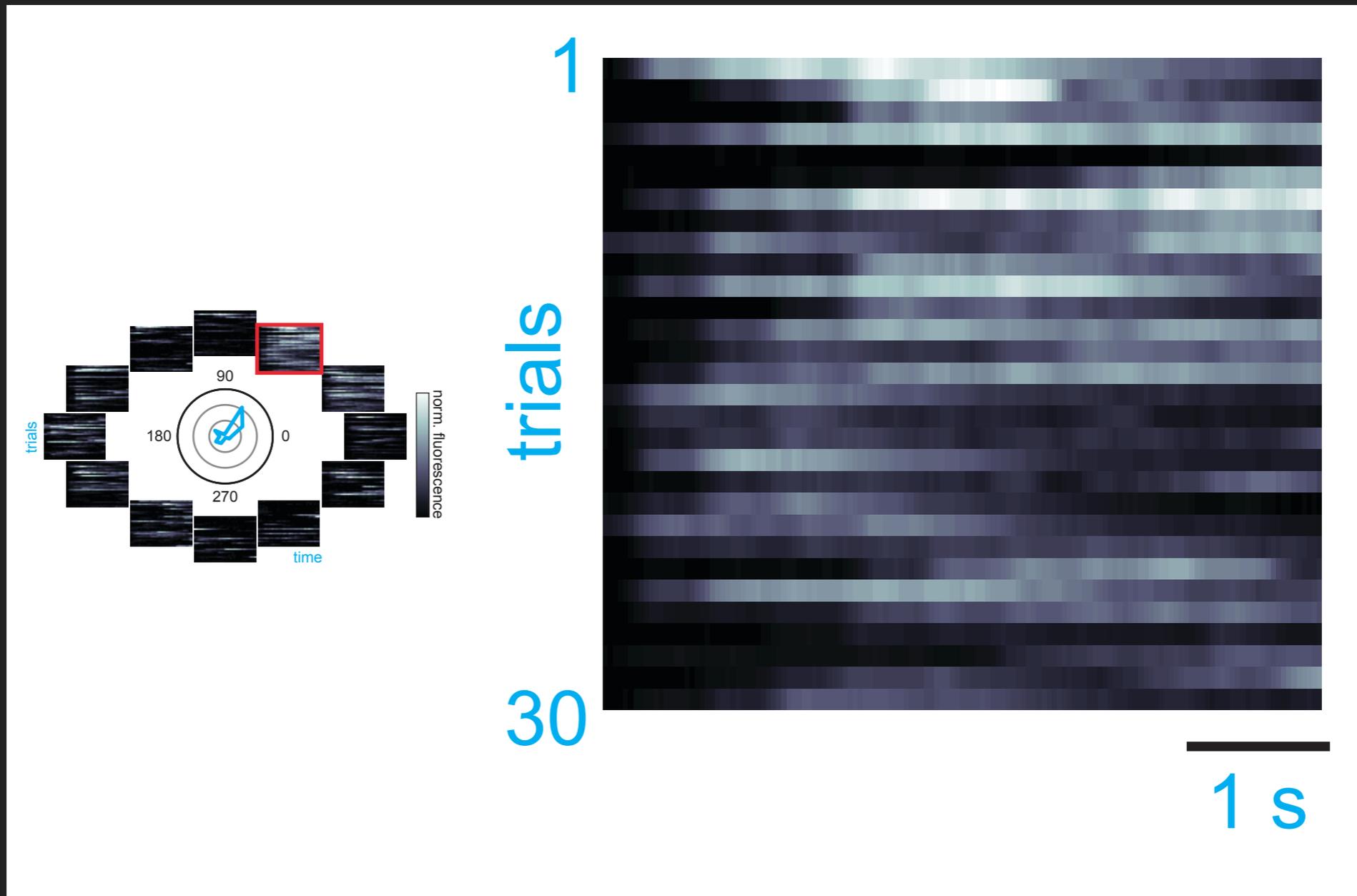
# REPRESENTATIVE TUNED AND UNTUNED RESPONSES



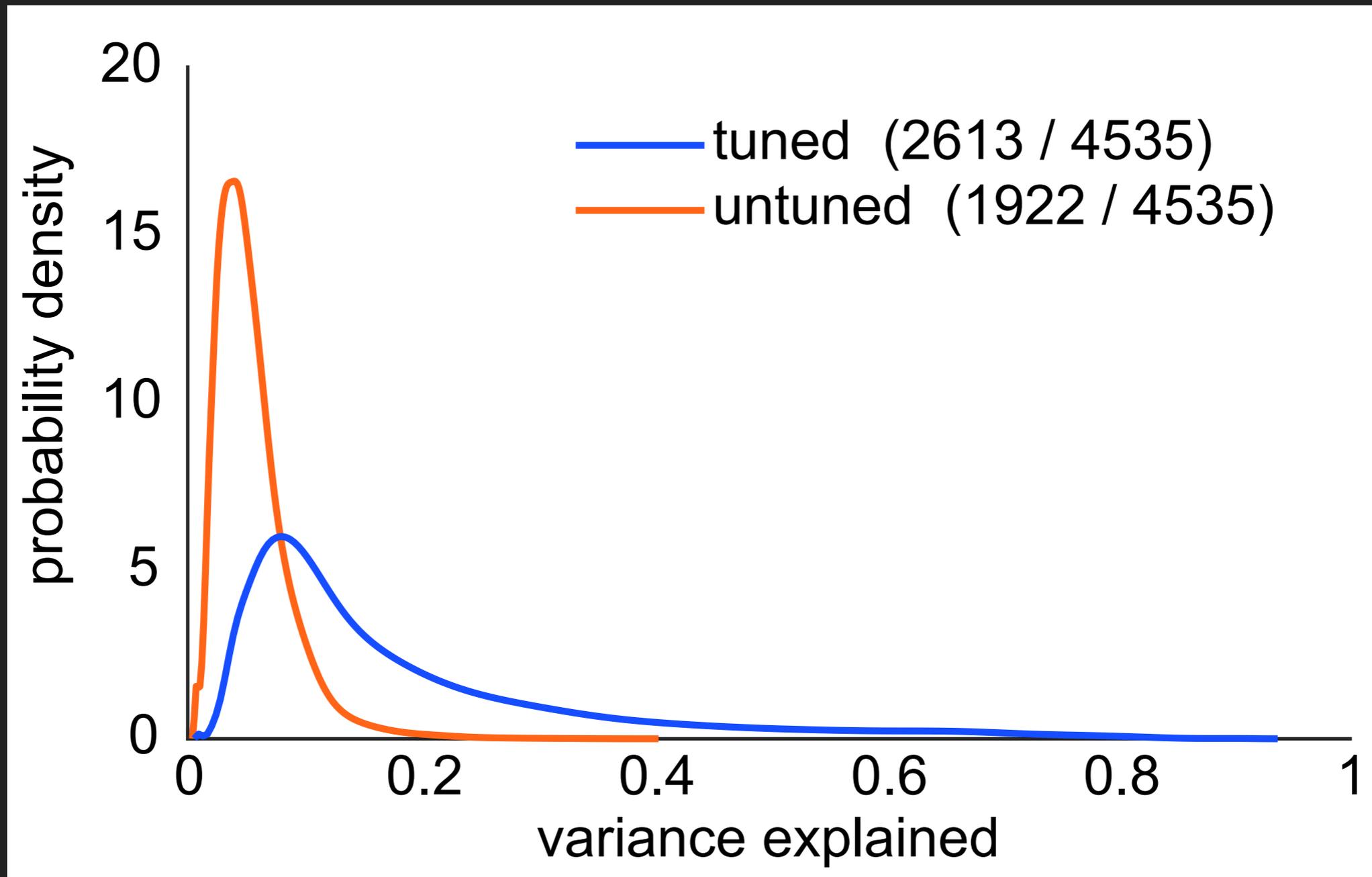
# TUNED NEURONS SHOW VARIABLE SINGLE TRIAL ACTIVITY



# TUNED NEURONS SHOW VARIABLE SINGLE TRIAL ACTIVITY



# TUNING DOESN'T PREDICT SINGLE TRIAL RESPONSES VERY WELL



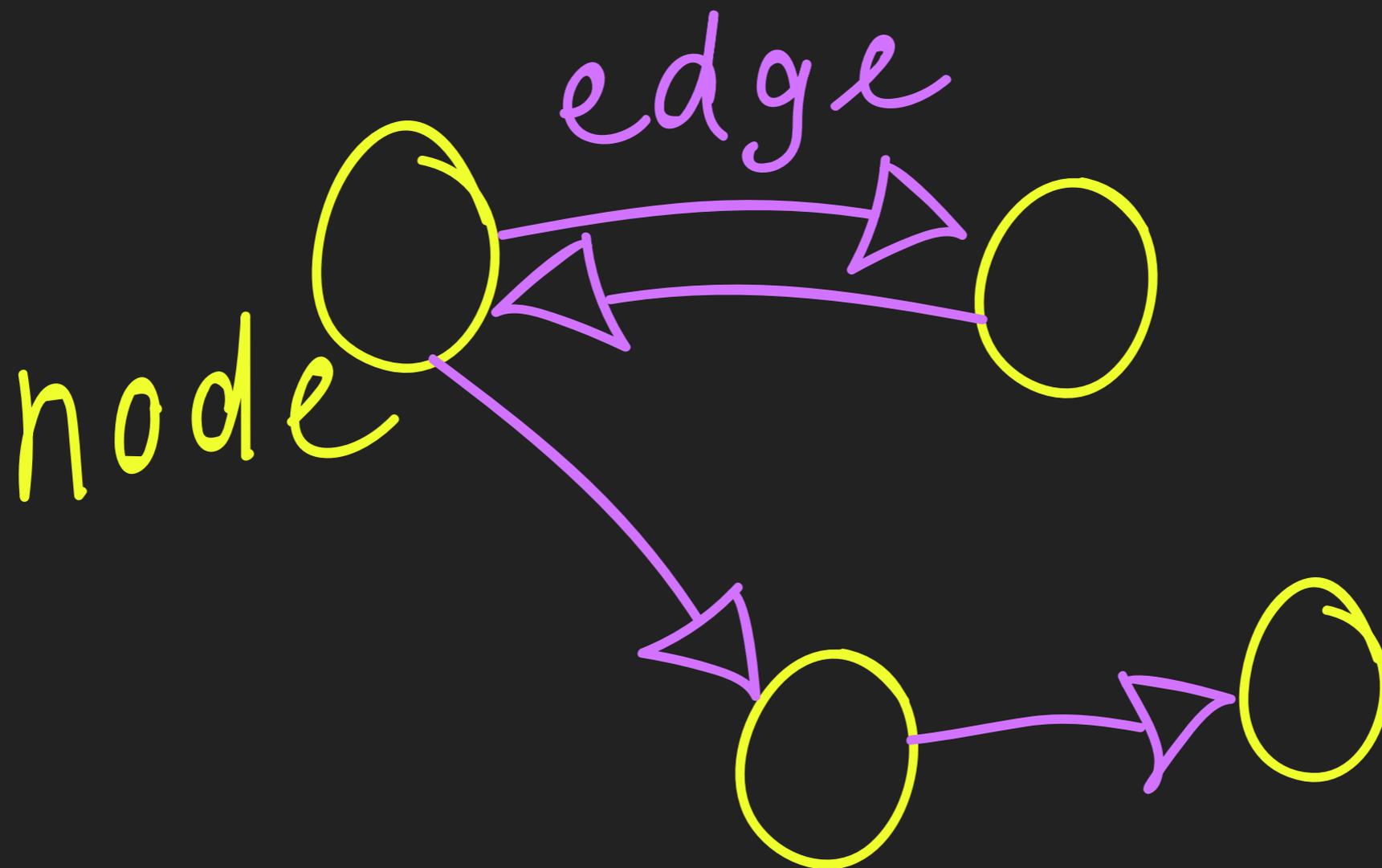
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## OUTLINE

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**Network:** A mathematical representation of a real-world complex system defined by a collection of nodes (vertices) and links (edges) between pairs of nodes.

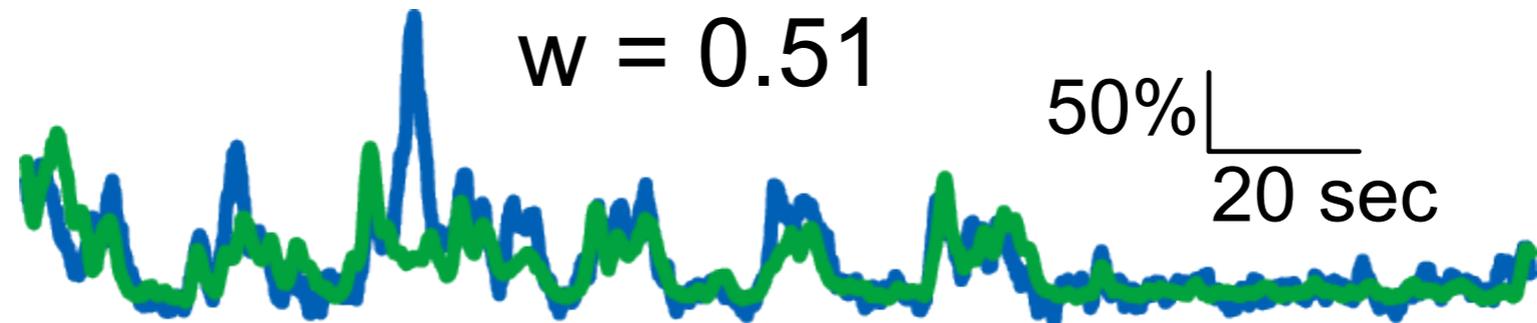


# BUILDING A FUNCTIONAL NETWORK USING PAIRWISE PARTIAL CORRELATION

Edge weight = partial correlation

$$w = 0.51$$

50% |  
20 sec



within movie activity  $i, j$

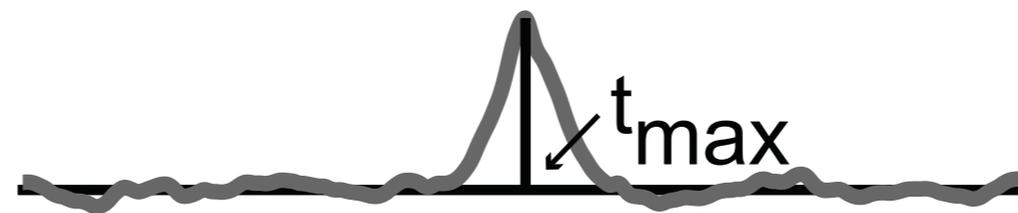


remaining movie average  $i, j$

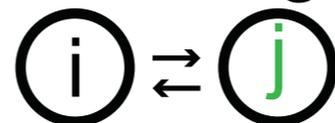


within movie average  $k \neq i, j$

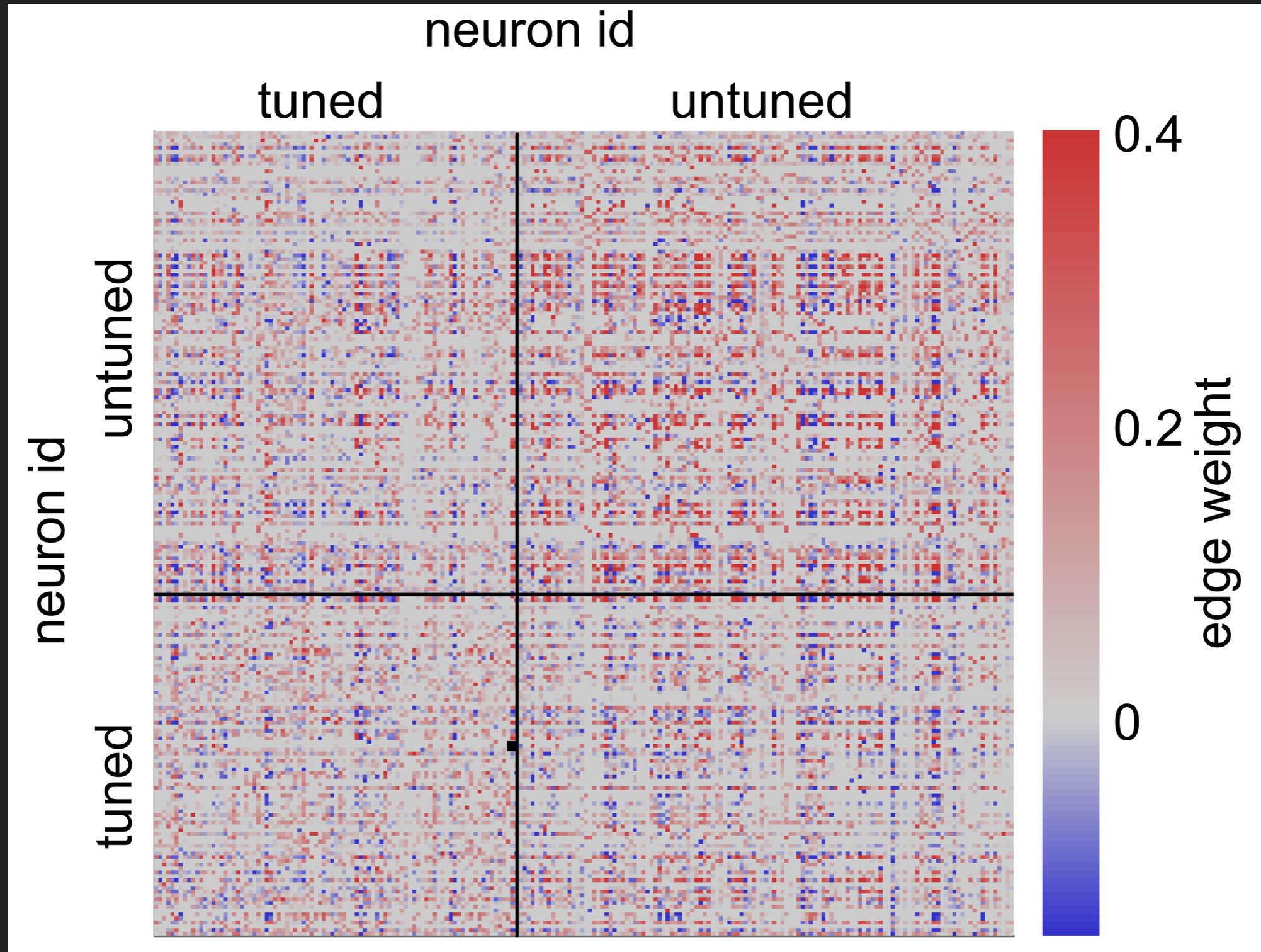
.....  
Directionality = correlogram lag



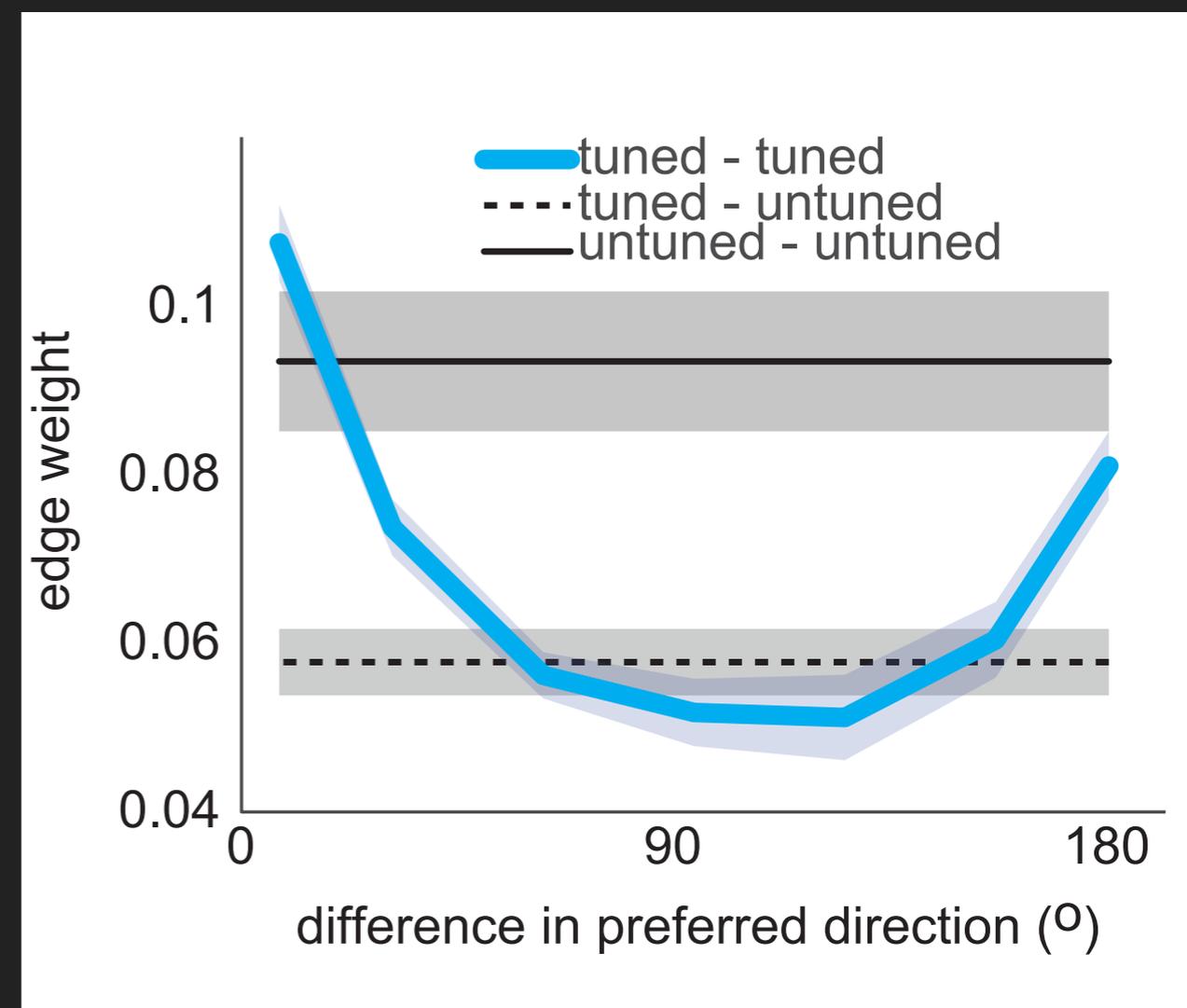
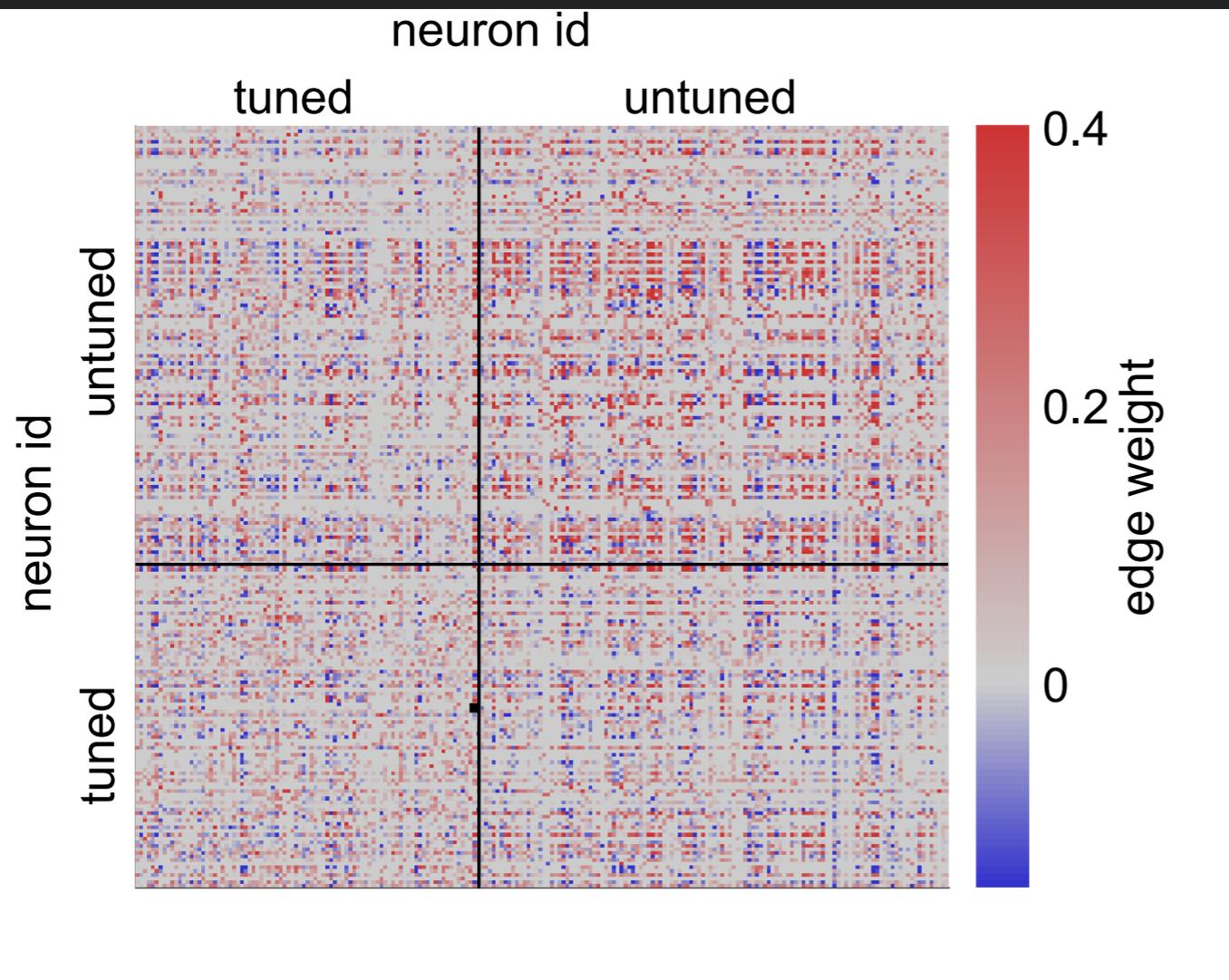
zero lag



# FUNCTIONAL NETWORKS CONTAIN EDGES BETWEEN TUNED AND UNTUNED NEURONS



# FUNCTIONAL NETWORKS REFLECT TUNING IN THE POPULATION

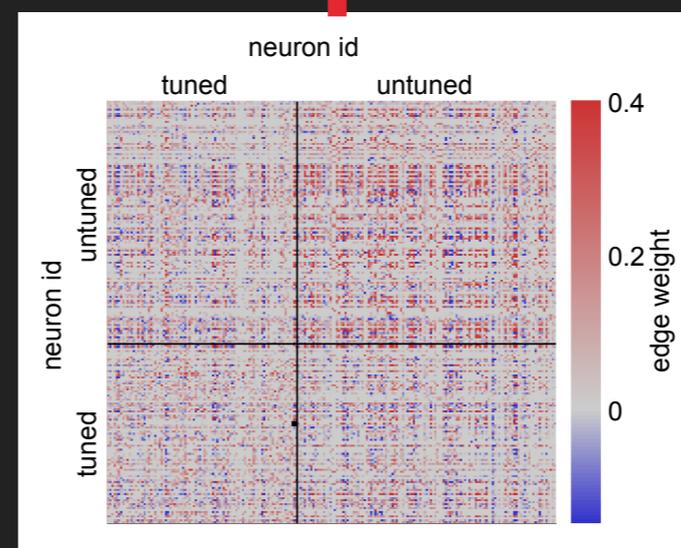
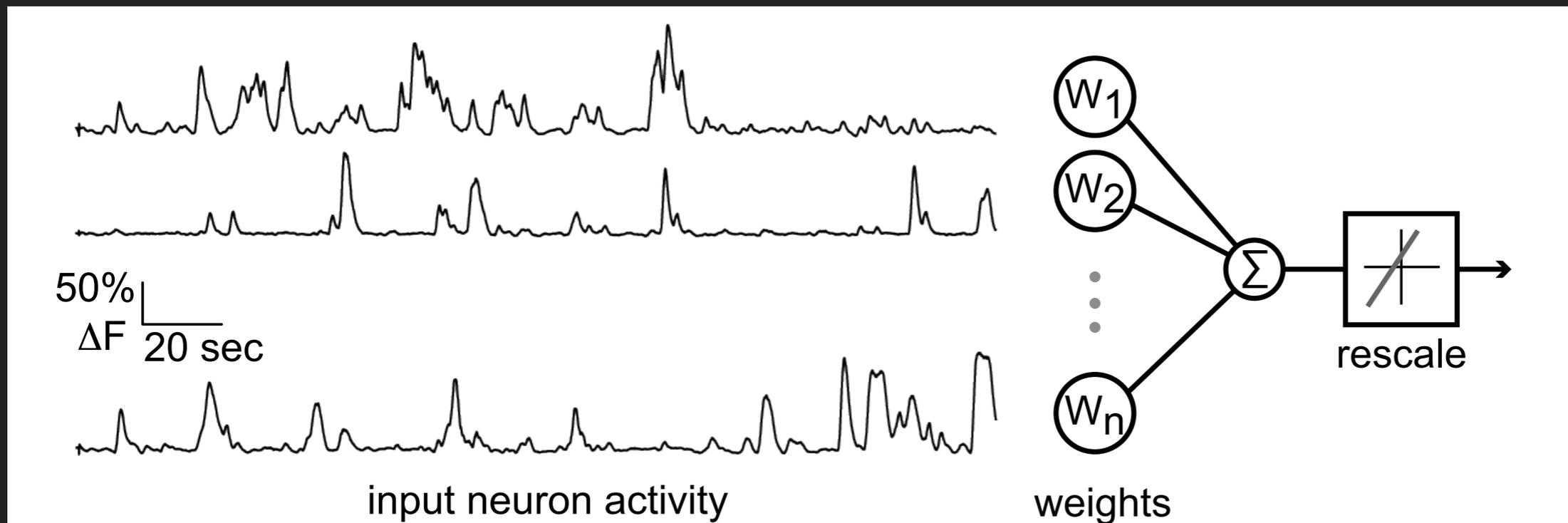


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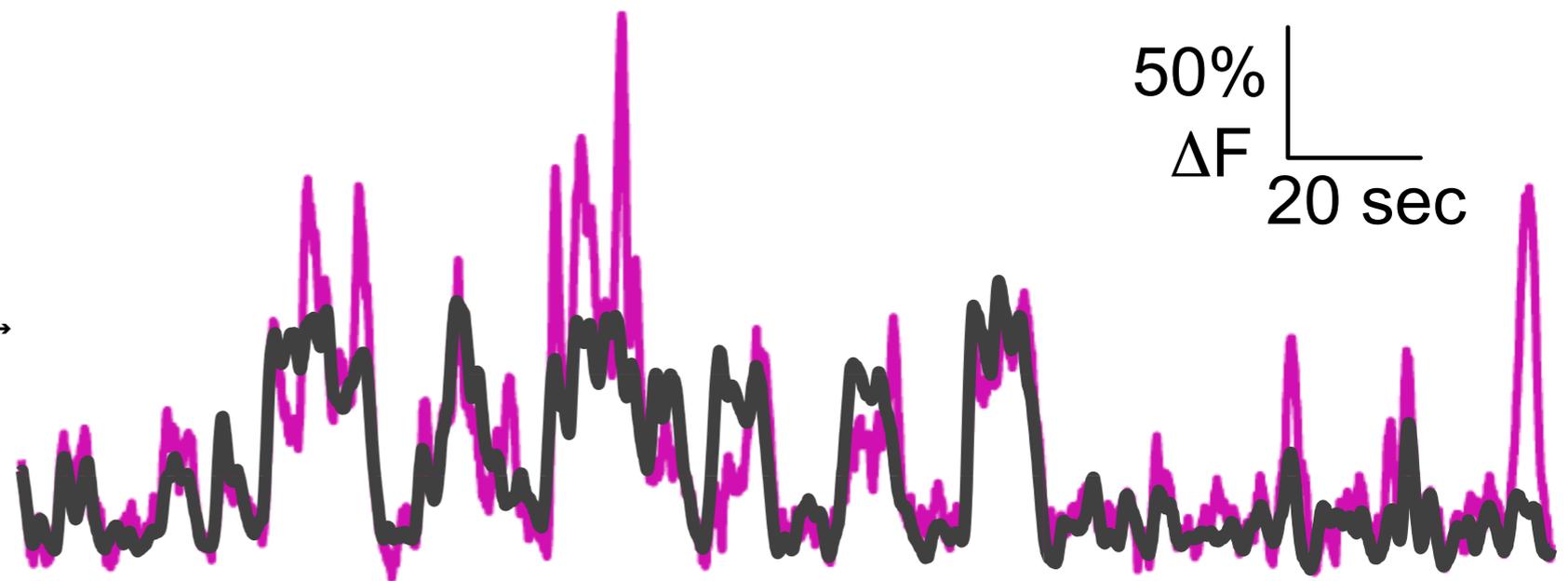
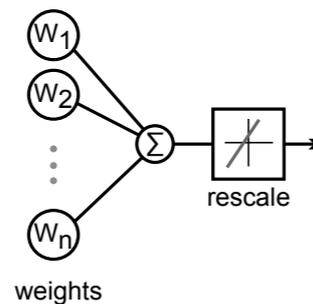
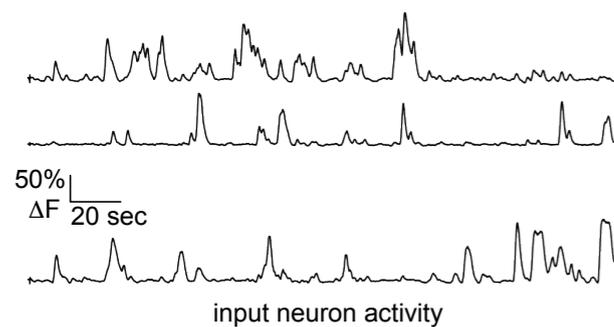
## OUTLINE

- ▶ Mouse V1 & high speed two-photon imaging
- ▶ What are functional networks?
- ▶ Functional networks accurately predict neuronal activity
- ▶ Higher order structure in functional networks

# MODELING NEURON RESPONSES USING FUNCTIONAL NETWORKS

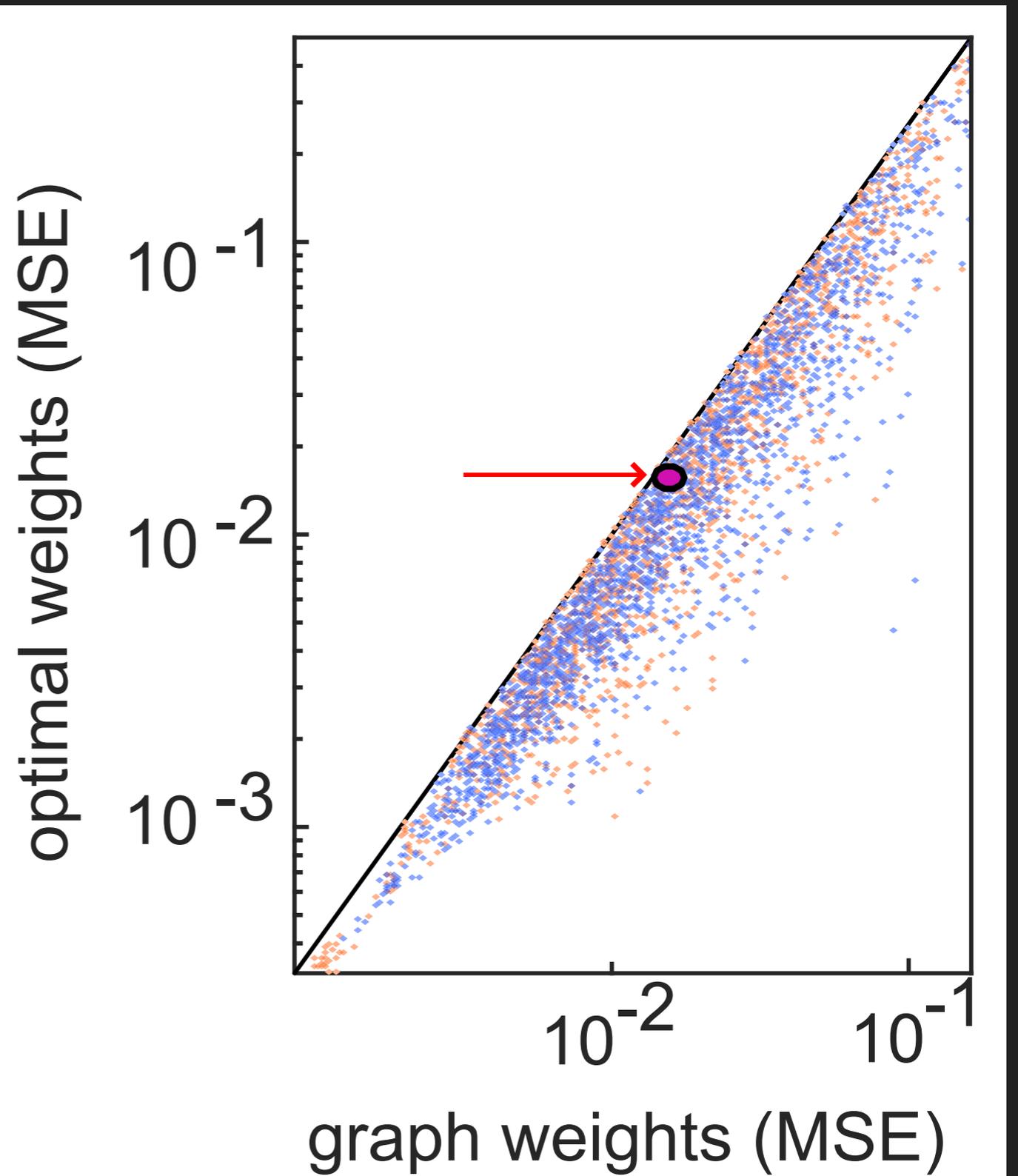
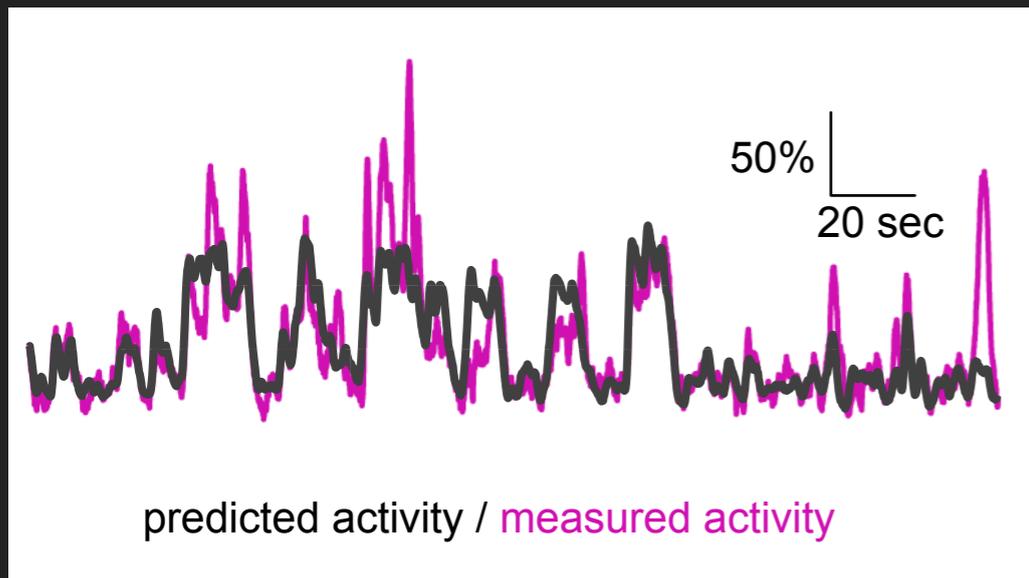


# ACCURATE PREDICTION OF MOMENT TO MOMENT ACTIVITY USING FUNCTIONAL NETWORKS

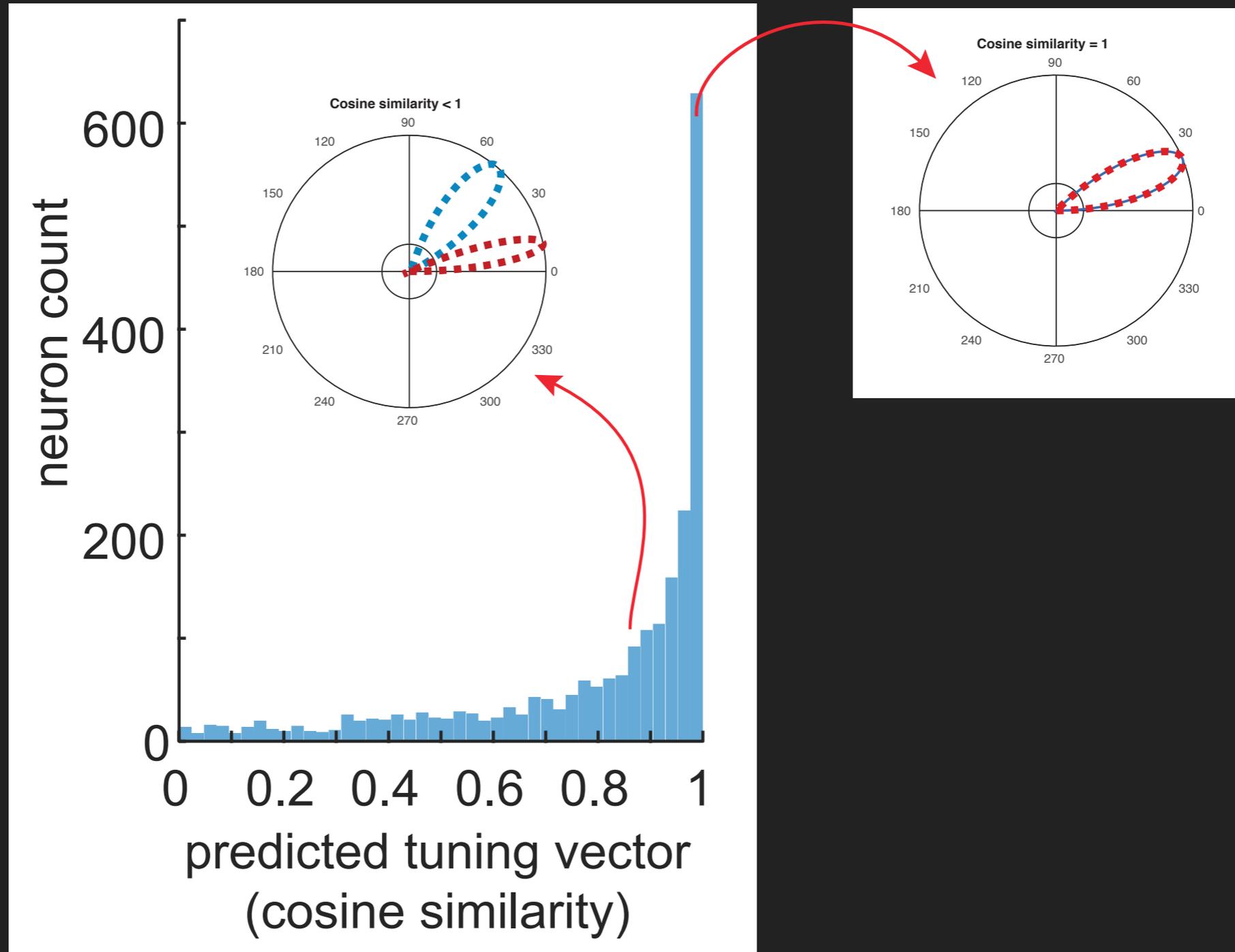


**predicted activity** / measured activity

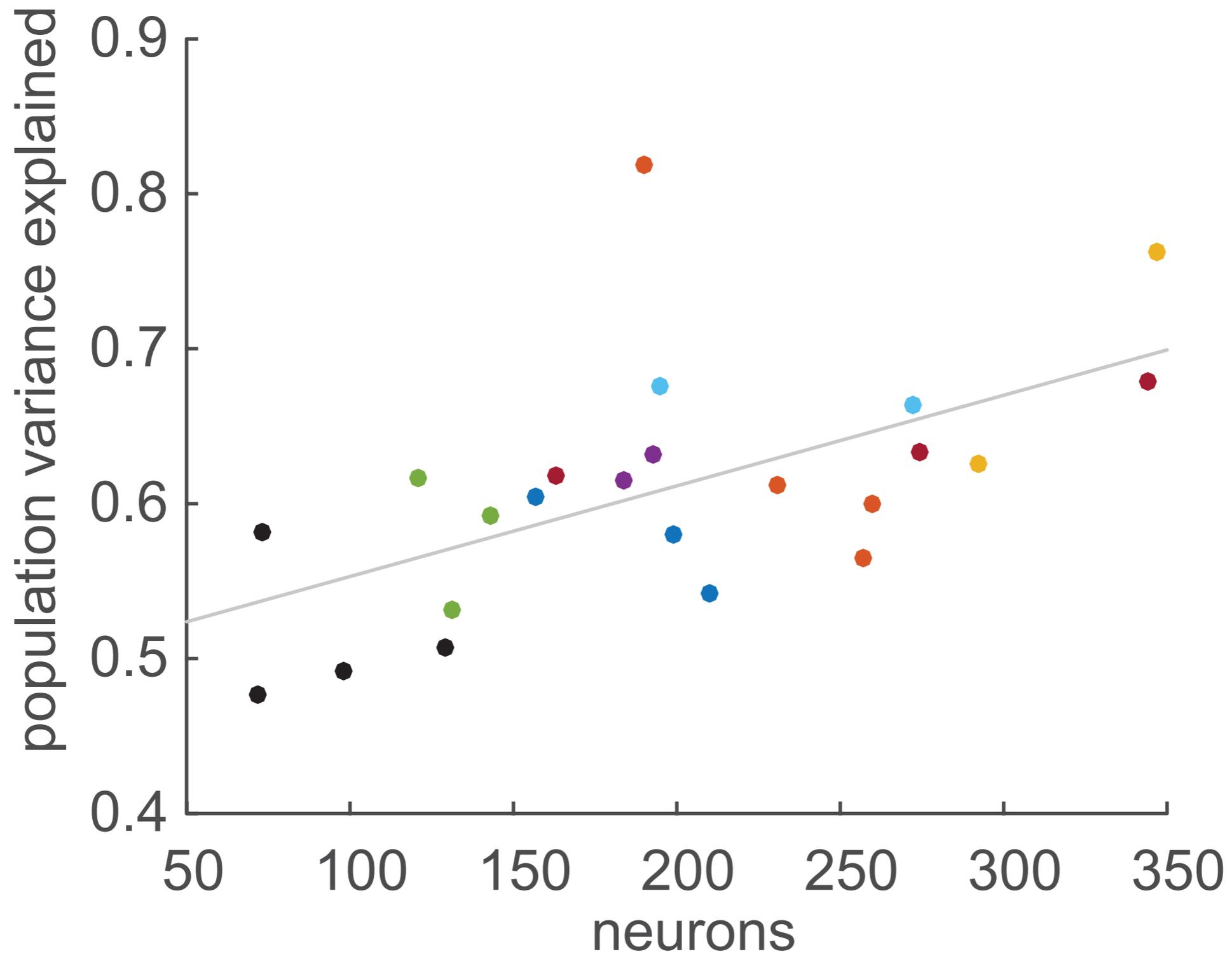
# FUNCTIONAL NETWORKS PROVIDE NEAR OPTIMAL PREDICTIONS OF SINGLE TRIAL RESPONSES



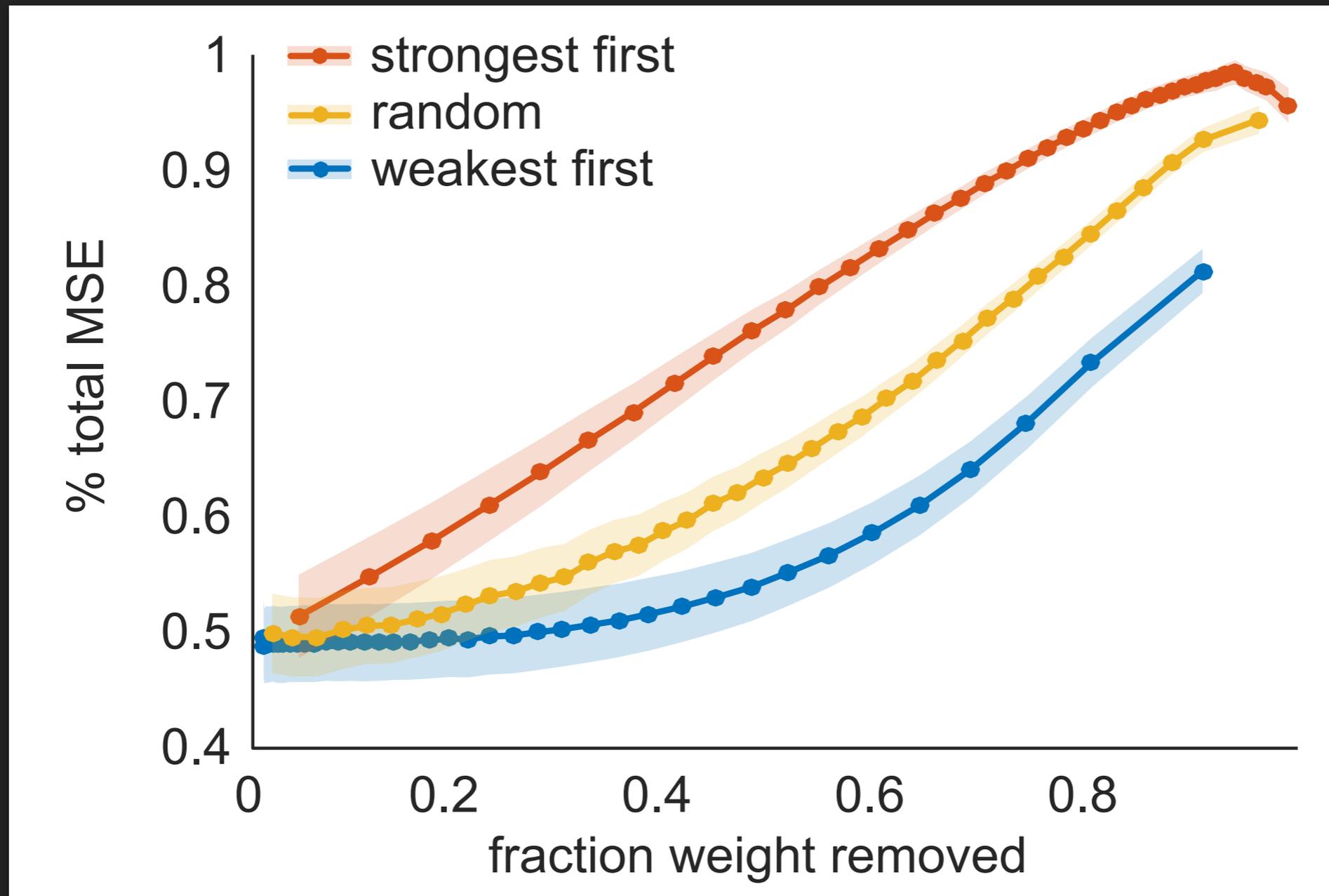
# FUNCTIONAL NETWORKS ALSO PREDICT TUNING



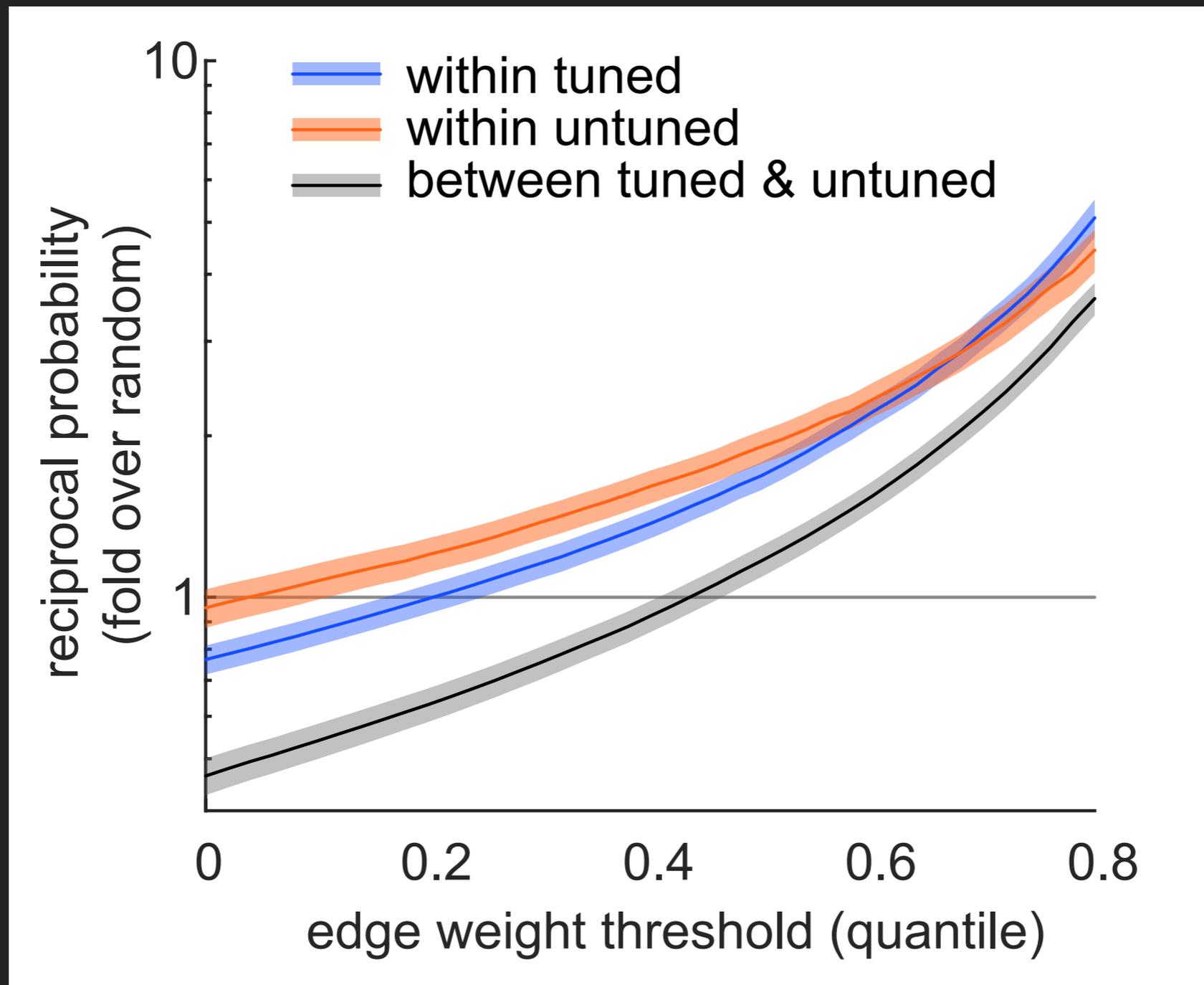
# POPULATION SIZE UNDERLIES PREDICTION ACCURACY



# LARGE WEIGHTS CONTRIBUTE DISPROPORTIONATELY TO PREDICTION ACCURACY



# RECURRENT CONNECTIONS ARE BIASED TOWARD LARGE EDGE WEIGHTS



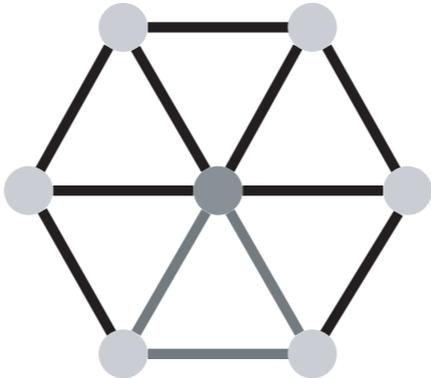
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## OUTLINE

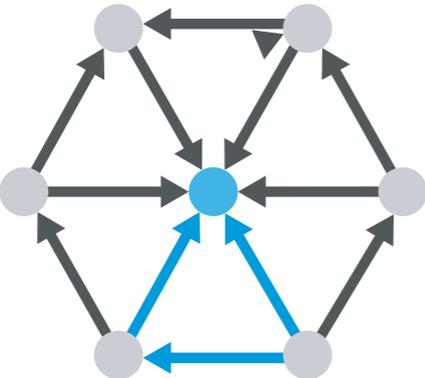
- ▶ Mouse V1 & high speed two-photon imaging
- ▶ What are functional networks?
- ▶ Functional networks accurately predict neuronal activity
  - ▶ **moment to moment prediction**
- ▶ Higher order structure in functional networks

# BEYOND PAIRWISE

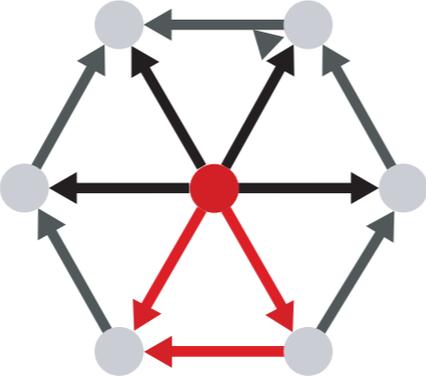
undirected



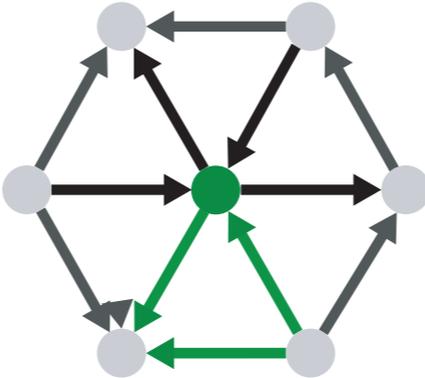
Directed



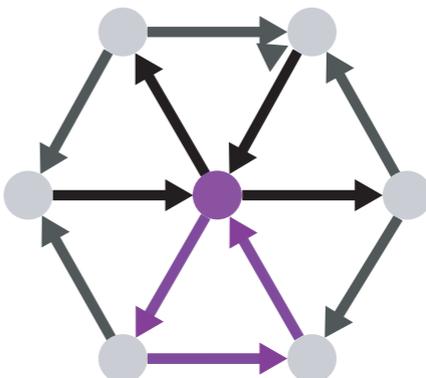
fan-in



fan-out

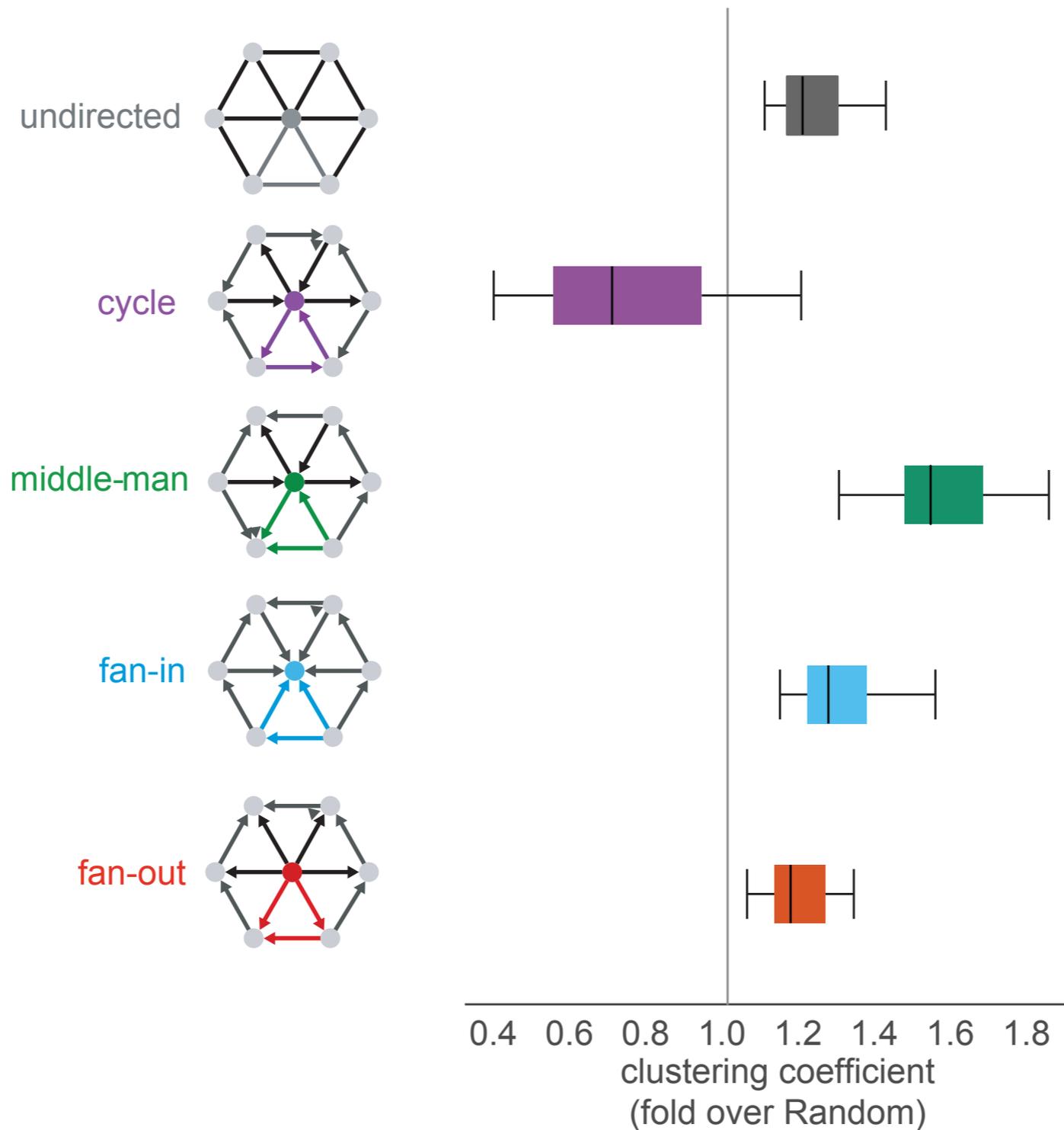


middle-  
man

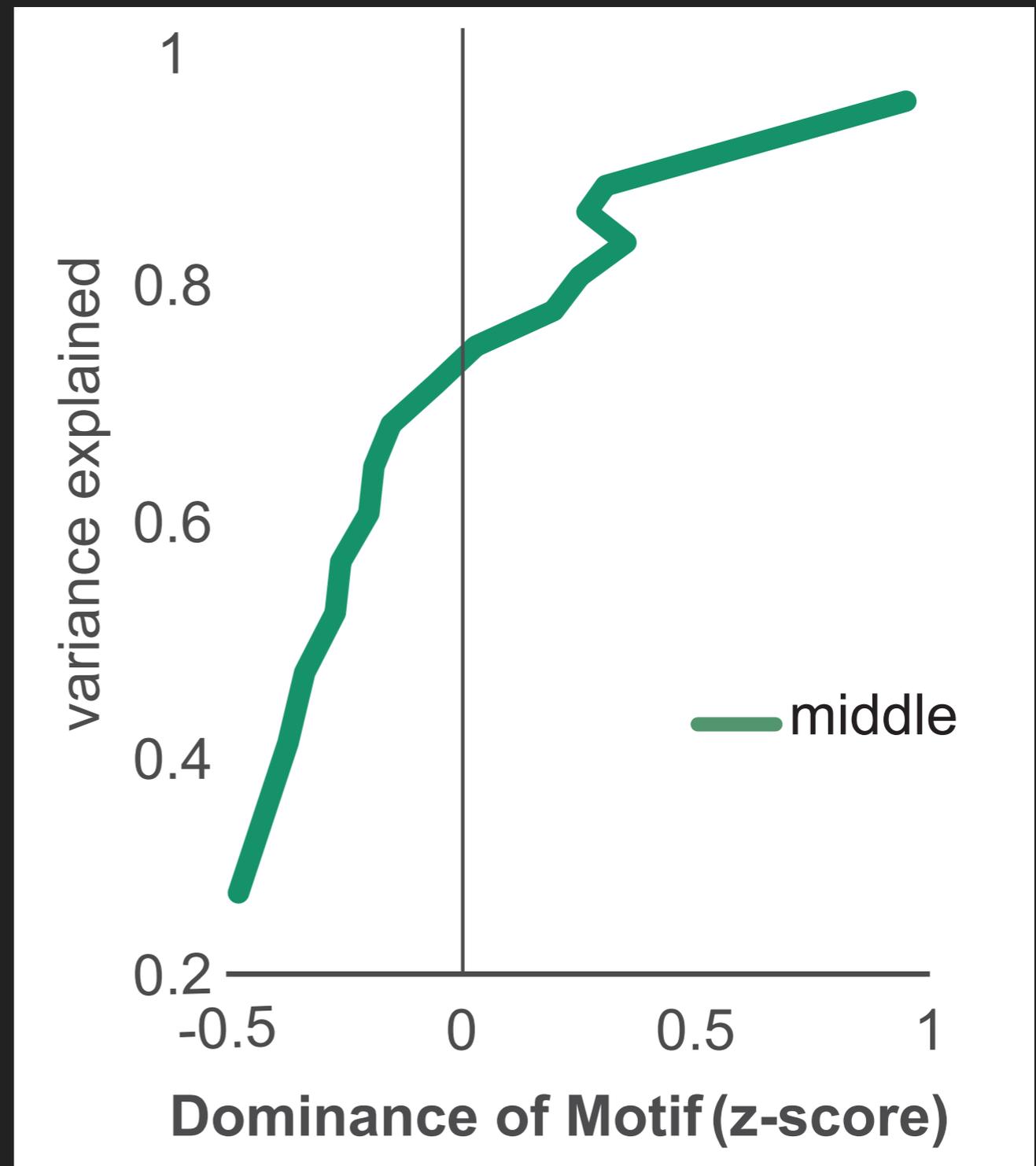
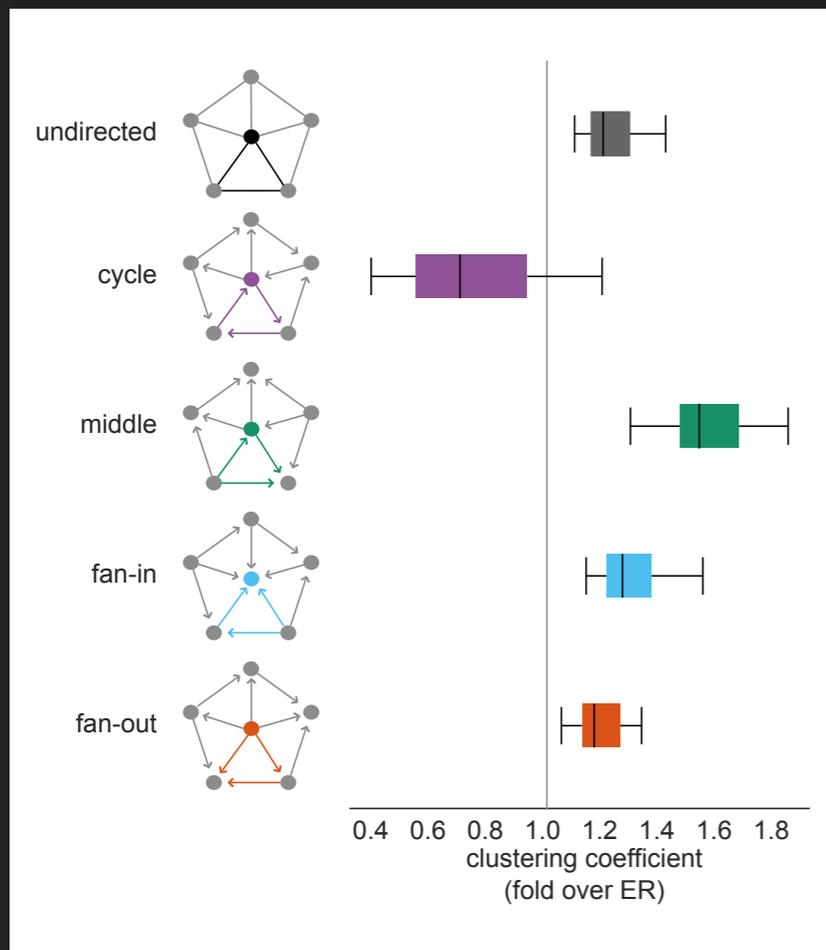


cycle

# TRIPLLET MOTIF STRUCTURE IN FUNCTIONAL NETWORKS



# TRIplet MOTIF STRUCTURE UNDERLIES PREDICTION ACCURACY



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## CONCLUSIONS

- ▶ Neurons are variable making prediction of single trial activity from tuning properties difficult
- ▶ Functional networks provide near optimal predictions of activity in individual neurons
  - ▶ And predict tuning
- ▶ Triplet correlations are predictive of more than 90% of a moment to moment activity

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# ASSEMBLIES

- ▶ Data demonstrates a loose coalition of neurons that co-vary with one another and consequently are predictive of one another
- ▶ Multineuronal activity shows pairwise timing differences as indicated by the fact that the majority of entries in the matrix are asymmetric
- ▶ But many unknowns

# ACKNOWLEDGMENTS

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Friederice Pirschen  
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Lucy Li  
SJ Weinberg  
Veronika Hanko  
Lane McIntosh  
Suchin Gururangan  
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Alexa Carlson  
Caroline Heimerl  
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Areknaz Khaligian  
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**FACCTS**



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