Toward a Single-Trial Understanding of Motor Preparation and Neural Variance

(Continuing on from Mark Churchland's talk)

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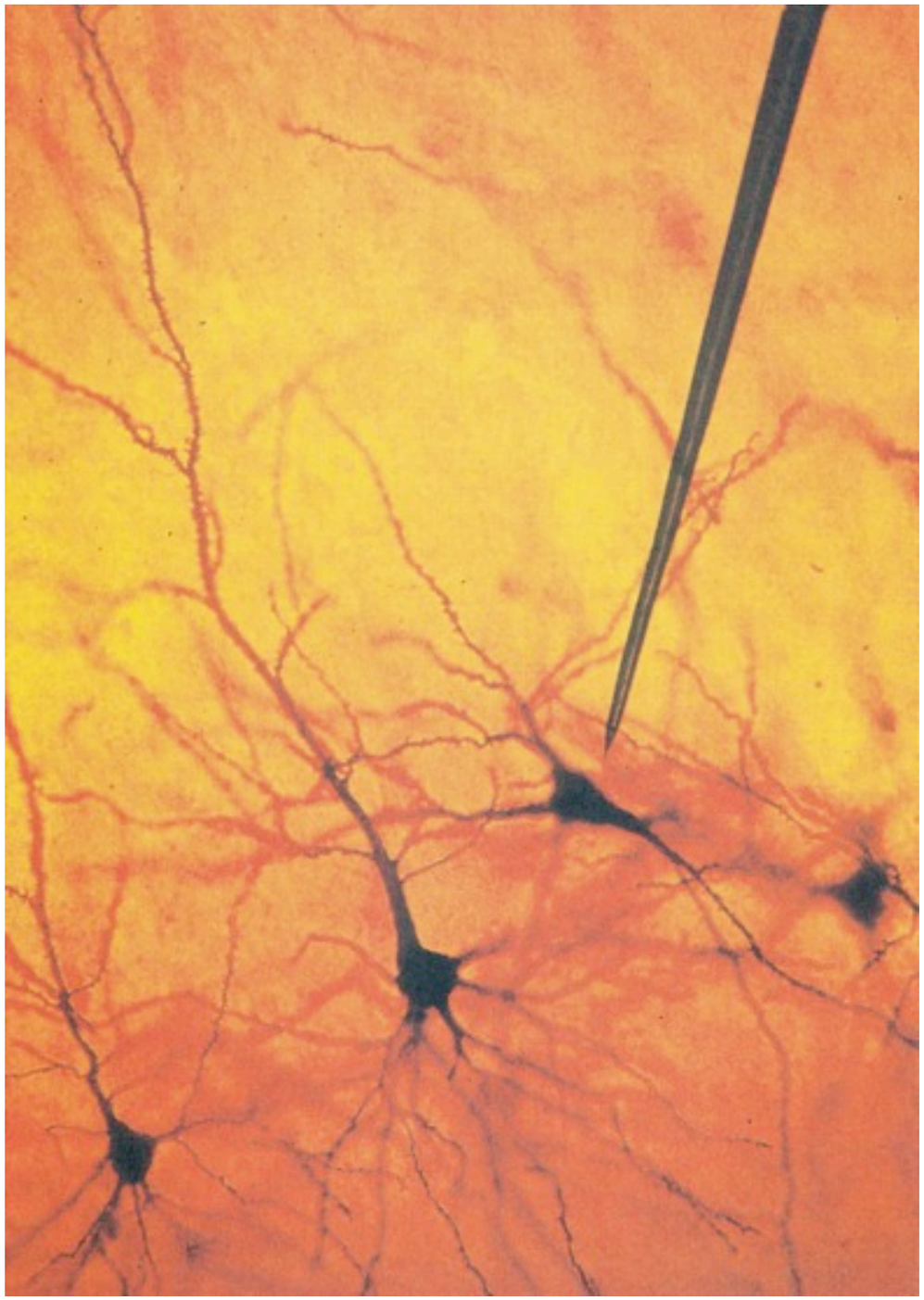
Stanford Institute for Neuro-Innovation and Translational Neuroscience

Bio-X/NeuroVentures and Neurosciences Programs

James H. Clark Center

Introduction



Hubel, *Scientific American*

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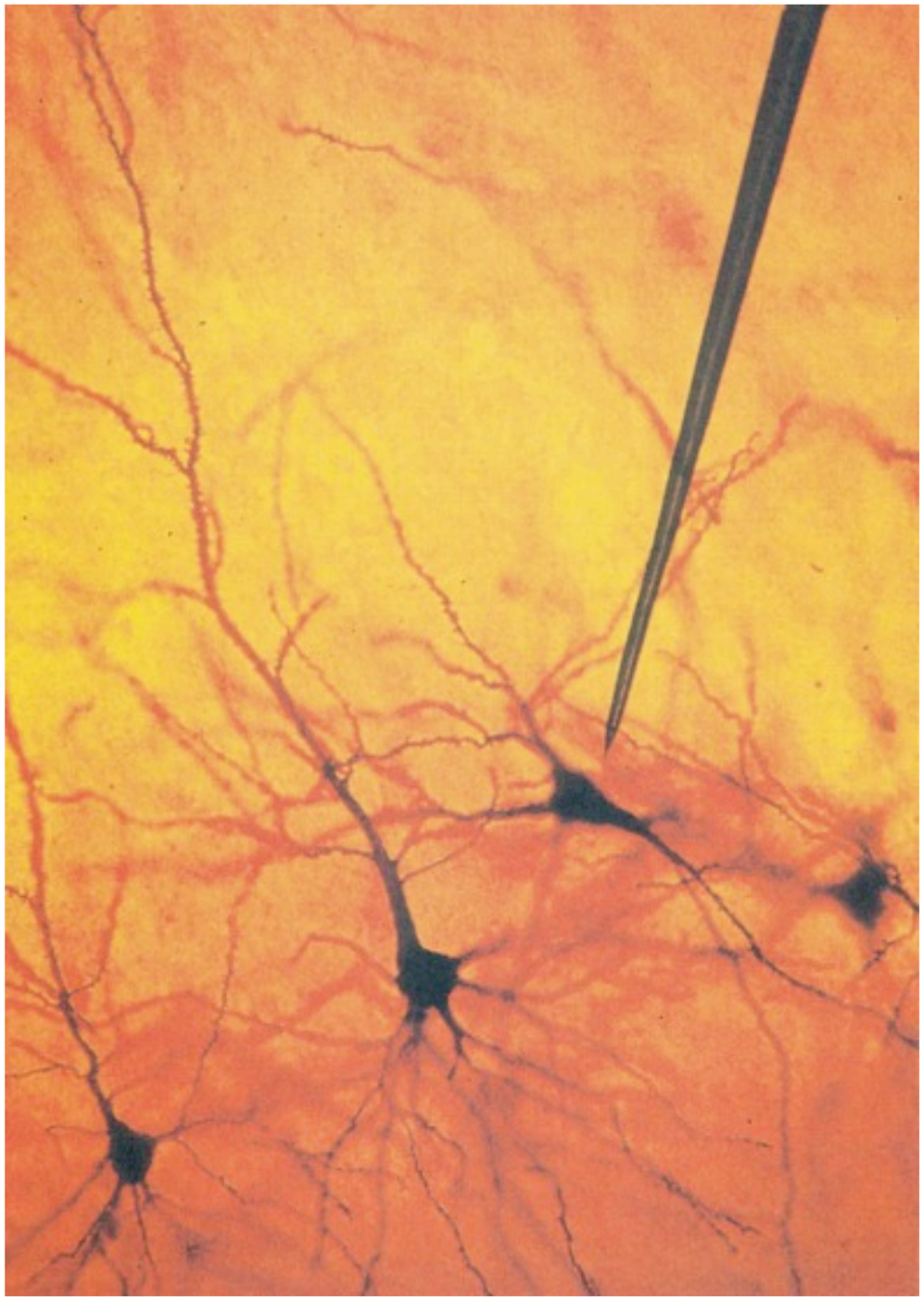

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- We all wish to understand how neural circuits behave

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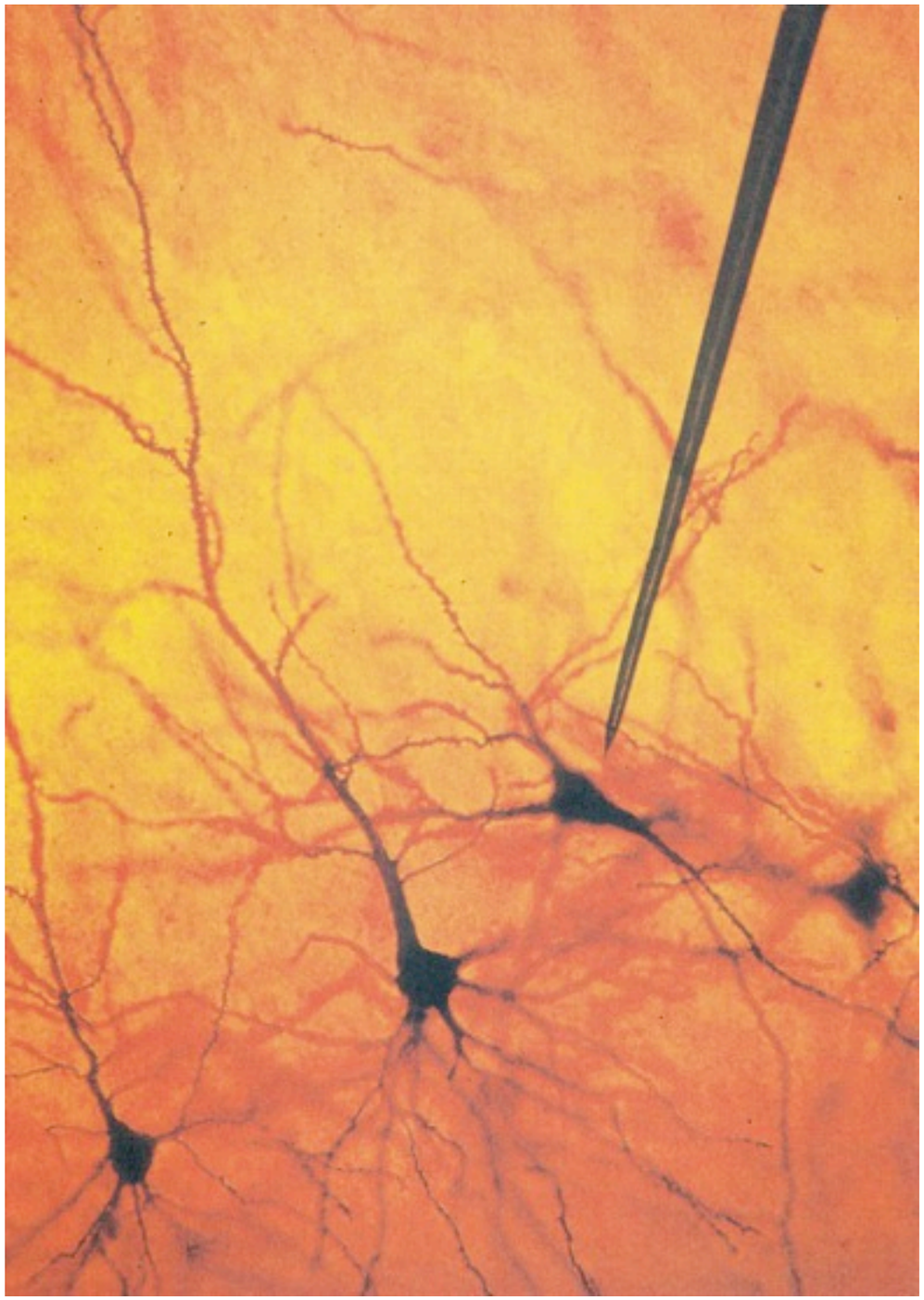

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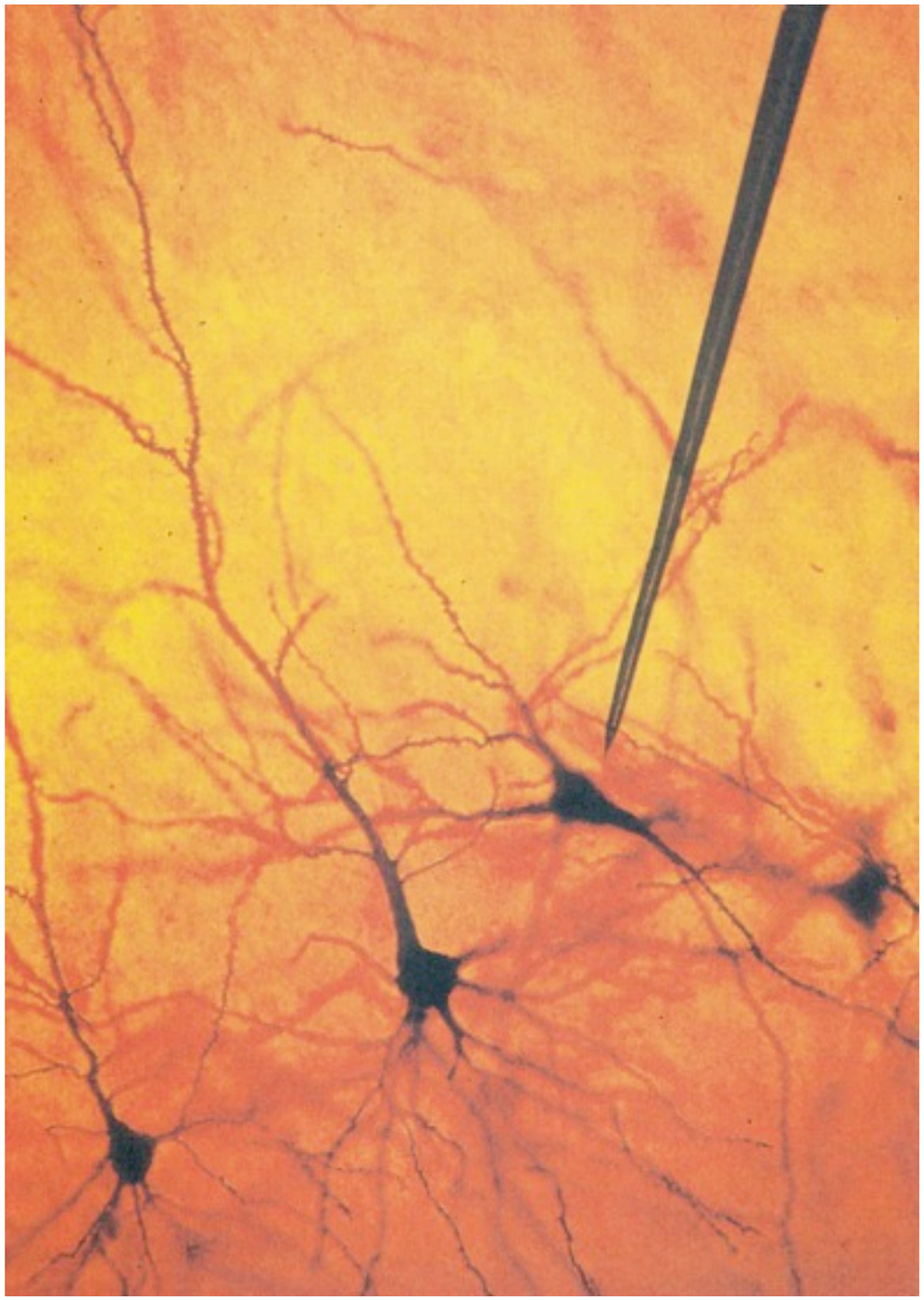

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    - Average activity (PSTH)

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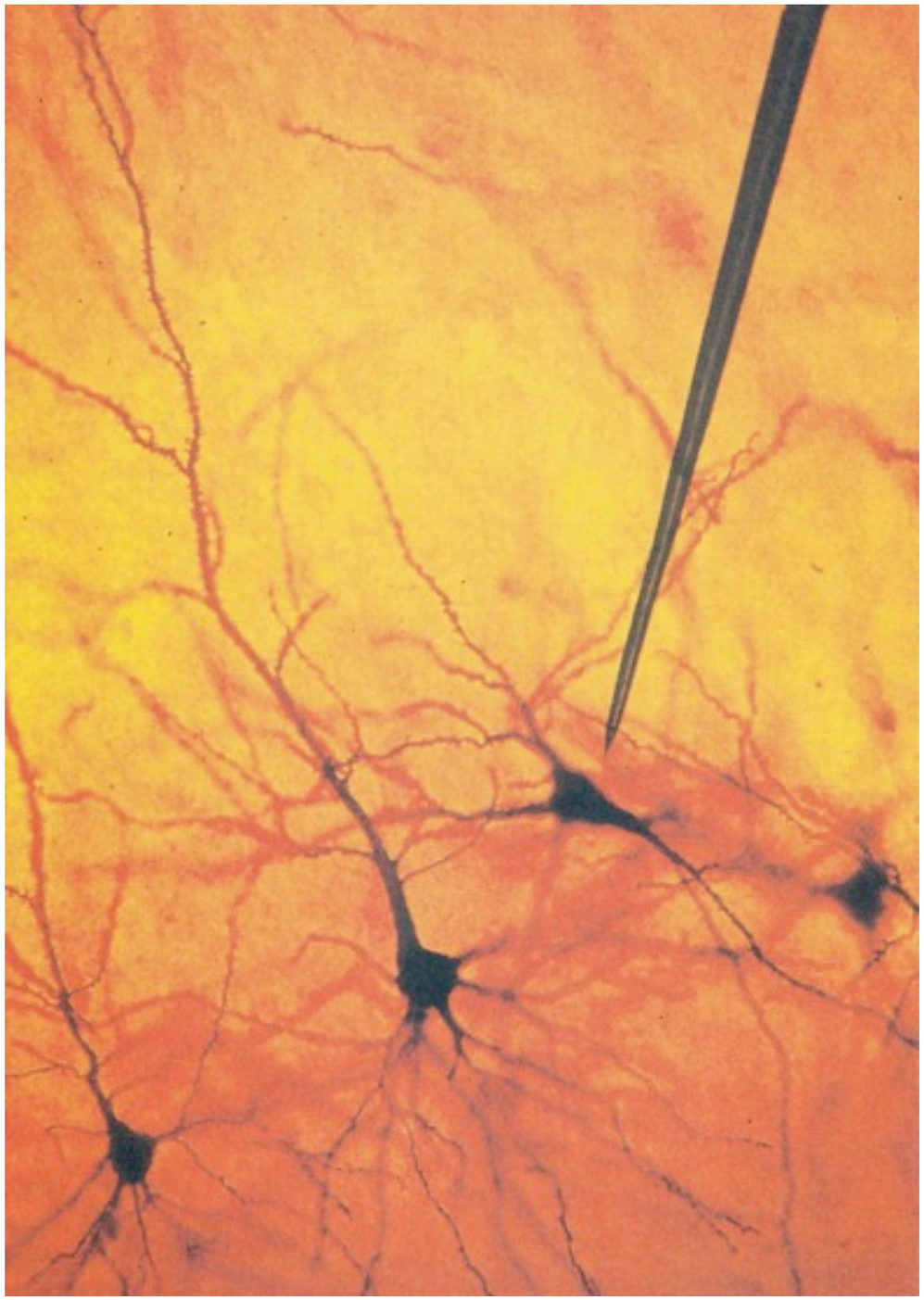

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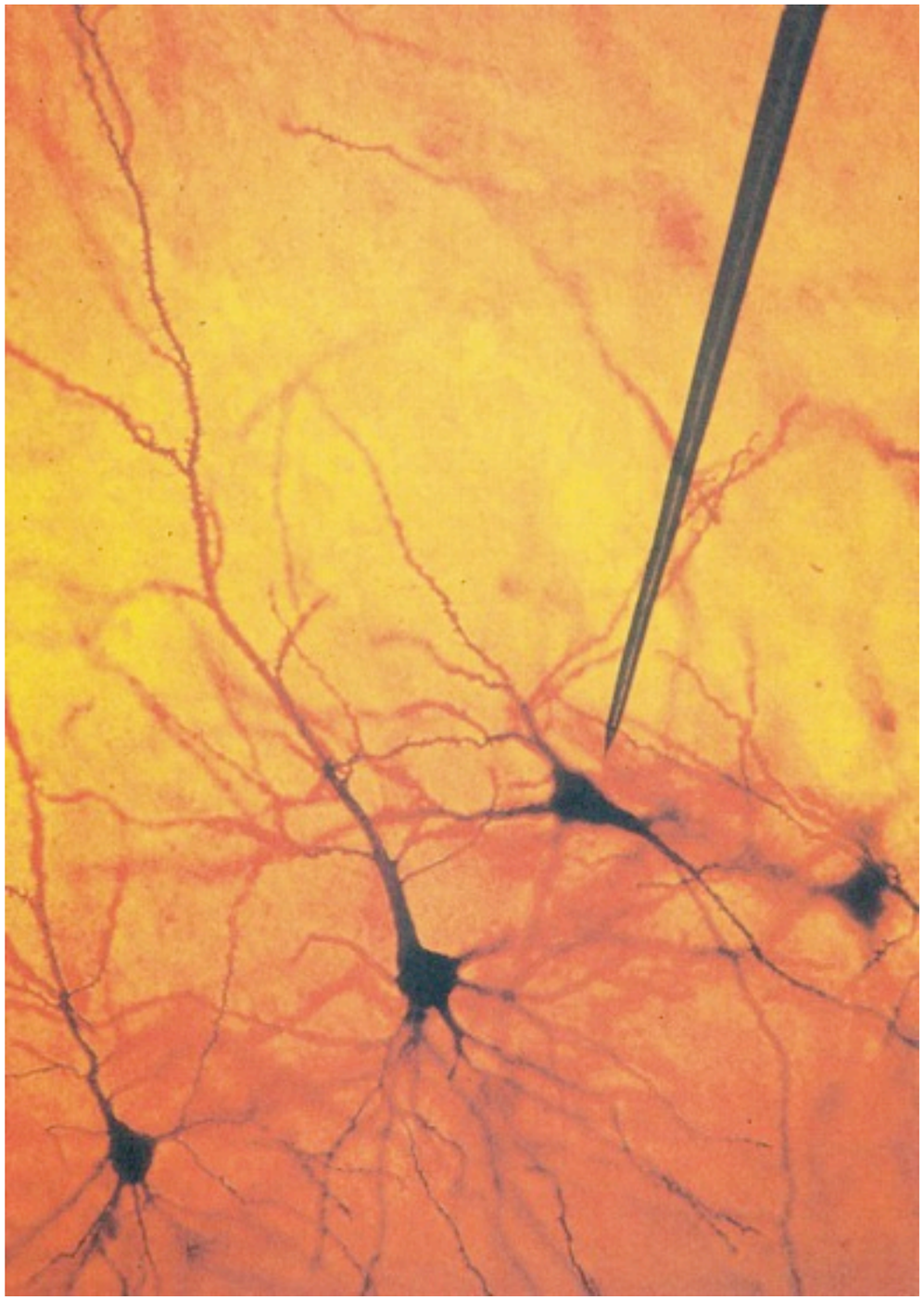

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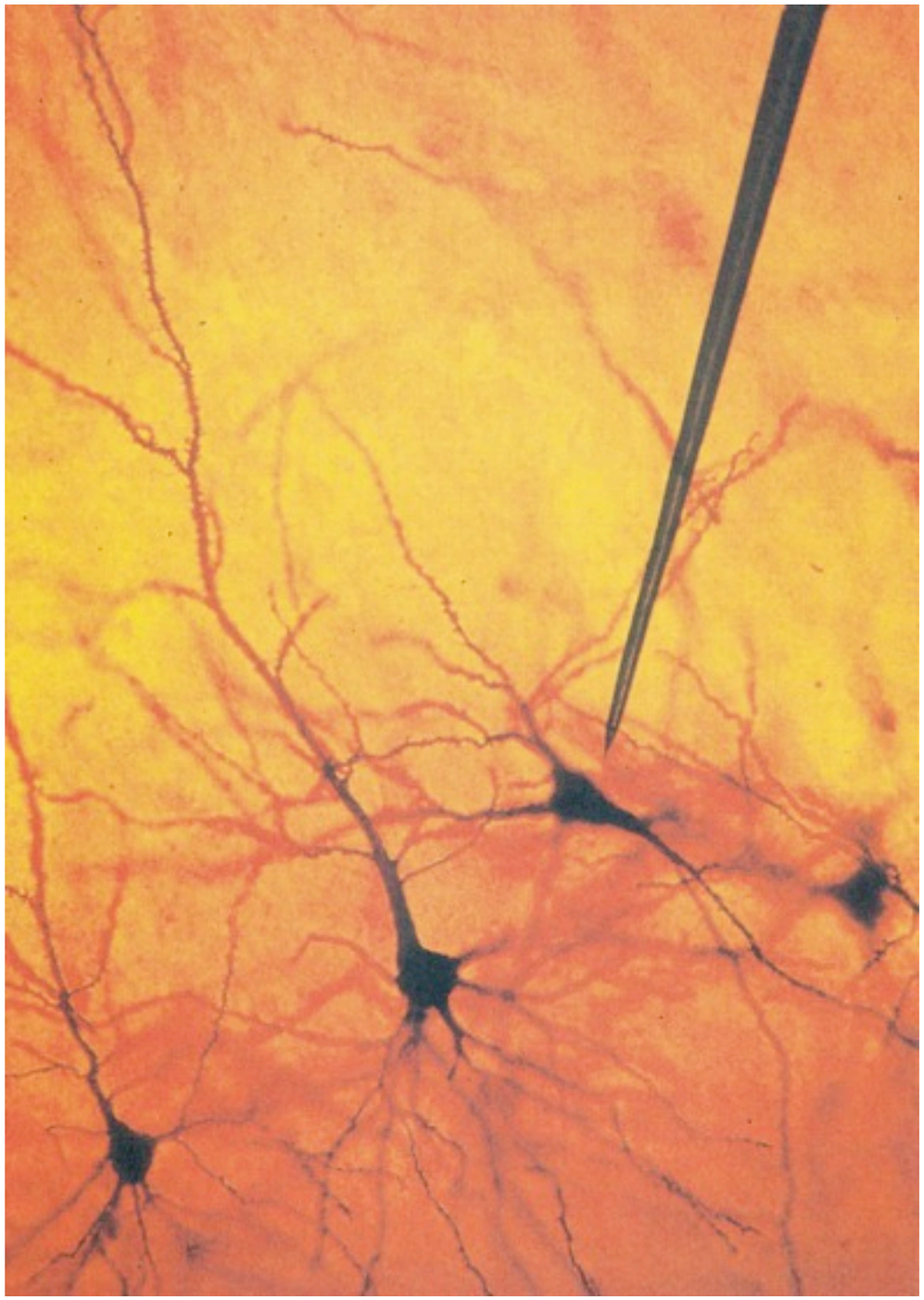

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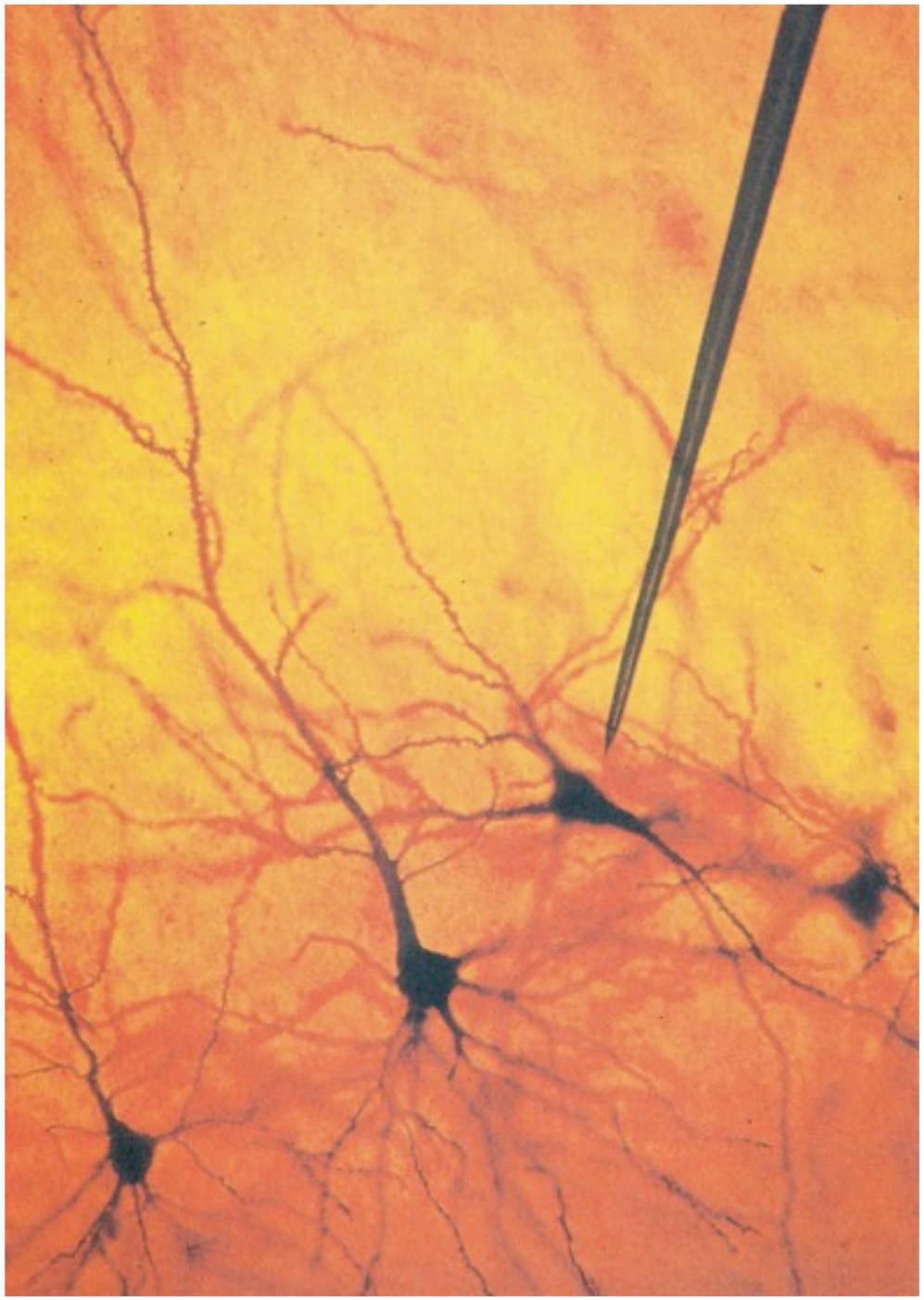

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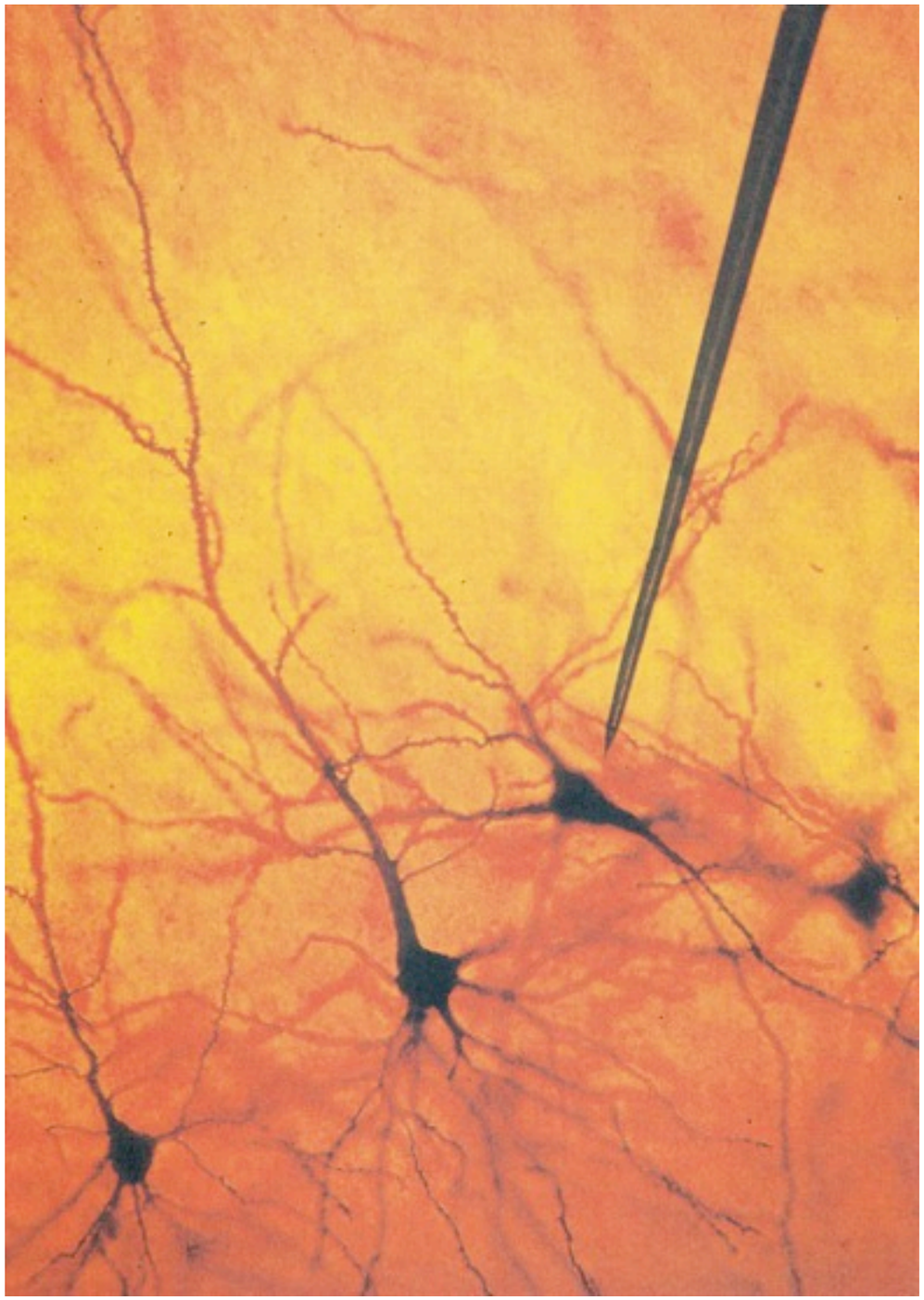

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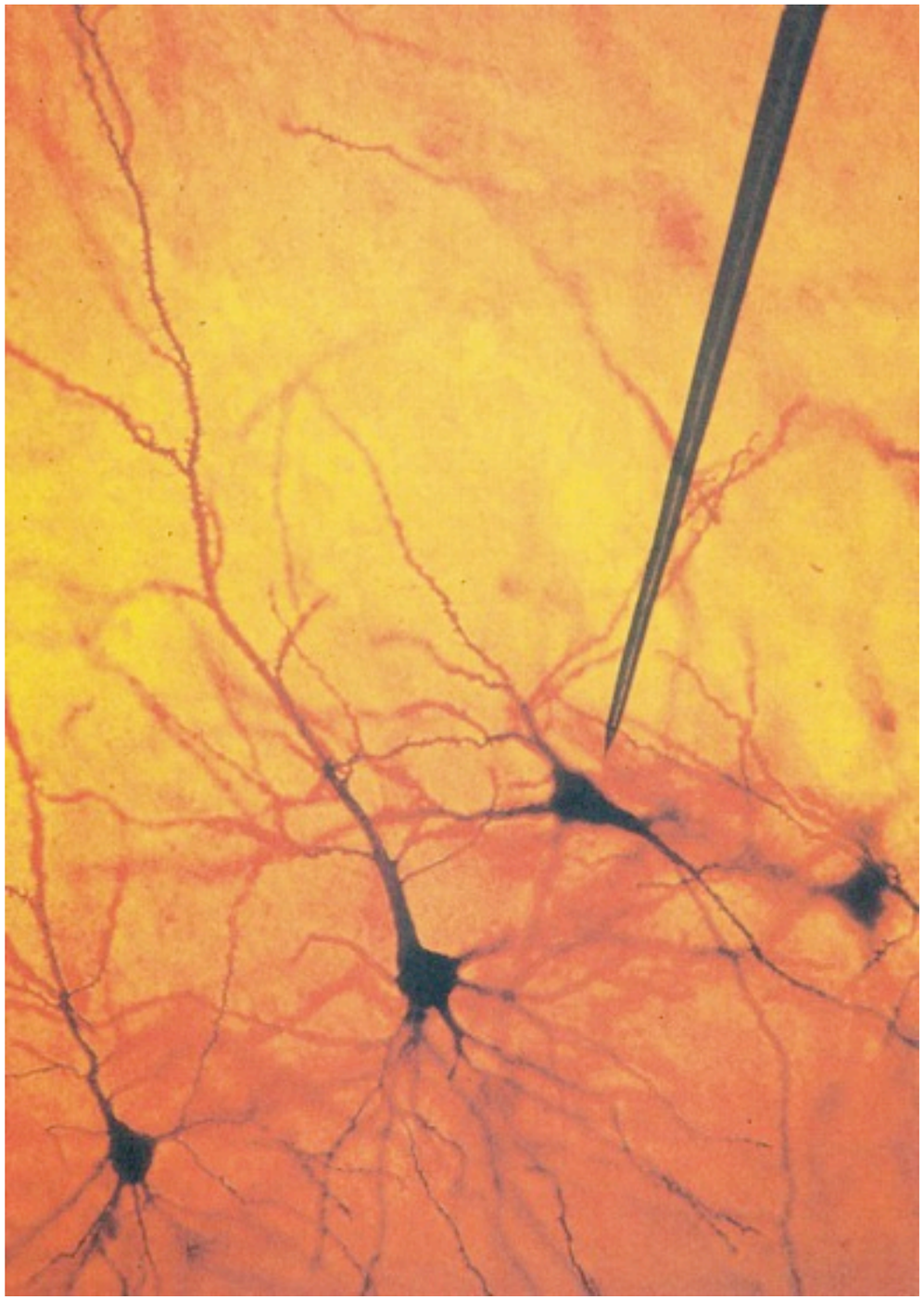

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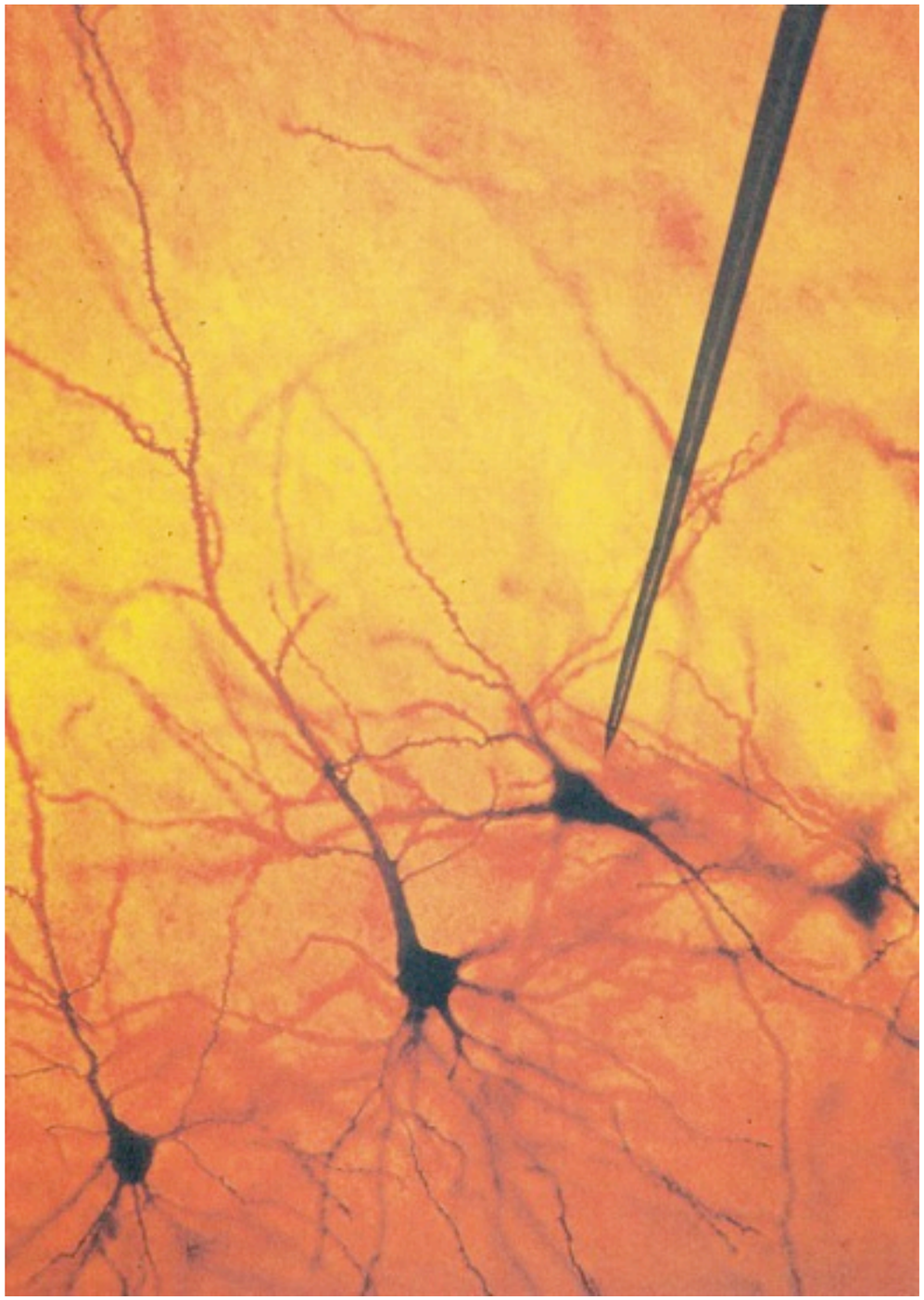

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    - Trial average or single trial

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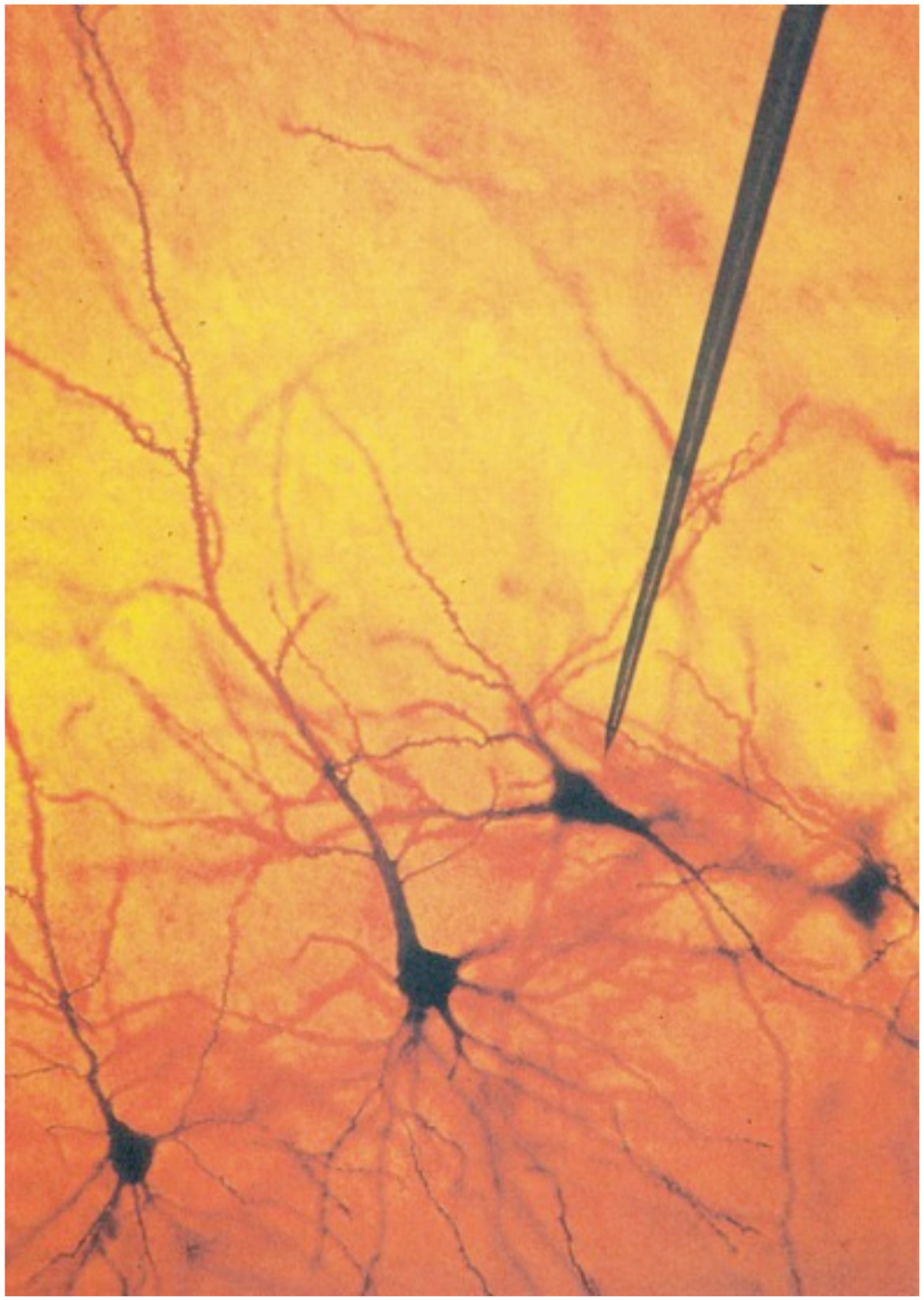

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    - Trial average or single trial

- Single-trial because different things can happen on different trials (on ms timescale)

Outline

- Reminder that neural state matters (state predicts reach speed)
- Visualizing neural state, and trajectories (dimensionality reduction)
- Can we learn anything from single-trial neural state trajectories?
  - neural correlate of reach reaction time
  - neural correlate of reach decision
- Summary & Acknowledgments

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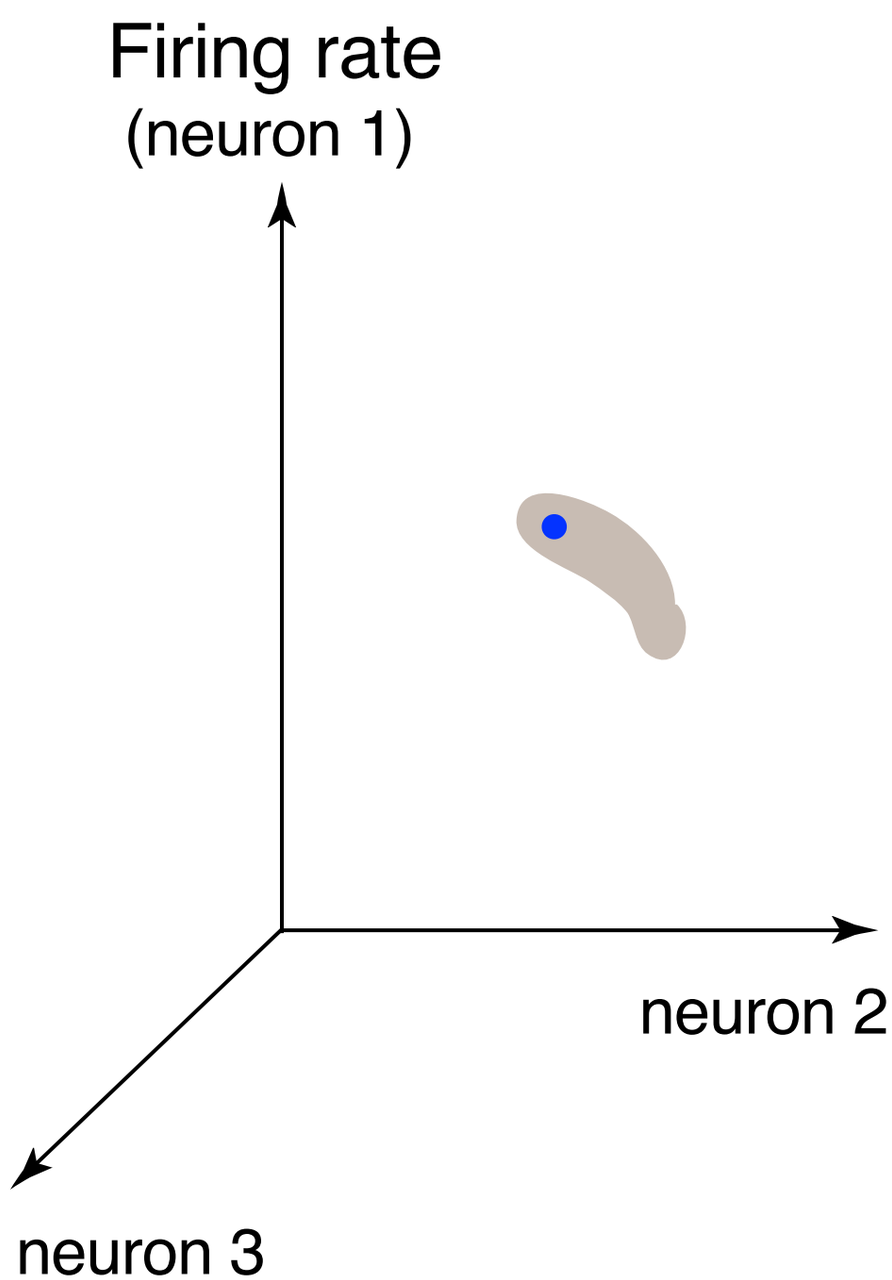
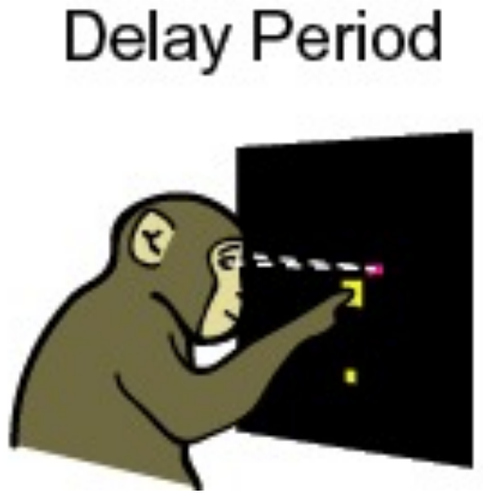
Reach Speed Experiment:
Hypothesis shown in a simple neural state space





Churchland et al. (2006) *J Neurosci*

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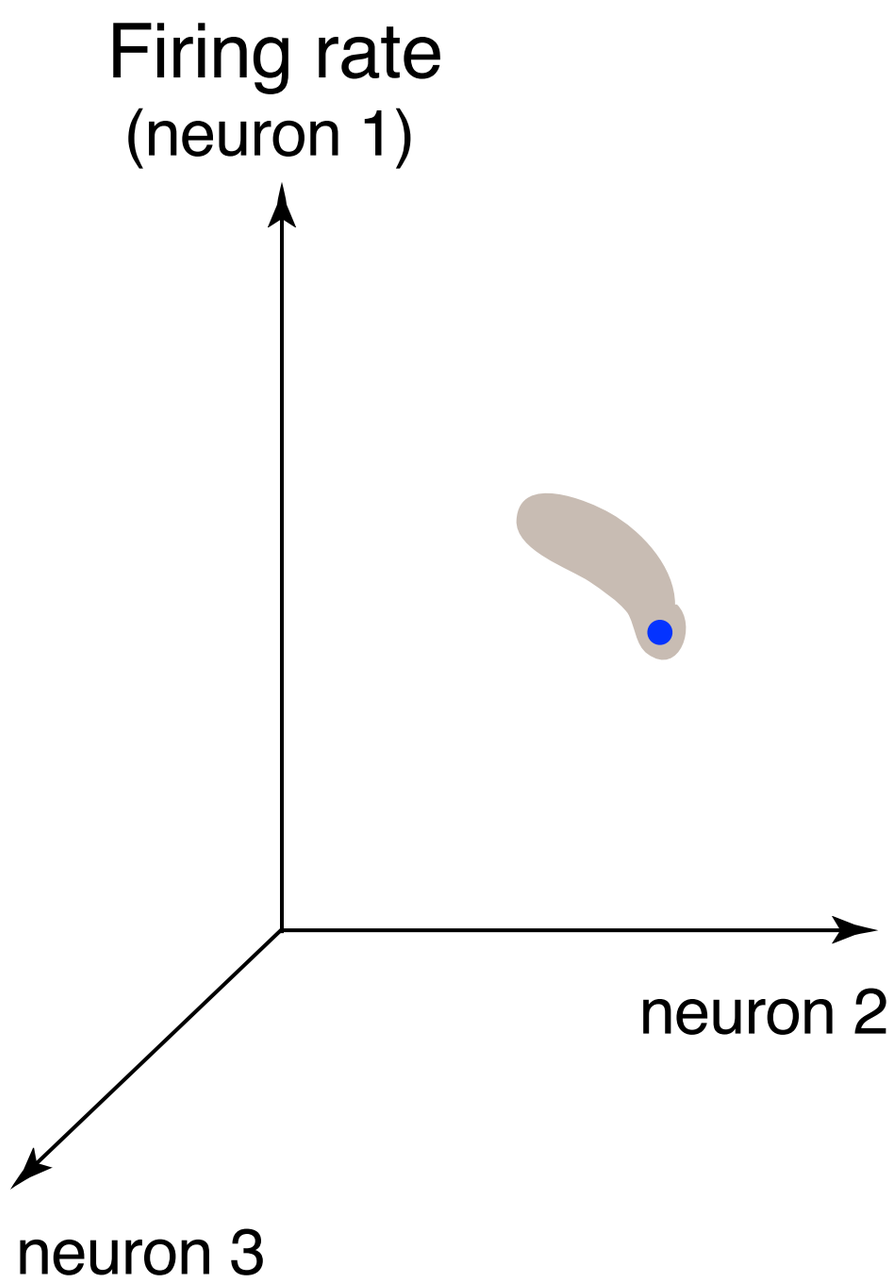

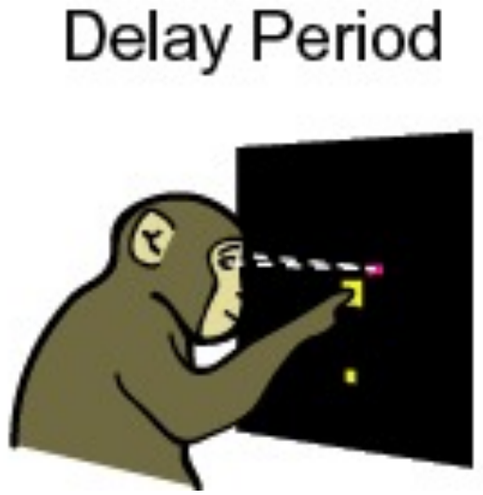

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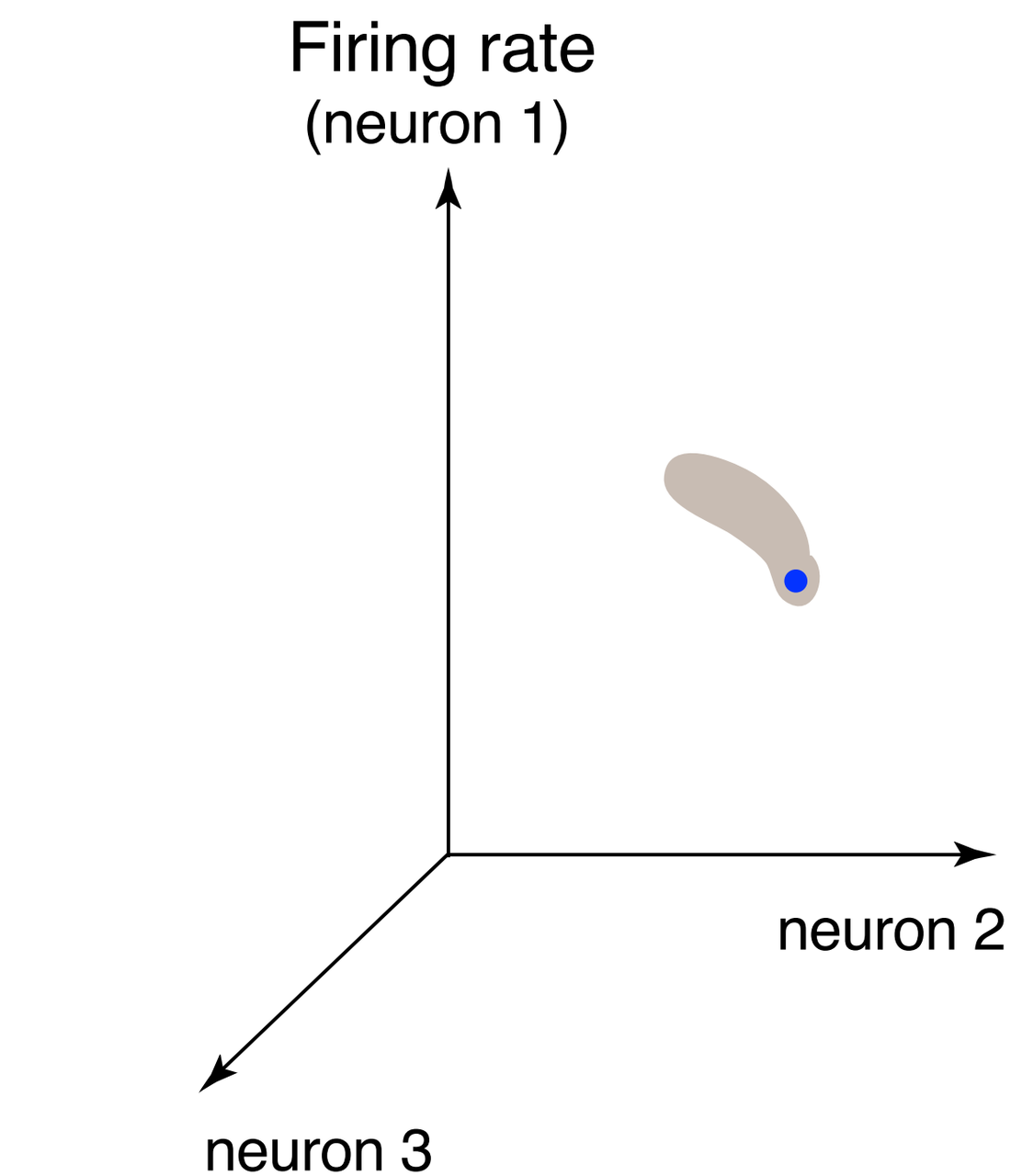
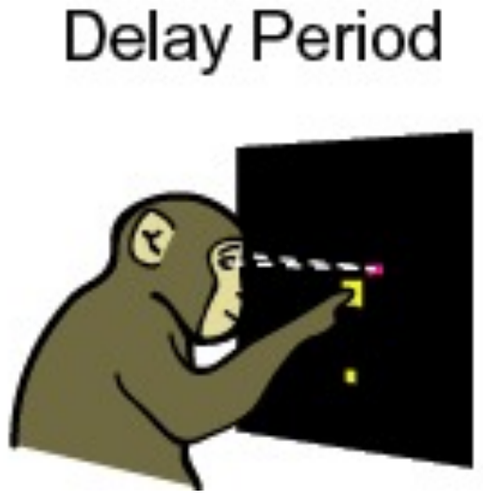




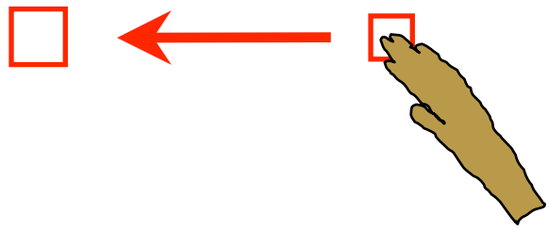
Exact neural state (pattern of neural activity) should matter to the reach

Equivalently, variability in neural state should lead to variability in the reach

Churchland et al. (2006) *J Neurosci*

Reach Speed Experiment: Arm Movement Behavior

Red instructs fast reach

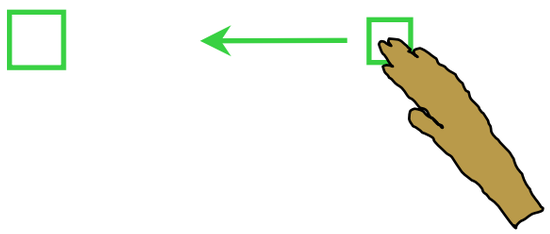


Churchland, Santhanam & Shenoy (2006) *J Neurophysiol*
Churchland, Afshar & Shenoy (2006) *Neuron*

Reach Speed Experiment: Arm Movement Behavior

Red instructs fast reach

Green instructs slower reach



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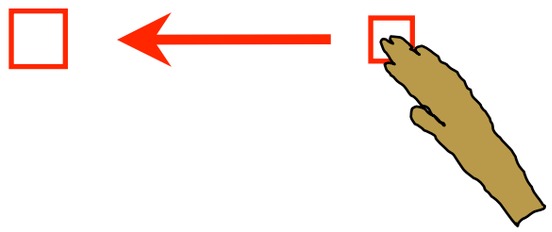
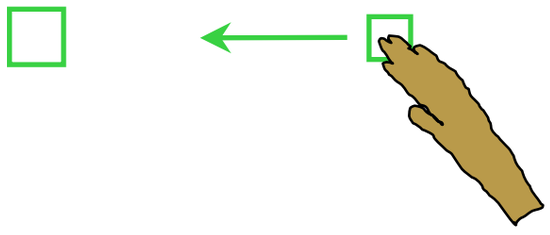
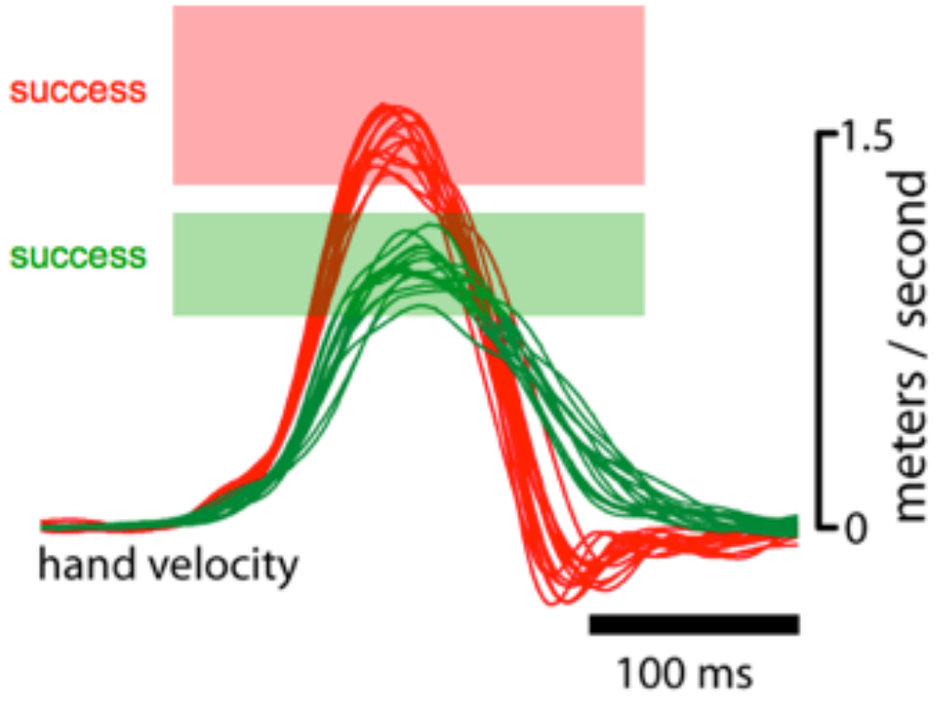


Green instructs slower reach





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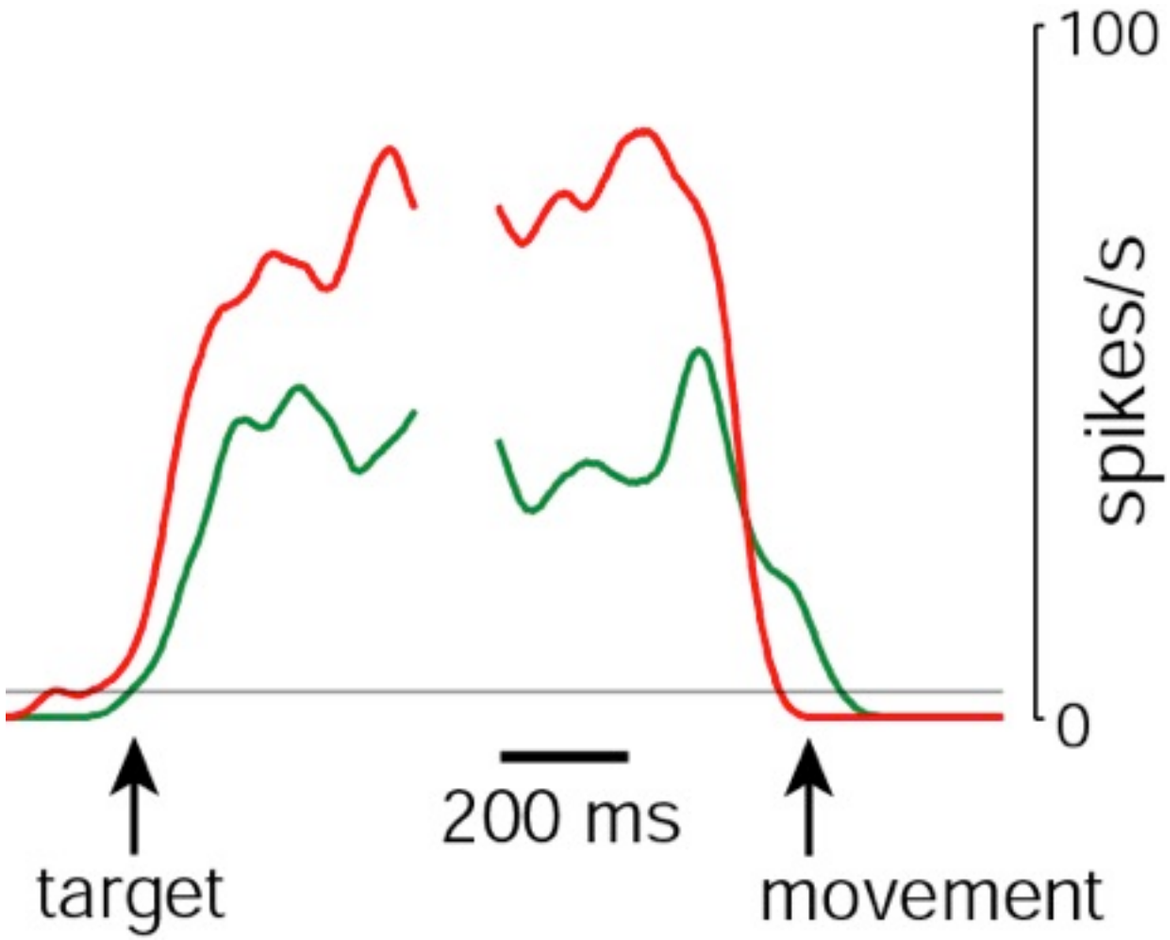
Reach Speed Experiment: Example PMdc neuron



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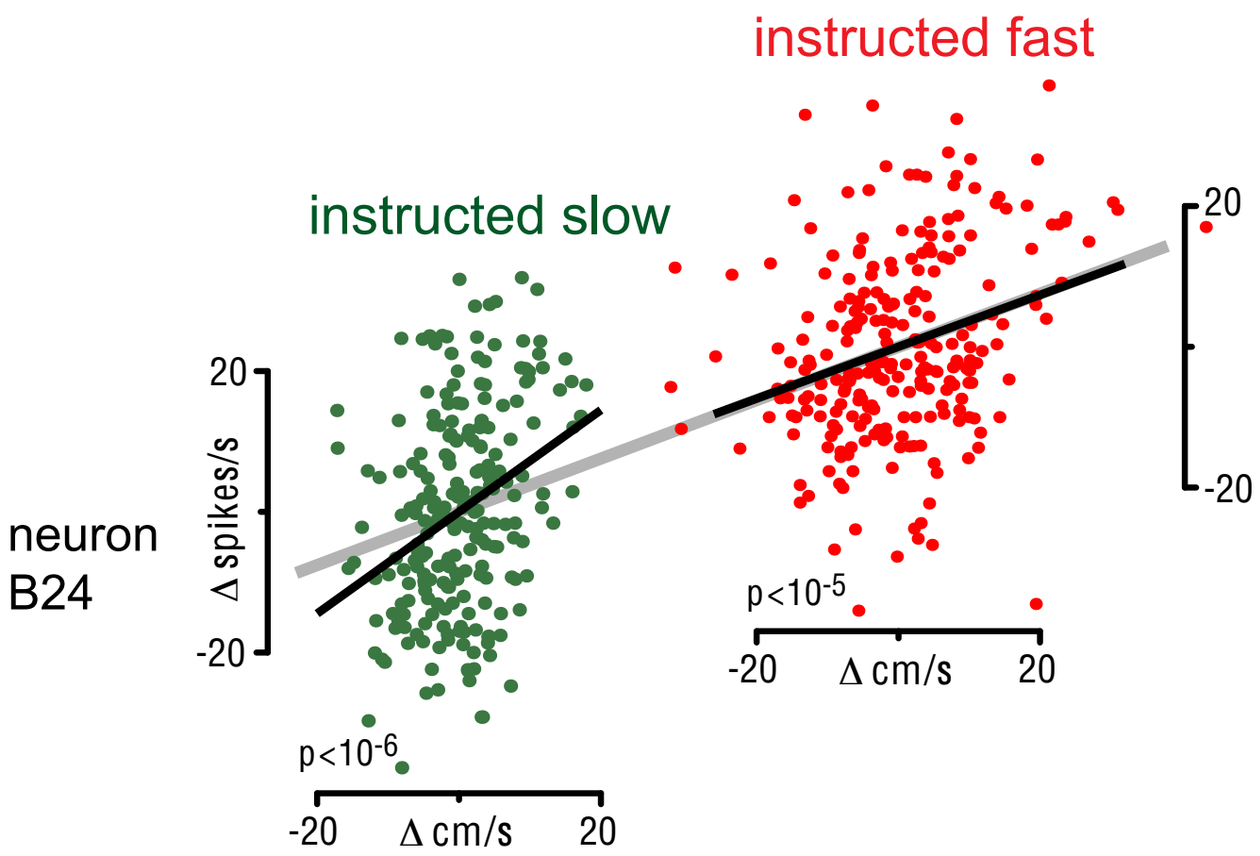

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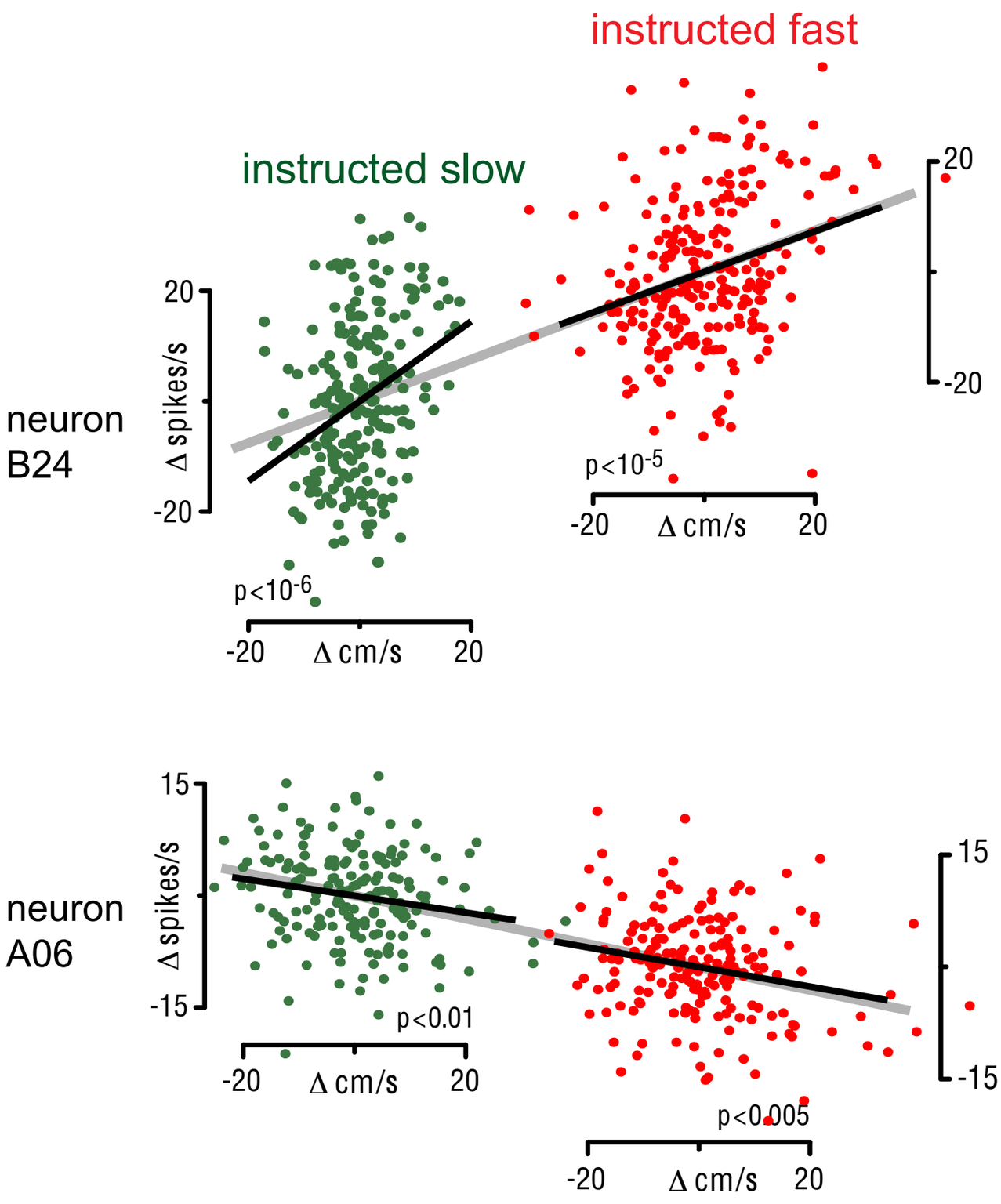

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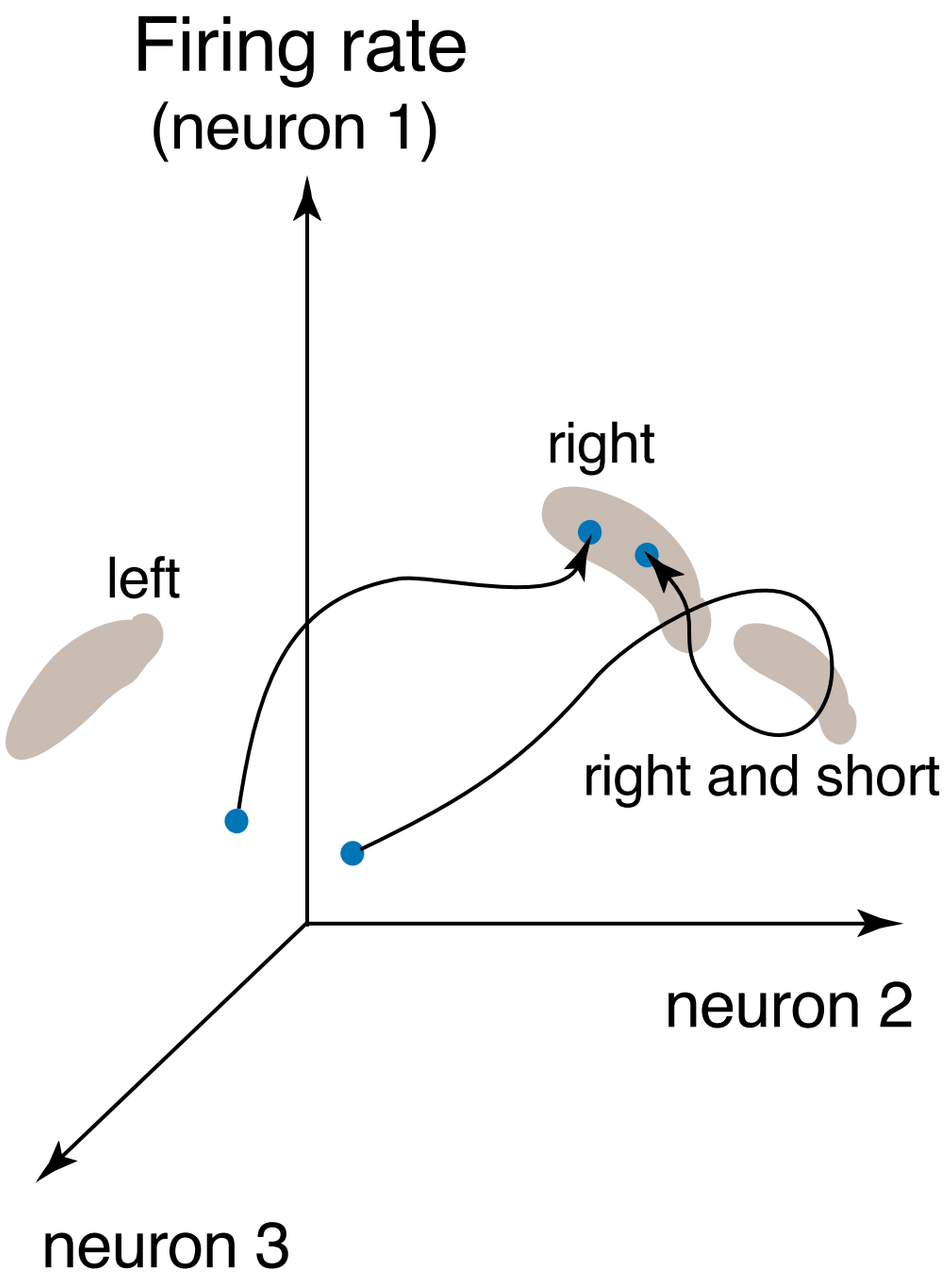

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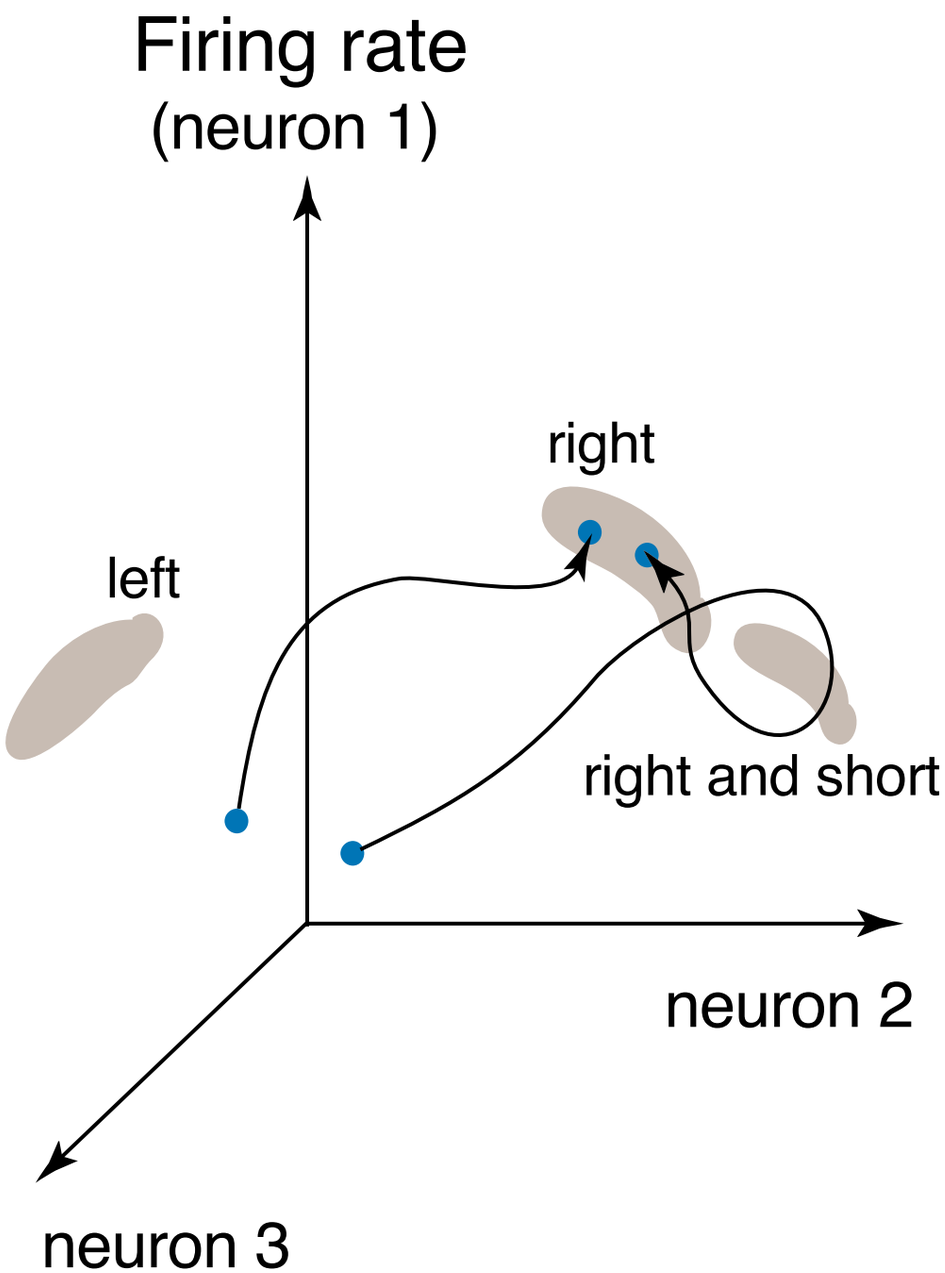

Churchland et al. (2007) *Current Opinion Neurobiology;* Yu et al. (2009) *J Neurophysiol*

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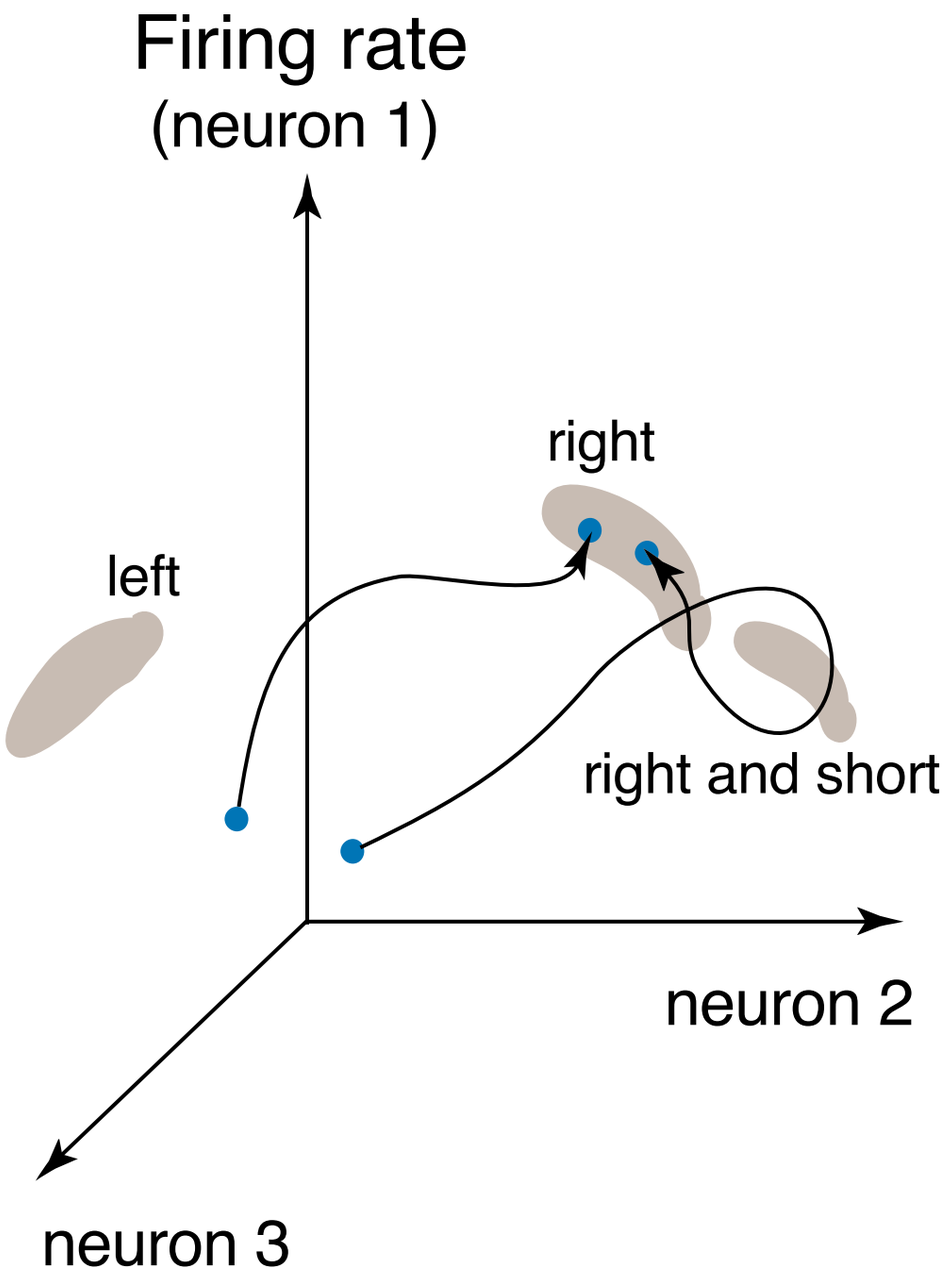

- Should be able to “see” these single-trial neural state trajectories, from data

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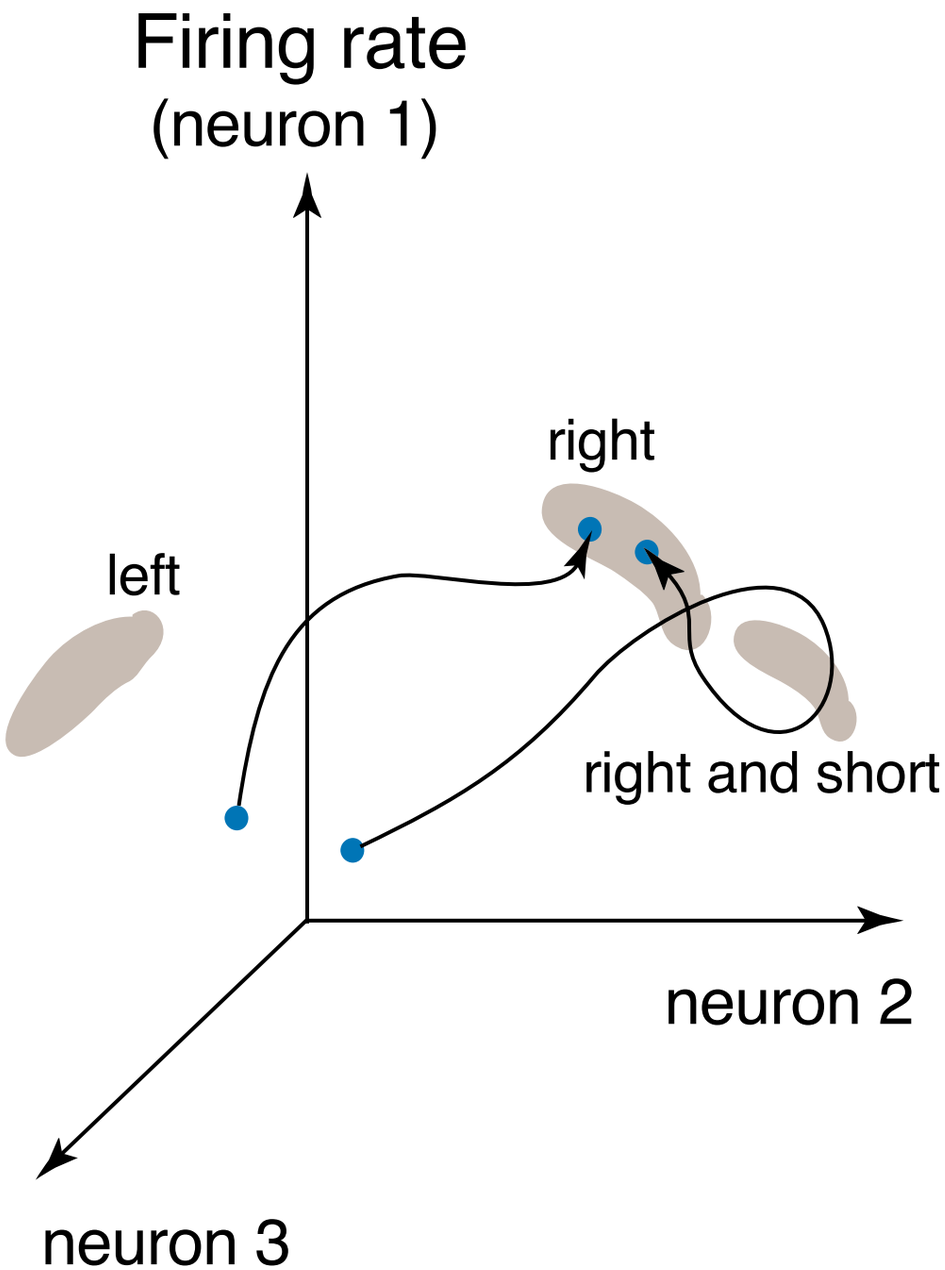

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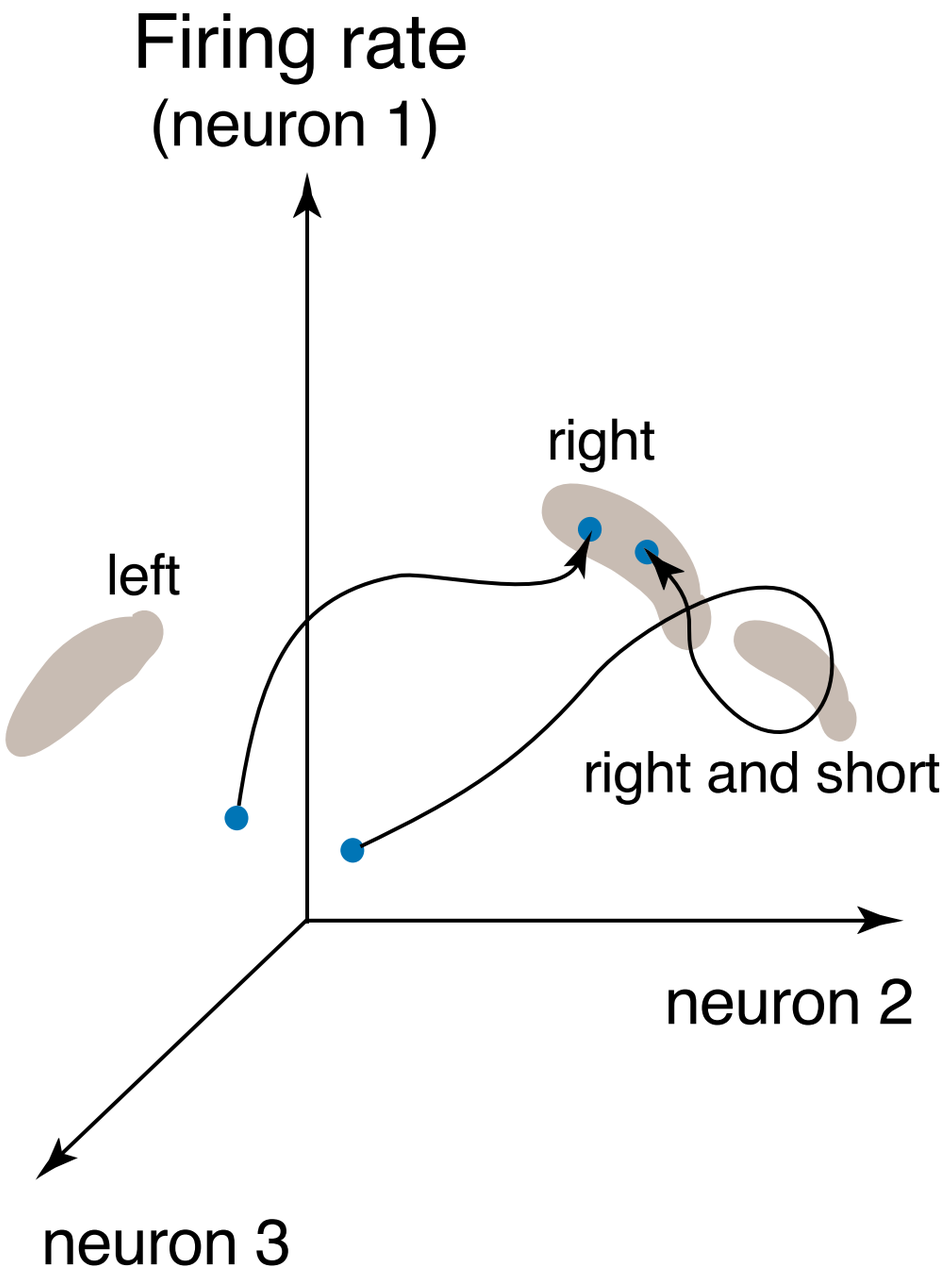

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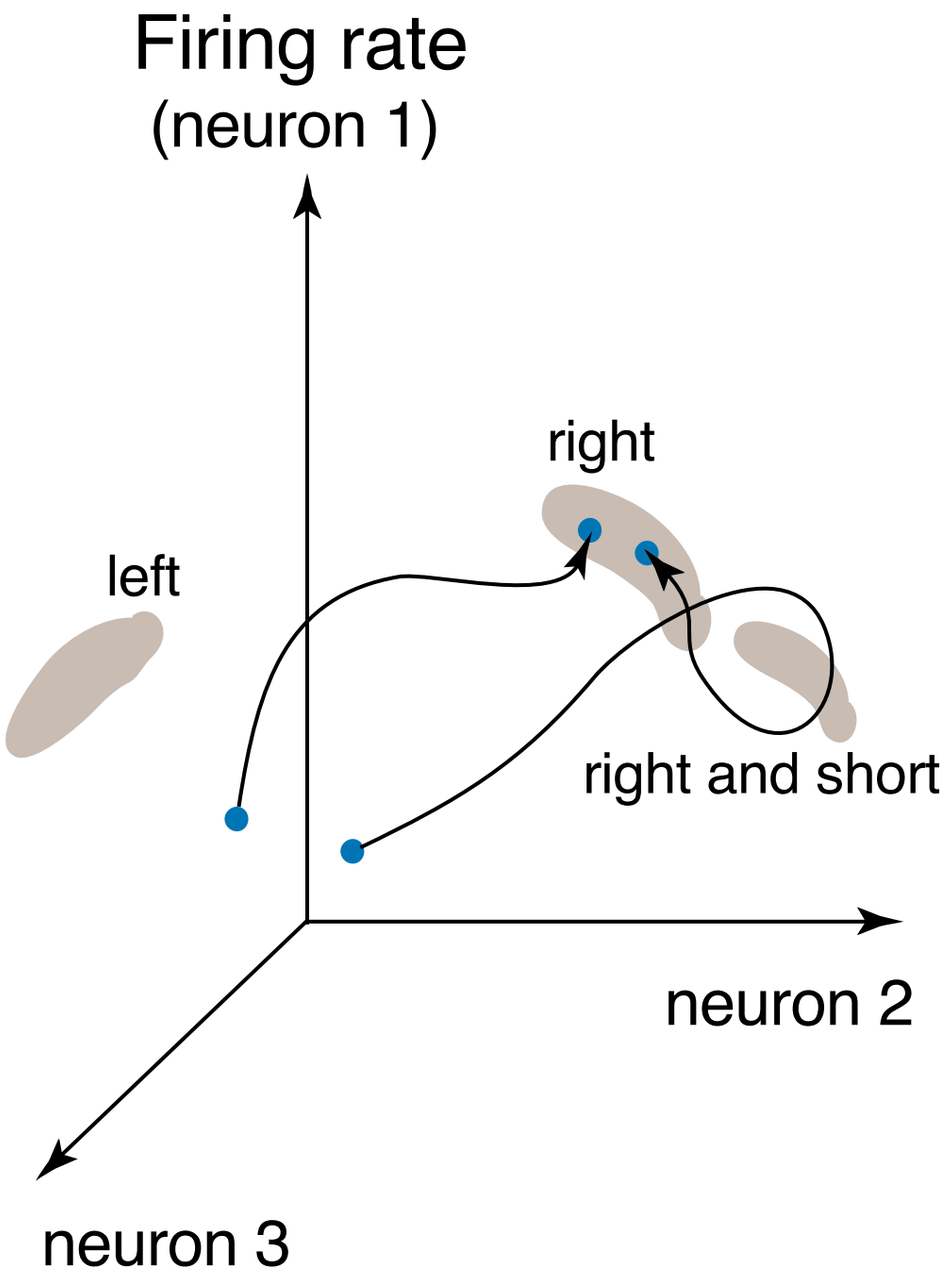

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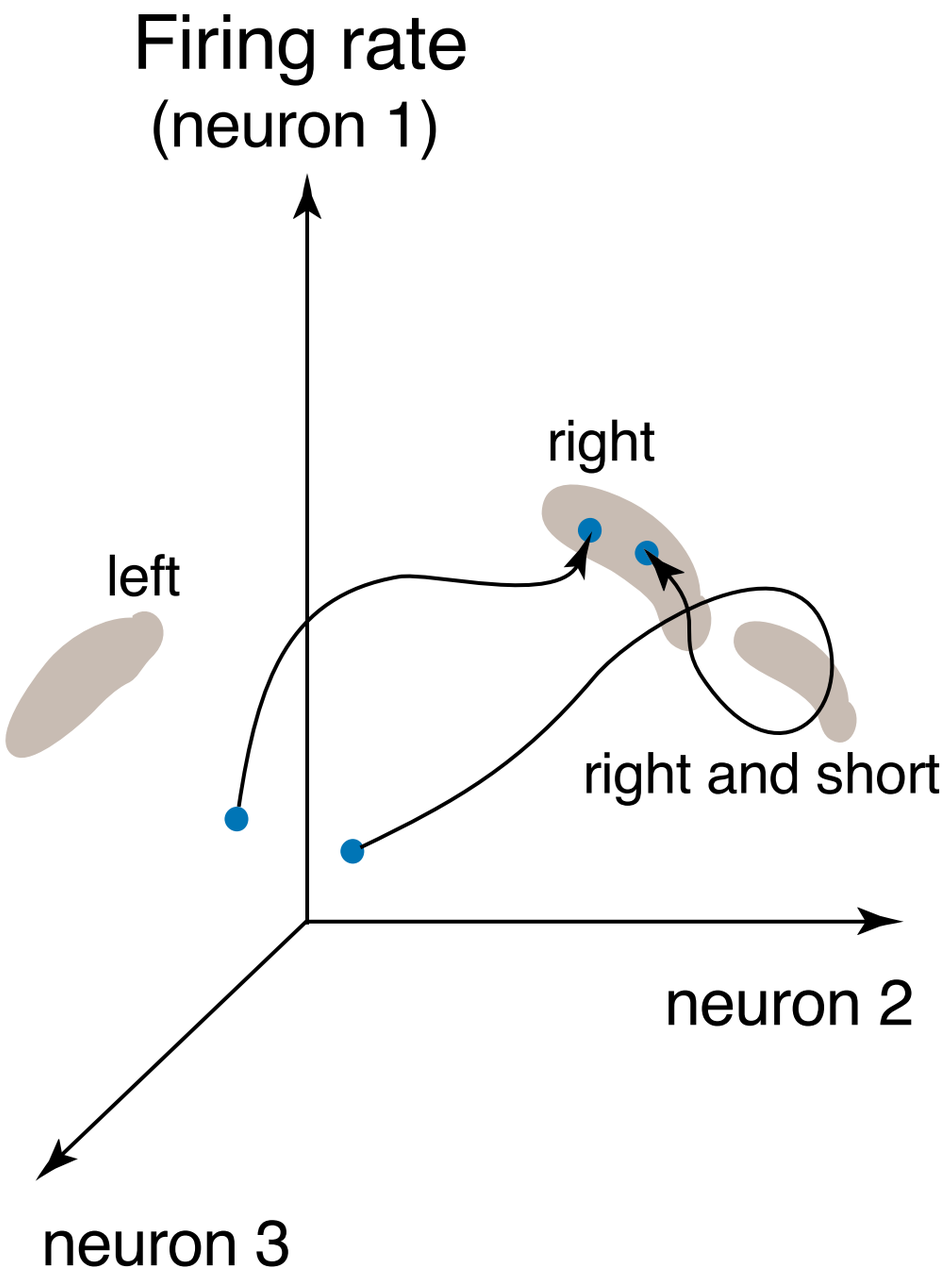

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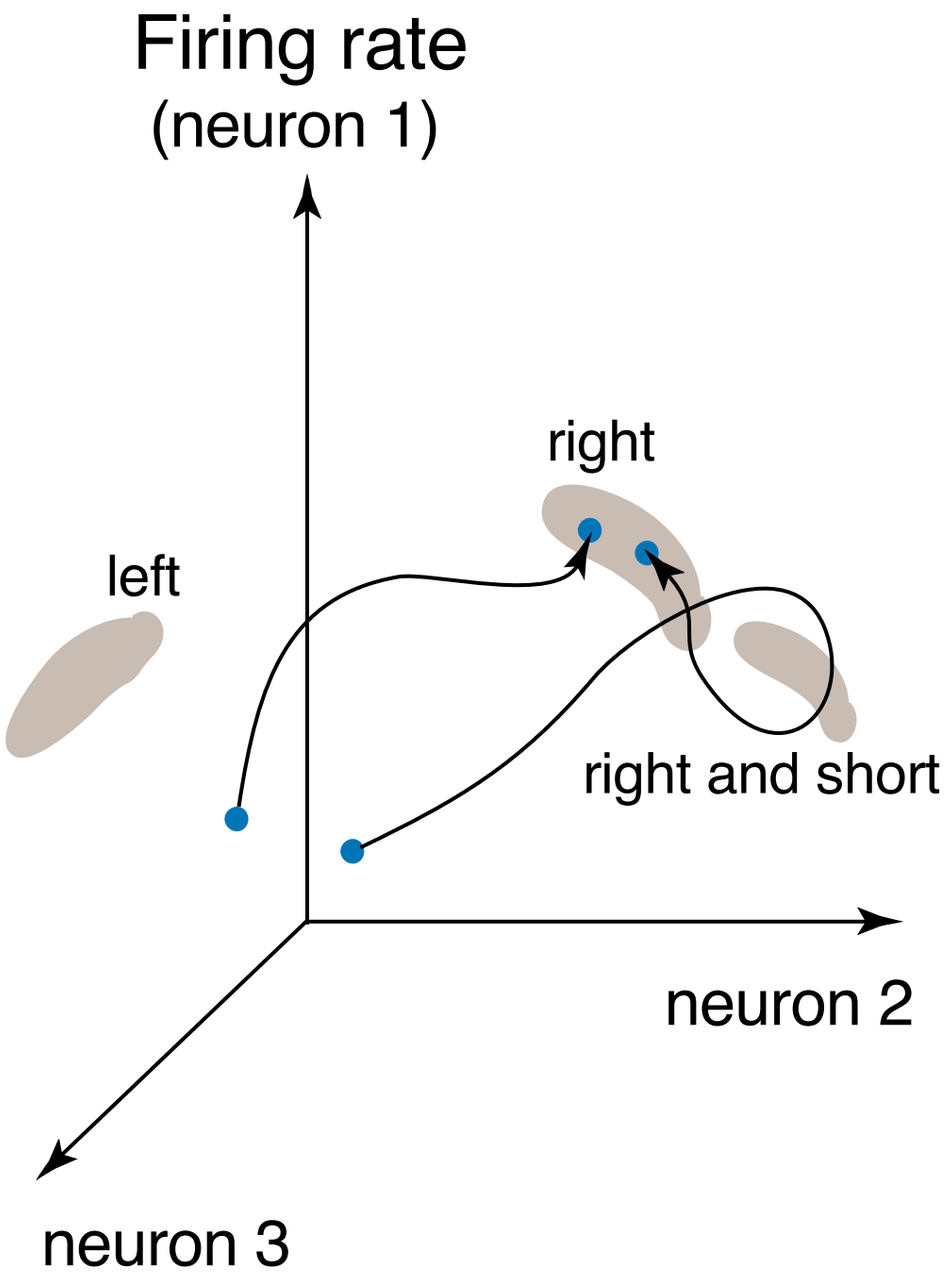

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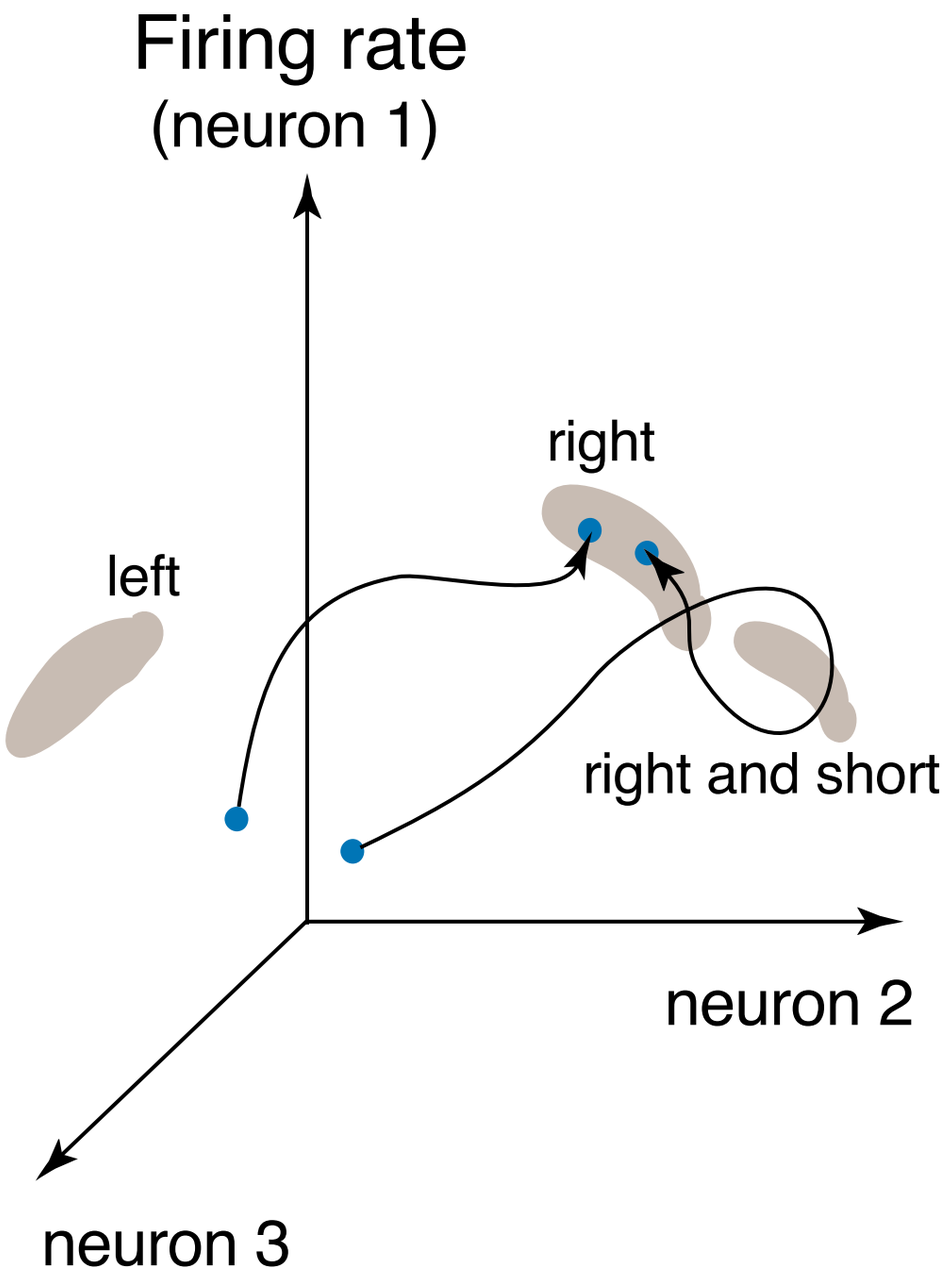

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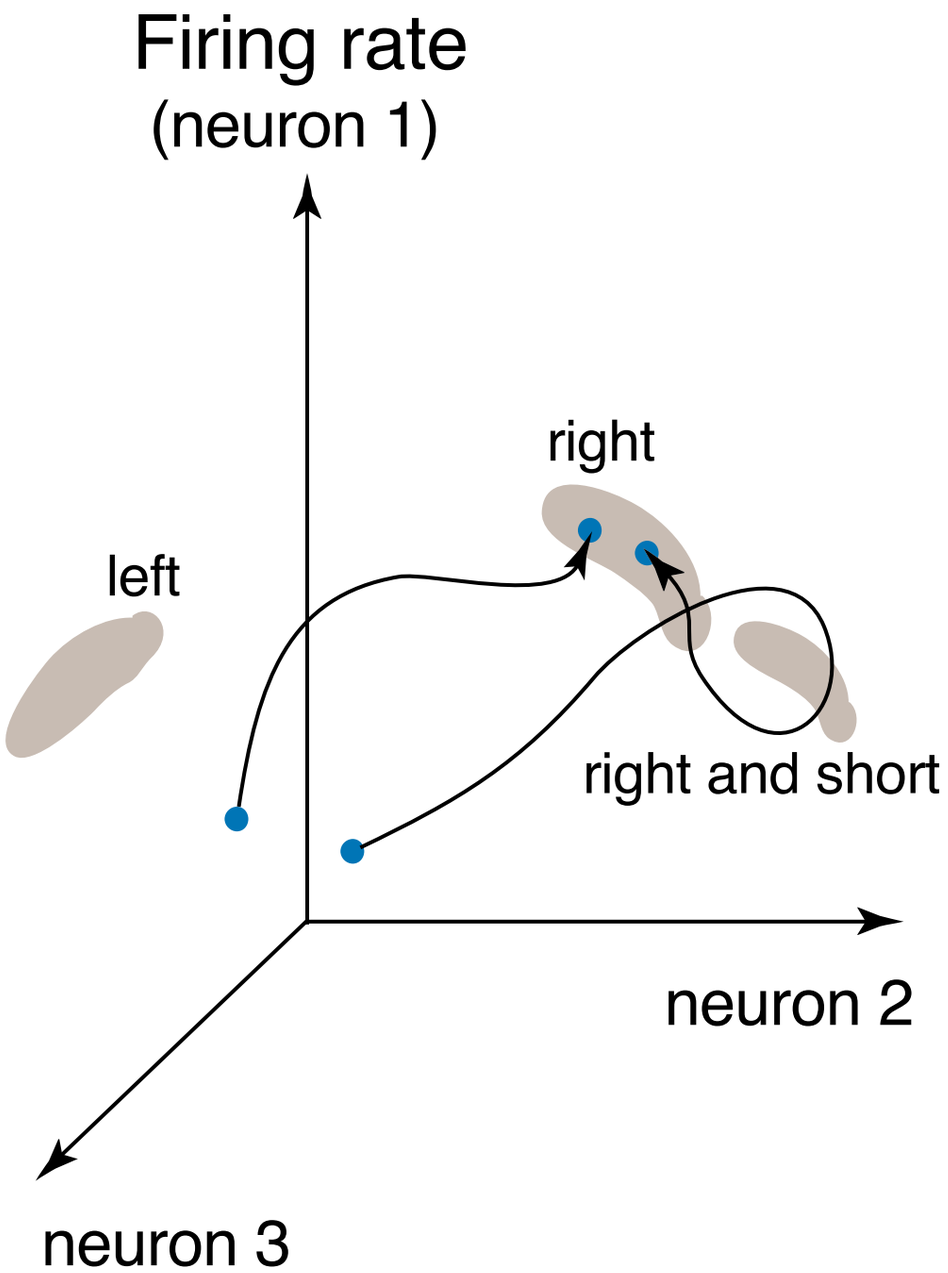

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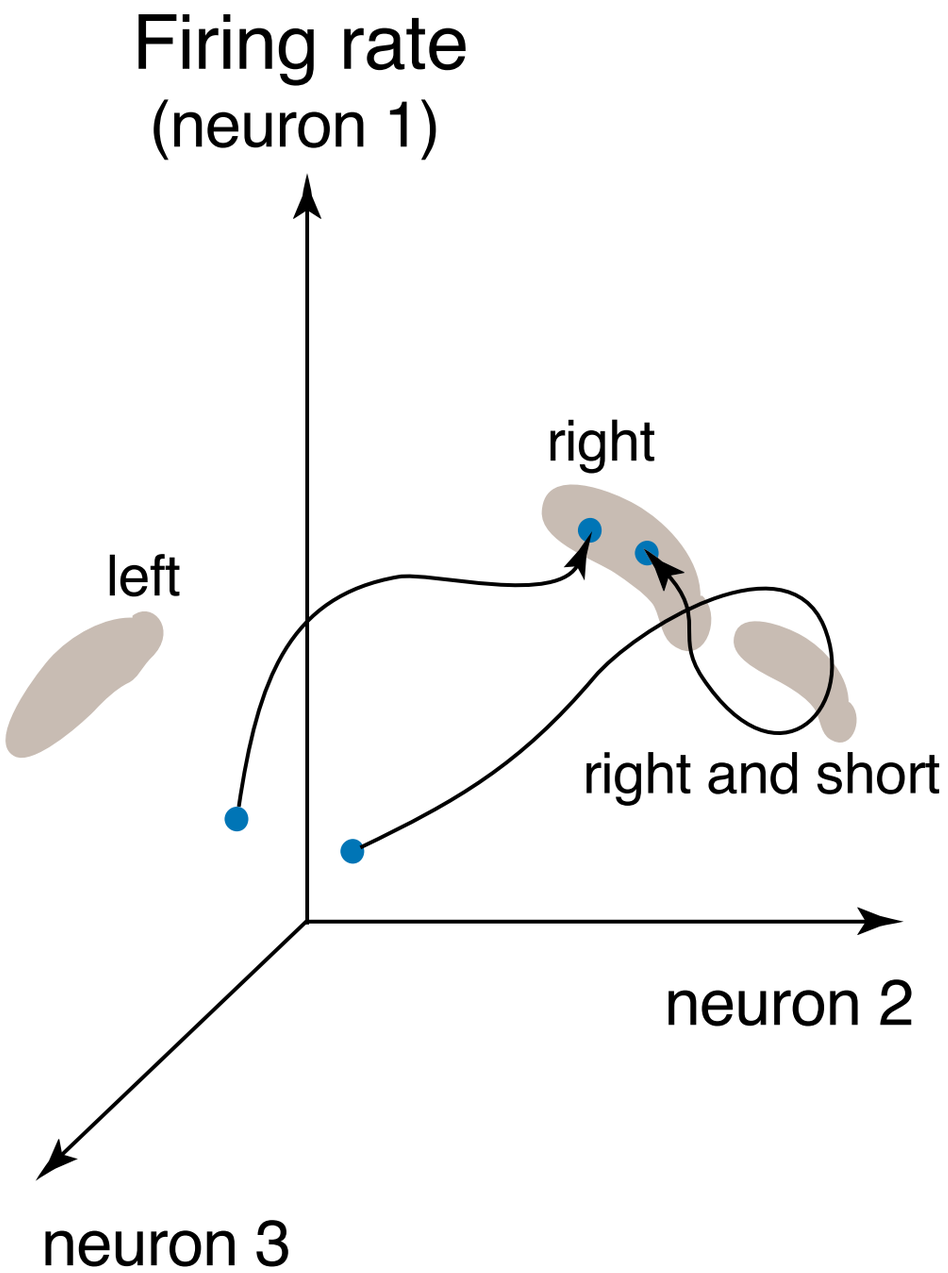

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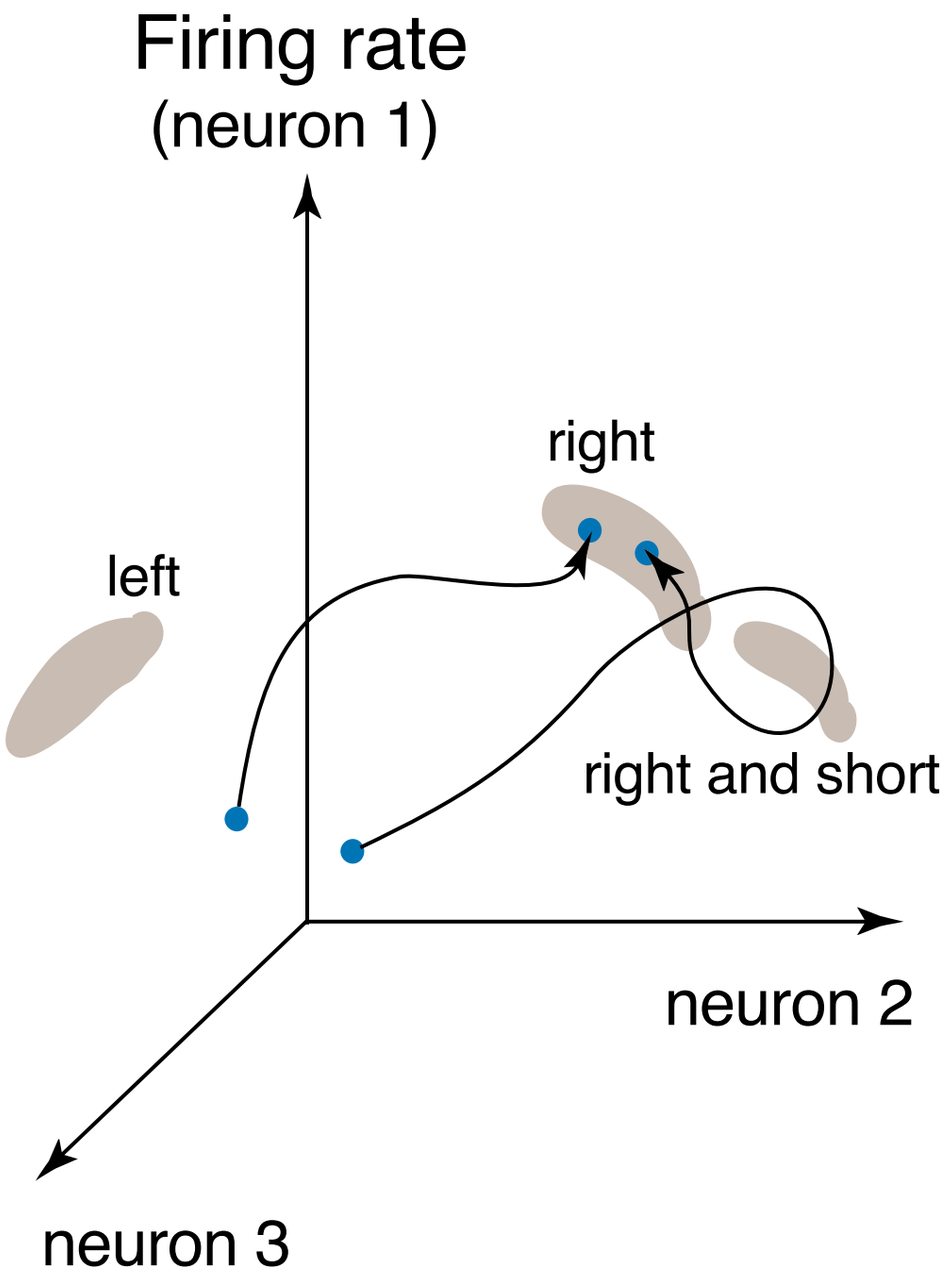

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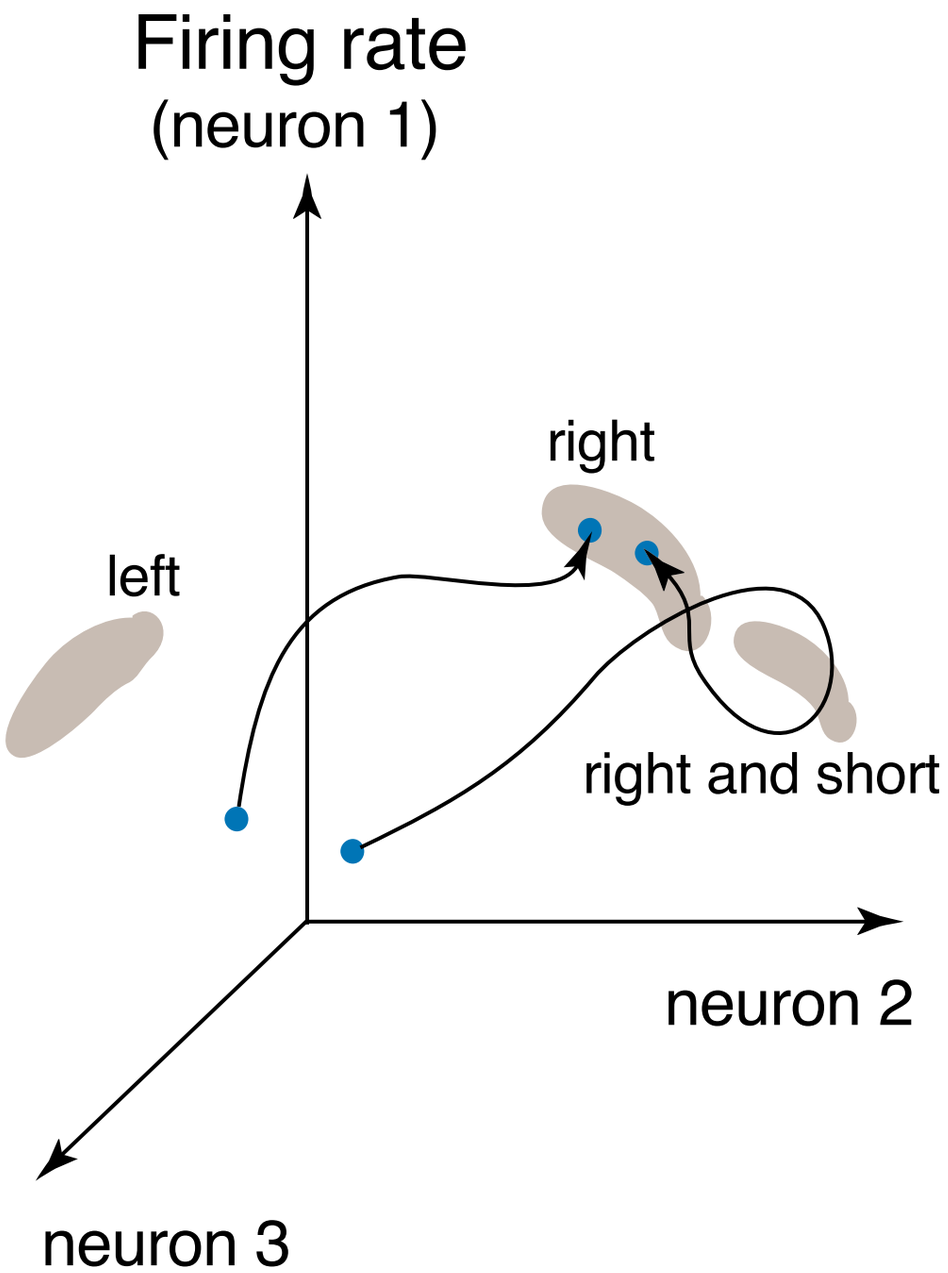

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- Dimensionality reduction techniques
  - Static: PCA, LLA, FA

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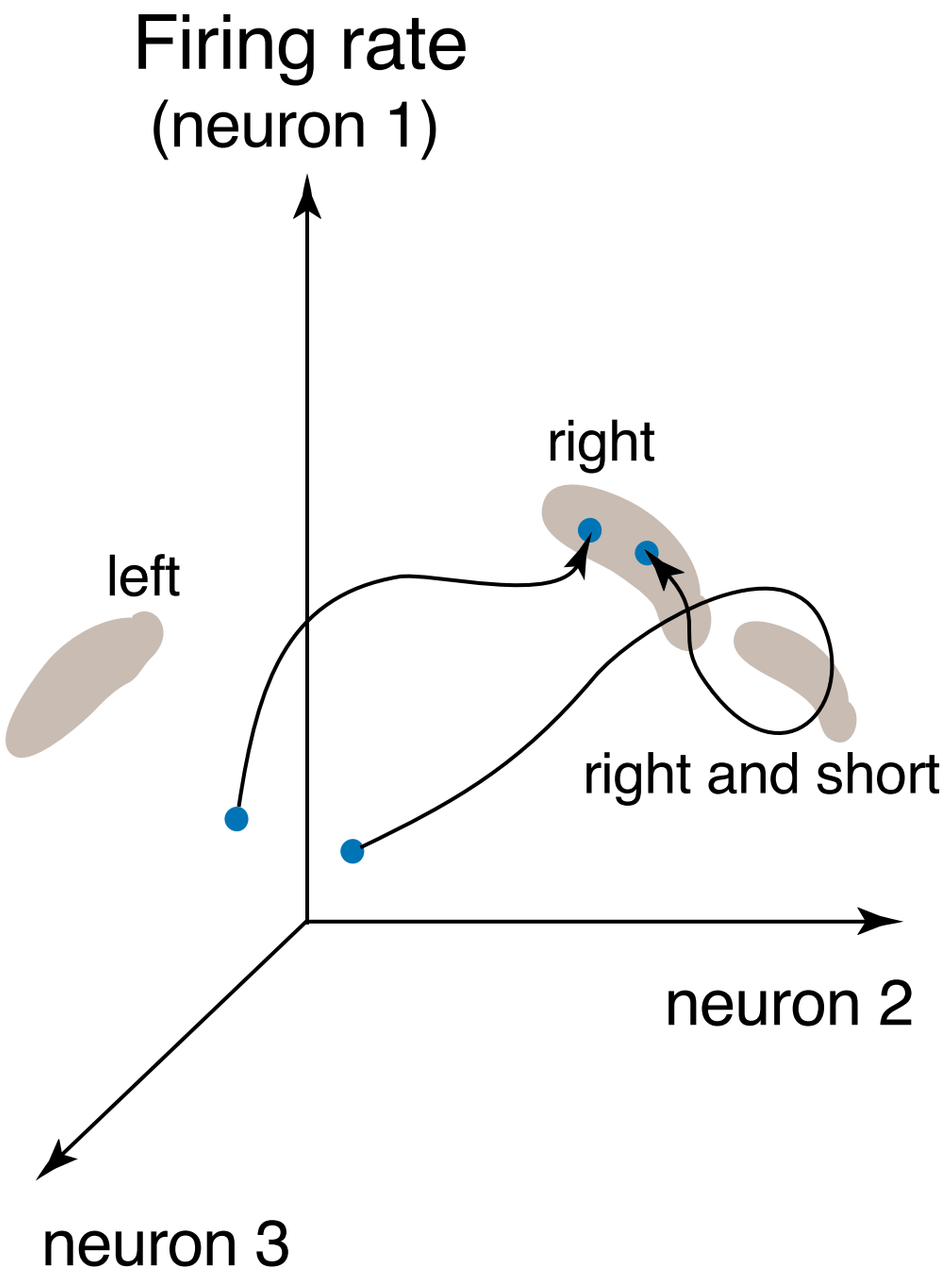
Visualizing Neural State, and Trajectories (Dimensionality Reduction)



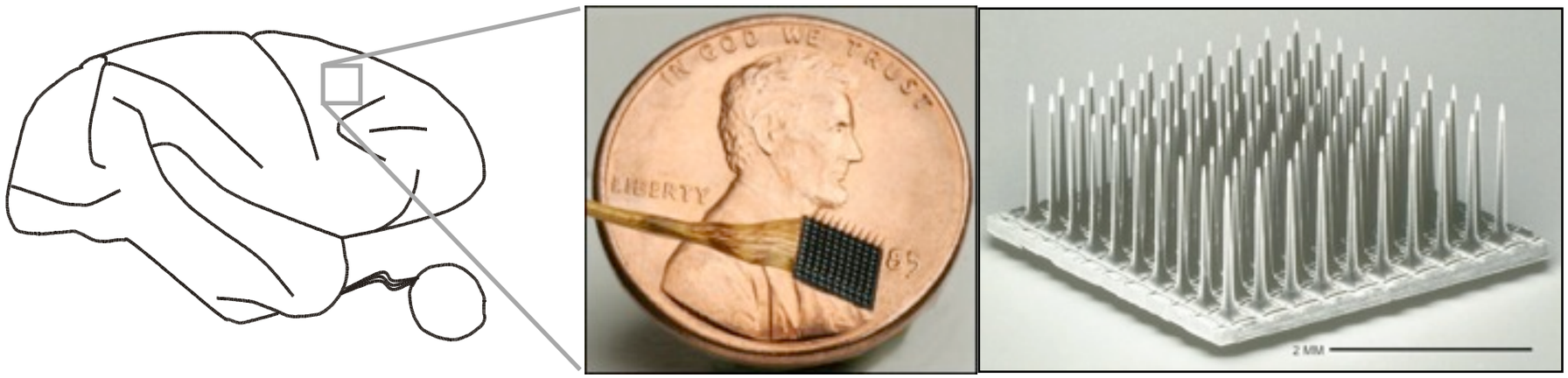
- Should be able to “see” these single-trial neural state trajectories, from data

- But need array recordings
  - Many neurons simultaneously
  - Activity from various neurons correlated
  - Implies lower D system (than # neurons)
  - So reduce D to de-noise (e.g., 10-15D)
    - Note: calculate correlates here
  - Lower D even more to plot (e.g., 3D)
    - Note: do not calculate correlates here

- Dimensionality reduction techniques
  - Static: PCA, LLA, FA
  - Dynamic: GPFA (Yu et al. 2009 *JNP*)

Churchland et al. (2007) *Current Opinion Neurobiology;* Yu et al. (2009) *J Neurophysiol*

Array Recordings and Raw Single-Trial Data



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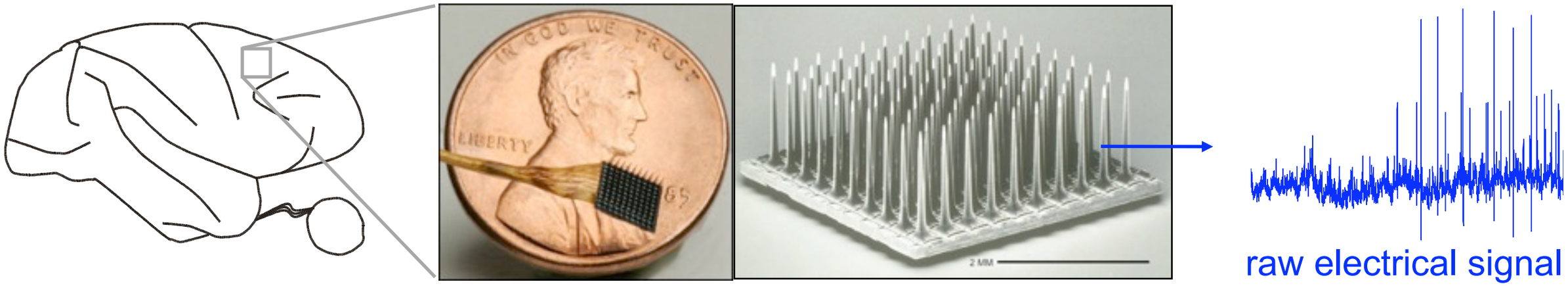

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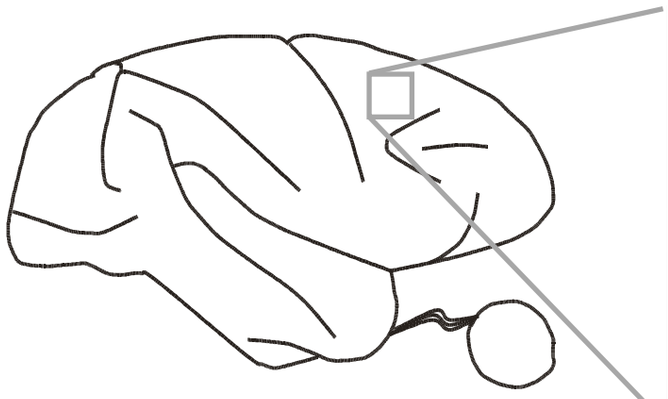
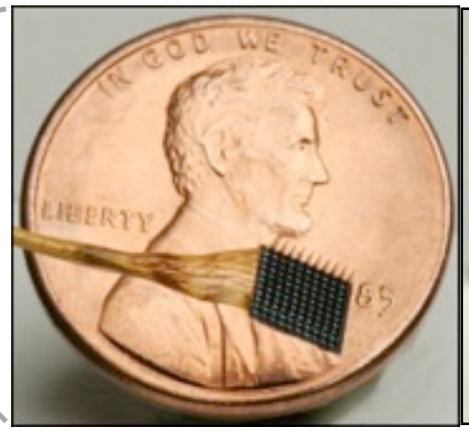
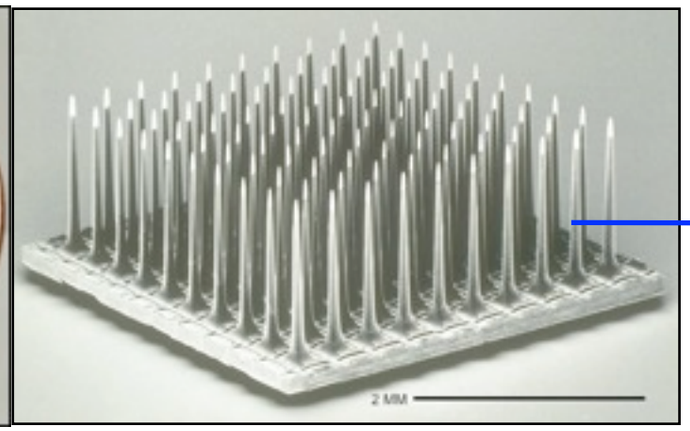
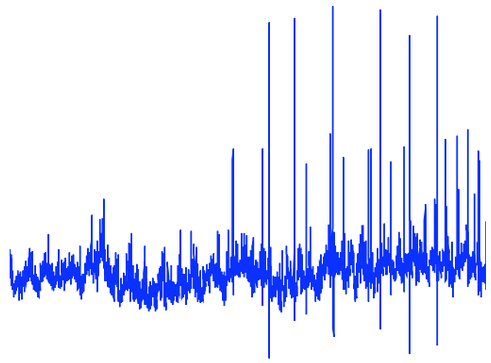
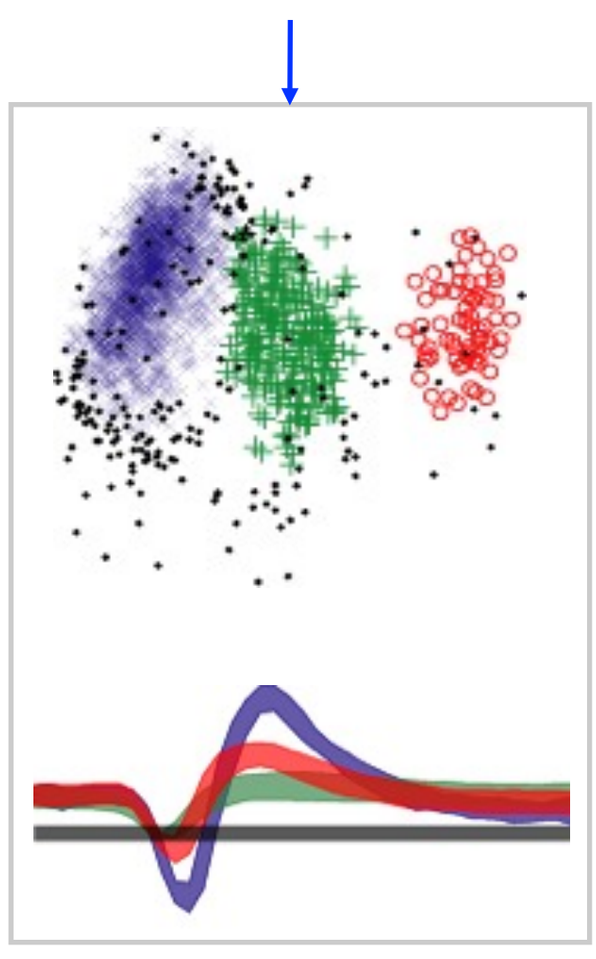








raw electrical signal



spike sorting

Santhanam et al. (2006) *Nature*

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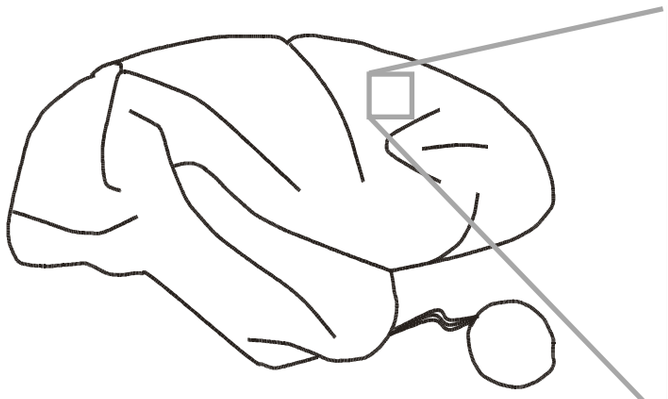

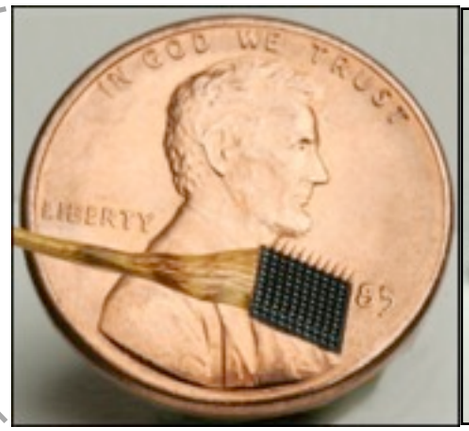

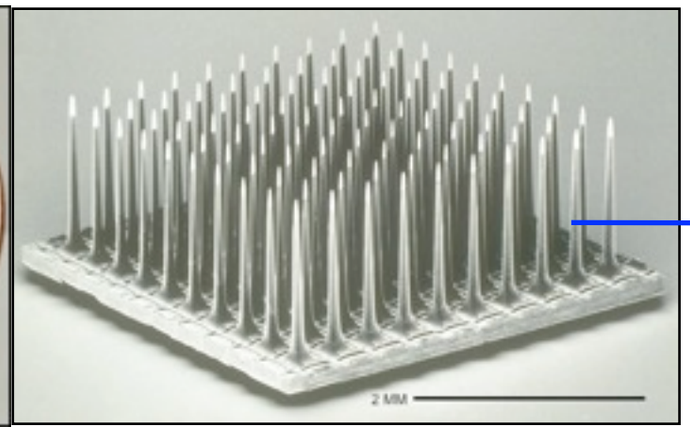

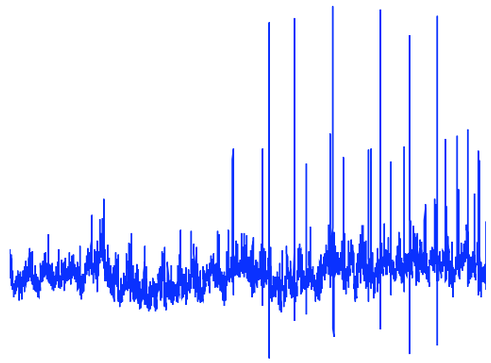

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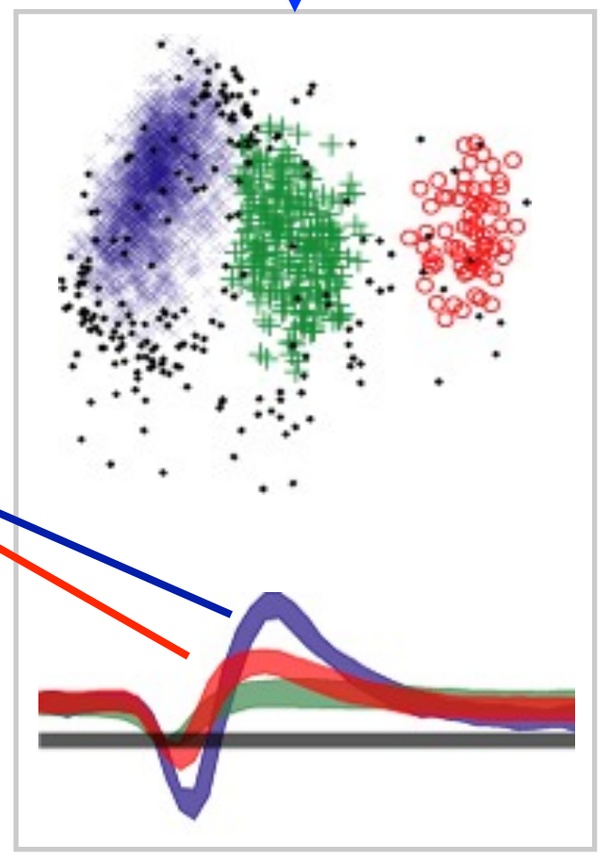

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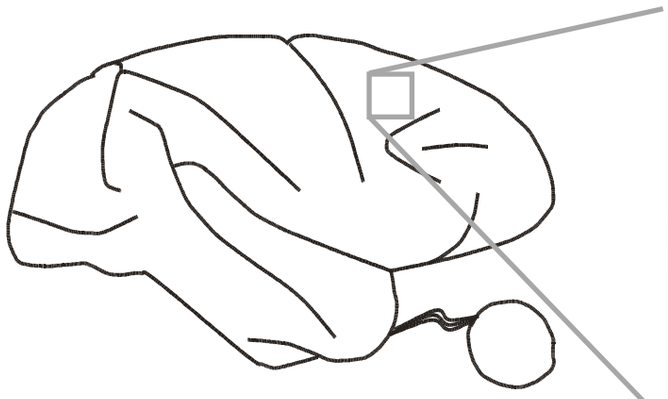
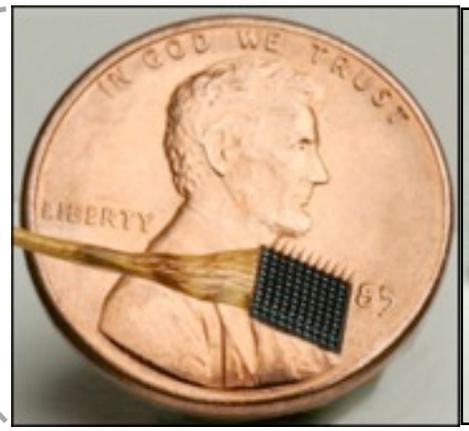
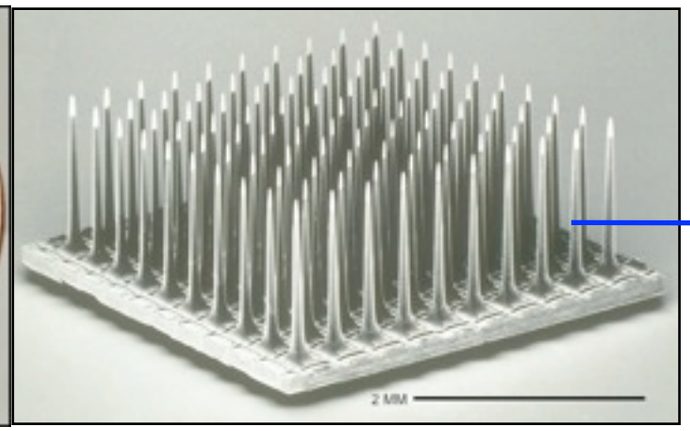
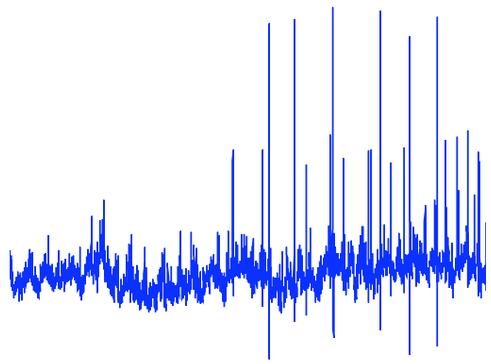






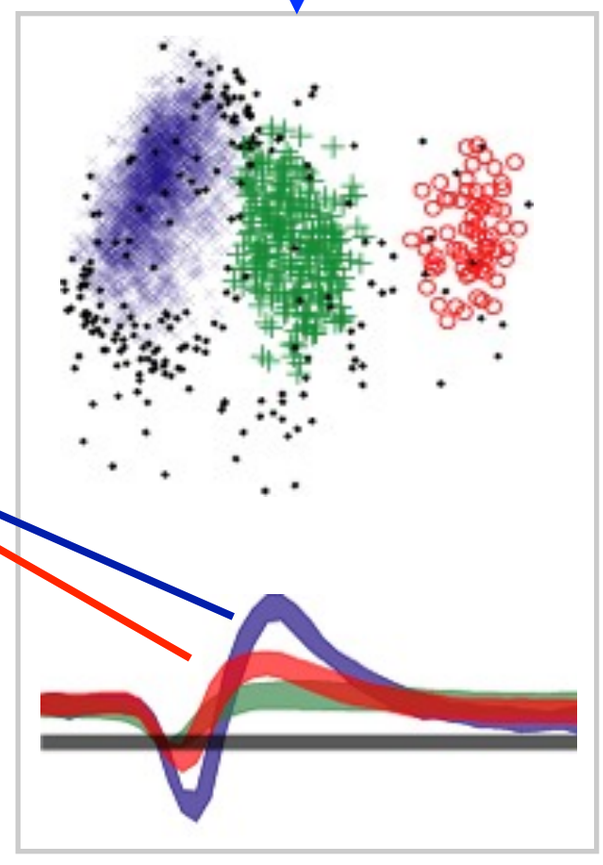


raw electrical signal

target cue go cue movement onset

Neurons

200 ms



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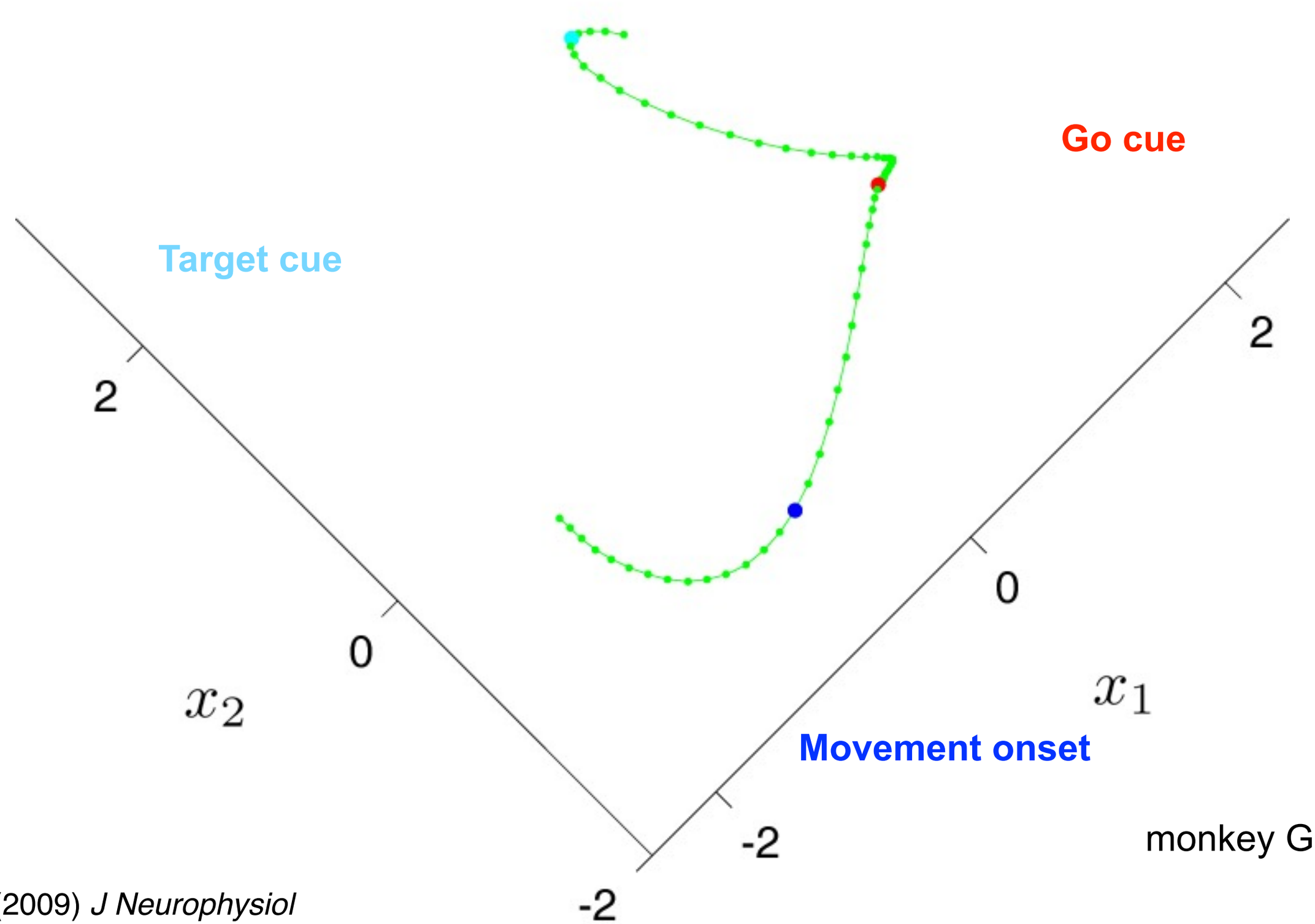
Visualizing Neural State, and Trajectories (in 2D)



monkey G

Yu et al. (2009) *J Neurophysiol*

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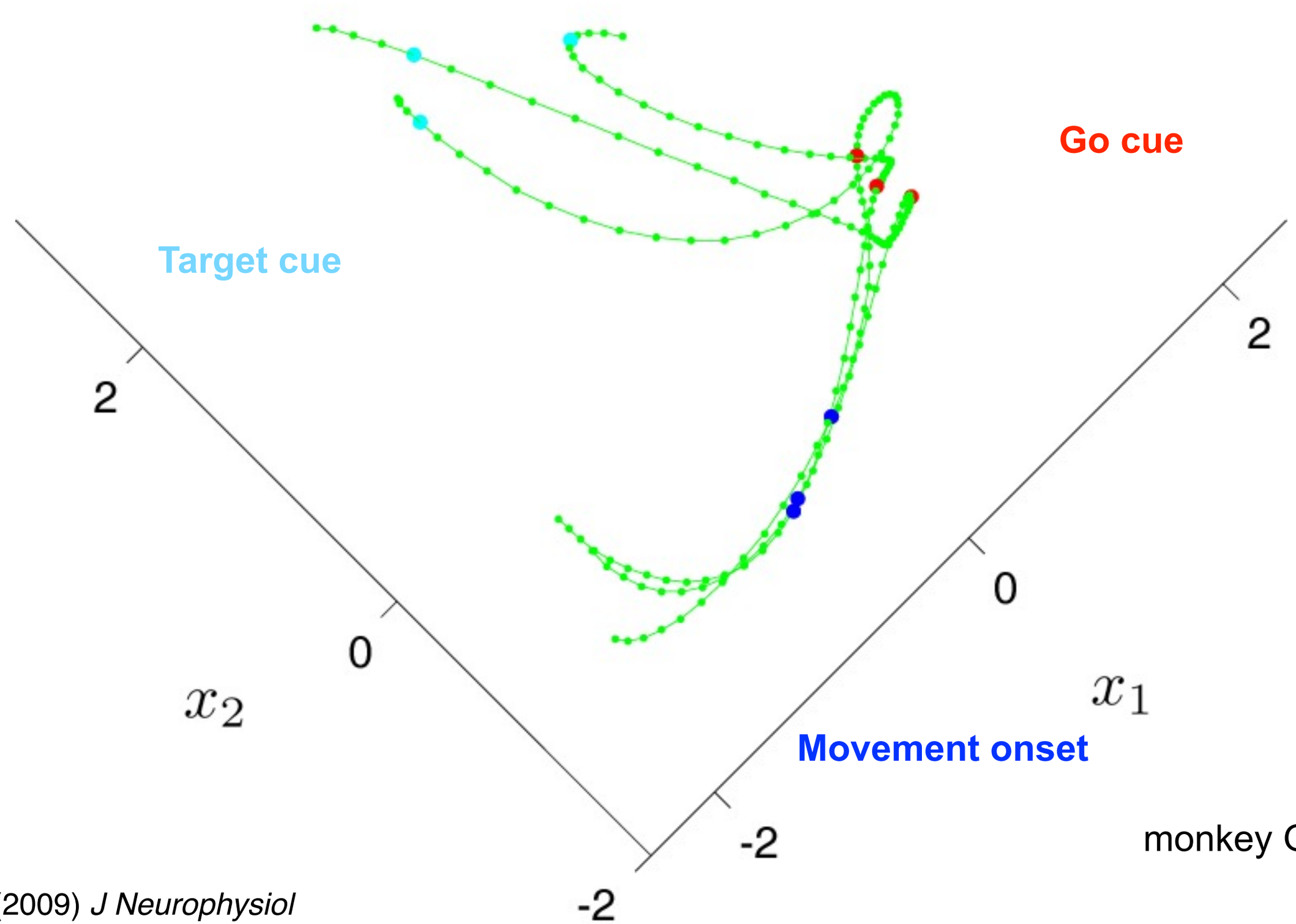

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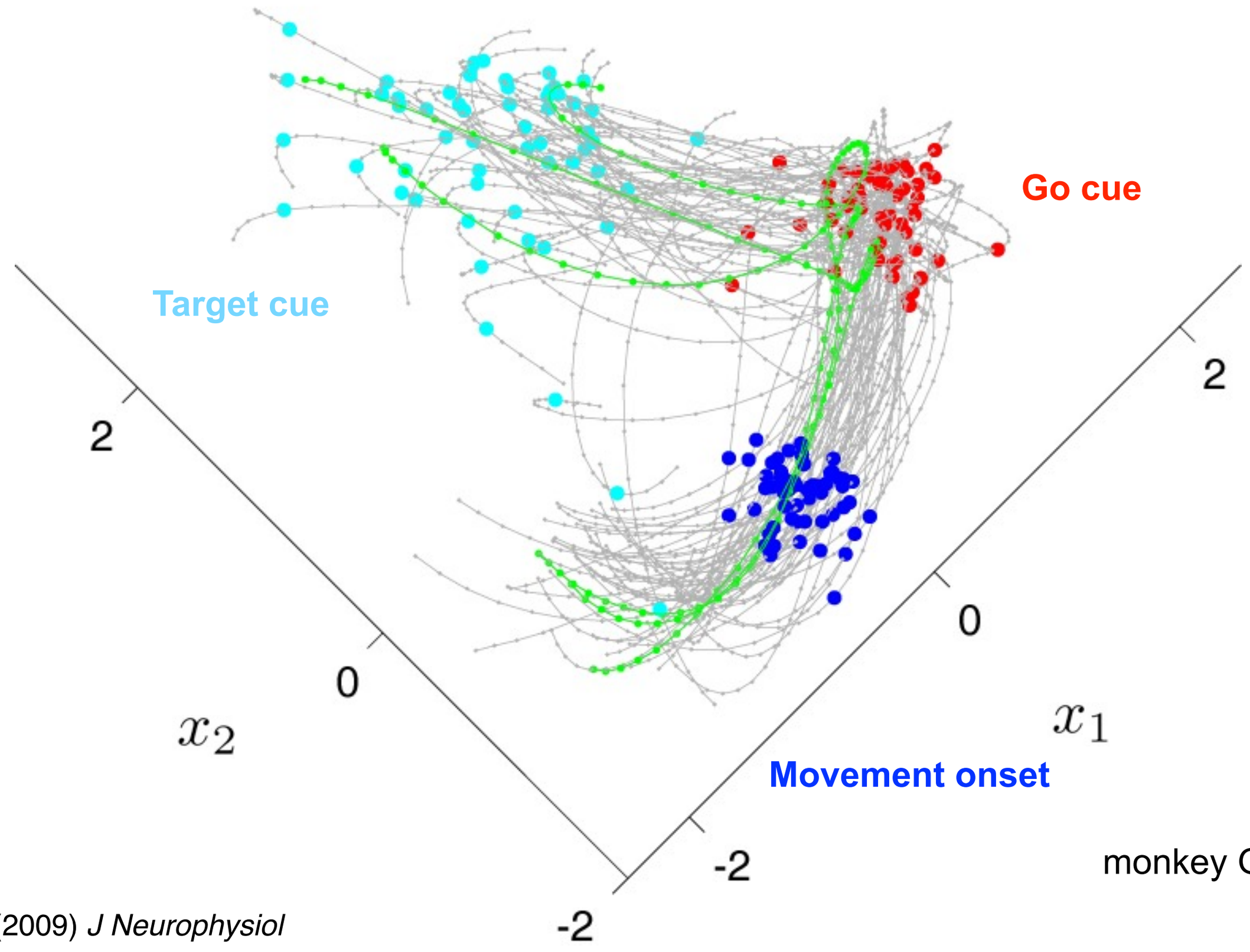

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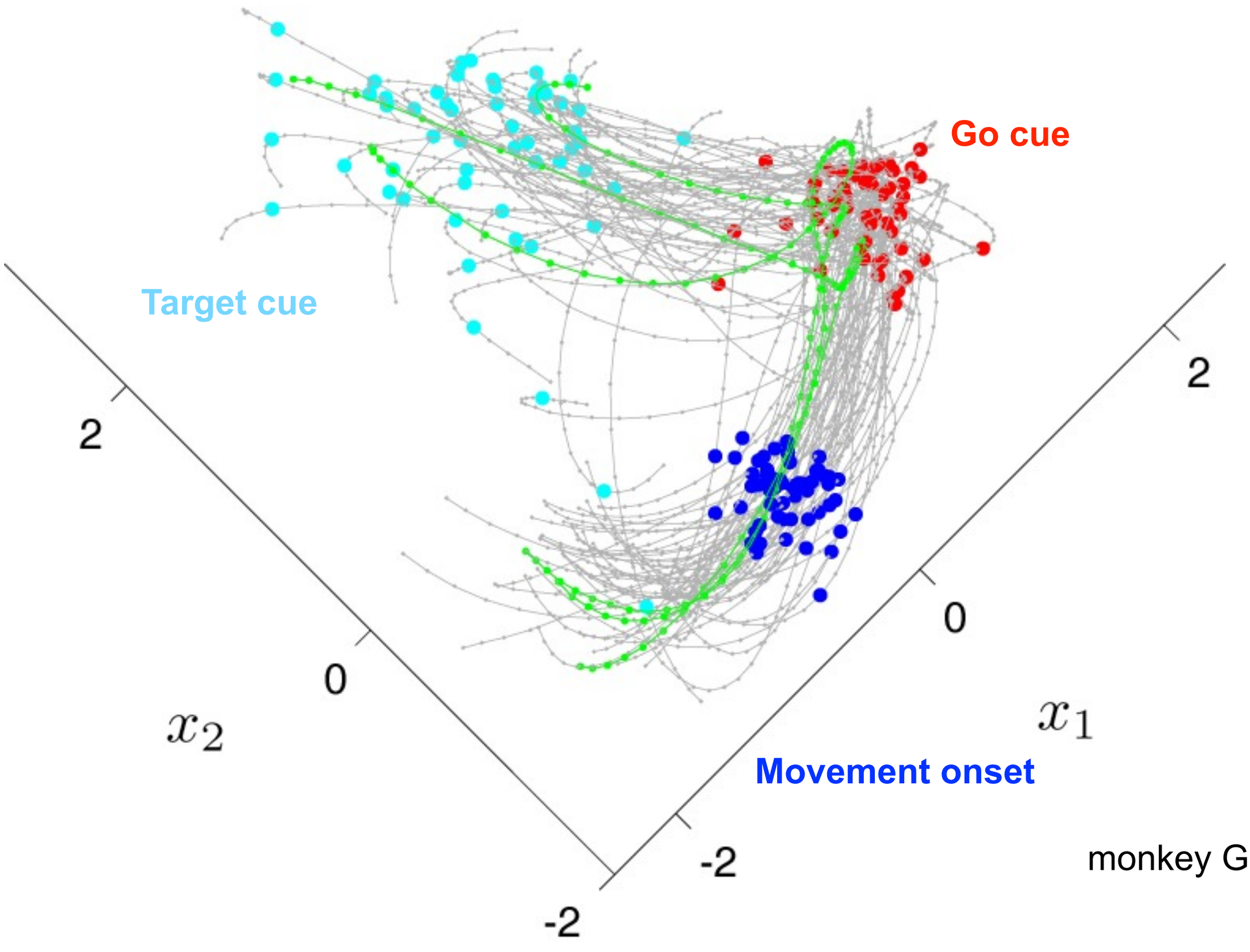

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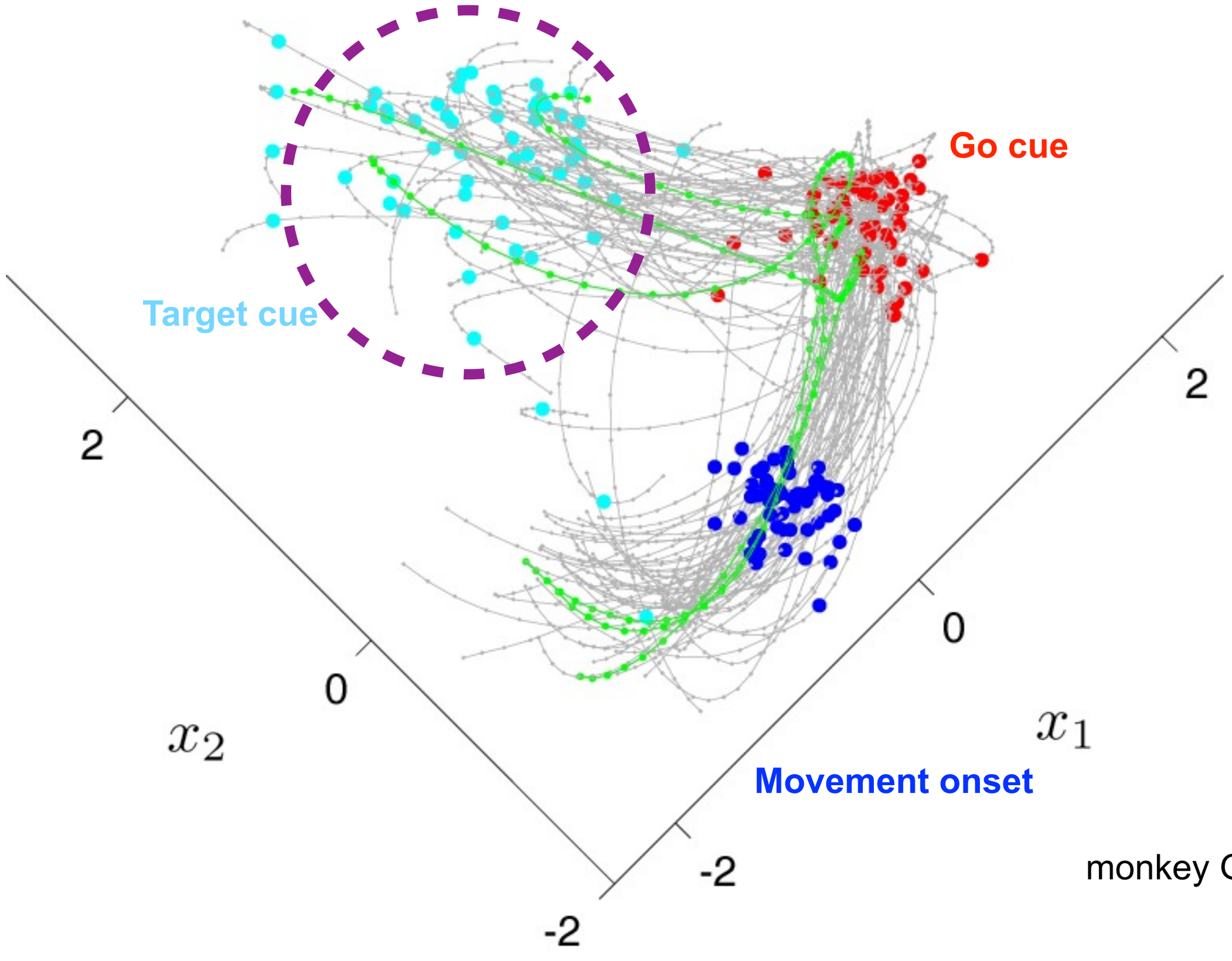

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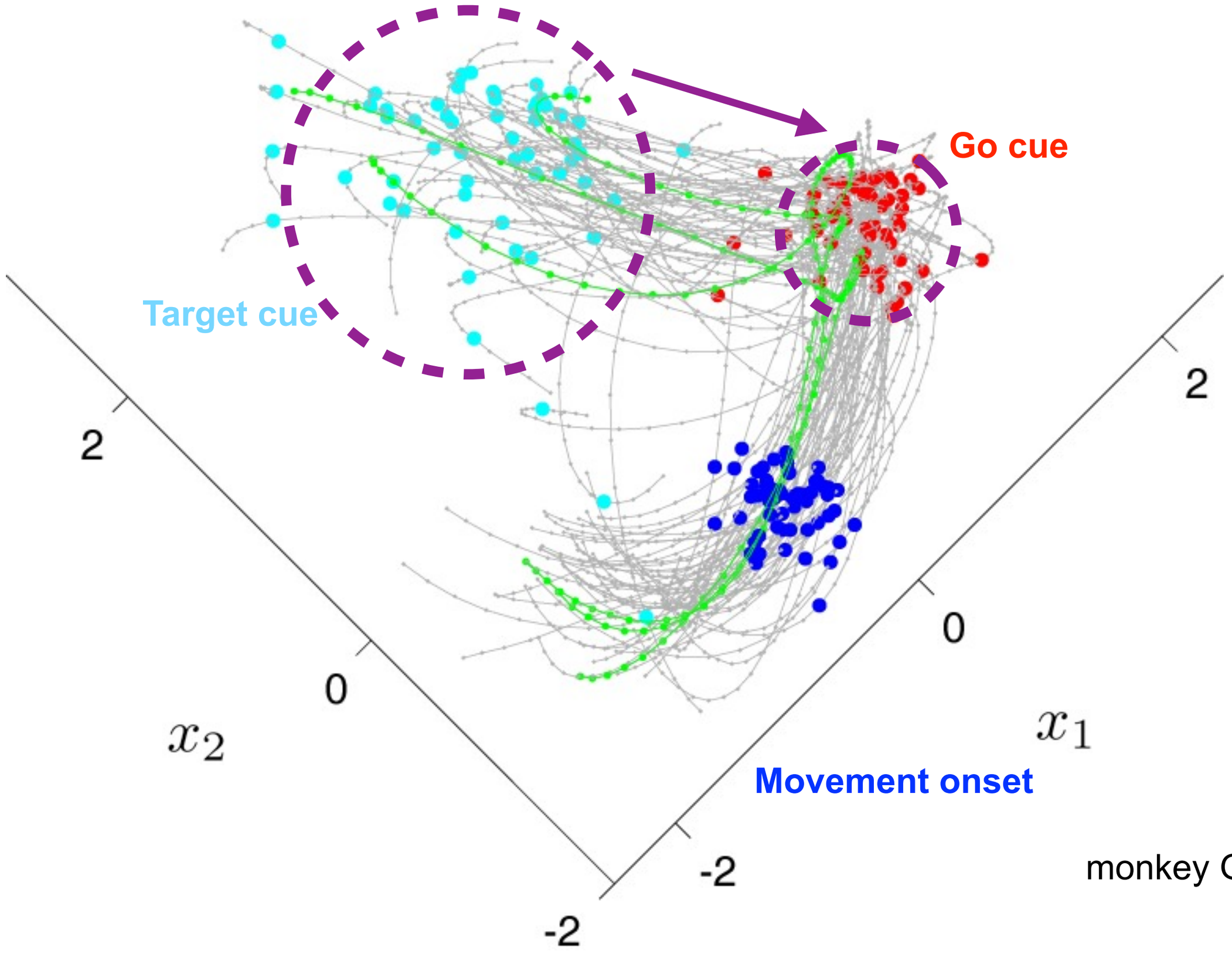

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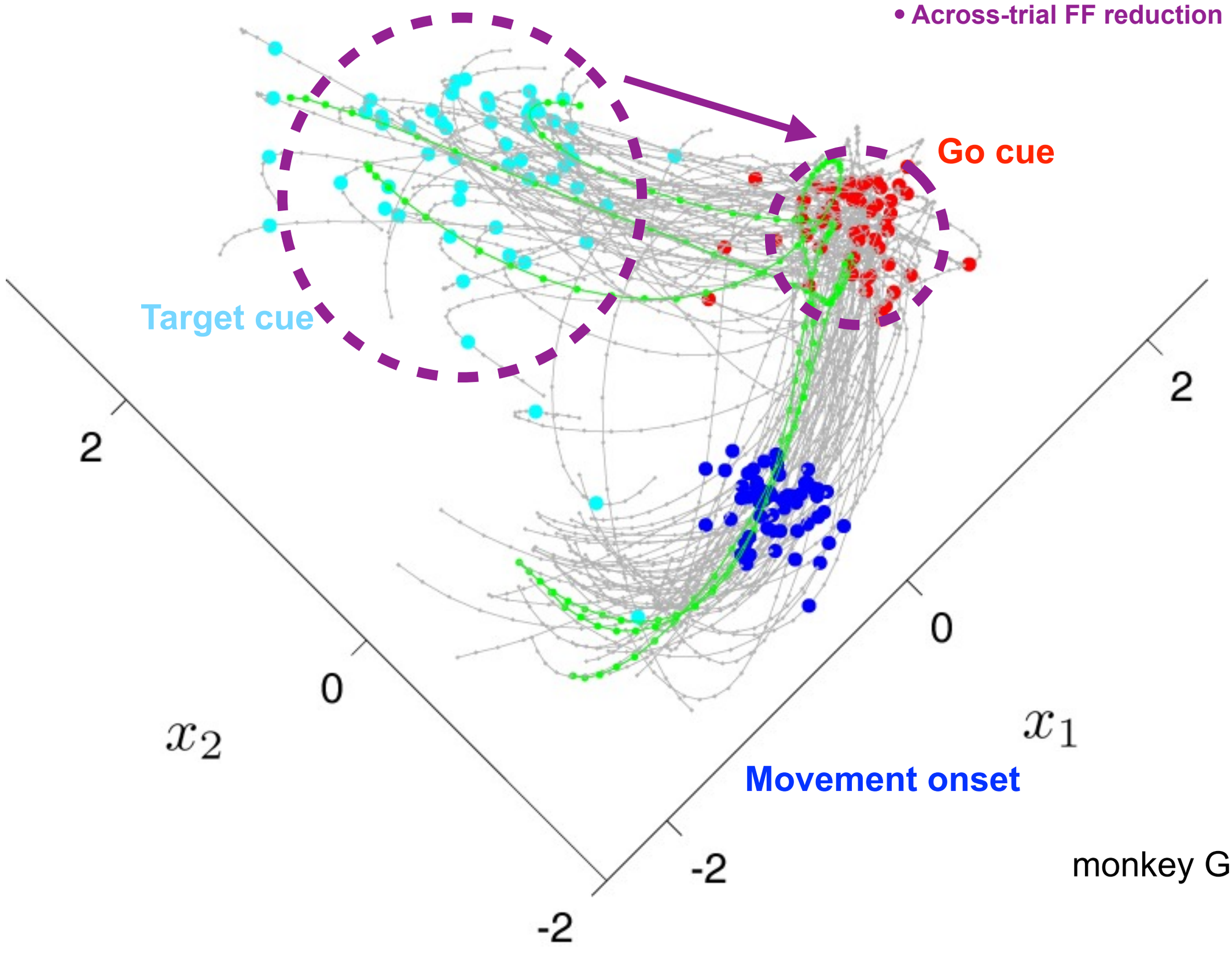

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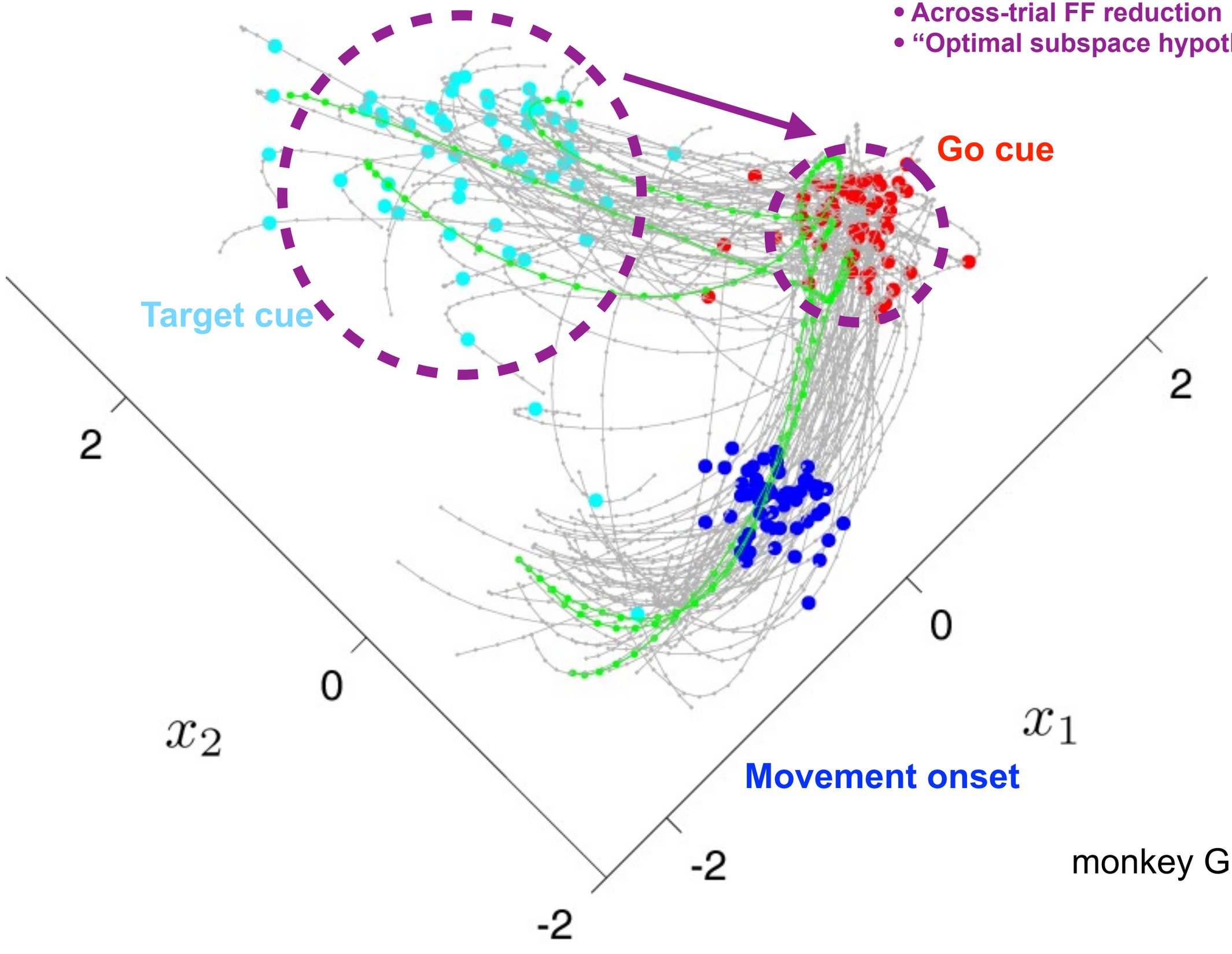

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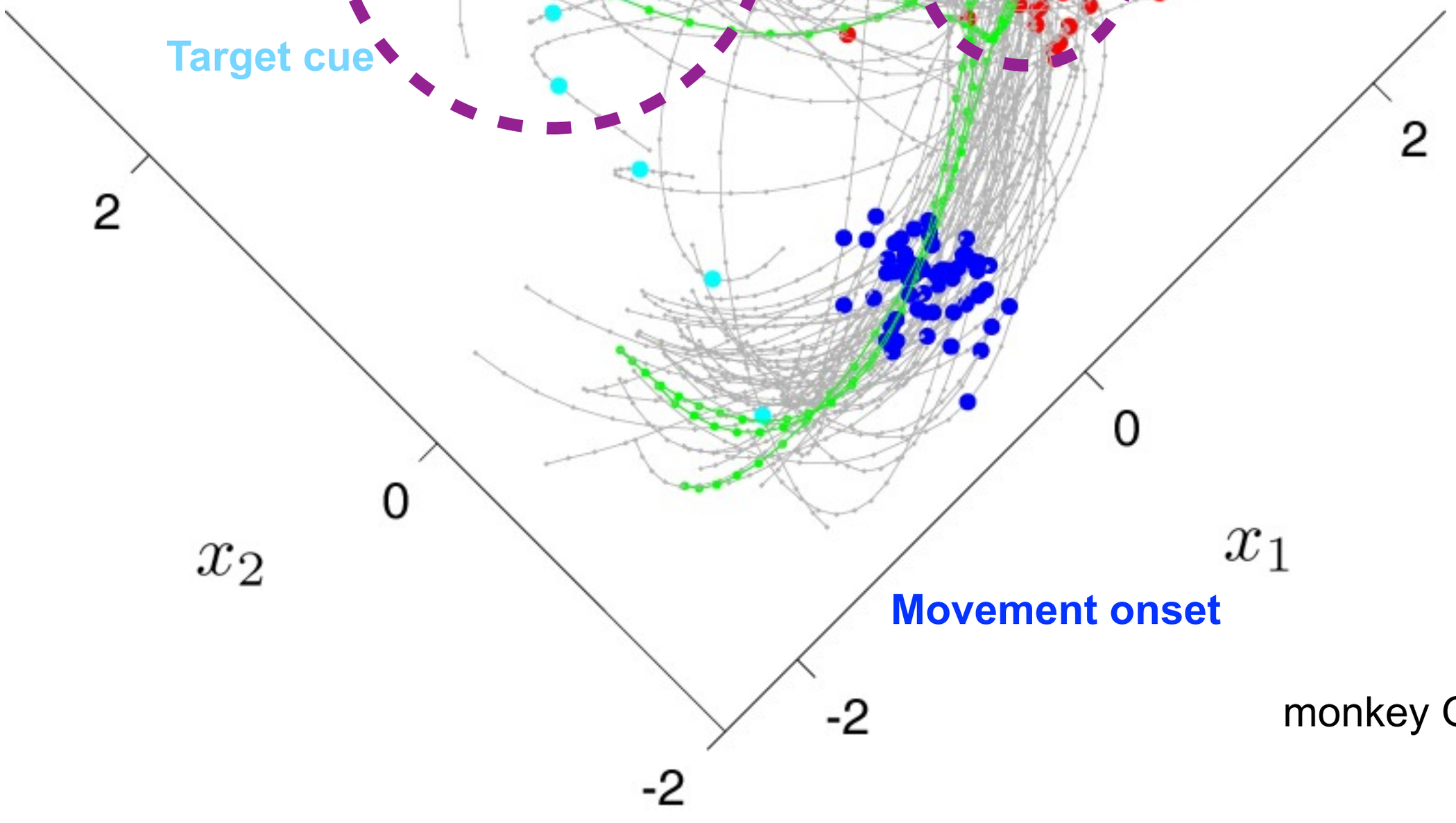
Go cue

Target cue



Movement onset

monkey G

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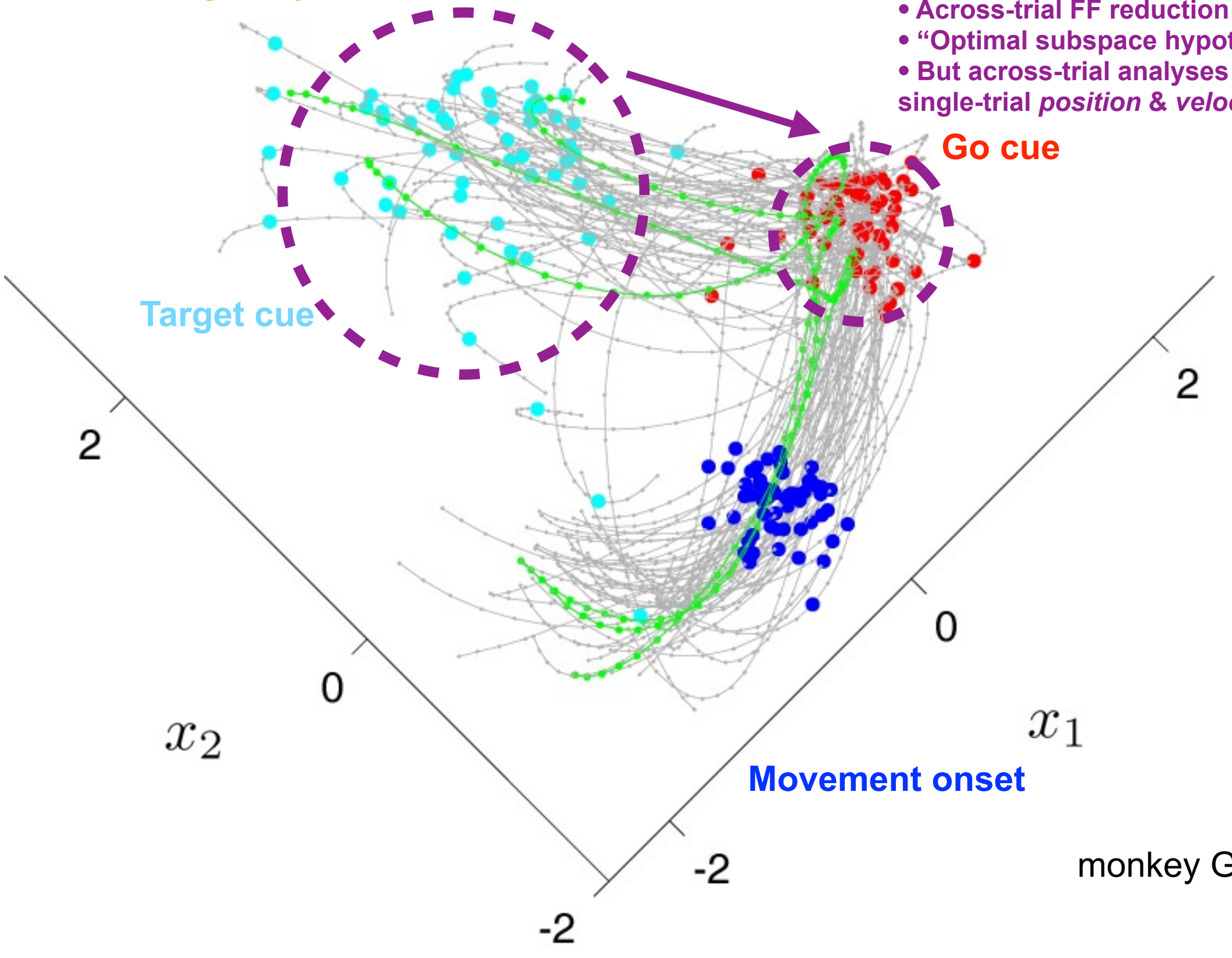

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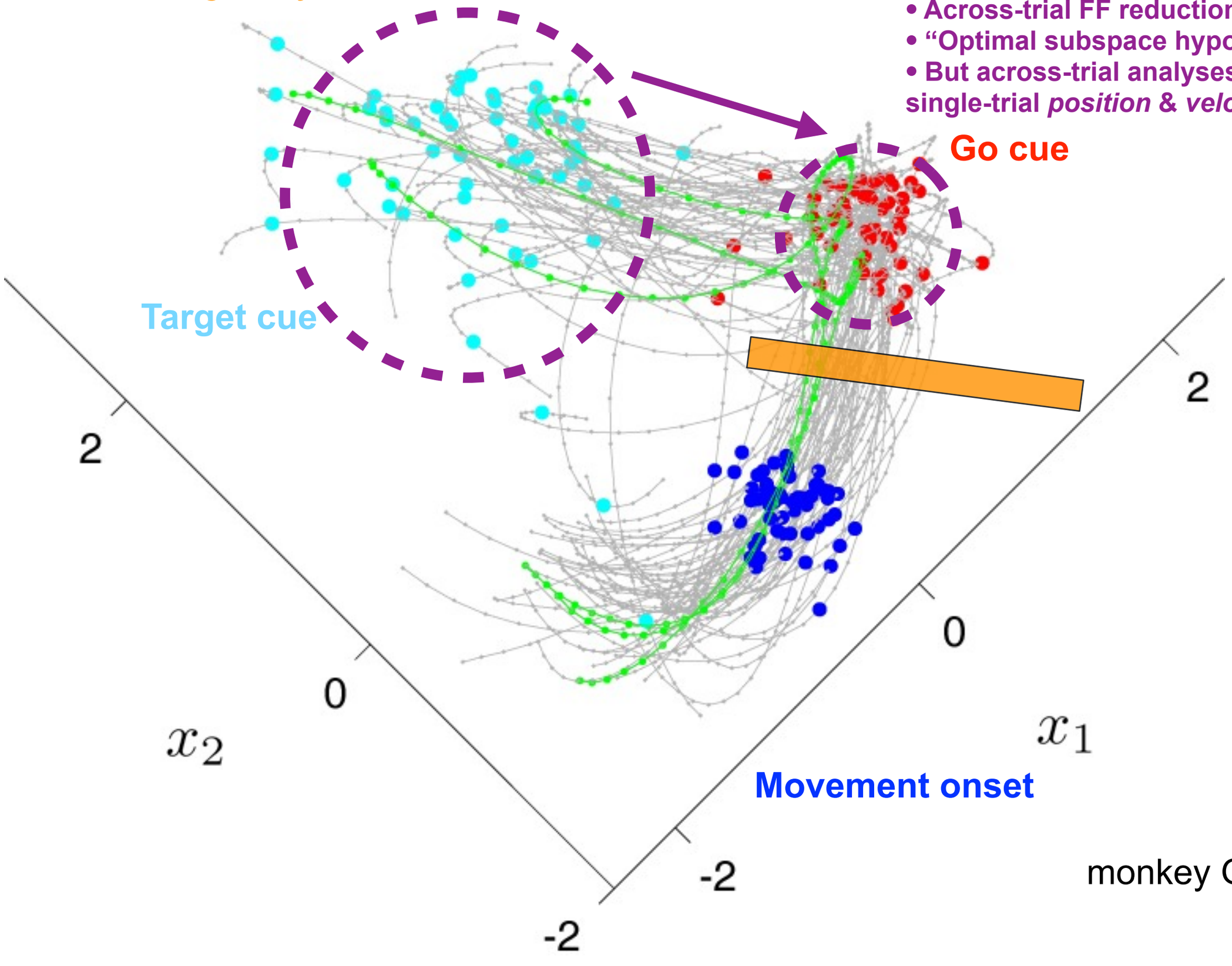

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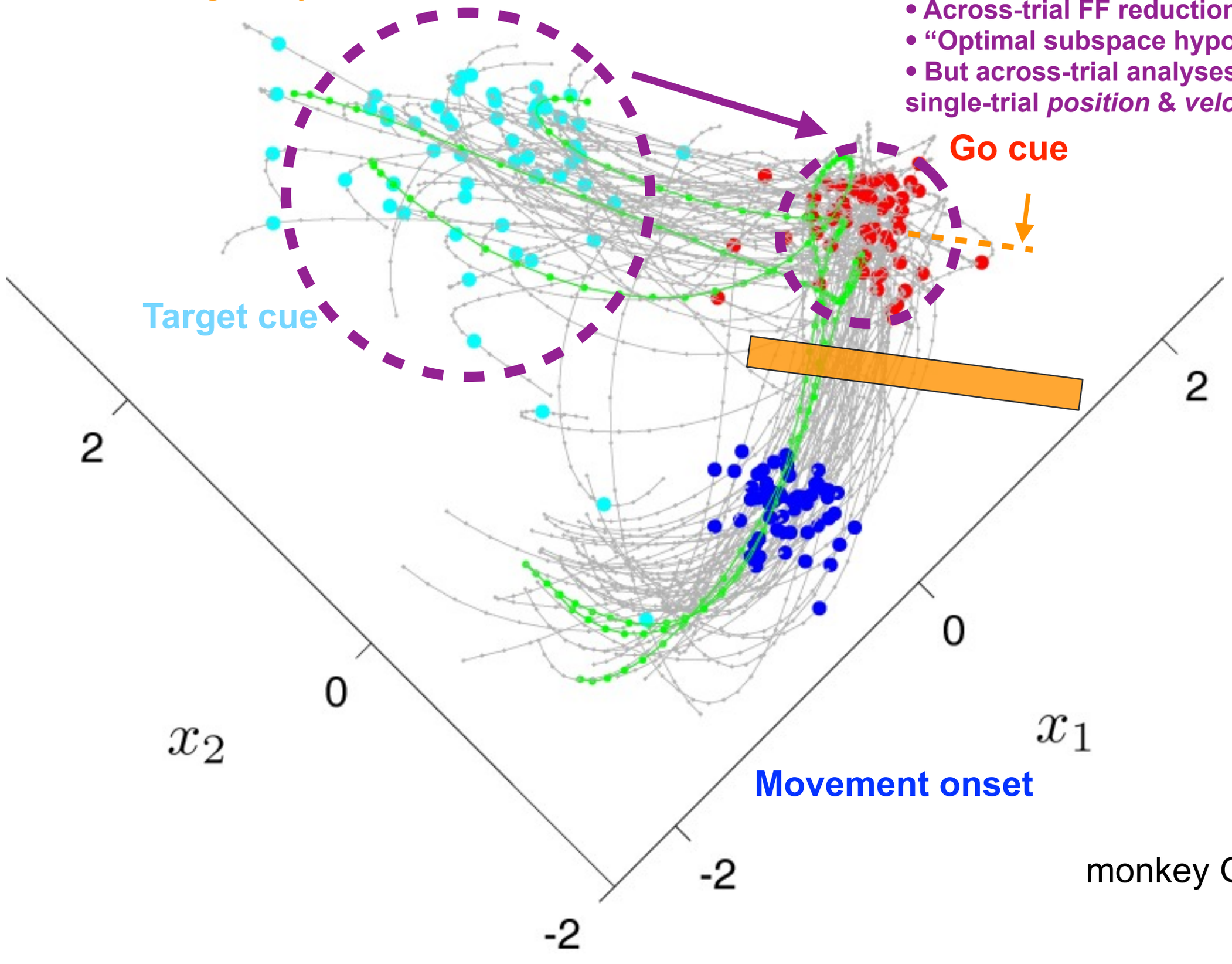

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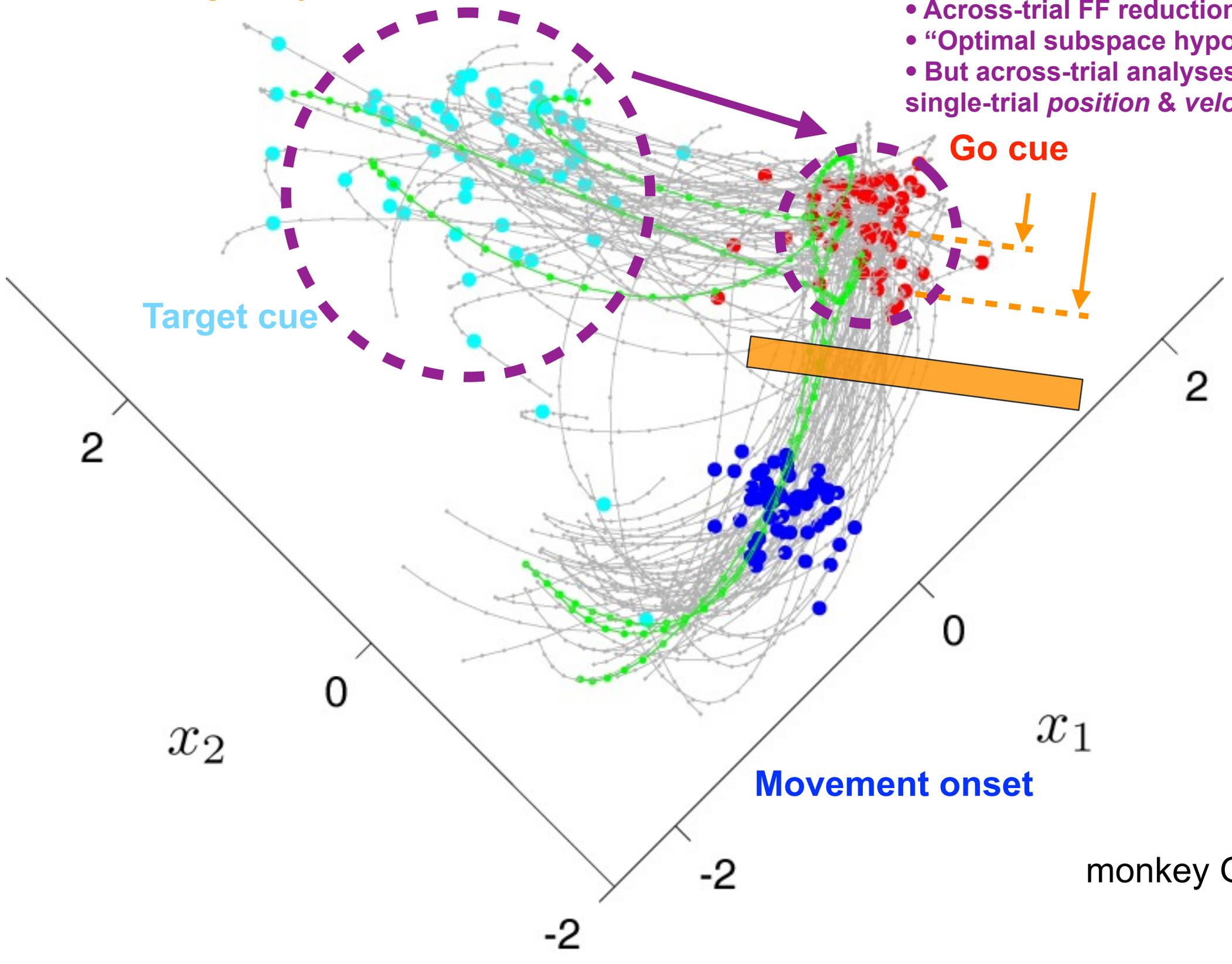

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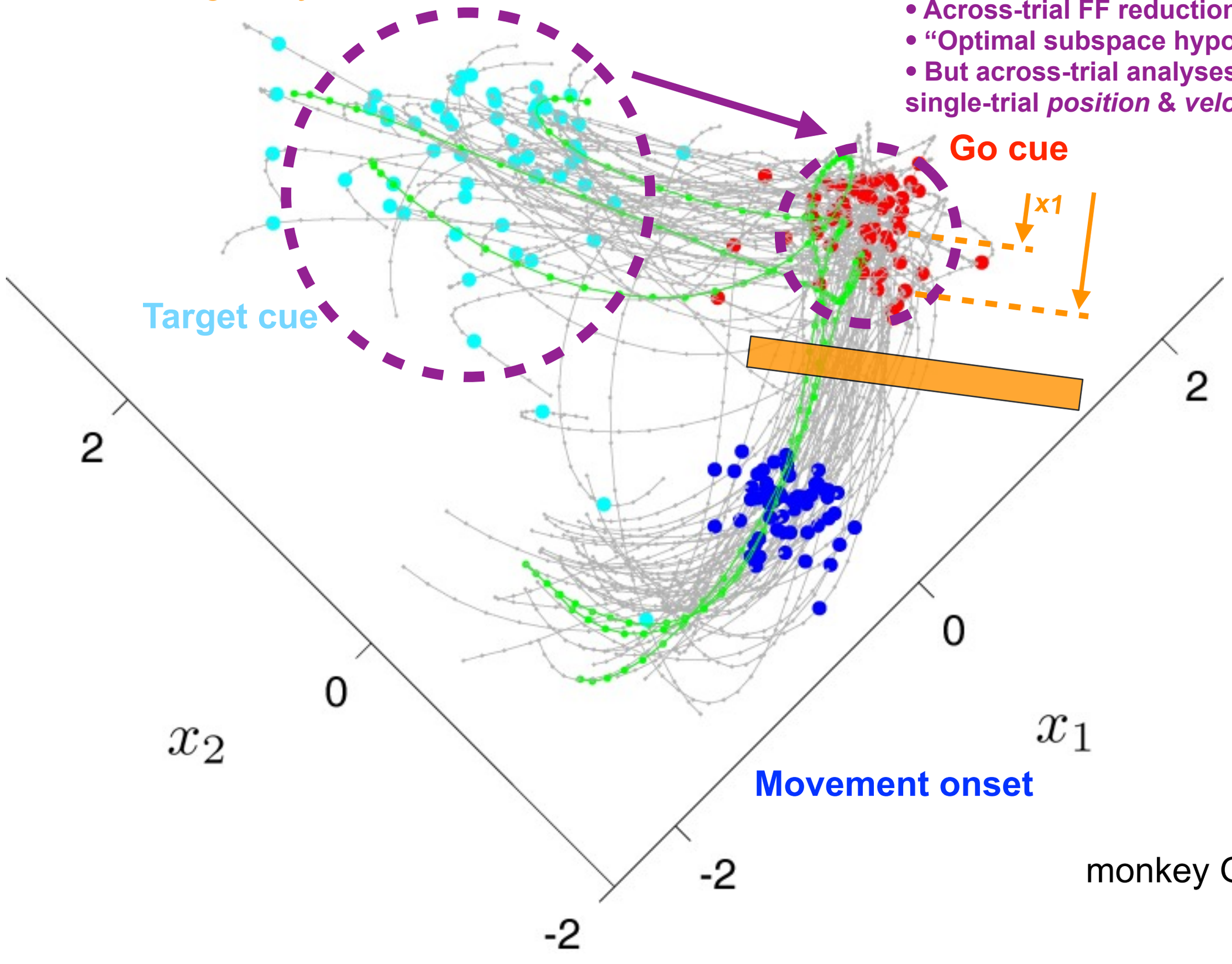

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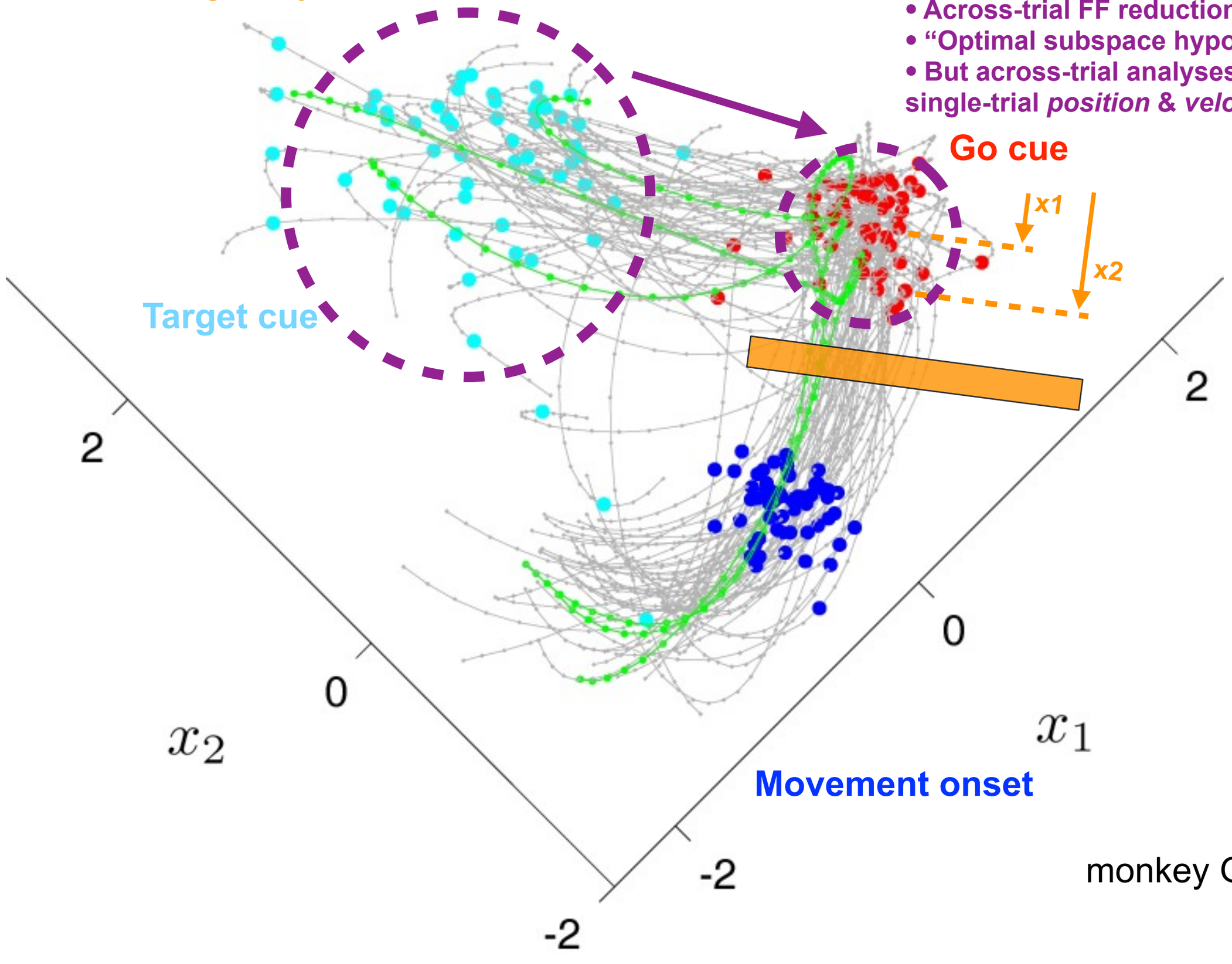

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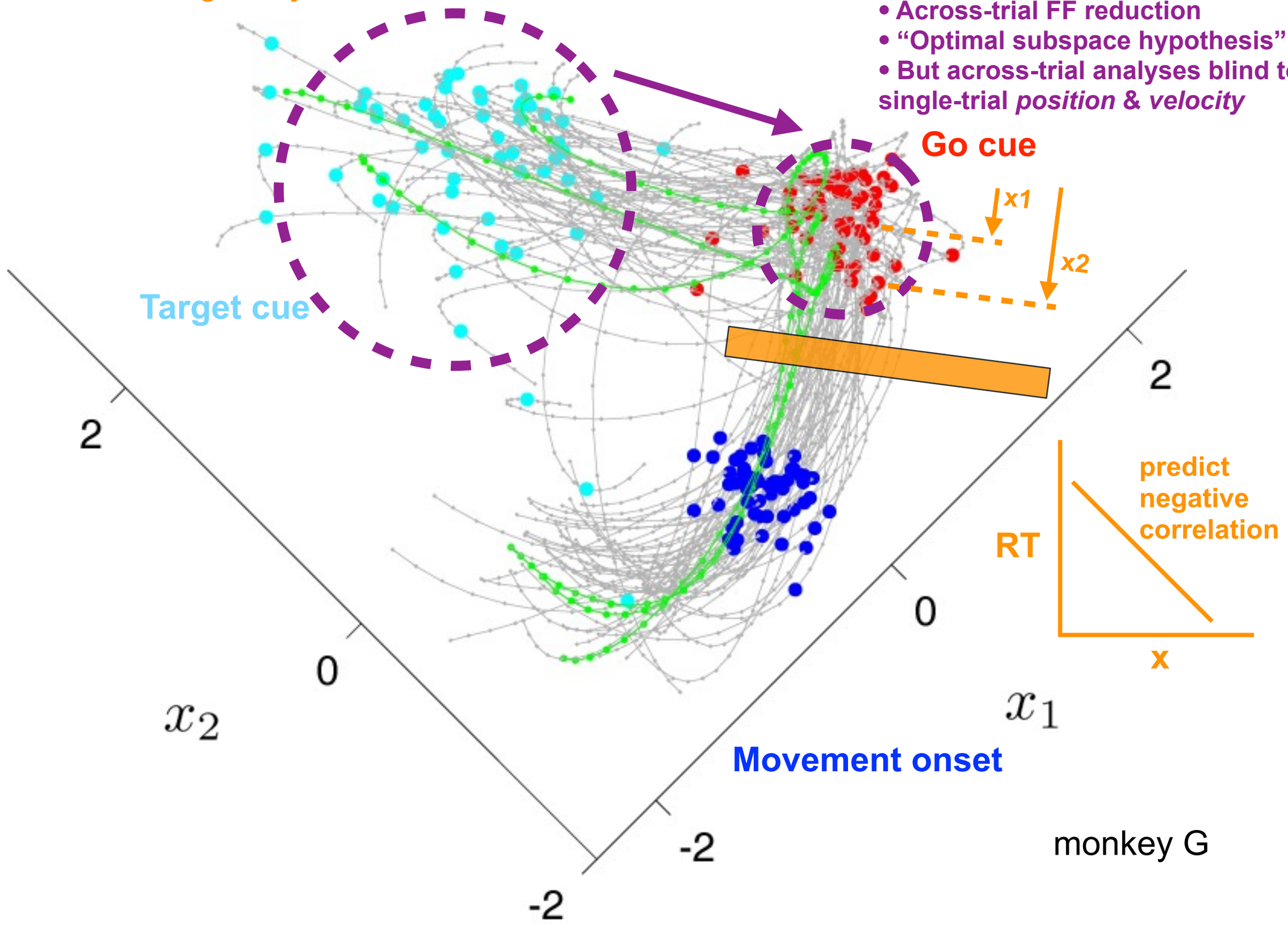
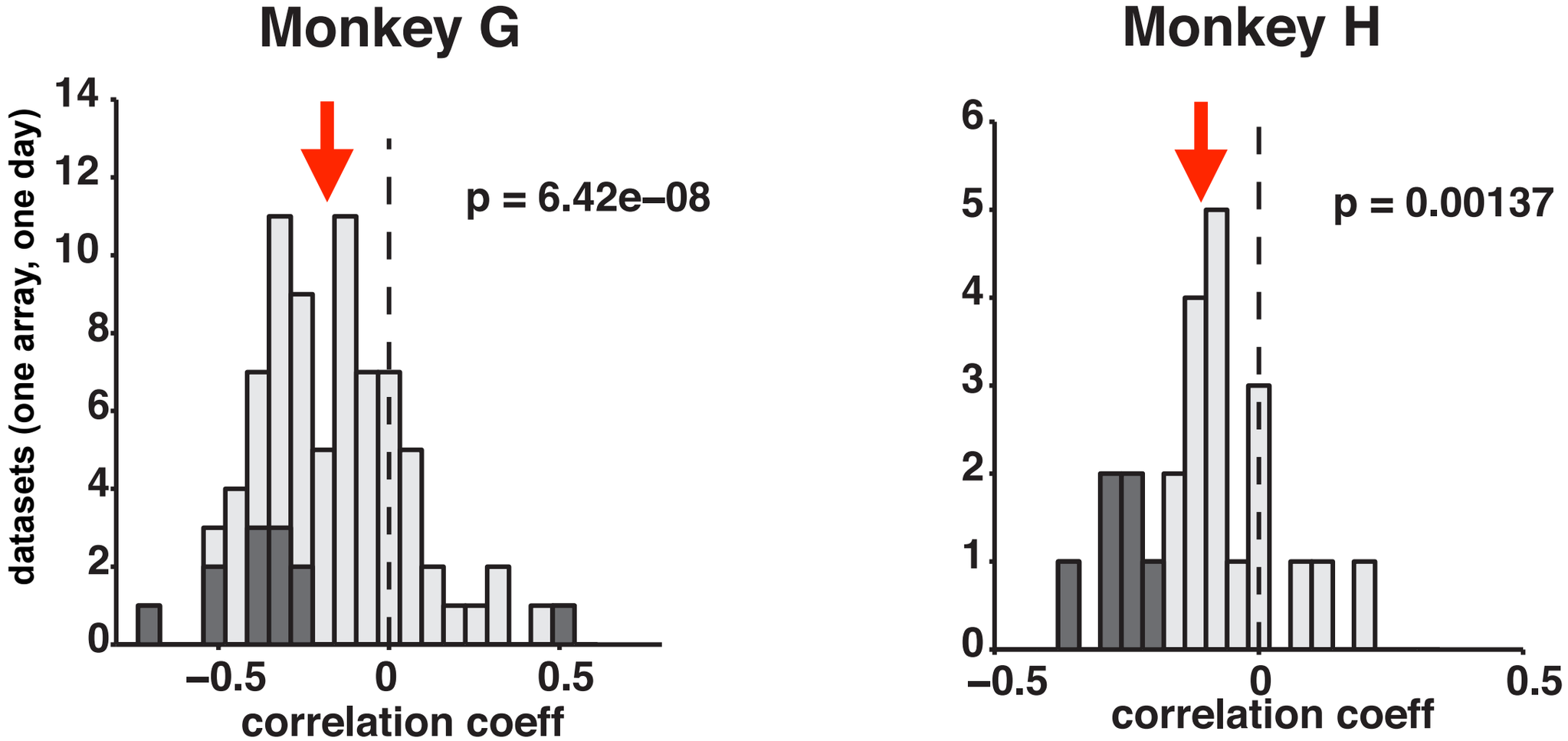


Single-Trial Neural State Correlate of RT: Position



Afshar, Santhanam, Yu, Ryu, Sahani & Shenoy. Single-trial neural correlates of arm movement preparation. *Submitted*

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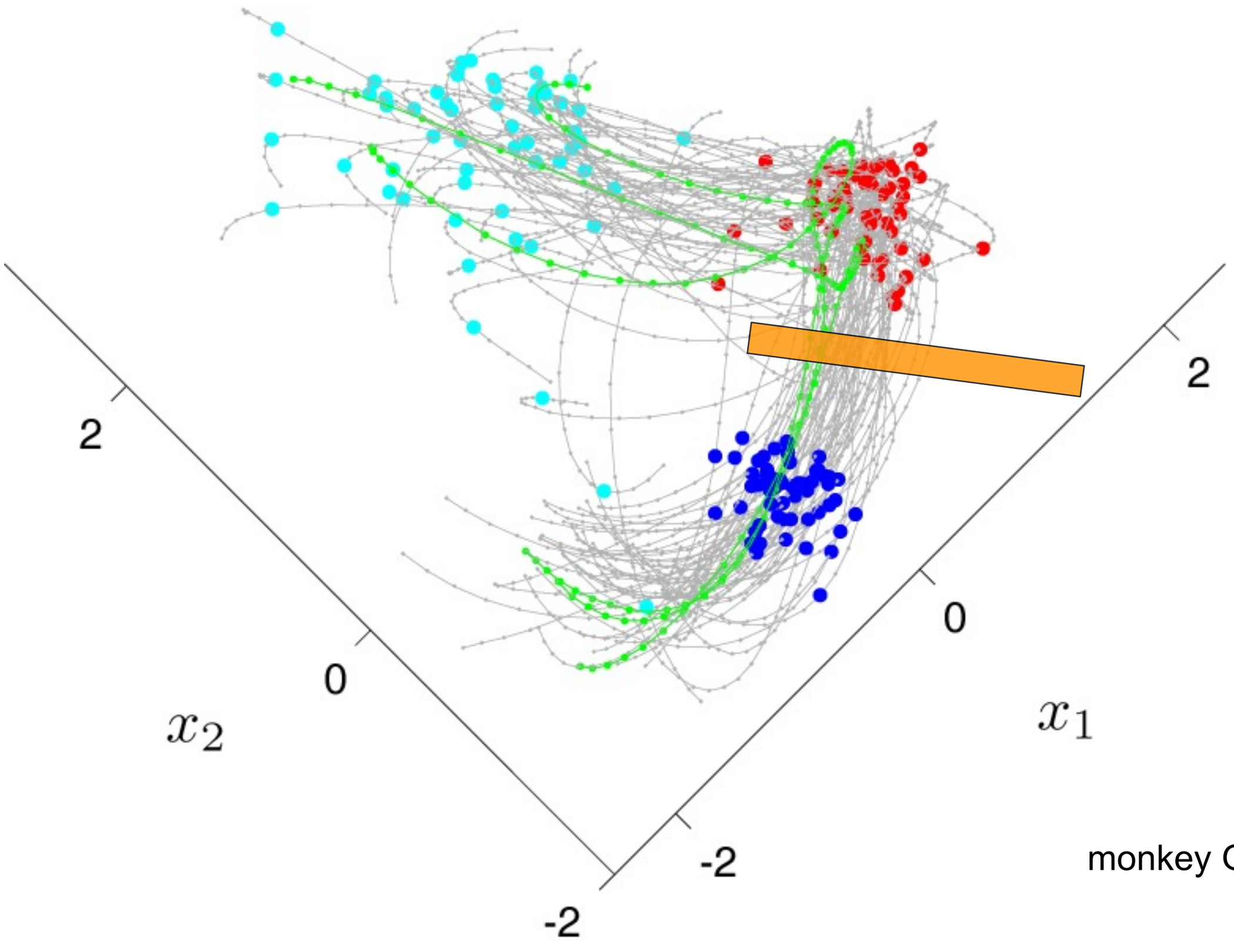

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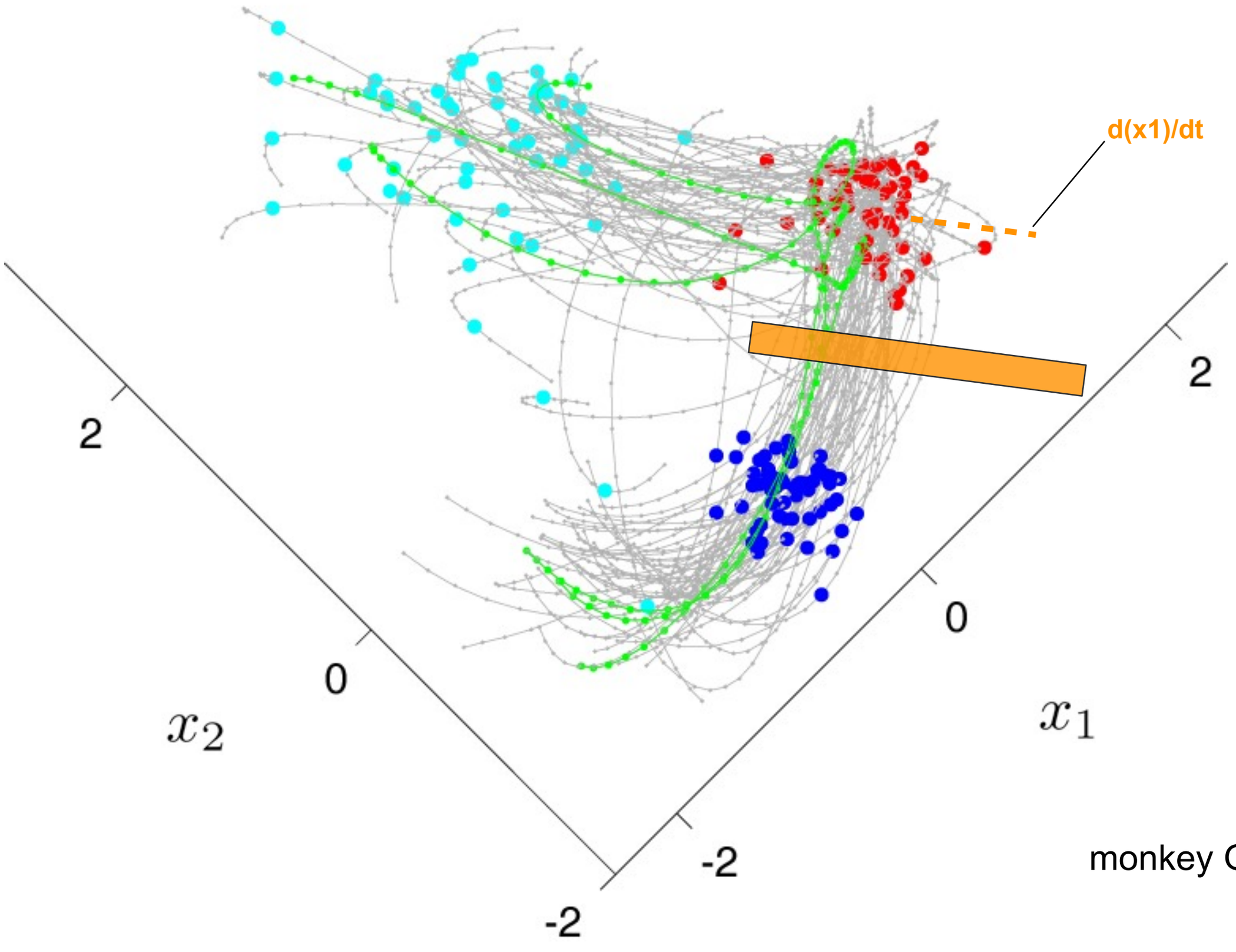

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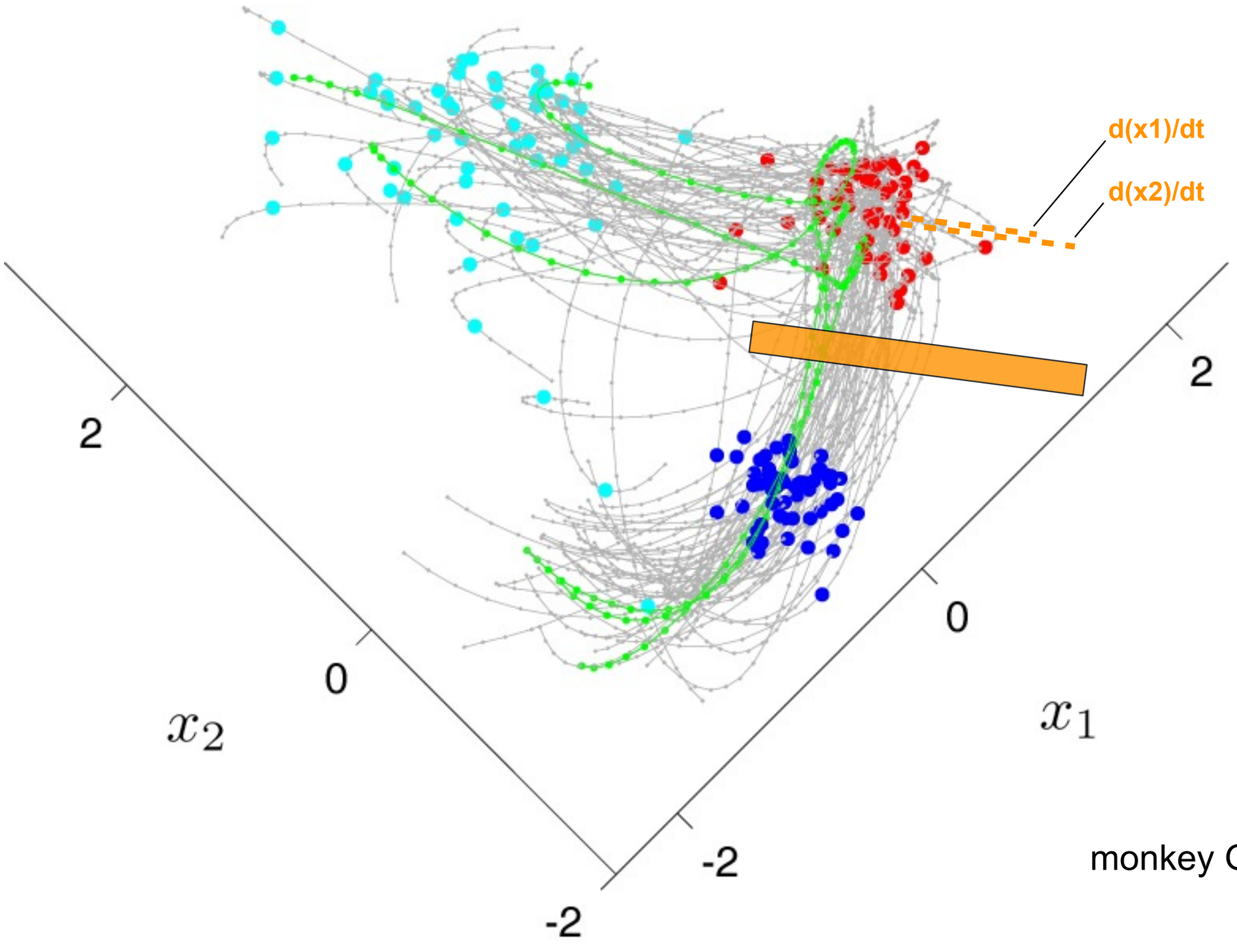

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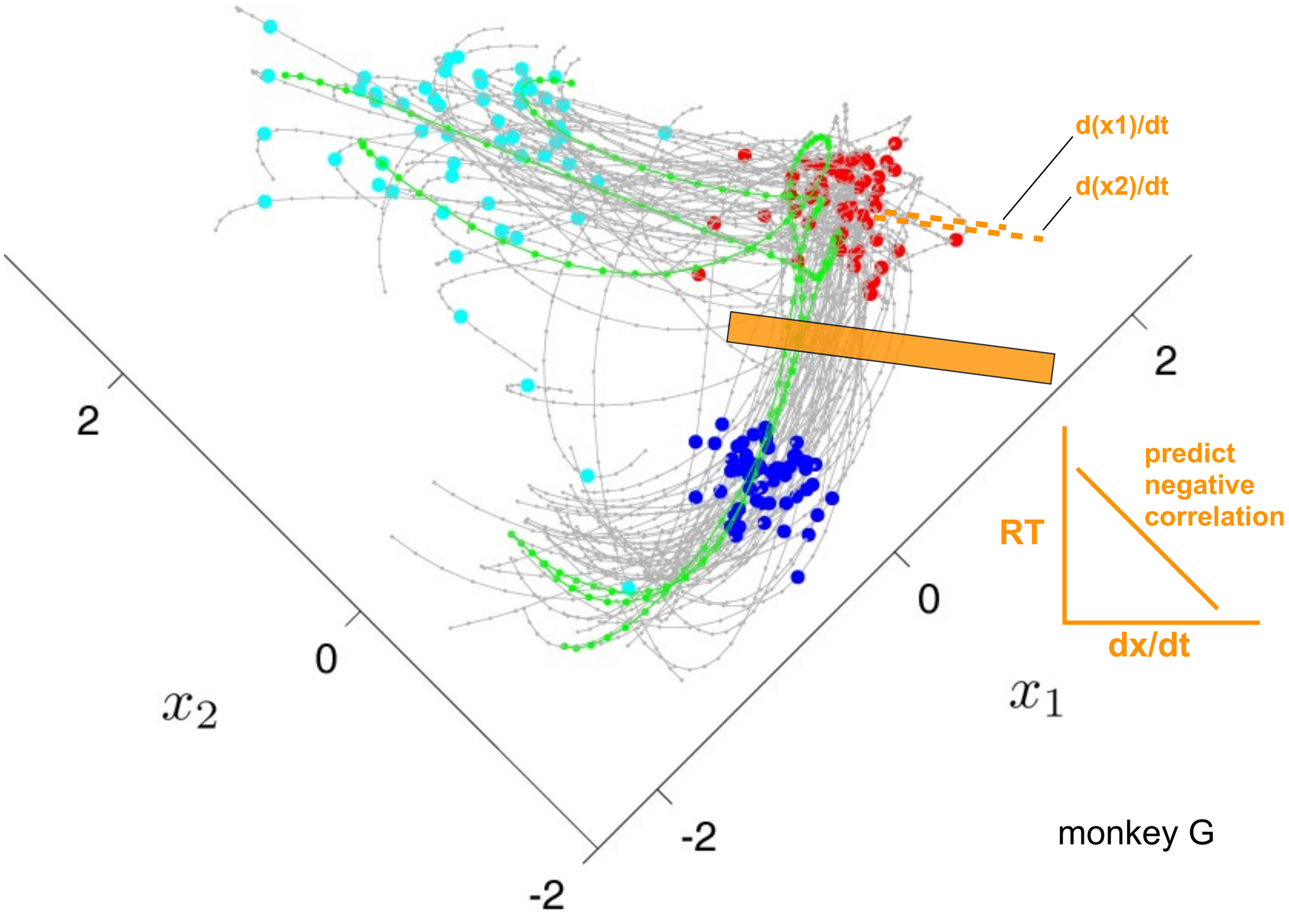
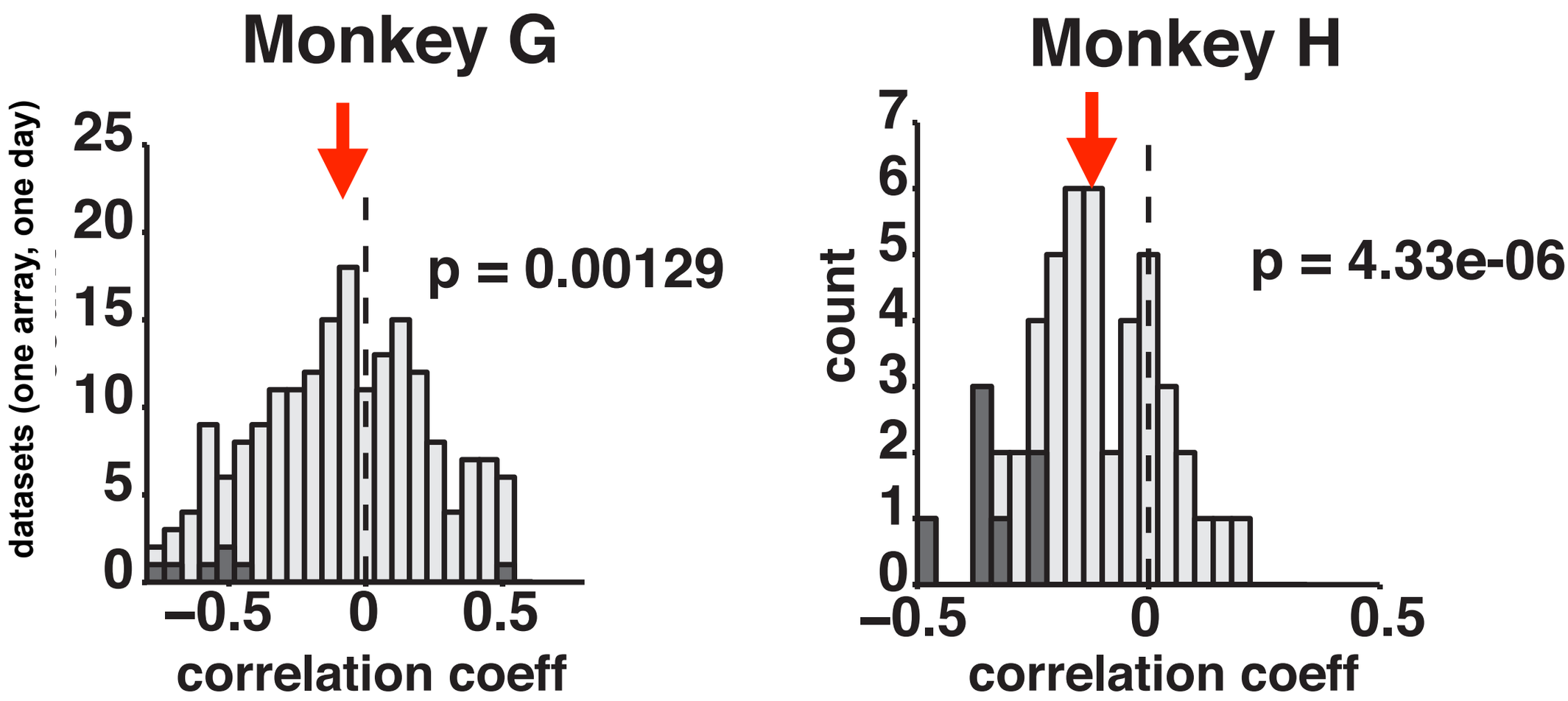


Single-Trial Neural State Correlate of RT: Position & Velocity



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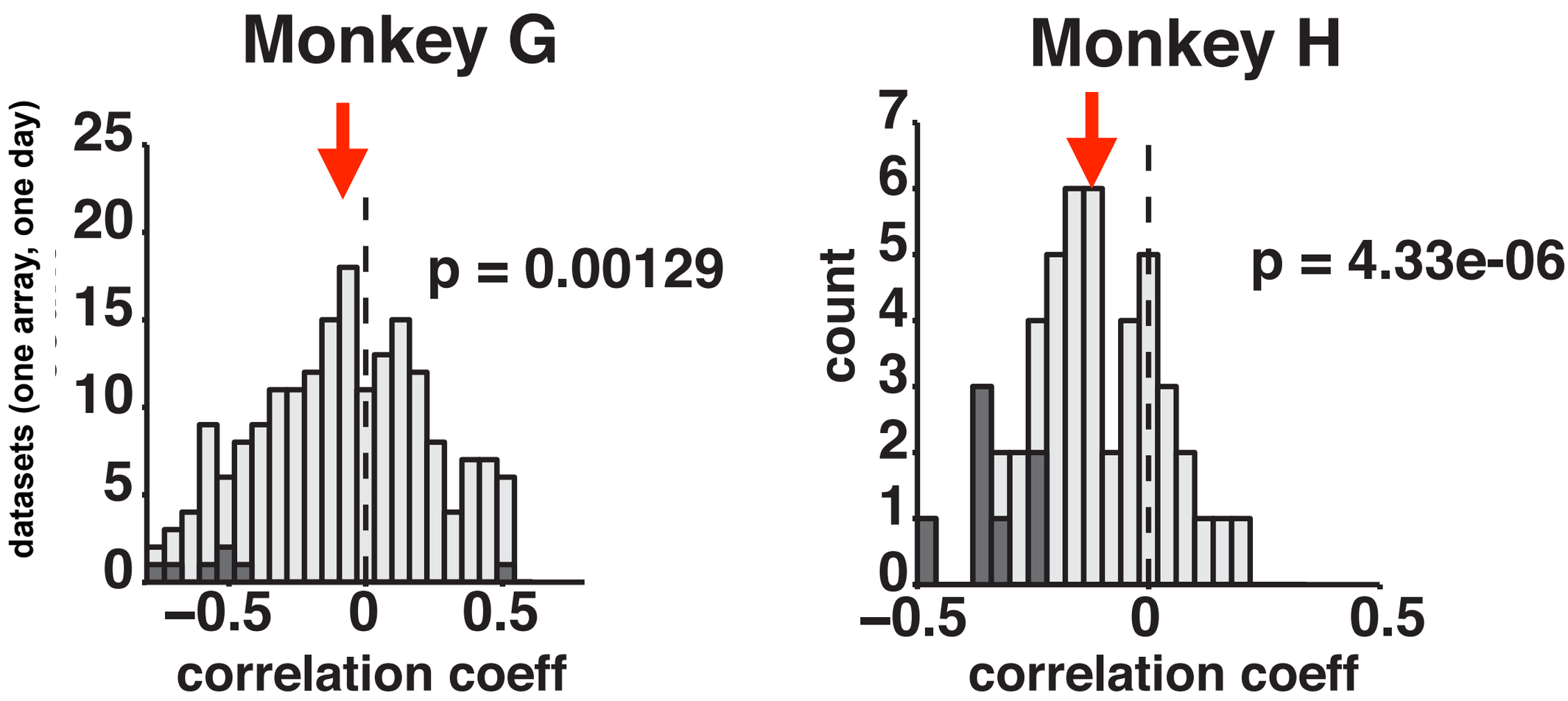
Four-fold increase in RT variance explained



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Rather Different Things Can Happen on Different Trials

Churchland et al. (2010) *Nature Neurosci* (supp mats video #2)

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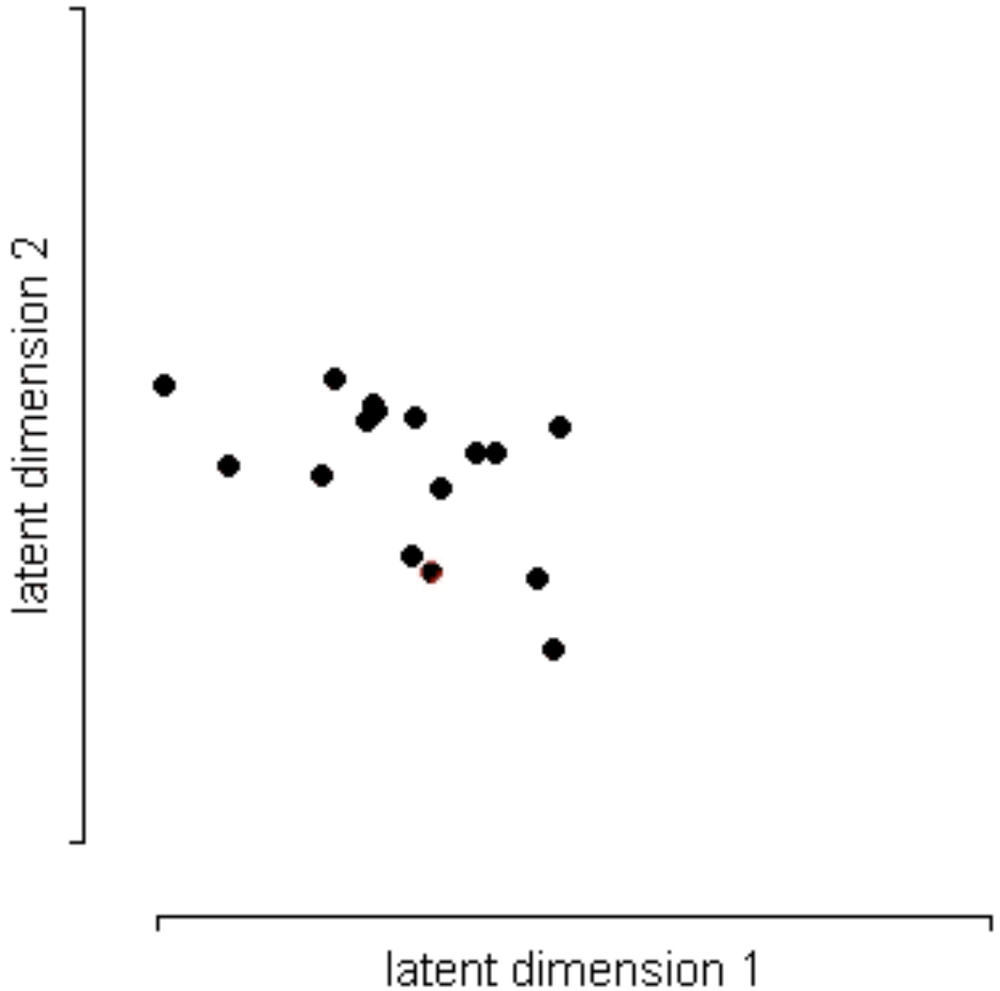

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Investigating Various Sensory, Cognitive & Motor Processes with a “Maze Task”

Kaufman et al. (2009) *J Neurophysiol*
Churchland et al. (2010) *Neuron*

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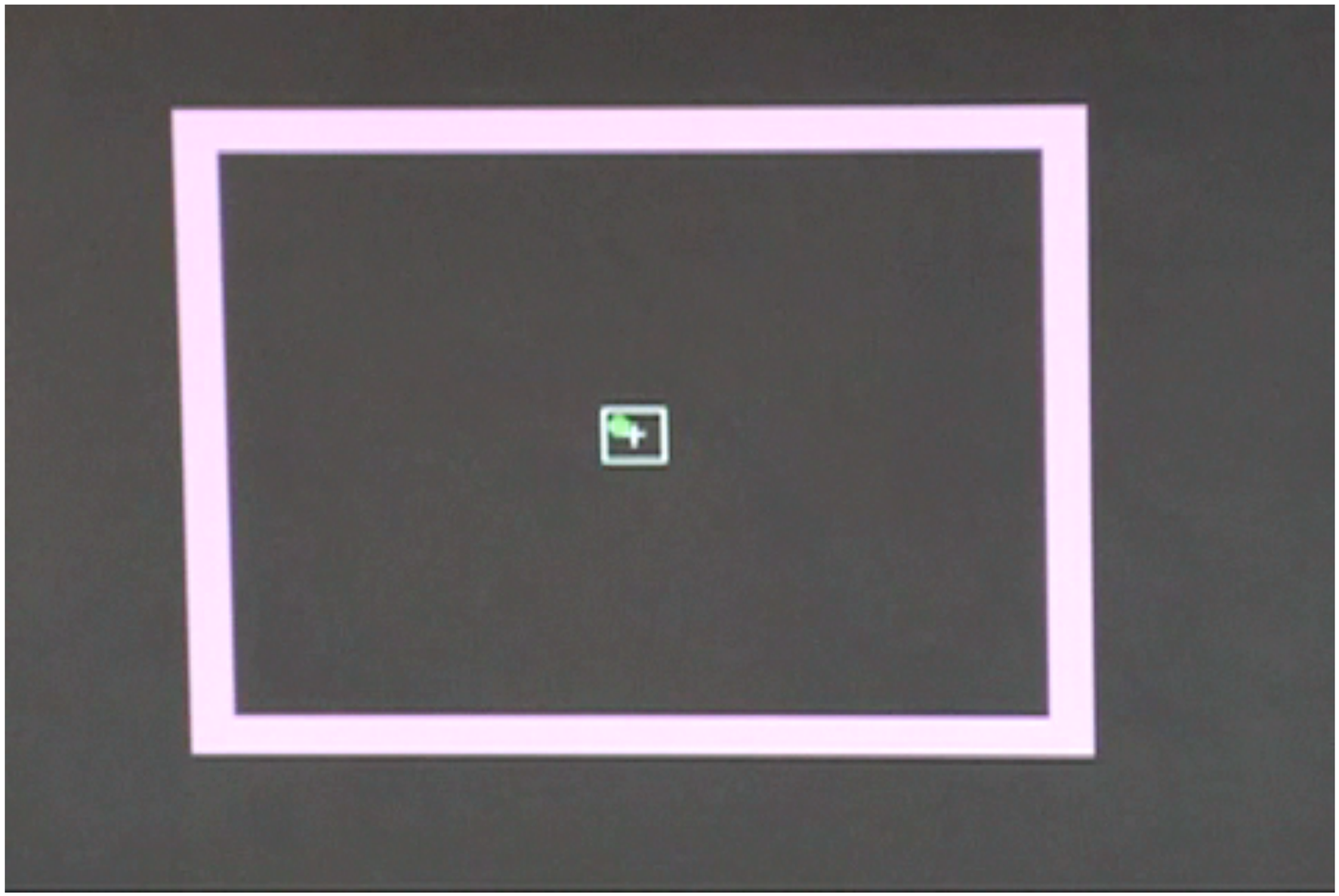

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Where to Start?

Can we “see” decision making?

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- "... advance the understanding of decision-making to the highly flexible and cognitive acts of vacillation and self-correction."

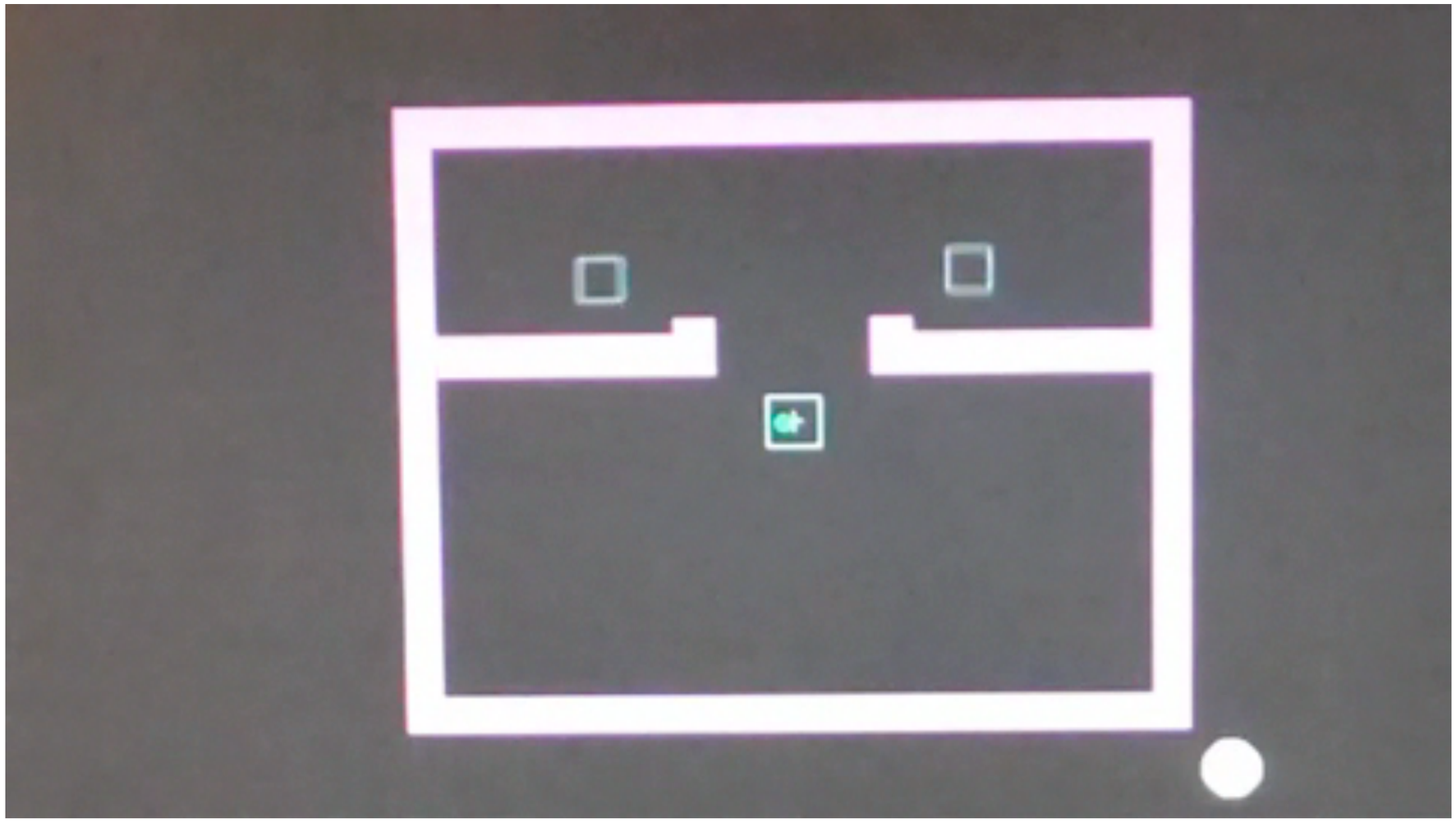
- We wondered if monkeys change their minds before initiating movement (during delay / plan period), which is a fully covert cognitive process. If so, when, how, and why?

A Decision Making Version of the Maze Task

Kaufman, Churchland, Ryu & Shenoy. Unpublished.

A Decision Making Version of the Maze Task

- Two targets appear in a instructed-delay reach task (randomized delay period)



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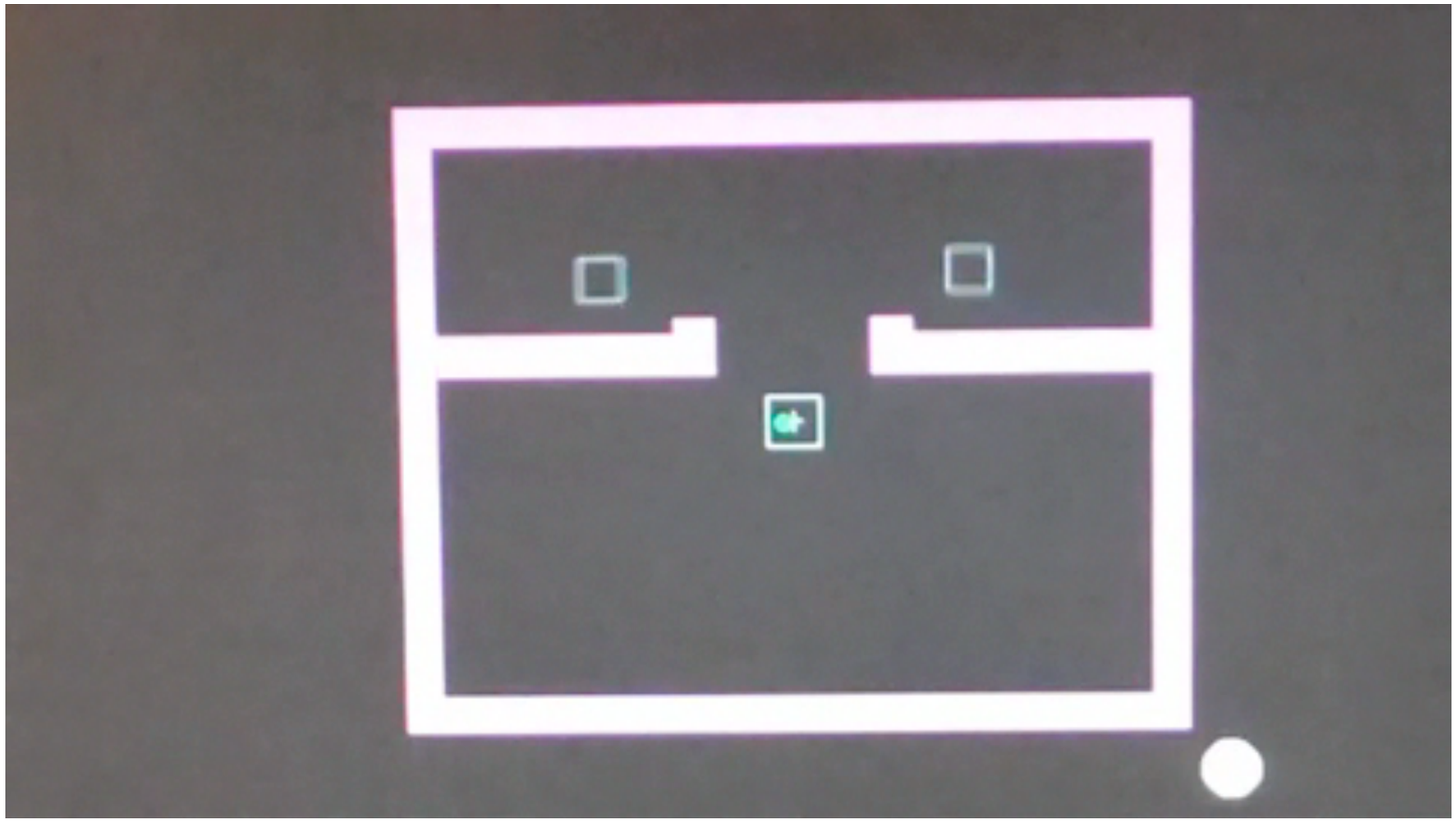

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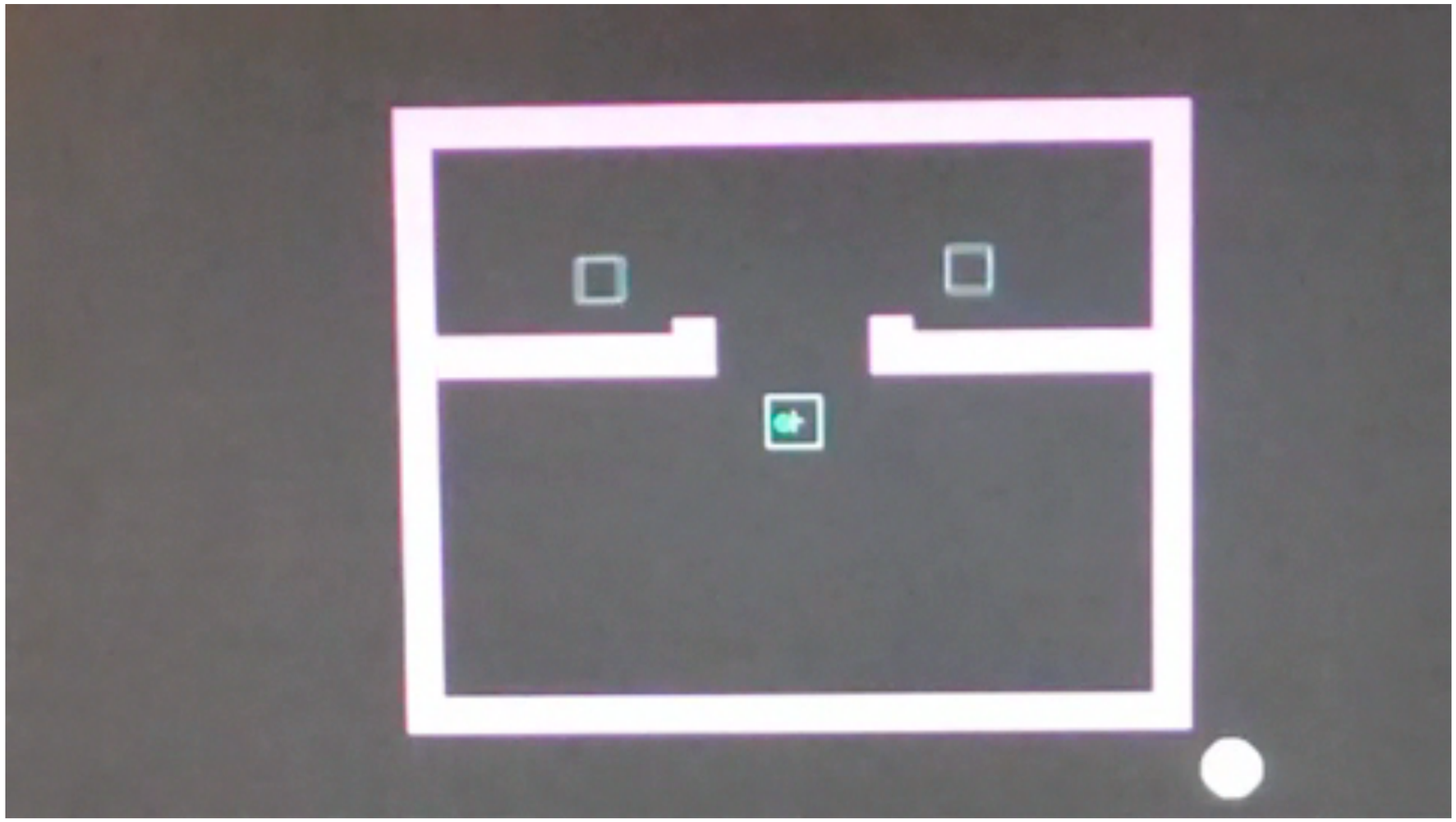

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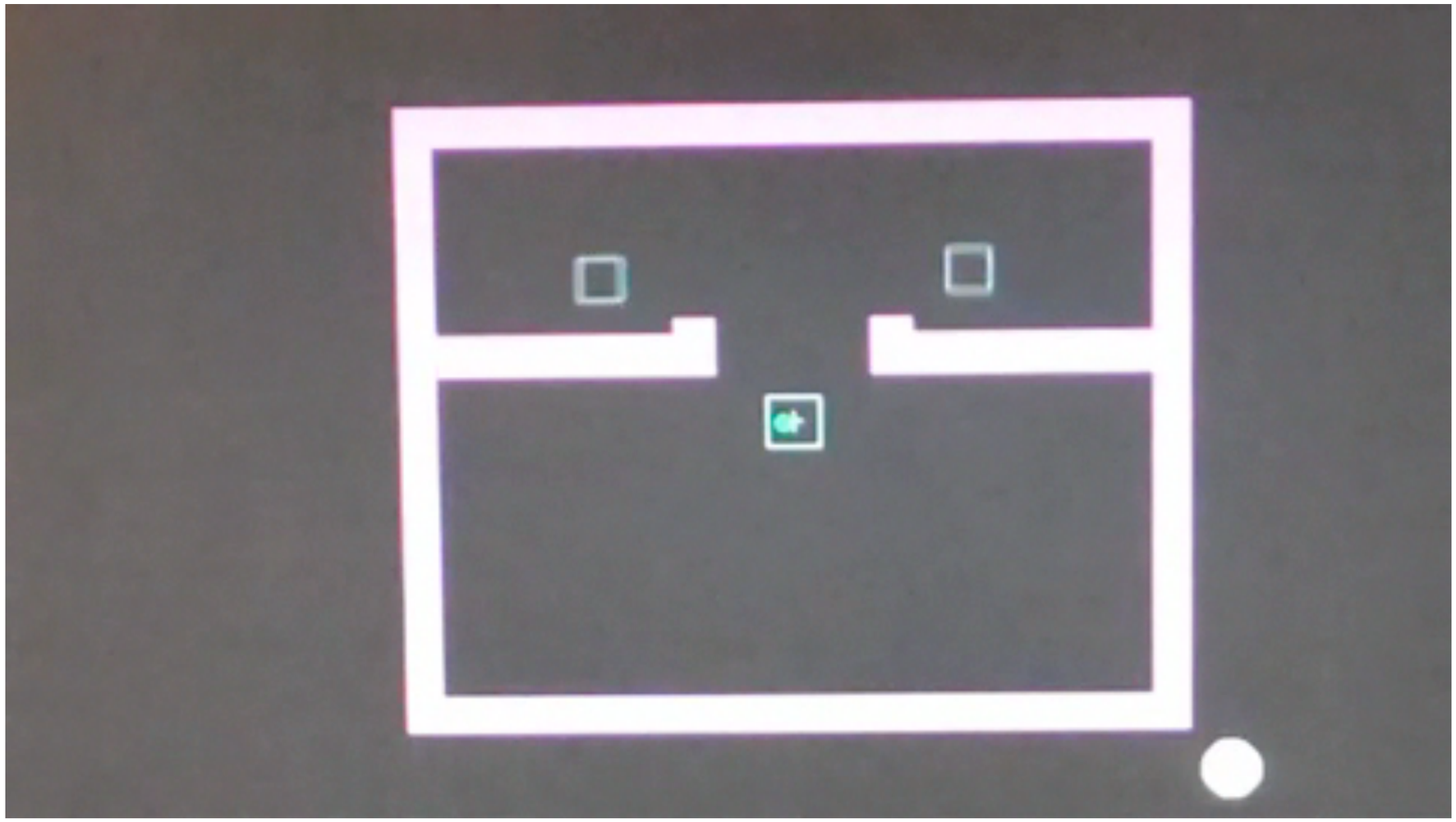

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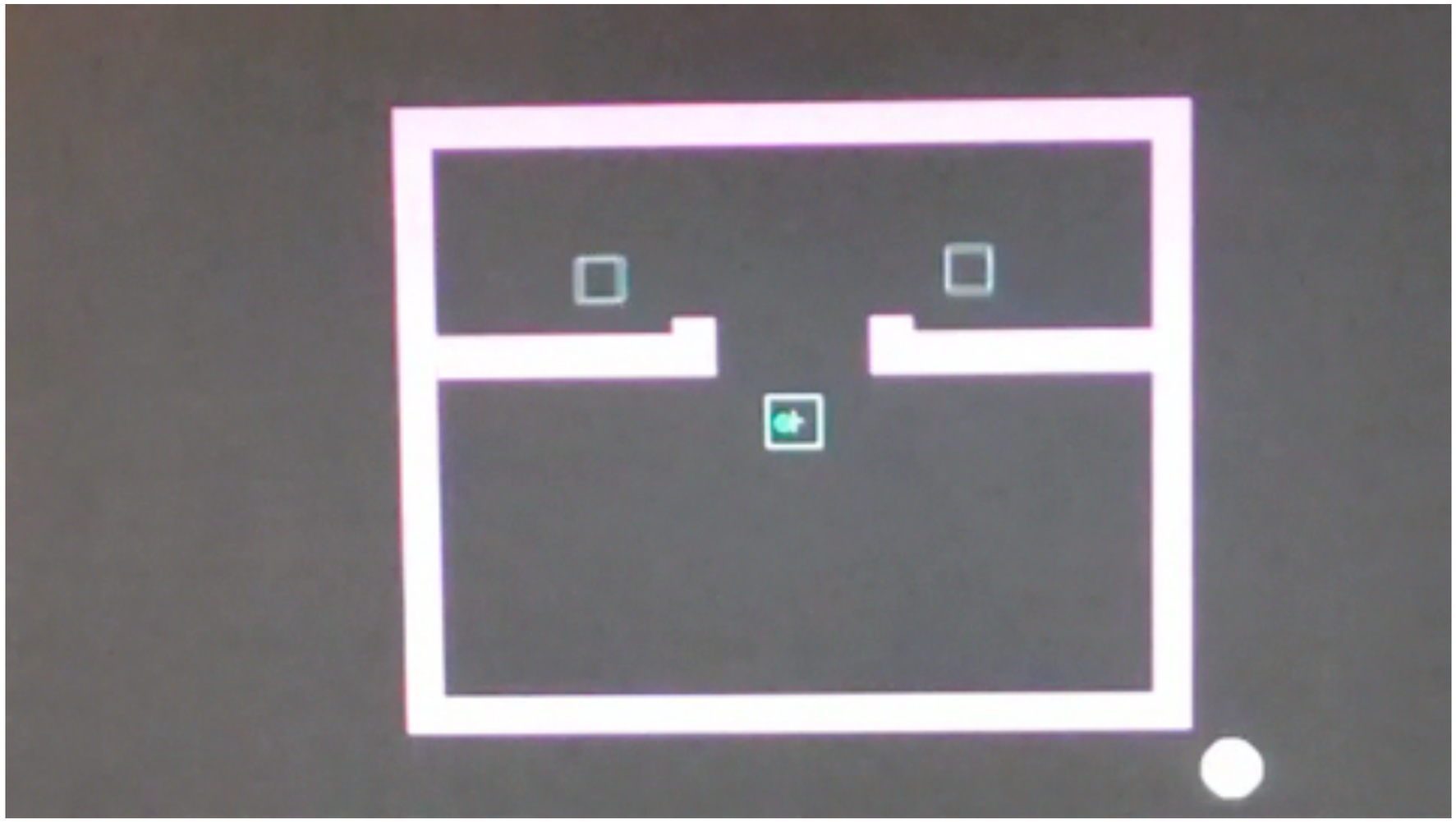

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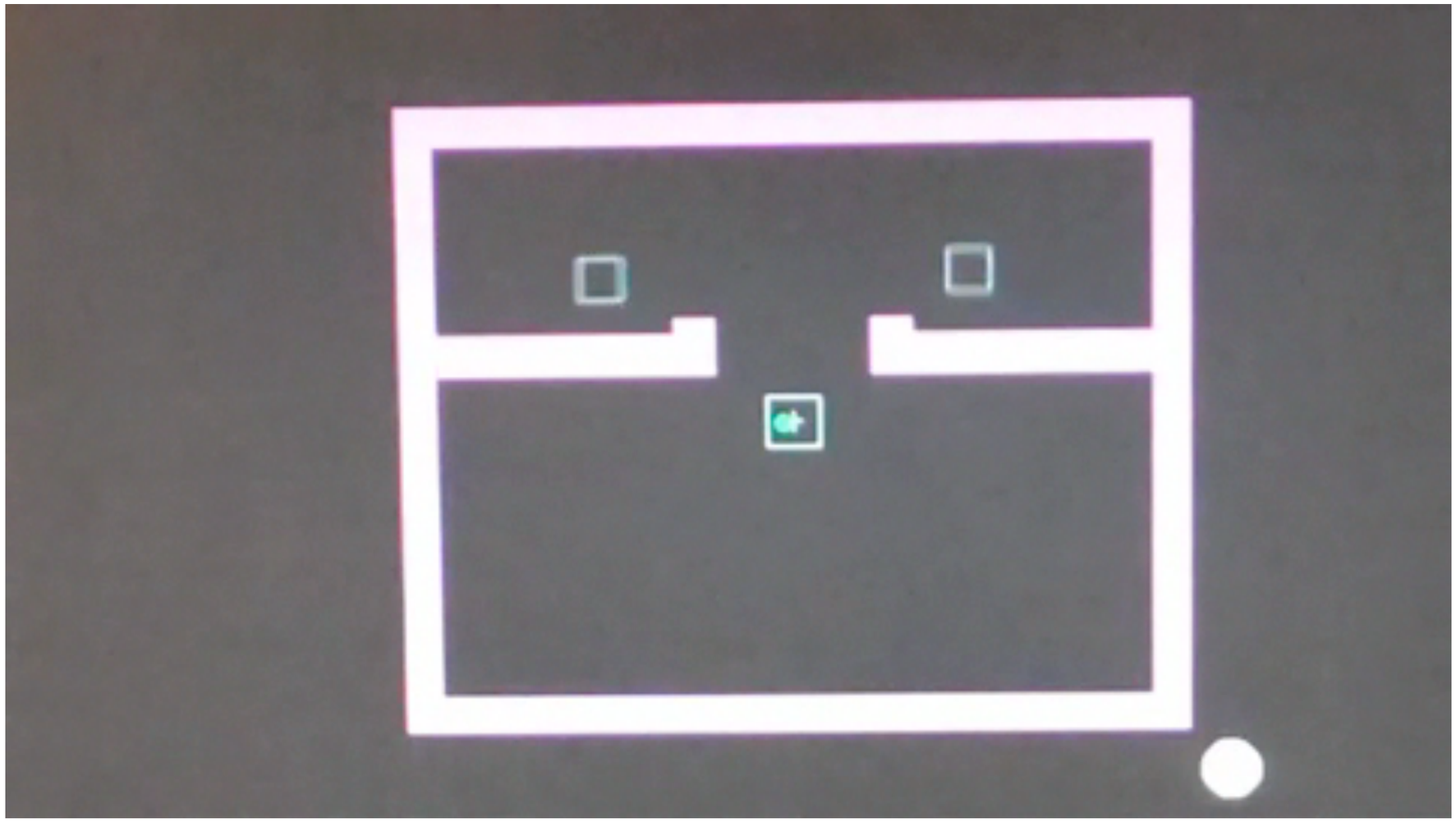

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A “Forced Left” Trial: Neural Prediction and Behavior

Prediction from neural activity (PMdc & M1 arrays)

Movie is 1/4 real-time speed

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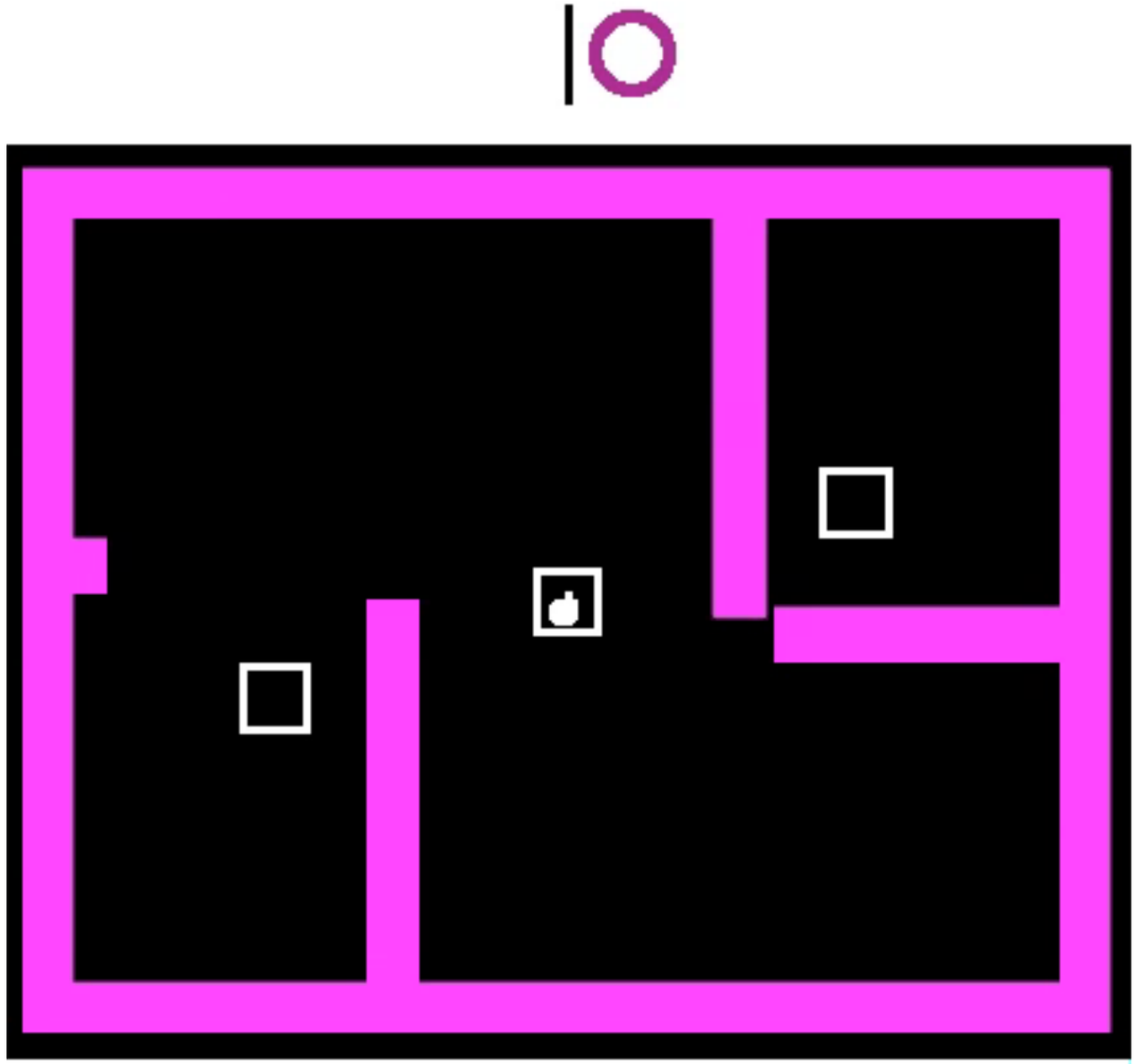

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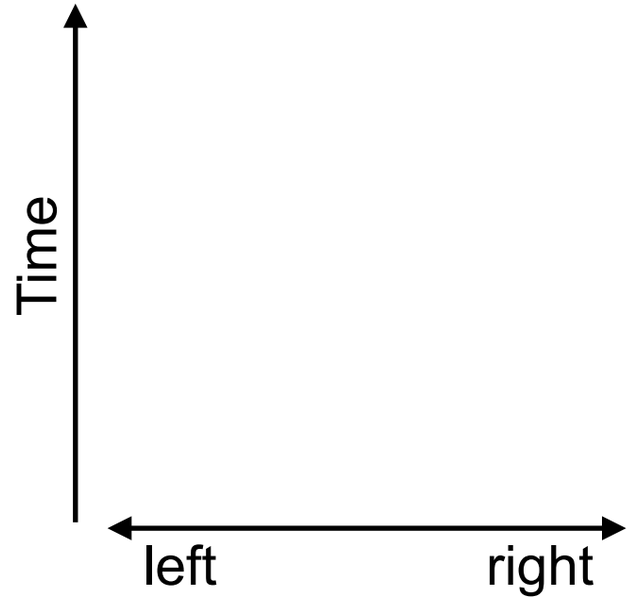

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Time-varying decision axis

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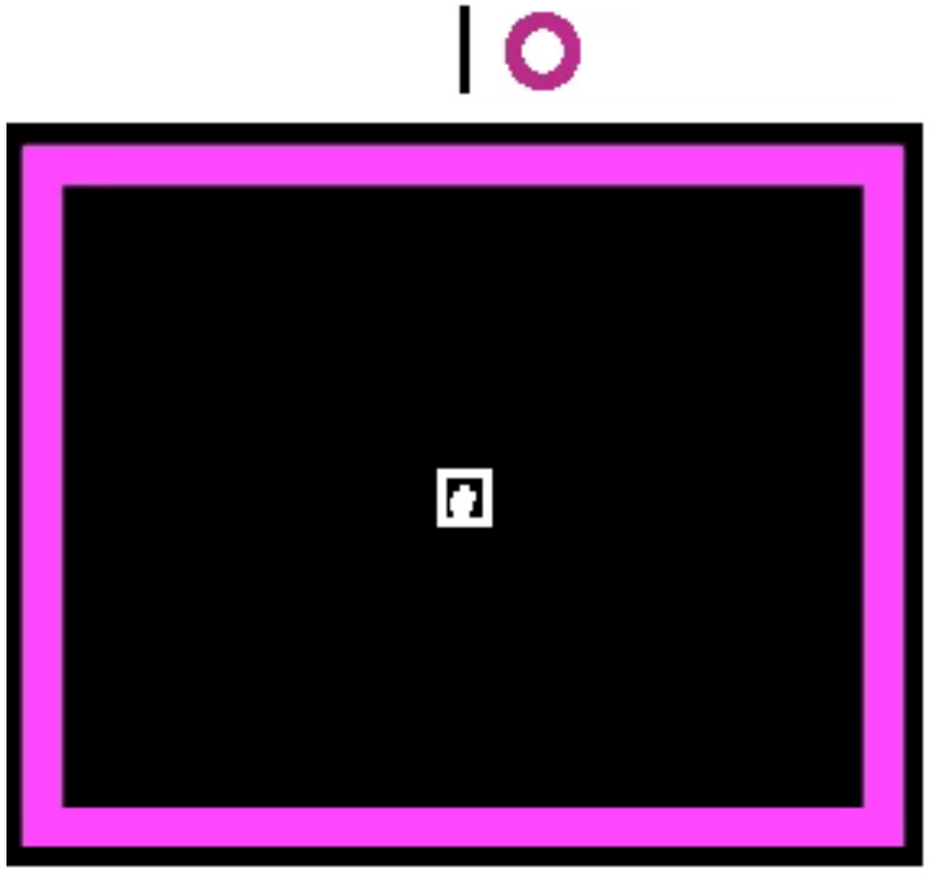

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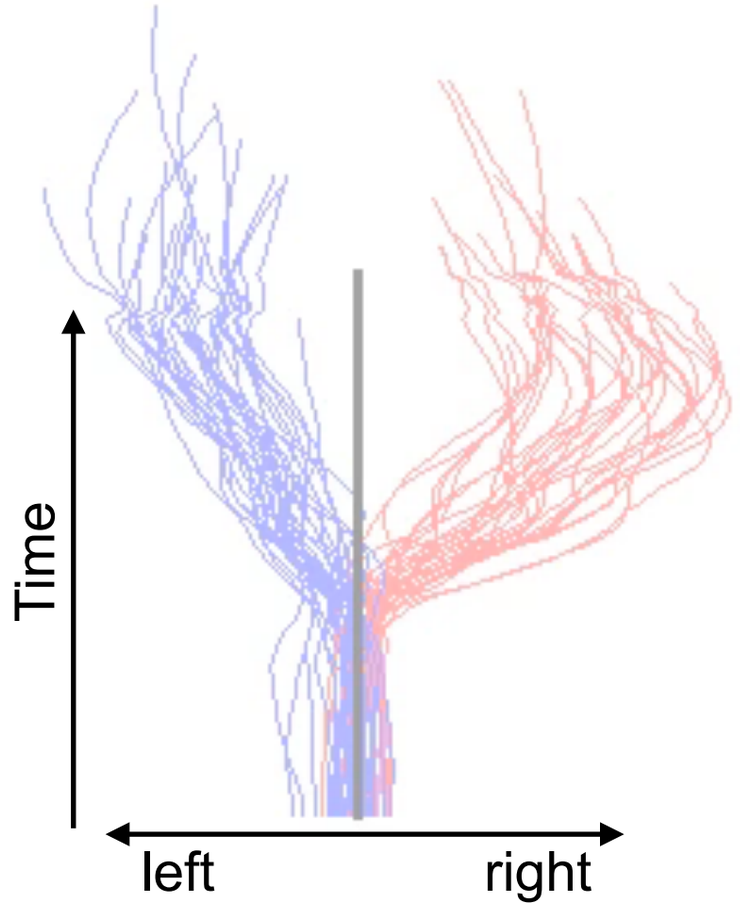

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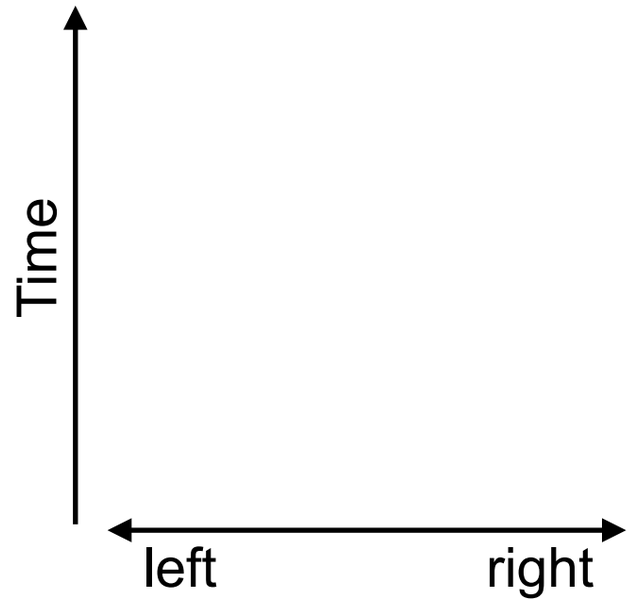

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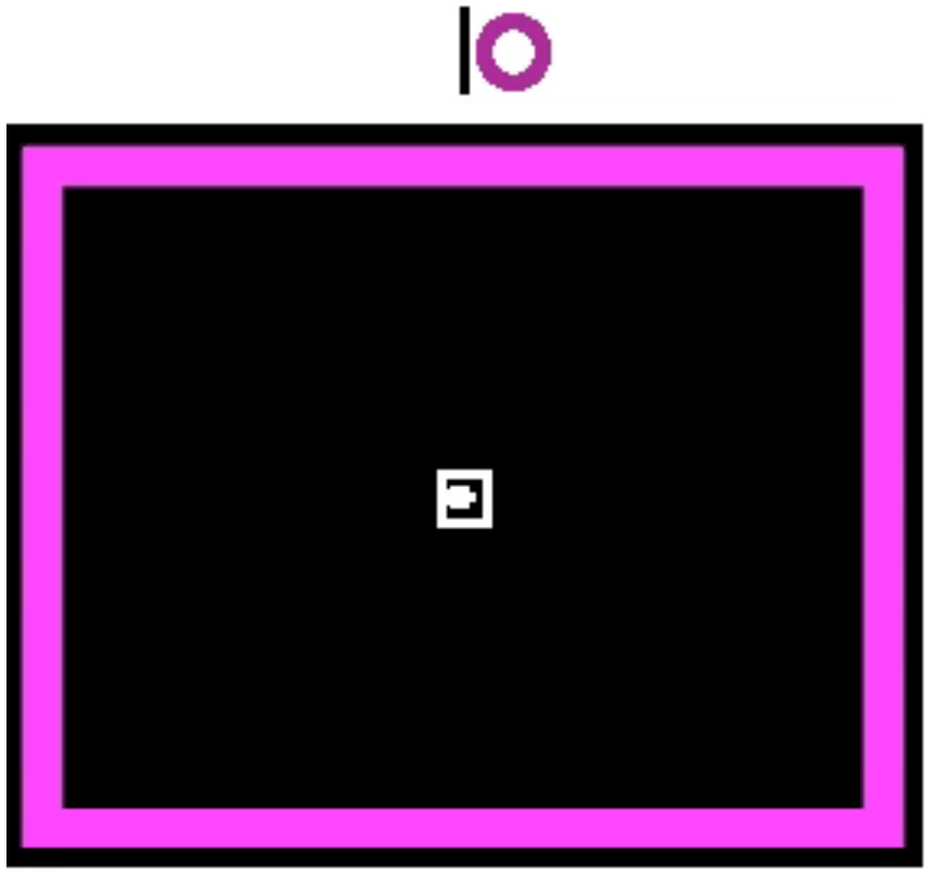

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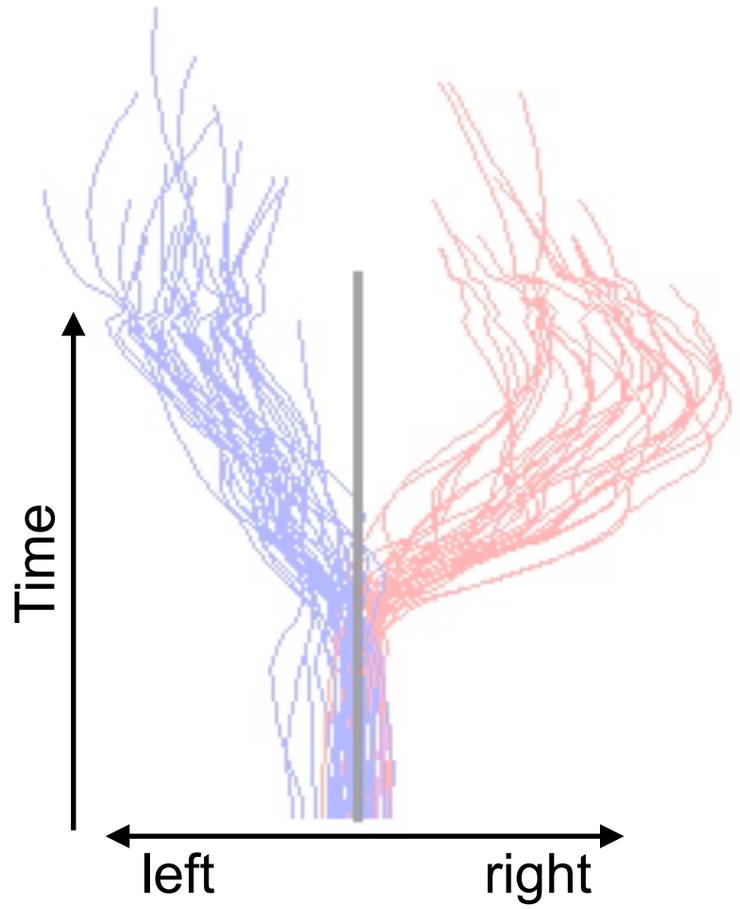

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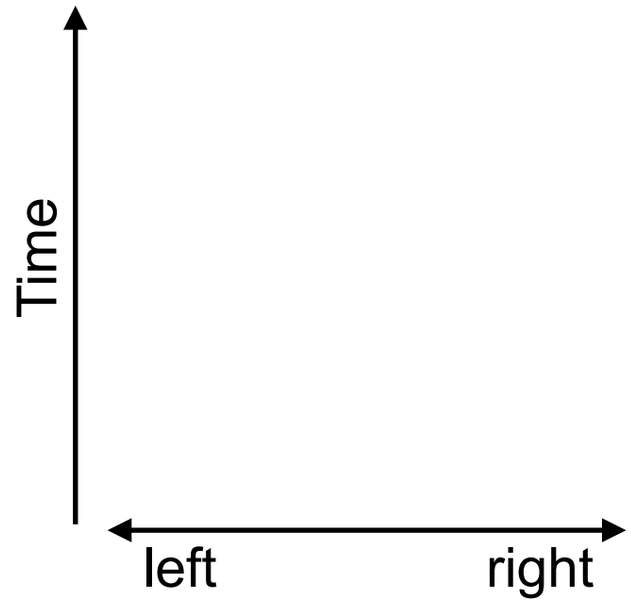

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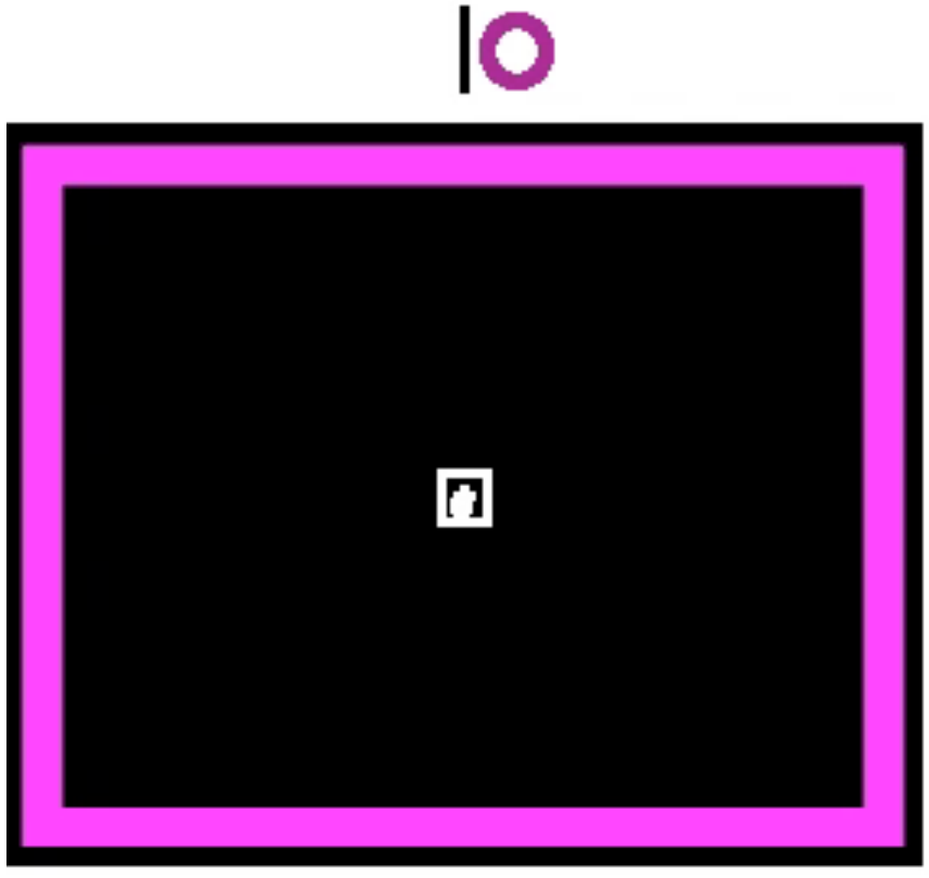

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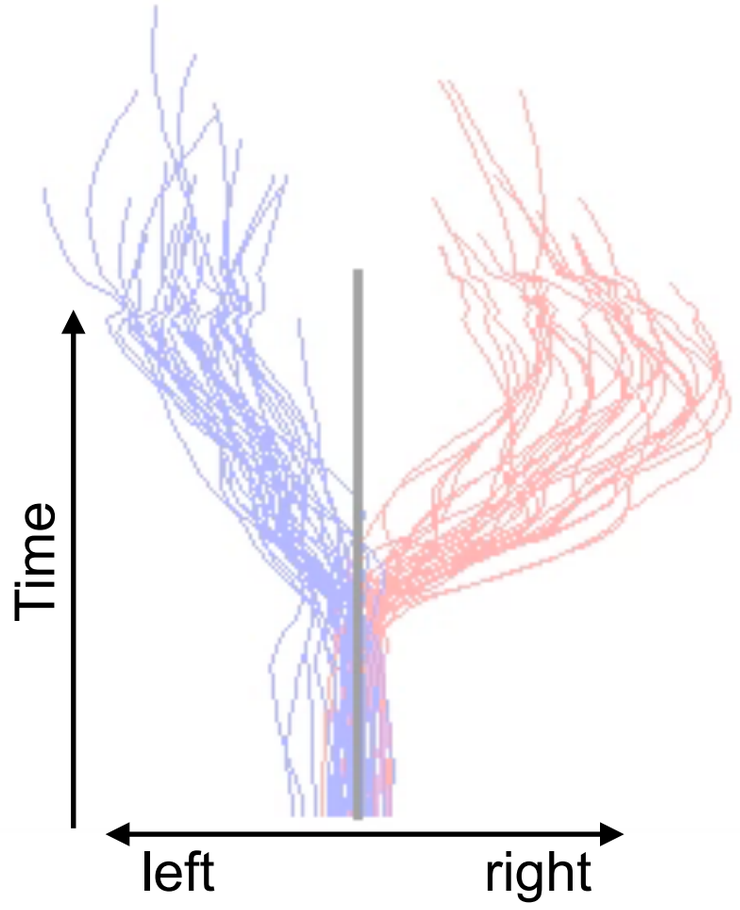

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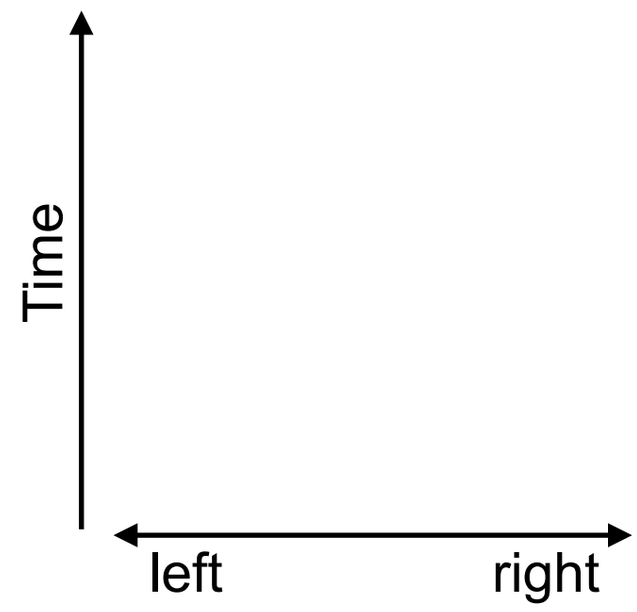

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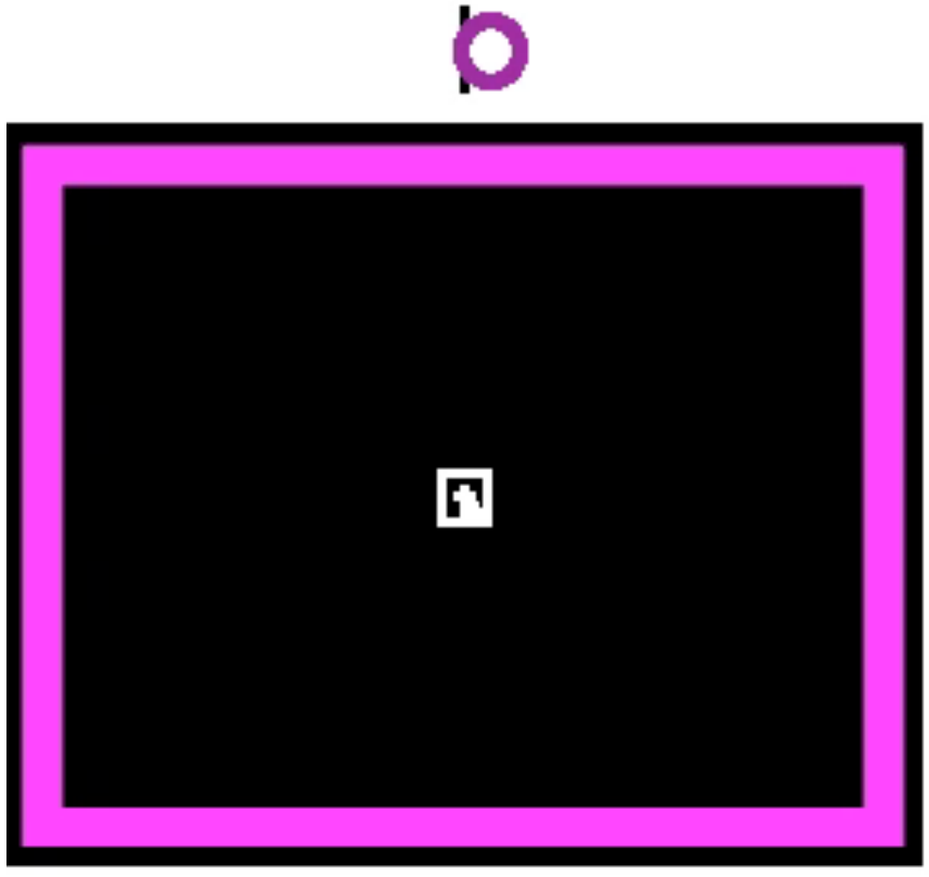

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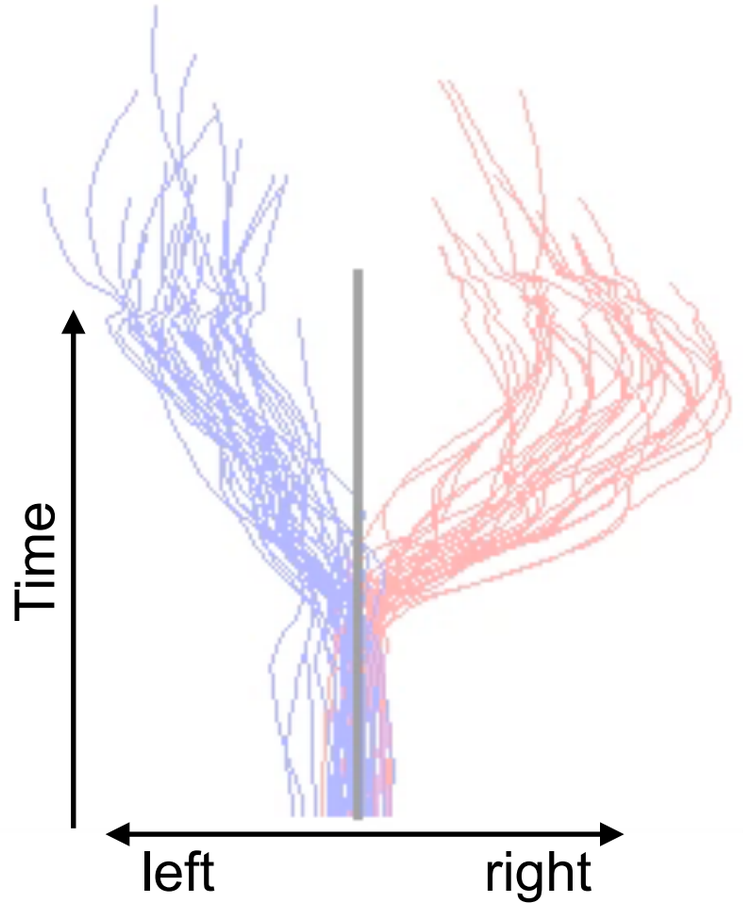

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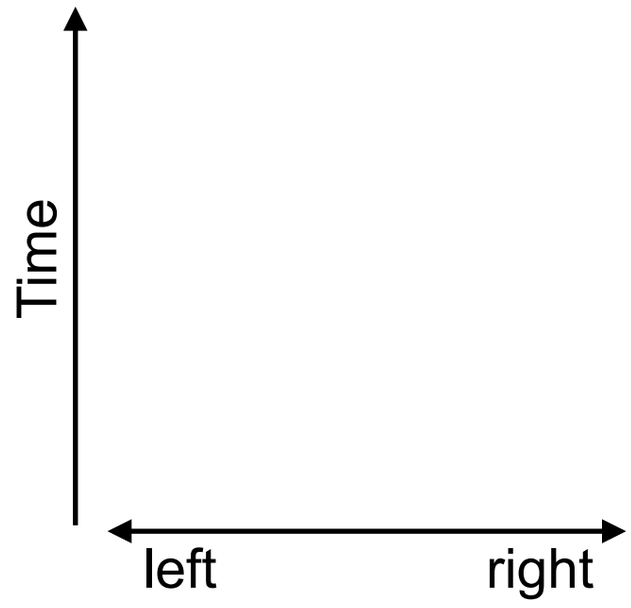

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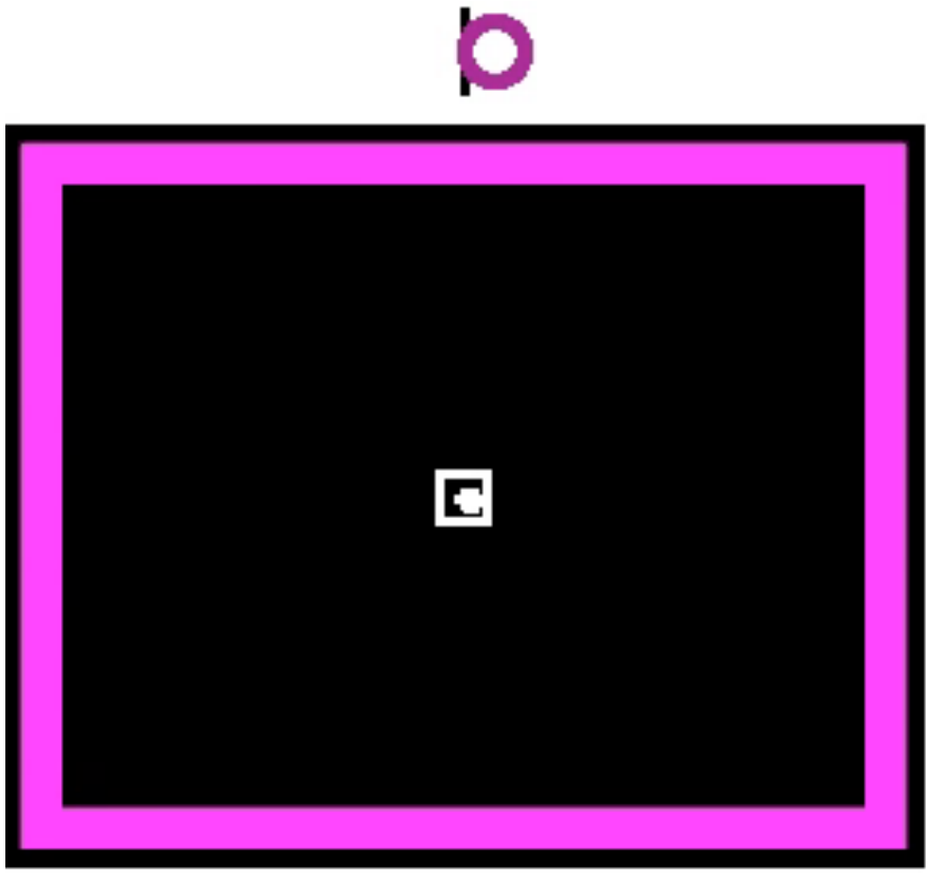

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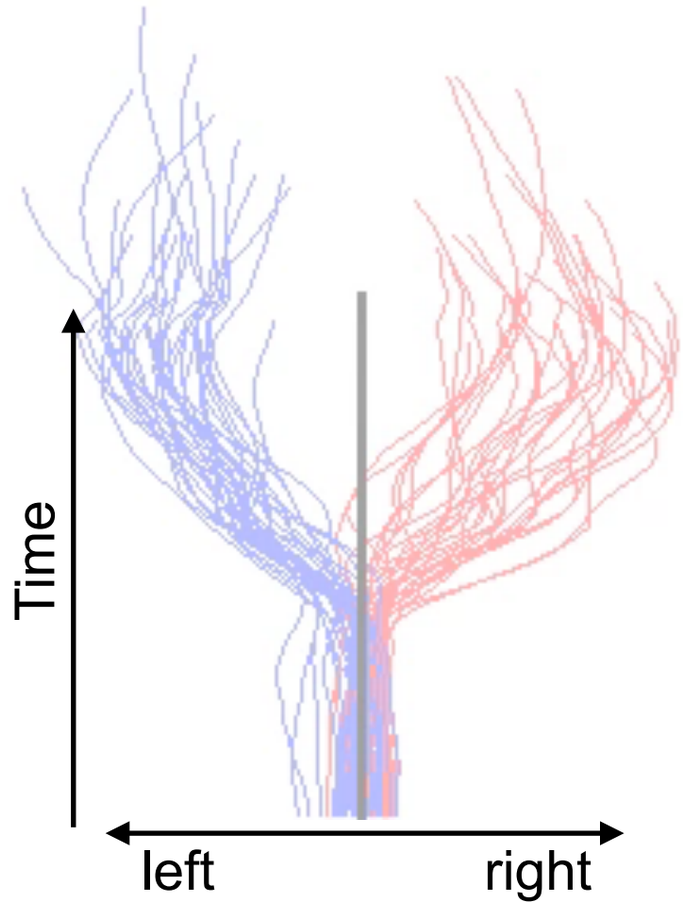

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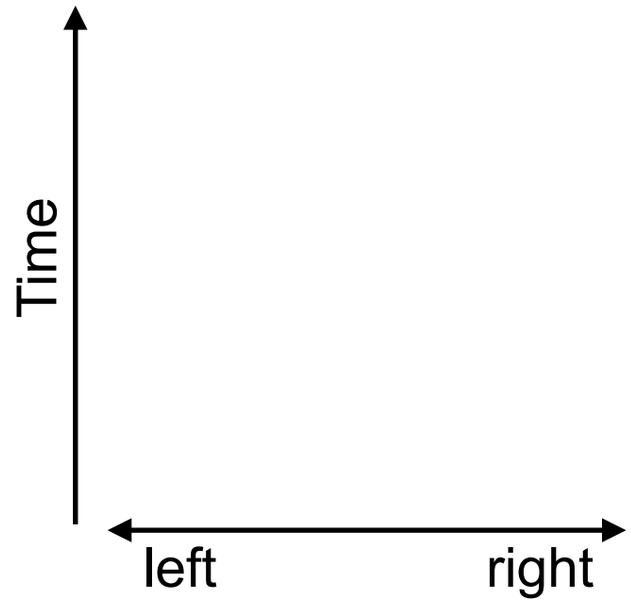

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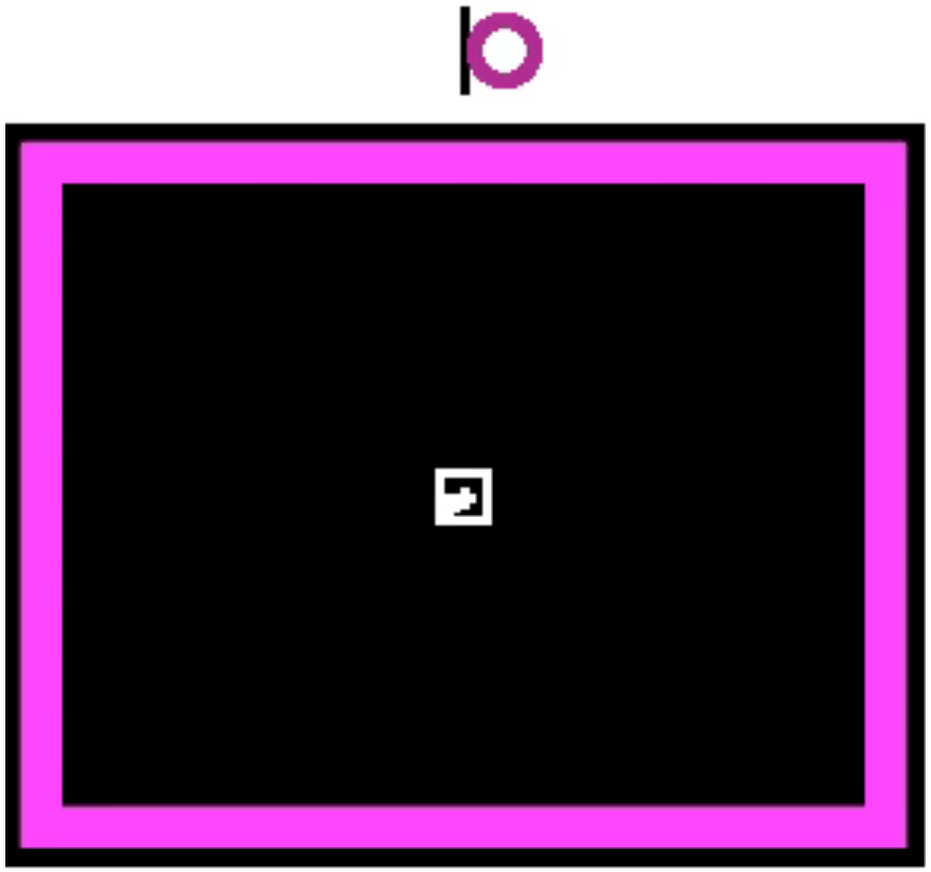

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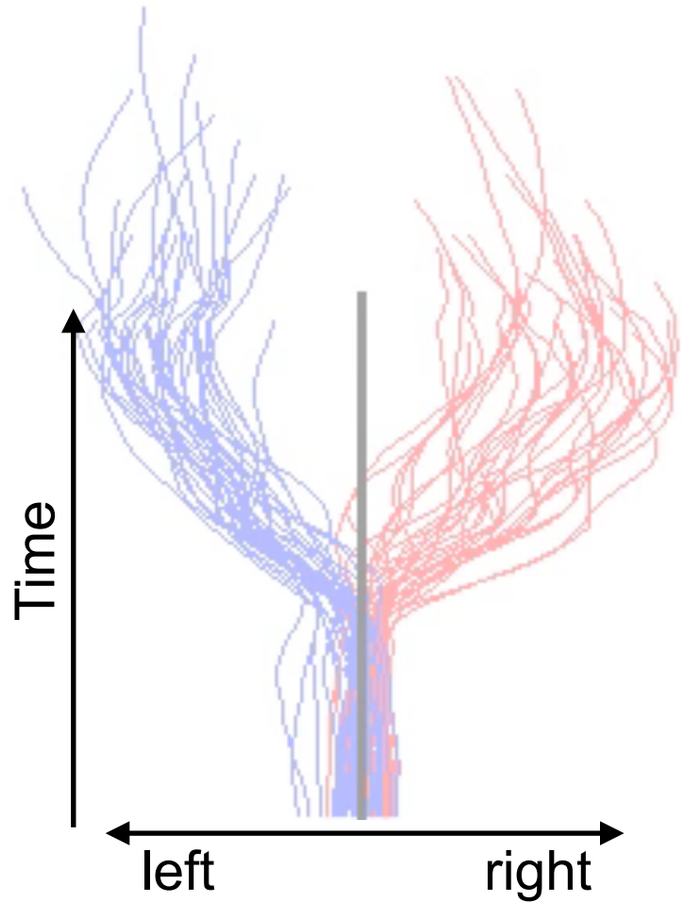

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Direct Observation of Single-Trial Neural Behavior
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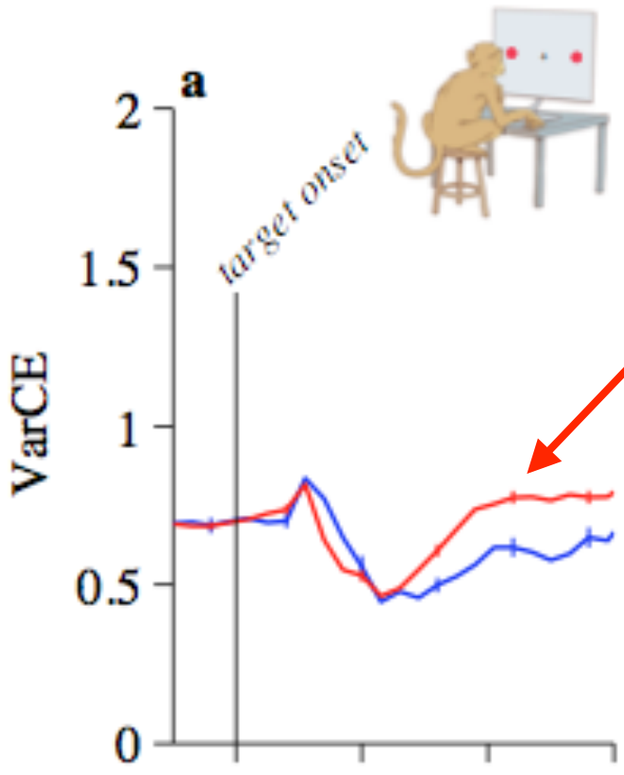
Churchland et al. Supp. Fig. 3



"This observation suggests that the lower average firing rate on the four-choice task **belies a broader mixture of firing rates from trial to trial**, most of which are lower in the four-choice task.

The lower average rate is probably not explained by a mechanism that invokes less excitation or greater suppression on all trials, owing perhaps to greater uncertainty (Basso and Wurtz, 1998), or normalization (Tolhurst and Heeger, 1997), or surround inhibition (Balan et al., 2008)."

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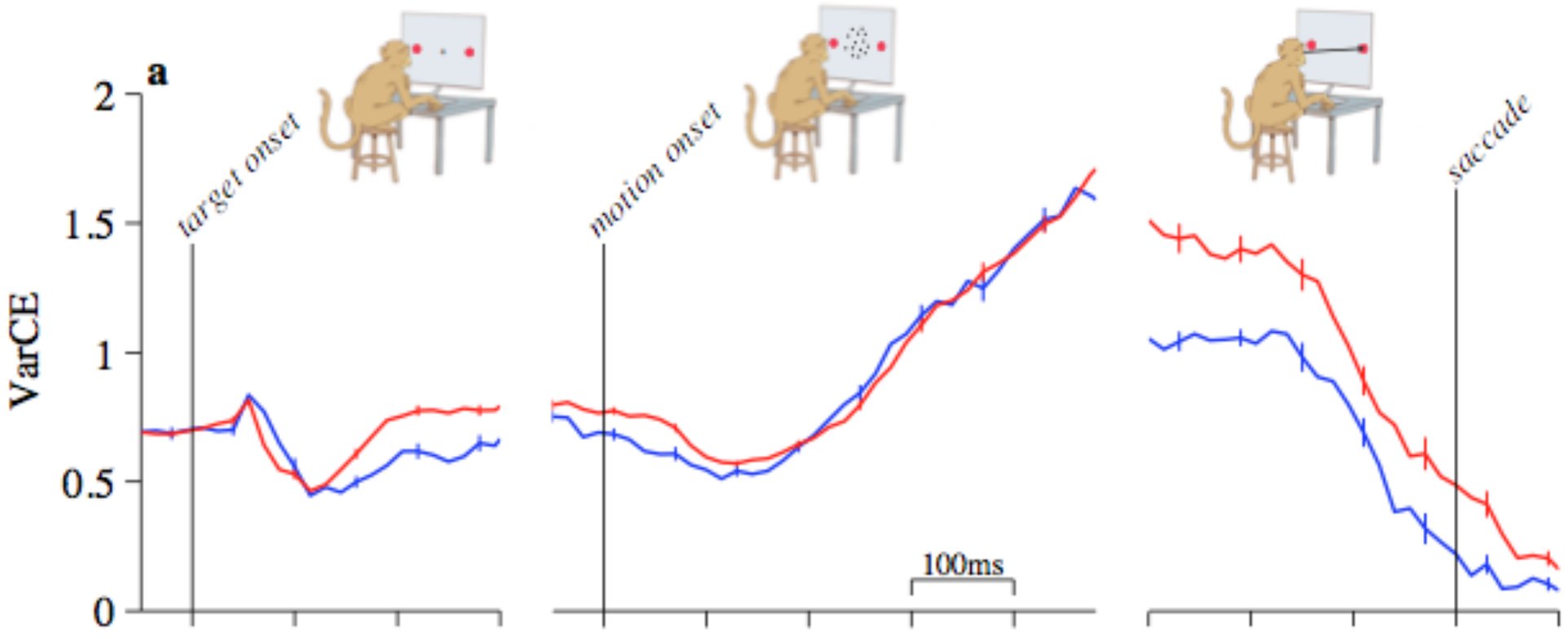

Outline

- Reminder that neural state matters (state predicts reach speed)
- Visualizing neural state, and trajectories (dimensionality reduction)
- Can we learn anything from single-trial neural state trajectories?
  - neural correlate of reach reaction time
  - neural correlate of reach decision
- **Summary & Acknowledgments**

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    - Large sources of variability (e.g., decision making)
    - Rare events (e.g., what happened on *that* trial?)

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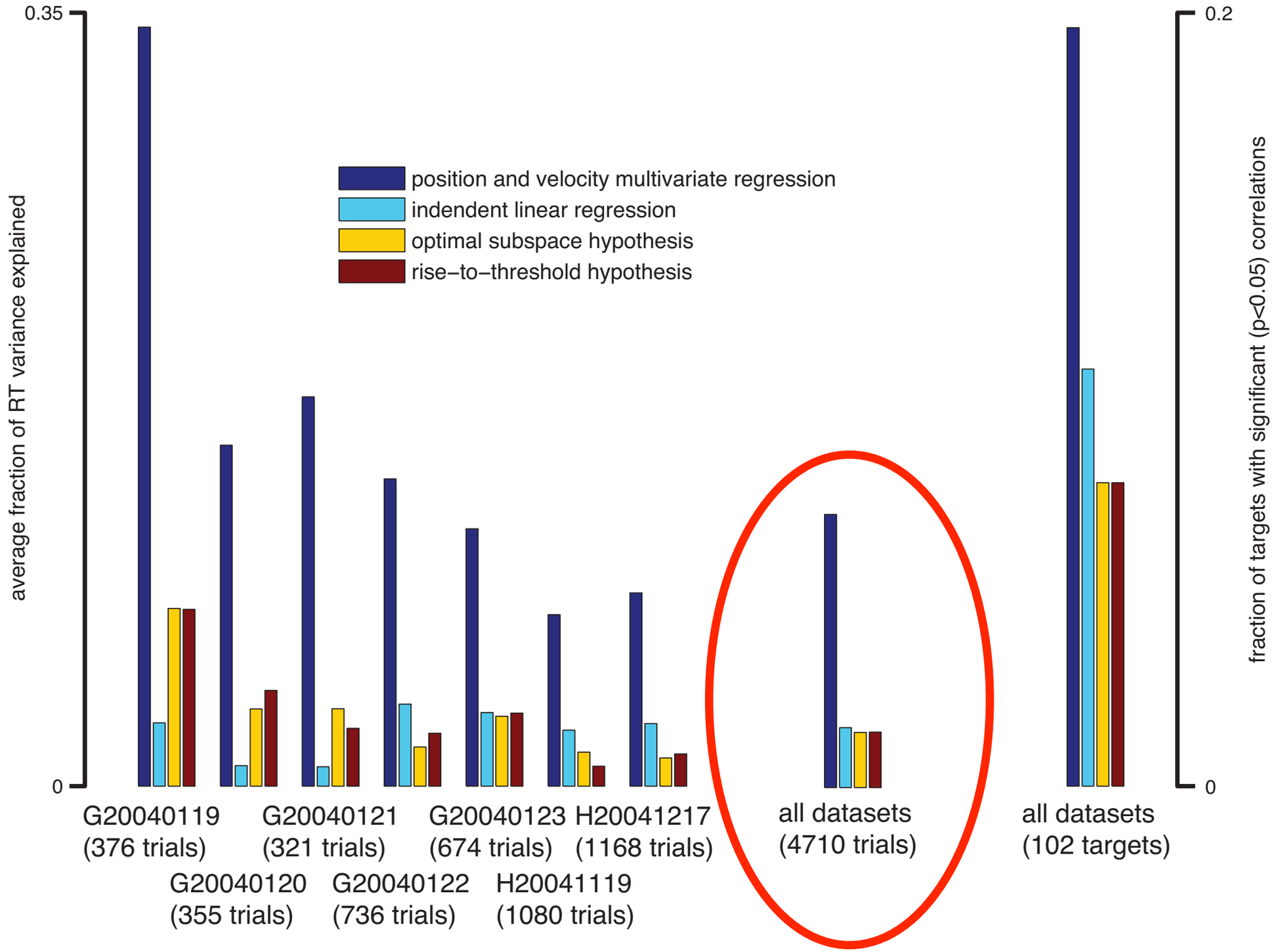
Whitaker Foundation
Weston Havens Foundation

Backup Slides

Can This Lead to a Better Single-Trial Correlate of RT?



Afshar, Santhanam, Yu, Ryu, Sahani & Shenoy. Single-trial neural correlates of arm movement preparation. *Submitted*