One dimensional dynamics of attention and decision making in area LIP

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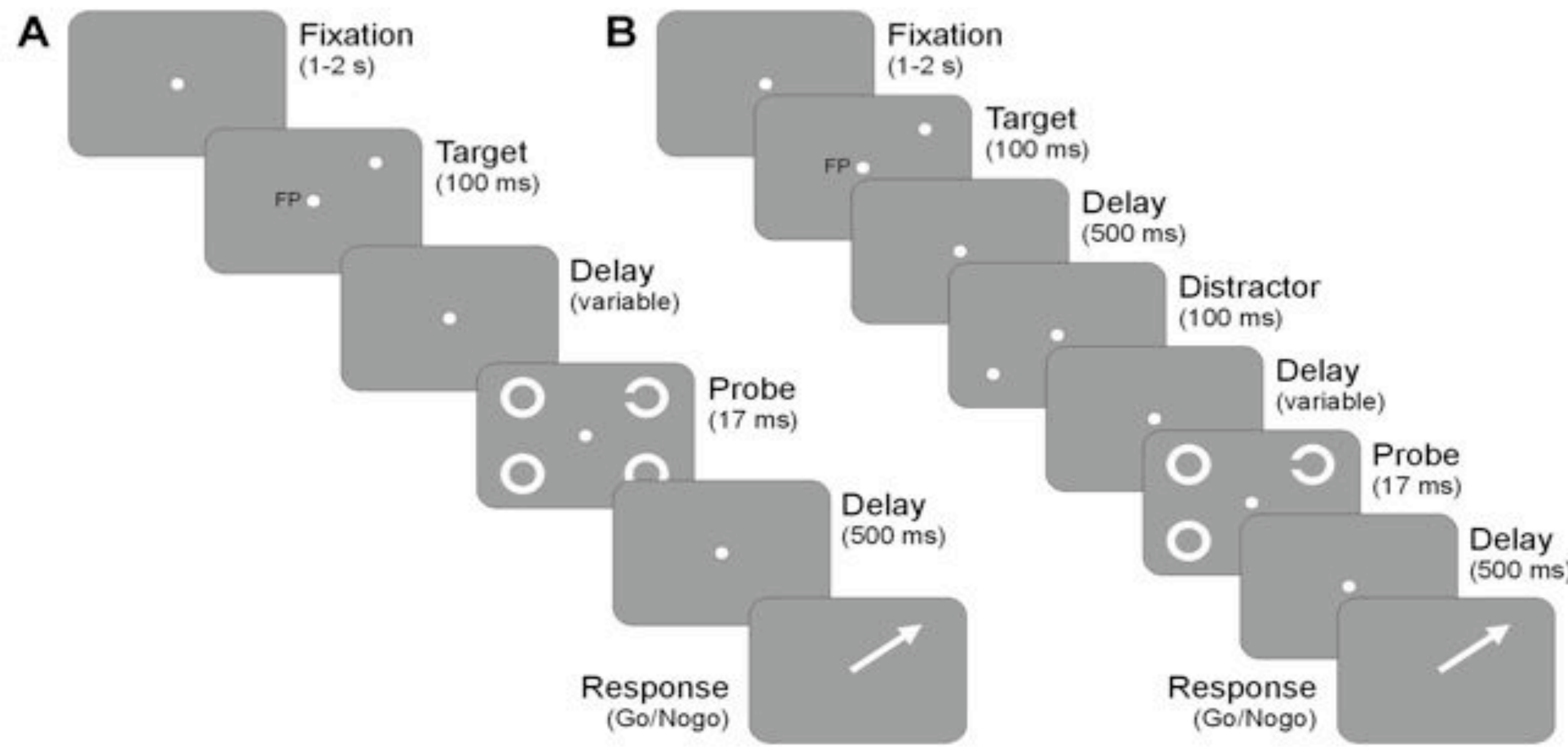
Ganguli et al., Neuron 2008

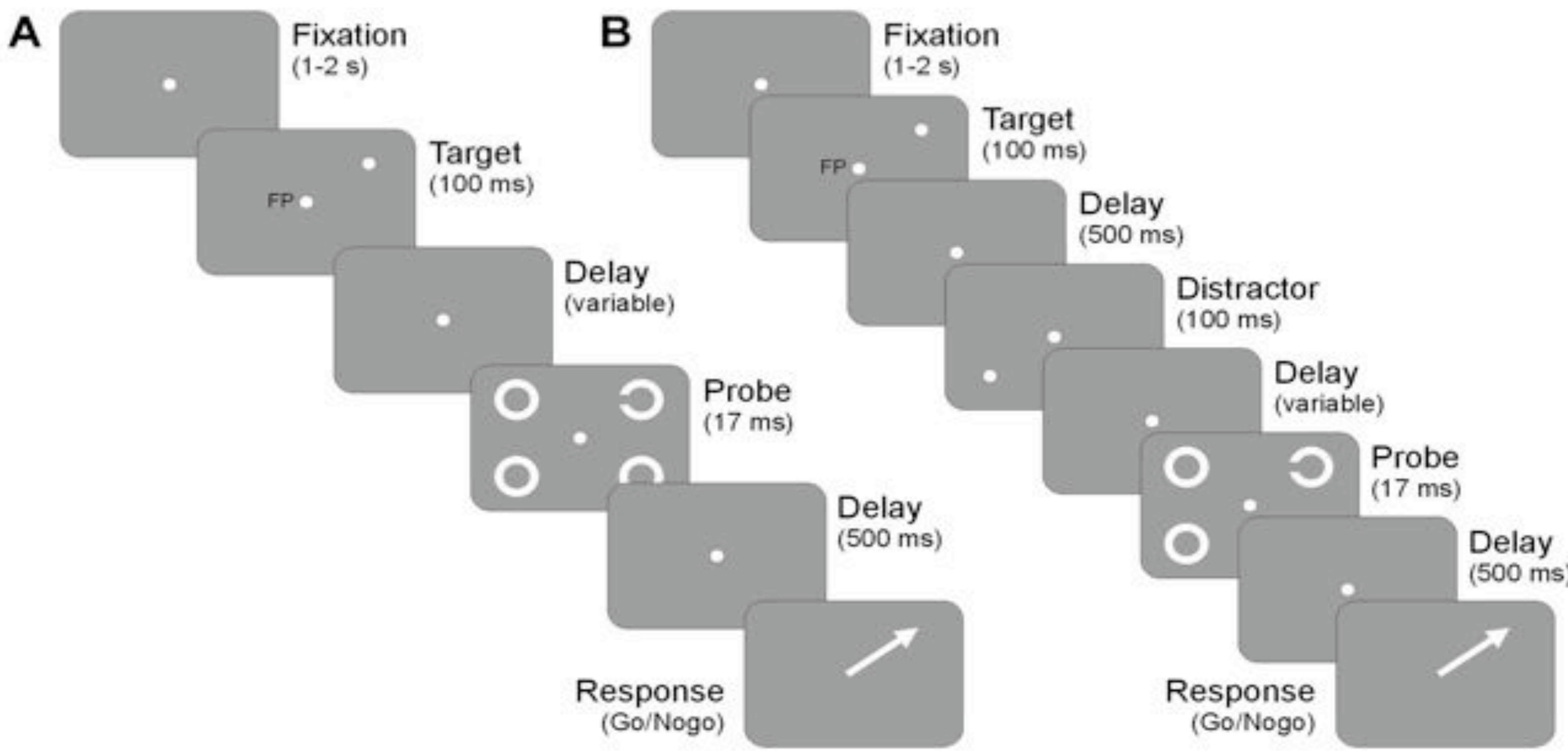
The Dynamics of Attention

- Goal: Top Down Attention
- Distractor: Bottom Up Attention
- Top Down wins back Attention
- What type of neuronal dynamics underlies this shifting attentional dynamics?

The task (Bisley and Goldberg, Science, 2003):



The task (Bisley and Goldberg, Science, 2003):



The locus of attention moves to the distractor for then returns back to the target within 375 ms.

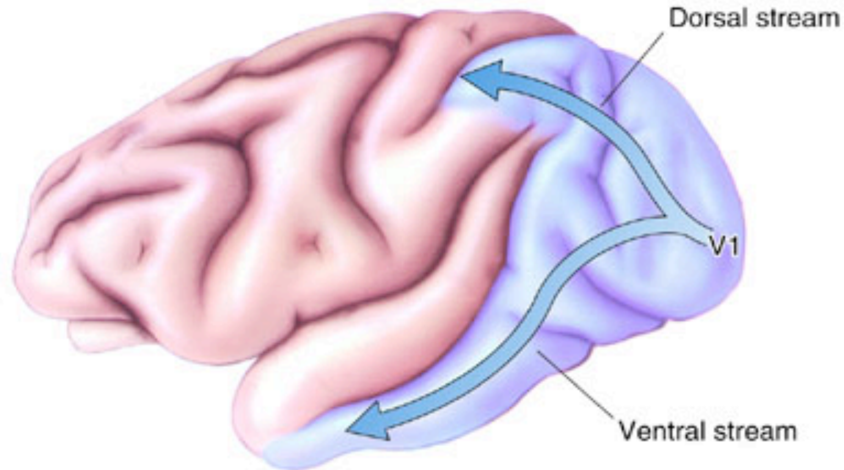
Lateral Intraparietal Cortex

Motor Planning:
Snyder et. al. 1997

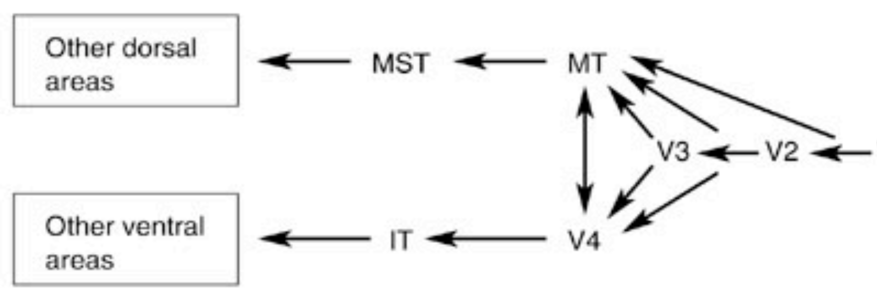
Decision Making:
Platt & Glimcher 1999
Shadlen & Newsome 2001

Reward:
Sugrue et.al. 2004
Dorris and Glimcher 2004

Attention:
Gottlieb et. al., 1998

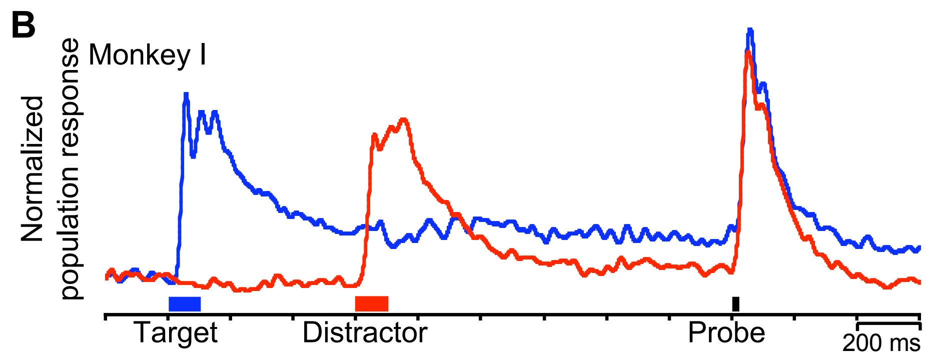


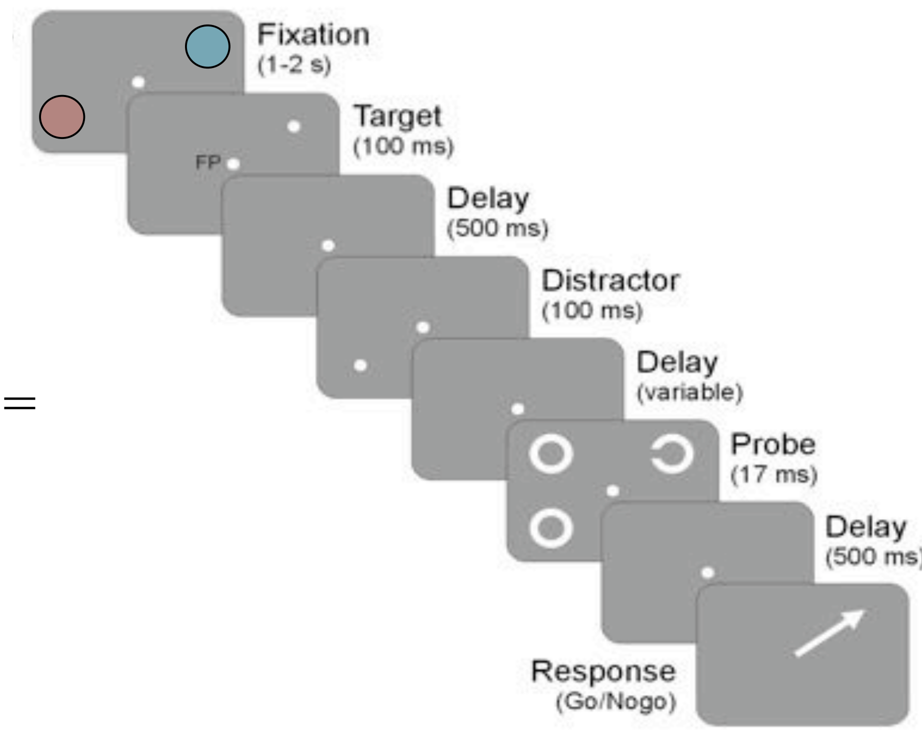
(a)



(c)

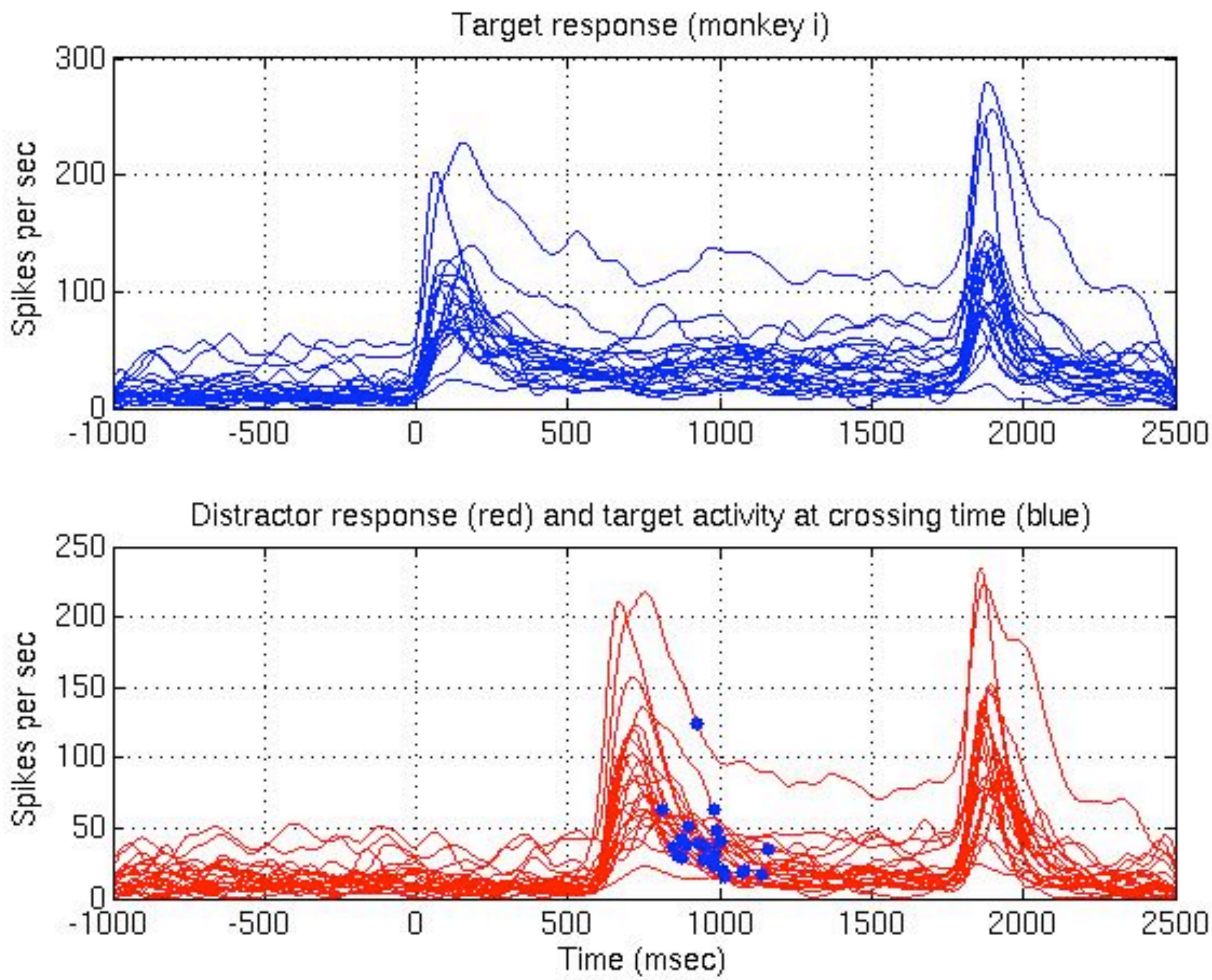
Trial Average Population Responses

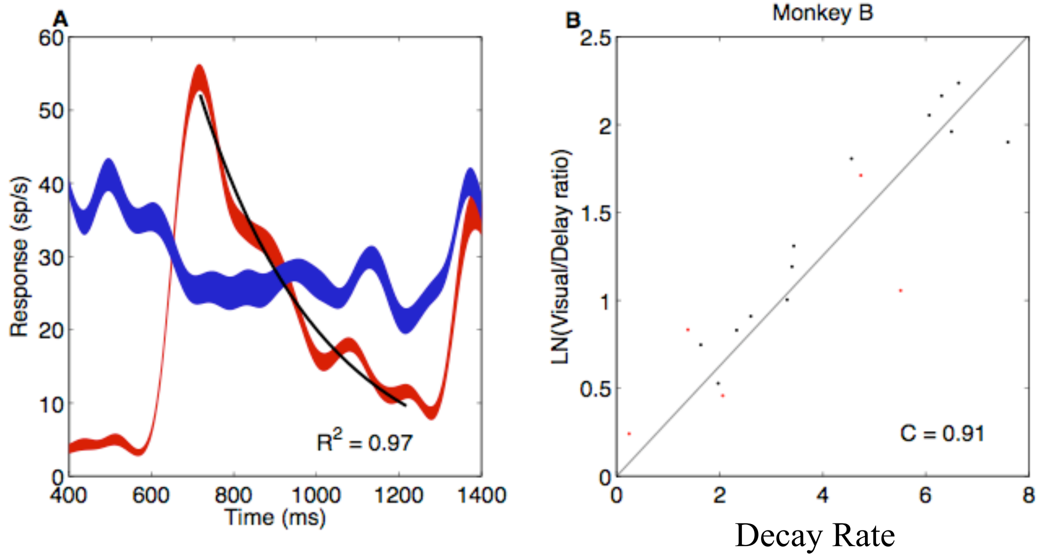




Locus of Attention =
RF of neurons with
Peak Activity
in LIP

Trial Average Single Neuron Response





Bisley, Goldberg 05

For each individual neuron, define

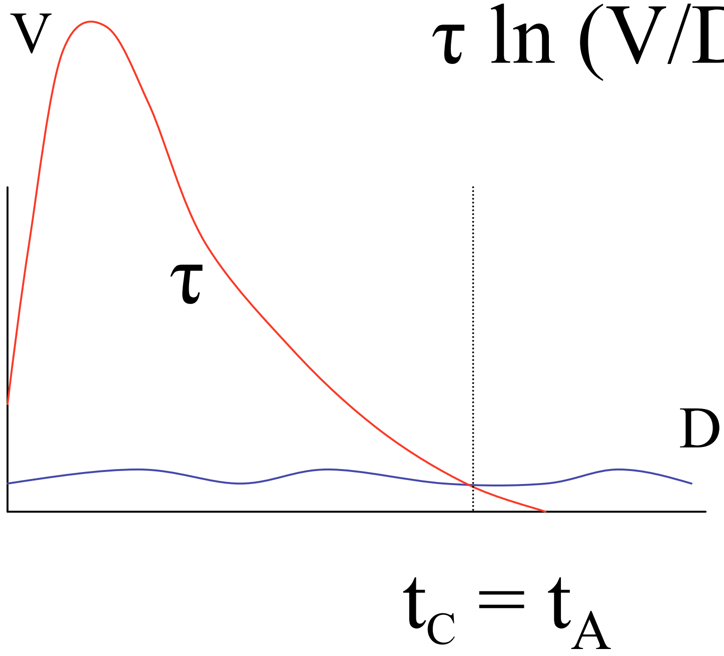
V = peak visual response to distractor (Bottom Up Attention)
τ = decay time of response to distractor

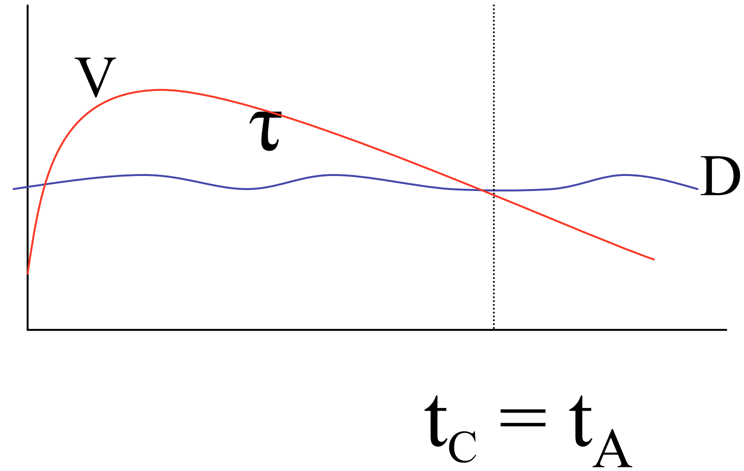
D = delay period response to target (Top Down Attention)

If there is a common crossing time t_c, then $V \exp(-t_c/\tau) = D$

Or equivalently, $\ln (V/D) = t_c/\tau$

$\tau \ln (V/D) = t_A$: WHY?





An important and robust behavioral time scale is predicted by noisy and heterogeneous single neuron dynamics!

No network explanation is allowed - the recorded neurons don’t talk to each other!

Any single neuron biophysics explanation would require fine tuning.

$\tau \ln (V/D) = t_A$: WHY?

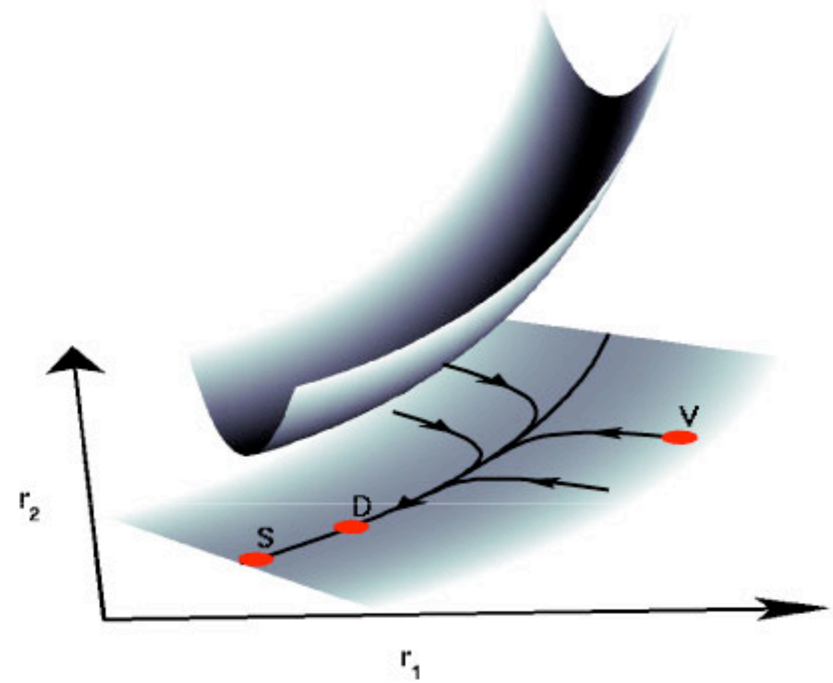
Network Dynamics: consider

population vector $\mathbf{r}(t)$ of responses of neurons at time t after distractor shown in RF

population vector $\mathbf{d}$ of responses of neurons in delay period after target shown in RF

common crossing time t_A means $\mathbf{r}(t_A) = \mathbf{d}$

$\mathbf{r}(t_A) = \mathbf{d}$: WHY?



- imagine **r**(t), once excited, quickly settles into a particular direction in firing rate space
- also imagine that the delay vector **d** lies in this direction as well, so they intersect
- this scenario does not require fine tuning

$\mathbf{r}(t_A) = \mathbf{d}$: WHY?

This will arise from network dynamics if:

(1) Dynamics of decay has one slow mode $\mathbf{m}_s$, all other modes decay quickly

(2) This slow mode is also the dominant mode in the sustained, delay dynamics

$$w/N \begin{pmatrix} 1 & 1 & \ldots & 1 & 1 \\ 1 & 1 & \ldots & 1 & 1 \\ & . & & . & \\ & . & & . & \\ 1 & 1 & \ldots & 1 & 1 \end{pmatrix}$$

Slow mode: $\begin{pmatrix} 1 \\ 1 \\ . \\ . \\ 1 \end{pmatrix}$

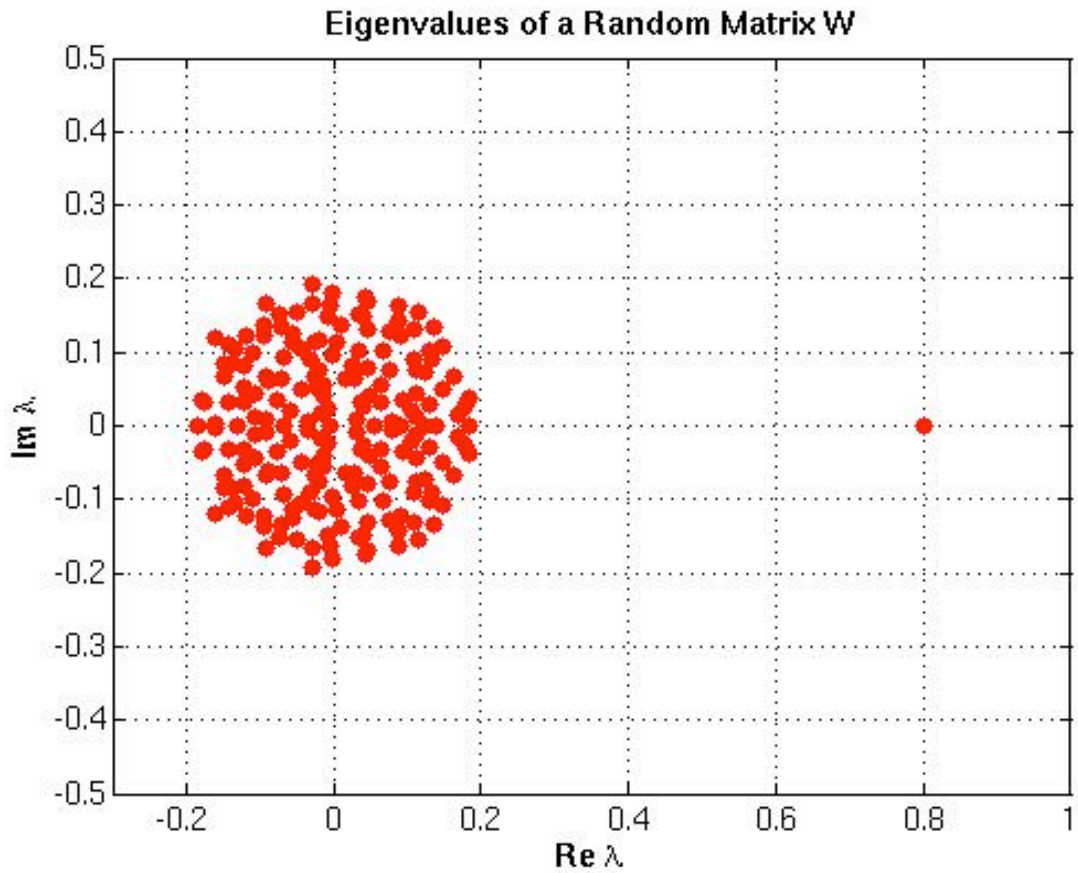
$\mathbf{r}(t) \propto \mathbf{m}_s$

$\mathbf{d} \propto \mathbf{m}_s$

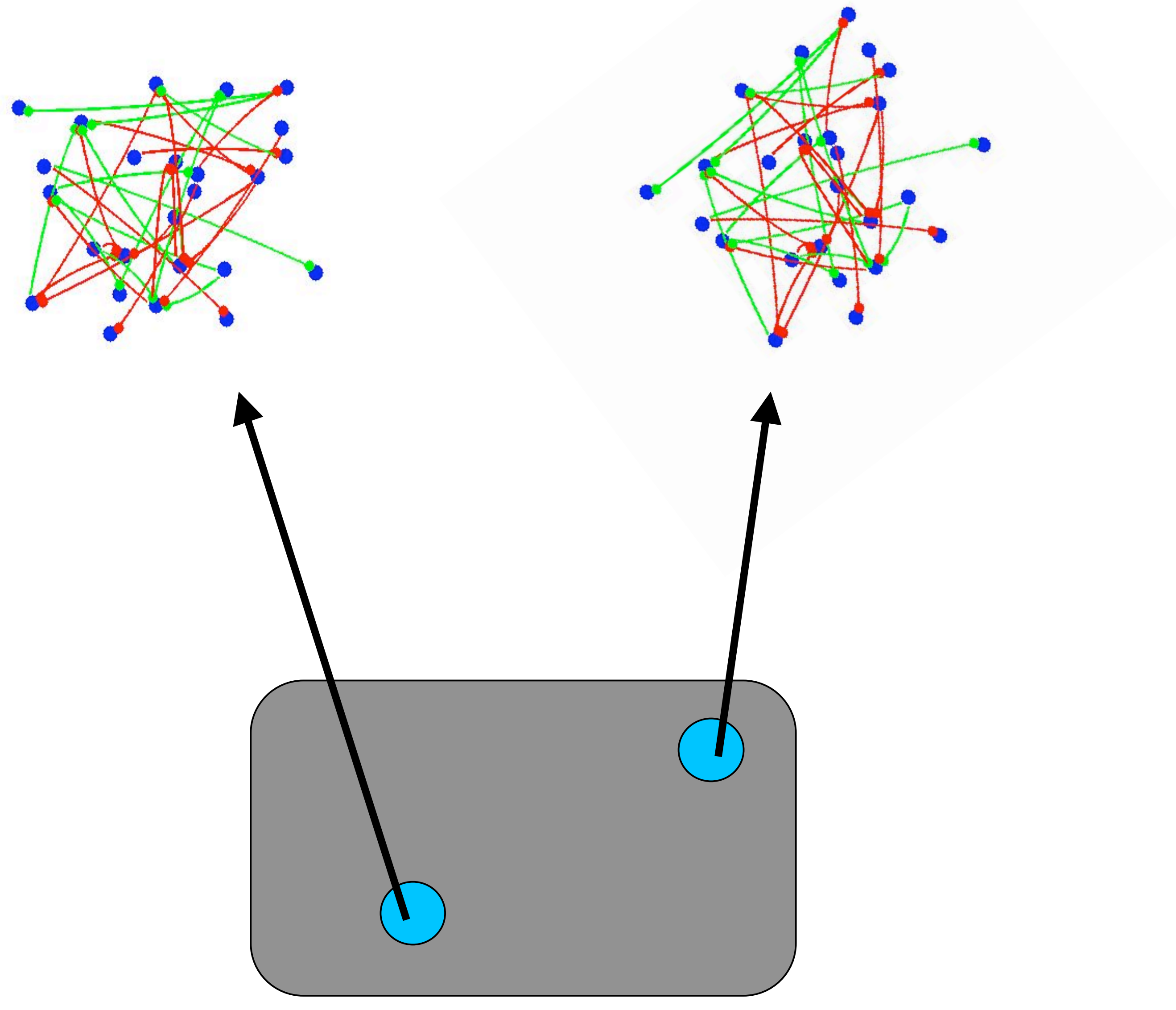
Eigenvector = Preferred Pattern or Mode of Activity across Neurons

Eigenvalue = Amount of feedback to that pattern (larger value -> slower decay)

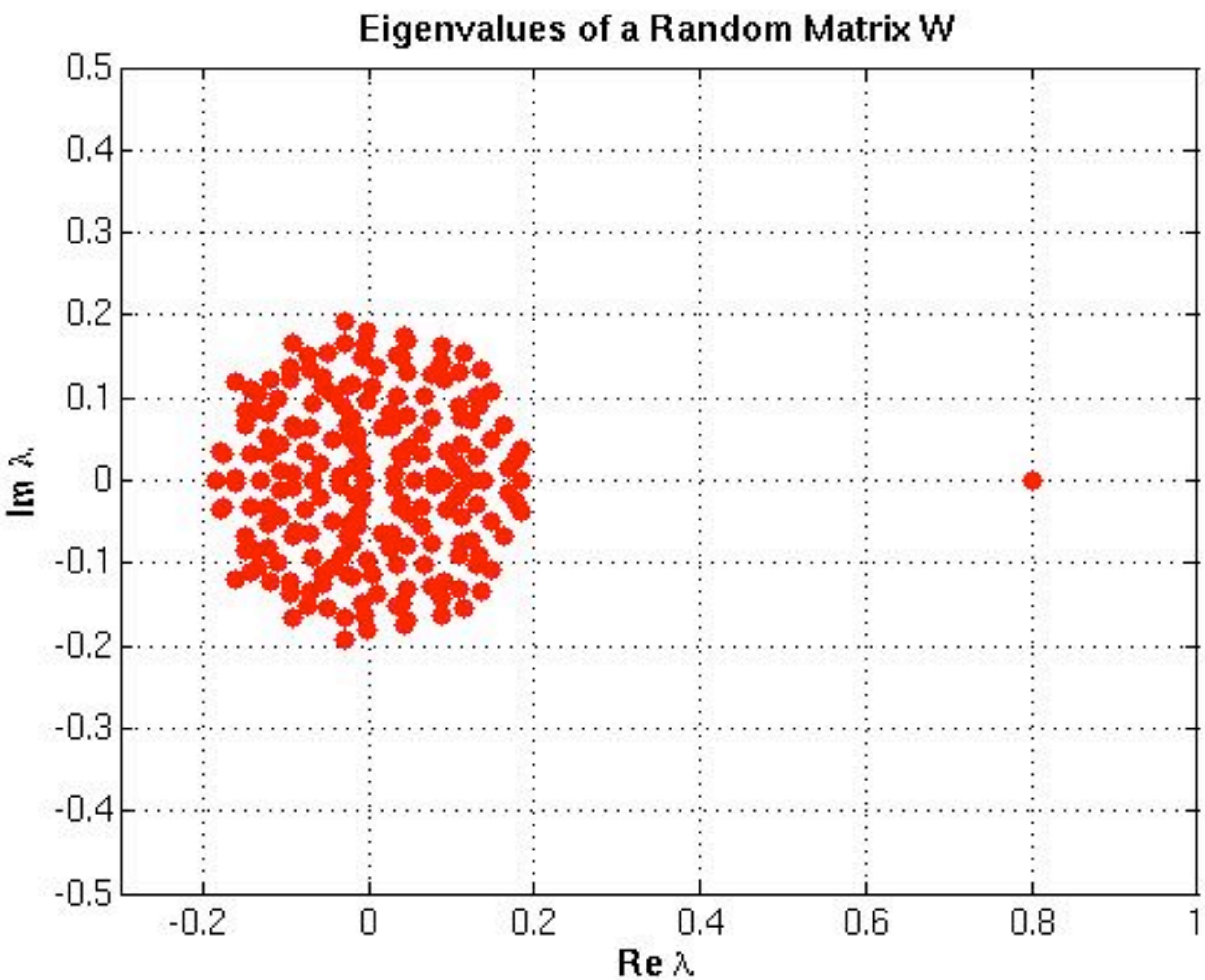
One dimensional dynamics without fine tuning.



The Full Problem



The time scale of attentional switching is robust.



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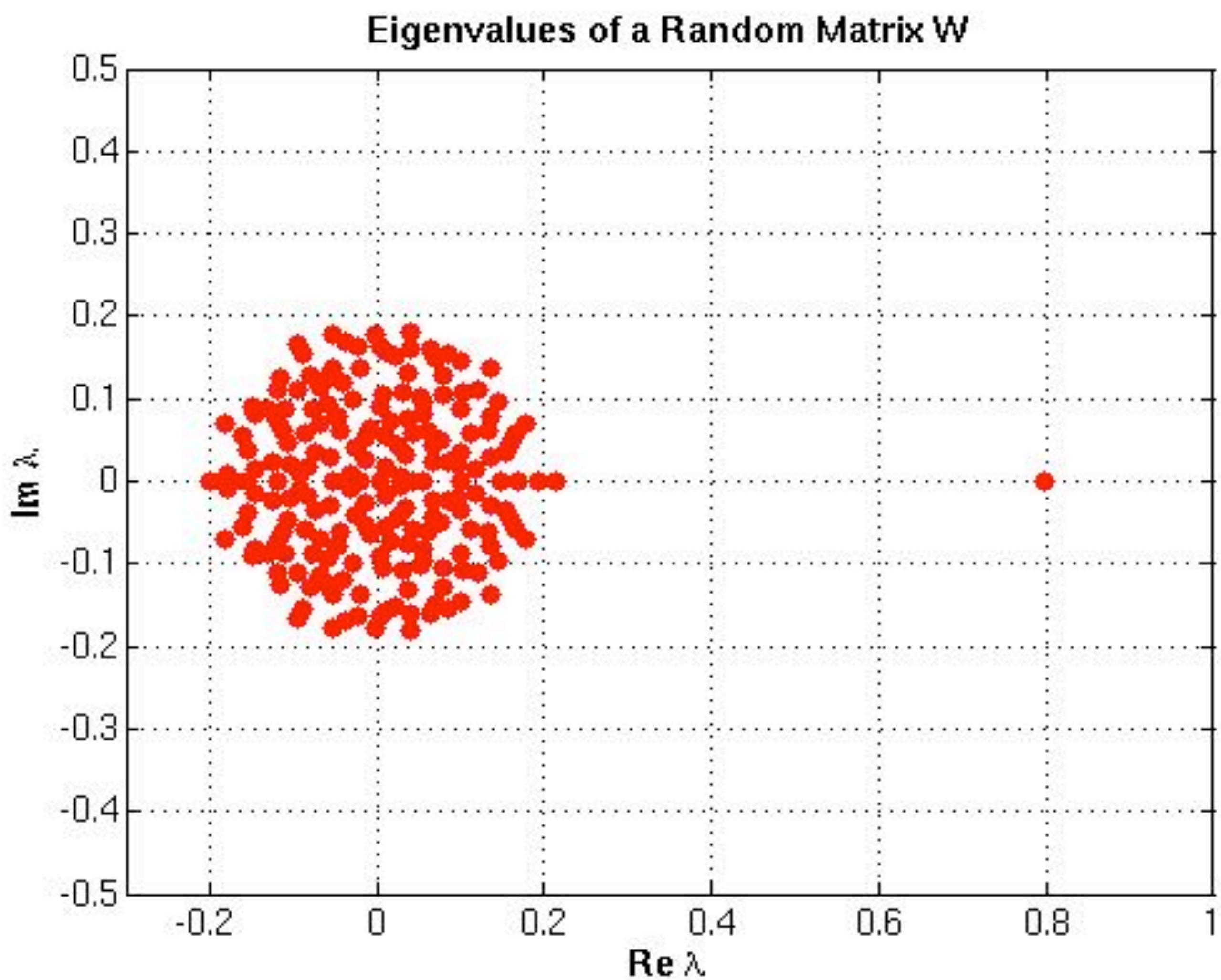
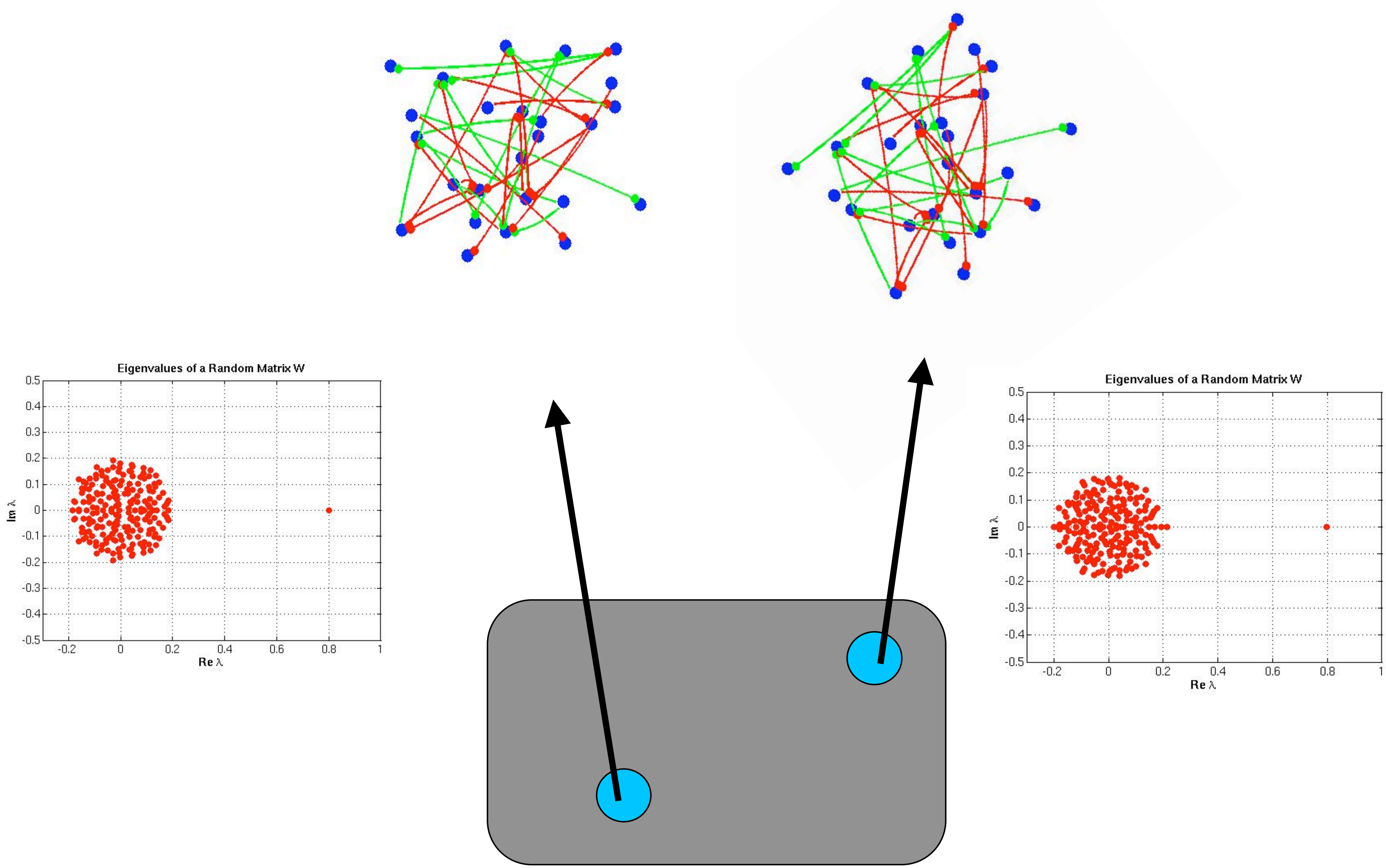
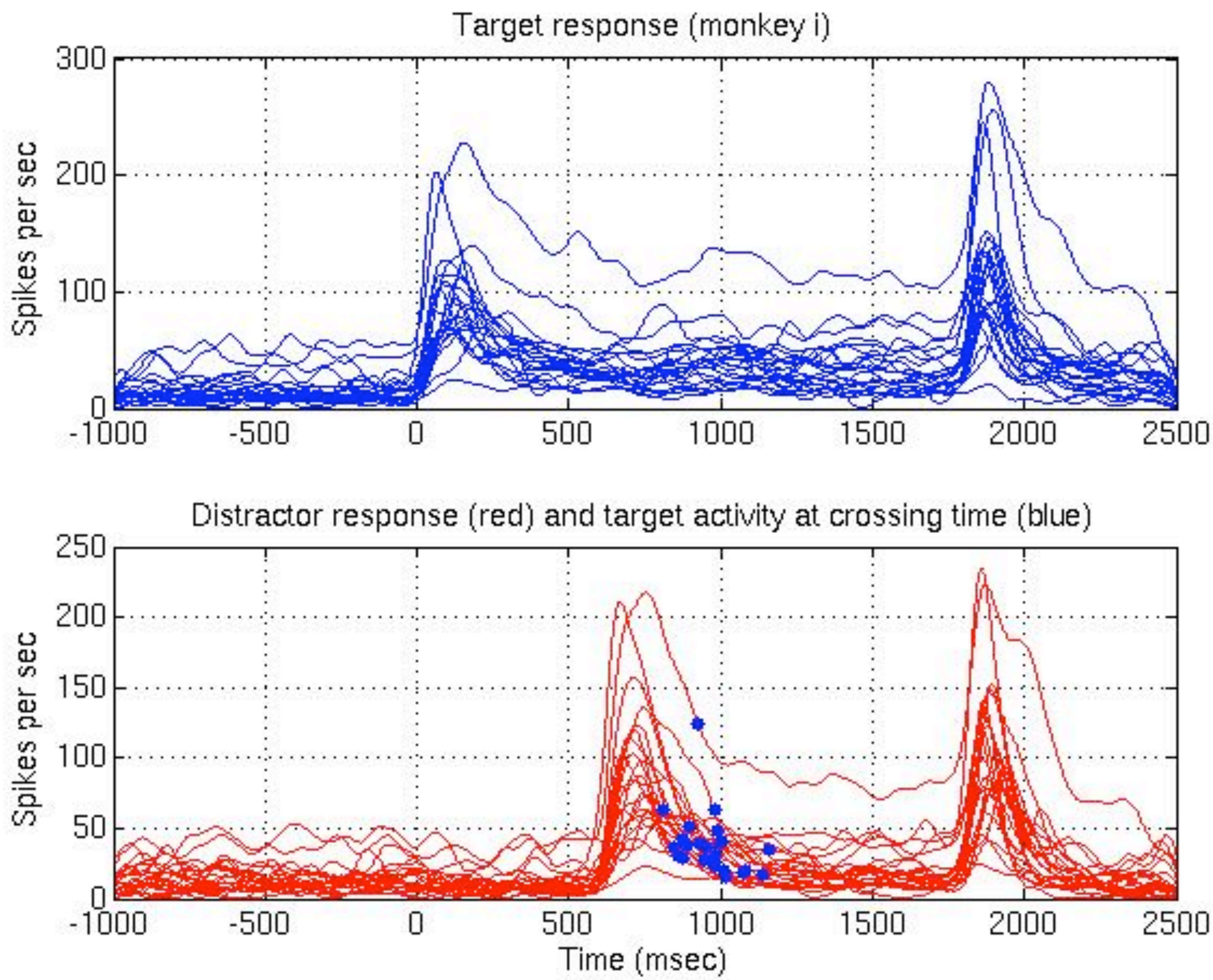


The Full Solution



Prediction: Original Single Neuron Data



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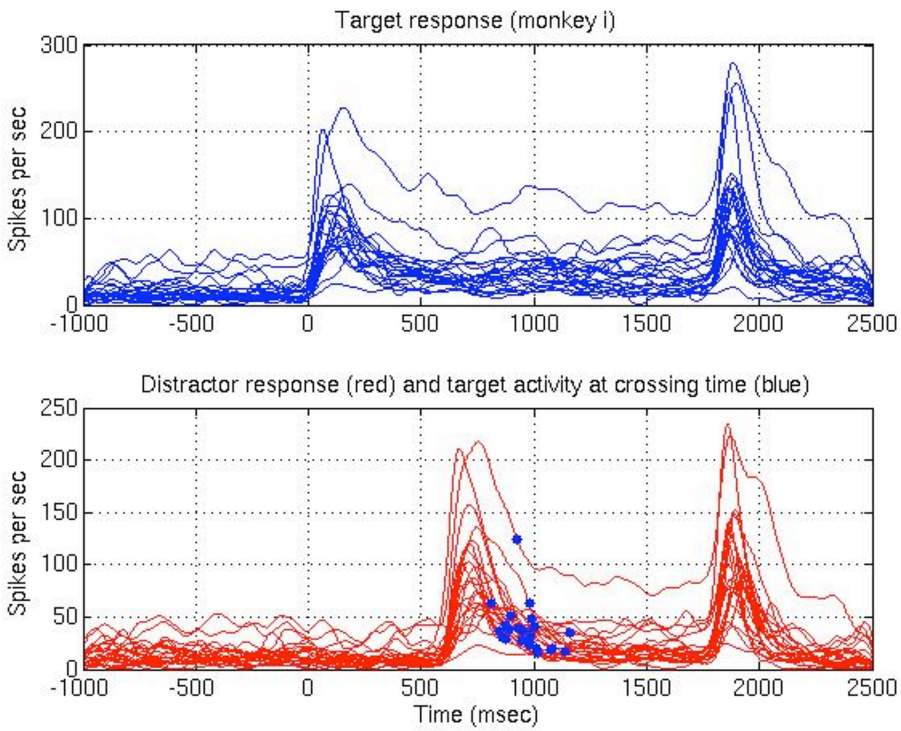
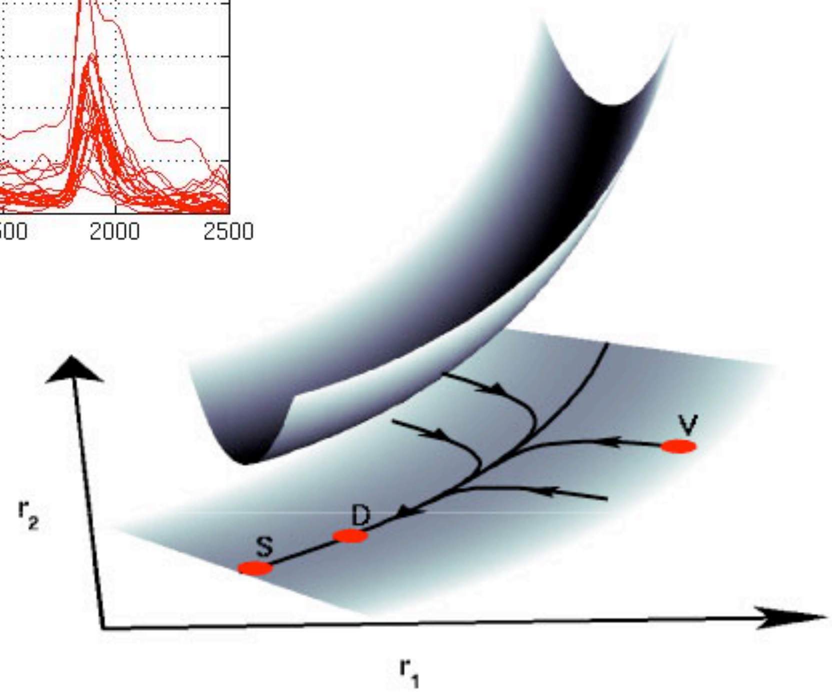
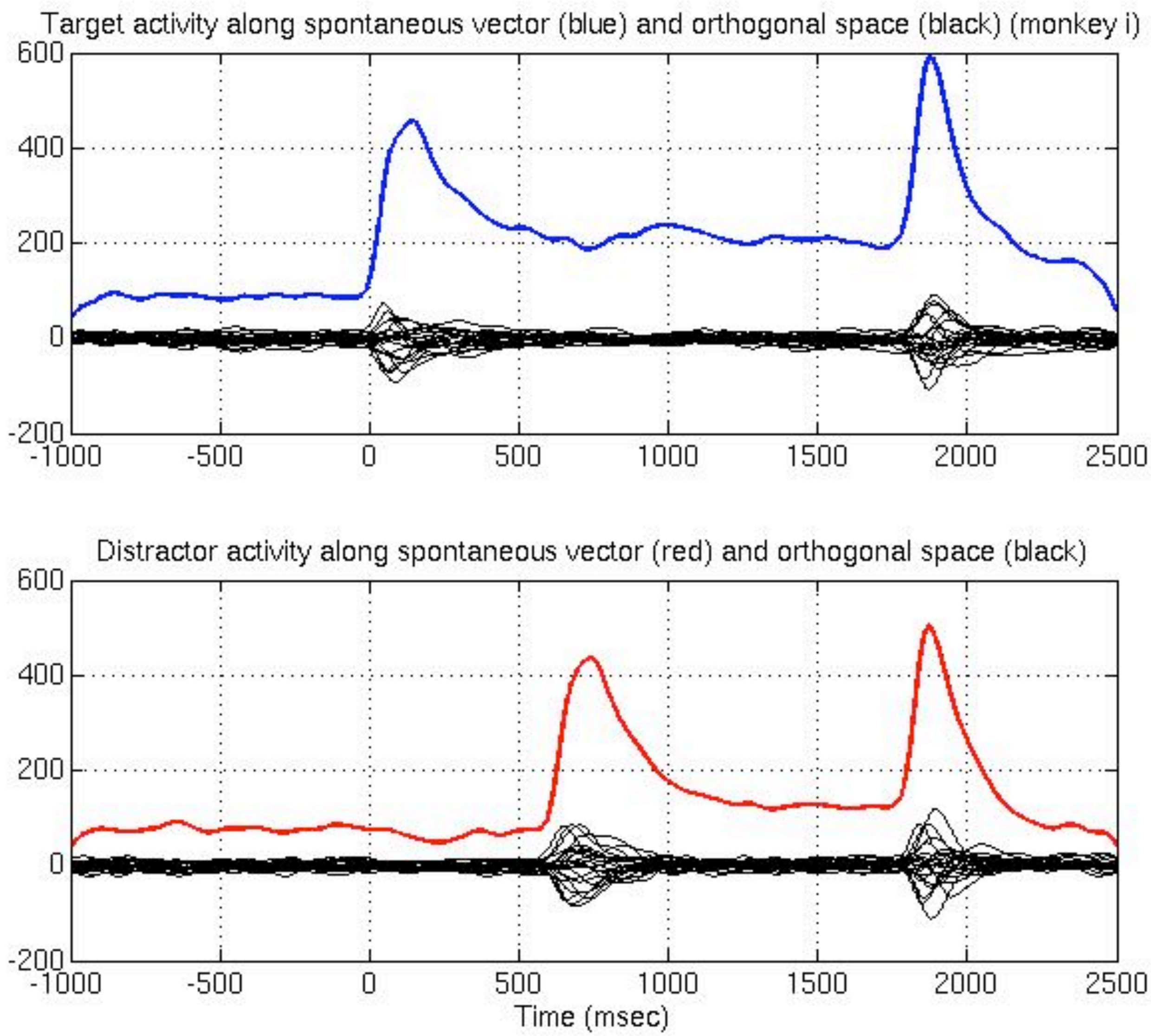
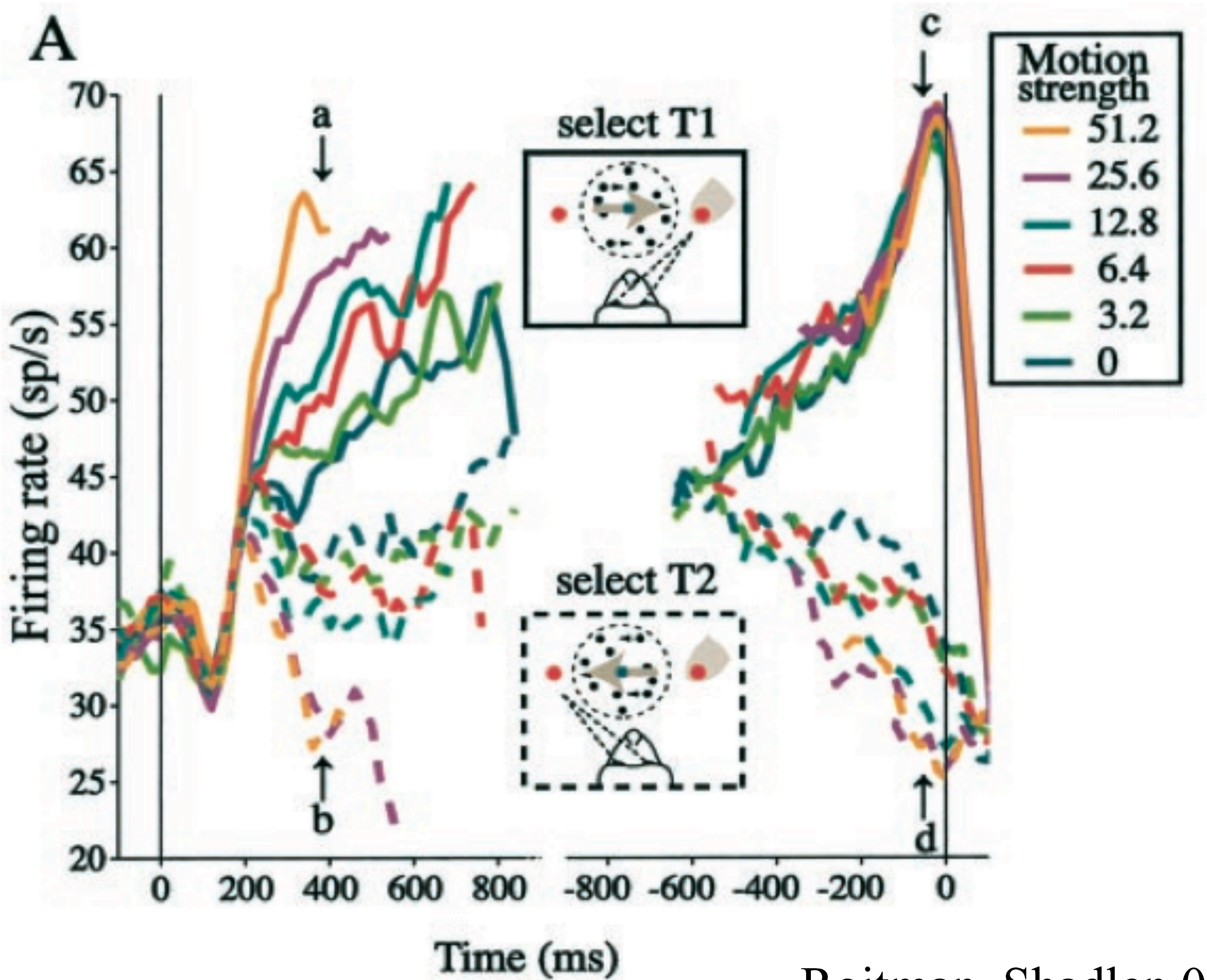




Activity along spontaneous versus other directions

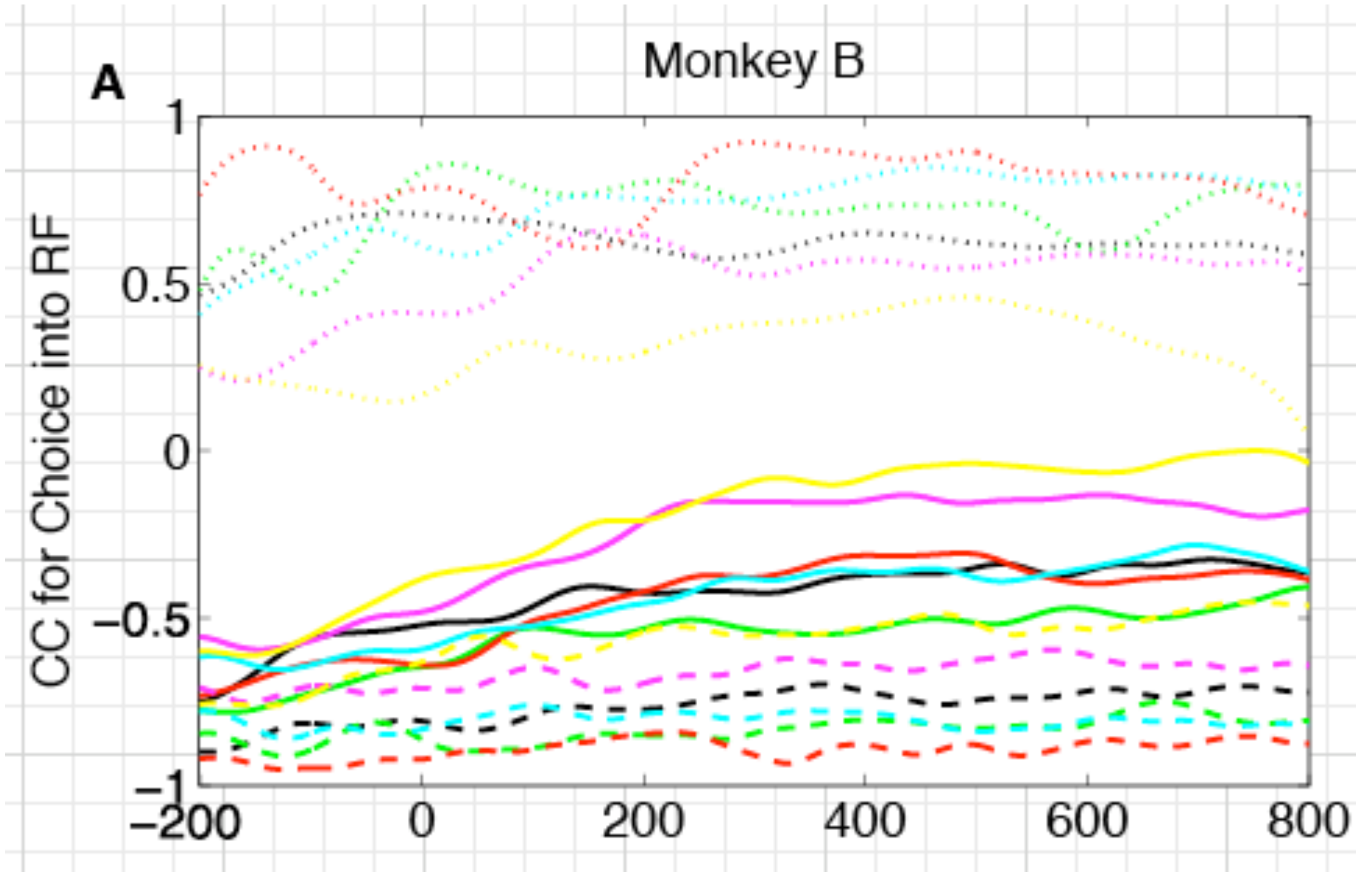


Same Neurons, Different Task: Decision Making



Roitman, Shadlen 02

Again One Dimensional Dynamics!



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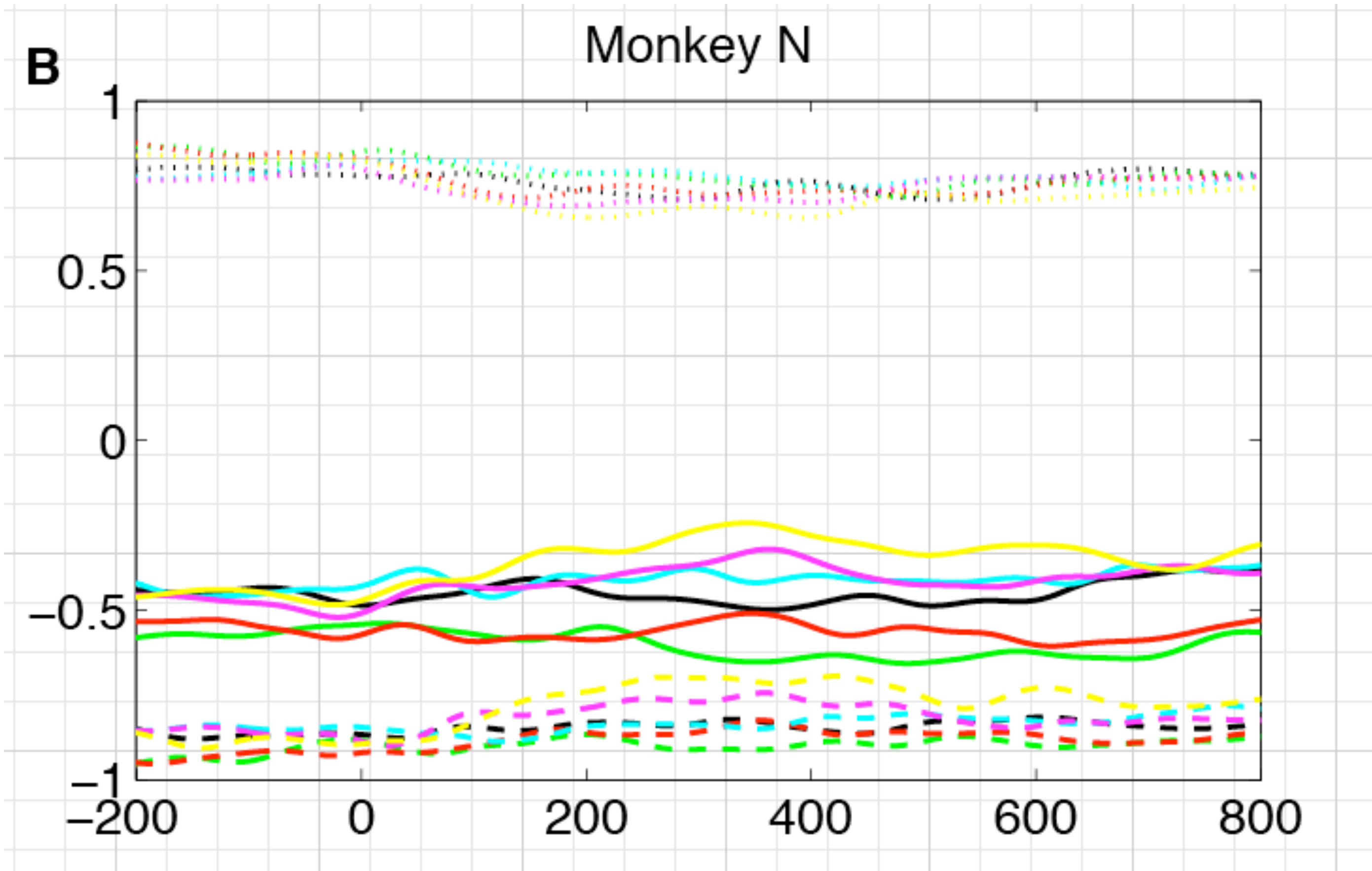

Summary

Start: Arcane observation: every neuron has a common crossing time; equals attentional switching time

Theory: Activity in LIP in each local region operates along its own one dimensional slow mode.

Robustness of attentional switching time scale is a free lunch.

Prediction Verified: All the action in both attention and decision making occurs along the spontaneous activity.