Course Outline

1. Introduction
2. Neuronal Signaling
3. Visual System
4. Computational Methods I
5. Decision making
6. Multi-modal Sensory Systems
7. Hippocampus, Spatial Cognition & Memory
8. Working memory
9. Motor Systems
10. Computational Methods II
11. Learning & Plasticity
12. Value and Reward
13. Project Presentation
14. Final Q&A

系统和计算神经科学导论

五、抉择

Decision Making

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- ❖Overview
- ❖DDM
- ❖SPRT
- ❖Confidence
- ❖Attractor Network

- ❖Overview
- ❖DDM
- ❖SPRT
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Definition

Different Types

- Perceptual decision making
- Value-based decision making
- Social decision making
- Other complex decision making

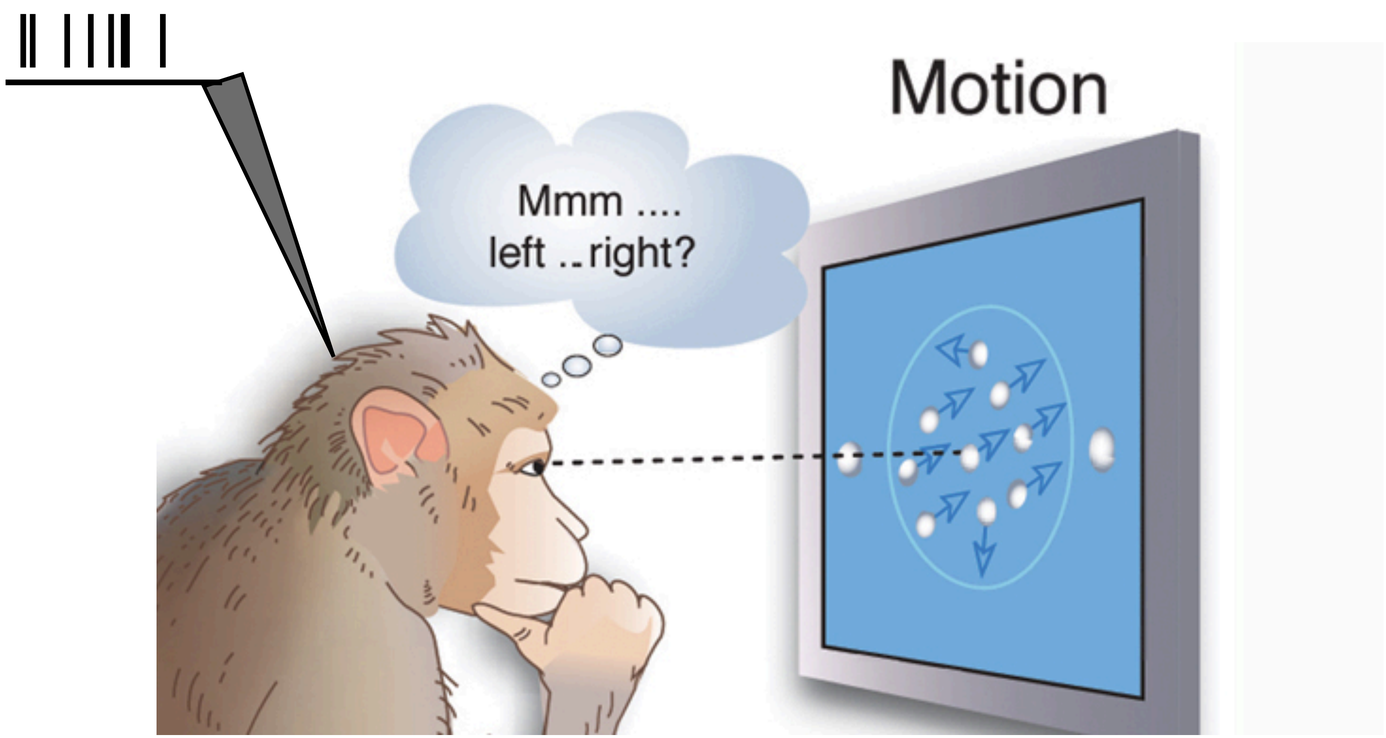
Different Types

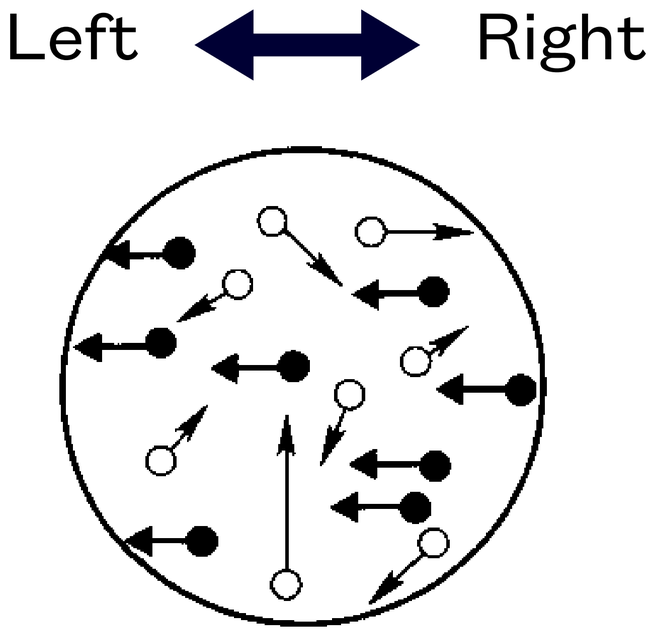
- Perceptual decision making
- Value-based decision making
- Social decision making
- Other complex decision making

- Overview
- **DDM**
- Probabilistic Reasoning
- Confidence
- Attractor Network

Random Dots Motion Direction Discrimination

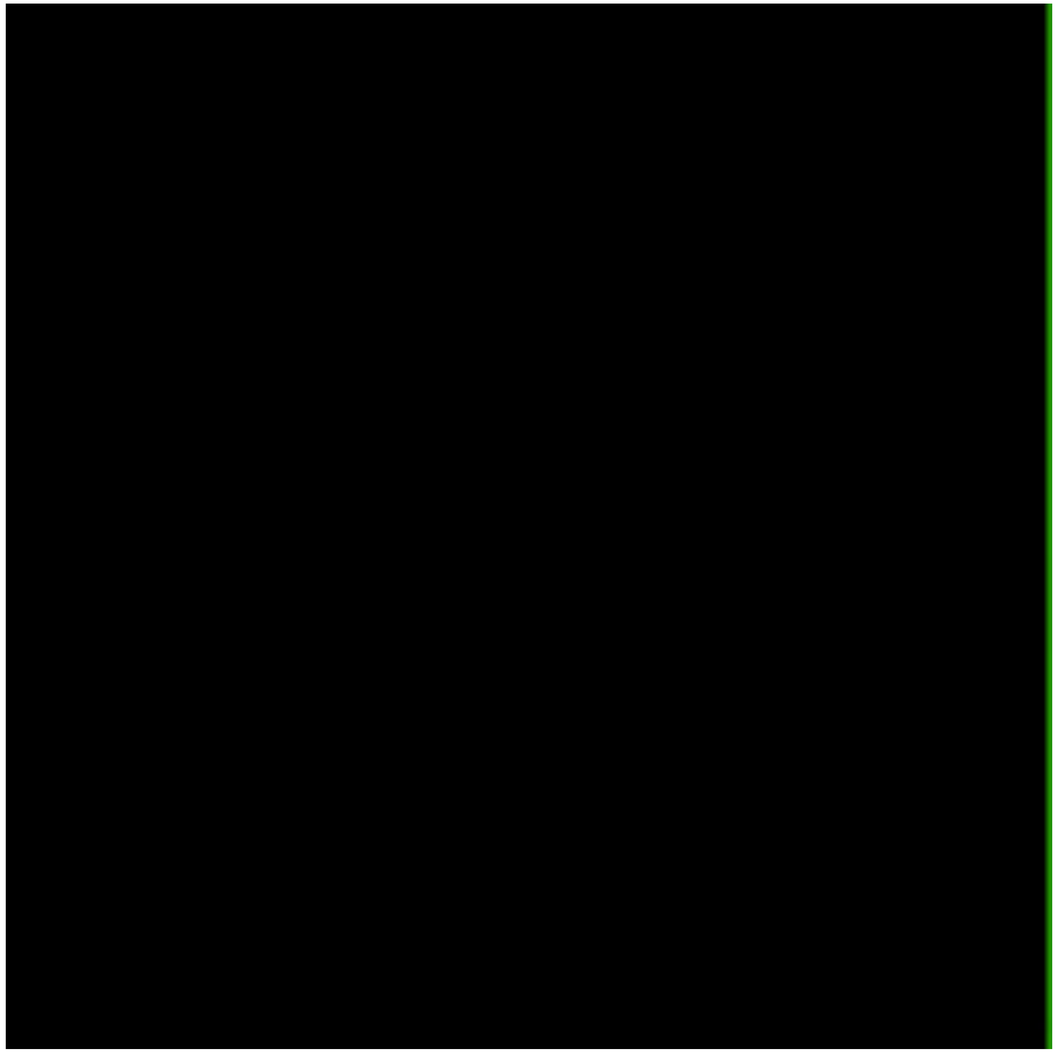
2-Alternative Forced Choice



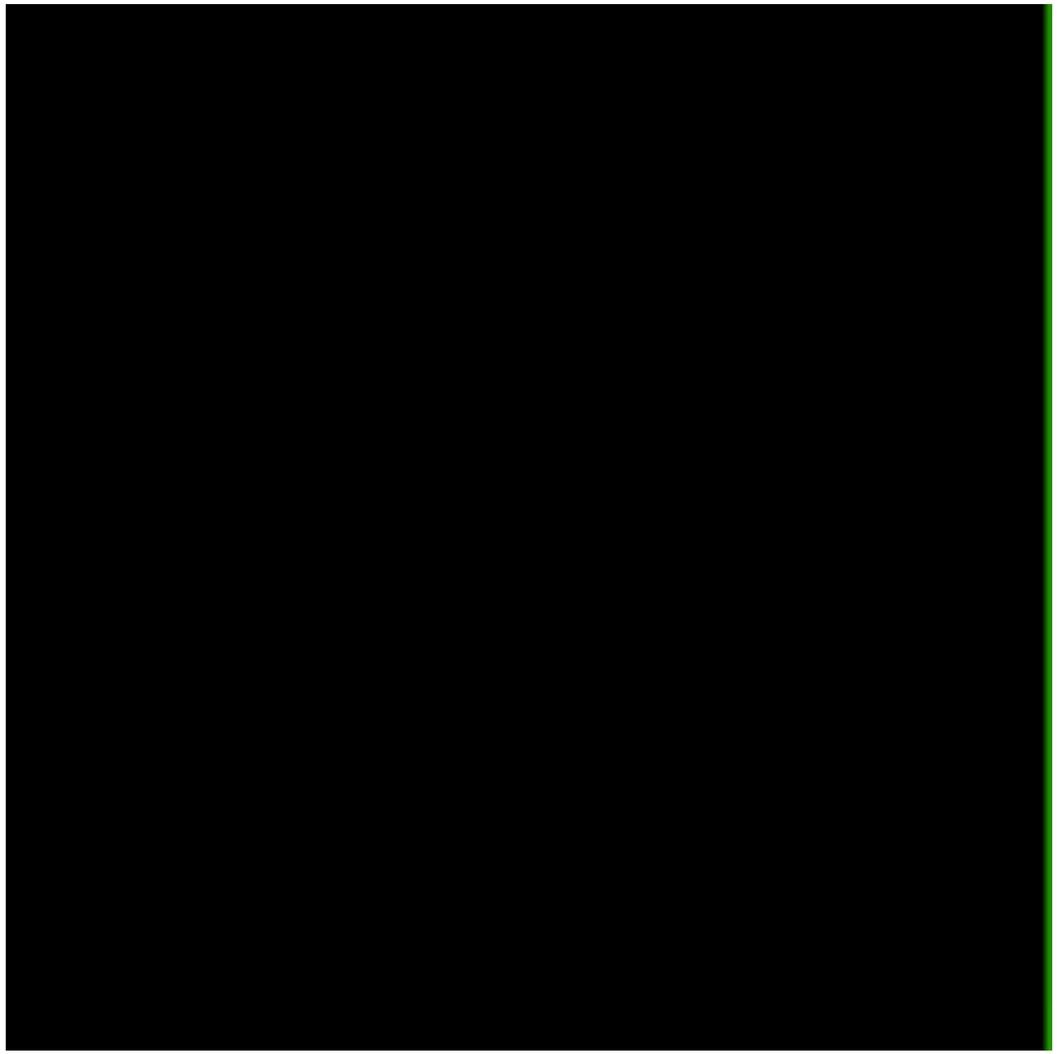


50% Coherence

Britten, Shadlen, Newsome and Movshon, J Neurosci., 1992

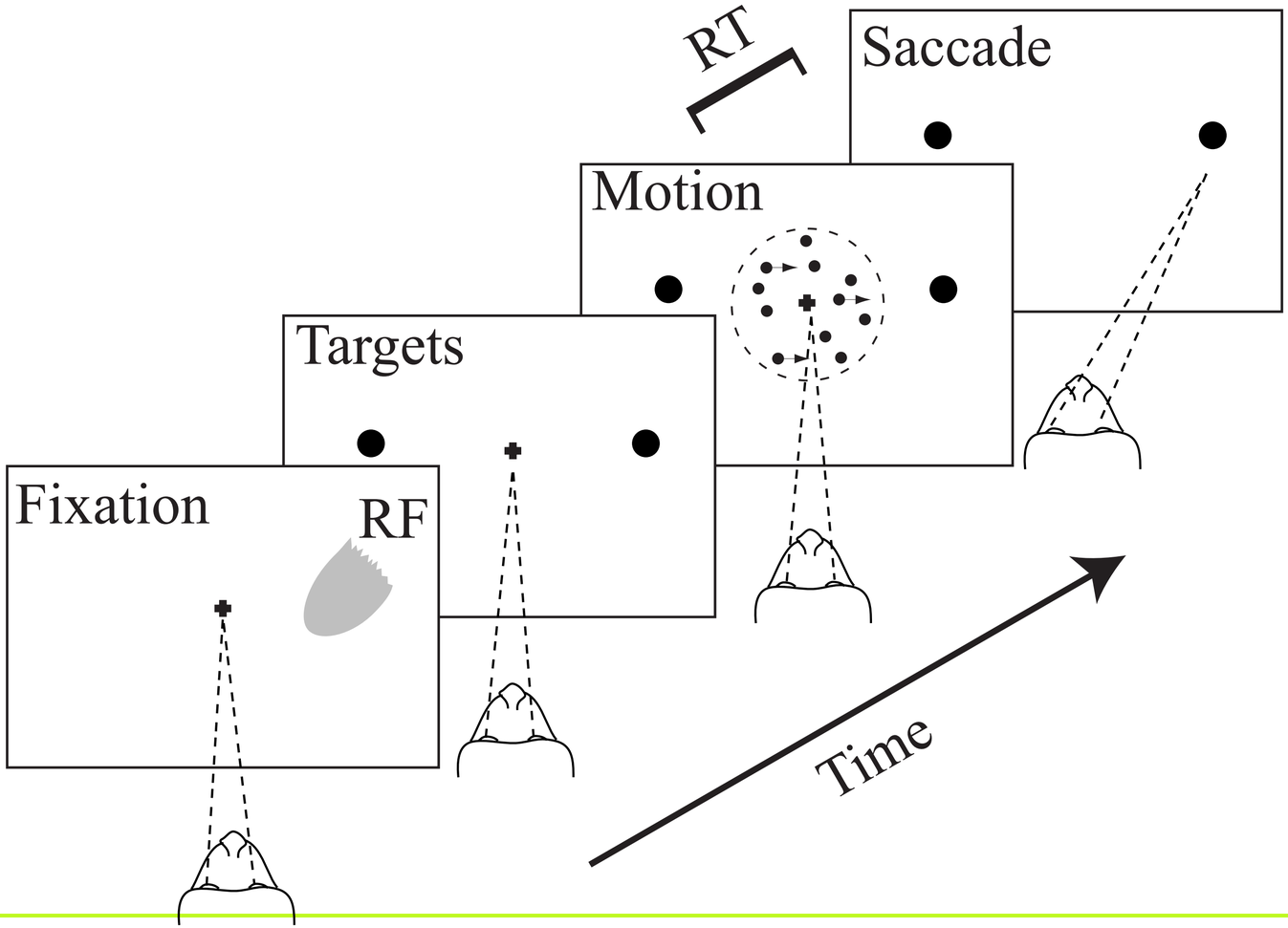


100%

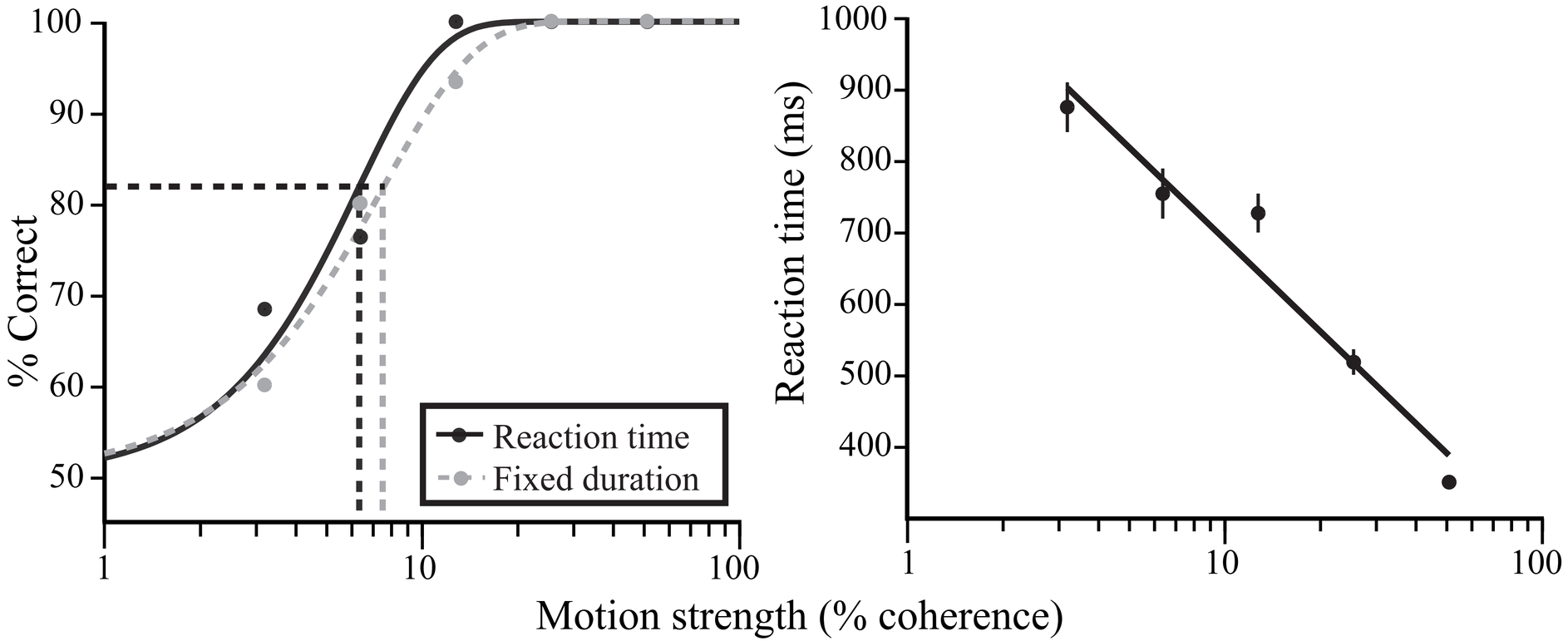


12.8%

Reaction Time Task

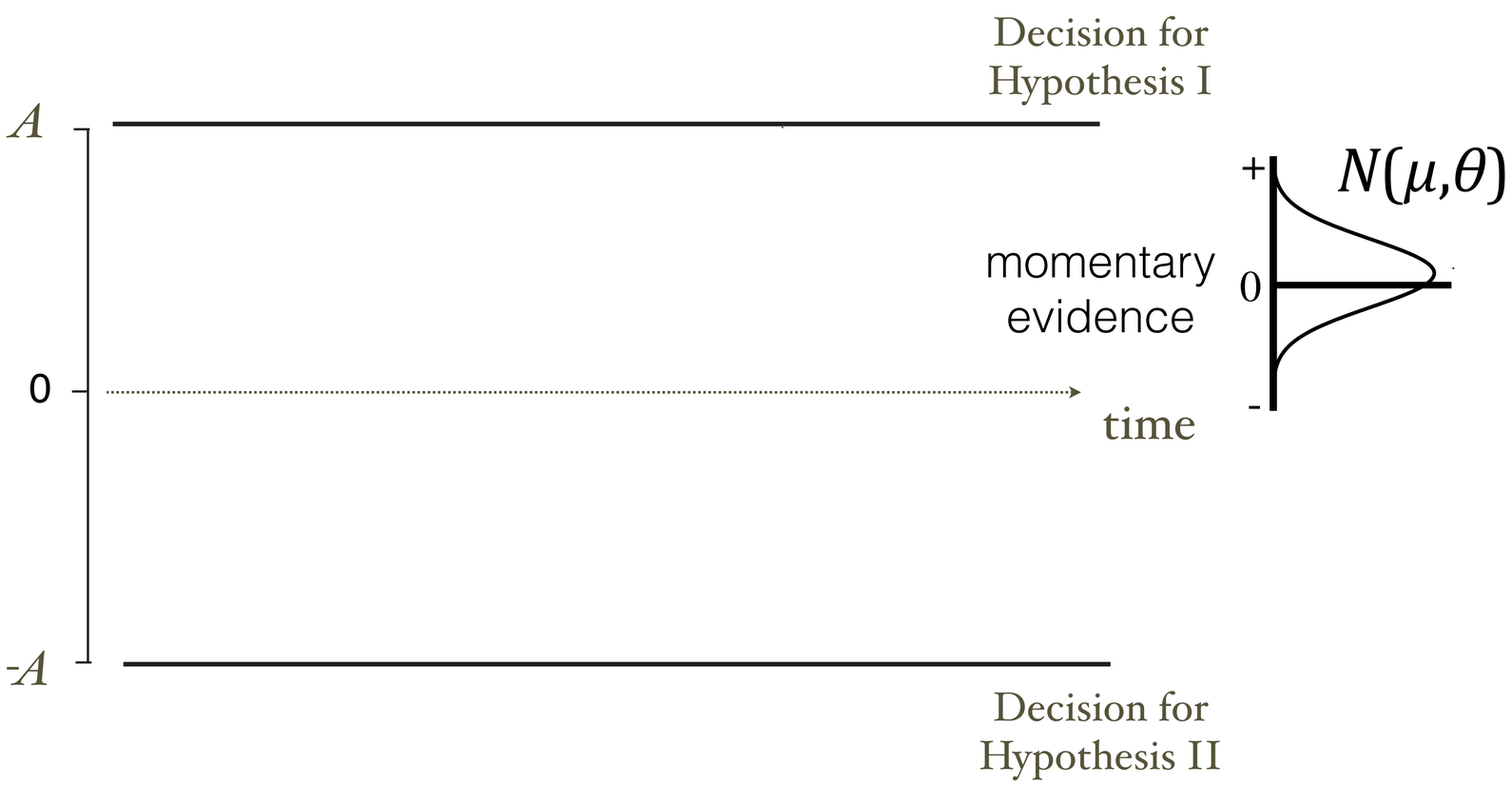


Psychometric and Chronometric Curves

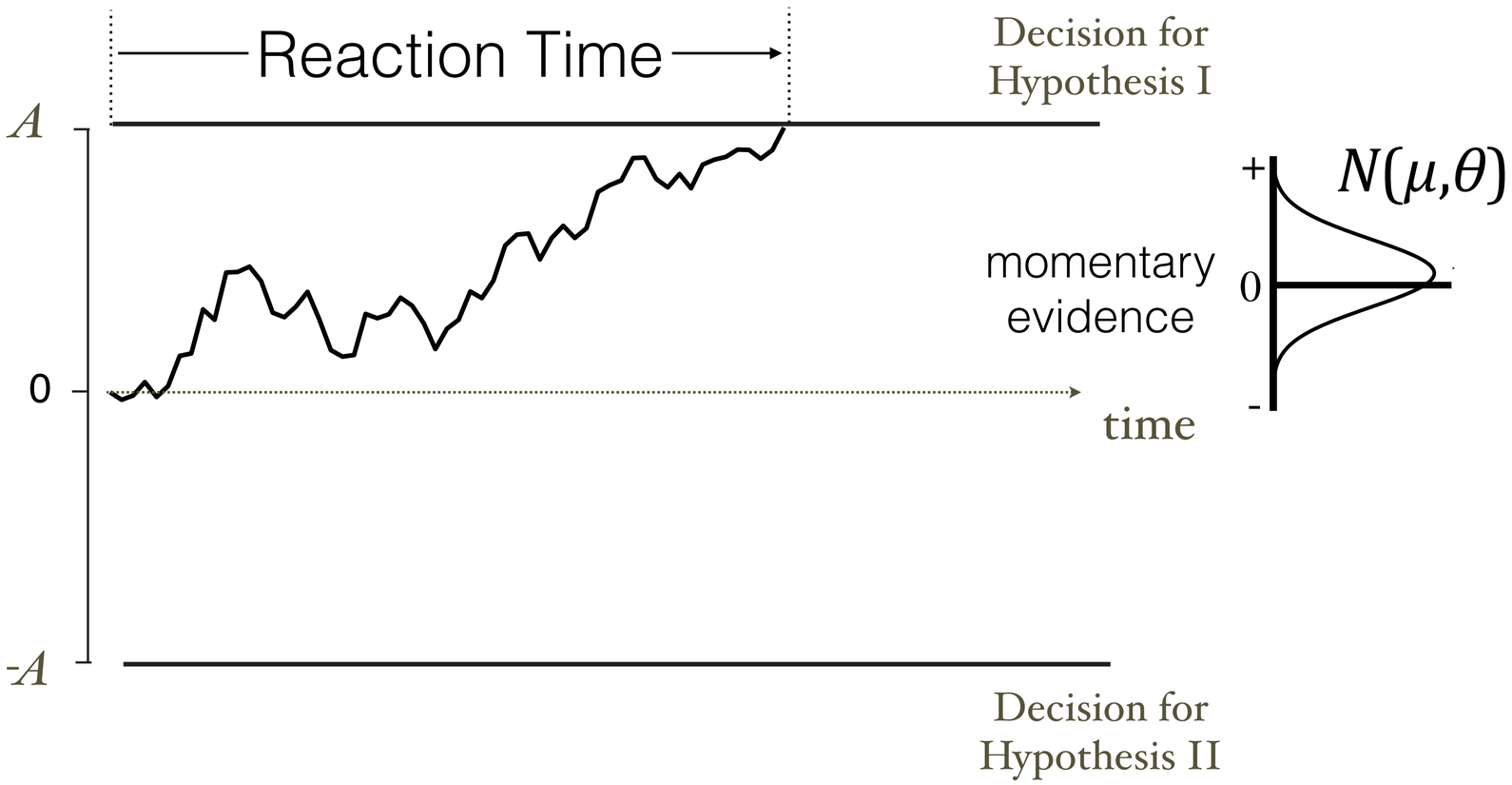


Roitman and Shadlen, J. Neurosci., 2002

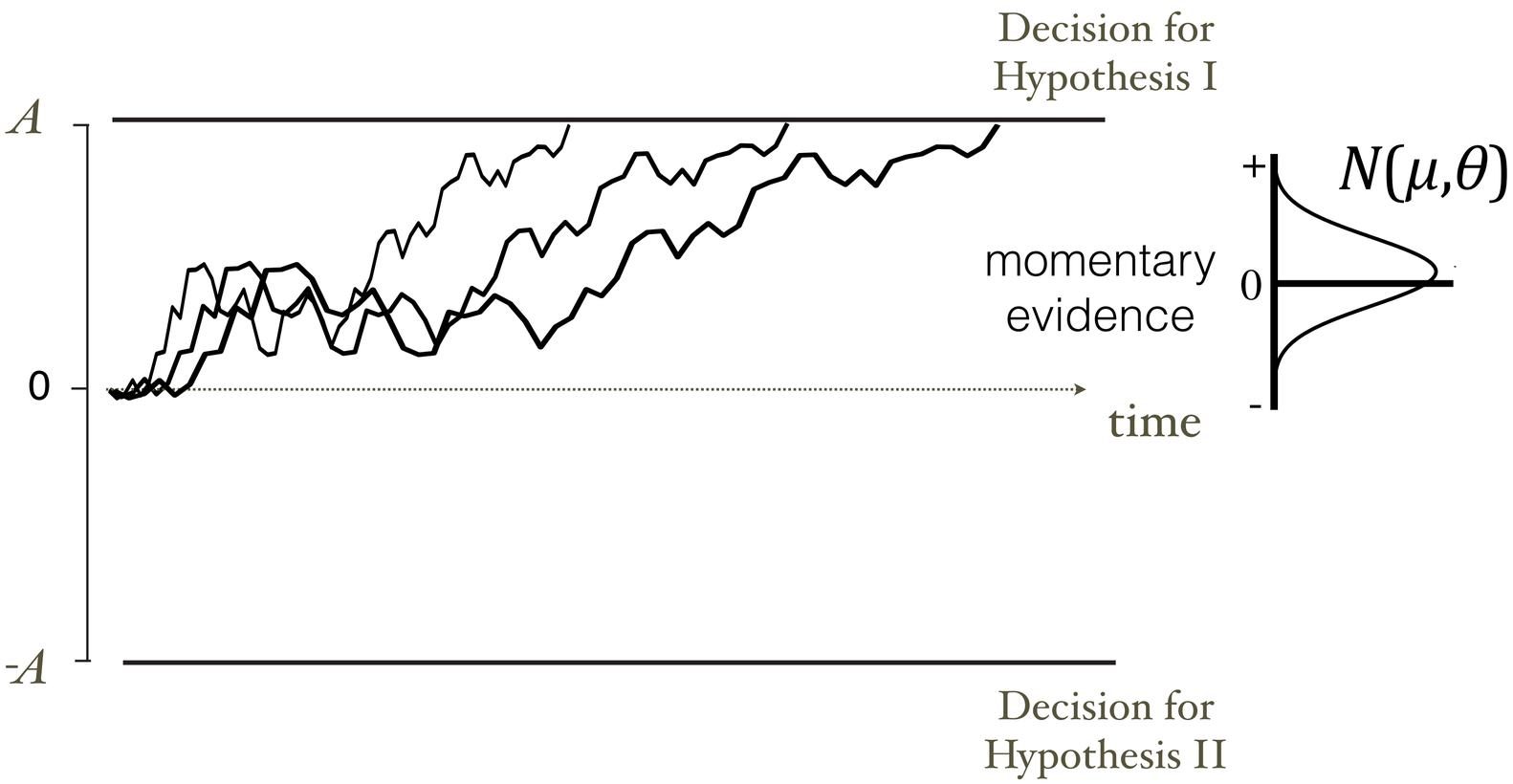
Drift Diffusion Model



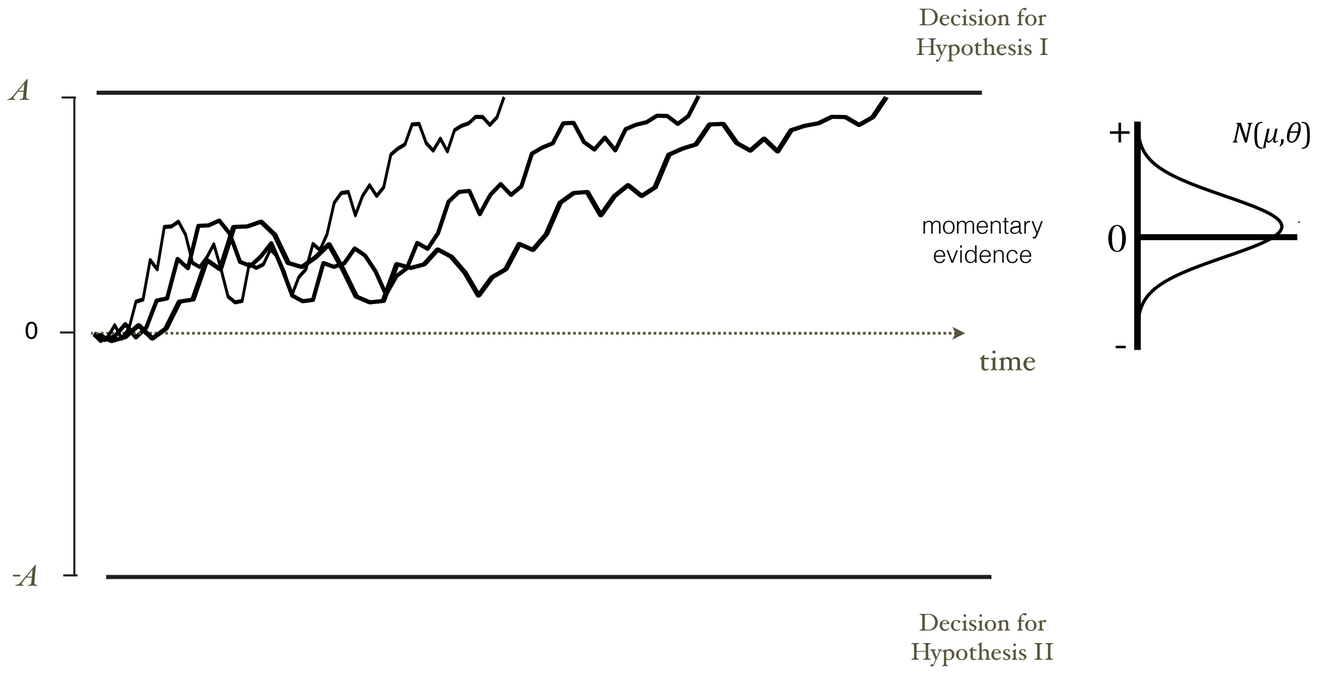
Drift Diffusion Model



Drift Diffusion Model



Drift Diffusion Model

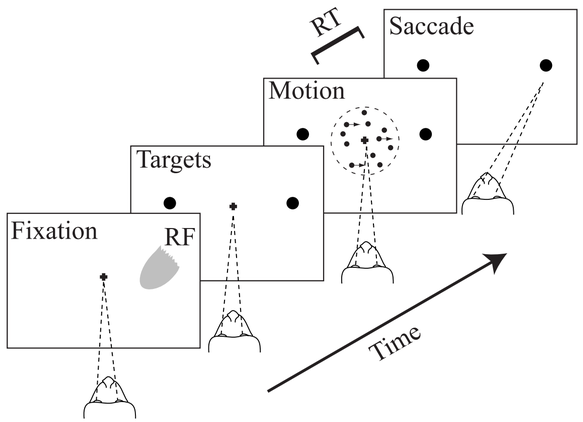


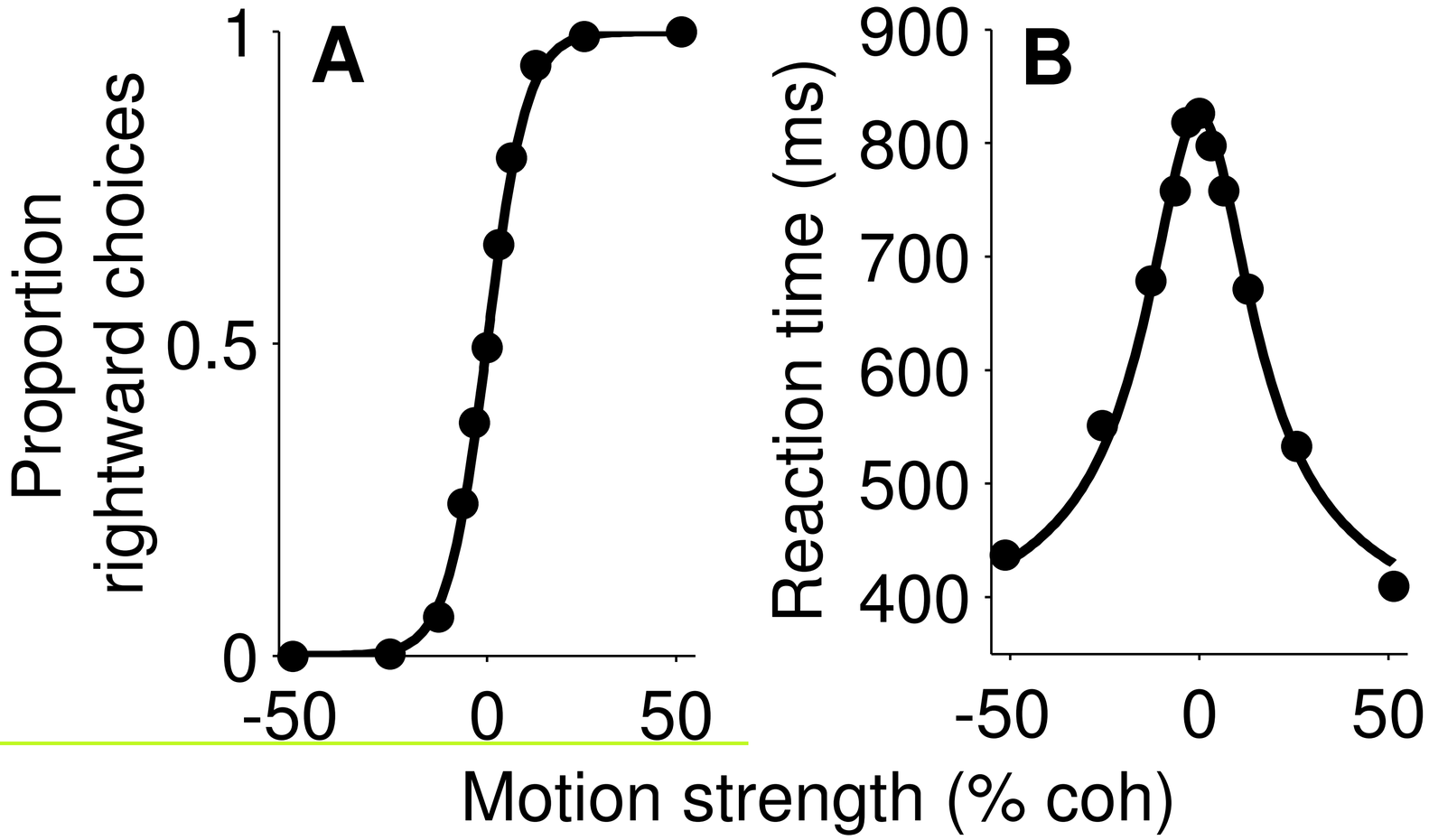
$$P_+ = \frac{1}{1 + e^{\frac{-2\mu}{\sigma^2} \bullet A}}$$

$$E[t] = \frac{A}{\mu} tanh(\frac{\mu A}{\sigma^2})$$

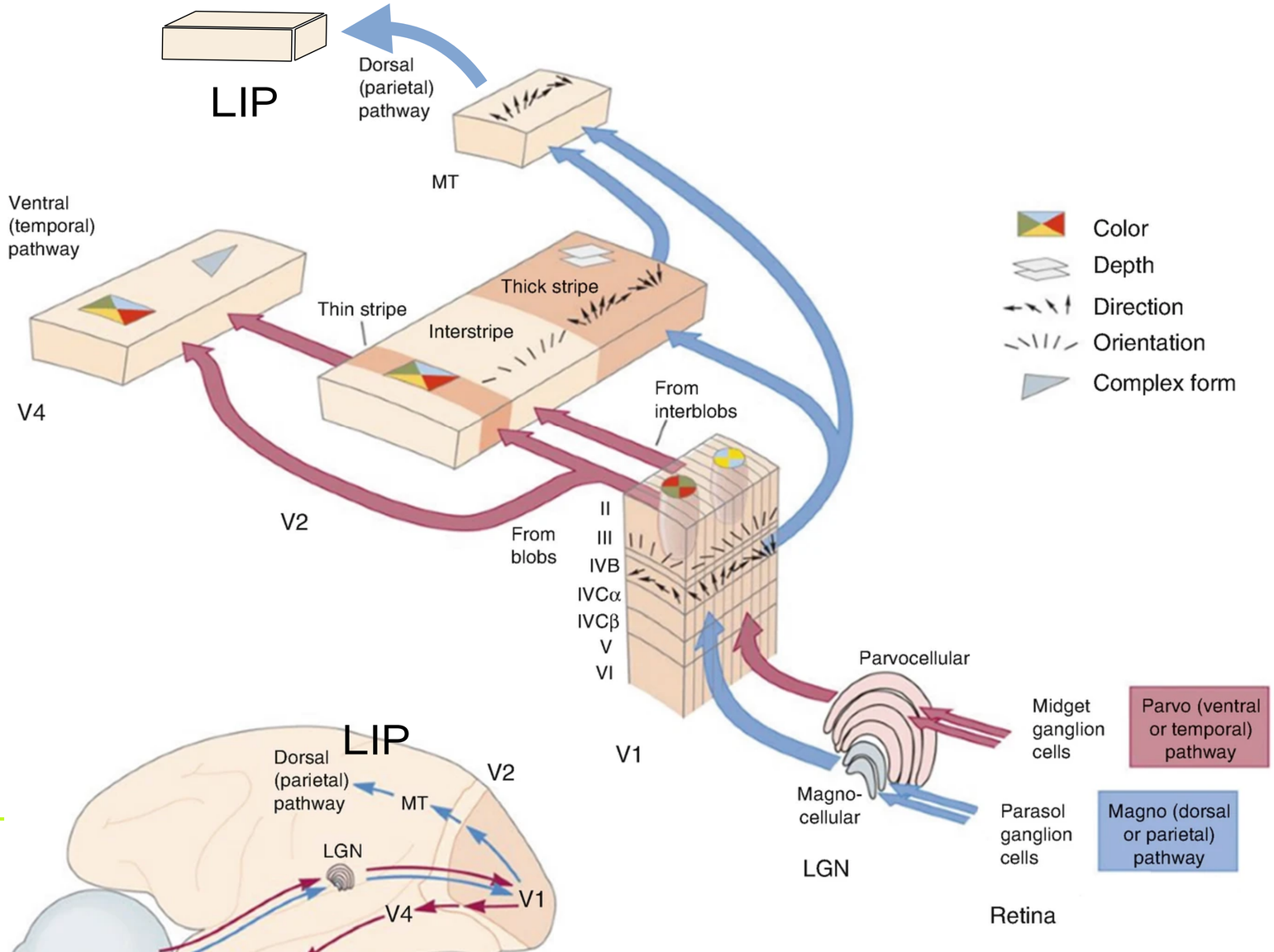
The speed and accuracy of a simple perceptual decision: A mathematical primer, Shadlen et al., 2005

Reaction Time Task

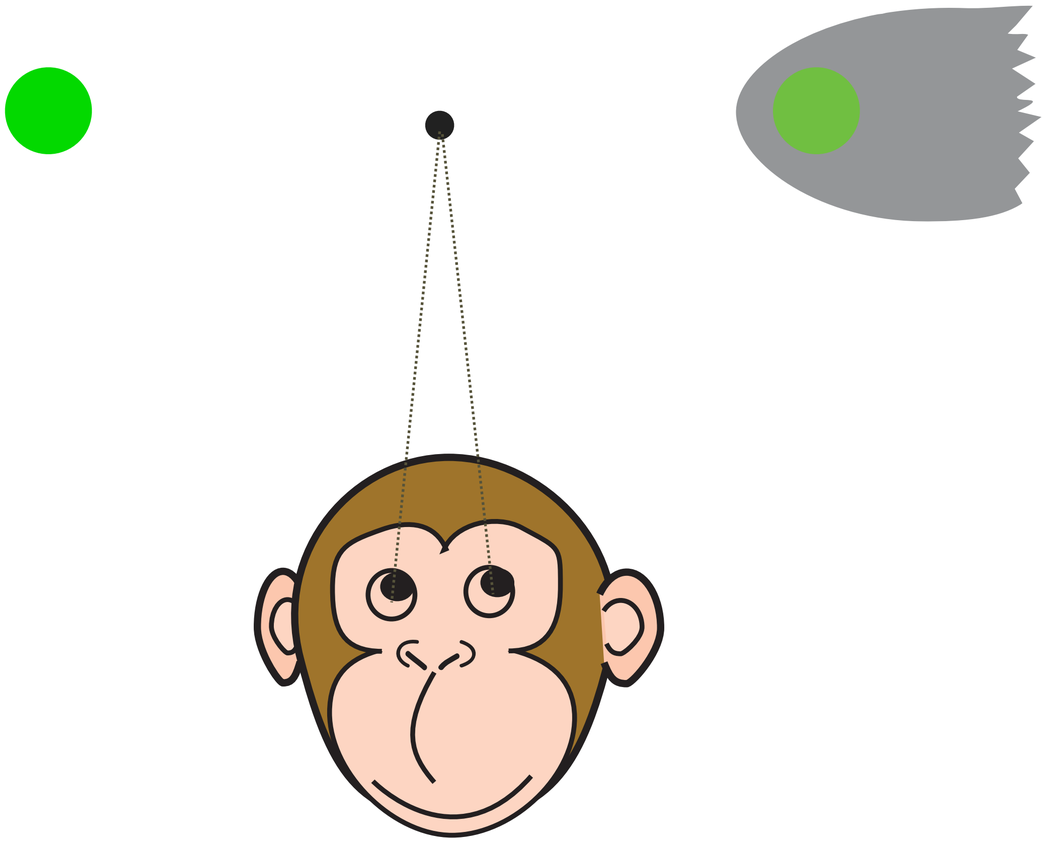




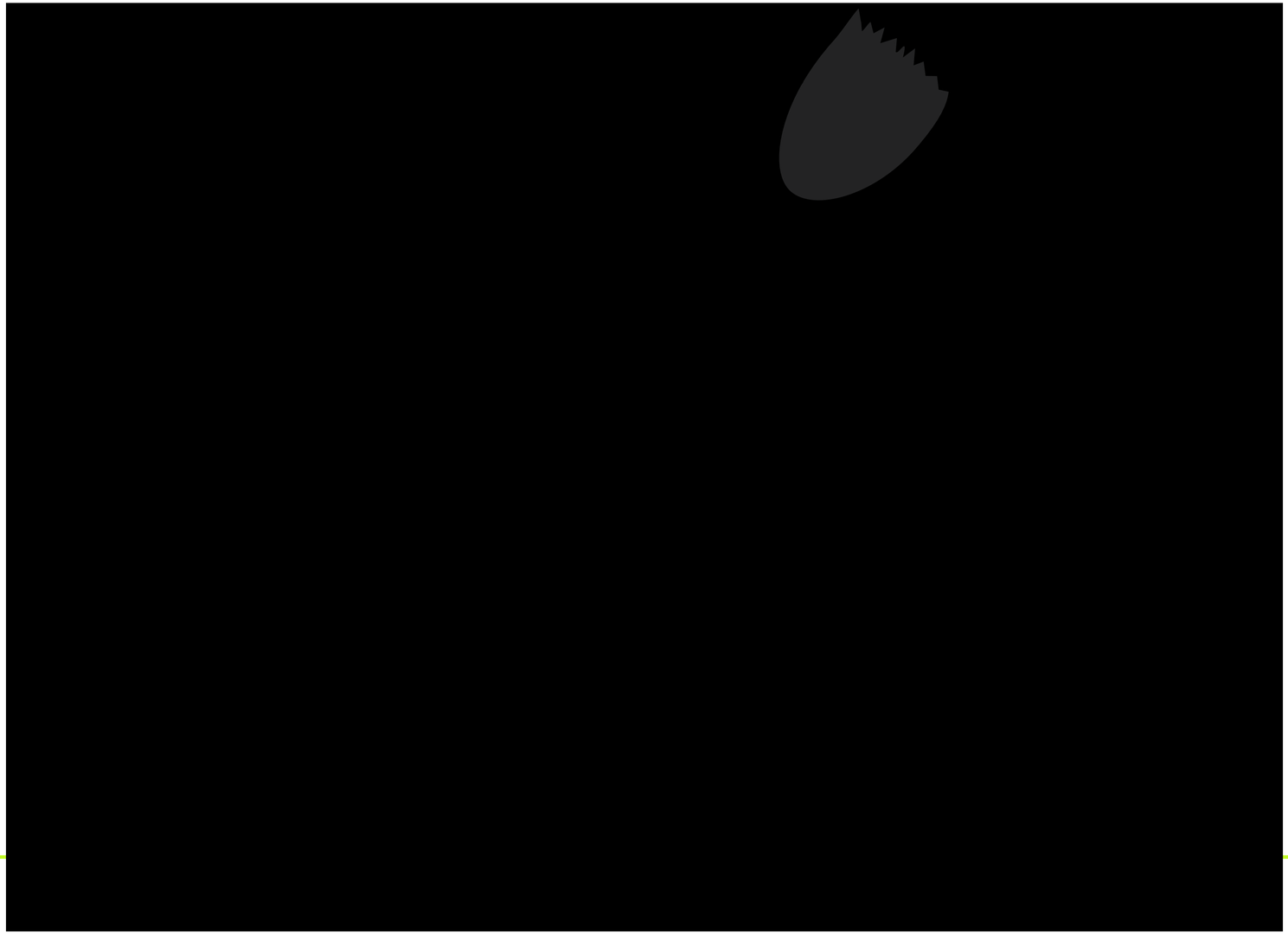
Lateral Intraparietal Area



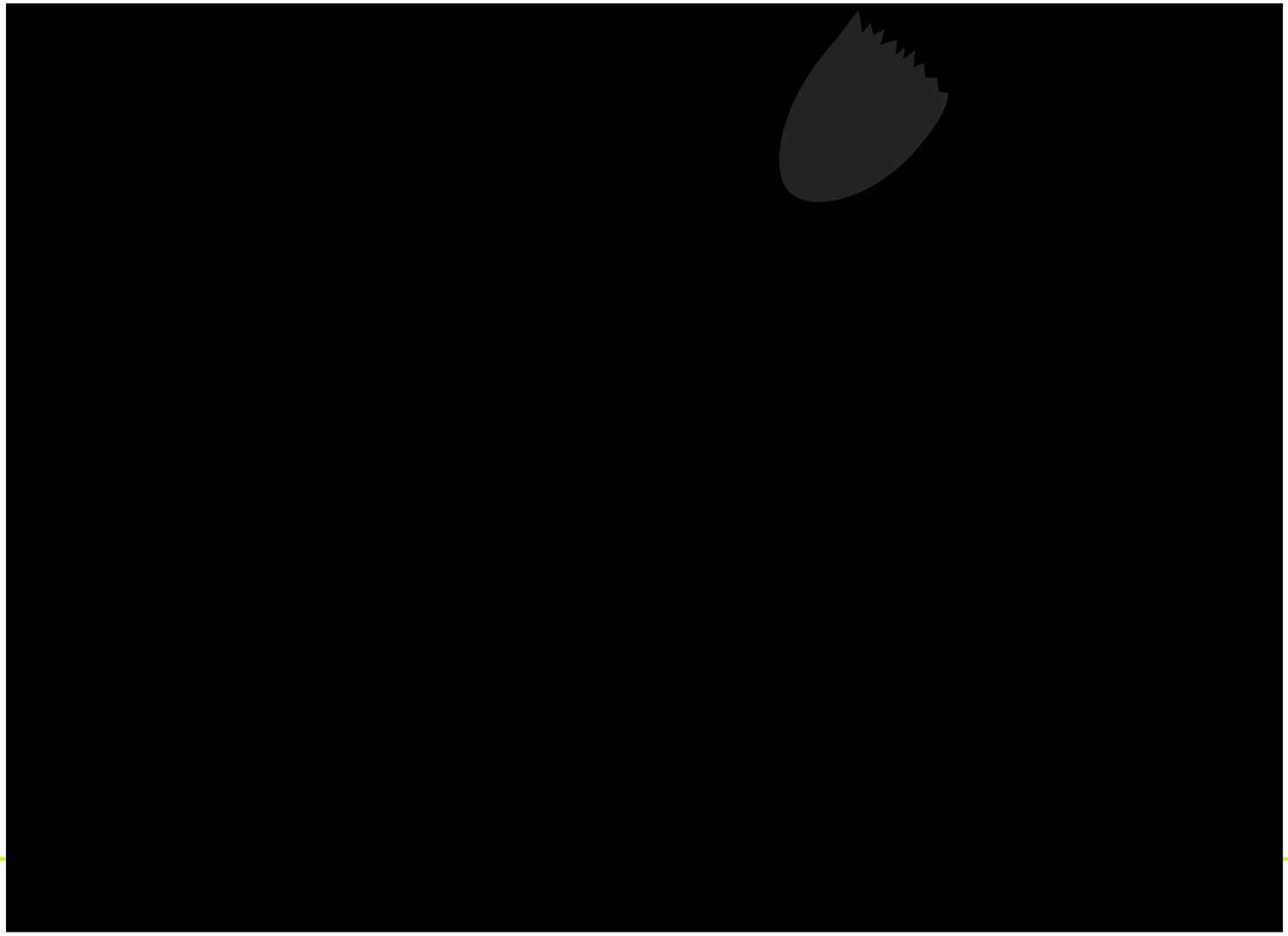
Response Field



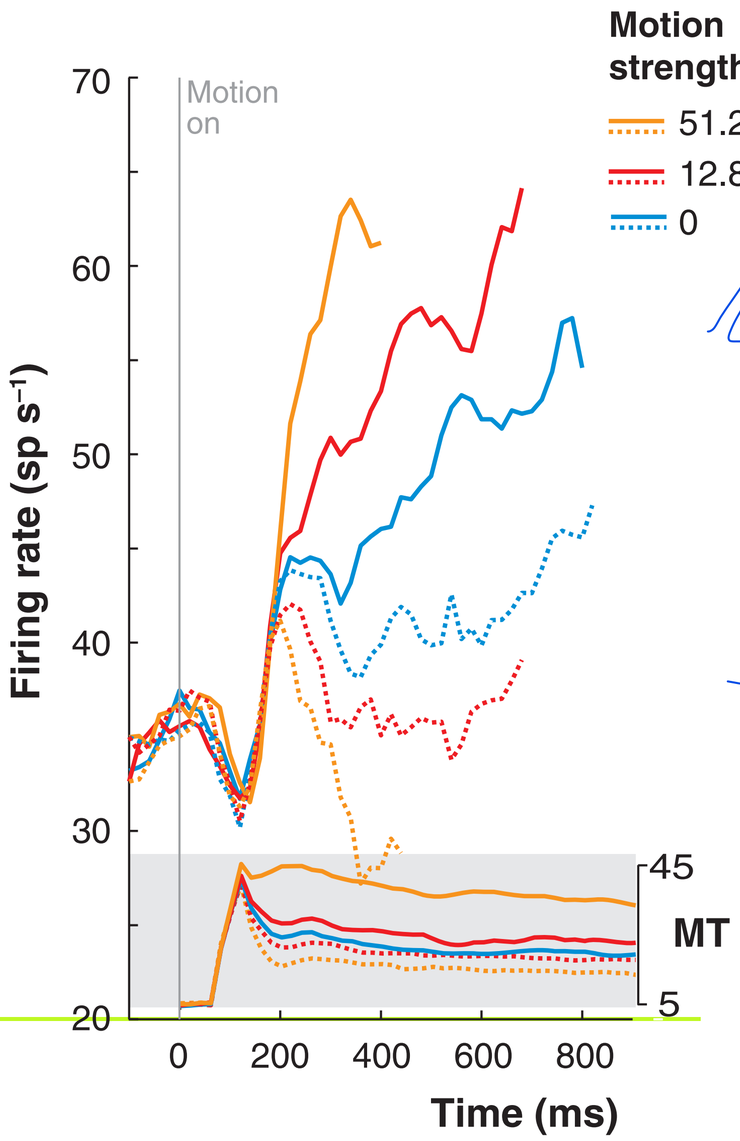
Example Neuron Movie

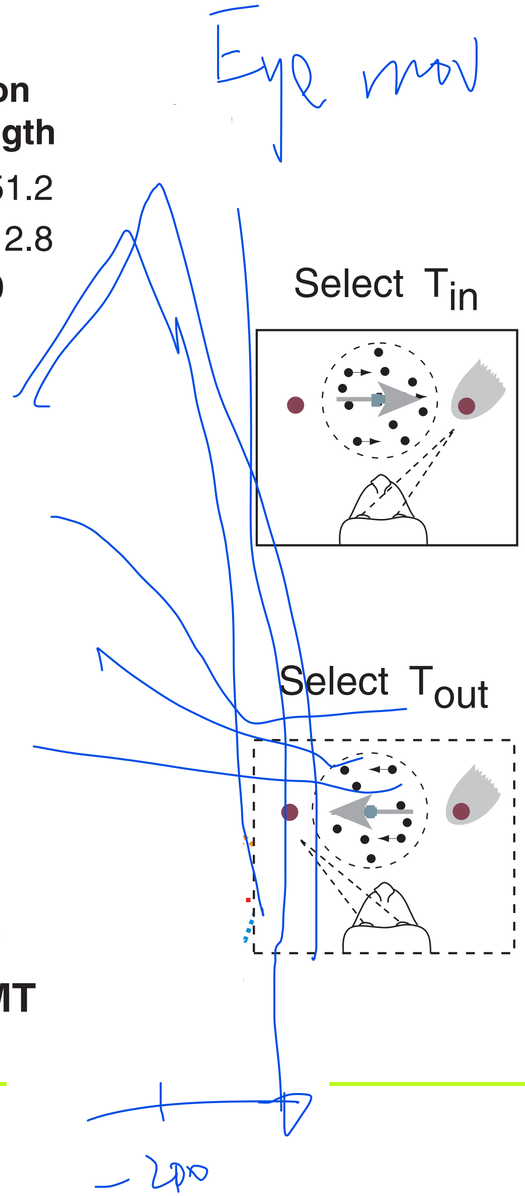


Example Neuron Movie



Ramping Activity



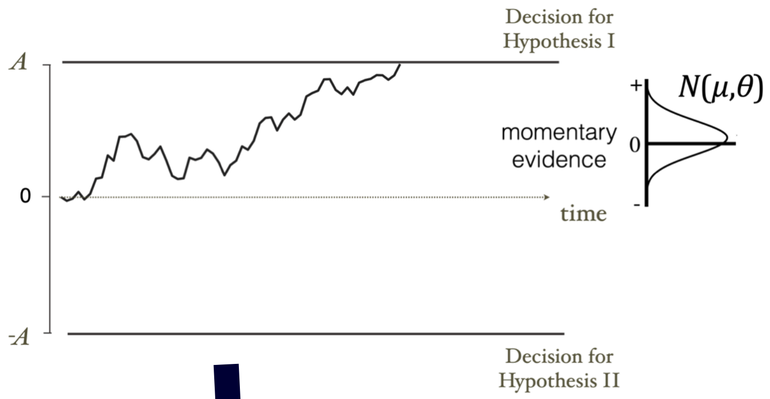


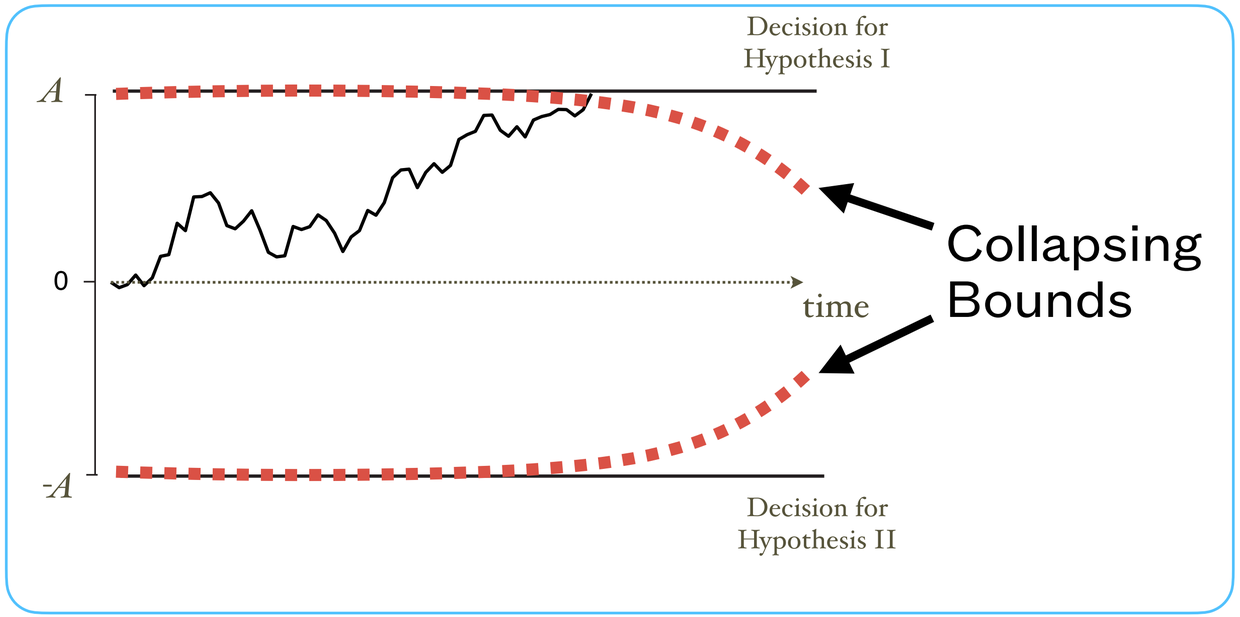
Gold & Shadlen, 2007

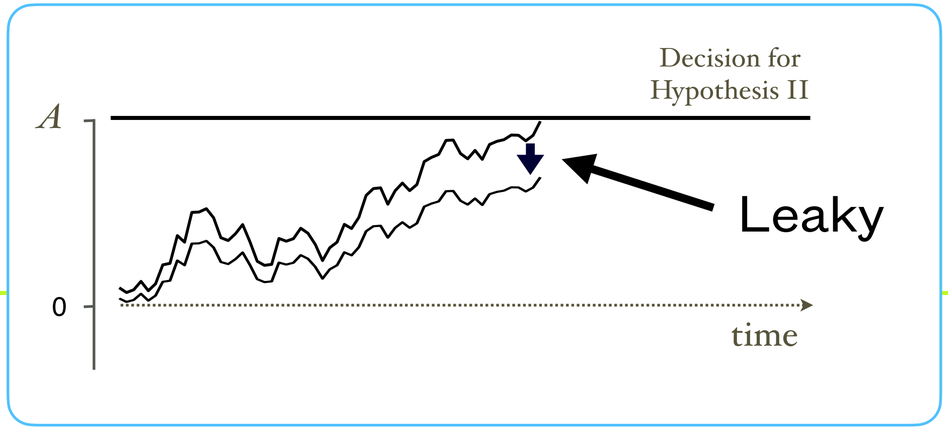
DDM Everywhere

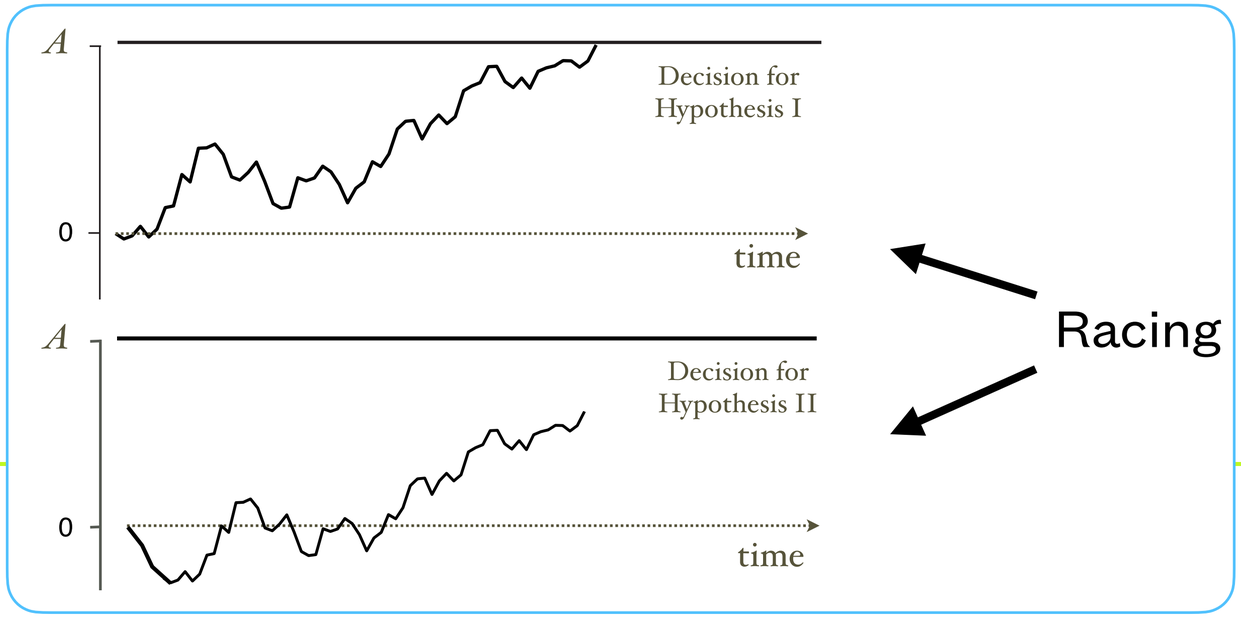
- Perceptual decision making (eg. Roitman and Shadlen, 2002)
- Value-based decision making (eg. Krajbich et al., 2012)
- Time (eg. Jazayeri and Shadlen, 2015)
- Memory retrieval (eg. Ratcliff, 1978, Gluth et al, 2015)
- Probabilistic reasoning (eg. Yang and Shadlen, 2007)
- Confidence (eg. Kiani and Shadlen, 2013)

Variations of DDM









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- **SPRT**
- Confidence
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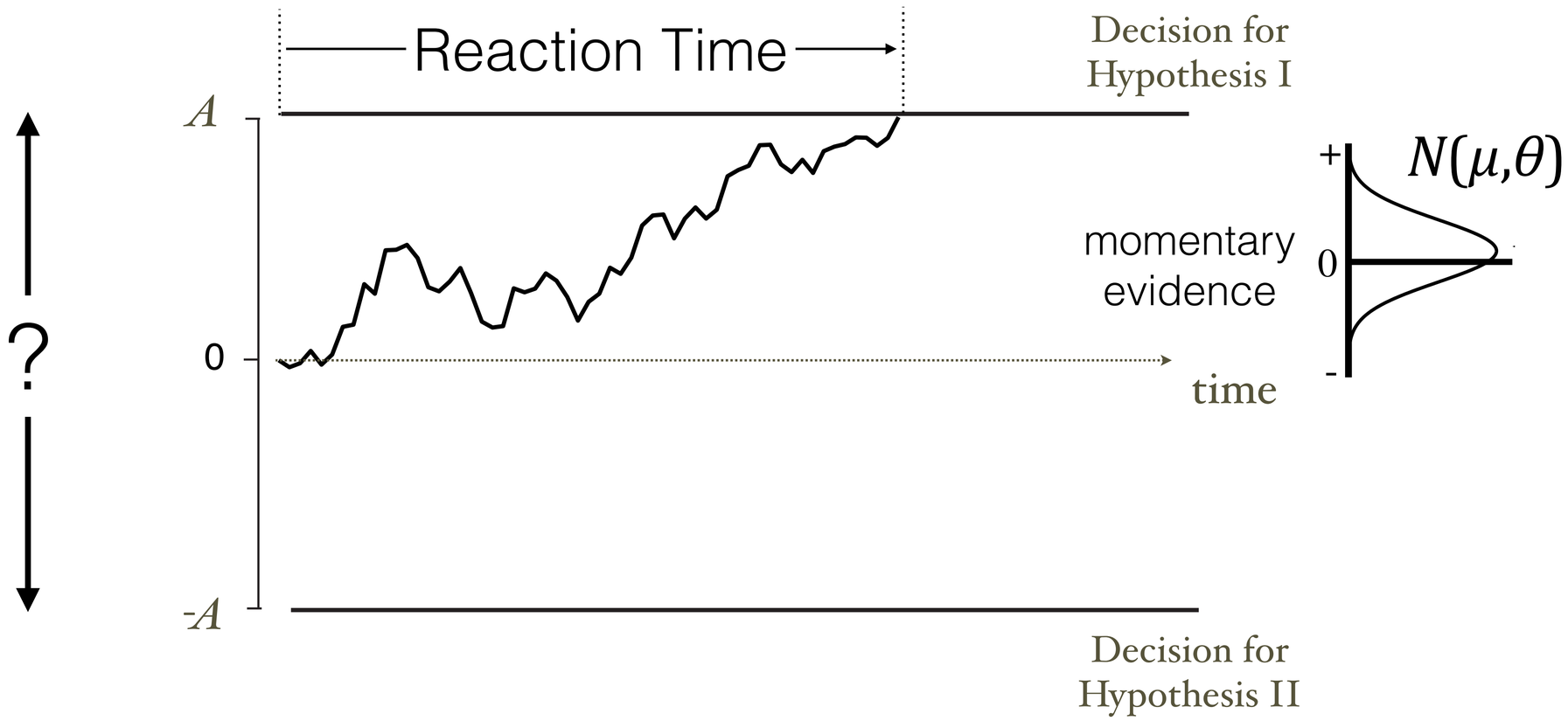
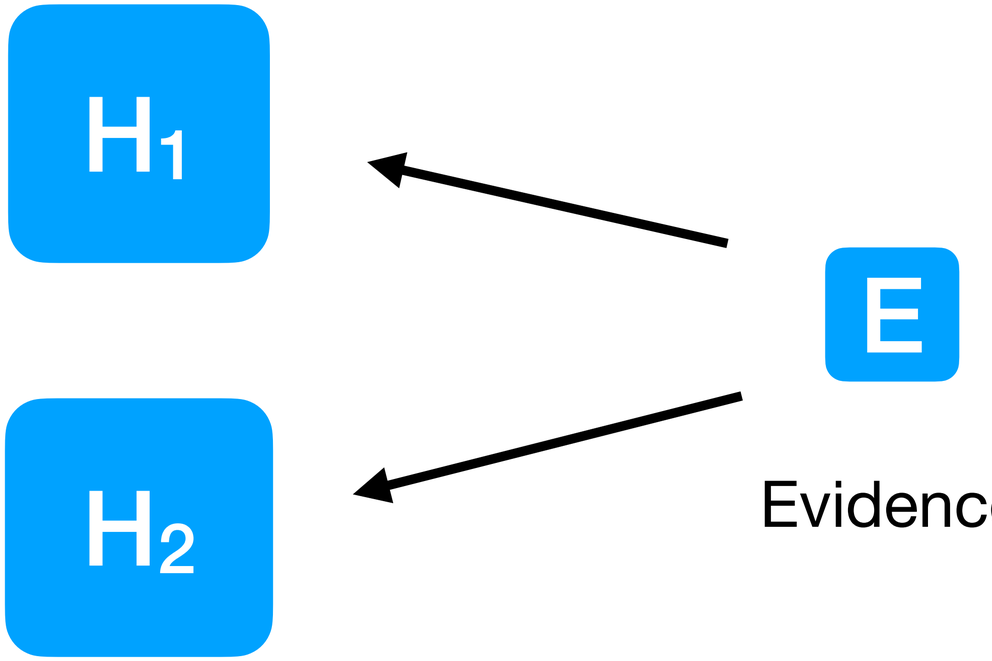
Drift Diffusion Model



Quantifying Evidence

$P(H_1 \mid E)$

$P(H_2 \mid E)$



Evidence

Hypotheses

Quantifying Evidence

$$P(H_1 \mid E) \propto P(E \mid H_1) * P(H_1)$$

$$P(H_2 \mid E) \propto P(E \mid H_2) * P(H_2)$$

Evidence

Quantifying Evidence

$$\frac{P(H_1 \mid E) \propto P(E \mid H_1) * P(H_1)}{P(H_2 \mid E) \propto P(E \mid H_2) * P(H_2)}$$

Evidence

Quantifying Evidence

$$\frac{P(H_1 \mid E)}{P(H_2 \mid E)} = \frac{P(E \mid H_1)}{P(E \mid H_2)} * \frac{P(H_1)}{P(H_2)}$$

Likelihood Ratio Bias

$$\frac{P(E_1 \mid H_1) * \ldots * P(E_n \mid H_1)}{P(E_1 \mid H_2) * \ldots * P(E_n \mid H_2)}$$

Quantifying Evidence

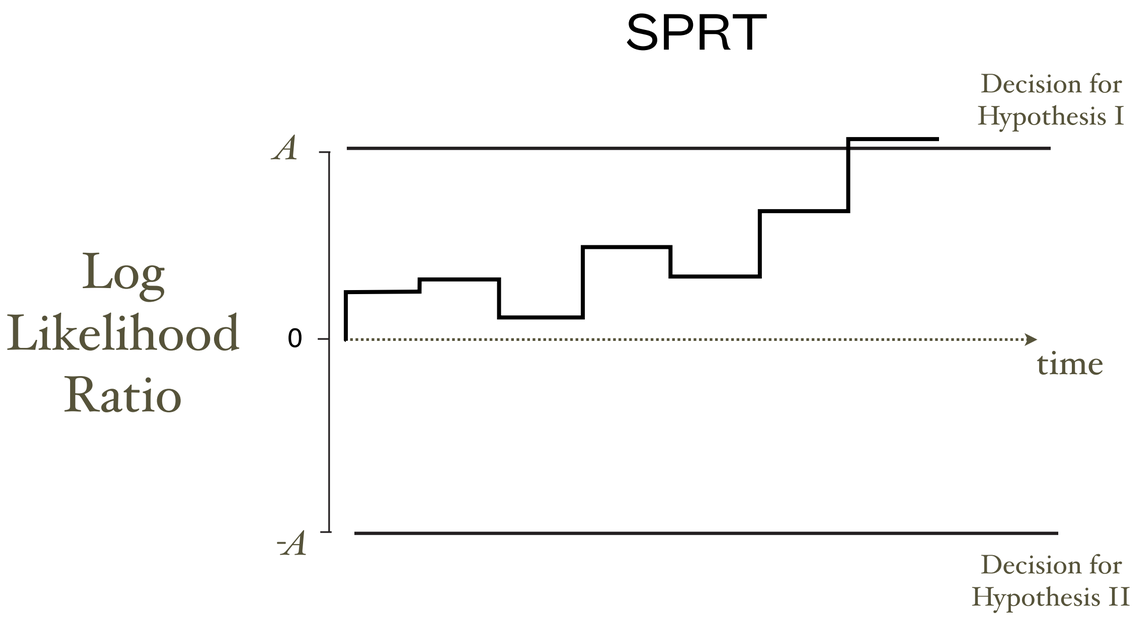
$$\frac{P(E_1 \mid H_1) * \ldots * P(E_n \mid H_1)}{P(E_1 \mid H_2) * \ldots * P(E_n \mid H_2)}$$

$$\Downarrow$$

$$log\frac{P(E_1 \mid H_1)}{P(E_1 \mid H_2)} + \ldots + log\frac{P(E_n \mid H_1)}{P(E_n \mid H_2)}$$

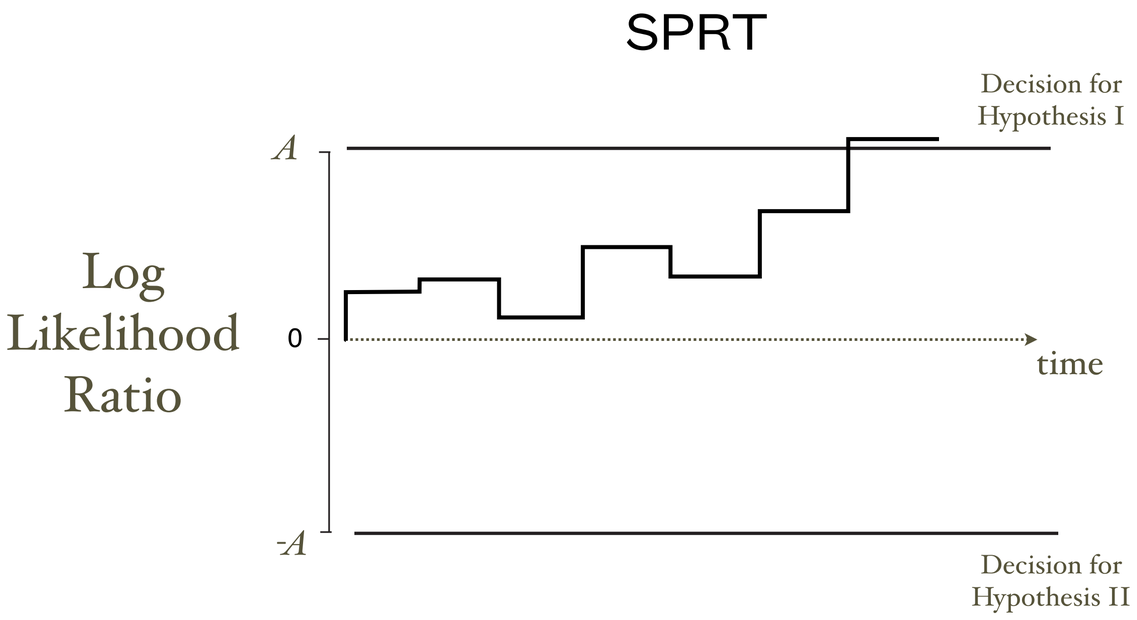
Log Likelihood Ratio

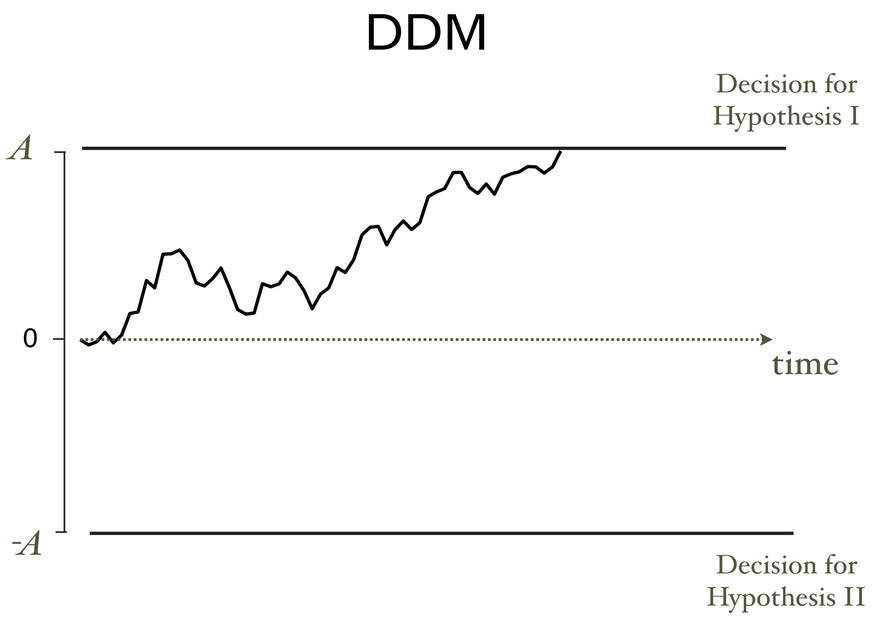
Sequential Probability Ratio Test



A. Wald, 1945

Sequential Probability Ratio Test <-> DDM

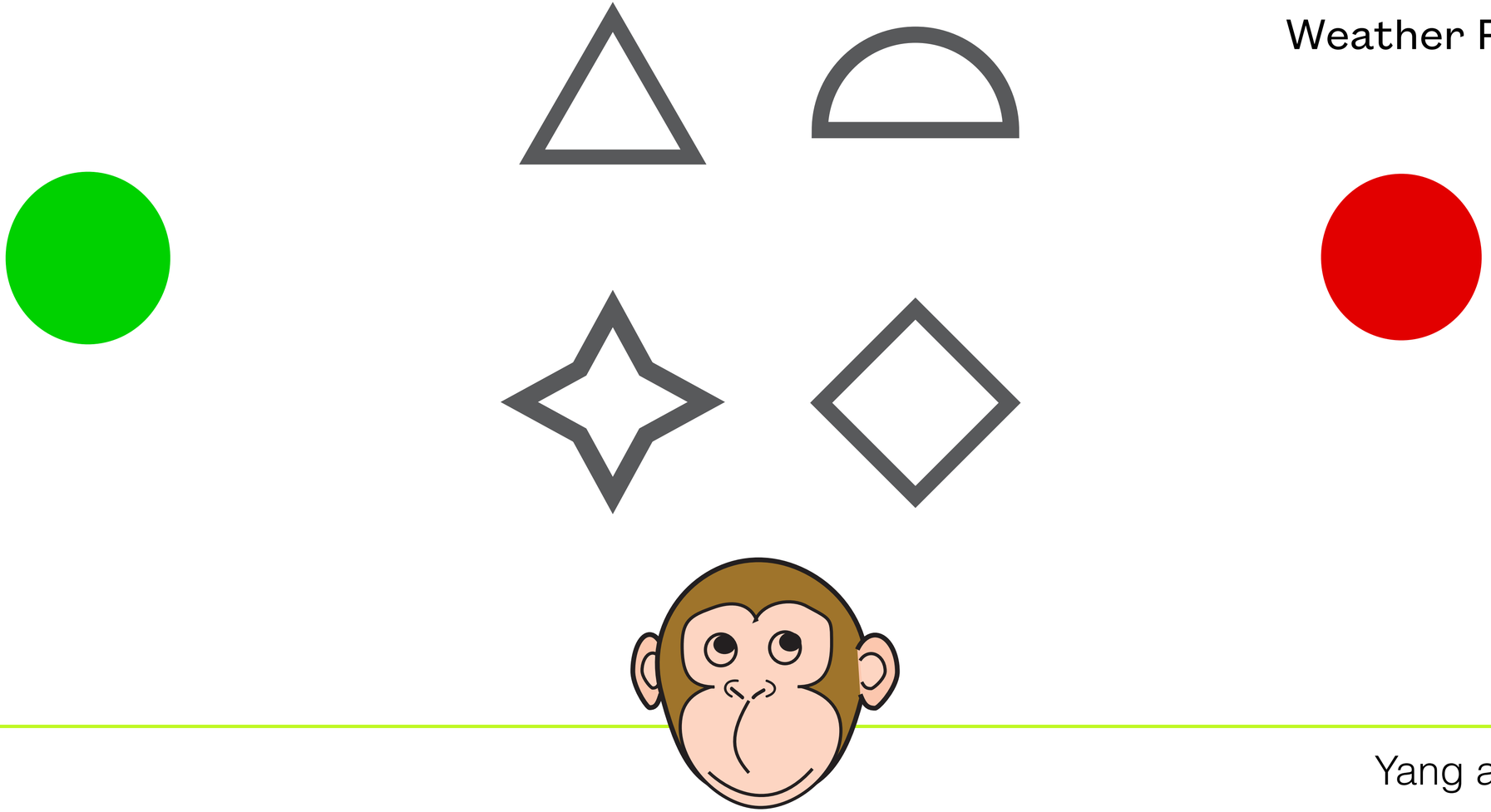




A. Wald, 1945

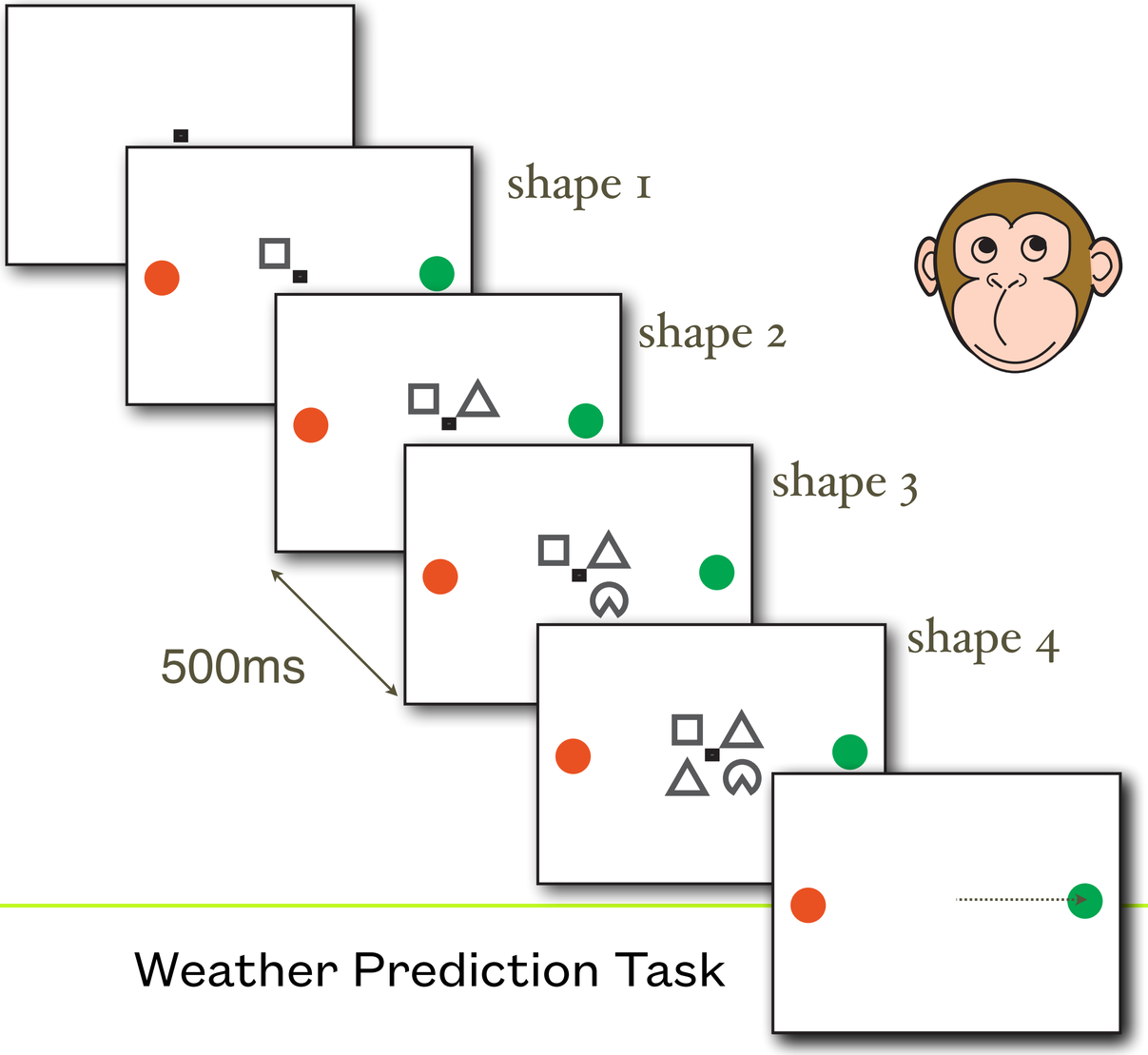
Probabilistic Reasoning

Weather Prediction Task



Yang and Shadlen, 2007

Probabilistic Reasoning



Weather Prediction Task

Yang and Shadlen, 2007

$$\sum \text{weights} = \log_{10} \frac{P(\text{shapes} \mid \text{red})}{P(\text{shapes} \mid \text{green})}$$

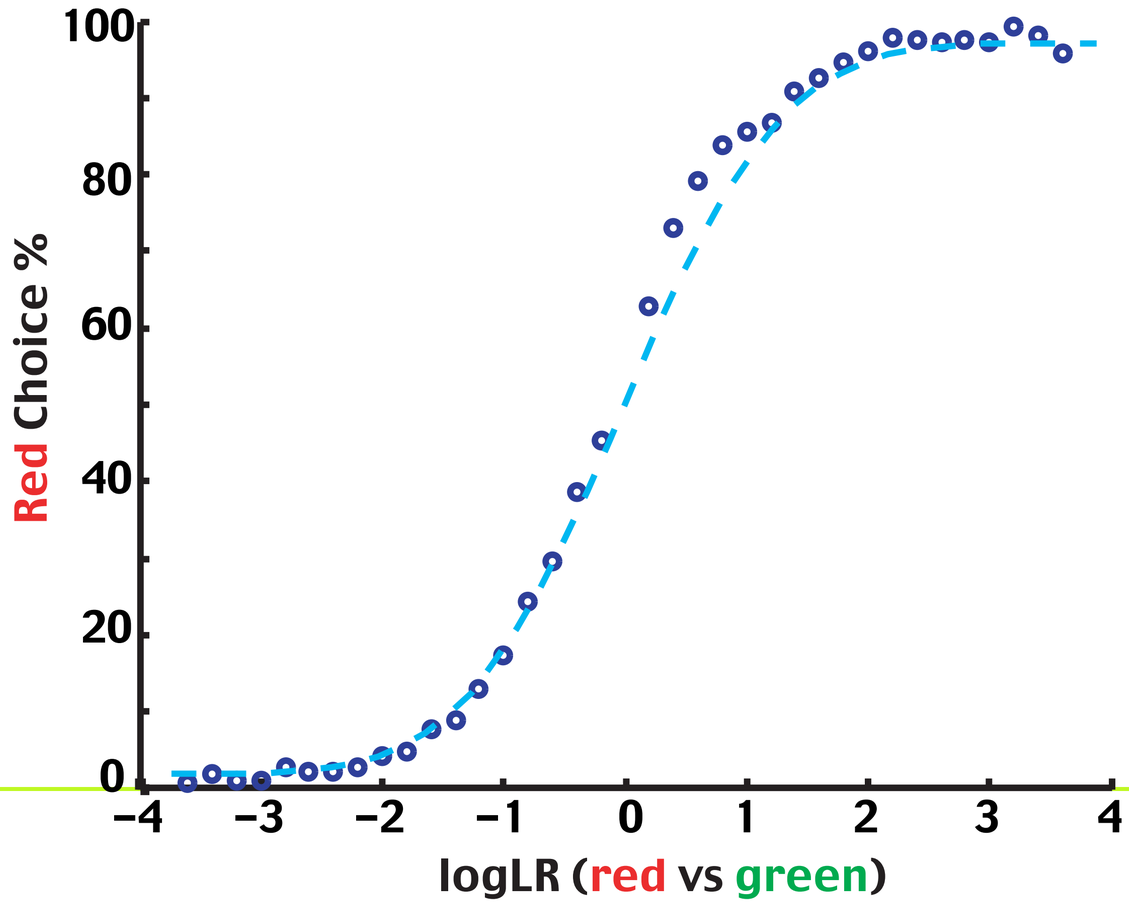
61%

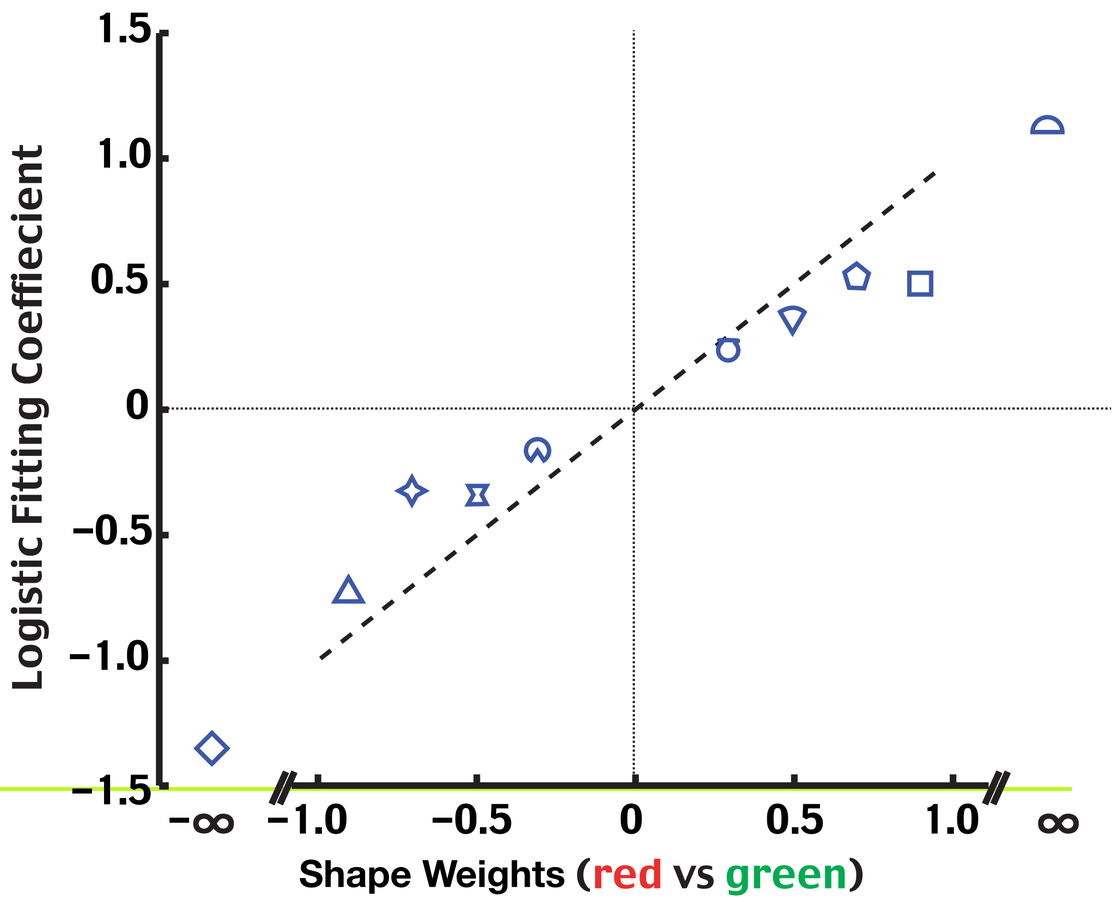
39%

−∞ −0.9 −0.7 −0.5 −0.3 0.3 0.5 0.7 0.9 ∞

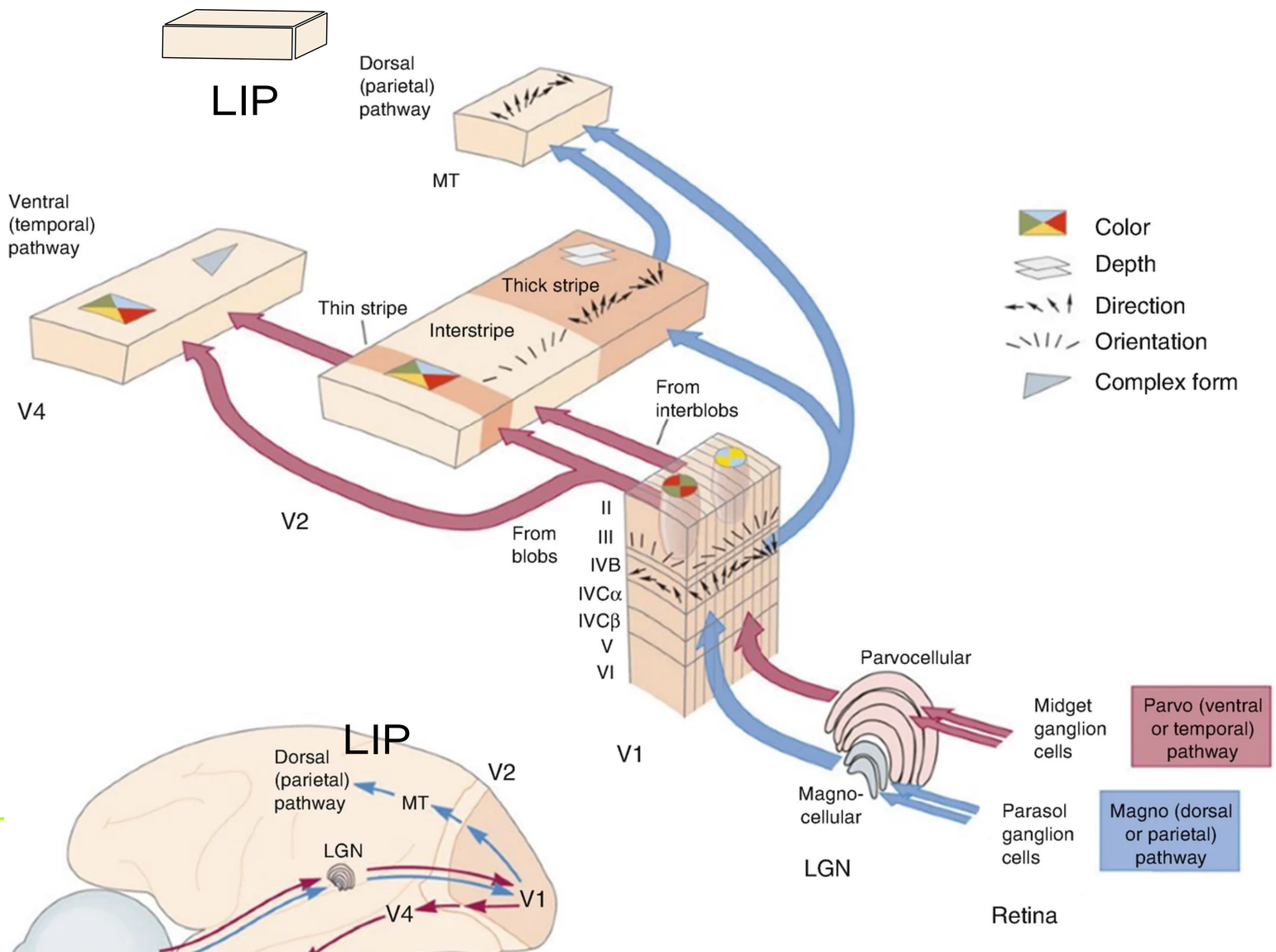
Monkey Performance

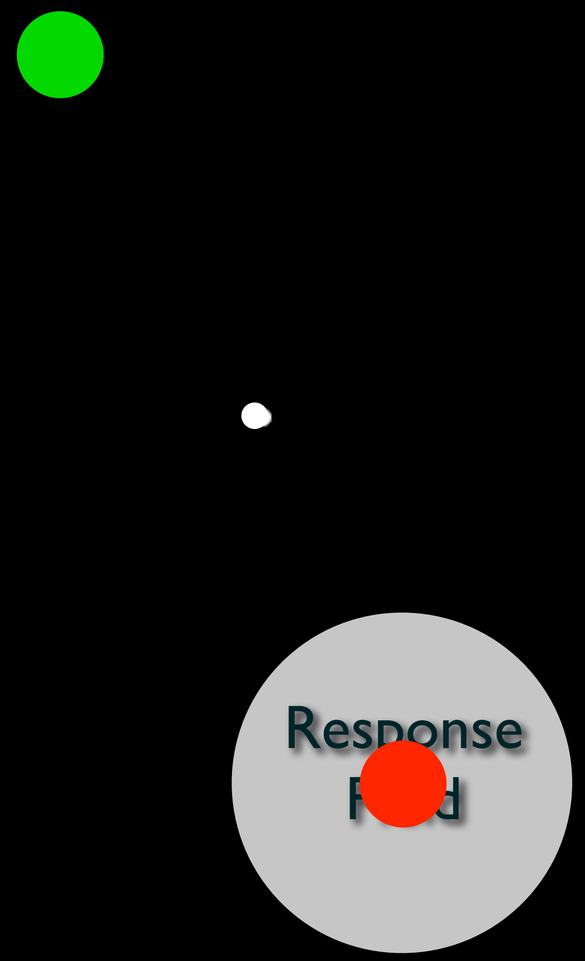
$$logit(Choice) \sim \sum_{i=1..10} \beta_i I_i$$





Target Brain Area: LIP





logLR
for Tin

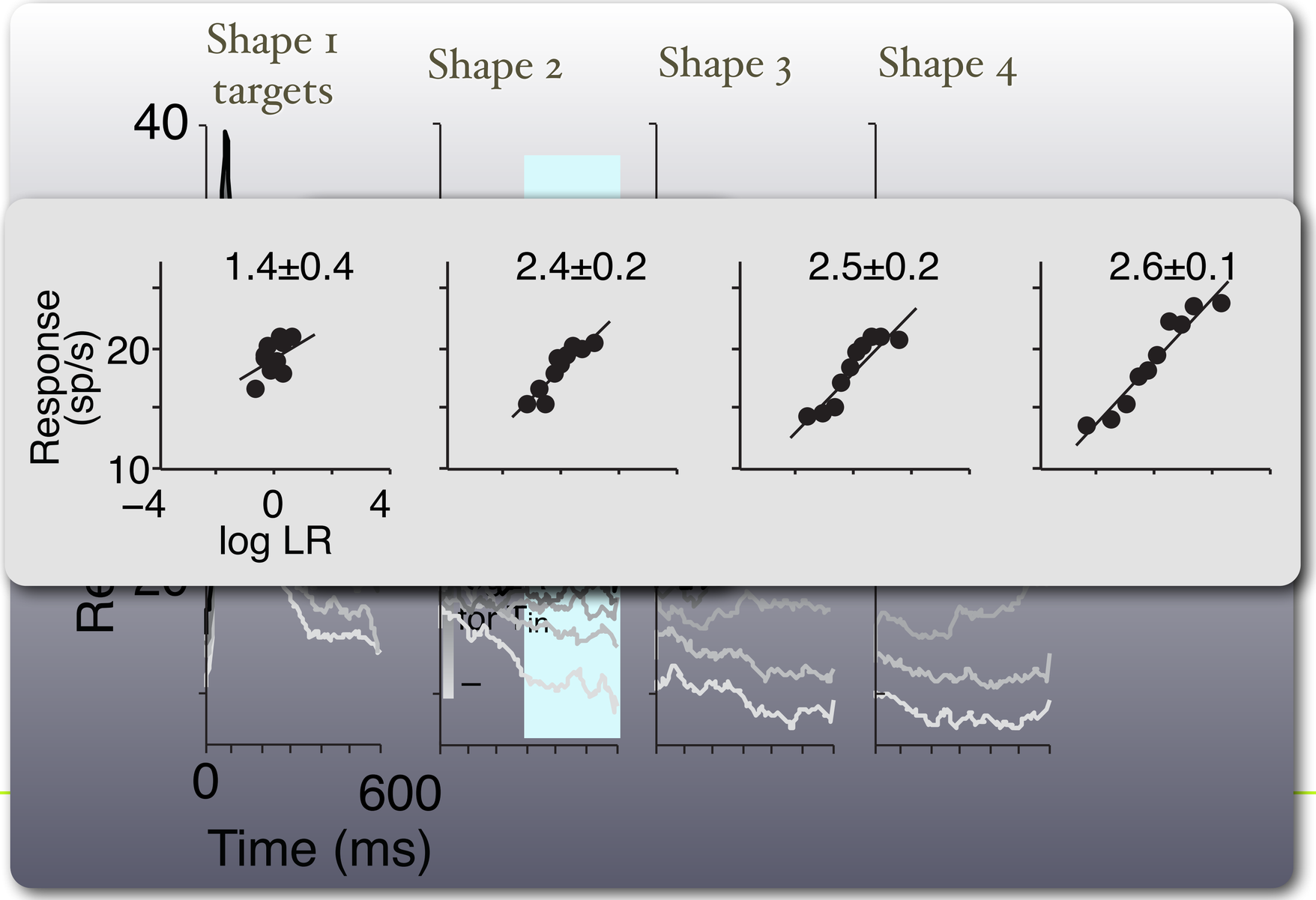
logLR
for Tin

logLR
for Tin

logLR
for Tin

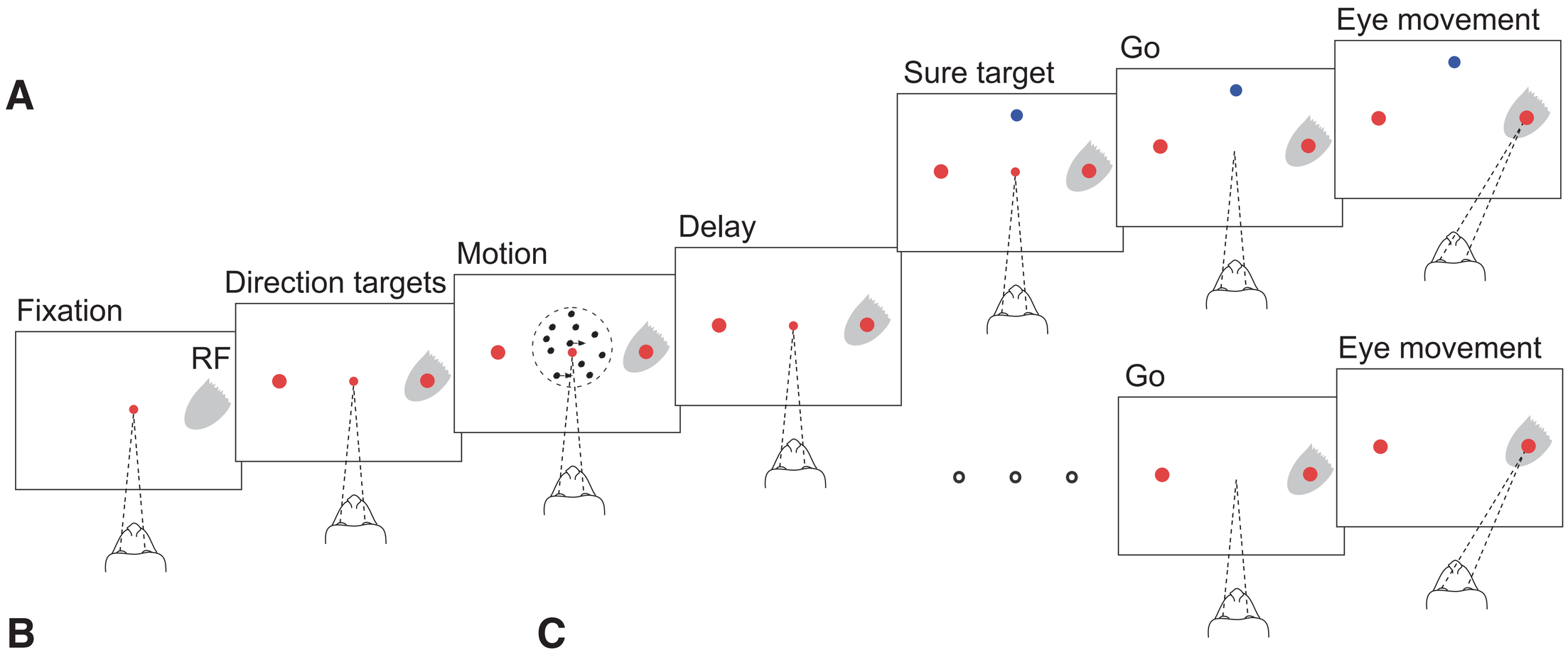
logLR
for Tin

LIP Neurons Encode logLR



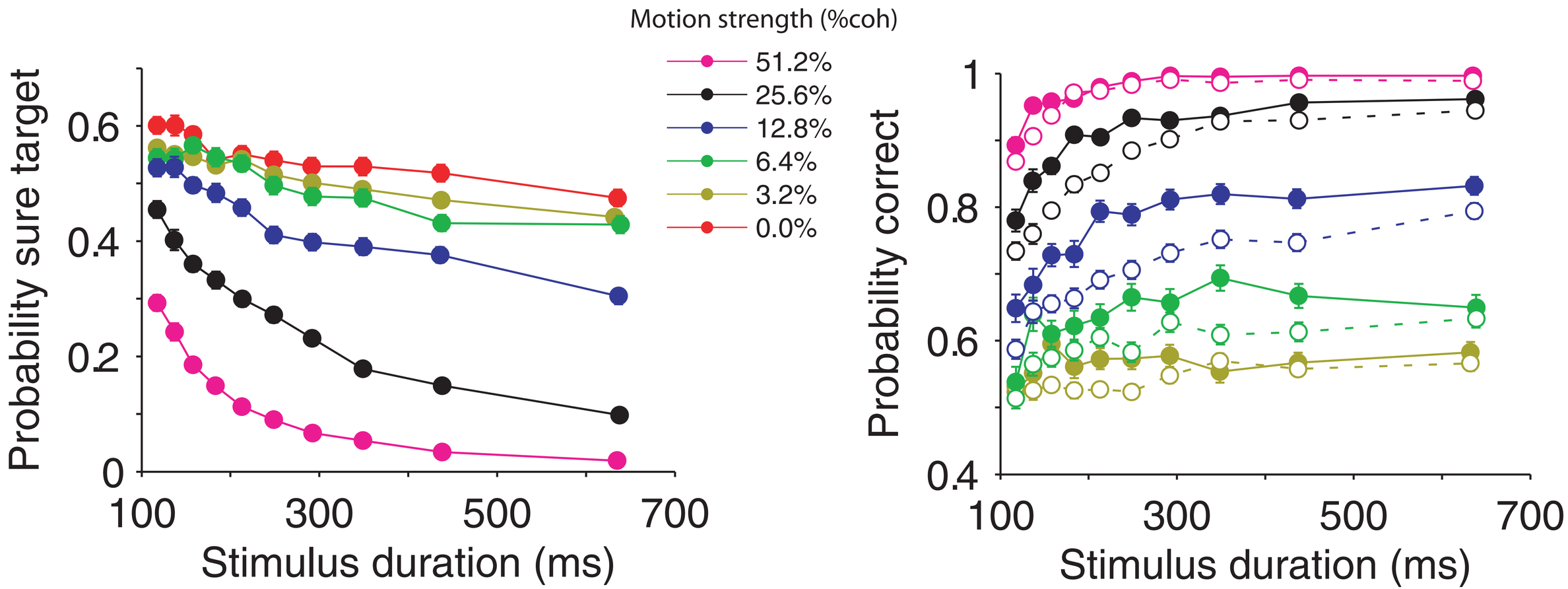
- Overview
- DDM
- SPRT
- **Confidence**
- Neural network Modeling

Confidence



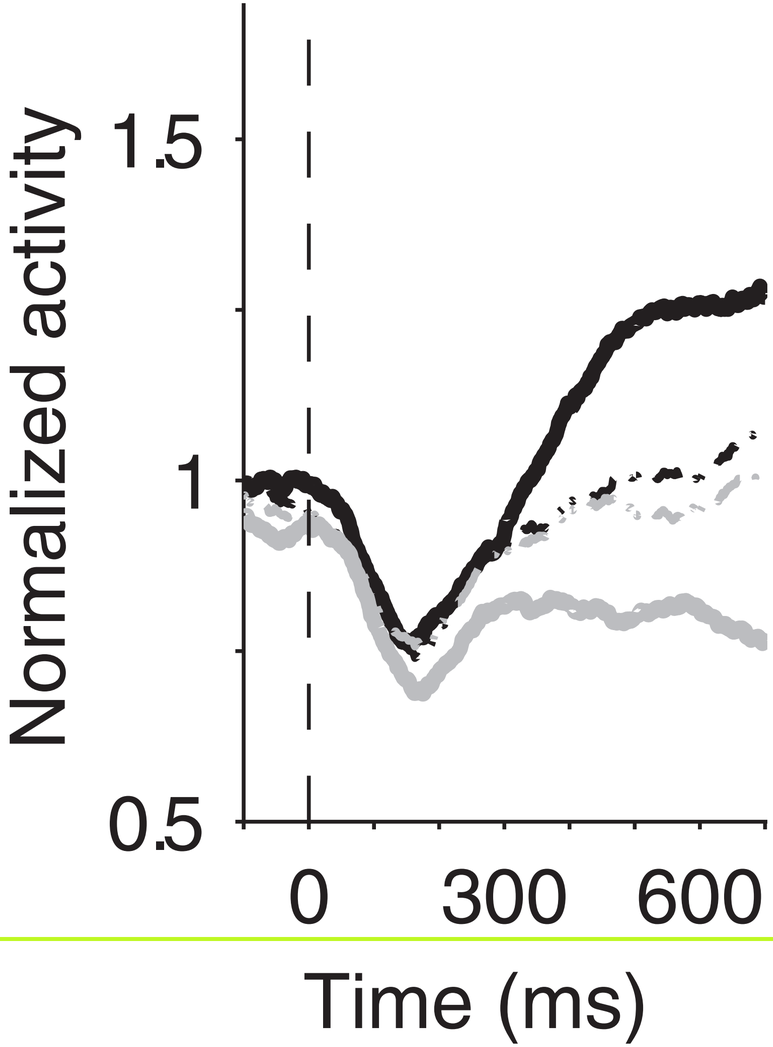
Kiani & Shadlen, 2009

Measuring Confidence



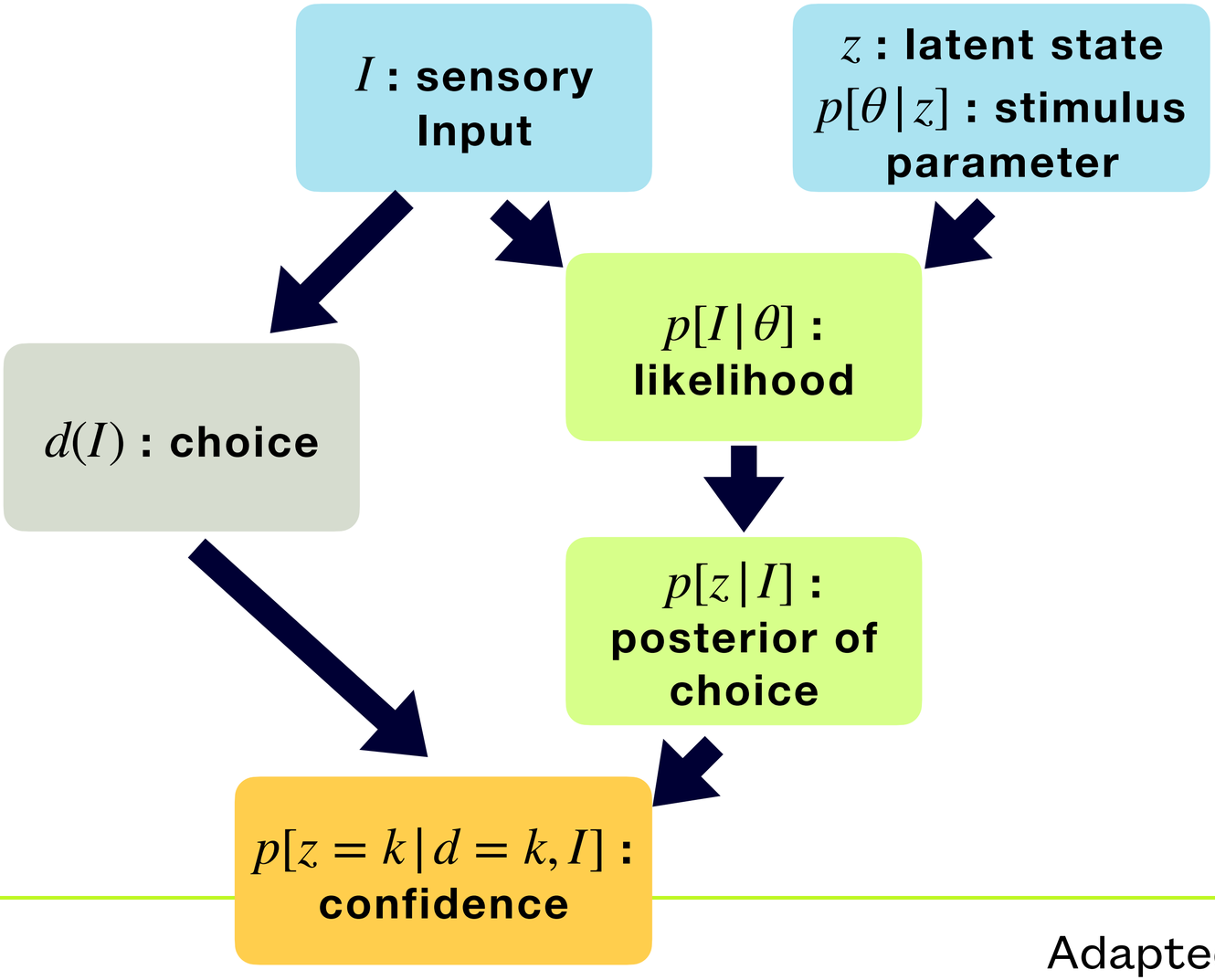
Kiani & Shadlen, 2009

Confidence Represented by LIP



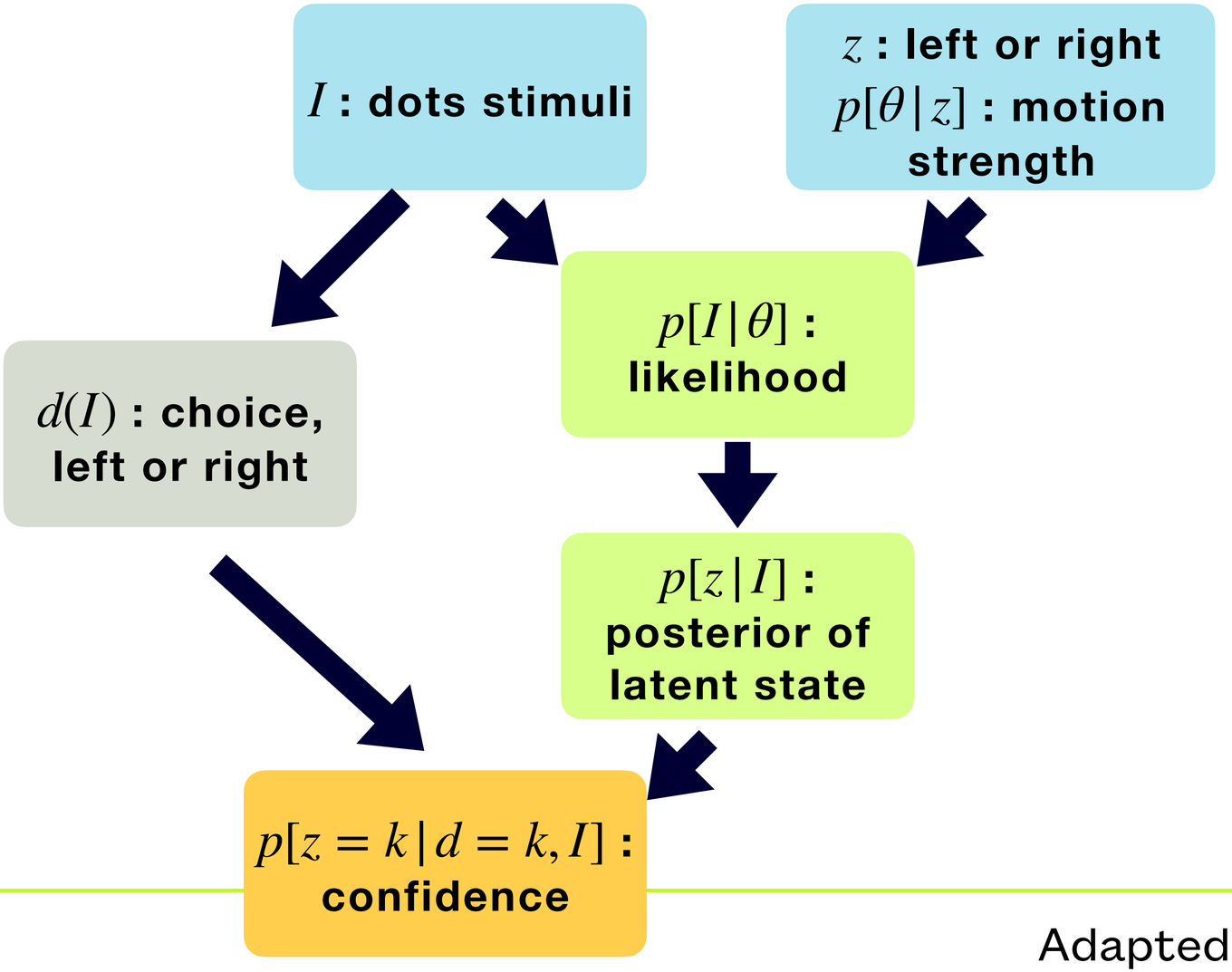
Kiani & Shadlen, 2009

Computing Confidence



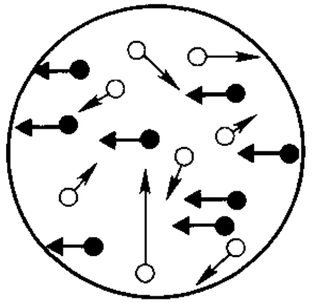
Adapted from Pouget et al., 2016

Computing Confidence



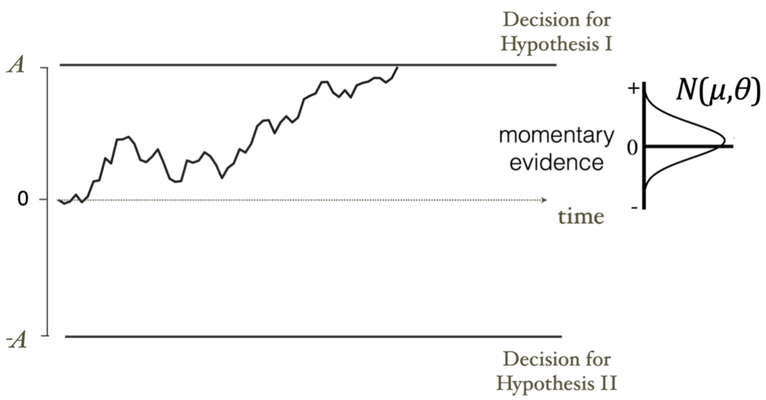
Adapted from Pouget et al., 2016

Meta-Cognition



Sensory

Cognition



Decision Making

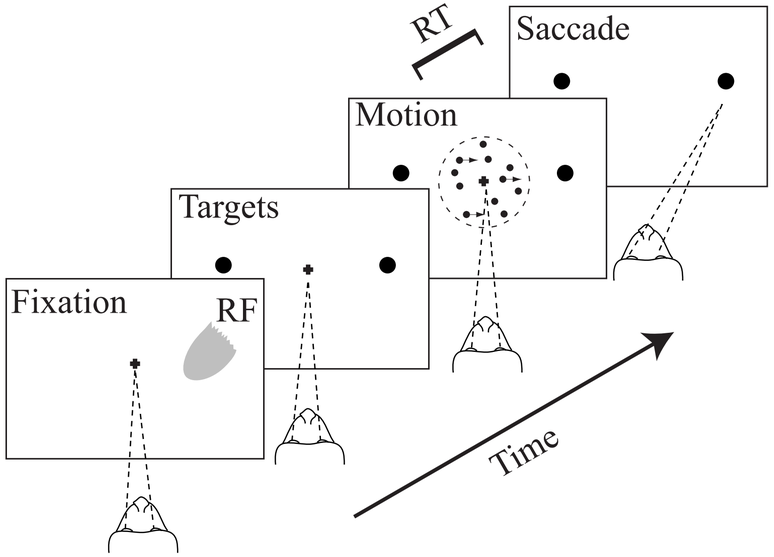
Meta-
Cognition

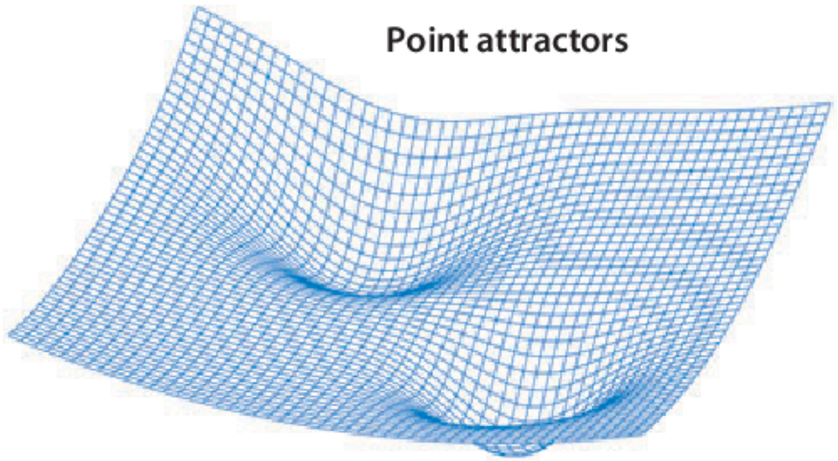
$$p[z = k \mid d = k, I]$$

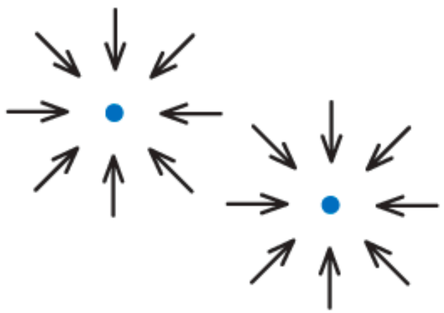
Confidence

- ❖Overview
- ❖DDM
- ❖SPRT
- ❖Confidence
- ❖**Attractor Network**

Attractor Networks

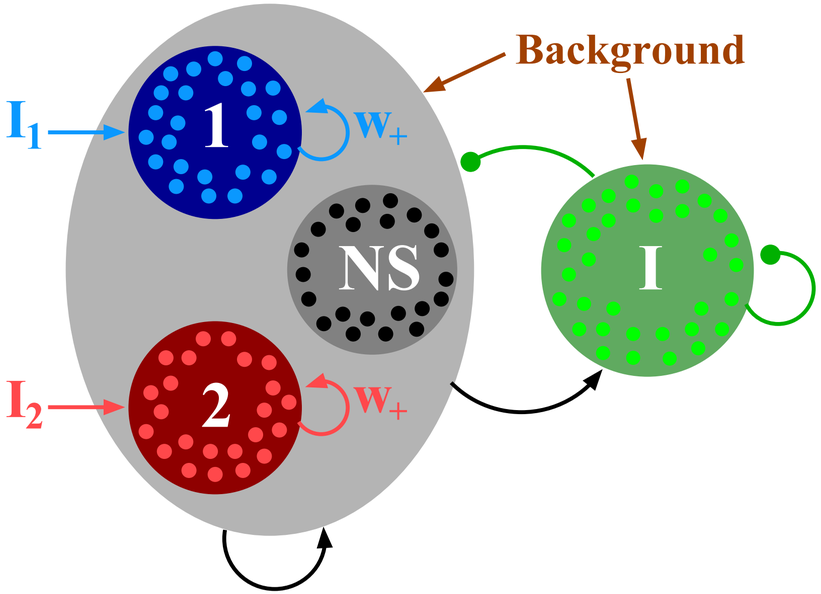


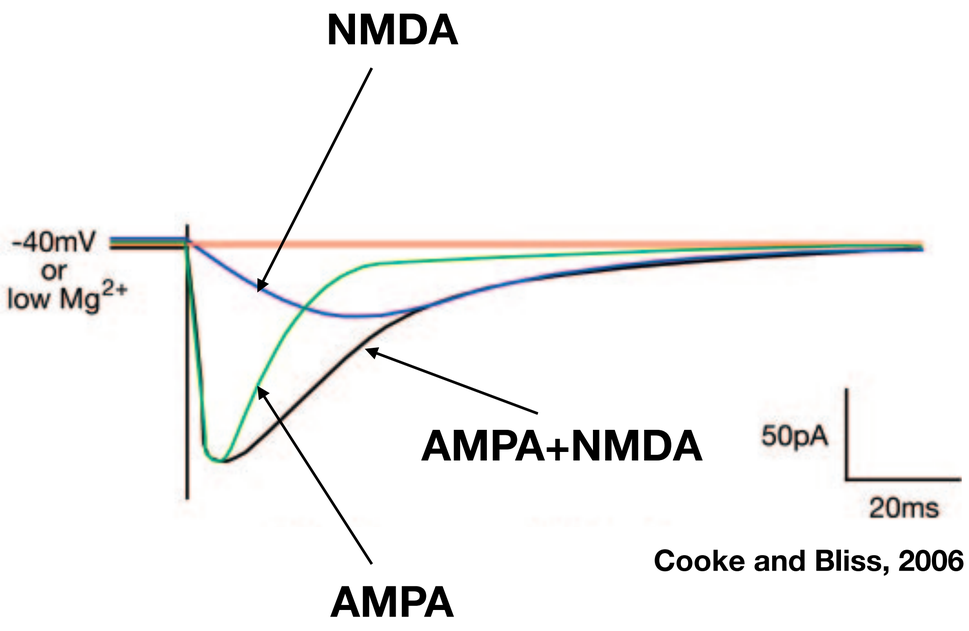




Network state space

Attractor Neural Network

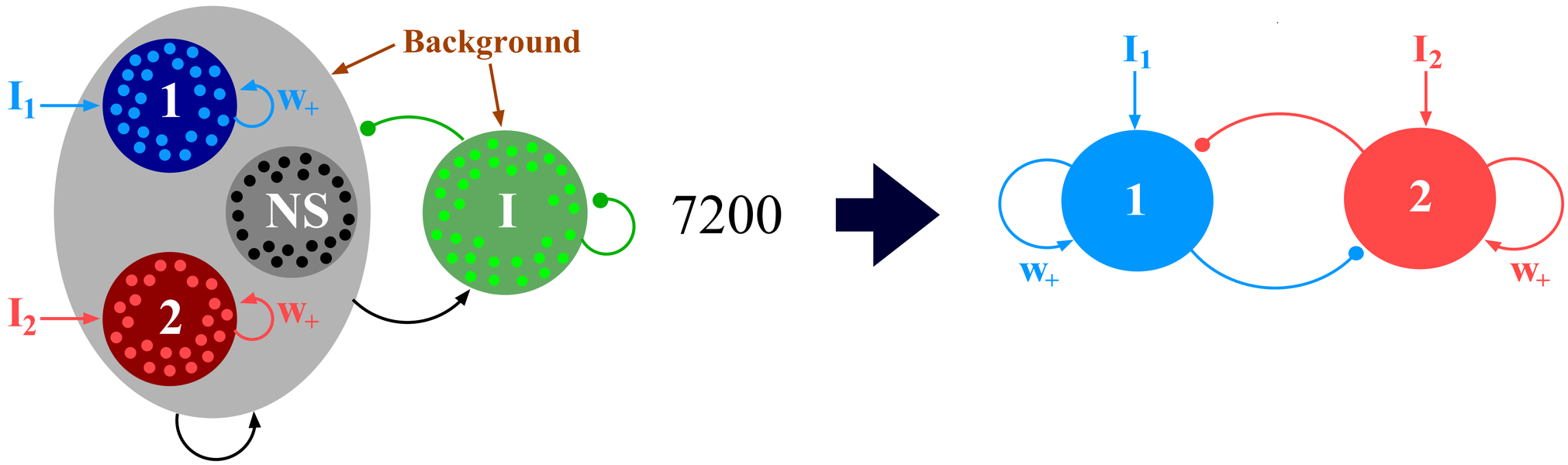




Cooke and Bliss, 2006

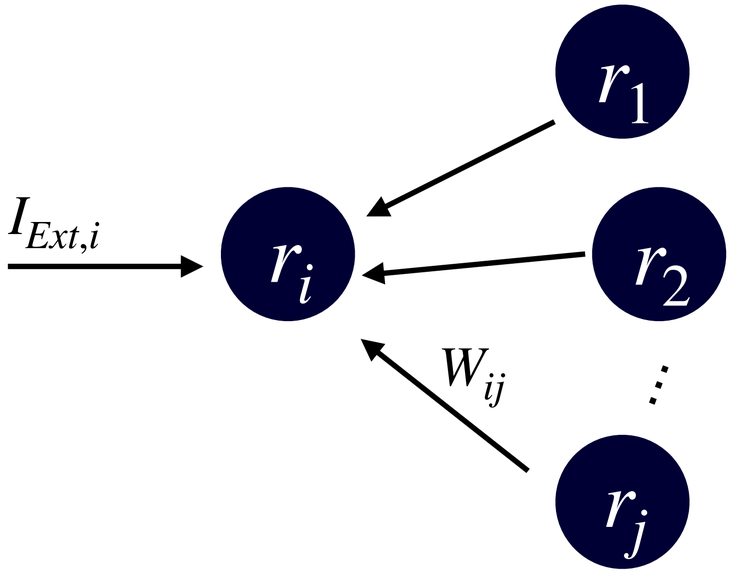
XJ Wang, 2002

Simplified Model



Wong & Wang 2006

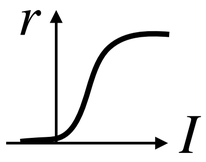
Rate Model of Neural Network Modeling



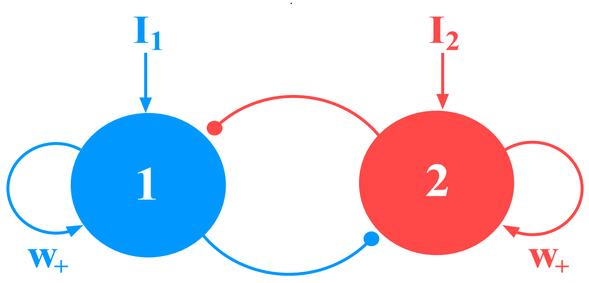
Time Constant

$$\tau_i \frac{dr_i}{dt} = -r_i + \Phi_i\left(\sum_j W_{ij} r_j + I_{Ext,i}\right)$$

Input-Output Transfer Function



Simplified Model



$$\frac{dS_{1,NMDA}}{dt} = -\frac{S_{1,NMDA}}{\tau_{NMDA}} + (1 - S_{1,NMDA})\gamma r_1$$

$$I_{syn,1} = J_{NMDA,11}S_{1,NMDA} - J_{NMDA,12}S_{2,NMDA} + J_{AMPA,11}r_1 - J_{AMPA,12}r_2 + I_0 + I_{input,1} + I_{noise,1}$$

$$r_1 = \phi(I_{syn,1})$$

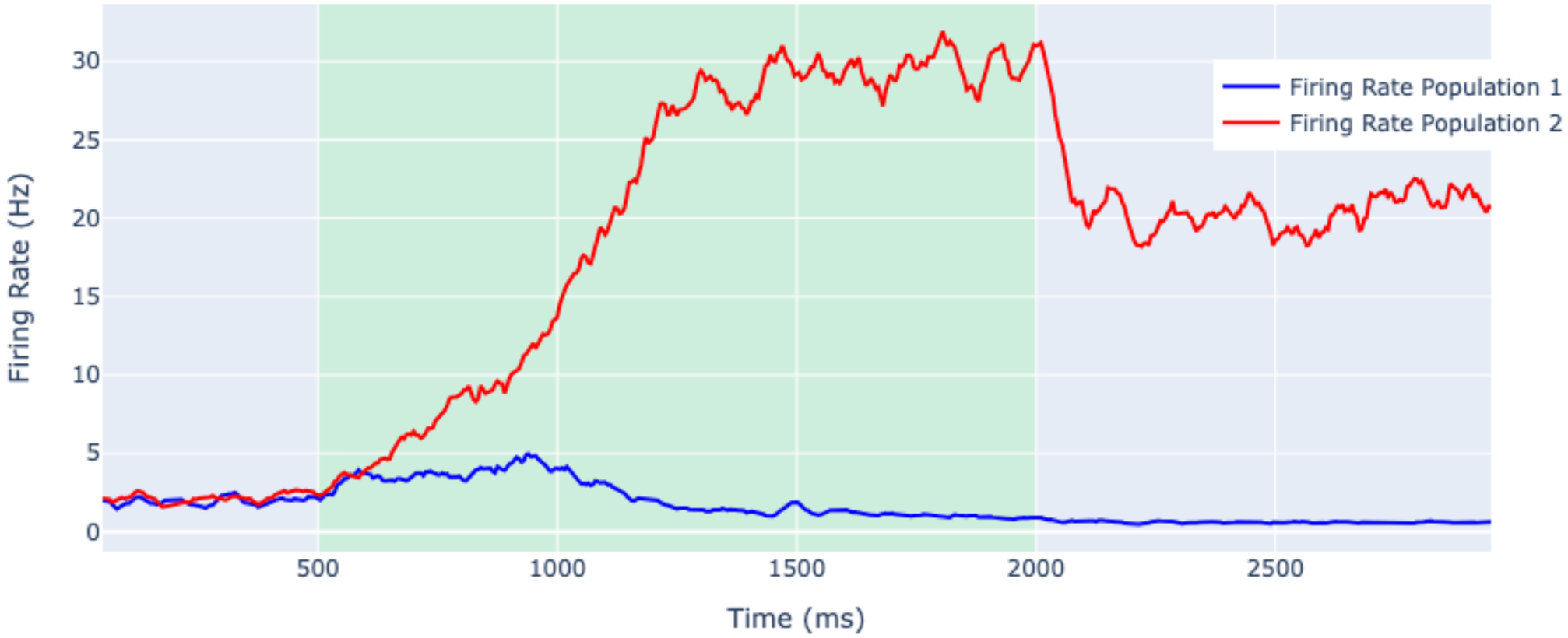
$$\frac{dS_{2,NMDA}}{dt} = -\frac{S_{2,NMDA}}{\tau_{NMDA}} + (1 - S_{2,NMDA})\gamma r_2$$

$$I_{syn,2} = J_{NMDA,22}S_{2,NMDA} - J_{NMDA,21}S_{1,NMDA} + J_{AMPA,22}r_2 - J_{AMPA,21}r_1 + I_0 + I_{input,2} + I_{noise,2}$$

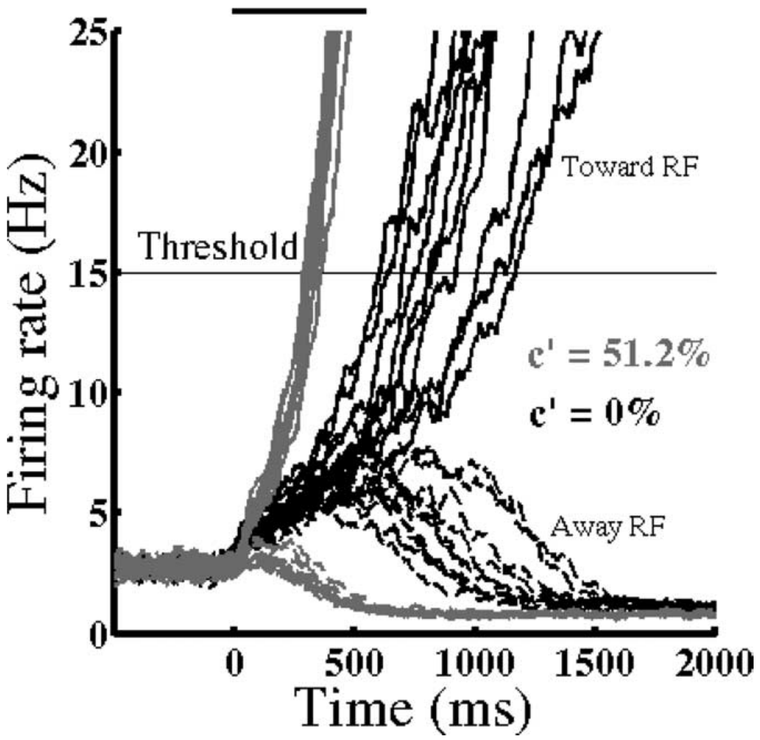
$$r_2 = \phi(I_{syn,2})$$

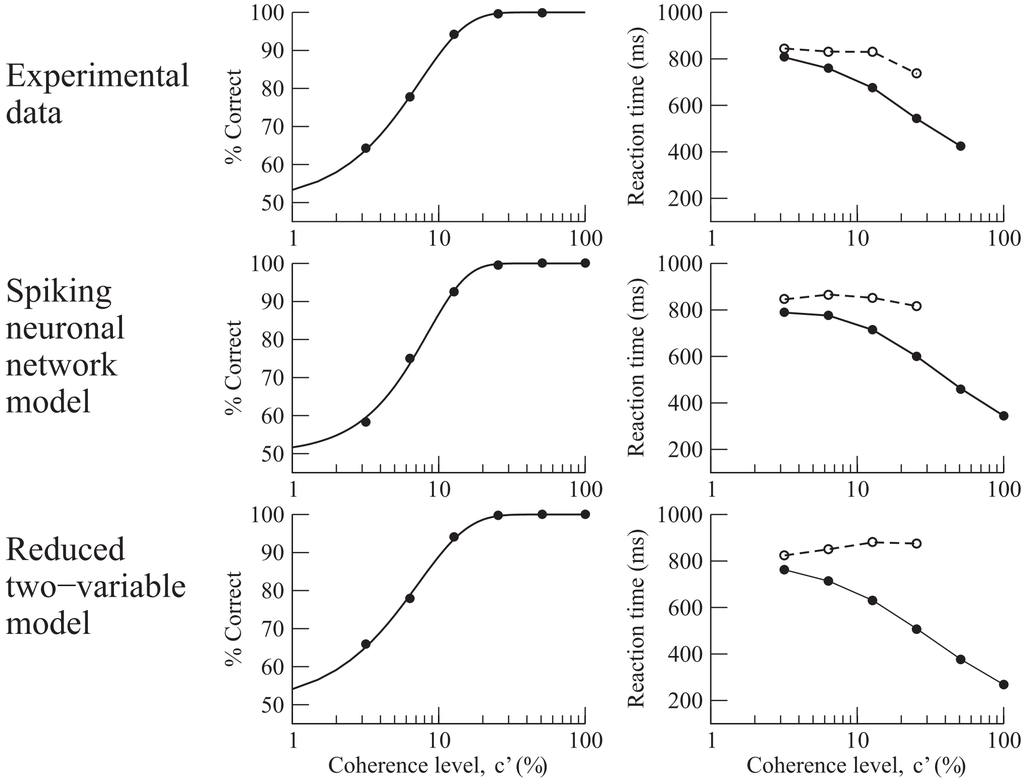
Wong & Wang 2006

Simplified Model



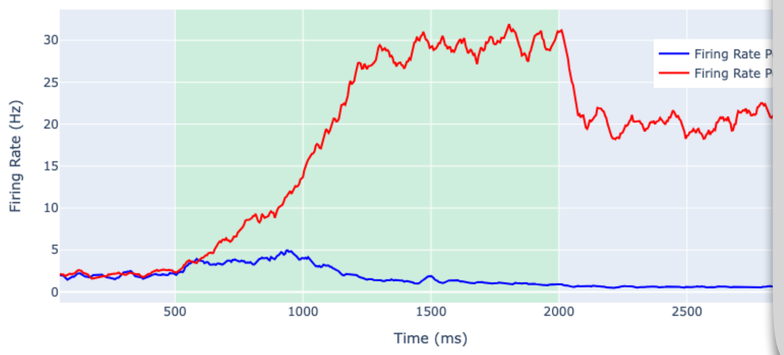
Model Performance

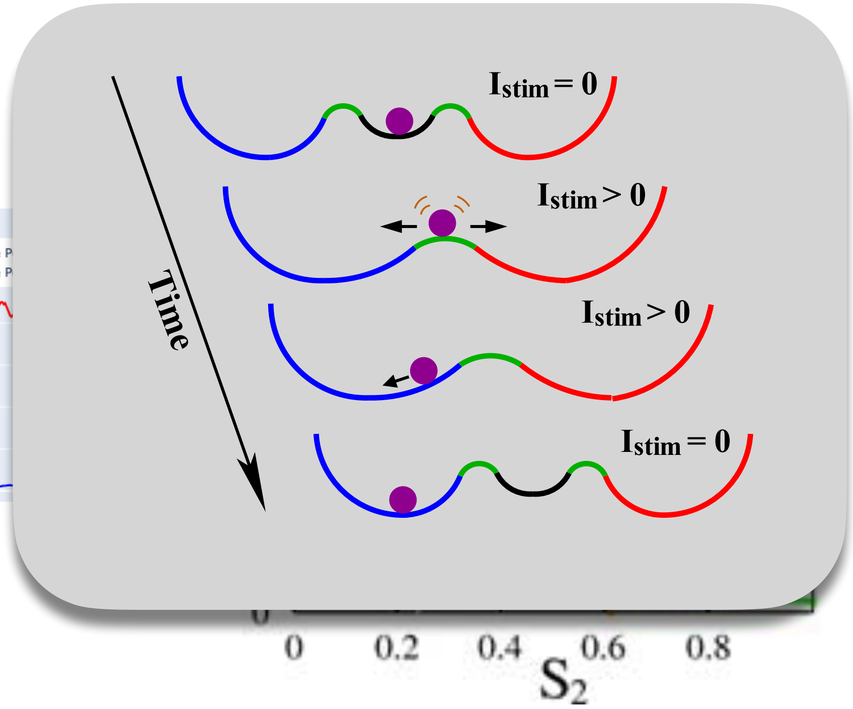


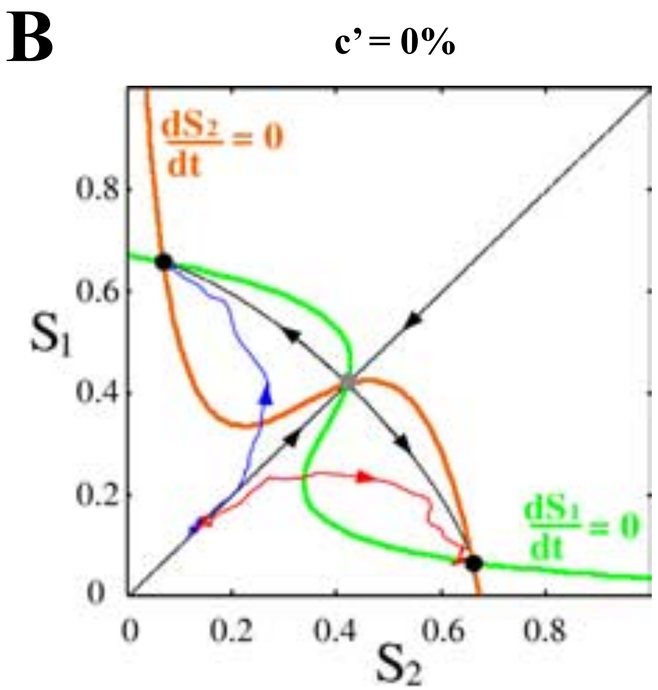


Wong & Wang 2006

Phase Plane

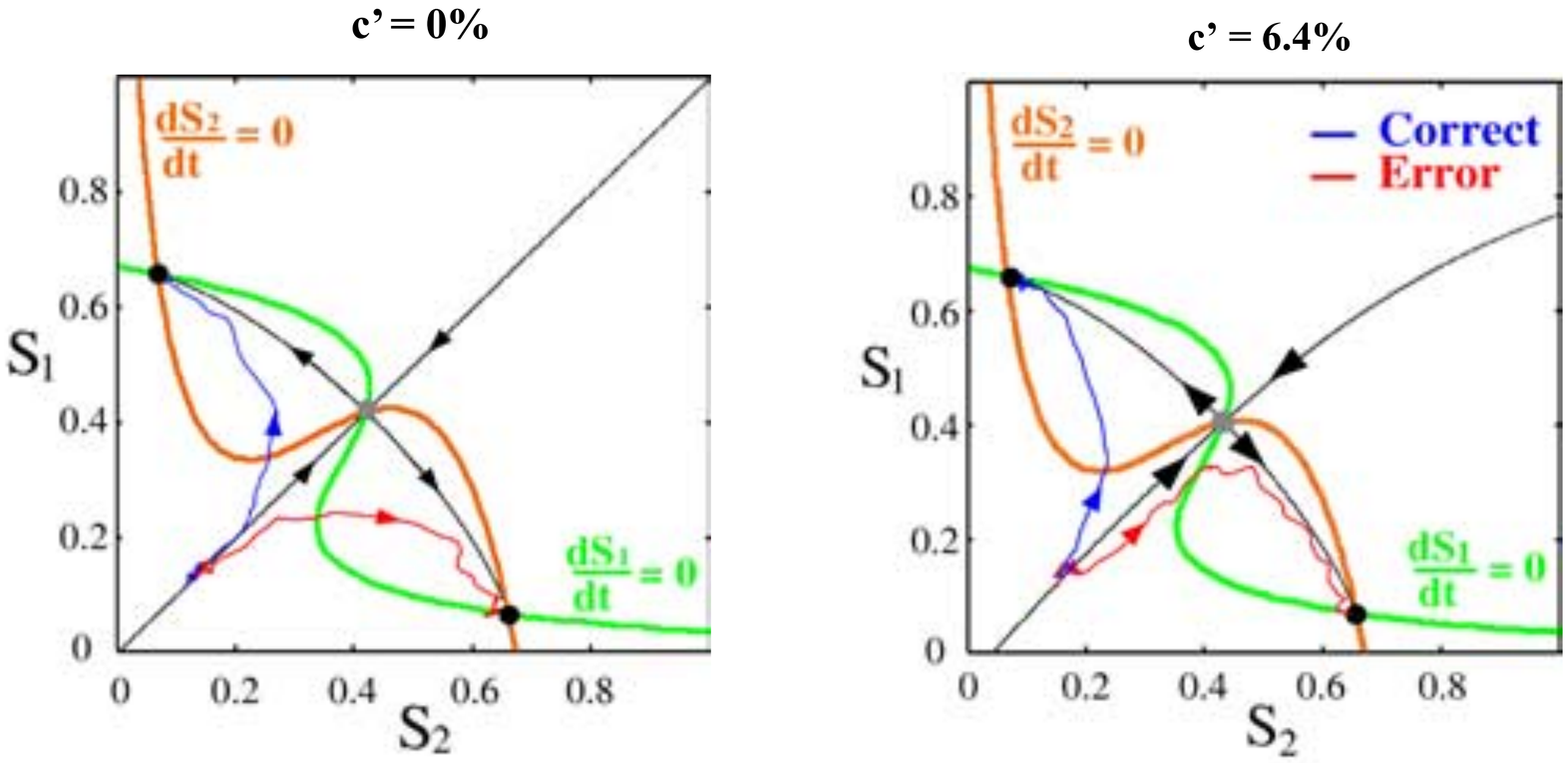






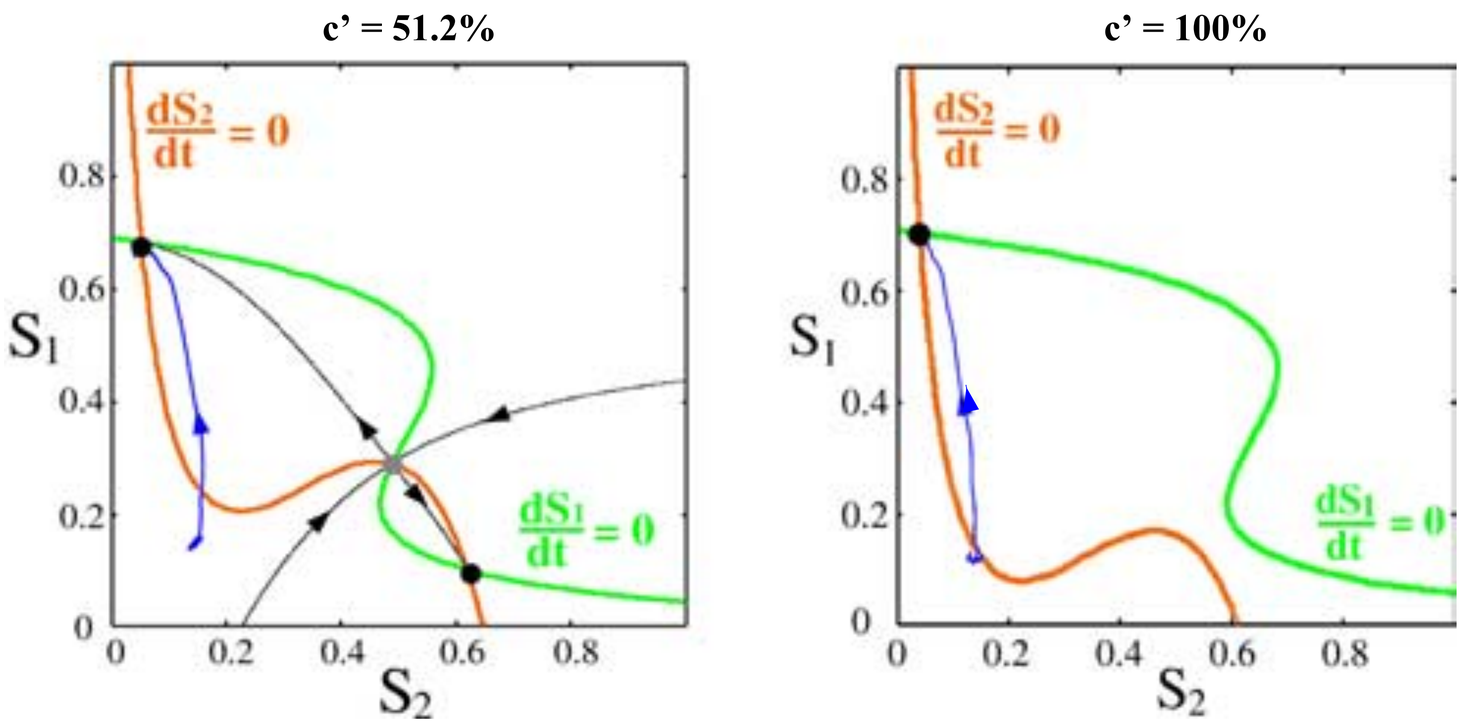
Wong & Wang 2006

Biased inputs



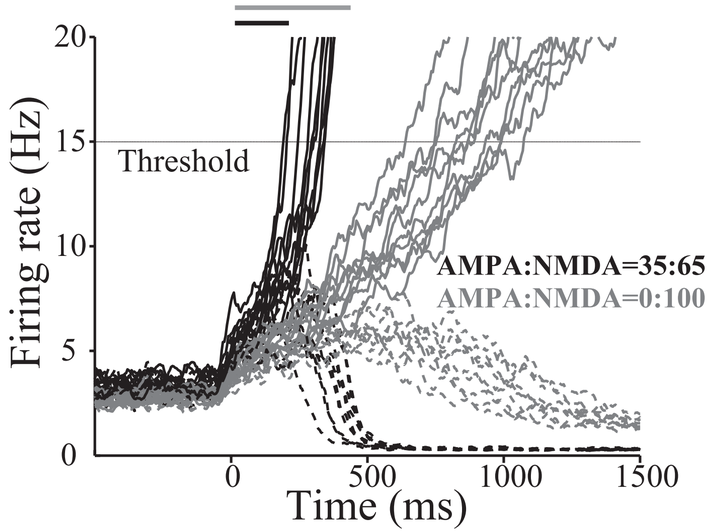
Wong & Wang 2006

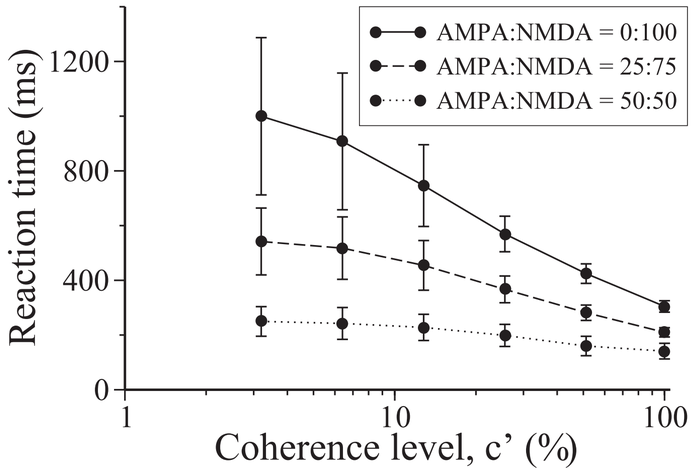
Extreme biases

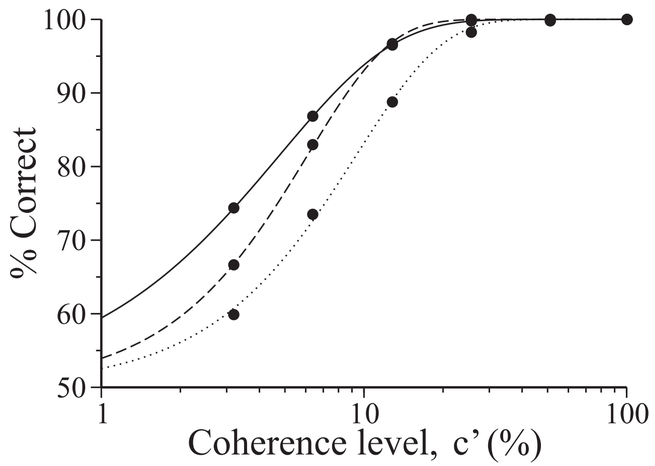


Wong & Wang 2006

NMDA is important







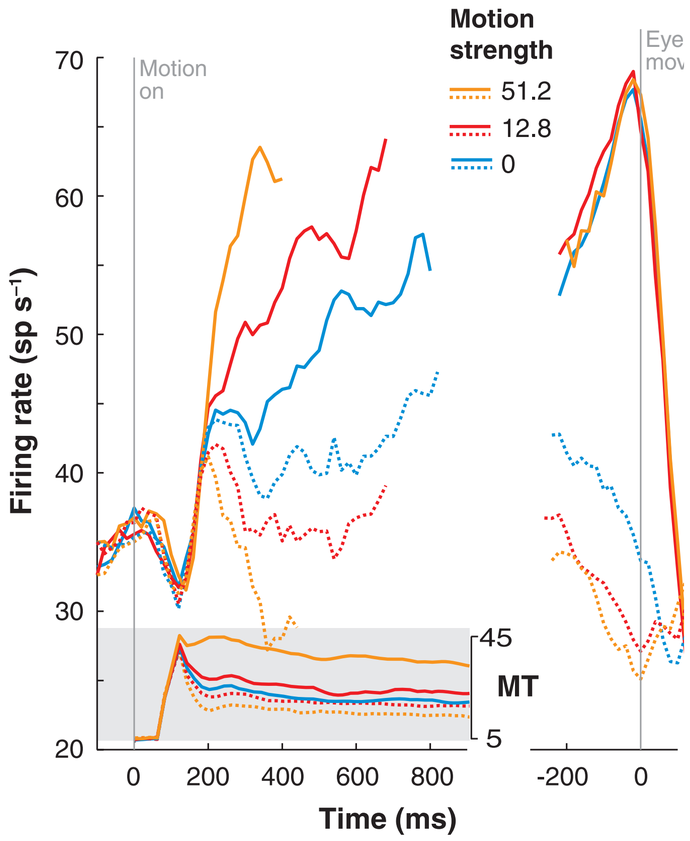
Wong & Wang 2006

Summary

- DDM
  - RDM, LIP, Ramping
- SPRT
  - LogLR, Probabilistic reasoning
- Confidence
  - Definition, meta-cognition
- Attractor Network
  - Neural network modeling, Phase plane

Homework

- Understand and play with the two simulation codes I send out
- DDM
  - Implement a variation of DDM based on this code (collapsing bound, leaky integration…), and compare its behavior against the standard DDM
- Attractor Network
  - Modify the code to plot the simulation for the figure on the right
  - Modify the code to add a decision mechanism (ref. Wong and Wang, 2006). Plot a psychometric and a chronometric curve.



Project Idea

- Design a decision-making experiment, measure the accuracy and reaction time, determine whether DDM is a good model for this experiment.