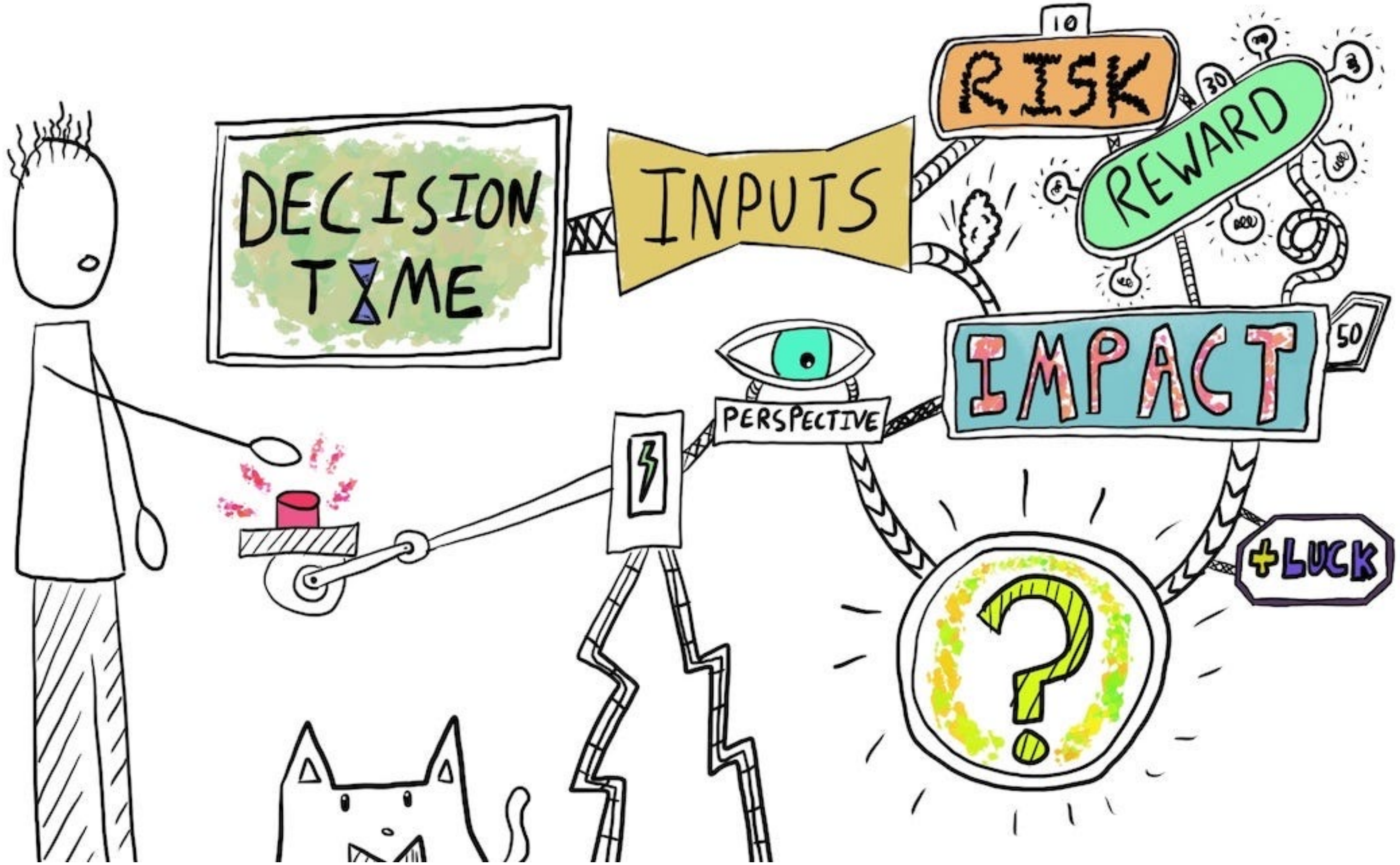
Decision-Making Network

Xiao Liu

Decision-making

Decision-making



目录 CONTENTS

01 LIP → Decision-Making

02 A Spiking Network of DM

03 Simulation of Spiking DM

04 A Rate Network of DM

05 Phase Plane Analysis

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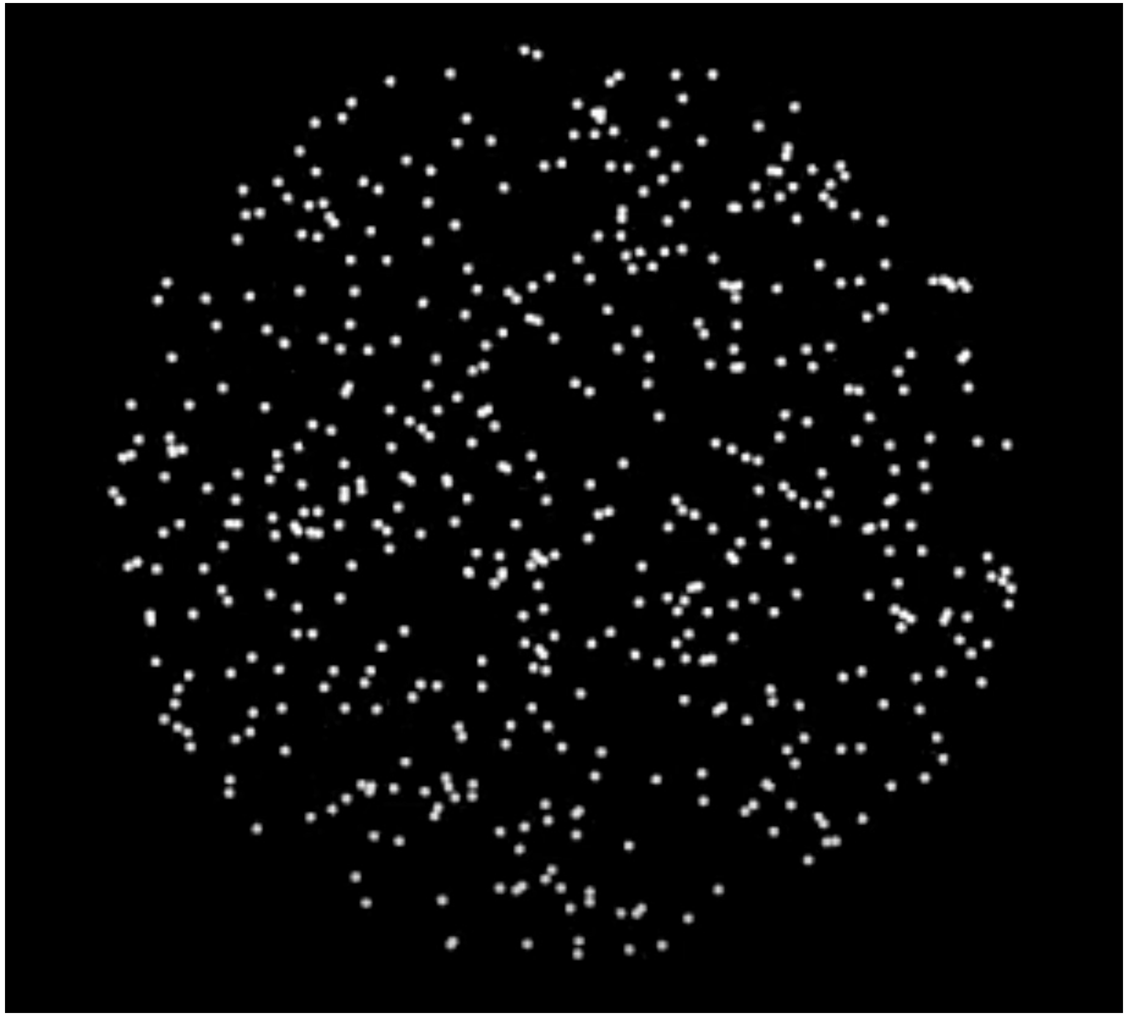
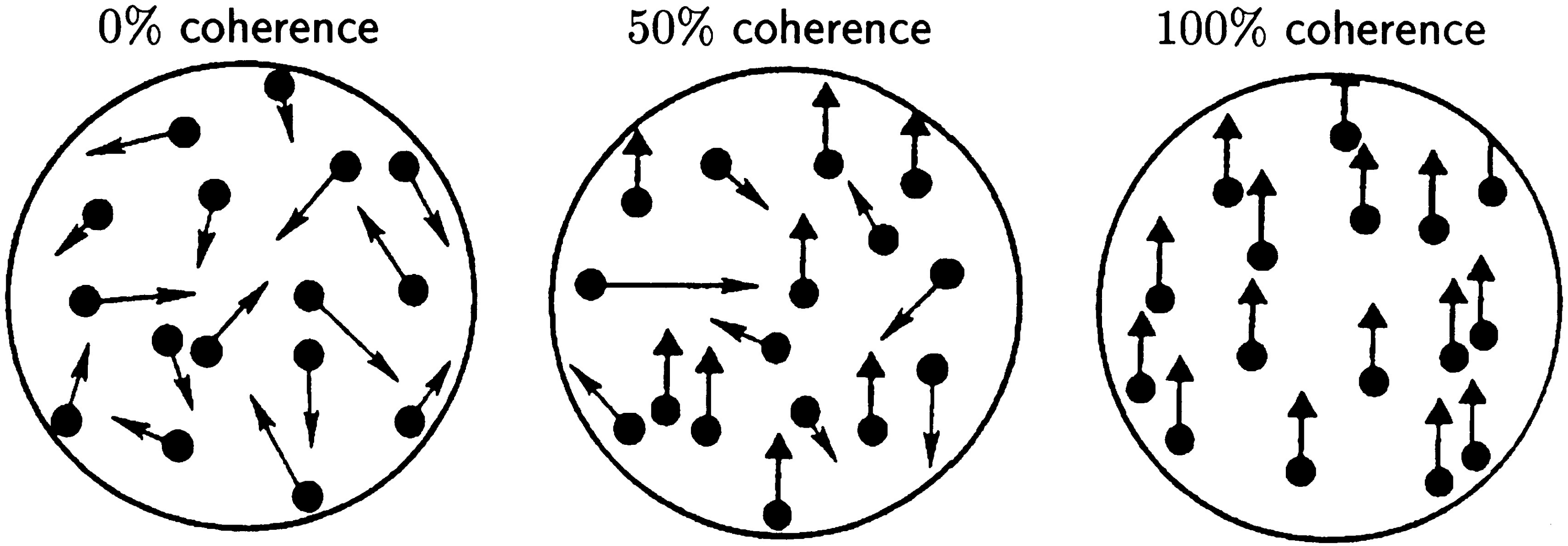
01

Decision-Making Task

COHERENT MOTION TASK

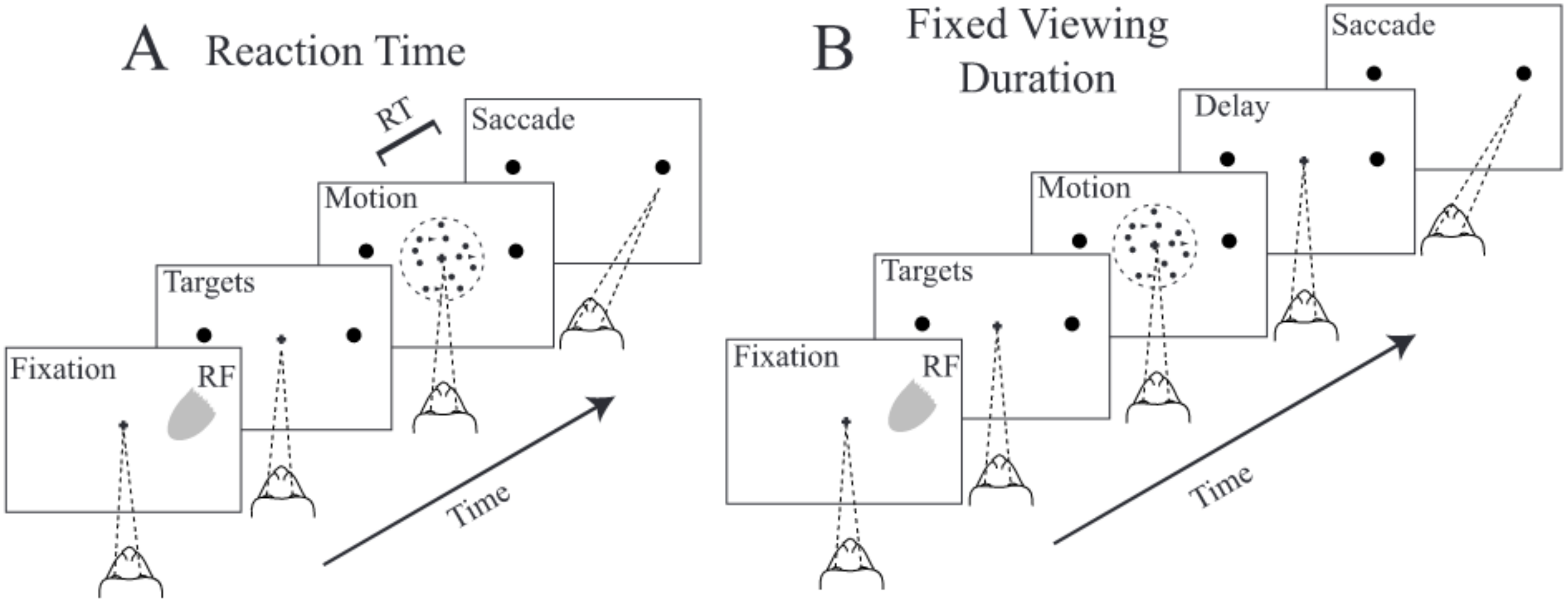


Coherence



Difficult 🡐 🡒 Easy

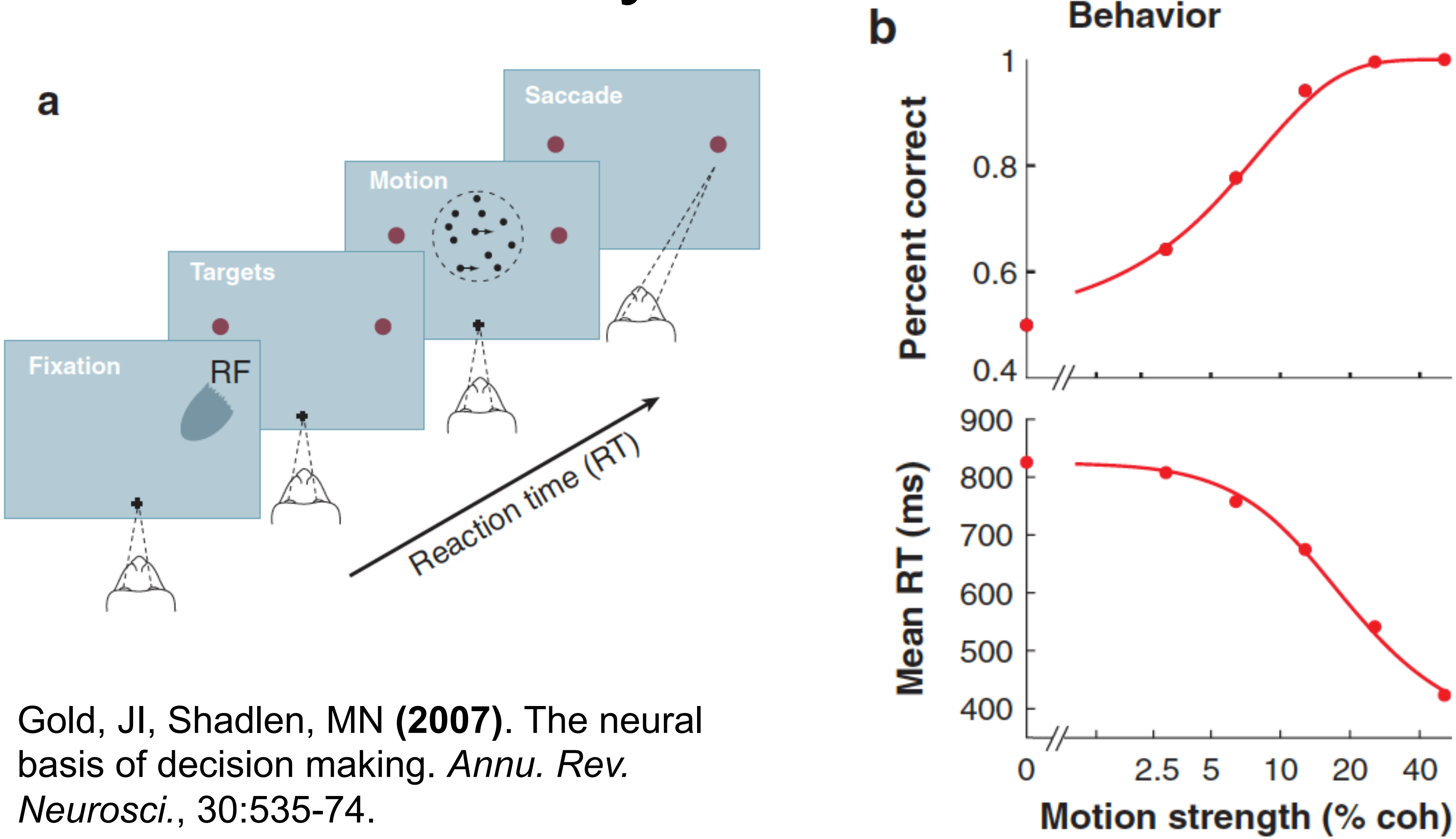
Reaction Time VS. Fixed Duration



Decision or motion?

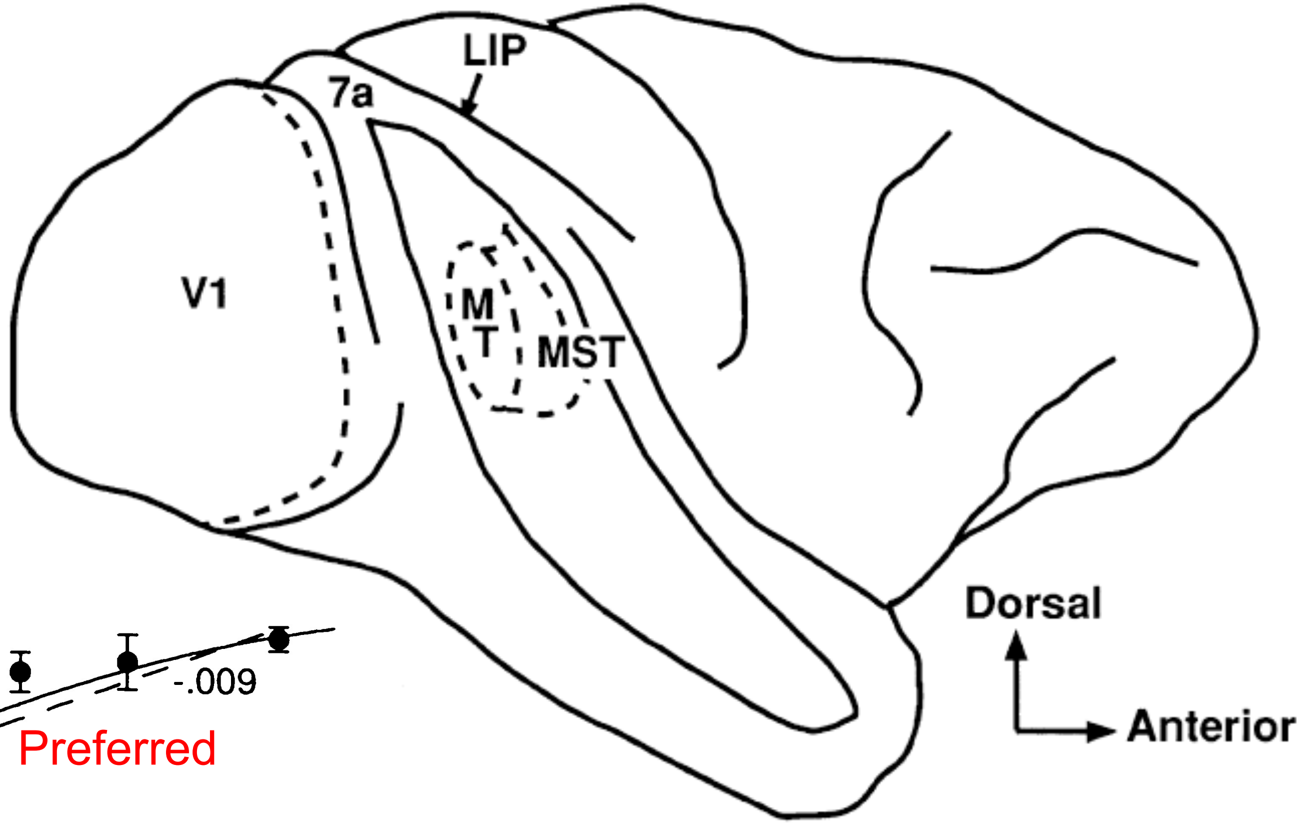
Roitman and Shadlen 2002

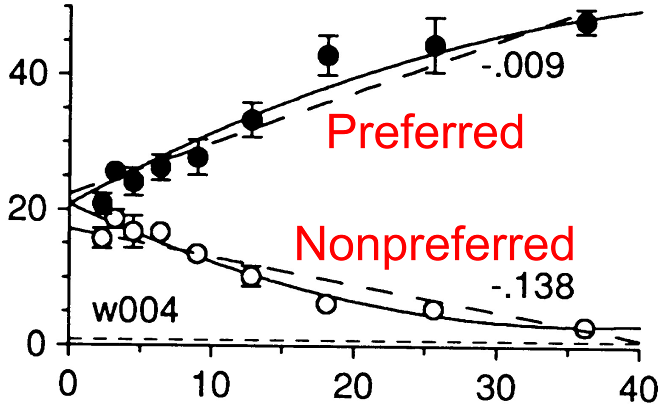
Effect of Difficulty

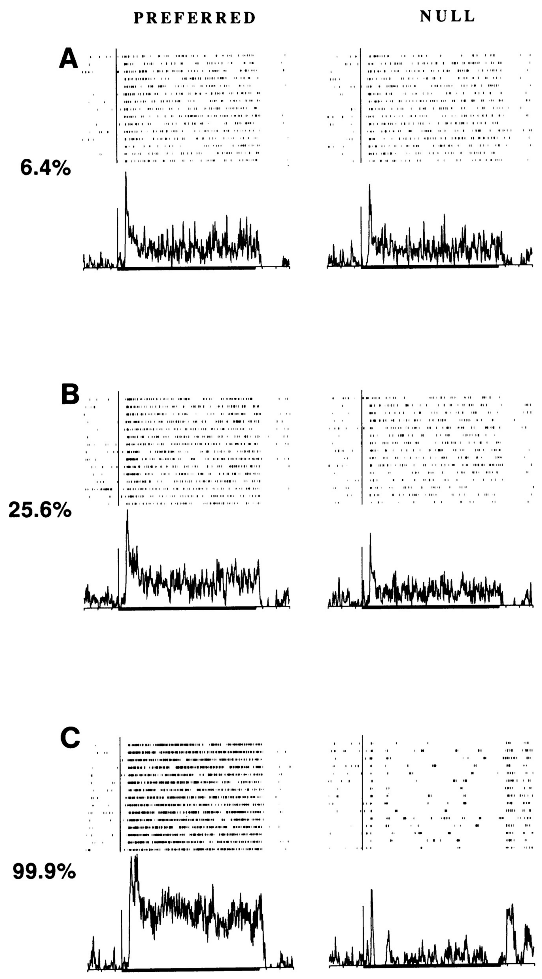


Gold, JI, Shadlen, MN **(2007)**. The neural basis of decision making. *Annu. Rev. Neurosci.*, 30:535-74.

Response of MT Neurons





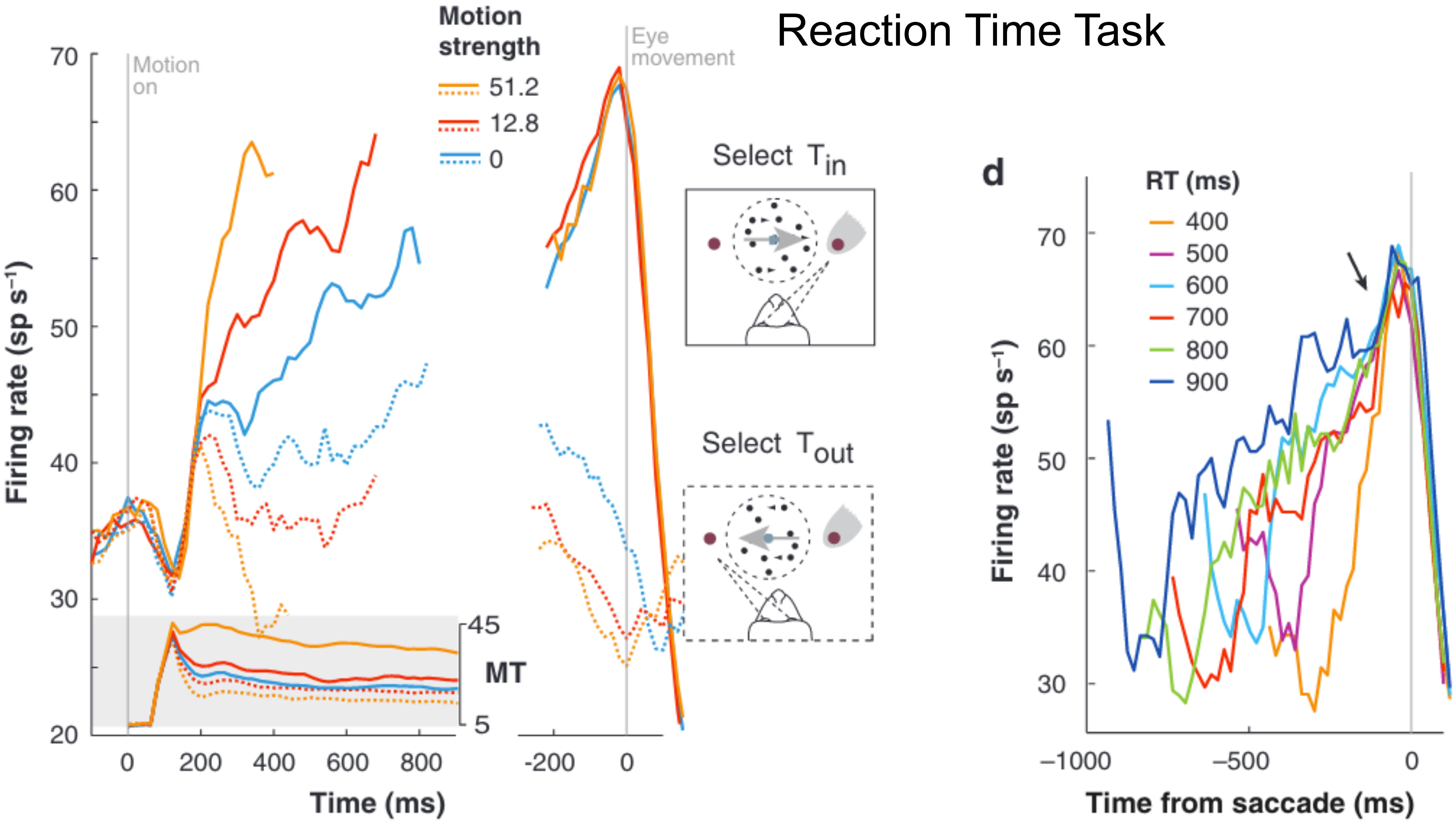


Britten et al. 1996

Response of LIP Neurons

LIP

Reaction Time Task



Roitman and Shadlen 2002

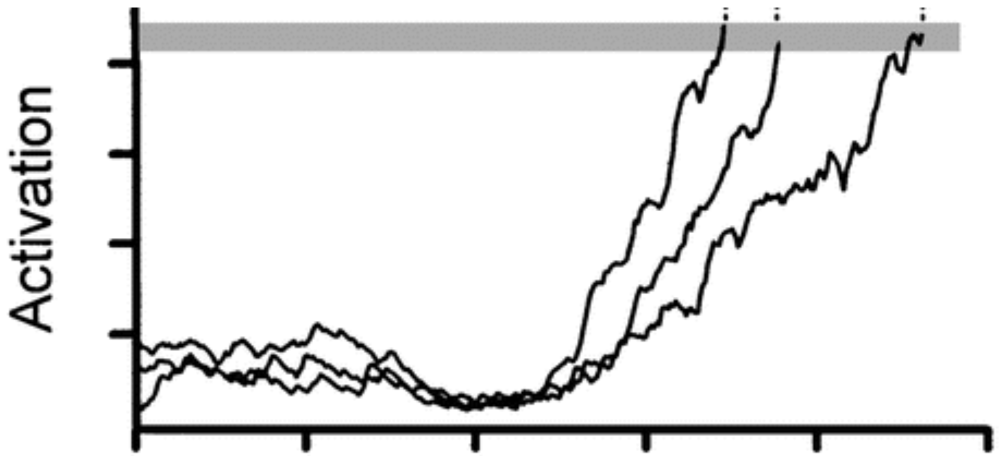
Ramping-to-threshold (perfect integrator) Model

$$\frac{dR}{dt} = I_A - I_B + \text{noise}, \qquad R(t) = (I_A - I_B)t + \int_0^t dt \text{ noise}.$$

$\tau_{network} = \infty$!

Accumulates information (evidence)

Ramping



- R Ratcliff, Psychol Rev (1978), diffusion model
- M Usher and JL McClelland, *Psychol Rev (2001) Race model*
- Green and Swets (1966) Signal Detection Theory and Psychophysics
- D Vickers (1979) Decision Processes in Visual Perception
- D Luce (1986) Response Time: their role in inferring elementary mental organization

02

A Spiking Network of DM

A cortical microcircuit model

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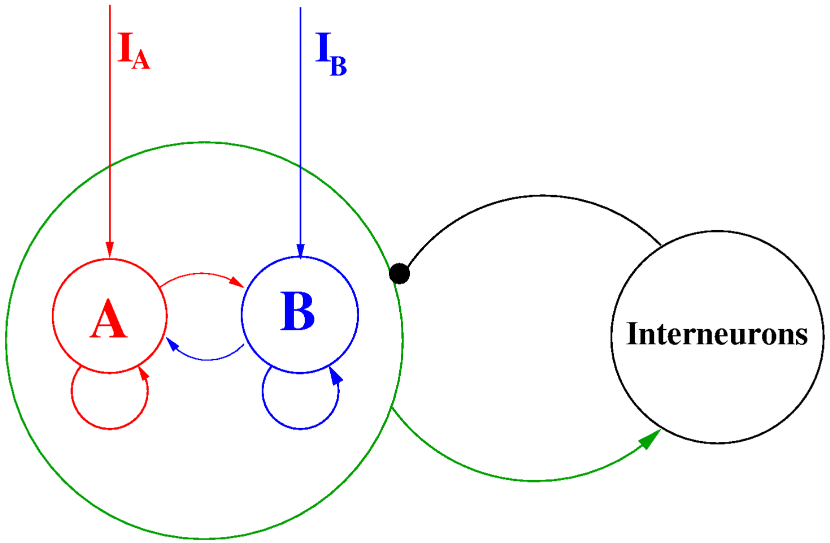


A=Upward motion B=Downward motion

- 2-population excitatory neurons (integrate-and-fire neurons driven by Poisson input)
- Slow reverberatory excitation mediated by the NMDA receptors at recurrent synapses
- Winner-take-all competition by feedback inhibition

Wang, Neuron 2002

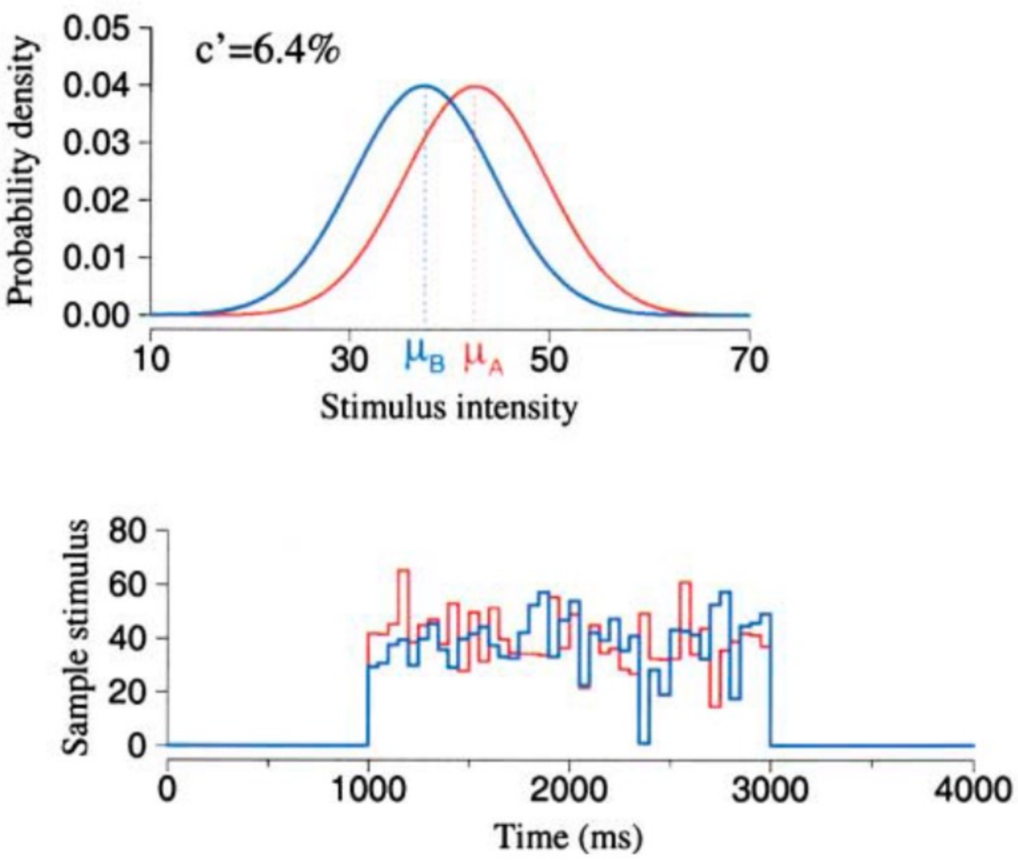
AMPA receptors (τ_{syn} = 1–3 ms)

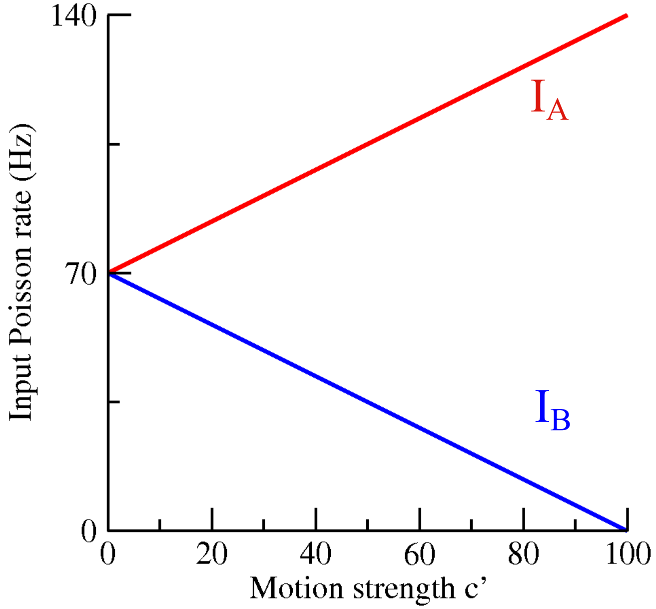
NMDA receptors (τ_{syn} = 50–100 ms).

- AMPA 受体和 NMDA 受体：它们都是谷氨酸的离子型受体，被结合后可以直接打开离子通道。相比于 AMPA 受体，NMDA 受体的离子通道通常会被一个镁离子（Mg^{2+}）堵住，即使离子通道已经打开，也没有电流通过。由于镁离子带正电，会受细胞内外电位差的影响，突触后膜去极化到一定程度后，镁离子就会离开离子通道，让 NMDA 受体可以对谷氨酸做出反应。因此，NMDA 的反应是比较慢的。

神经计算建模实战 第4.1章节

Coherence-Dependent Input

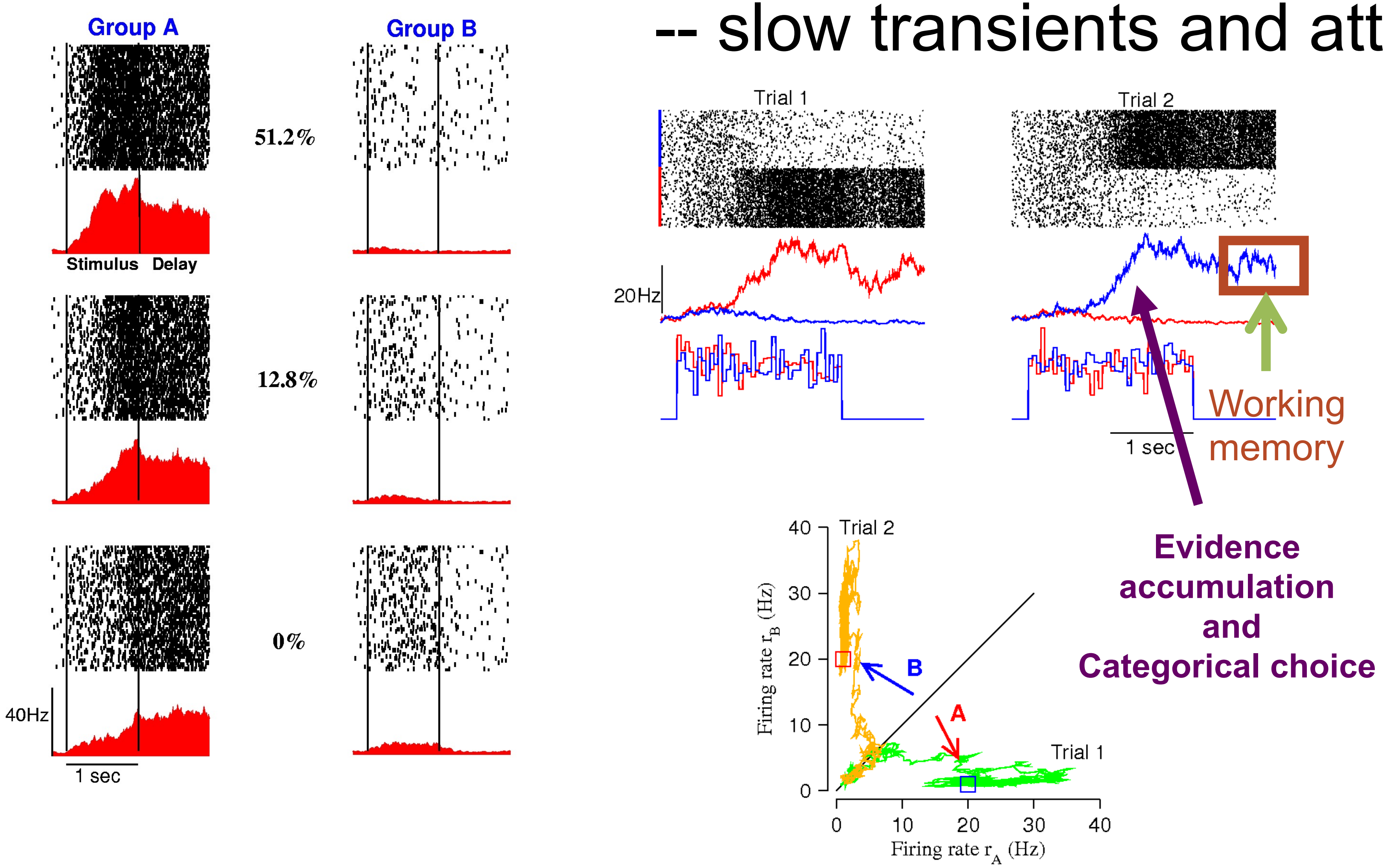




$c' = (I_A - I_B)/(I_A + I_B)$

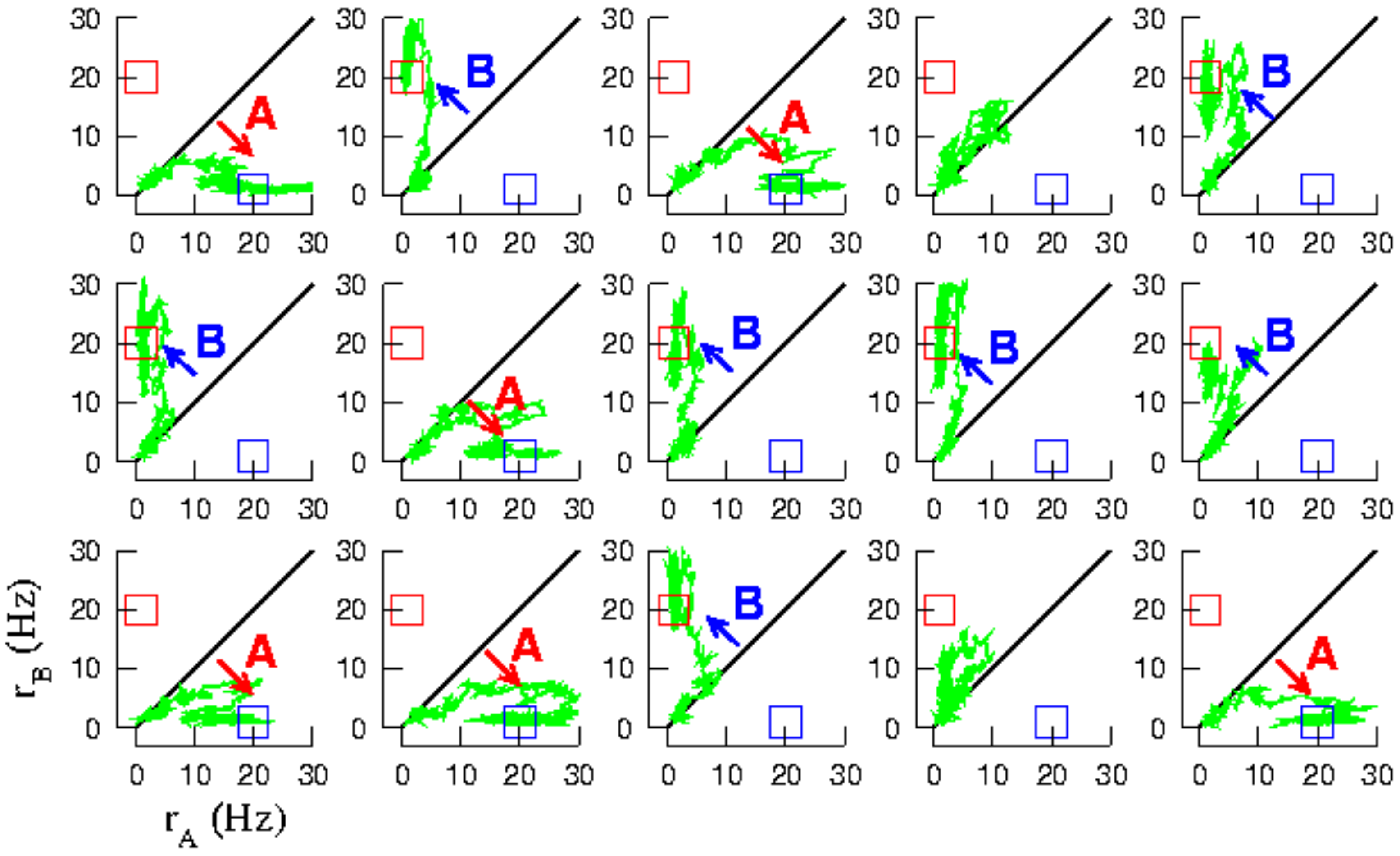
Duality of this model

-- slow transients and attractor states



Spontaneous symmetry breaking and stochastic decision making

Coherence=0%

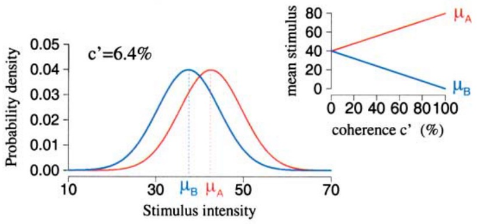


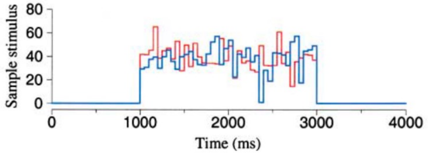
03

Simulation of Spiking DM

A Cortical Microcircuit Model

I^{ext}:





$$C_m \frac{dV(t)}{dt} = -g_L(V(t) - V_L) - I_{syn}(t)$$

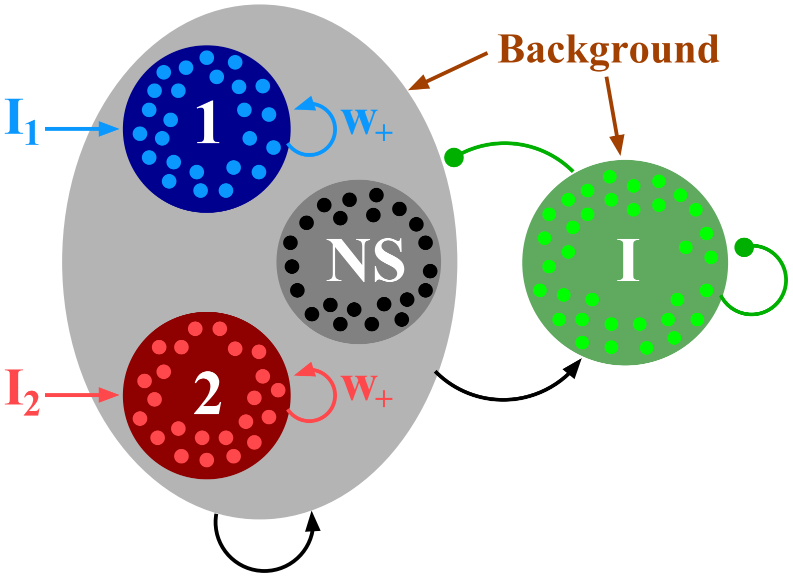
$$I_{syn}(t) = I_{\text{ext,AMPA}}(t) + I_{\text{rec},AMPA}(t) + I_{\text{rec},NMDA}(t) + I_{\text{rec,GABA}}(t)$$

$$I_{\text{ext,AMPA}}(t) = g_{\text{ext,AMPA}}(V(t) - V_E) s^{\text{ext,AMPA}}(t)$$

$$I_{\text{rec,AMPA}}(t) = g_{\text{rec,AMPA}}(V(t) - V_E) \sum_{j=1}^{C_E} w_j s_j^{AMPA}(t)$$

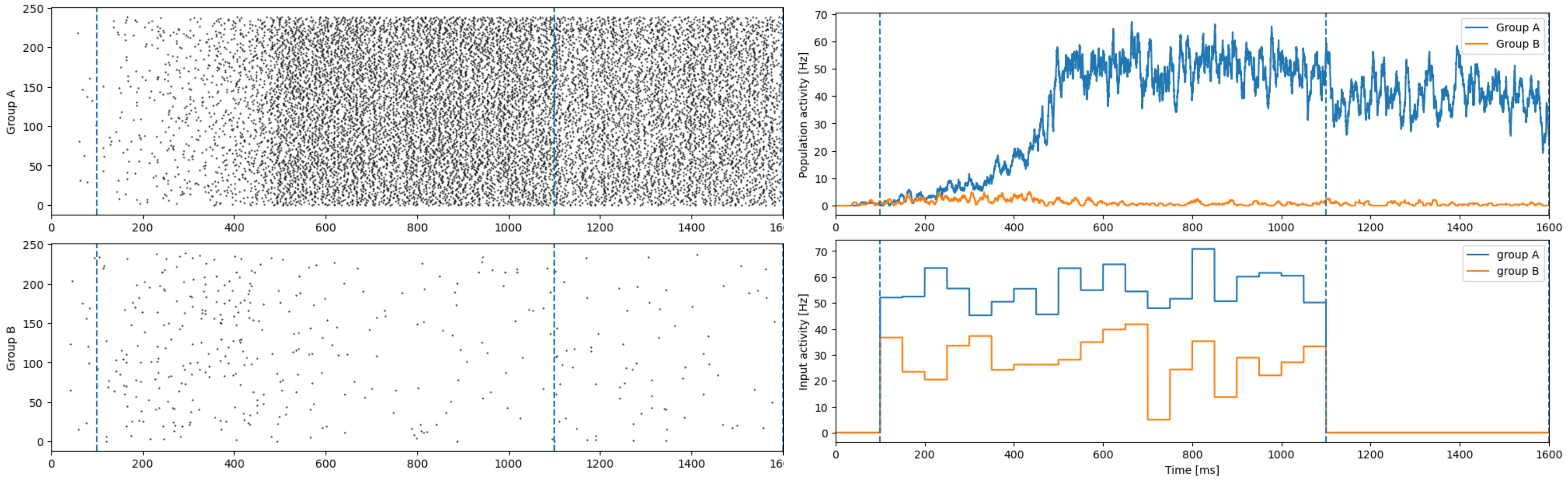
$$I_{\text{rec,NMDA}}(t) = \frac{g_{\text{NMDA}}(V(t) - V_E)}{(1 + [\text{Mg}^{2+}] \exp(-0.062V(t))/3.57)} \sum_{j=1}^{\text{C}_E} w_j s_j^{\text{NMDA}}(t)$$

$$I_{\text{rec,GABA}}(t) = g_{\text{GABA}}(V(t) - V_I) \sum_{j=1}^{C_1} s_j^{\text{GABA}}(t)$$



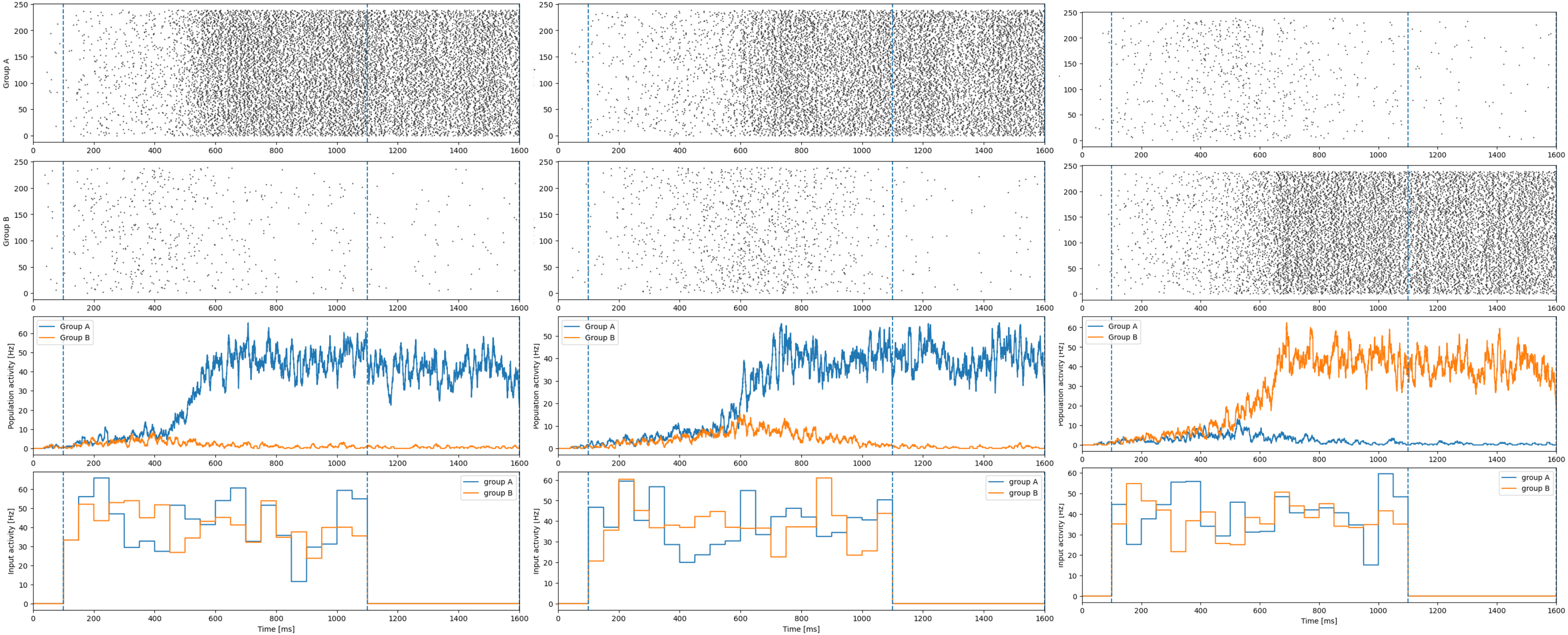
$$w_j = \begin{cases} w_+ > 1, \\ w_- < 1, \\ others = 1. \end{cases}$$

Results



Coherence = 25.6%

Stochastic Decision Making

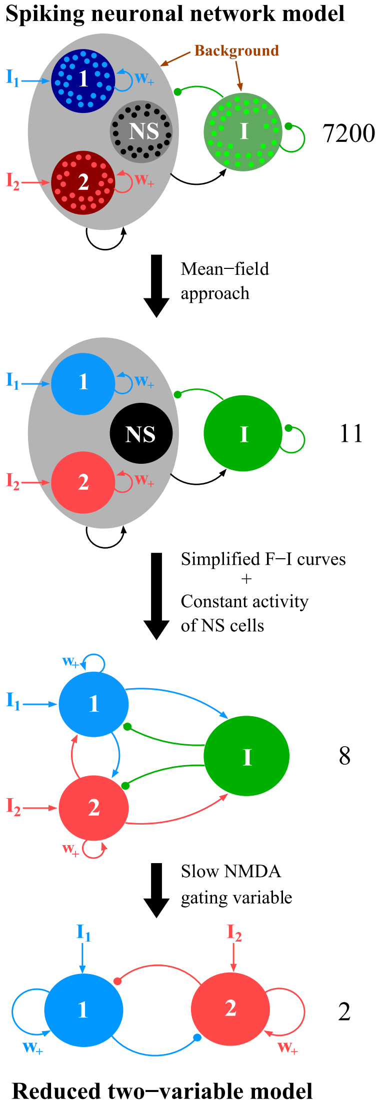


Coherence = 0%

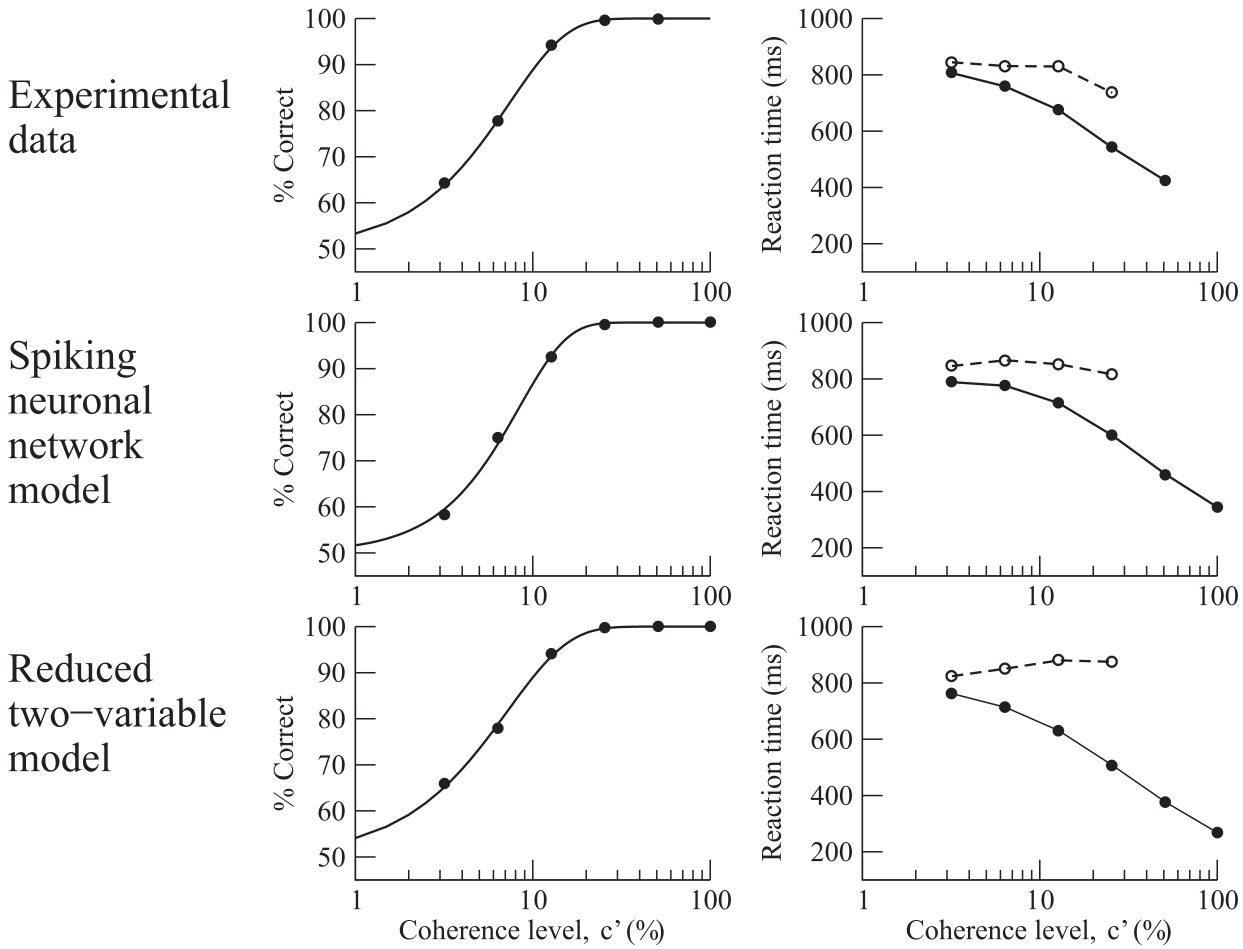
04

A Rate Network of DM

Reduced Model



Mean-field Theory



Model Reduction

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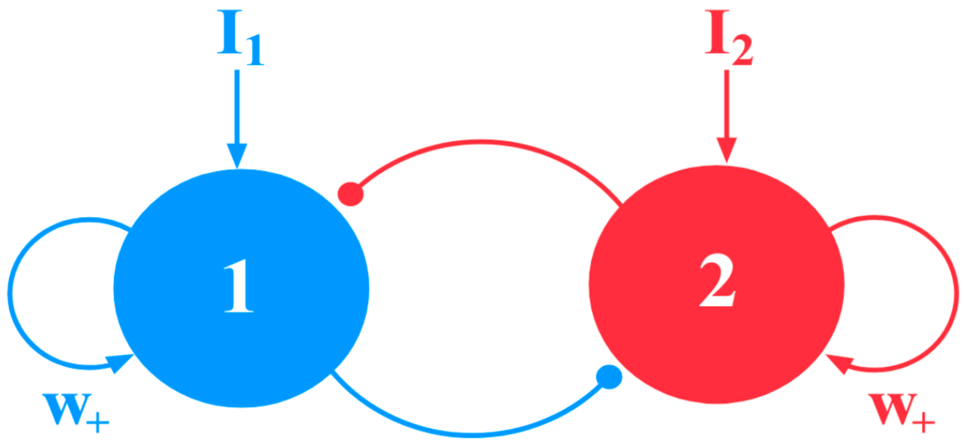


Synaptic variables

$$\frac{dS_1}{dt} = F(x_1)\gamma(1 - S_1) - S_1/\tau_s$$
$$\frac{dS_2}{dt} = F(x_2)\gamma(1 - S_2) - S_2/\tau_s$$

Input current to each population

$$x_1 = J_E S_1 + J_I S_2 + I_0 + I_{noise1} + J_{\text{ext}}\,\mu_1$$
$$x_2 = J_E S_2 + J_I S_1 + I_0 + I_{noise2} + J_{\text{ext}}\,\mu_2$$

Coherence-dependent inputs

$$\mu_1 = \mu_0\left(1 + c'/100\right)$$
$$\mu_2 = \mu_0\left(1 - c'/100\right)$$

Background input

$$I_0 + I_{noise}$$

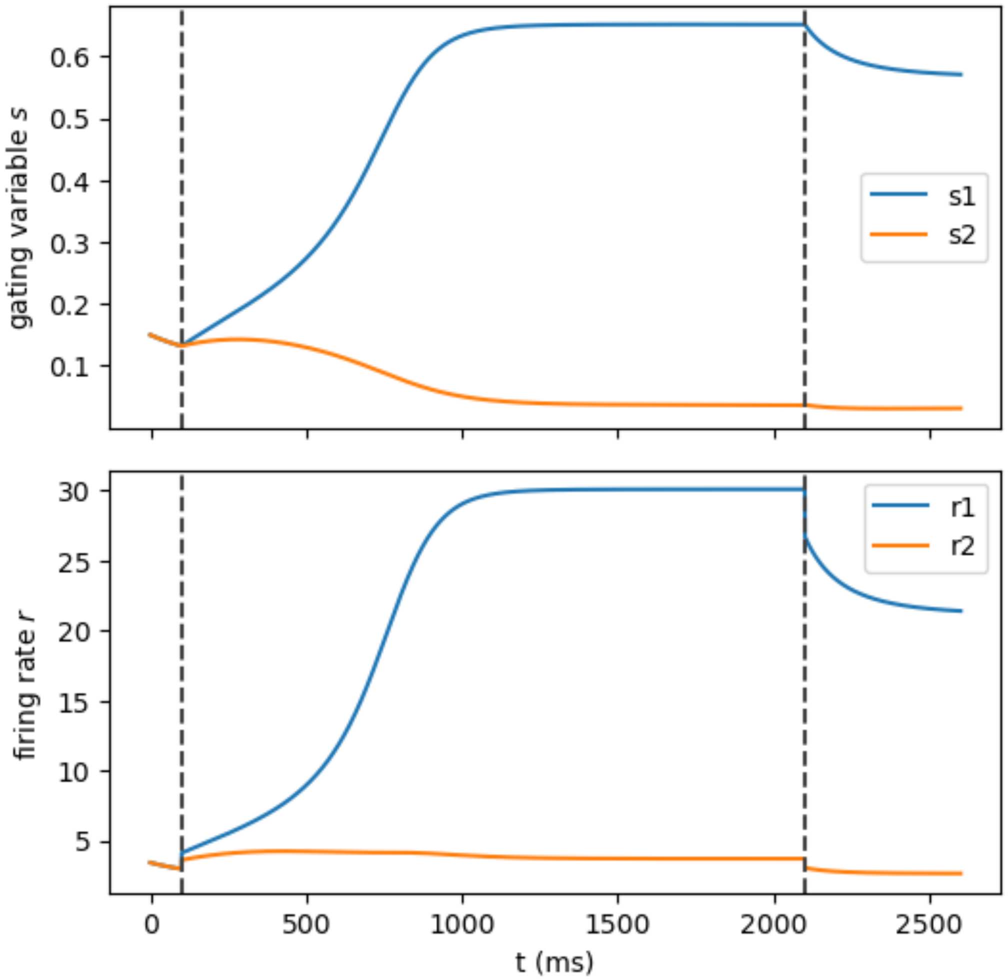
$$dI_{noise1} = -I_{noise1}\frac{dt}{\tau_0} + \sigma dW$$
$$dI_{noise2} = -I_{noise2}\frac{dt}{\tau_0} + \sigma dW$$

Firing rates $\quad r_i = F(x_i) = \dfrac{ax_i - b}{1 - \exp(-d(ax_i - b))}$

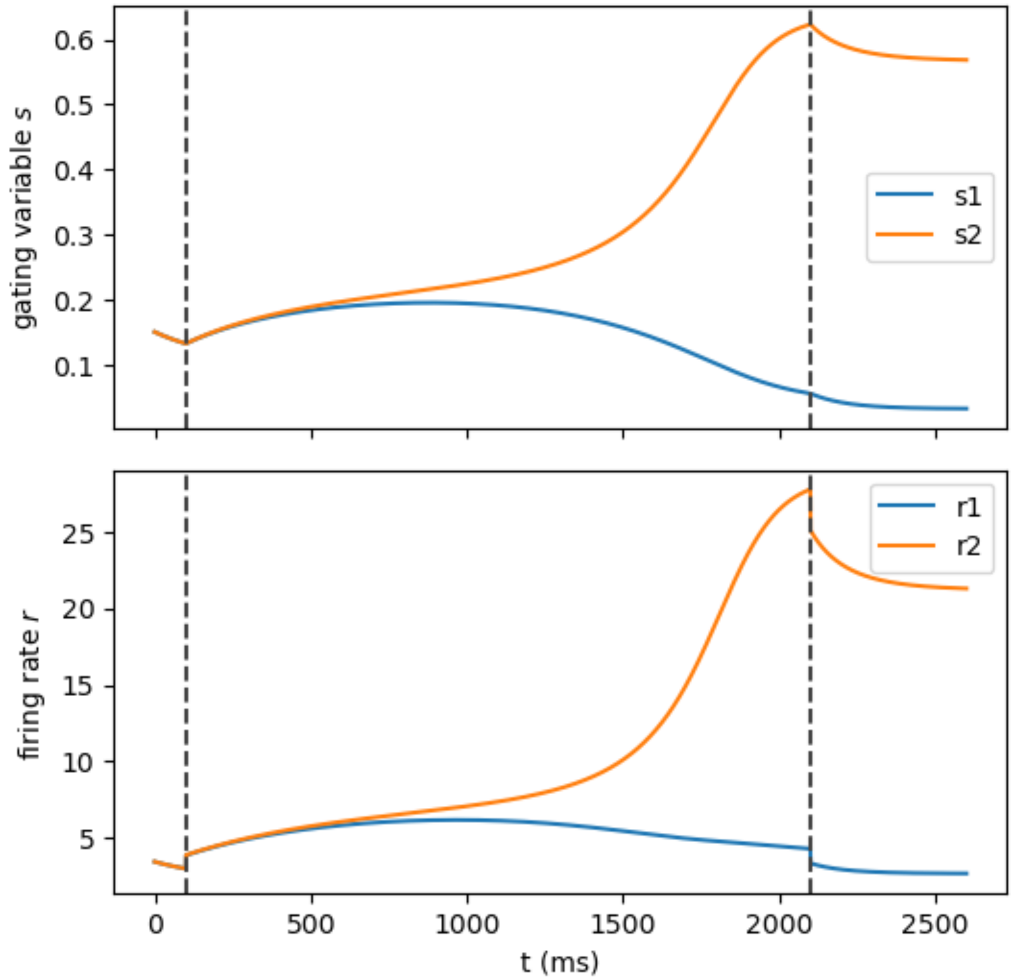
$\gamma, a, b, d, J_E, J_I, J_{\text{ext}}, I_0, \mu_0, \tau_{\text{AMPA}}, \sigma_{\text{noise}}$ are fixed parameters.

Results

Coherence = 25.6%



Coherence = -1%



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05

Phase Plane Analysis

Model implementation

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Synaptic variables

$$\frac{dS_1}{dt} = F(x_1)\gamma(1 - S_1) - S_1/\tau_s$$
$$\frac{dS_2}{dt} = F(x_2)\gamma(1 - S_2) - S_2/\tau_s$$

```python
@bp.odeint
def int_s1(s1, t, s2, coh=0.5, mu=20.):
    x1 = JE * s1 + JI * s2 + Ib + JAext * mu * (1. + coh/100)
    r1 = (a * x1 - b) / (1. - bm.exp(-d * (a * x1 - b)))
    return - s1 / tau + (1. - s1) * gamma * r1

@bp.odeint
def int_s2(s2, t, s1, coh=0.5, mu=20.):
    x2 = JE * s2 + JI * s1 + Ib + JAext * mu * (1. - coh/100)
    r2 = (a * x2 - b) / (1. - bm.exp(-d * (a * x2 - b)))
    return - s2 / tau + (1. - s2) * gamma * r2
```

Input current to each population

$$x_1 = J_E S_1 + J_I S_2 + I_0 + I_{noise1} + J_{\text{ext}}\,\mu_1$$
$$x_2 = J_E S_2 + J_I S_1 + I_0 + I_{noise2} + J_{\text{ext}}\,\mu_2$$

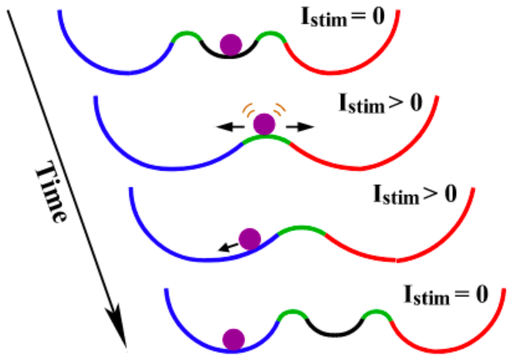
Coherence-dependent inputs

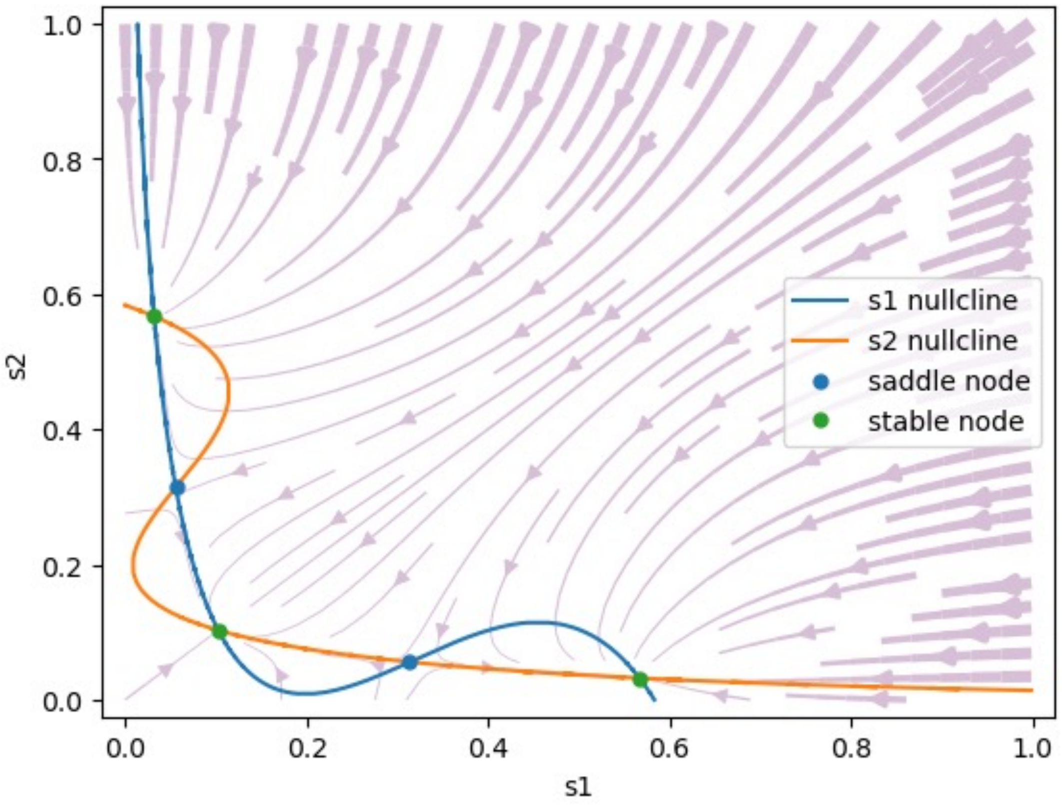
$$\mu_1 = \mu_0\left(1 + c'/100\right)$$
$$\mu_2 = \mu_0\left(1 - c'/100\right)$$

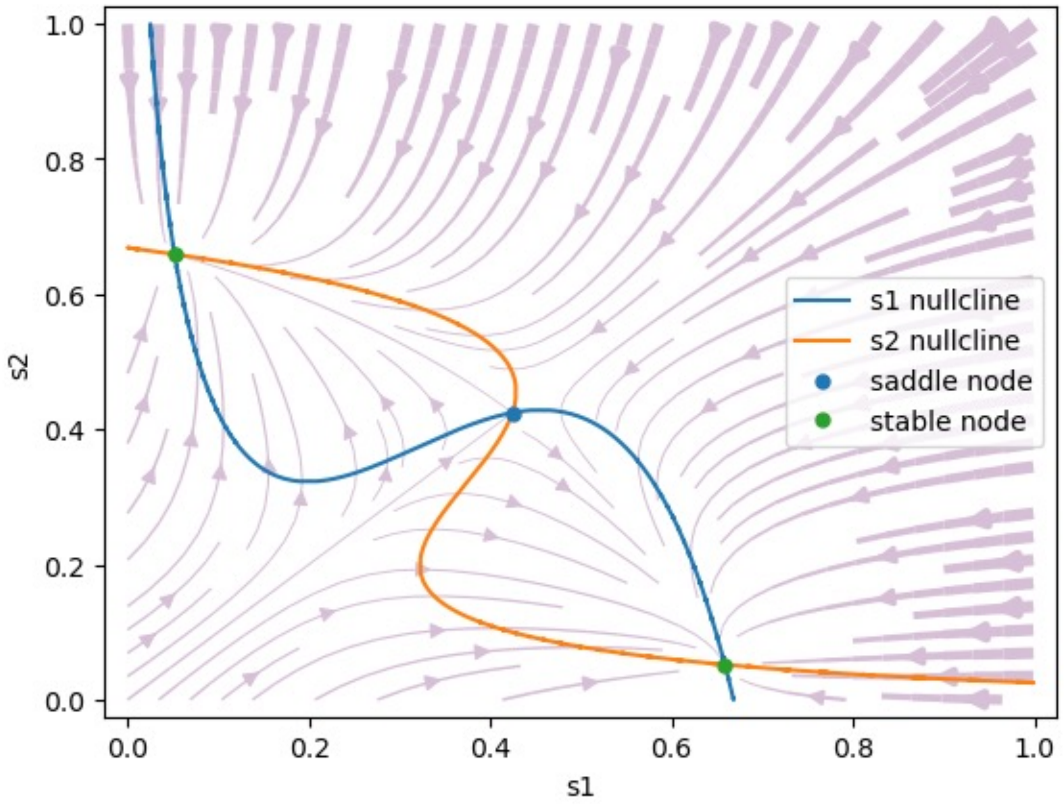
Firing rates $\quad r_i = F(x_i) = \dfrac{ax_i - b}{1 - \exp(-d(ax_i - b))}$

$\gamma, a, b, d, J_E, J_I, J_{\text{ext}}, I_0, \mu_0, \tau_{\text{AMPA}}, \sigma_{\text{noise}}$ are fixed parameters.

Without / with input







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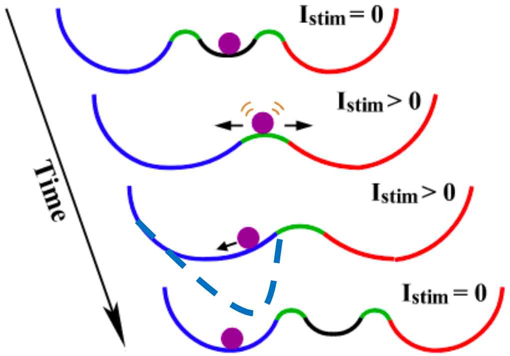
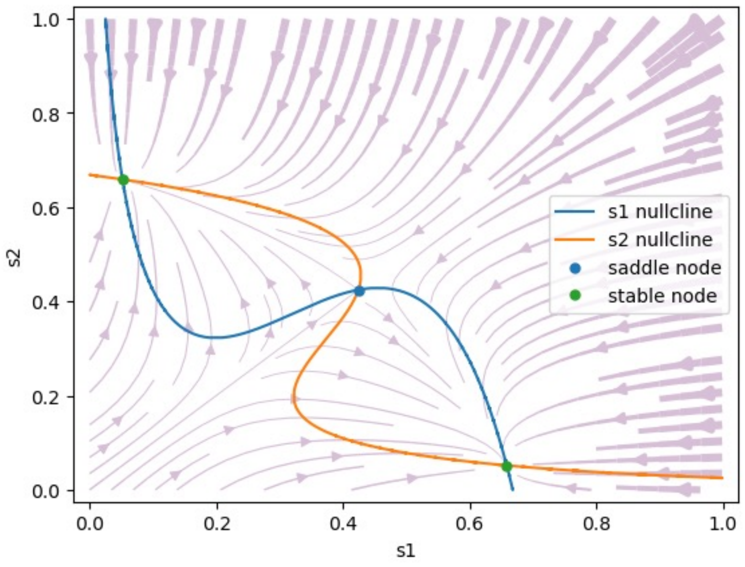
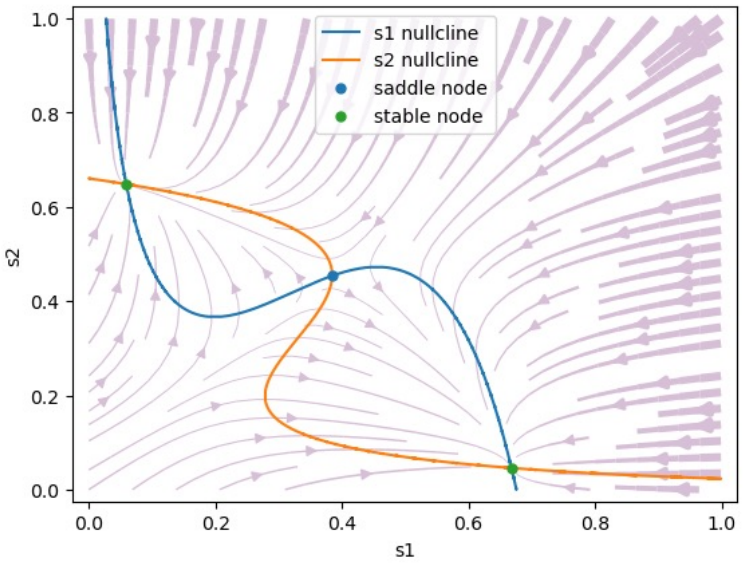
Coherence ⬆️



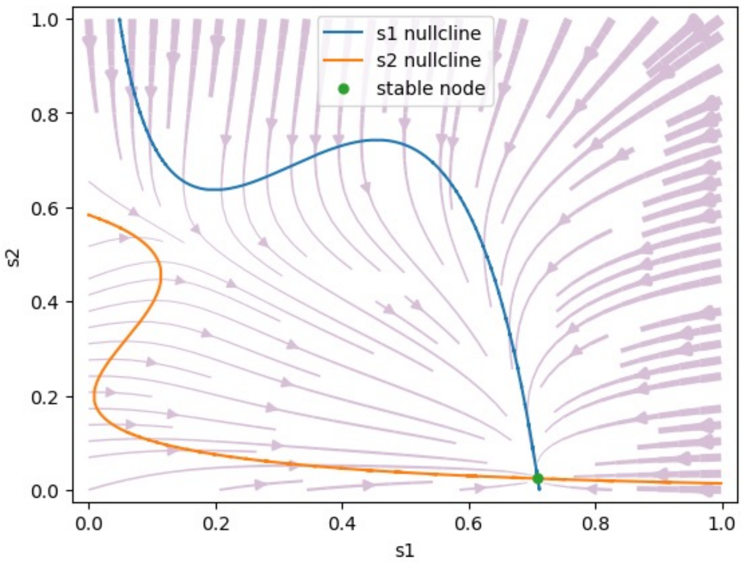
0%



14%

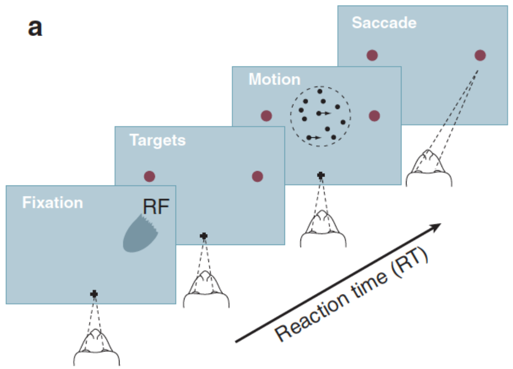


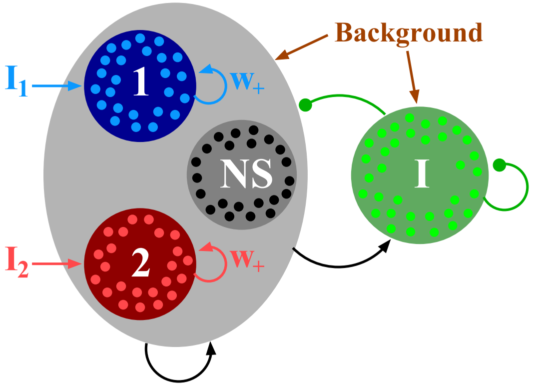
100%

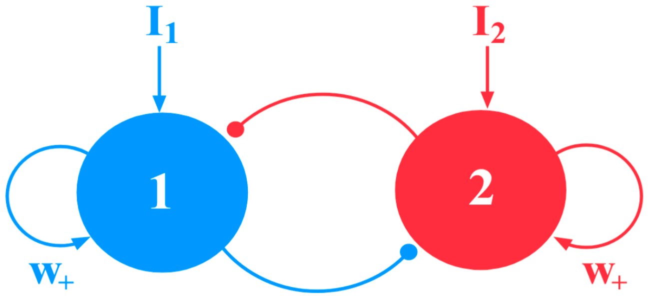


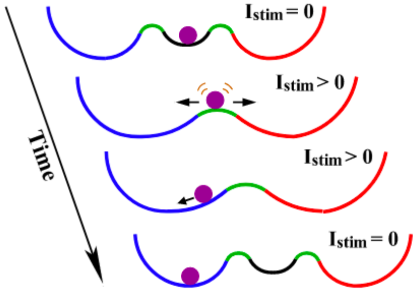
Take Home Message

Slow NMDA → ramping









Computational Neuroscience