To do or not to do? The neural circuit dynamics of decision making and action control

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How do we make a decision?

By julie3jax


AREA POTTERIES
SOUTH
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POTTERY HIGHWAY
NC SCENIC BYWAY
BEGIN
6
BEGIN
1
3
TO
NORTH
INTERSTATE
73
WEST
INTERSTATE
74
TO
NORTH
220
TO
SOUTH
INTERSTATE
73
EAST
INTERSTATE
74
TO
SOUTH
220

Theory of decision making

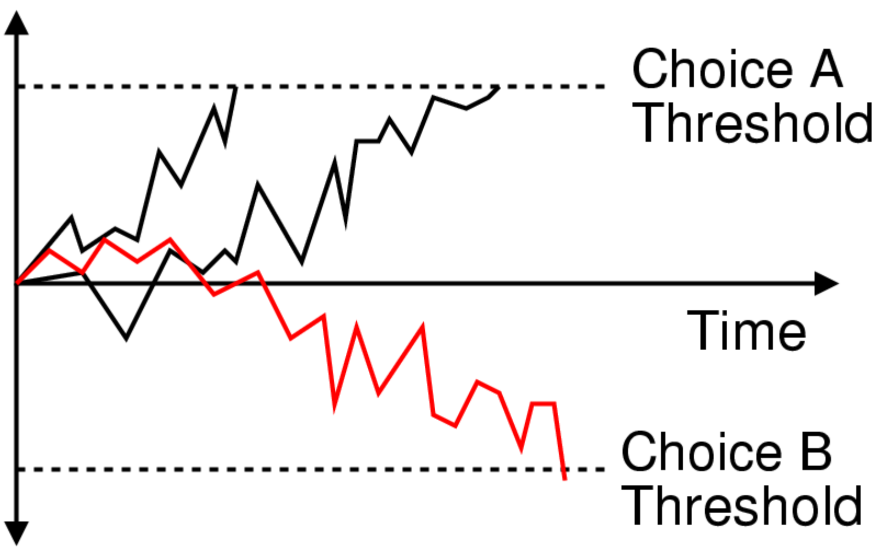
Choosing option A or B after acquiring information through the sensory systems

Drift diffusion model

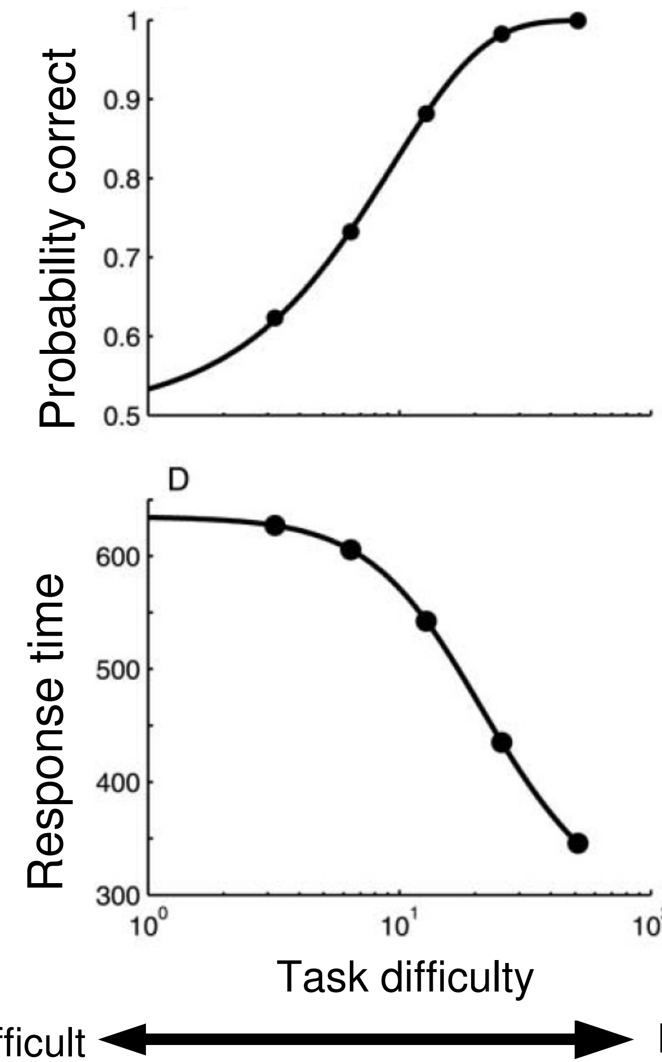
$$\frac{dx}{dt} = I + \delta$$

Information

Noise

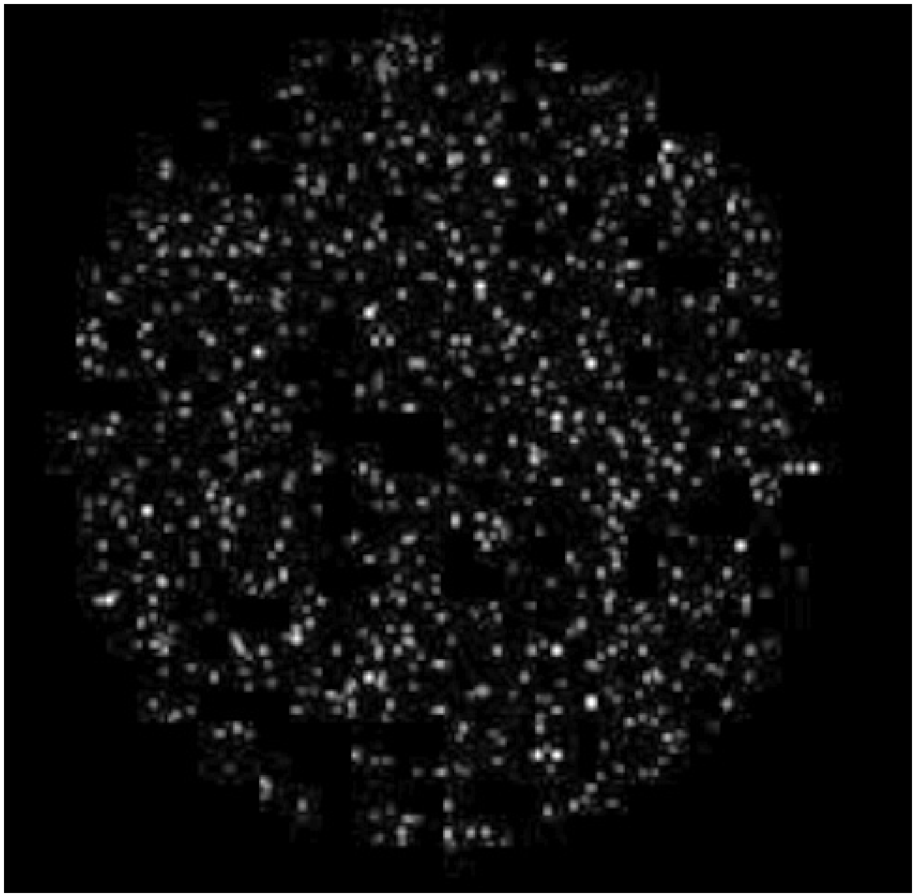


Ratcliff, R. & Smith, P.L. Psychol. Rev. 111, 333–367 (2004).



Gold JI & Shadlen MN. Neuron 36, 299–308 (2002).

Visual Discrimination: The random dot task



Pioneered by Newsome & Shadlen

Task difficulty: coherence level

Percentage of light dots moving coherently in the same direction

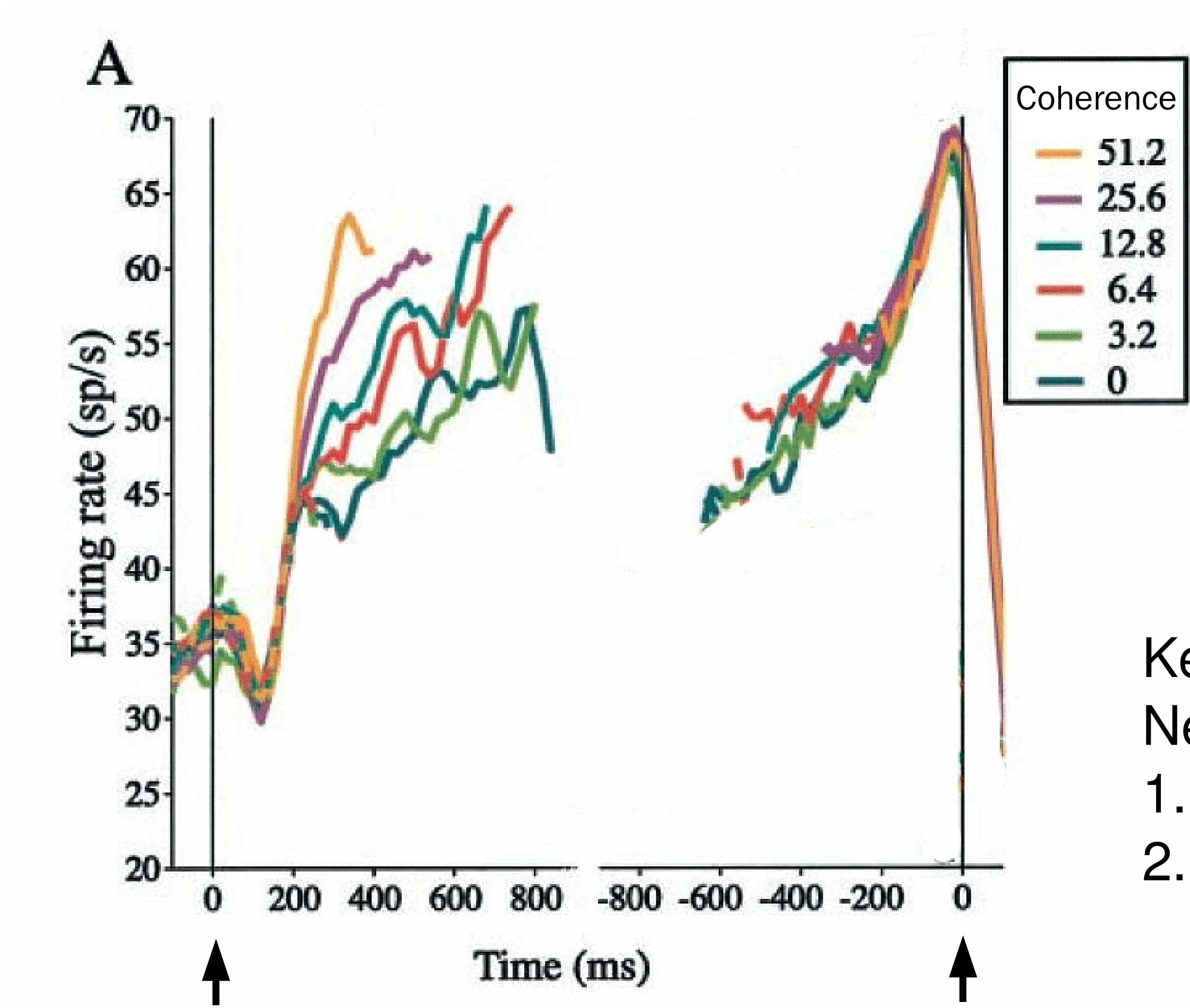
Behavioral measurements

Response time
Performance

Neuronal measurements

Neural activity (firing rate) in parietal cortex

Neural activity in lateral Intraparietal (LIP) Area



Stimulus onset

Decision

Indicated by a saccade
(=rapid eye movement)

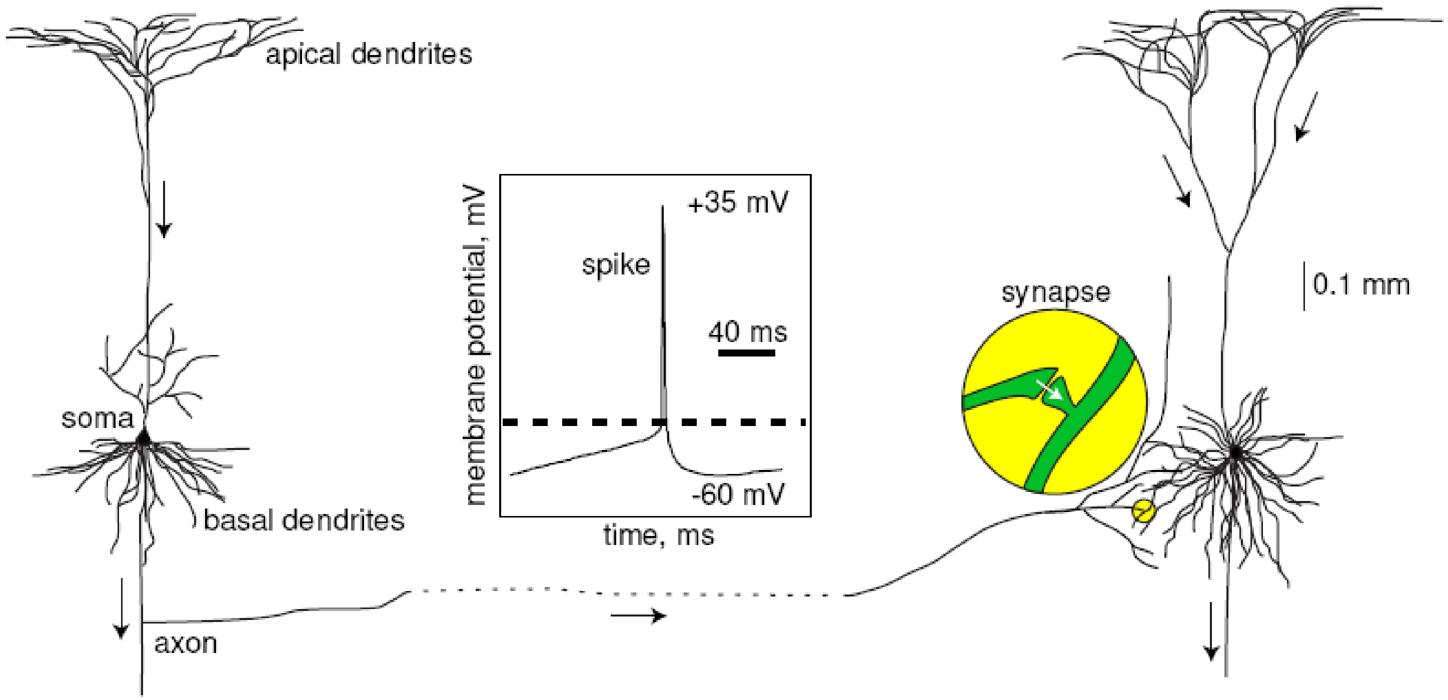
Roitman JD & Shadlen MN, *J. Neurosci.* **22** 9475 (2002)

Neurons in LIP accumulate the visual information

Key questions:
Neural mechanisms of
1. ramping activity
2. threshold crossing detection

Some neural dynamics basics

Neurons, spikes and synapses



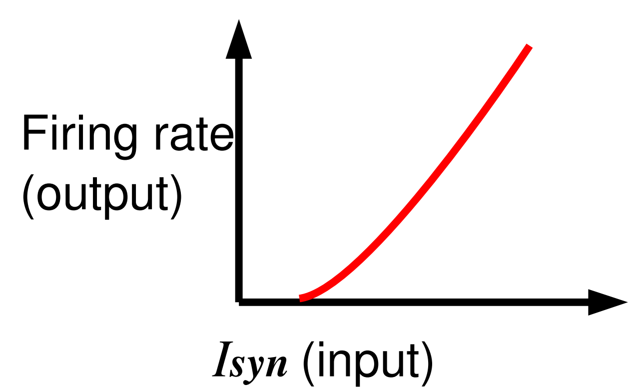
E. M. Izhikevich, Dynamical systems in Nuroscience, MIT press 2007

The leaky integrate and fire model

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

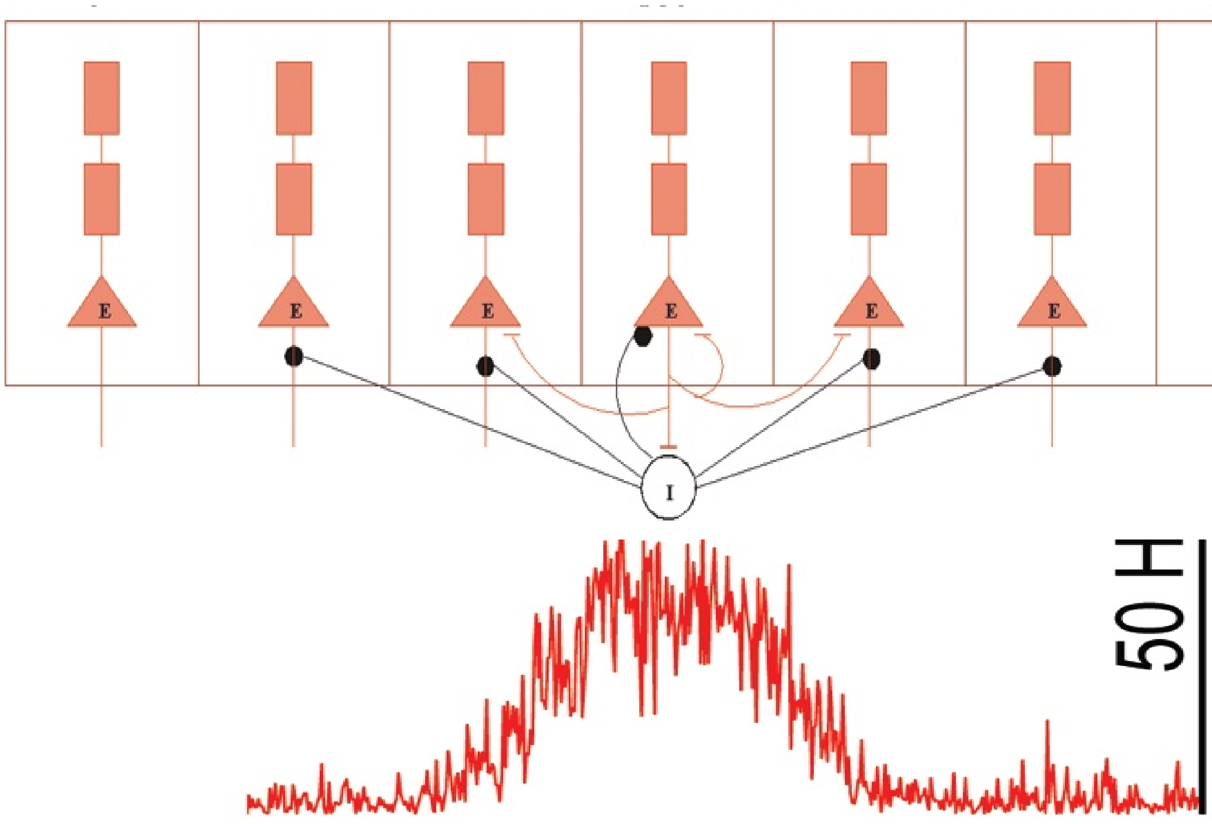
Leaky current

Synaptic input: excitatory or inhibitory



How can a neural circuit integrate input?

A canonical micro-circuit of cortex

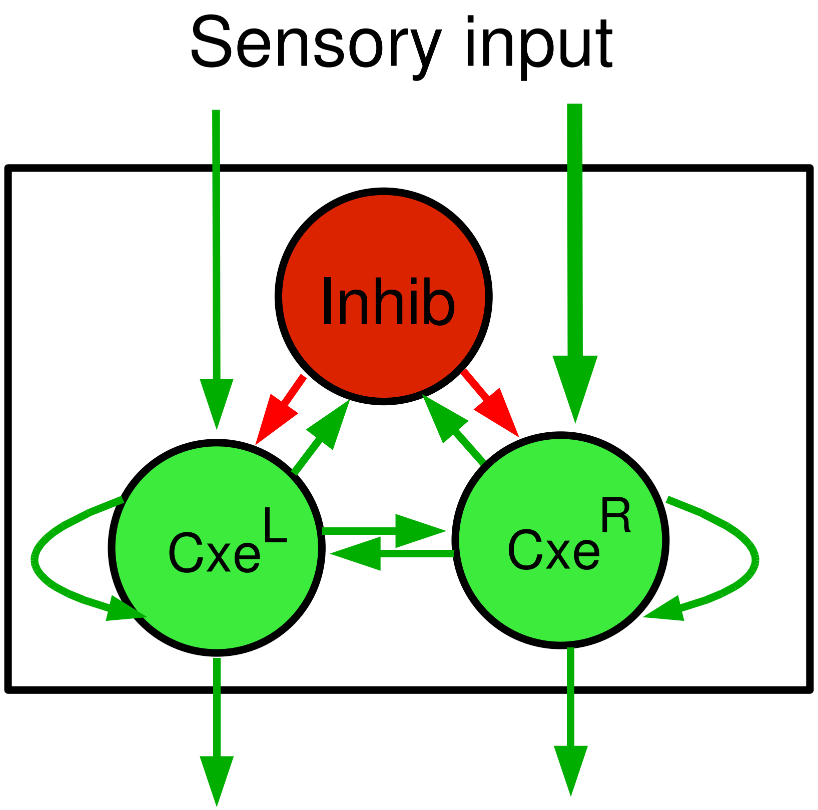


Constantinidis C, Wang X-J (2004) A neural circuit basis for spatial working memory. Neuroscientist 10, 553-565

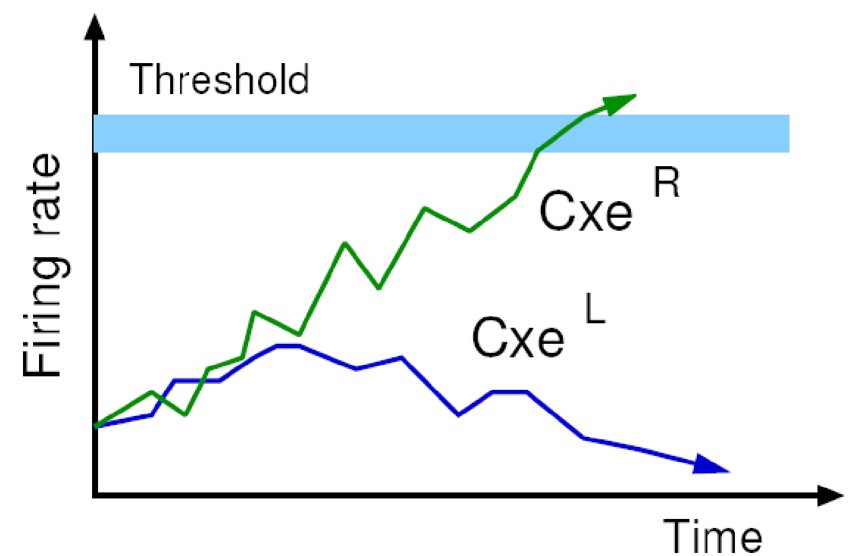
Local excitation and global inhibition

LIP model – Attractor neural network

Wang XJ. *Neuron* **36** 955 (2002)

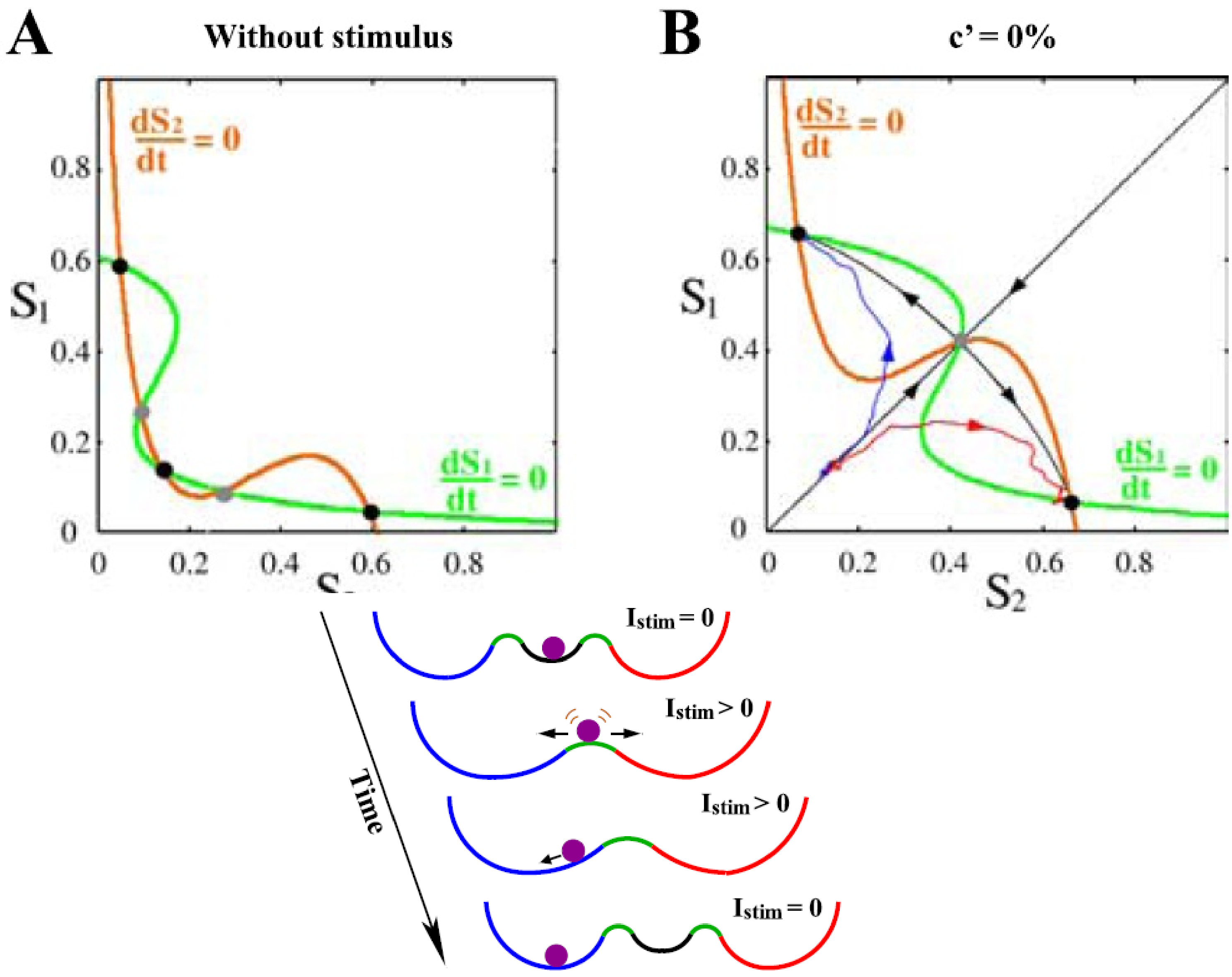


The model can reproduce the ramping neural activity



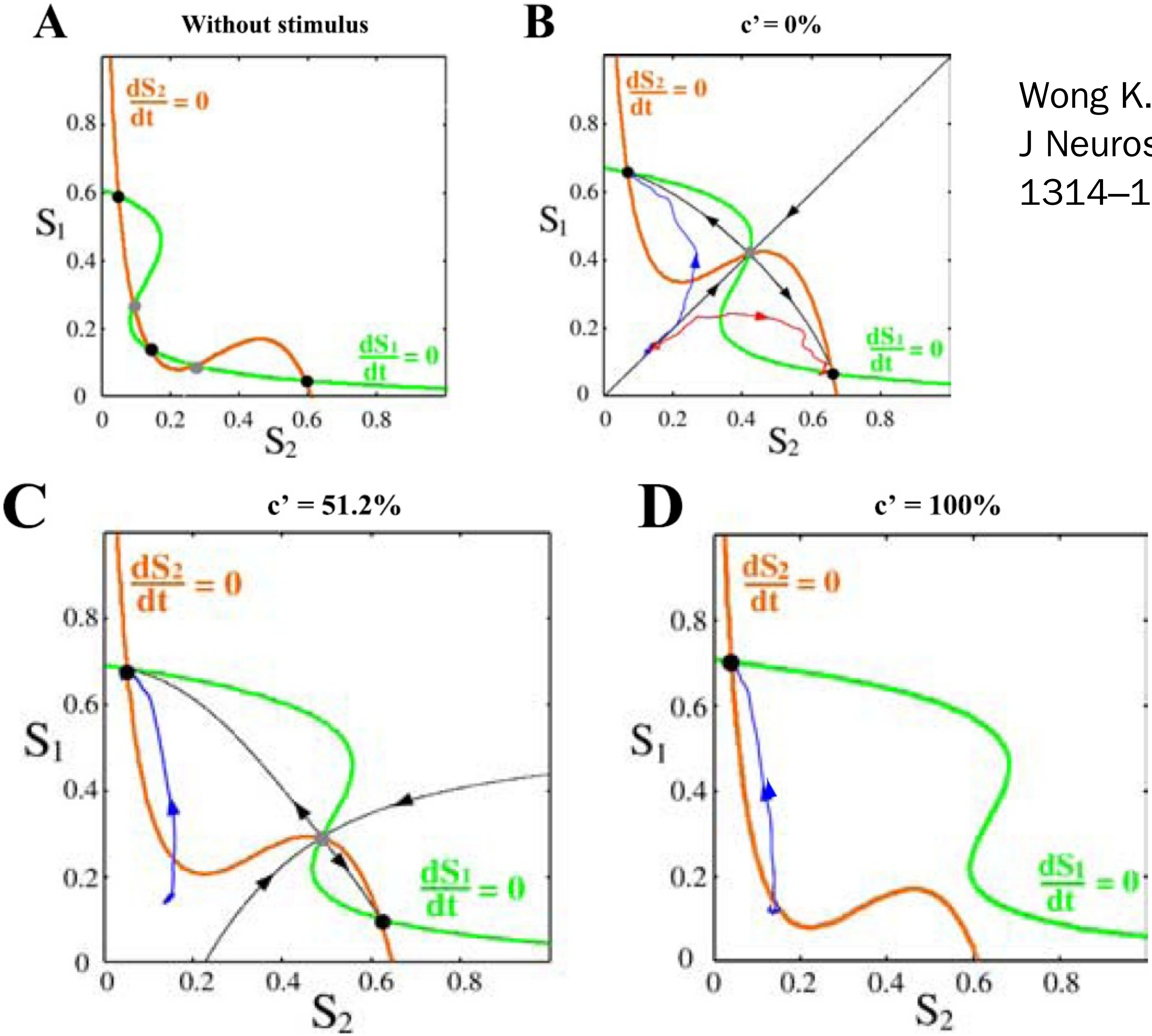
Key question: What is the neural mechanism for detecting the threshold crossing?

The dynamics of the attractor neural network



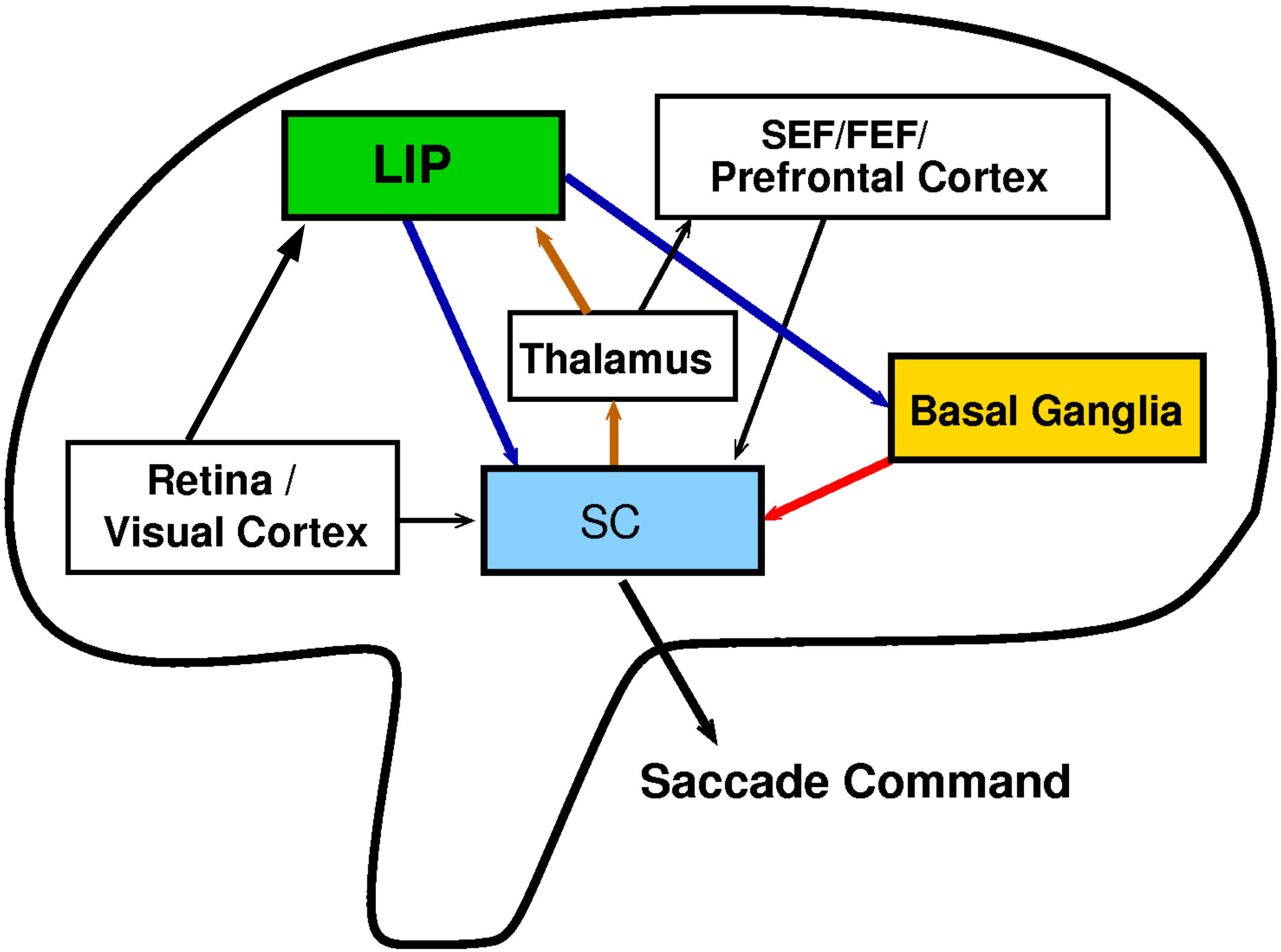
Wong K.-F. & Wang X.-J. J Neurosci 26, 1314–1328 (2006).

The dynamics of the attractor neural network



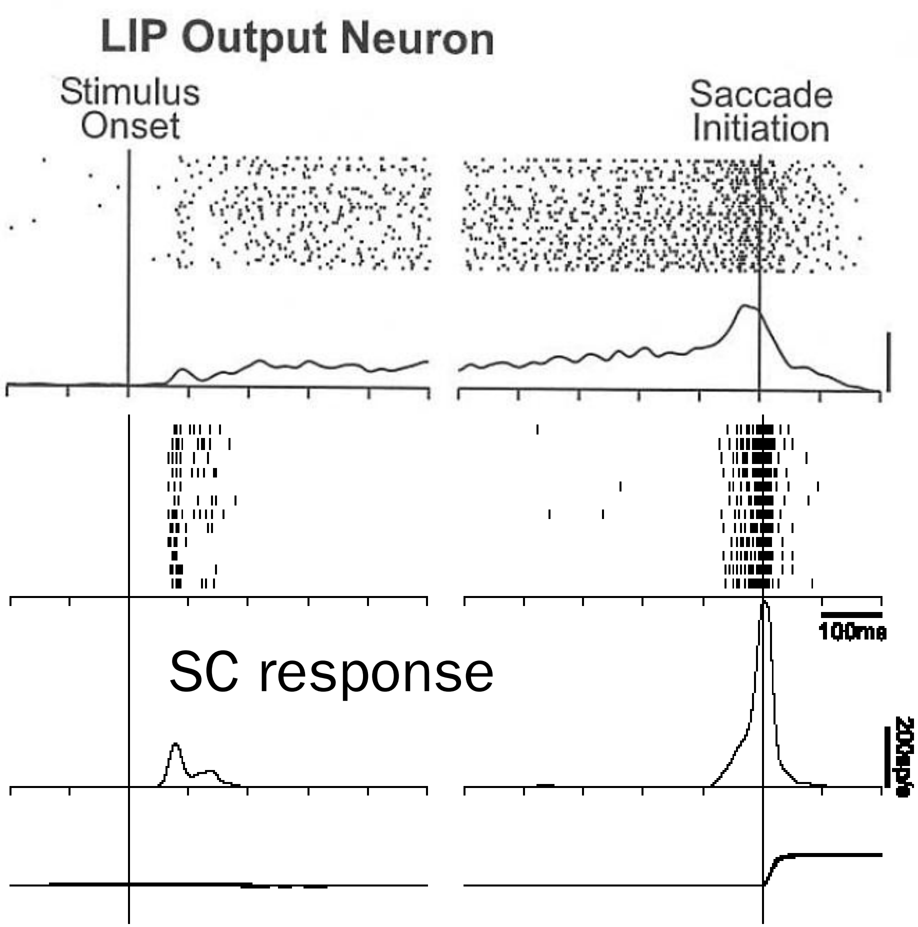
Wong K.-F. & Wang X.-J.
J Neurosci 26,
1314–1328 (2006).

Networks of Saccadic eye movement control



Our model focuses on two pathways: LIP->SC and LIP-> Basal Ganglia->SC

Superior Colliculus (SC)



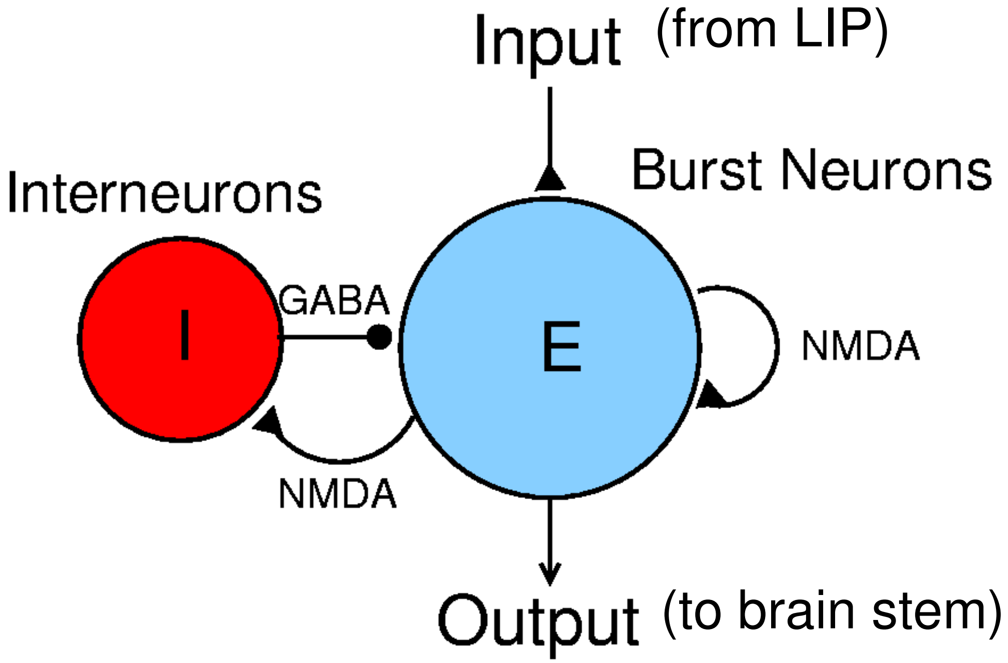
SC features:

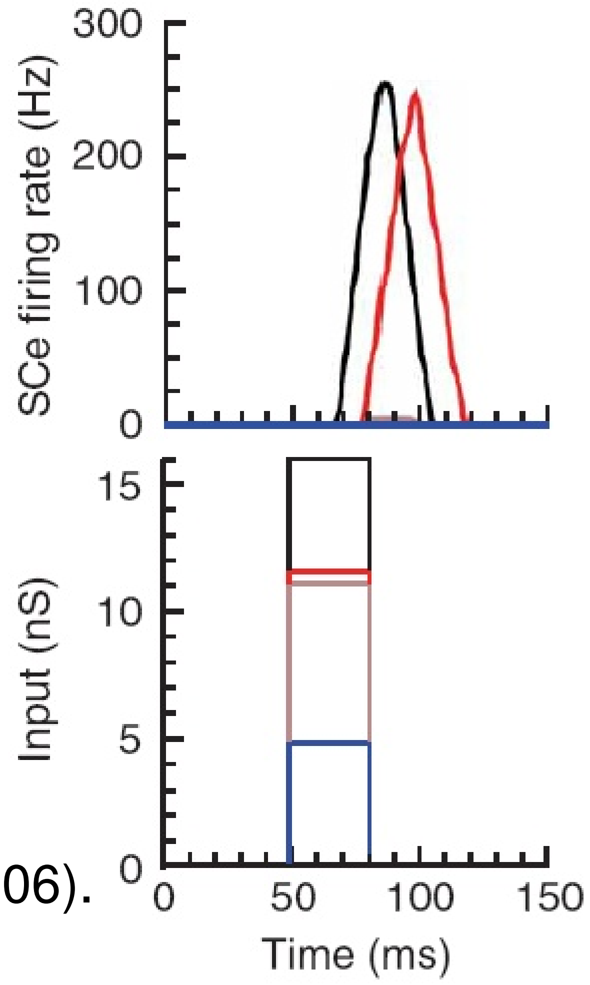
1. Threshold crossing detection.
2. Burst (200-400Hz) generation

Wurtz RH *et al. Vision Res.* **41** 3399 (2001).
Munoz DP *et. al.* Can. J. Physiol. Pharmacol. **78** 934 (2000).

The SC Burst Model: Burst Mechanism

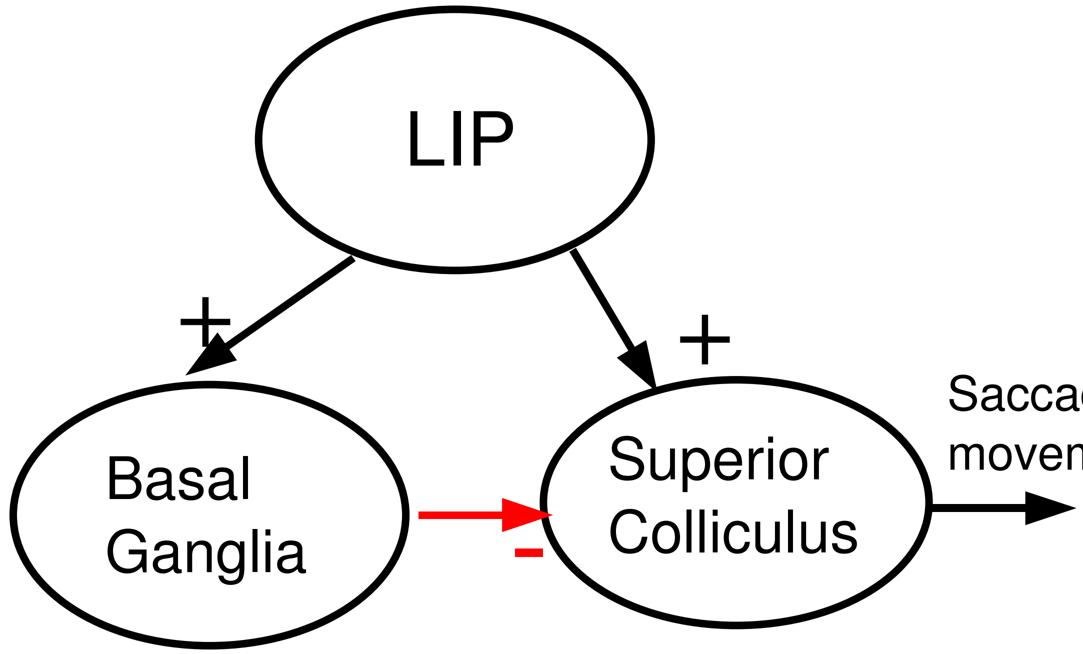
Feedback inhibition shuts down burst neurons





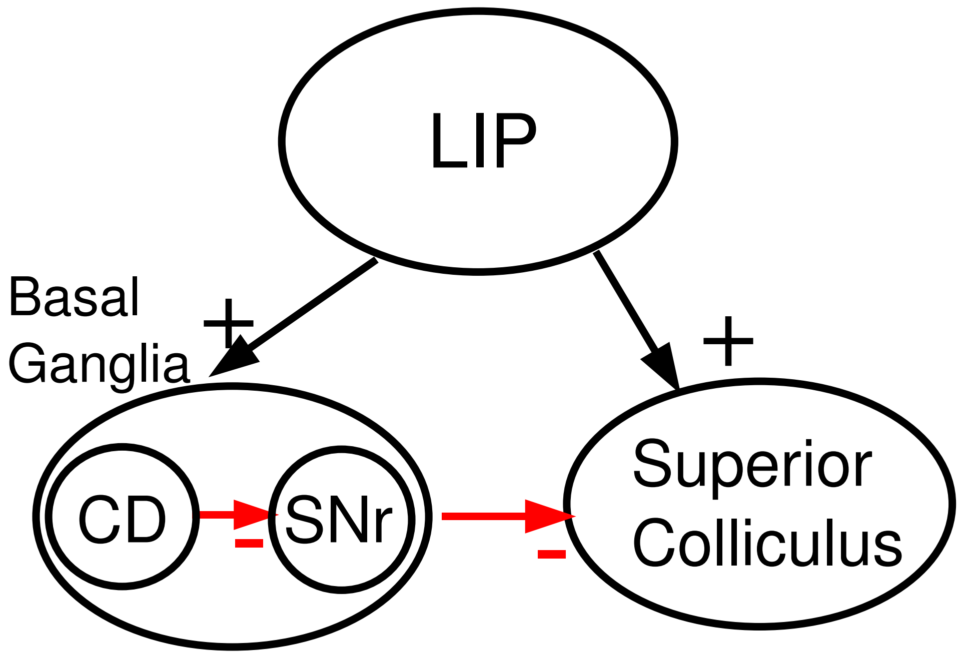
Lo C.-C., Wang X.-J. Nat Neurosci **9**, 956–963 (2006).

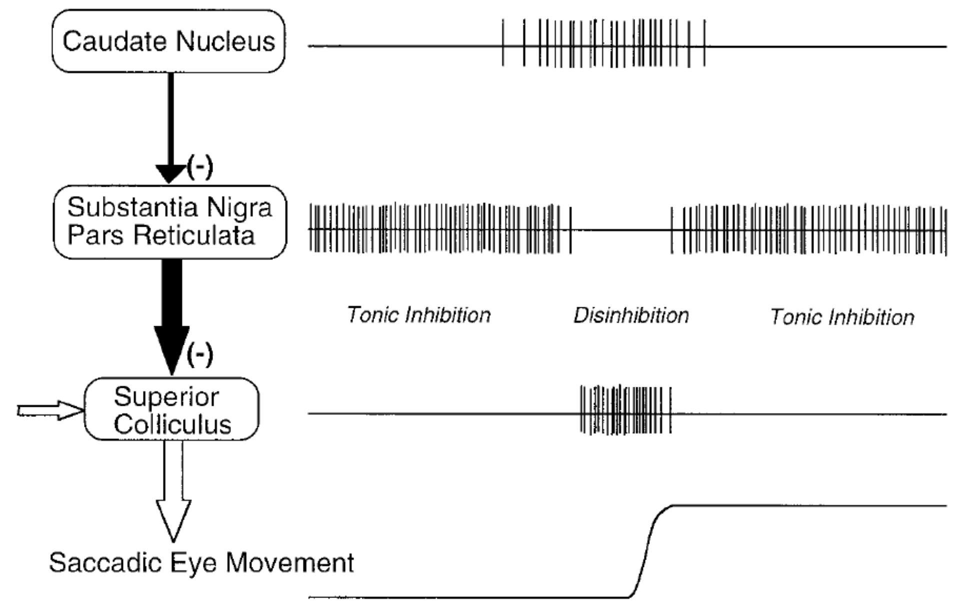
Circuit of saccadic eye movement control



What is the role of basal ganglia in initiating an eye movement?

The full model of decision threshold

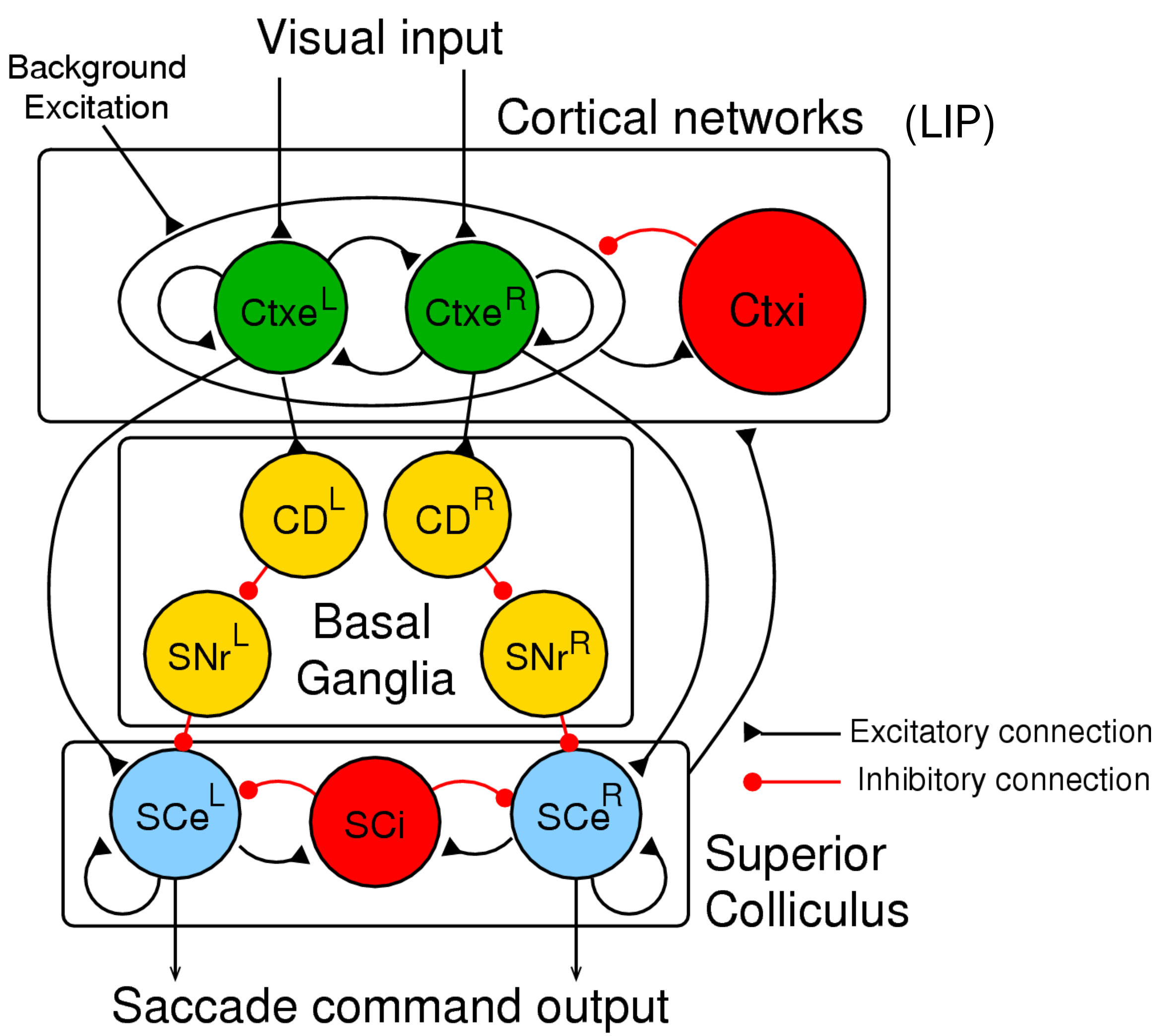


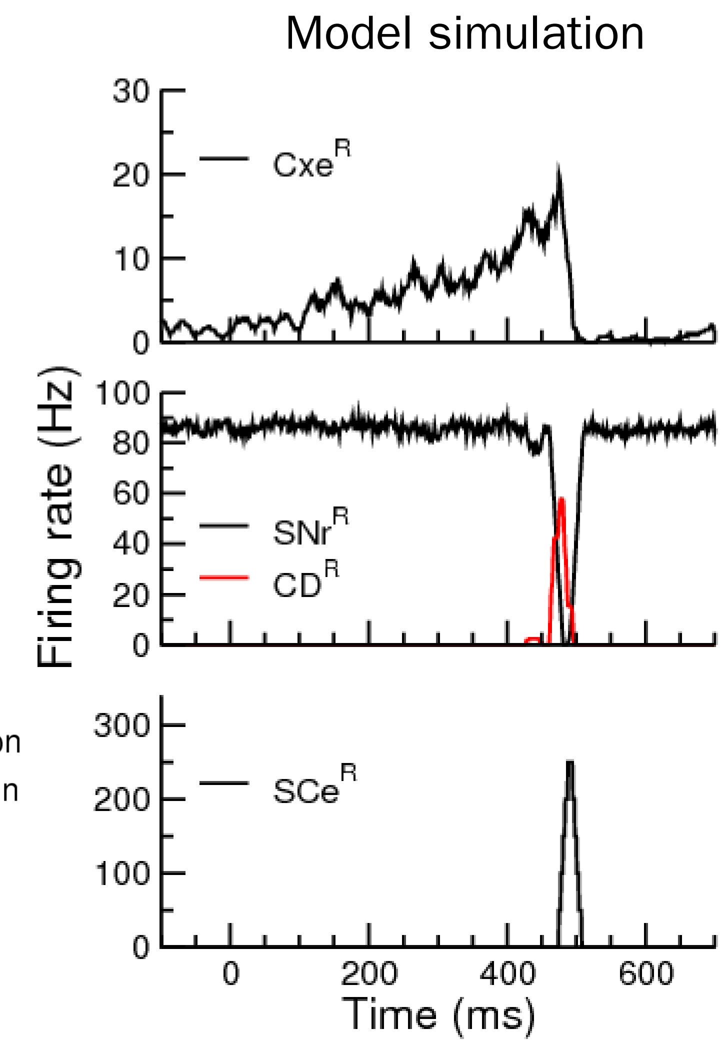


Hikosaka O, Takikawa Y, Kawagoe R. Physiol. Rev. 80 953, 2000

Lo C.-C., Wang X.-J. Nat Neurosci **9**, 956–963 (2006).

The full model of decision threshold

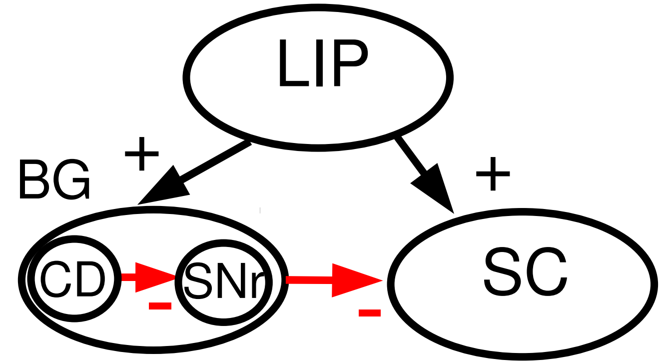


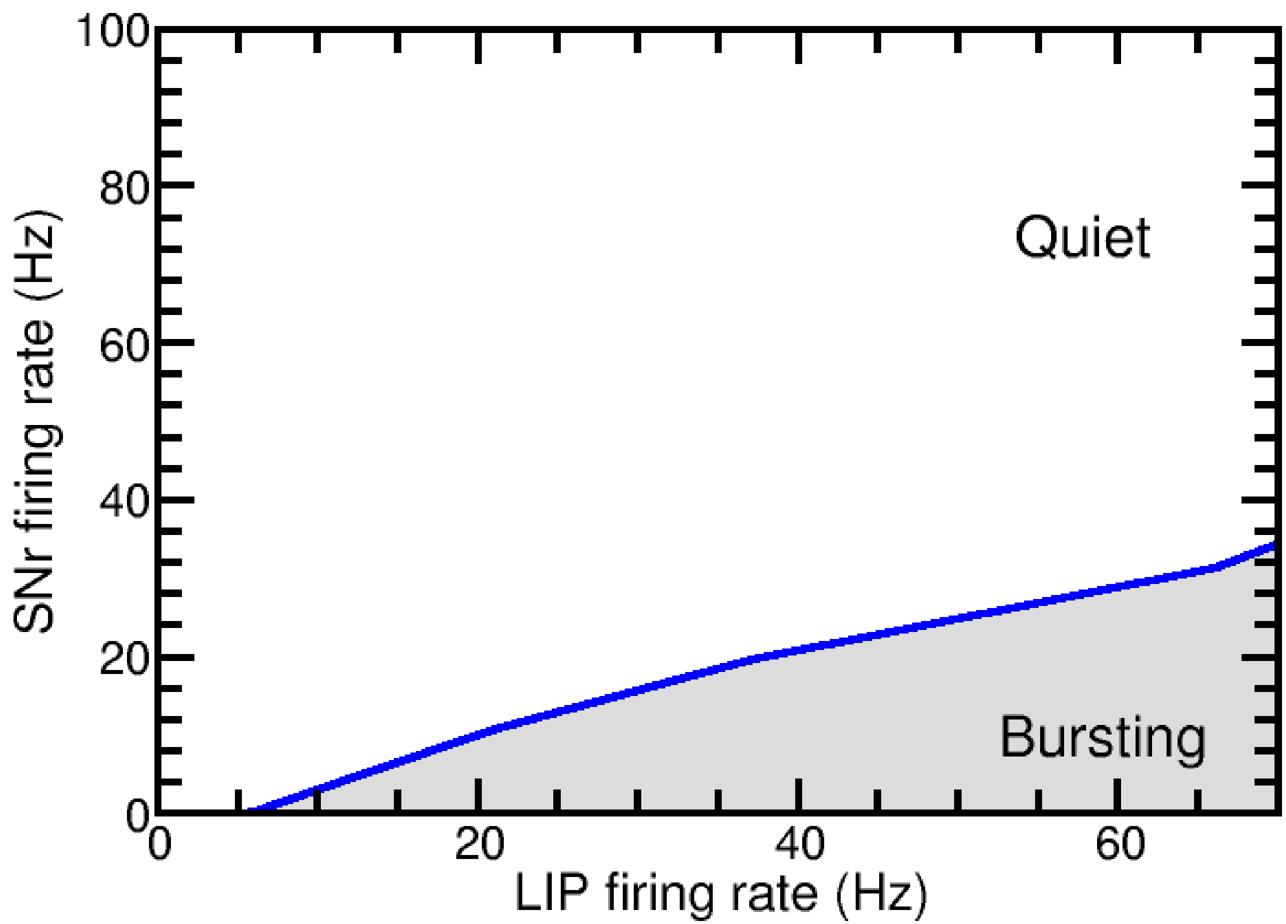


Lo C.-C., Wang X.-J. Nat Neurosci **9**, 956–963 (2006).

Phase plane

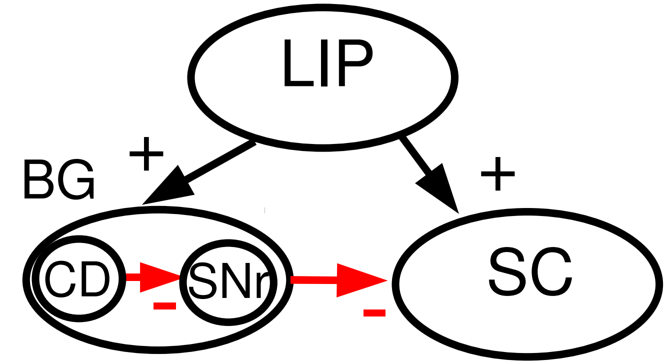
SC has two states: Quiet & Bursting

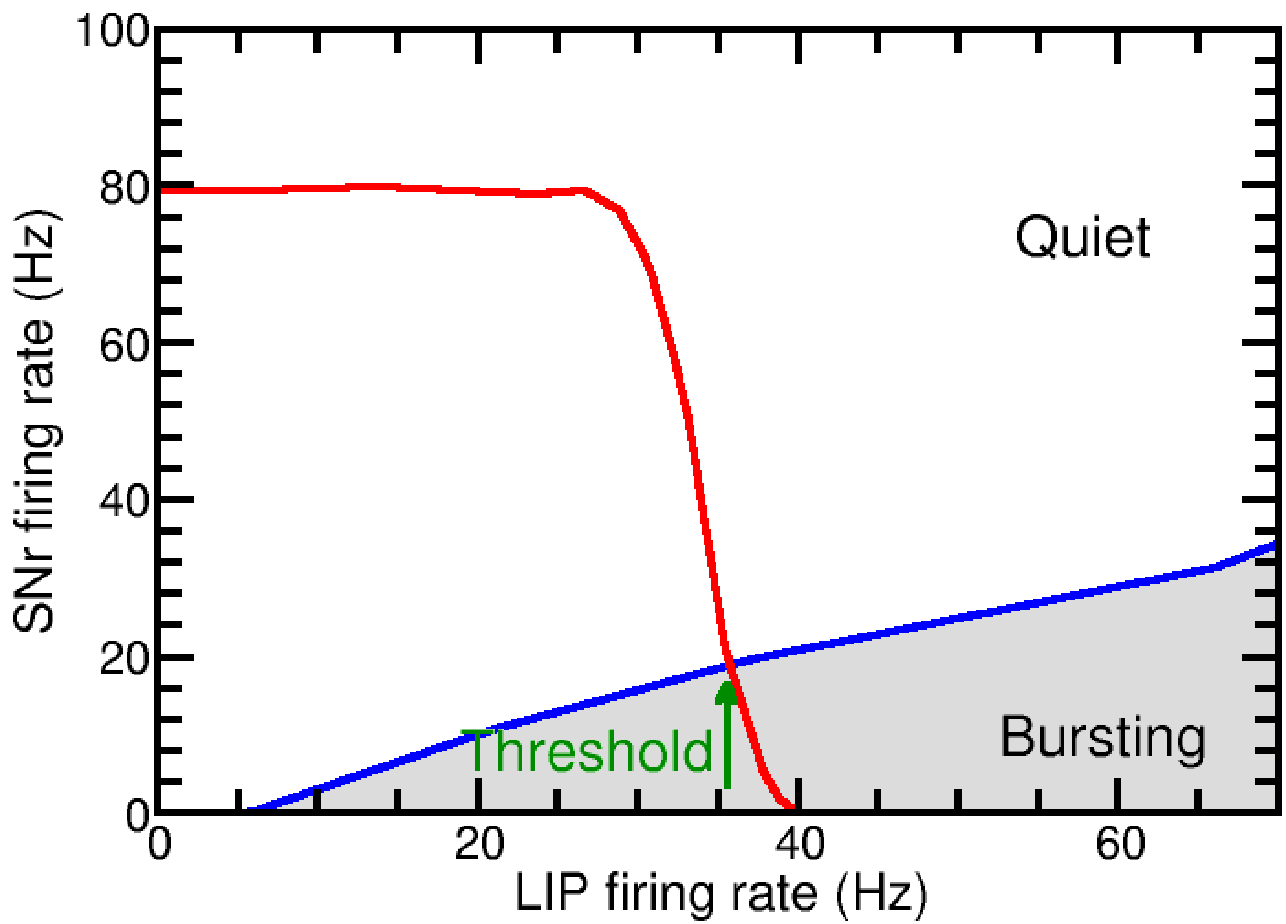




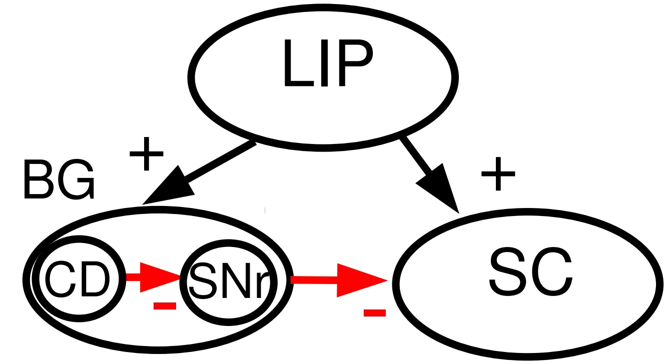
SNr-LIP Trajectory

The threshold is determined by the intersection between the SNr-LIP trajectory (black) and quiet-burst boundary (blue)

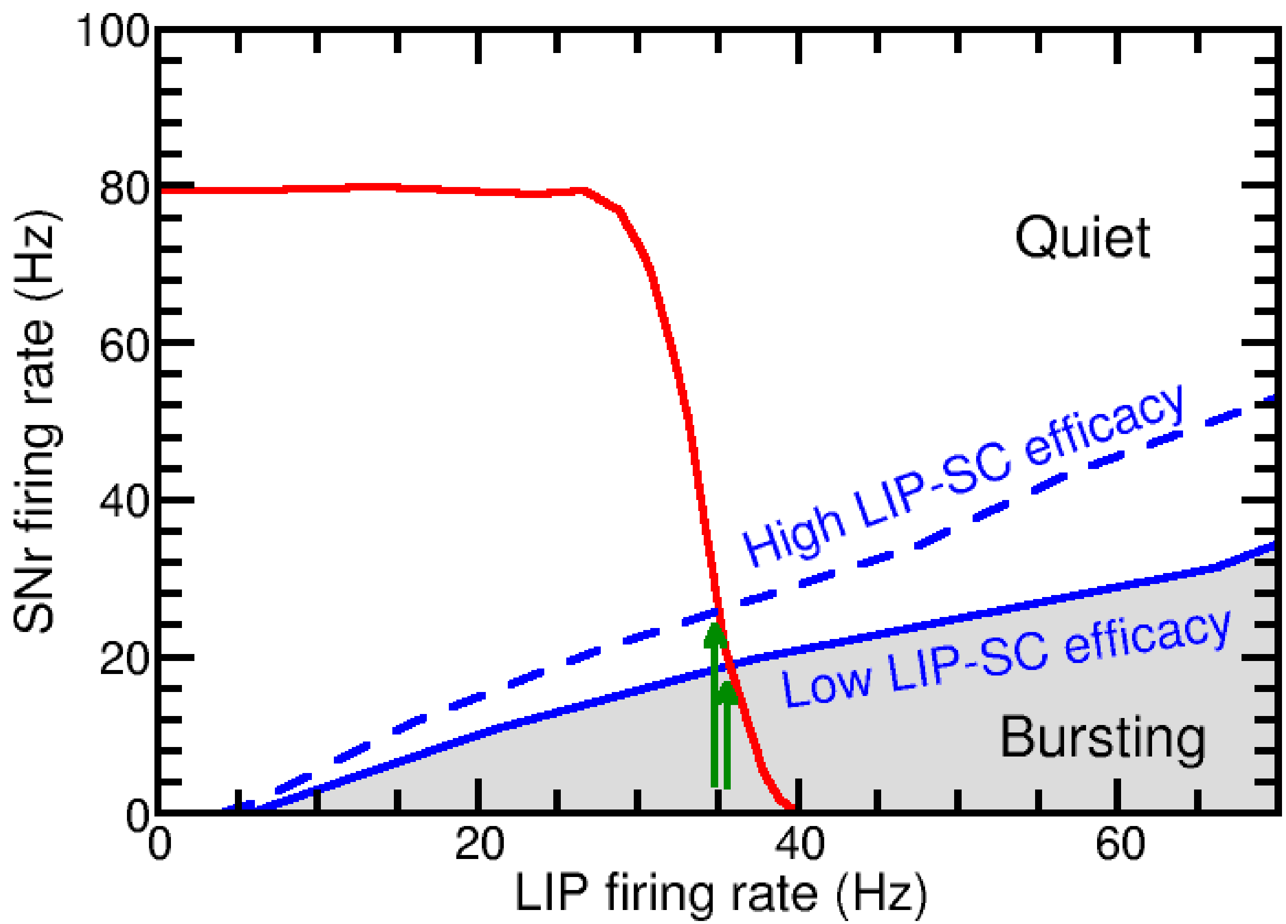




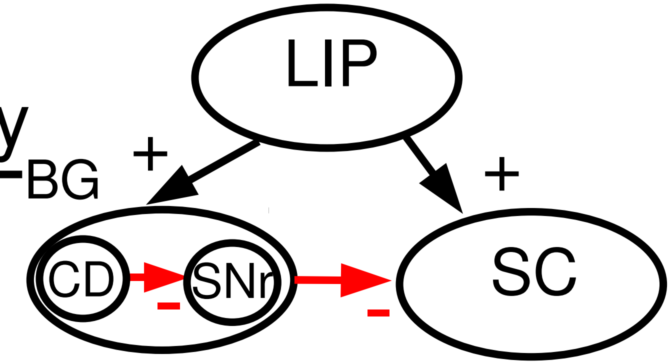
Threshold Variation: LIP->SC Efficacy



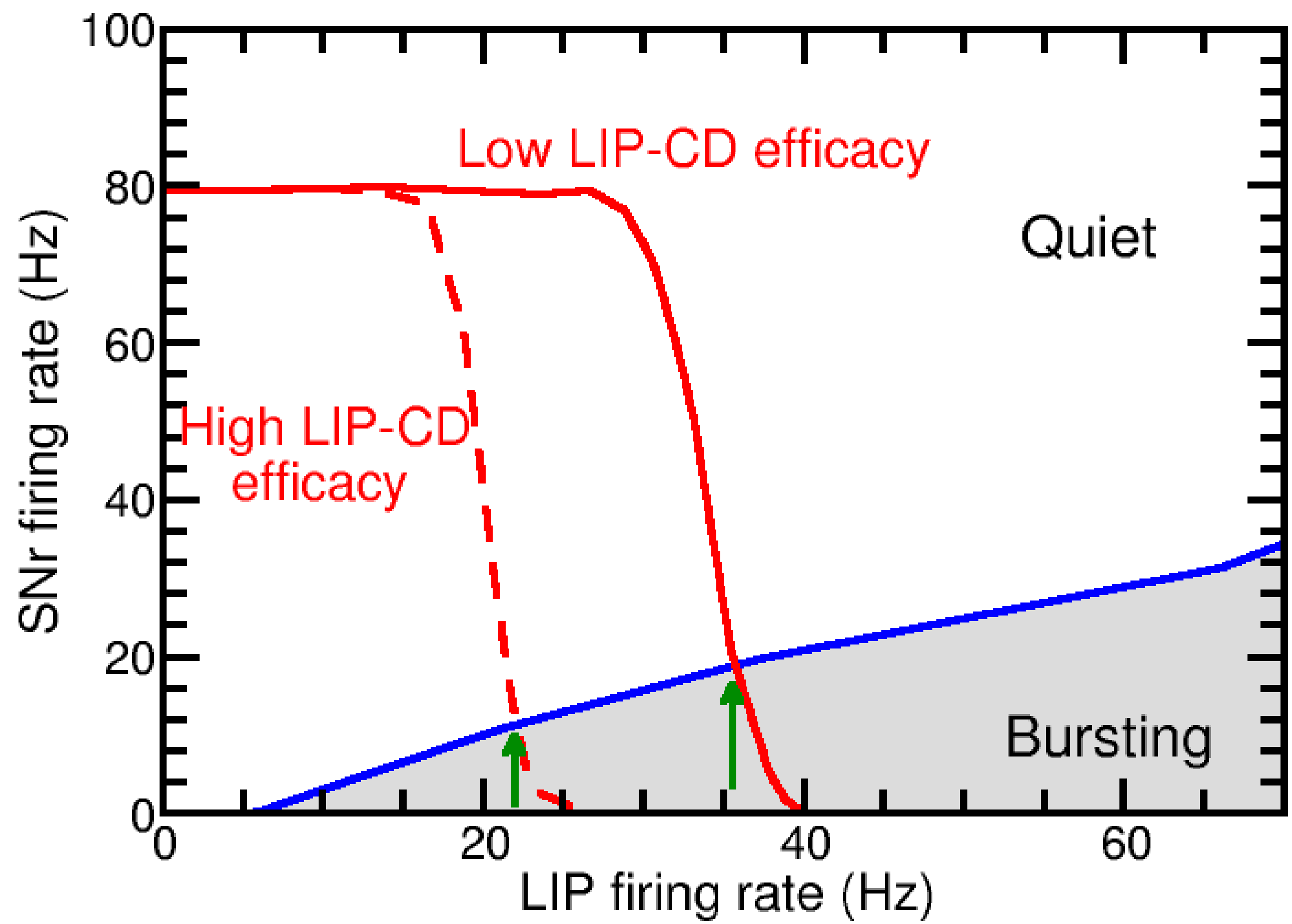
Changing LIP->SC synaptic strength
has a small effect on the threshold



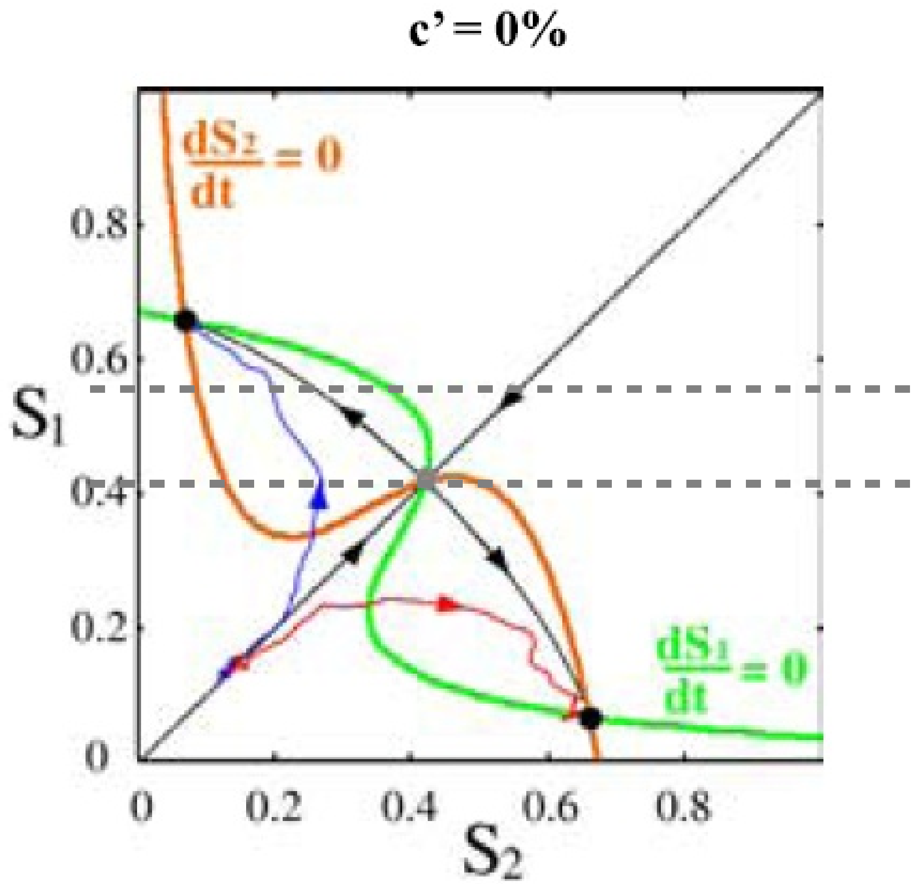
Threshold Variation: LIP->CD Efficacy



Changing LIP->Caudate synaptic strength significantly affects the threshold



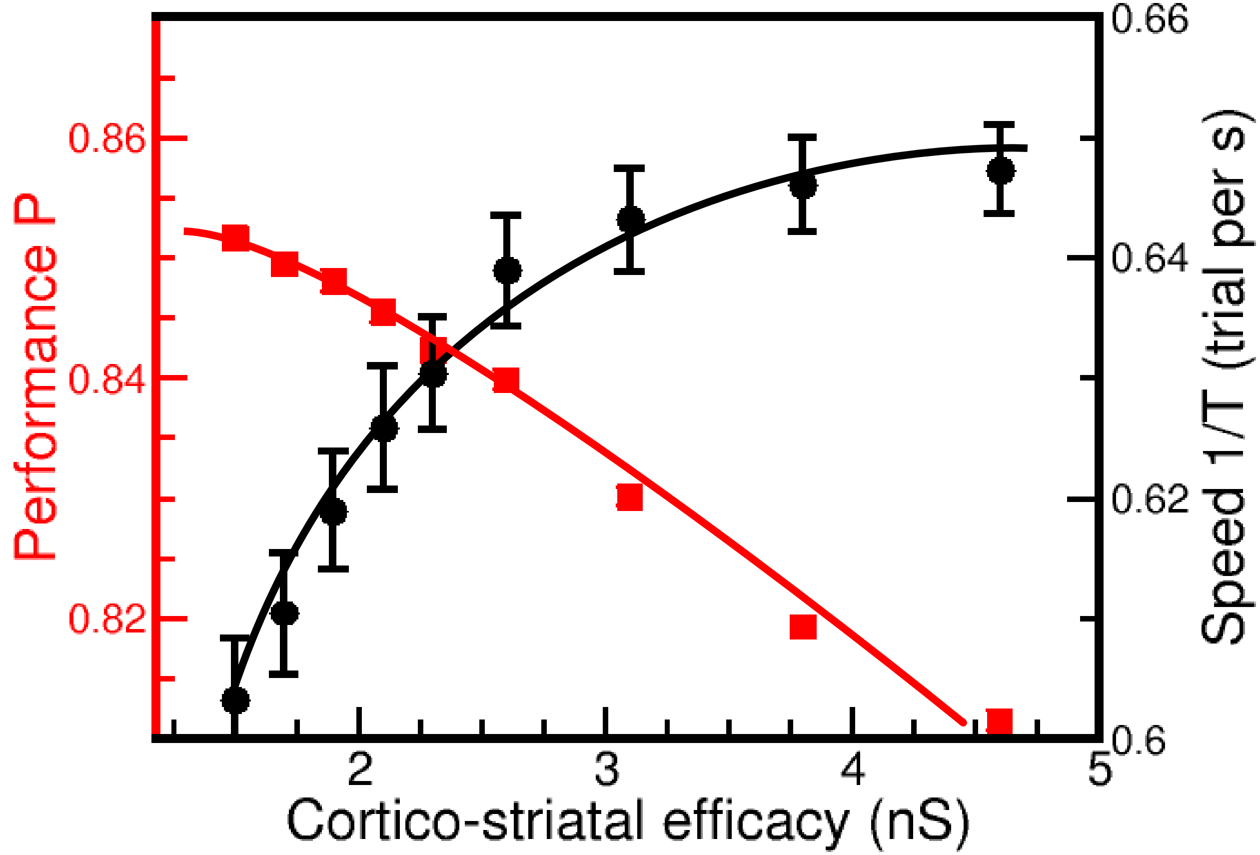
Why is the decision threshold important?



Where to put the threshold for S1?

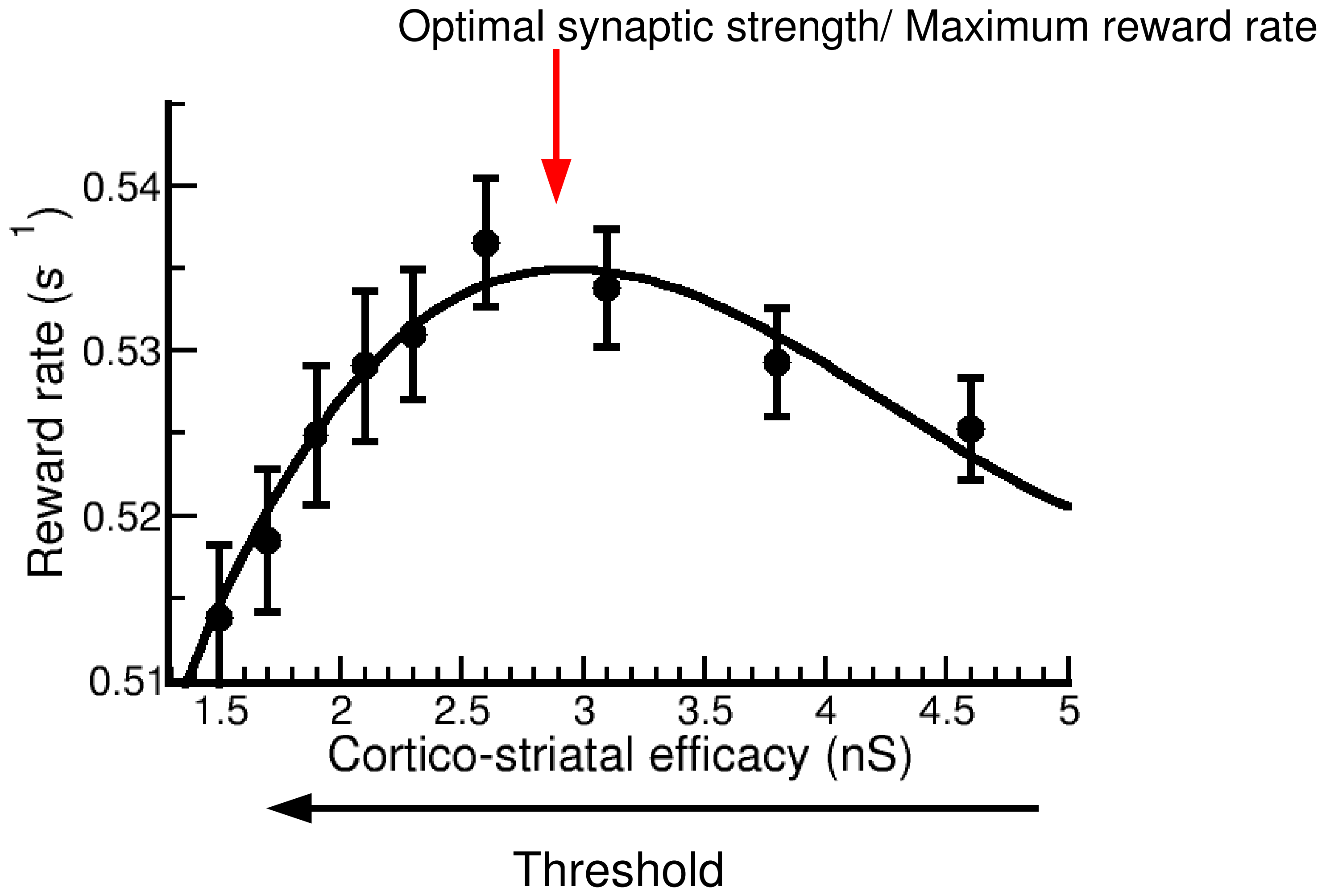
What animal cares: Reward rate

$$R = \frac{P}{T} = \frac{\text{Average performance}}{\text{Average trial time}}$$



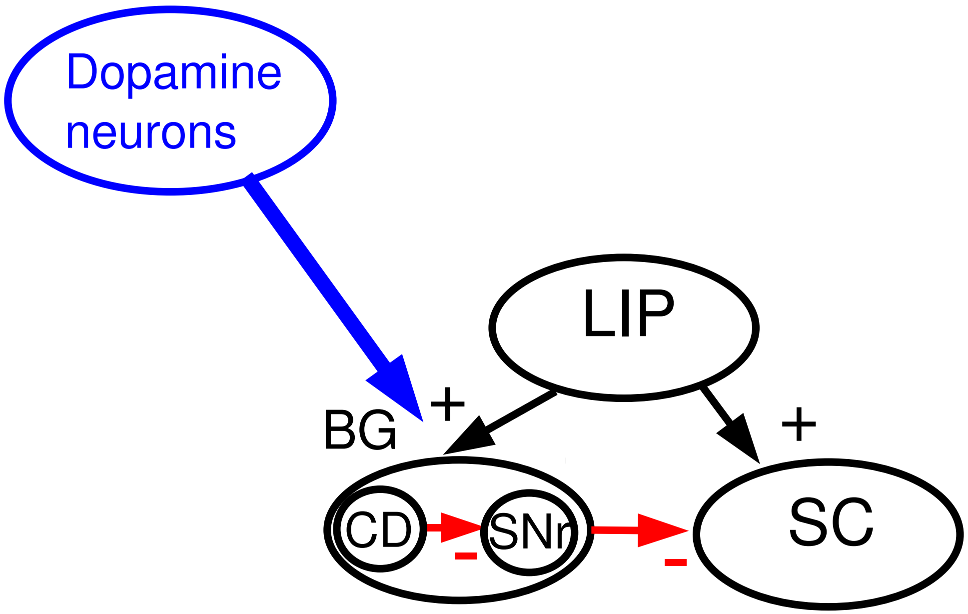
Is there a optimal threshold which yields a maximum reward rate?

Dependence of the reward rate on the threshold



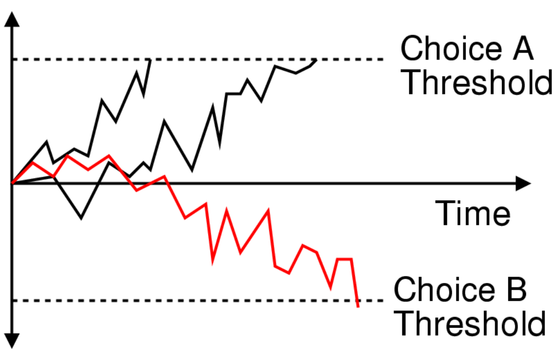
Now, there is a optimal state, but how does the biological system find it?

Hint: dopamine

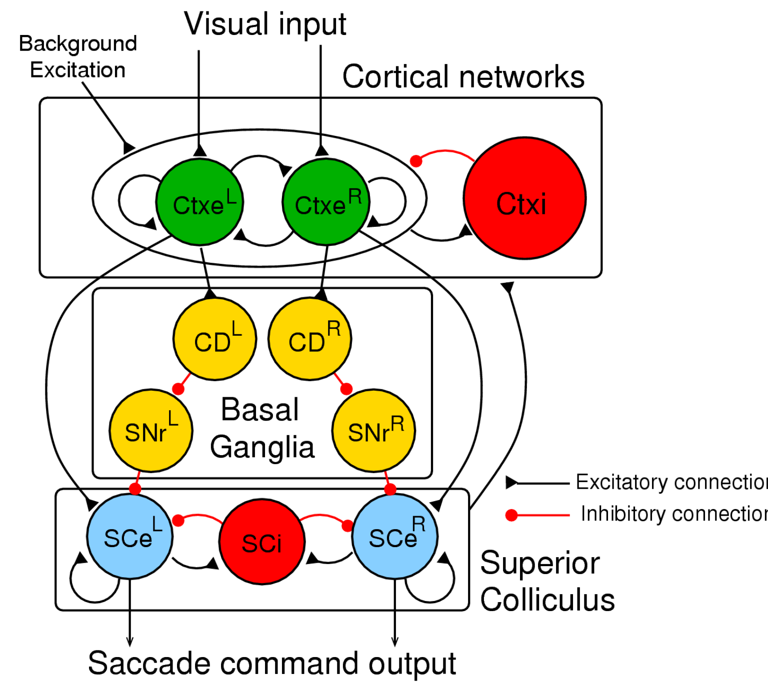


Summary I: Model for decision making

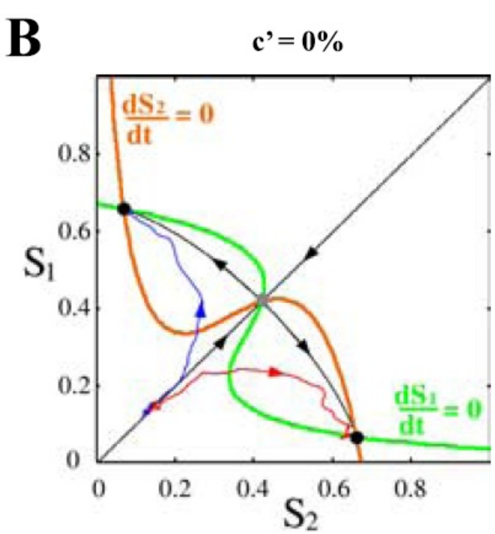
1. Traditional drift diffusion model



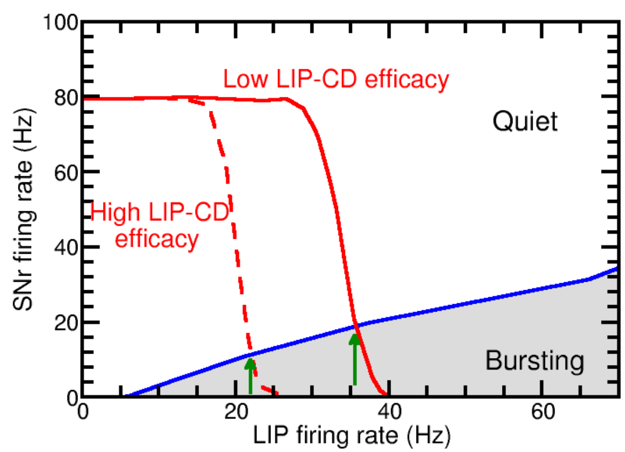
2. Large scale neural circuit model



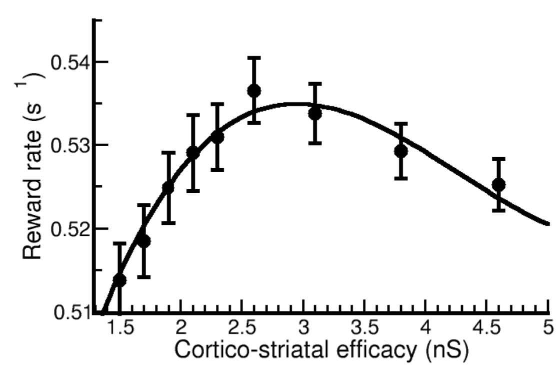
3. Attractor dynamics



4. Threshold determination



5. Decision optimization



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New Course

Neural Dynamics and Modeling I
神經動力學與模型 I

2009 Fall semester, two credits
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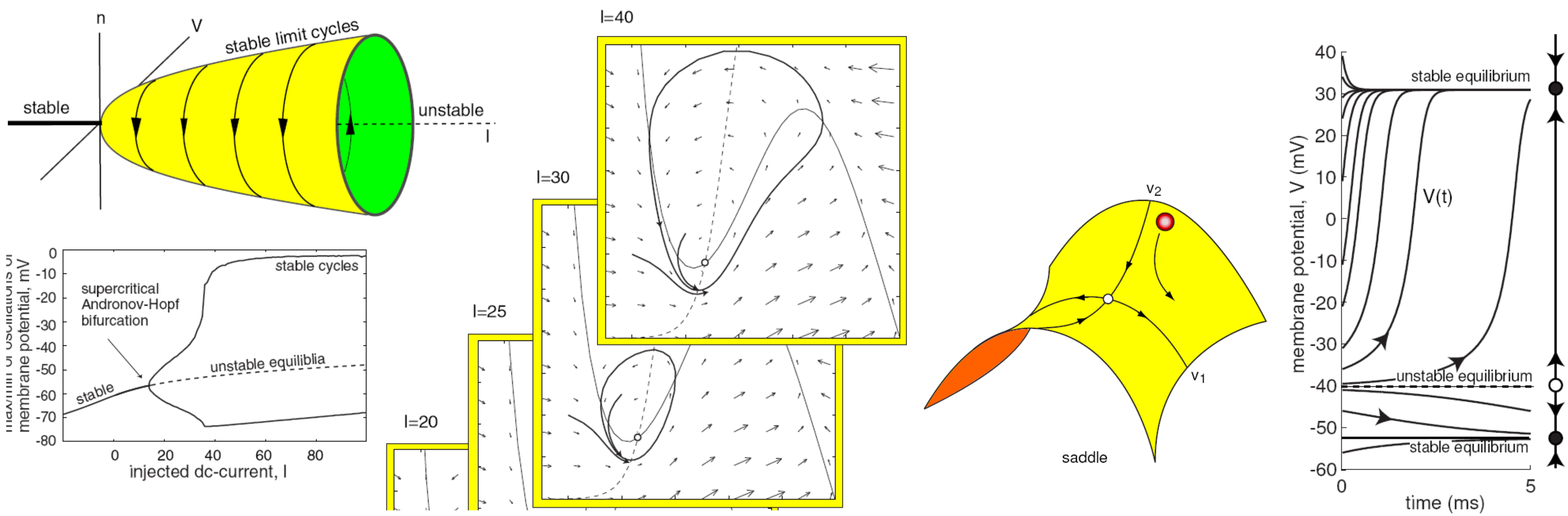
Institute of system neuroscience (系統神經研究所)



E. M. Izhikevich, Dynamical systems in Nuroscience, MIT press 2007

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