Week 12 – Decision models

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Biological Modeling of Neural Networks:

Week 12 – Decision models: Competitive dynamics

Wulfram Gerstner

EPFL, Lausanne, Switzerland

12.1 Review: Population dynamics
- competition

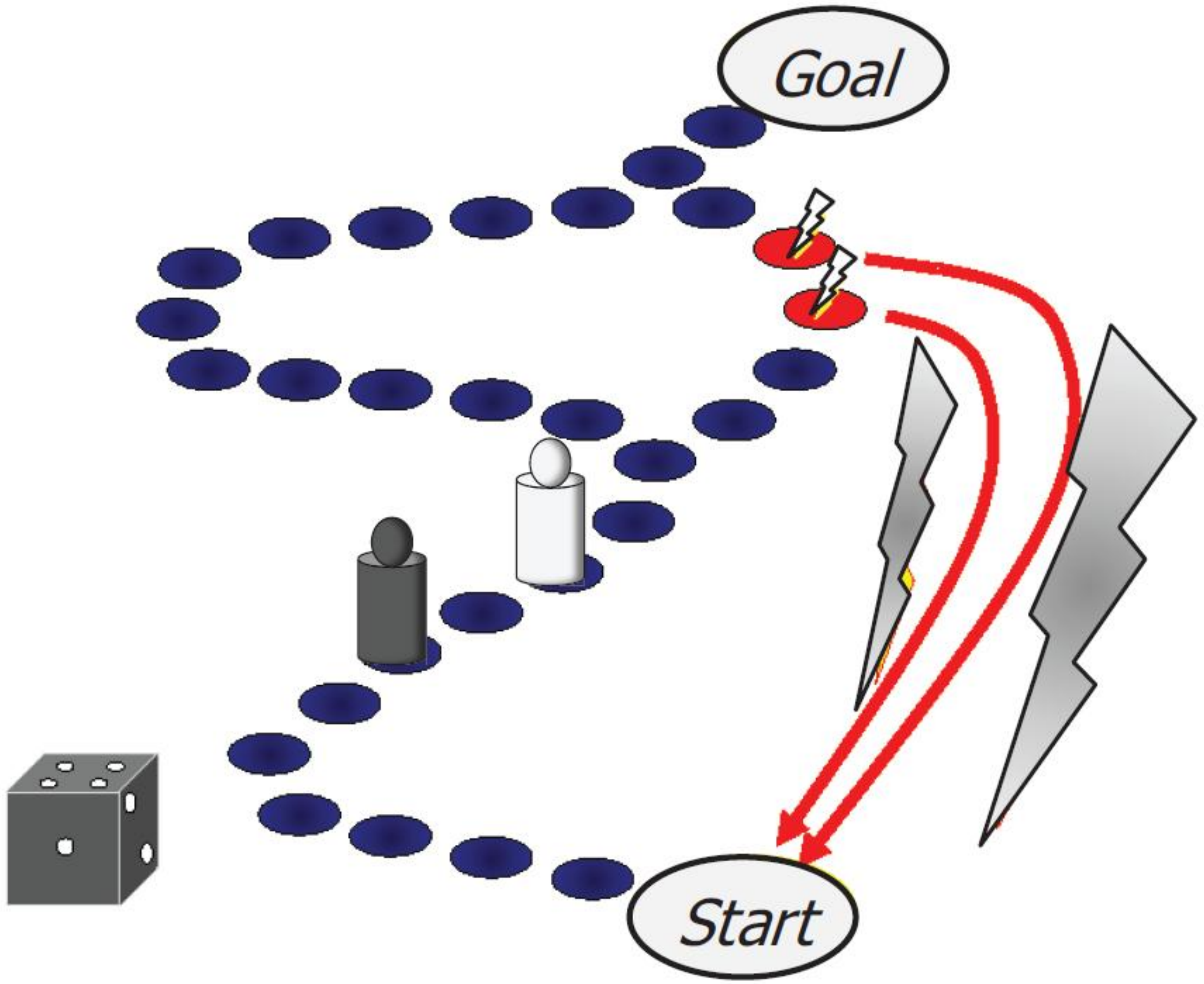
12.2 Perceptual decision making
- V5/MT
- Decision dynamics: Area LIP

12.3 Theory of decision dynamics
- shared inhibition
- effective 2-dim model

12.4. Decisions in connected pops.
- unbiased case
- biased input

12.5. Decisions, actions, volition
- the problem of free will

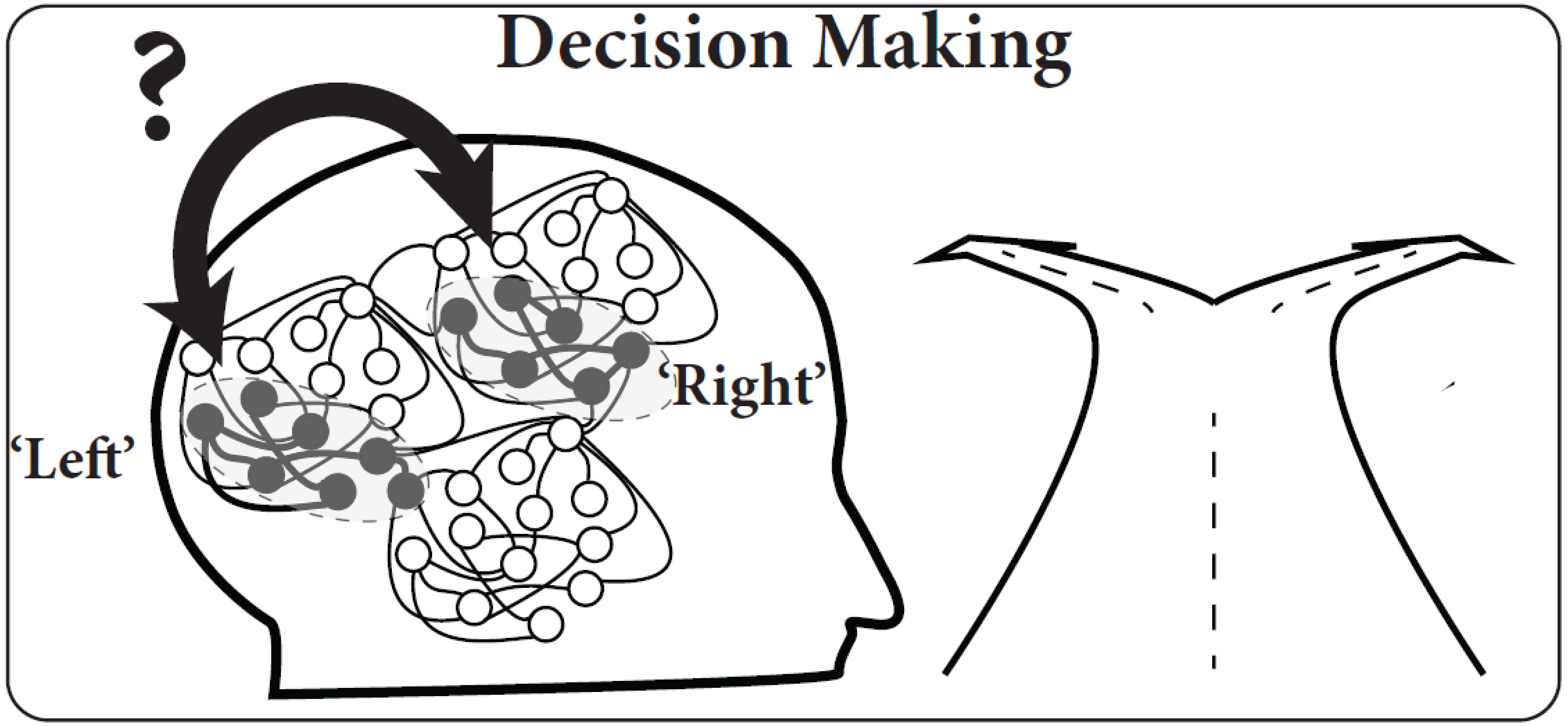
Week 12-part 1: How do YOU decide?



Week 12-part 1: Decision making

turn

Left? Right?



Week 12-part 1: Review: High-noise activity equation

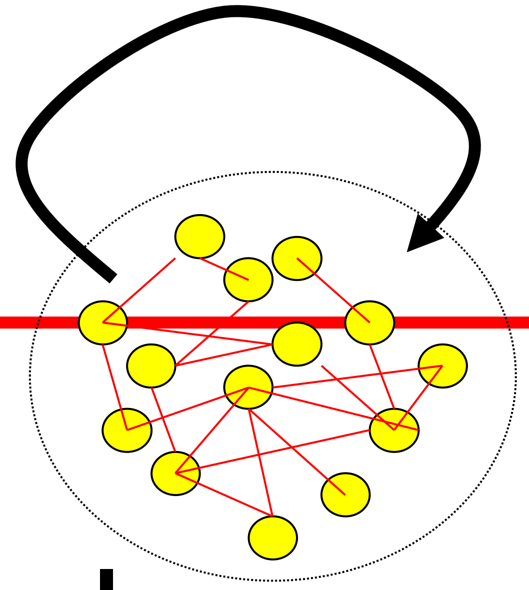
Population activity

$$A(t) = F(h(t))$$

Membrane potential caused by input

$$\tau \frac{d}{dt} h(t) = -h(t) + R\ I(t)$$

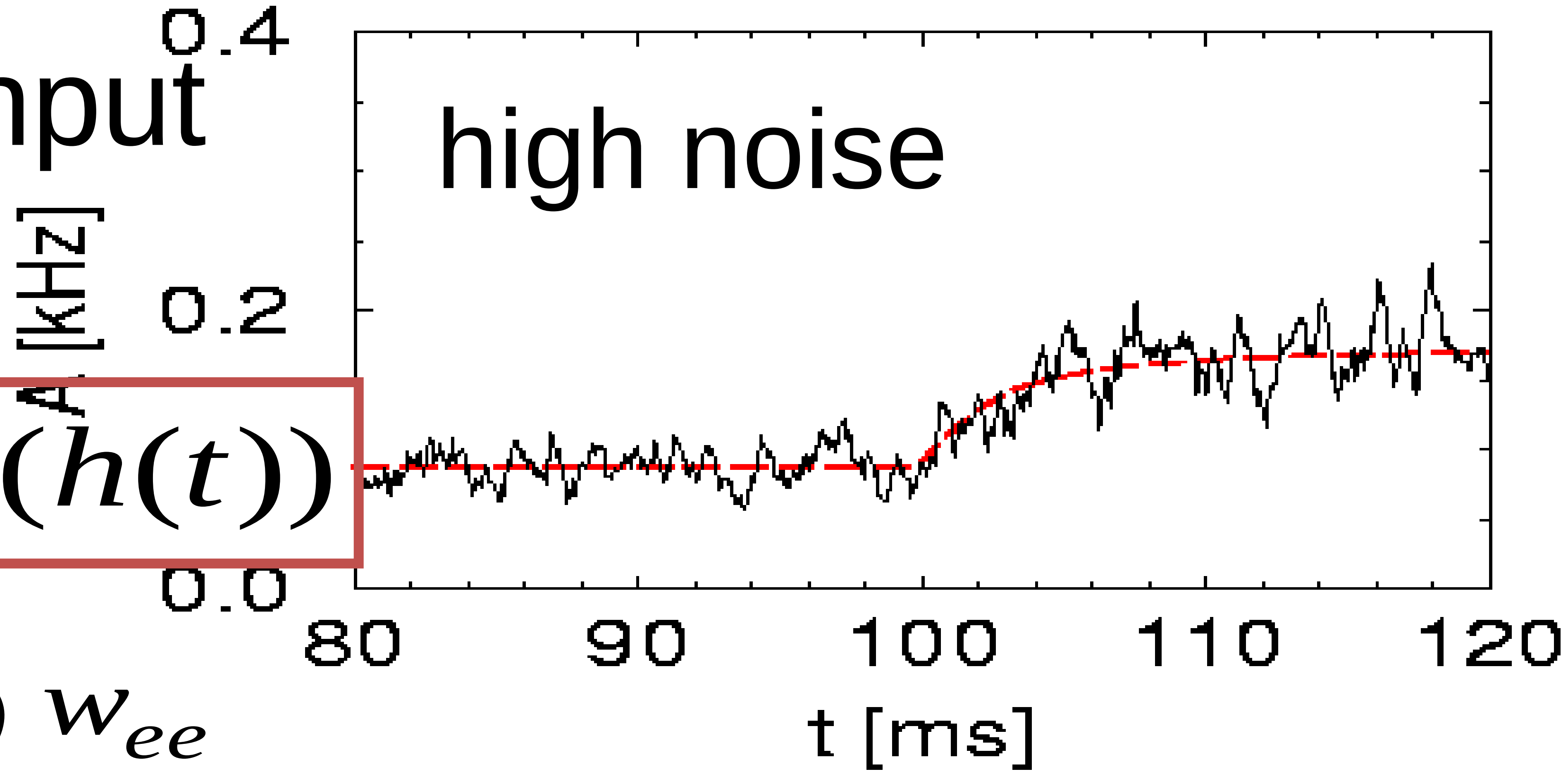
$$\boxed{\tau \frac{d}{dt} h(t) = -h(t) + R\, I^{ext}(t) + w_{ee}\ F(h(t))}$$

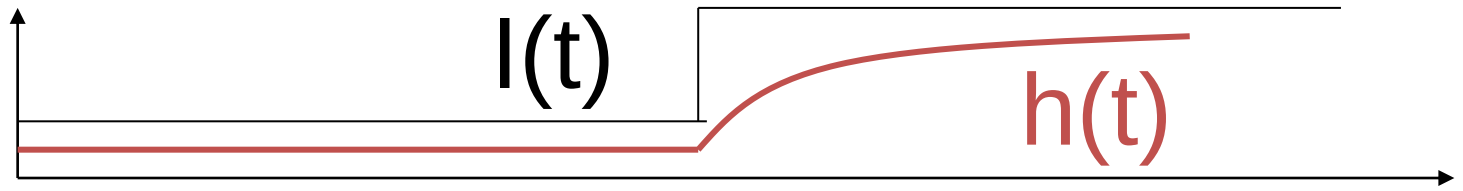


w_{ee}

noise model A

(escape noise/fast noise)





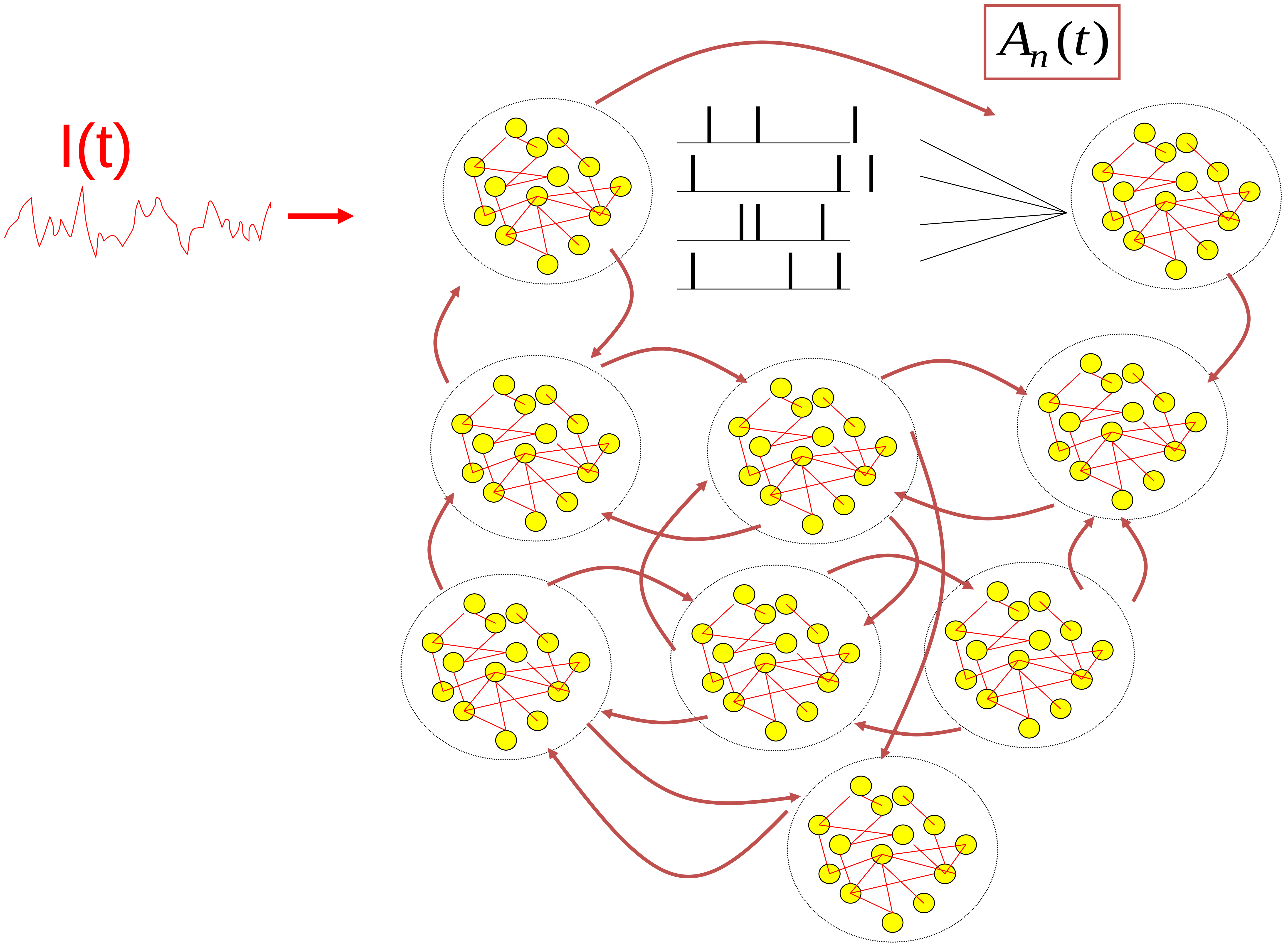
slow transient

$$\boxed{A(t) = F(h(t))}$$

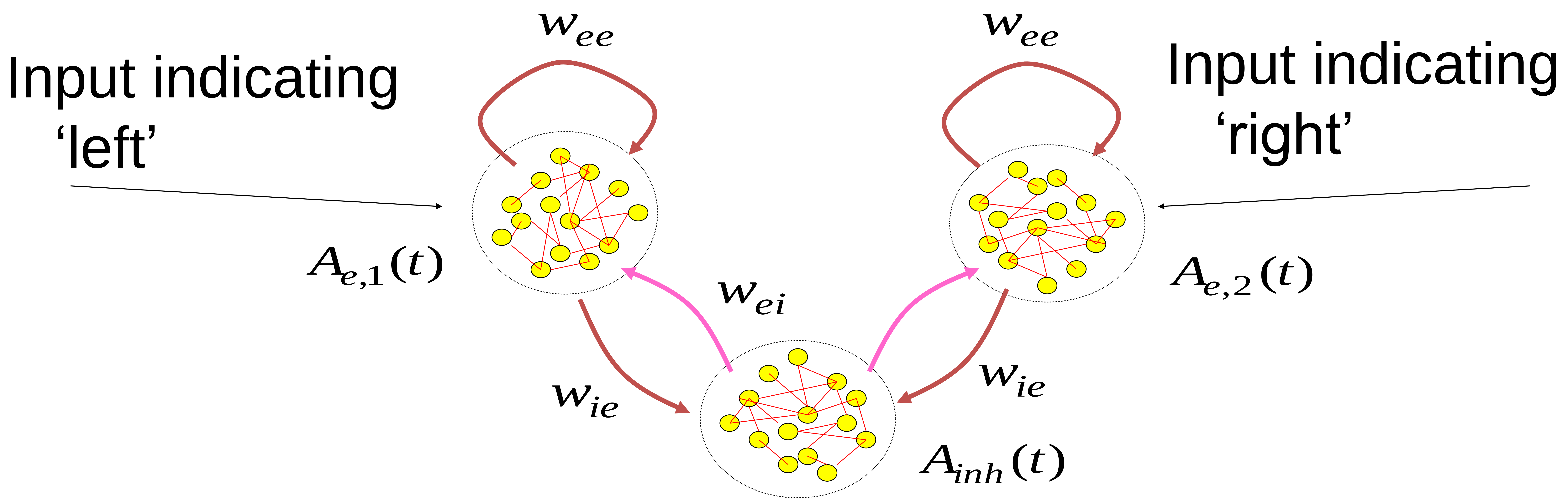
Attention:

- valid for high noise only, else transients might be wrong
- valid for high noise only, else spontaneous oscillations may arise

Week 12-part 1: Review: microscopic vs. macroscopic



Week 12-part 1: Competition between two populations



Week 12-part 1: How do YOU decide?

Week 12 – Decision models

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Biological Modeling of Neural Networks:

Week 12 – Decision models: Competitive dynamics

Wulfram Gerstner

EPFL, Lausanne, Switzerland

12.1 Review: Population dynamics
- competition

12.2 Perceptual decision making
- V5/MT
- Decision dynamics: Area LIP

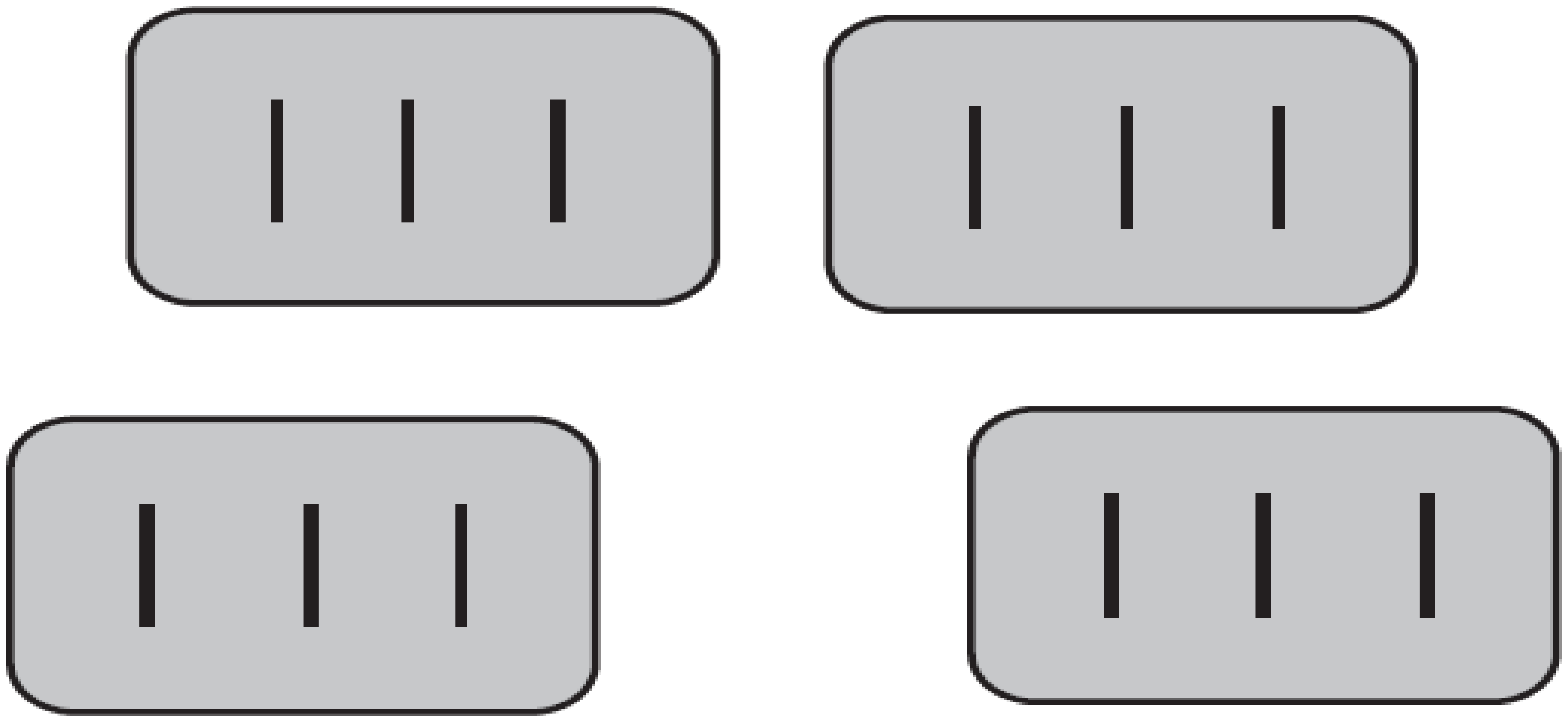
12.3 Theory of decision dynamics
- shared inhibition
- effective 2-dim model

12.4. Decisions in connected pops.
- unbiased case
- biased input

12.5. Decisions, actions, volition
- the problem of free will

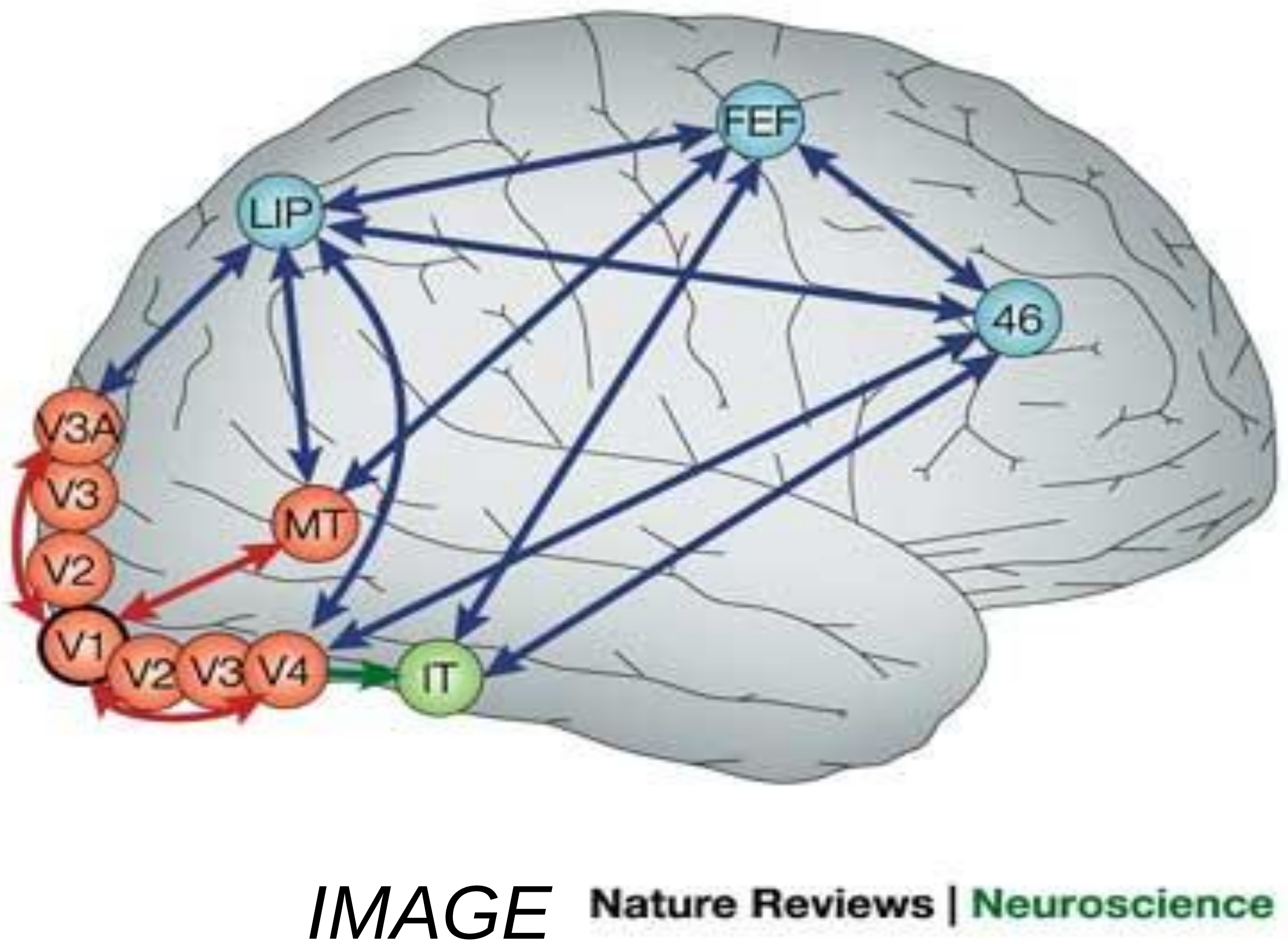
Week 12-part 2: Perceptual decision making?

‘Is the middle bar shifted to the left or to the right?’

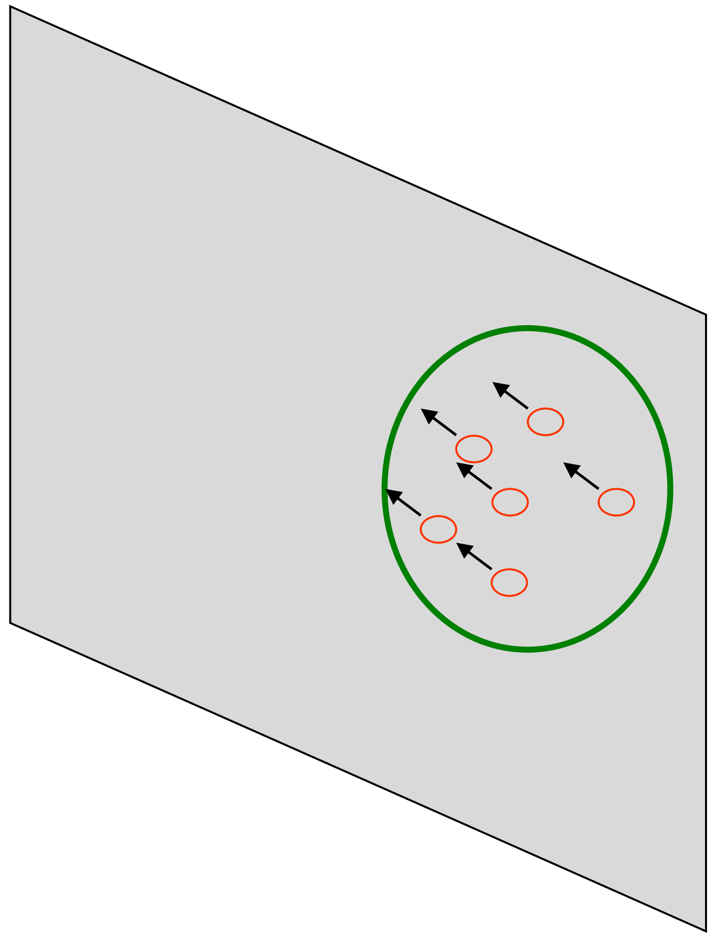


Week 12-part 2: Detour: receptive fields in V5/MT

visual
cortex



IMAGE



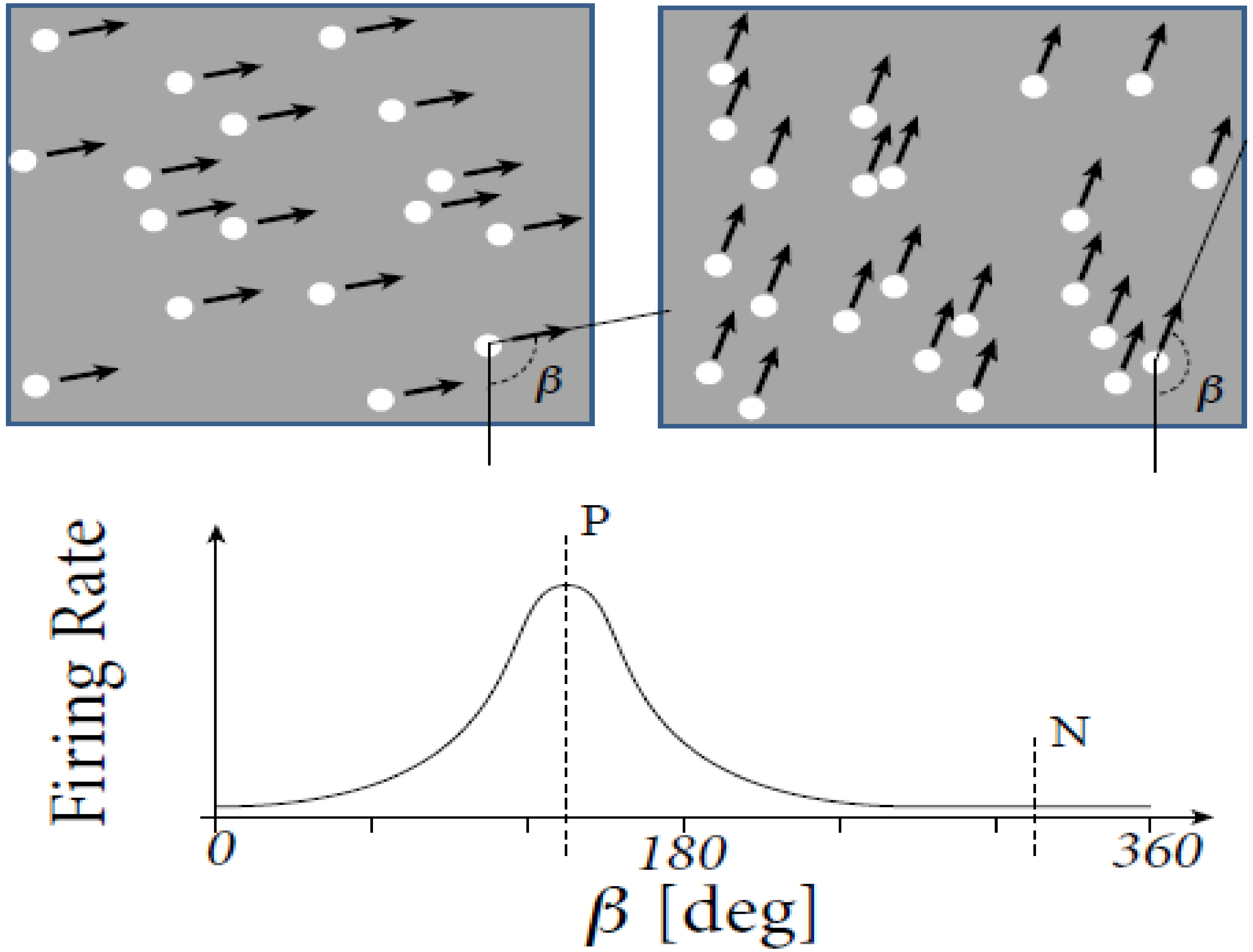
1) Cells in visual cortex MT/V5 respond to motion stimuli

2) Neighboring cells in visual cortex MT/V5 respond to motion in similar direction cortical columns

Albright, Desimone,Gross, J. Neurophysiol, 1985

Week 12-part 2: Detour: receptive fields in V5/MT

Recordings from a single neuron in V5/MT



Receptive Fields depend on direction of motion

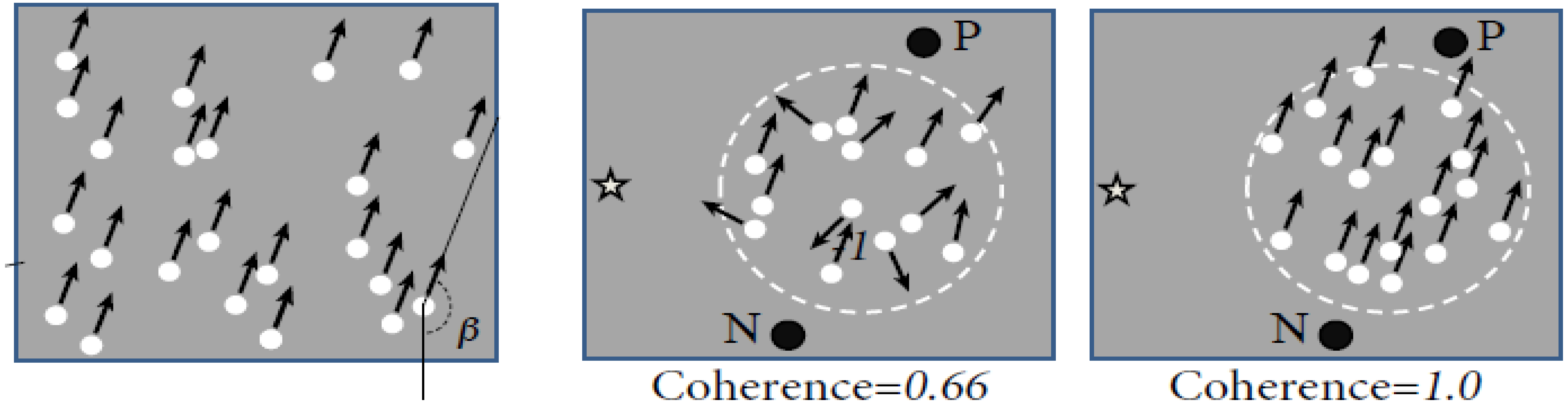
Random moving dot stimuli:

e.g.Salzman, Britten, Newsome, 1990

Roitman and Shadlen, 2002

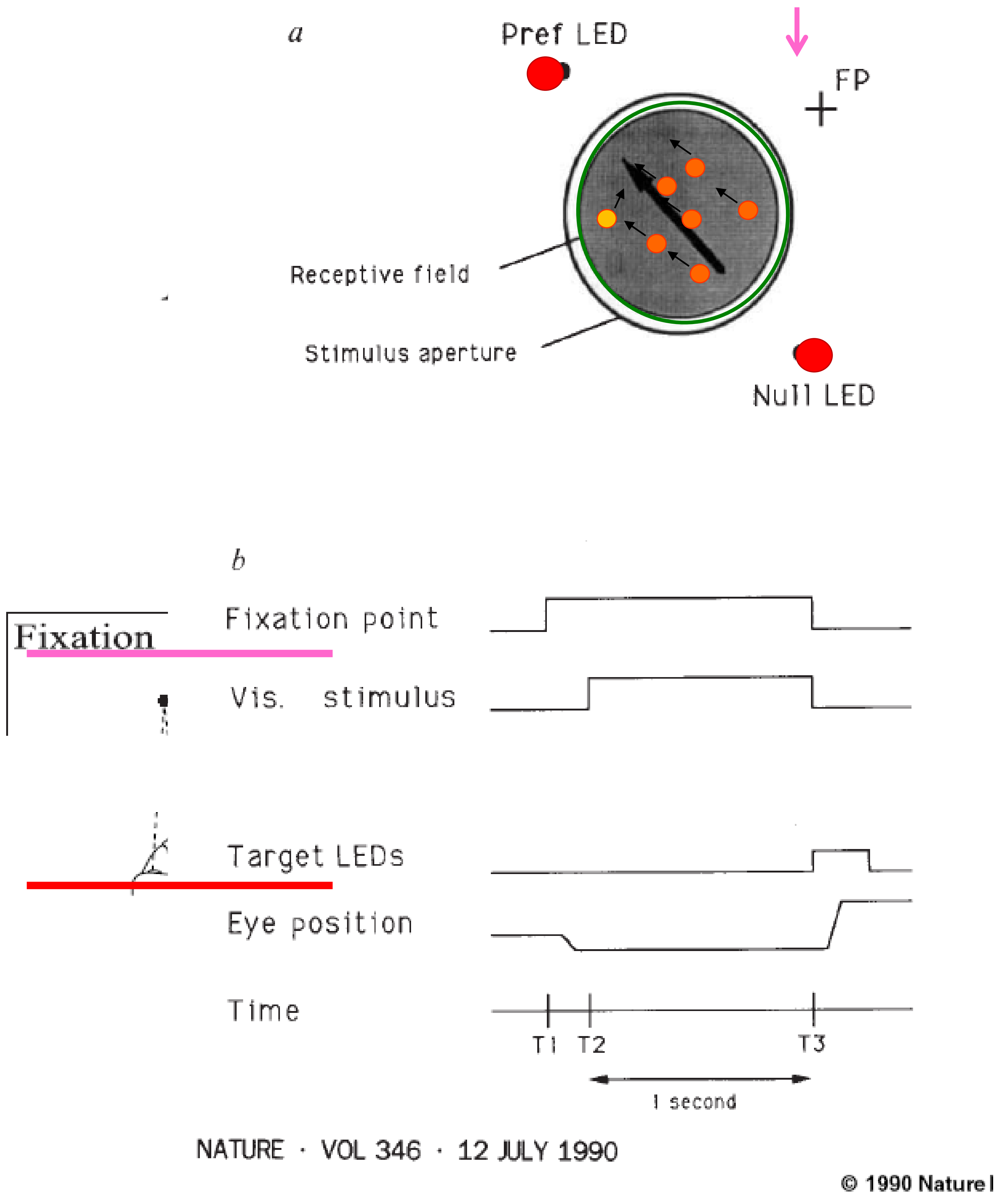
Gold and Shadlen 2007

Week 12-part 2: Detour: receptive fields in V5/MT



Receptive Fields depend
on direction of motion: β = preferred direction = P

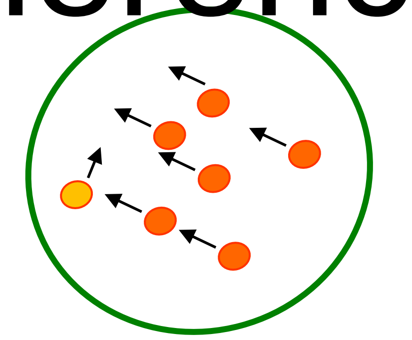
Week 12-part 2: Experiment of Salzman et al. 1990



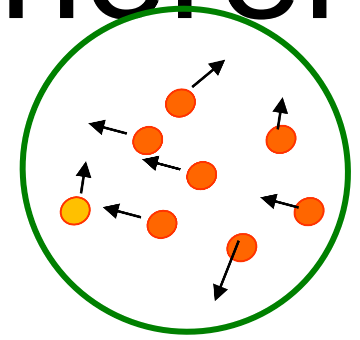
Eye movement

Image: Salzman, Britten, Newsome, 1990

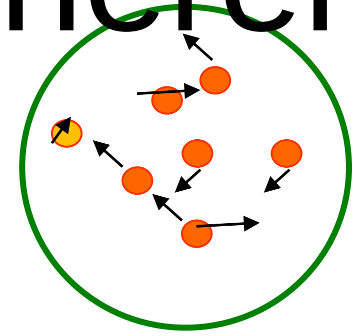
coherence 0.8=80%



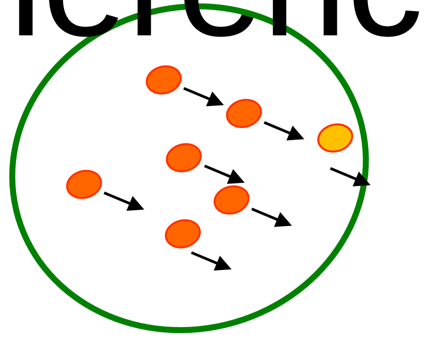
coherence 0.5 = 50%



coherence 0.0



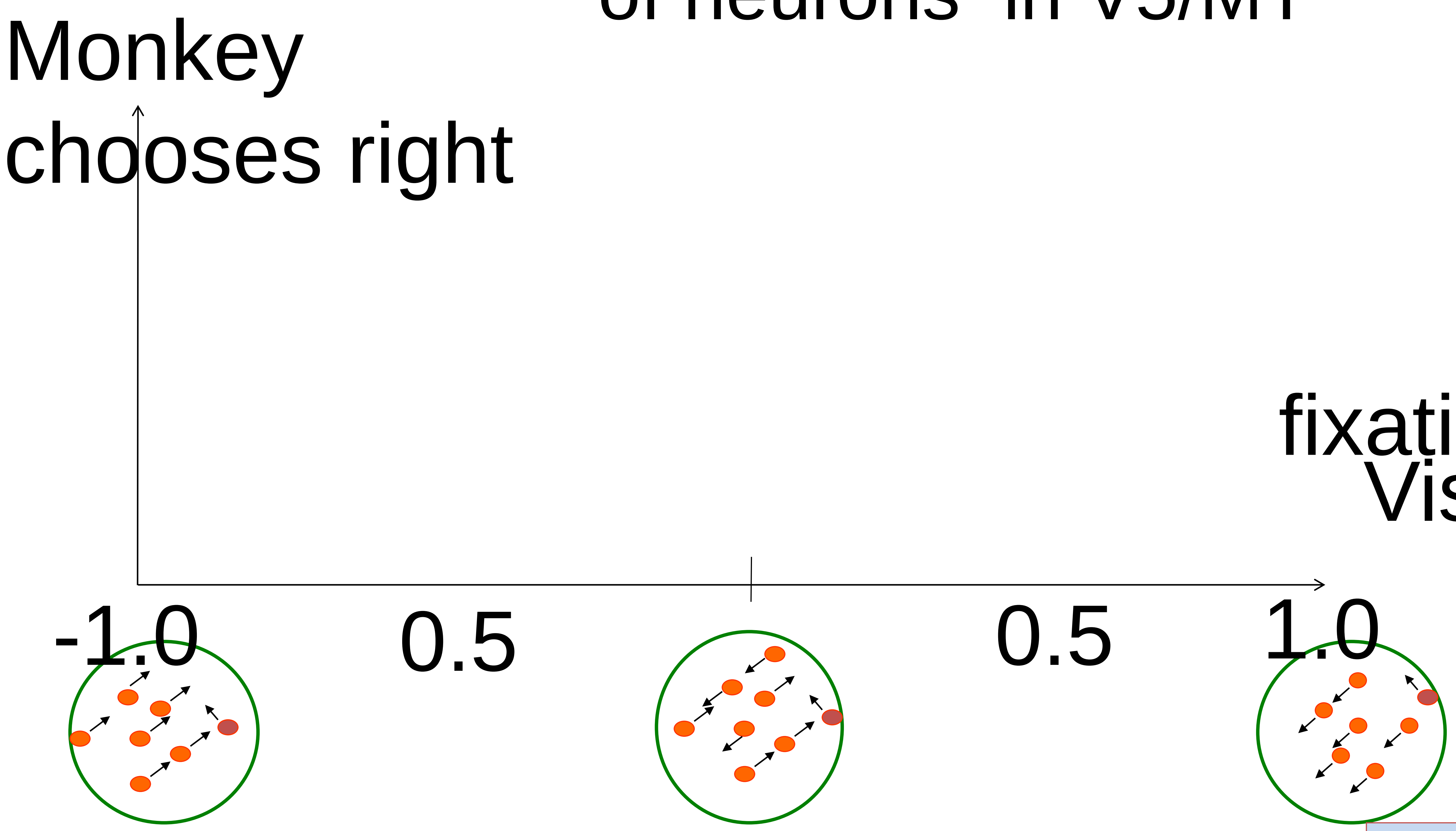
coherence -1.0

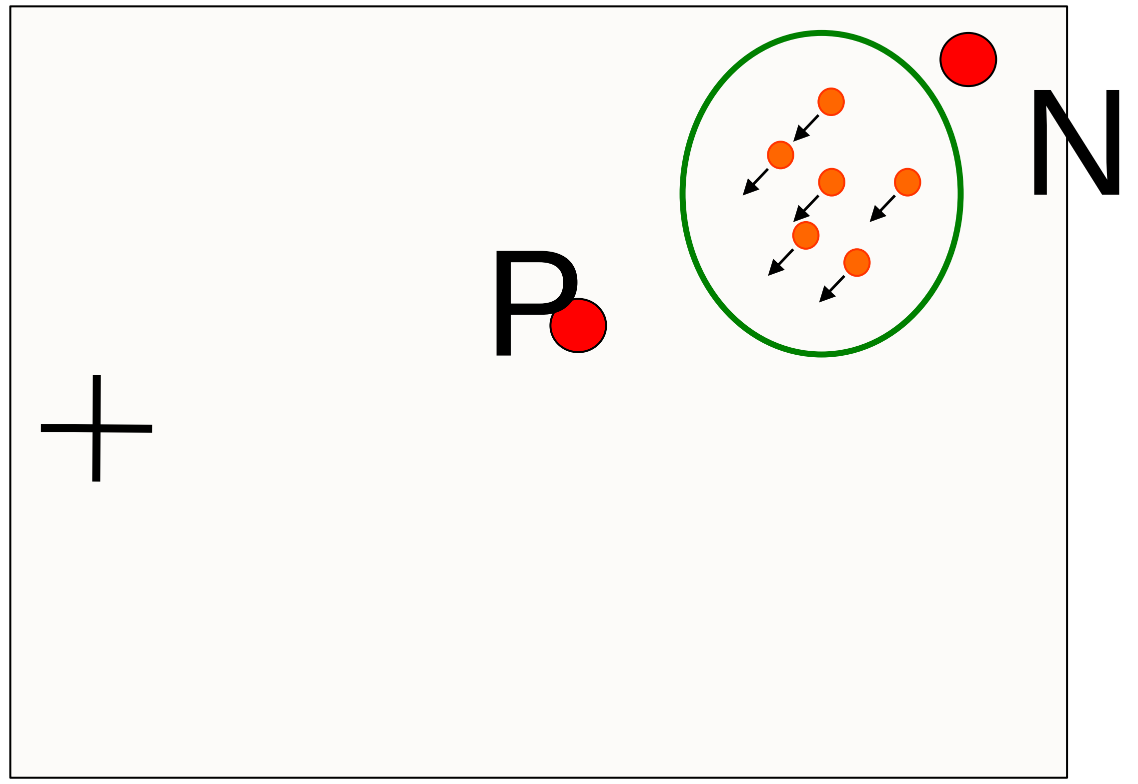


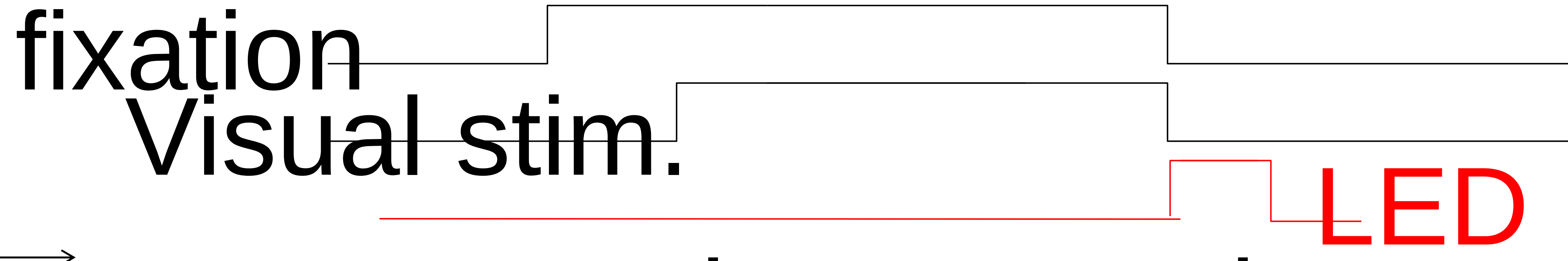
opposite direction

Week 12-part 2: Experiment of Salzman et al. 1990

Monkey behavior w. or w/o Stimulation of neurons in V5/MT







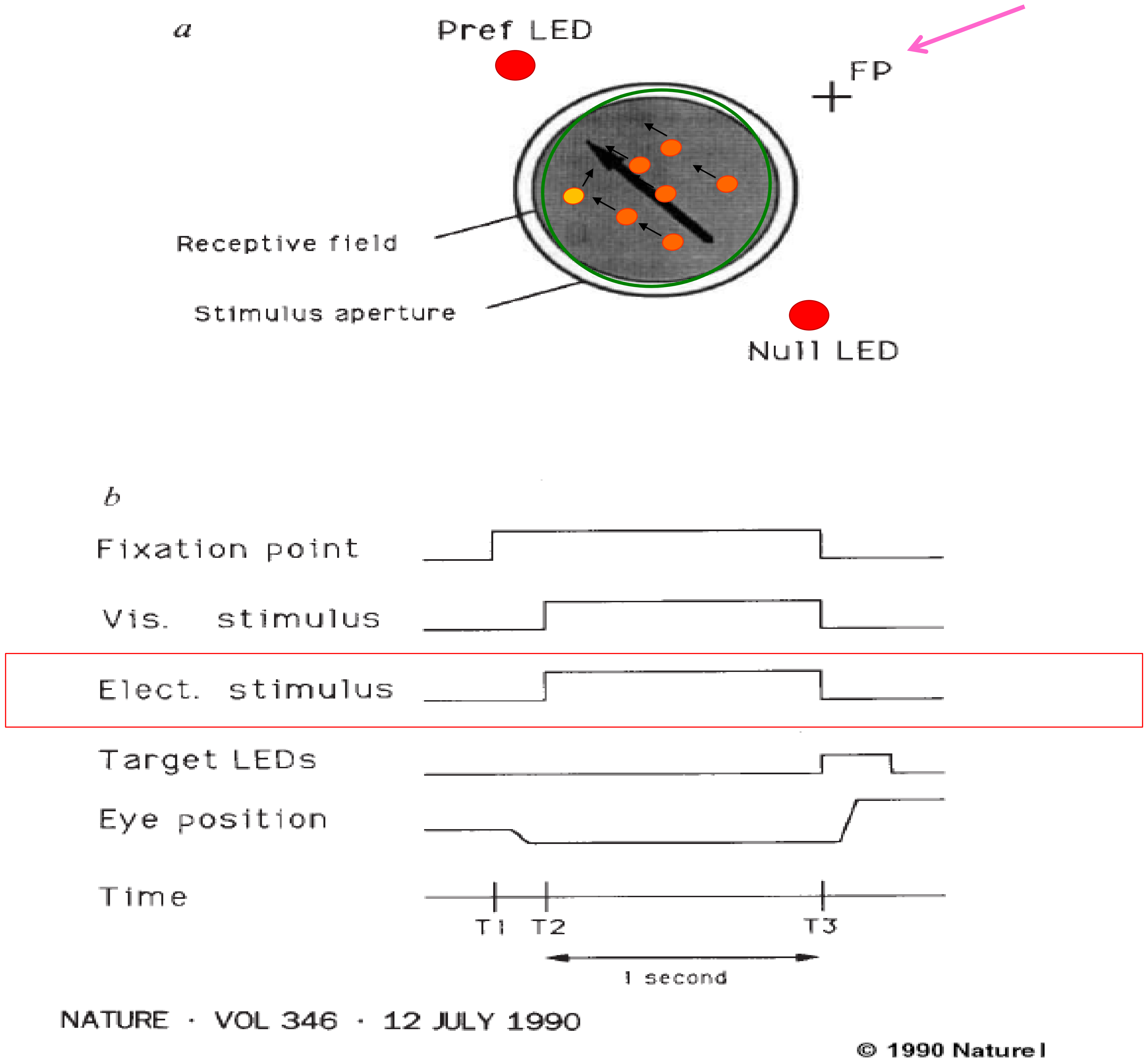
X = coherent motion to bottom right

No bias, each point moves in random direction

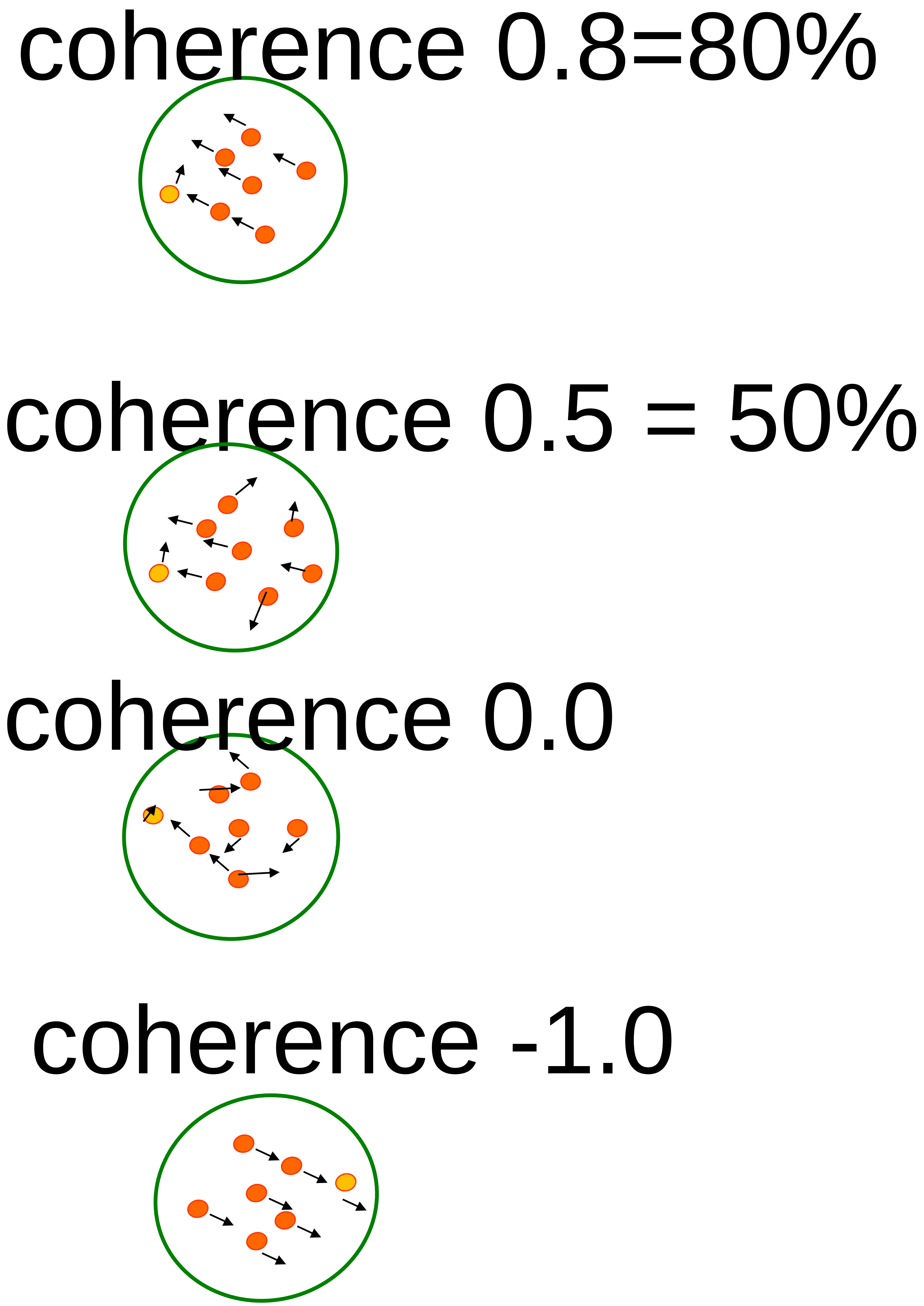
Salzman, Britten, Newsome, 1990

Blackboard:
Motion detection/stimulation

Week 12-part 2: Experiment of Salzman et al. 1990

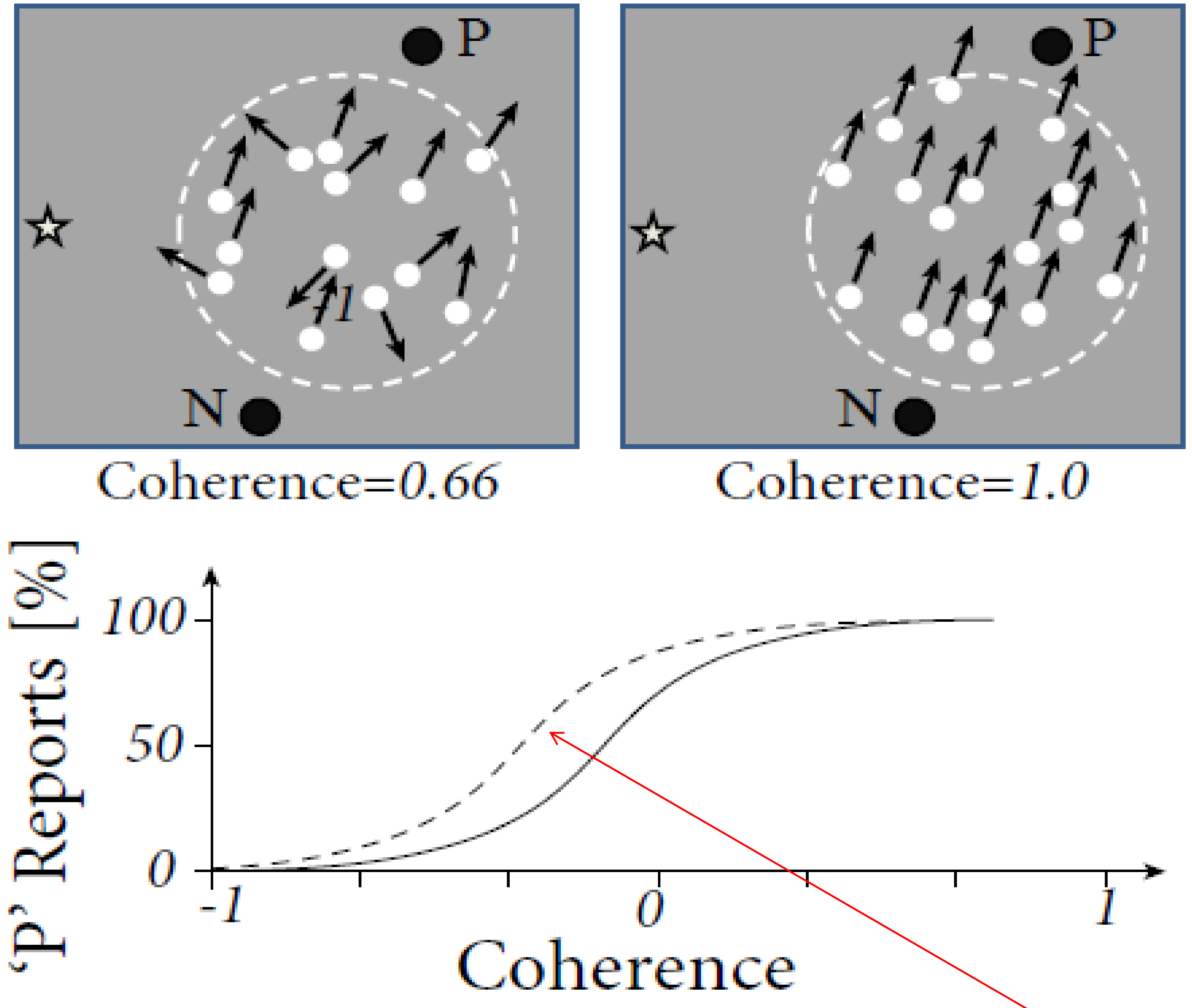


excites this group of neurons



Week 12-part 2: Experiment of Salzman et al. 1990

Behavior: psychophysics



With stimulation

Week 12 – Decision models

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Biological Modeling of Neural Networks:

Week 12 – Decision models: Competitive dynamics

Wulfram Gerstner

EPFL, Lausanne, Switzerland

12.1 Review: Population dynamics
- competition

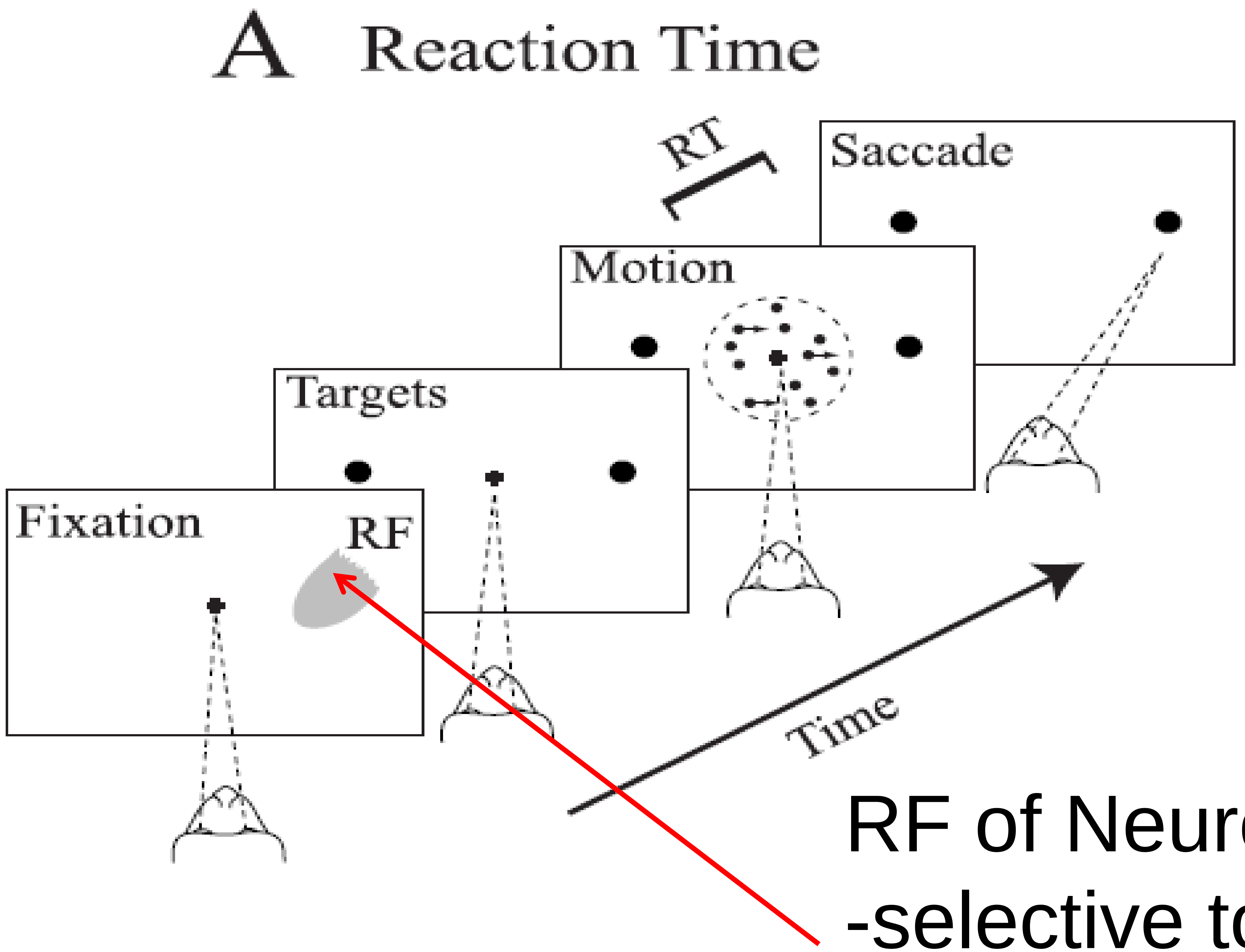
12.2 Perceptual decision making
- V5/MT
- Decision dynamics: Area LIP

12.3 Theory of decision dynamics
- shared inhibition
- effective 2-dim model

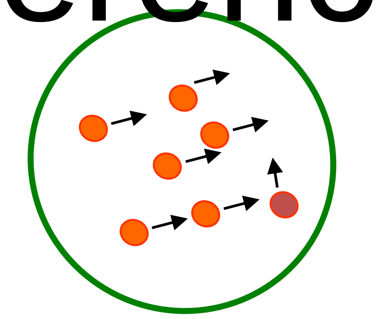
12.4. Decisions in connected pops.
- unbiased case
- biased input

12.5. Decisions, actions, volition
- the problem of free will

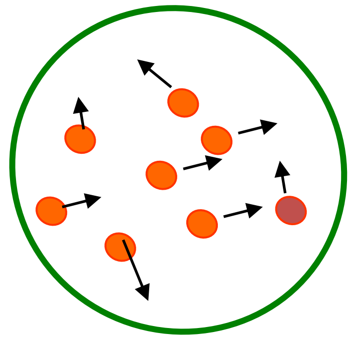
Week 12-part 2: Experiment of Roitman and Shadlen in LIP (2002)



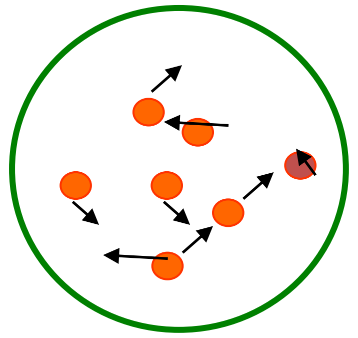
coherence 85%



coherence 50%



coherence 0%



RF of Neuron in LIP:
-selective to target of saccade
-increases faster if signal is stronger
- activity is noisy

LIP is somewhere between MT (movement detection) and Frontal Eye Field (saccade control)

Roitman and Shadlen 2002

Week 12-part 2: Experiment of Roitman and Shadlen in LIP (2002)

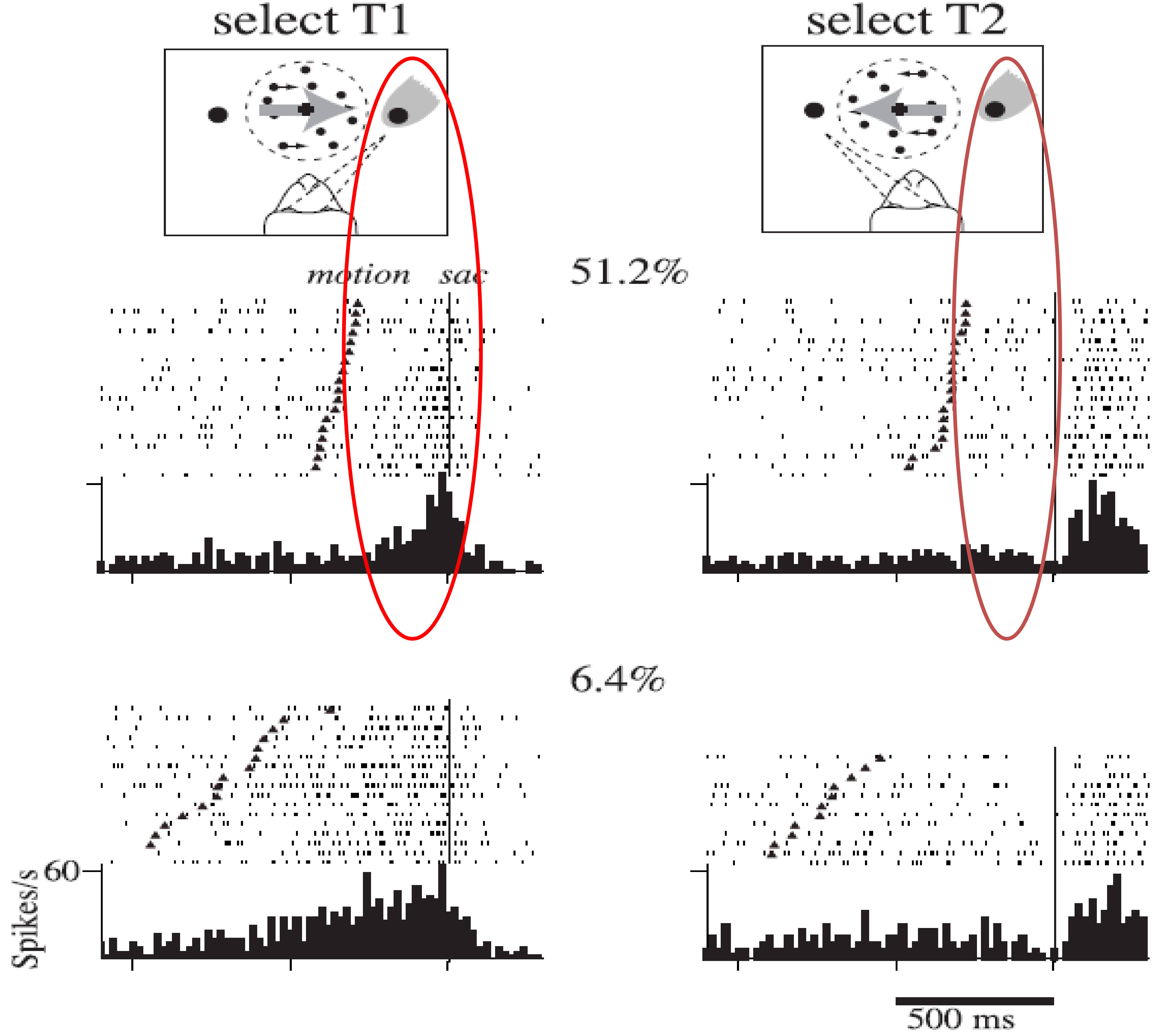


Figure 4. Response of an LIP neuron during the RT-direction-

Neurons in LIP:
-selective to target of saccade
-increases faster if signal is stronger
- activity is noisy

LIP is somewhere between MT (movement detection) and Frontal Eye Field (saccade control)

Quiz 1, now

Receptive field in LIP

[ ] related to the target of a saccade

[ ] depends on movement of random dots

Week 12– Decision models, part 3

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Biological Modeling of Neural Networks:

Week 12 – Decision models: Competitive dynamics

Wulfram Gerstner

EPFL, Lausanne, Switzerland

Week 12-part 3: Theory of decision dynamics

$$A_n(t) = F(h_n(t))$$

activity equations

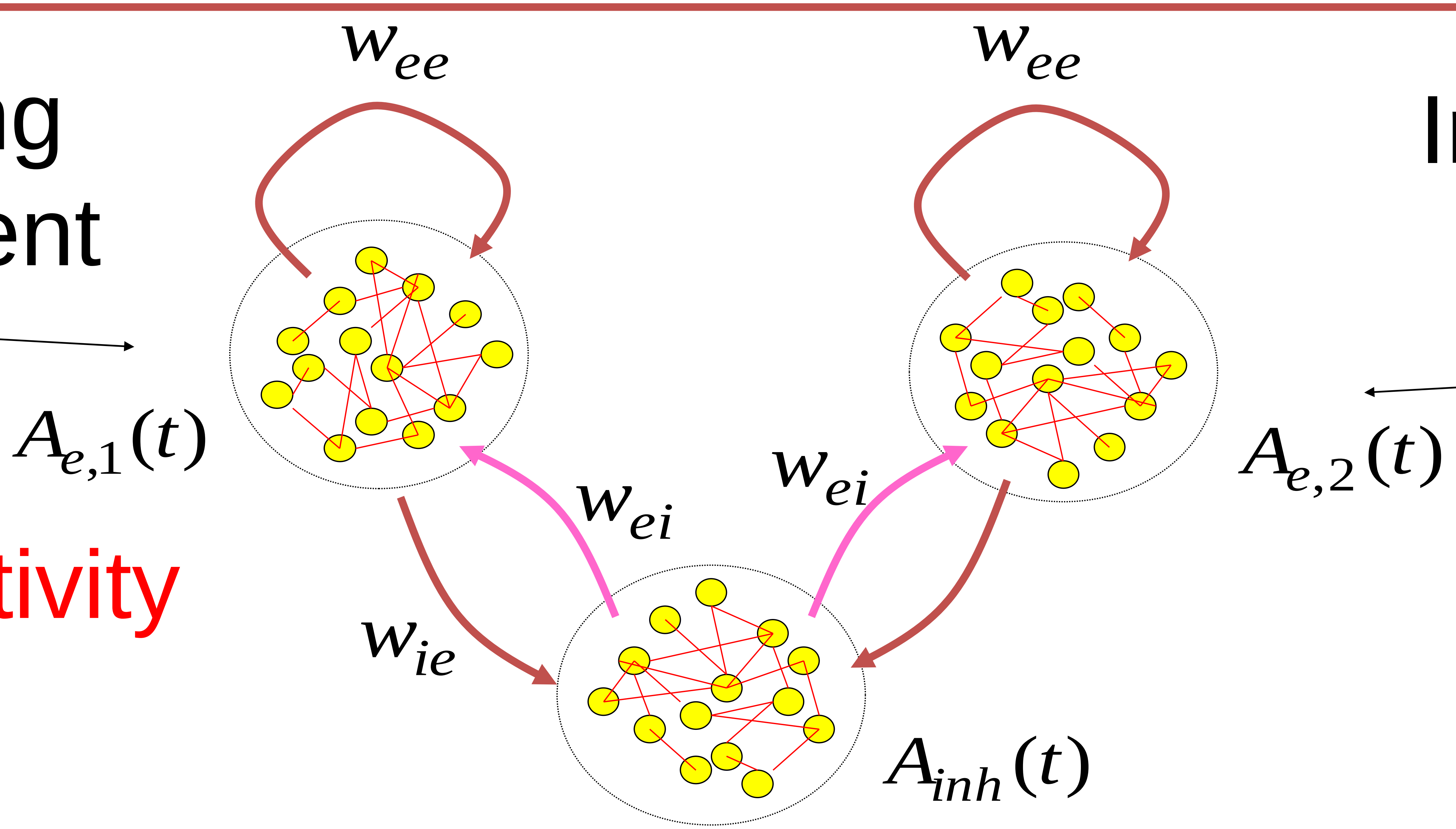
Membrane potential caused by input

$$\tau \frac{d}{dt} h_1(t) = -h_1(t) + R\, I_1^{ext}(t) + w_{ee}\, F(h_1(t)) + w_{ei}\, F(h_{inh}(t))$$

$$\tau \frac{d}{dt} h_2(t) = -h_2(t) + R\, I_2^{ext}(t) + w_{ee}\, F(h_2(t)) + w_{ei}\, F(h_{inh}(t))$$

Input indicating left movement

Input indicating right moveme



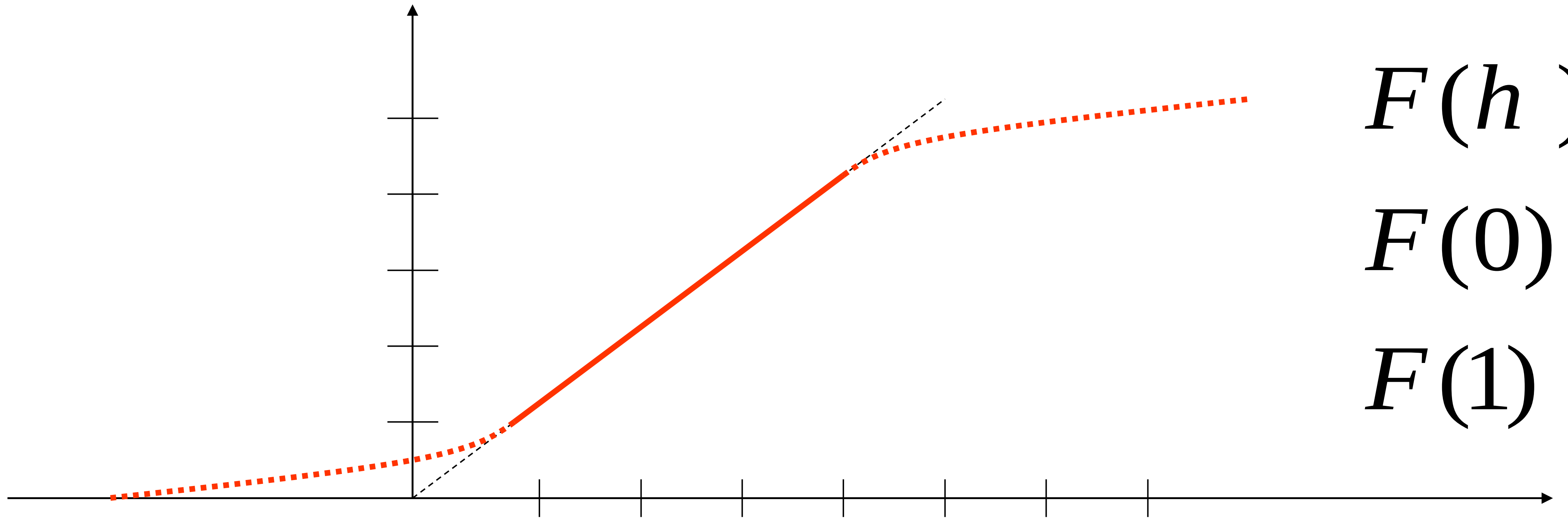
Blackboard: reduction from 3 to 2 equations

ctivity

Population activity

$$A_n(t) = F(h_n(t))$$

activity equations



$$F(h) = h \quad for \quad 0.2 < h < 0.8$$

$$F(0) = 0.1$$

$$F(1) = 0.9$$

Inhibitory Population

$$A_{inh}(t) = F(h_{inh}(t)) = h_{inh}(t) = w_{ie}(A_{e,1}(t) + A_{e,2}(t))$$

Blackboard:

Linearized inhibition

Week 12-part 3: Effective 2-dim. model

$$A_n(t) = F(h_n(t))$$

activity equations

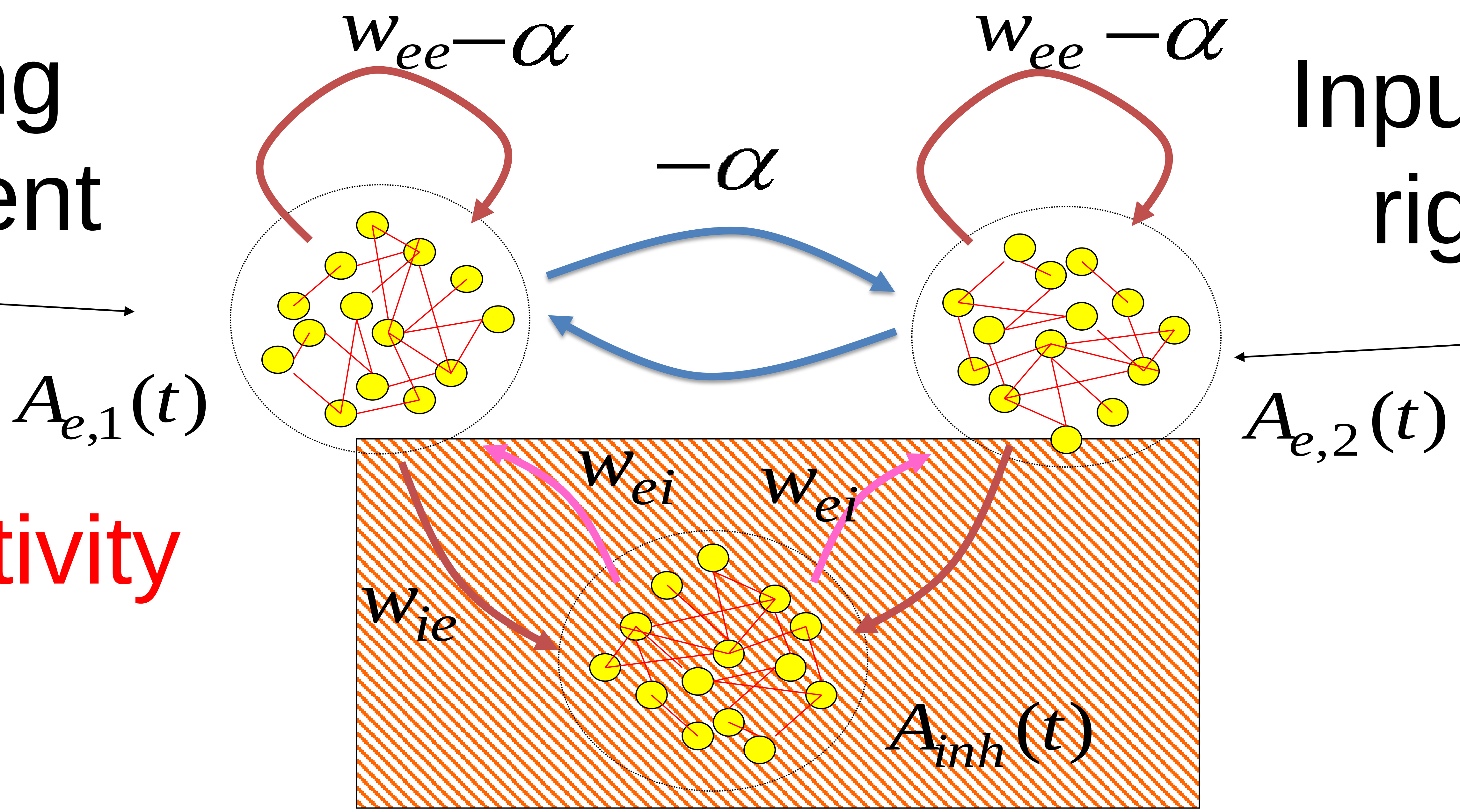
Membrane potential caused by input

$$\tau \frac{d}{dt} h_1(t) = -h_1(t) + h_1^{ext}(t) + (w_{ee} - \alpha) F(h_1(t)) - \alpha F(h_2(t))$$

$$\tau \frac{d}{dt} h_2(t) = -h_2(t) + h_2^{ext}(t) + (w_{ee} - \alpha) F(h_2(t)) - \alpha F(h_1(t))$$

Input indicating left movement

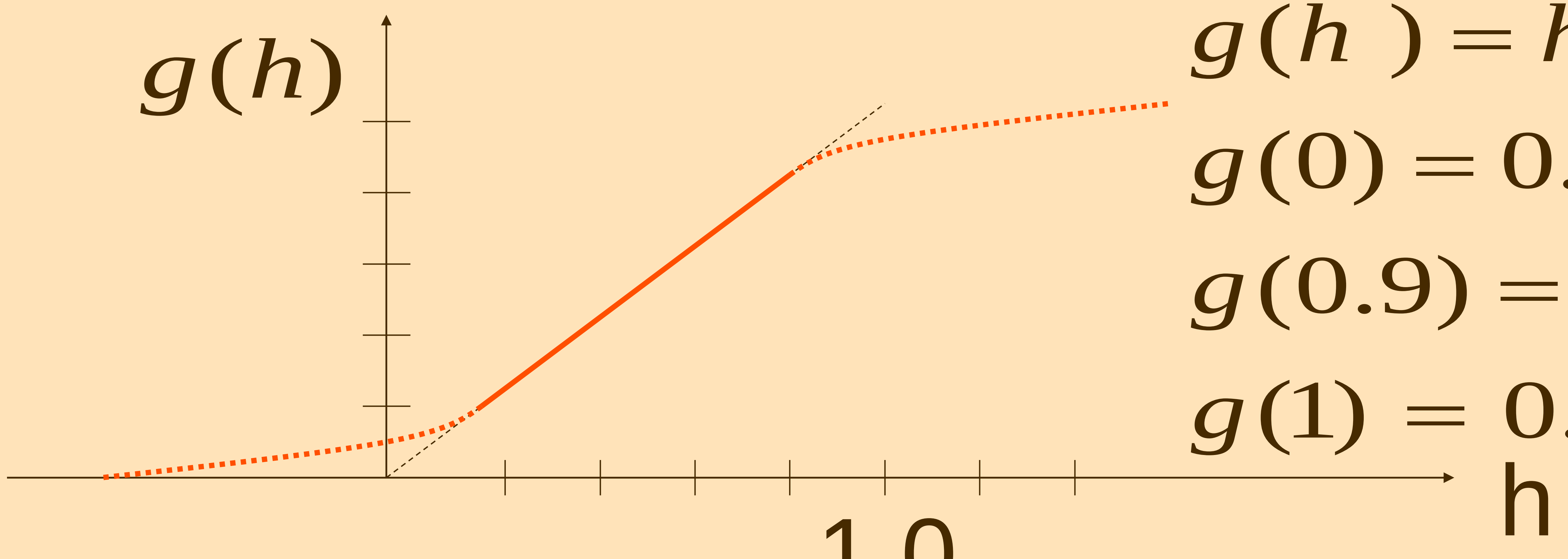
Input indicating right movement



population activity

Exercise 1 now: draw nullclines and flow arrows

$$\tau \frac{d}{dt} h_1(t) = -h_1(t) + h_1^{ext}(t) + (w_{ee} - \alpha) g(h_1(t)) - \alpha\, g(h_2(t))$$



$g(h) = h \quad for \quad 0.2 < h < 0.8$

$g(0) = 0.1$

$g(0.9) = 0.85$

$g(1) = 0.9$

$h_1^{ext} = h_2^{ext} = 0.8; \; w_{ee} = 1.5; \;\; \alpha = 1$

$\frac{d}{dt} h_1 = 0$

h_1	$g(h_2)$	h_2
1.0		
0.8		
0.2		
0.0		

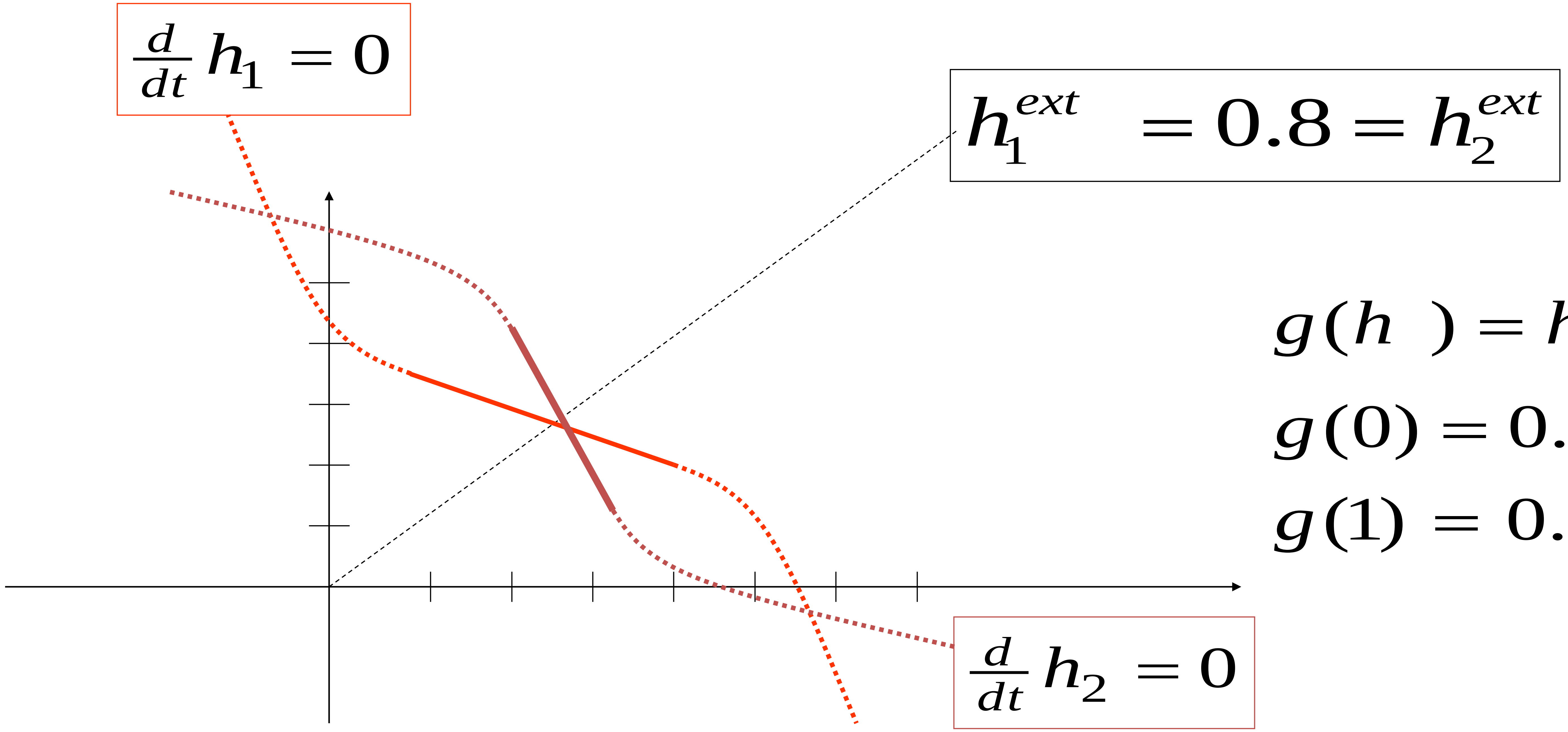
$\frac{d}{dt} h_2 = 0$

h_2	$g(h_1)$	h_1
1.0		
0.8		
0.2		
0.0		

Next Lecture at 10:36

Week 12-part 3: Theory of decision dynamics

Phase plane, strong external input



$g(h\ ) = h \quad for \quad 0.2 < h < 0.8$

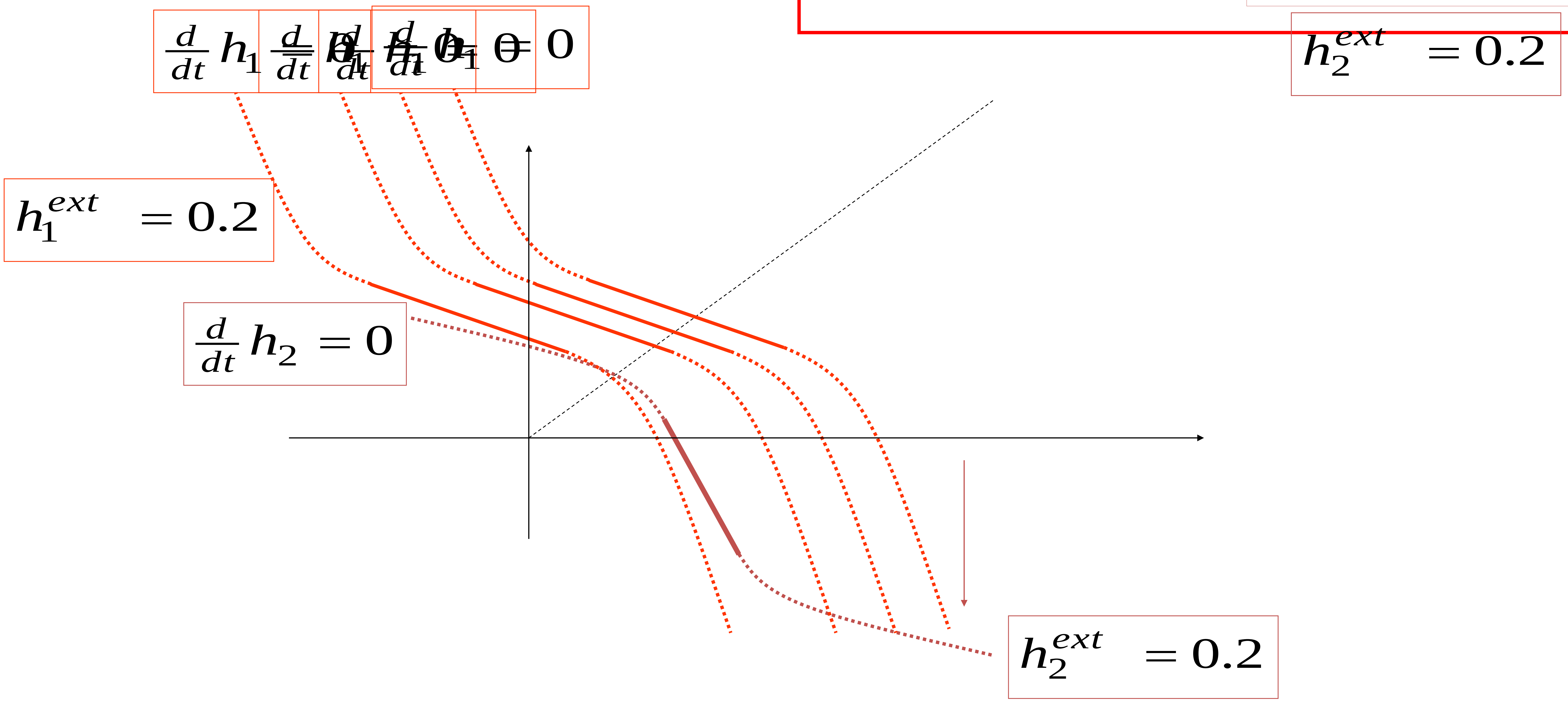
$g(0) = 0.1$

$g(1) = 0.9$

Week 12-part 3: Theory of decision dynamics: biased input

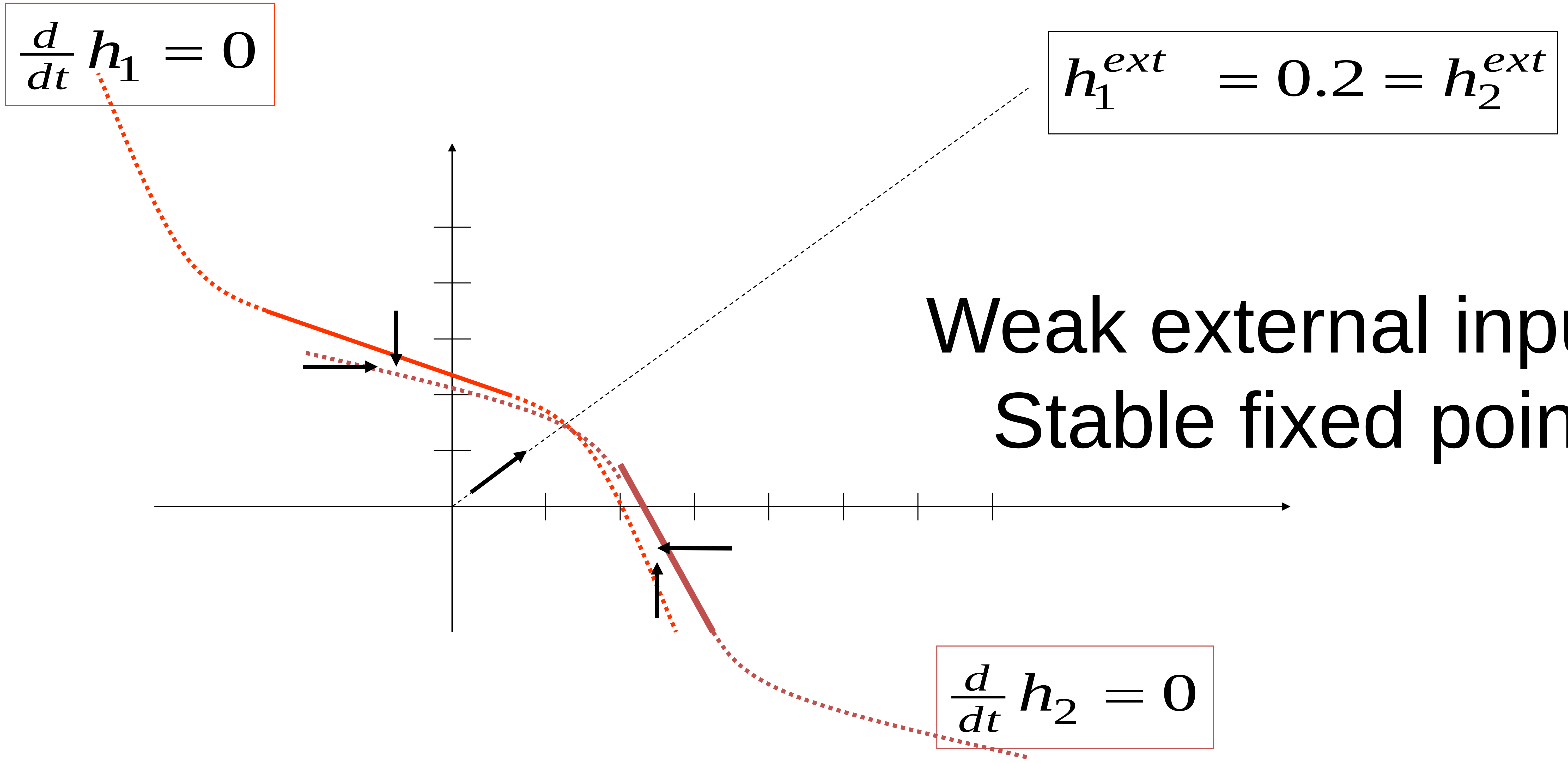
Population activity

Phase plane – biased input: $h_2^{ext} < h_1^{ext}$



Week 12-part 3: Theory of decision dynamics: unbiased weak

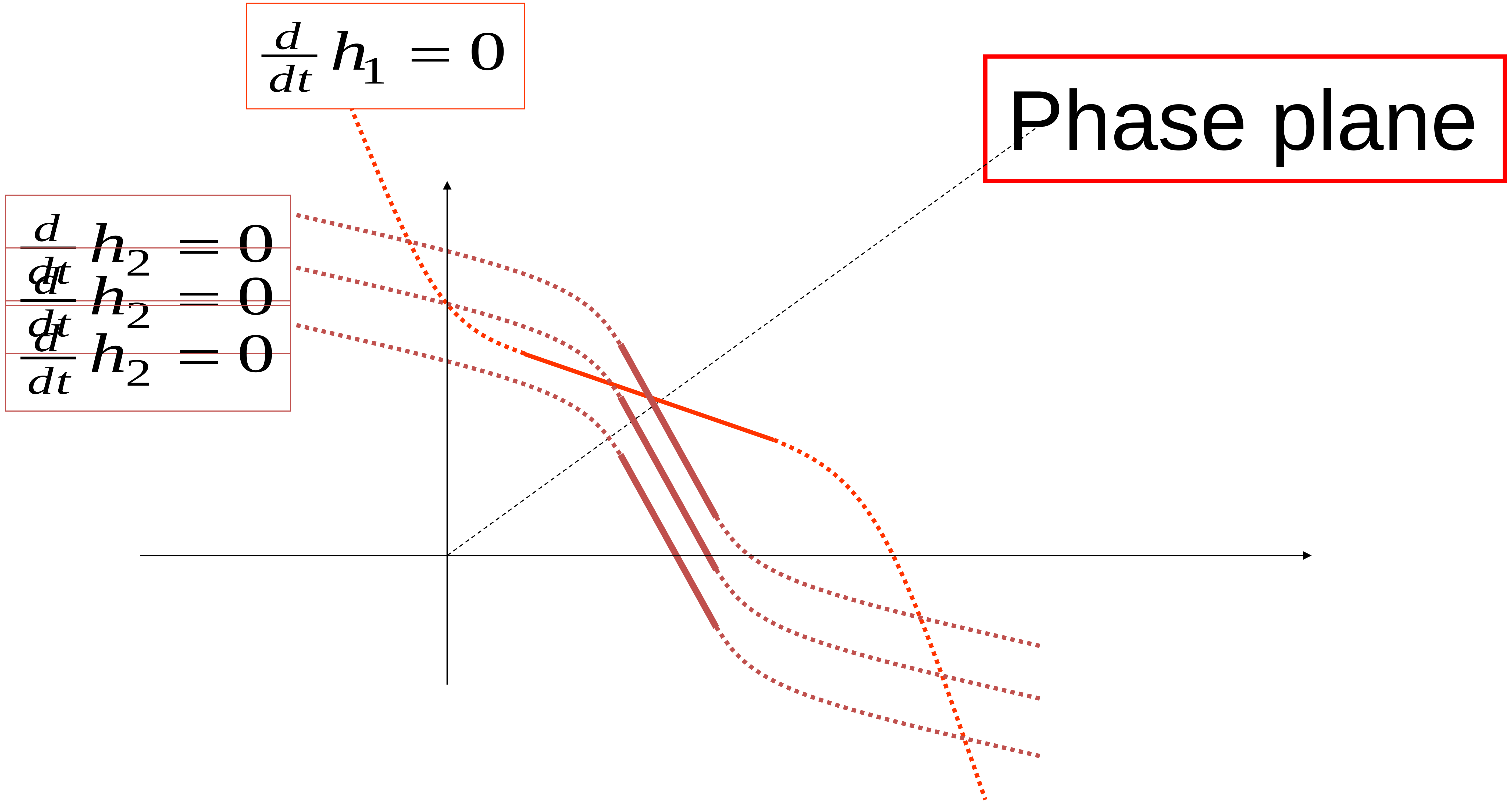
Phase plane – symmetric but small input



Weak external input:
Stable fixed point

Week 12-part 3: decision dynamics: unbiased strong to biased

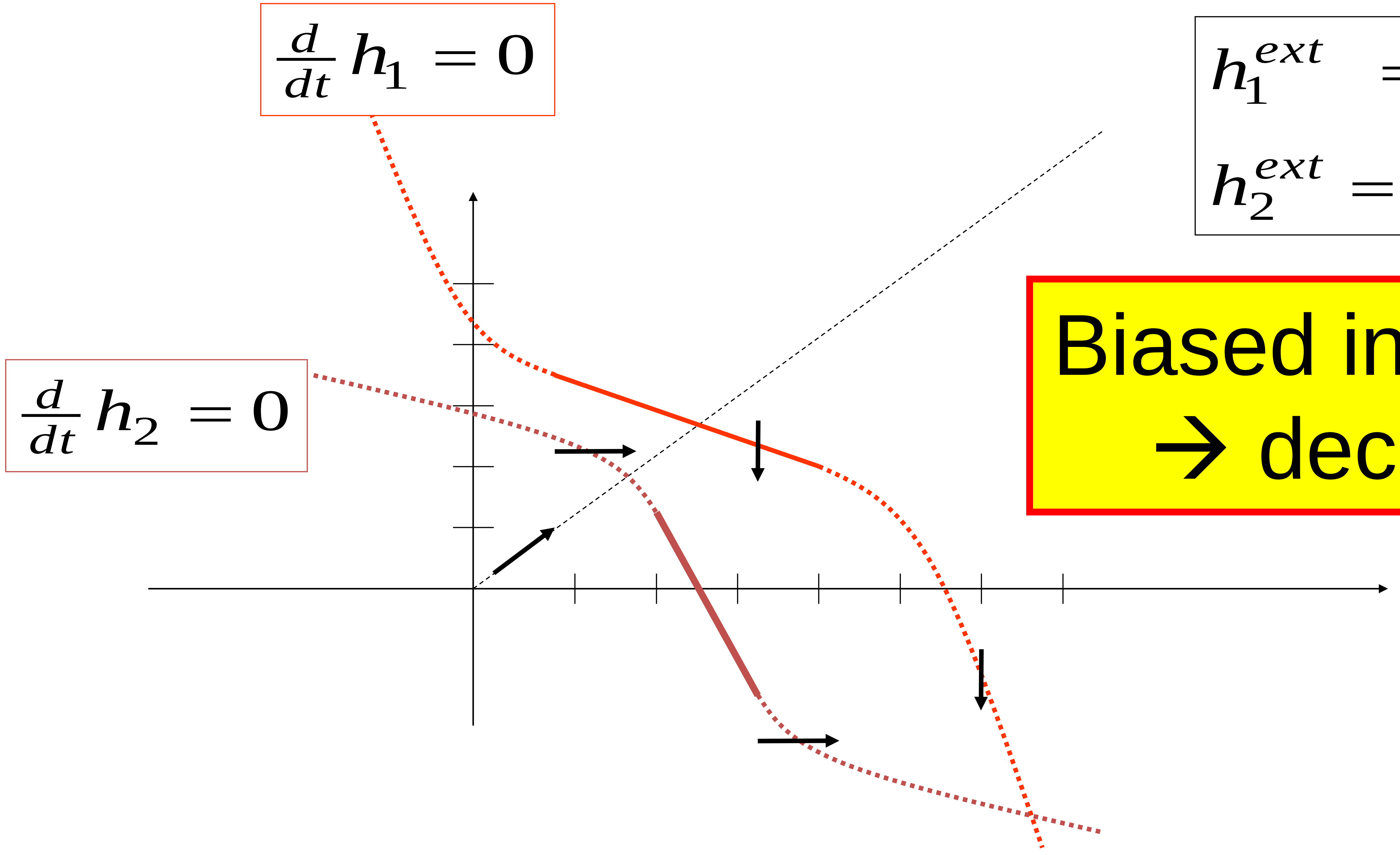
Symmetric, but strong input



Week 12-part 3: Theory of decision dynamics: biased strong

Population activity

Phase plane



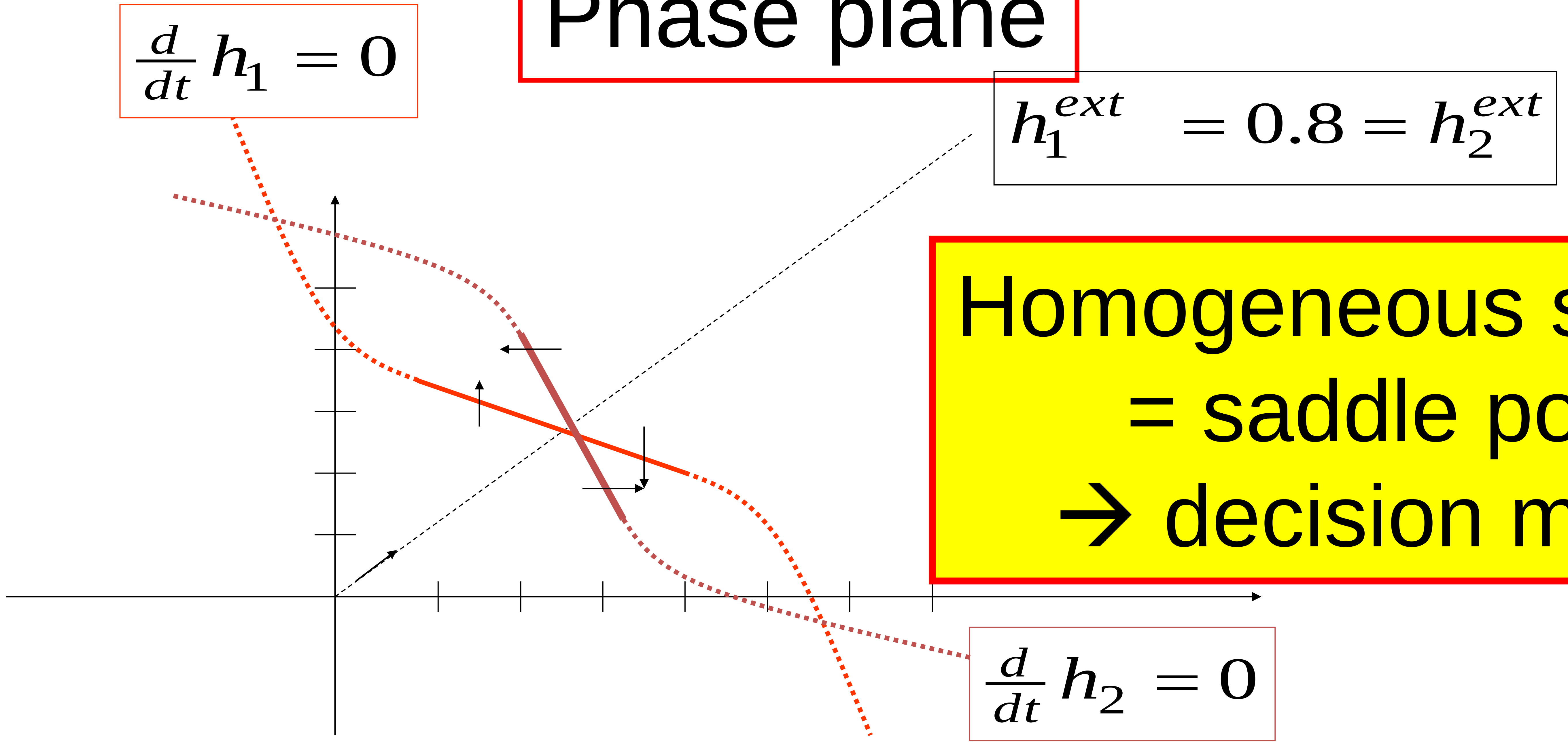
$h_1^{ext} = 0.8;$

$h_2^{ext} = 0.2$

Biased input = stable fixed point
→ decision reflects bias

Week 12-part 3: Theory of decision dynamics: unbiased strong

Phase plane



Homogeneous solution

= saddle point

→ decision must be taken

Week 12– Decision models, part 3

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Biological Modeling of Neural Networks:

Week 12 – Decision models: Competitive dynamics

Wulfram Gerstner

EPFL, Lausanne, Switzerland

12.1 Review: Population dynamics
- competition

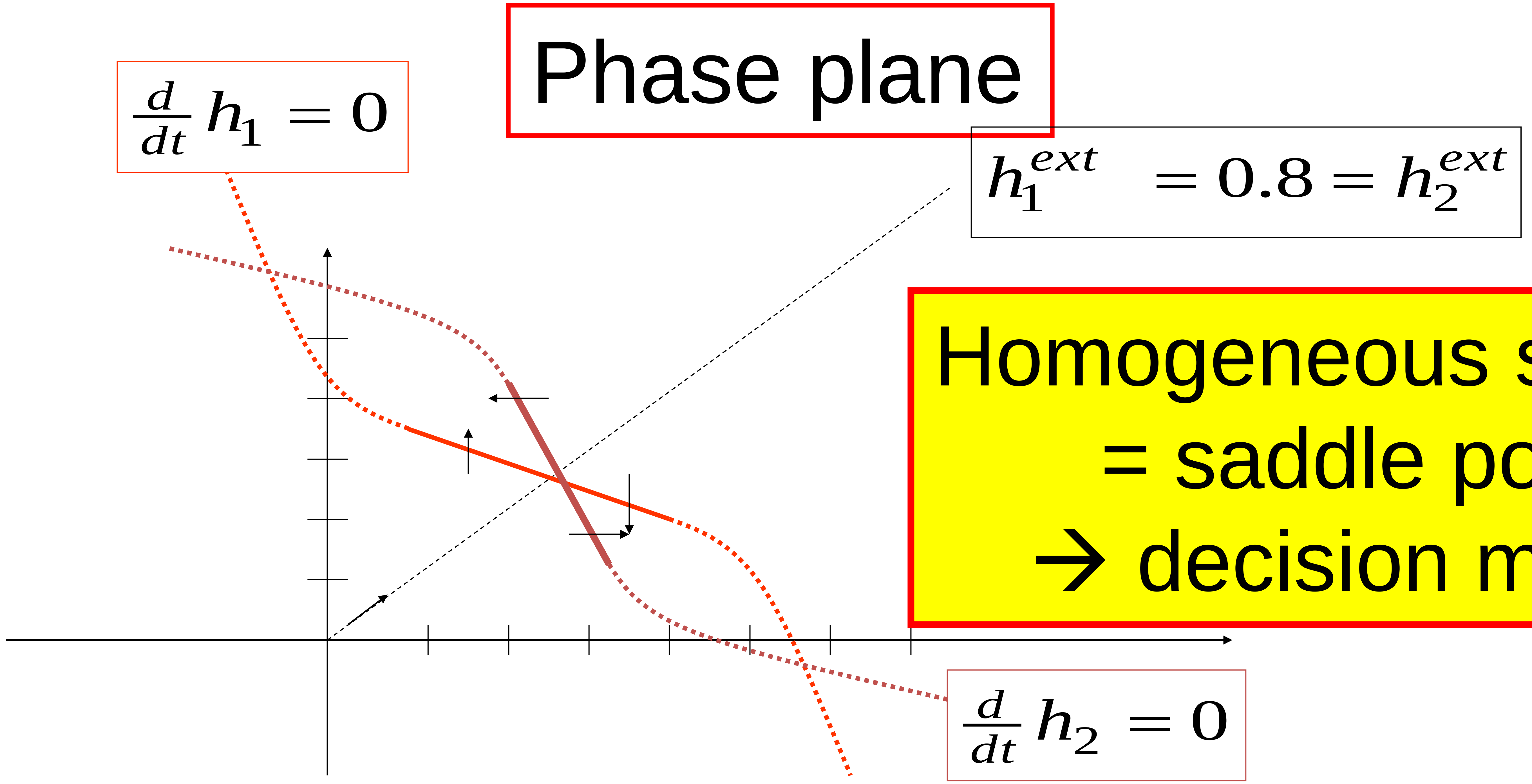
12.2 Perceptual decision making
- V5/MT
- Decision dynamics: Area LIP

12.3 Theory of decision dynamics
- shared inhibition
- effective 2-dim model

12.4. Decisions in connected pops.
- unbiased case
- biased input

12.5. Decisions, actions, volition
- the problem of free will

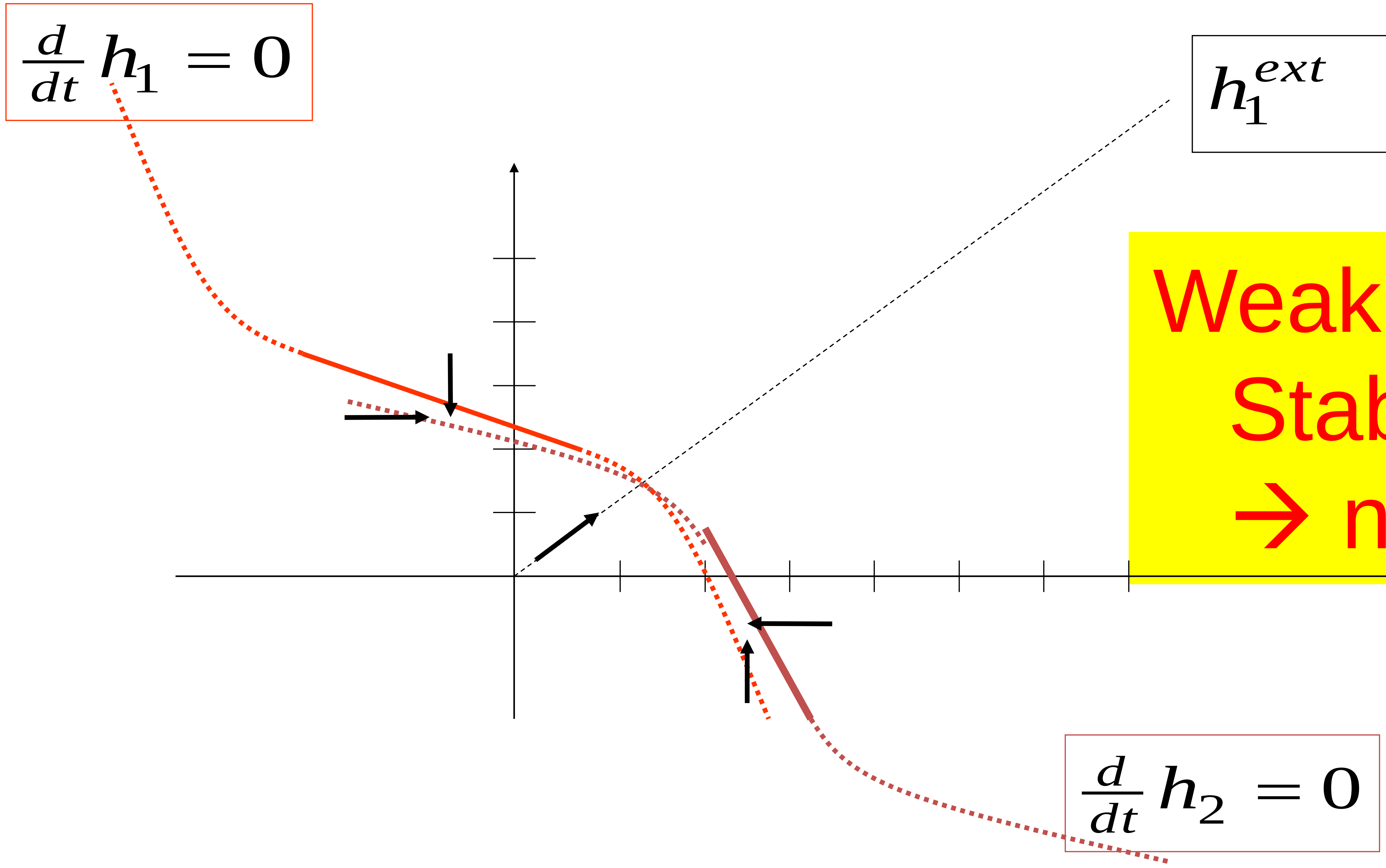
Week 12-part 4: Review: unbiased strong



Homogeneous solution
= saddle point
→ decision must be taken

Week 12-4: Review: unbiased weak

Phase plane – symmetric but small input



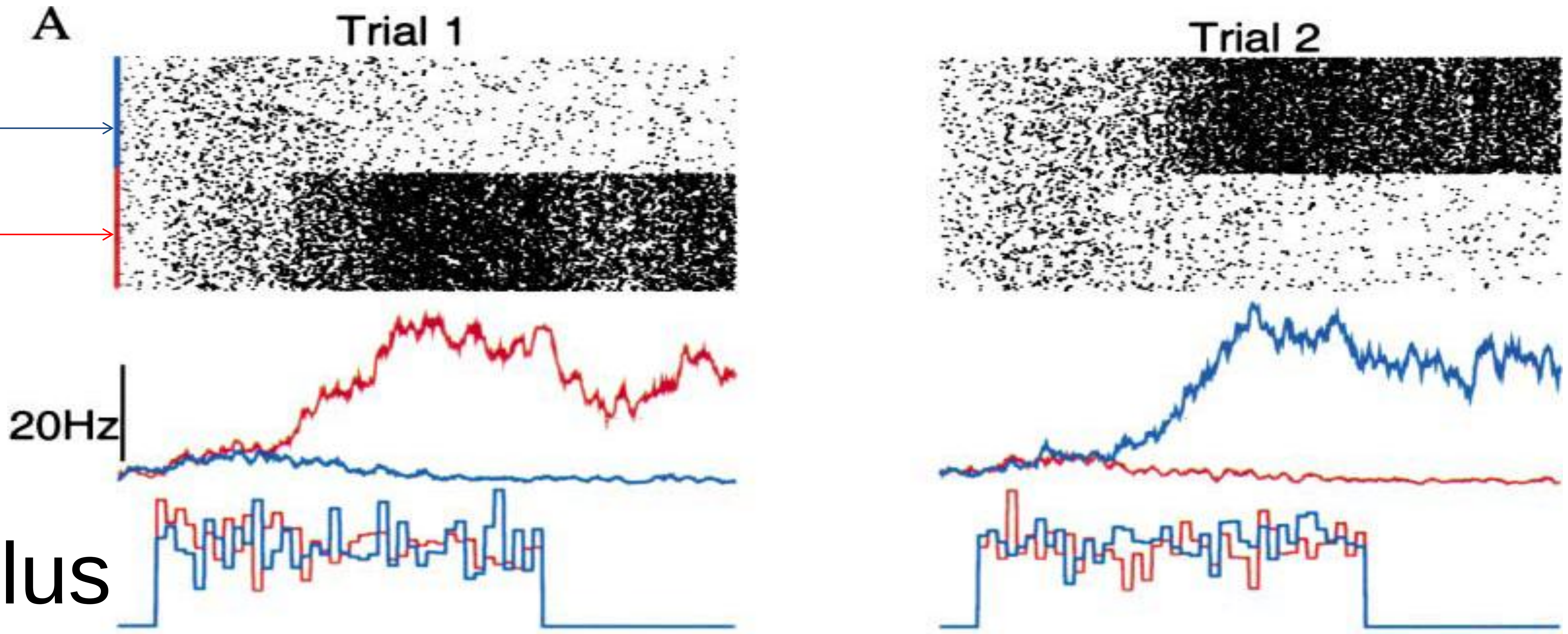
Weak external input:
Stable fixed point
→ no decision

Simulation of 3 populations of spiking neurons, unbiased strong input

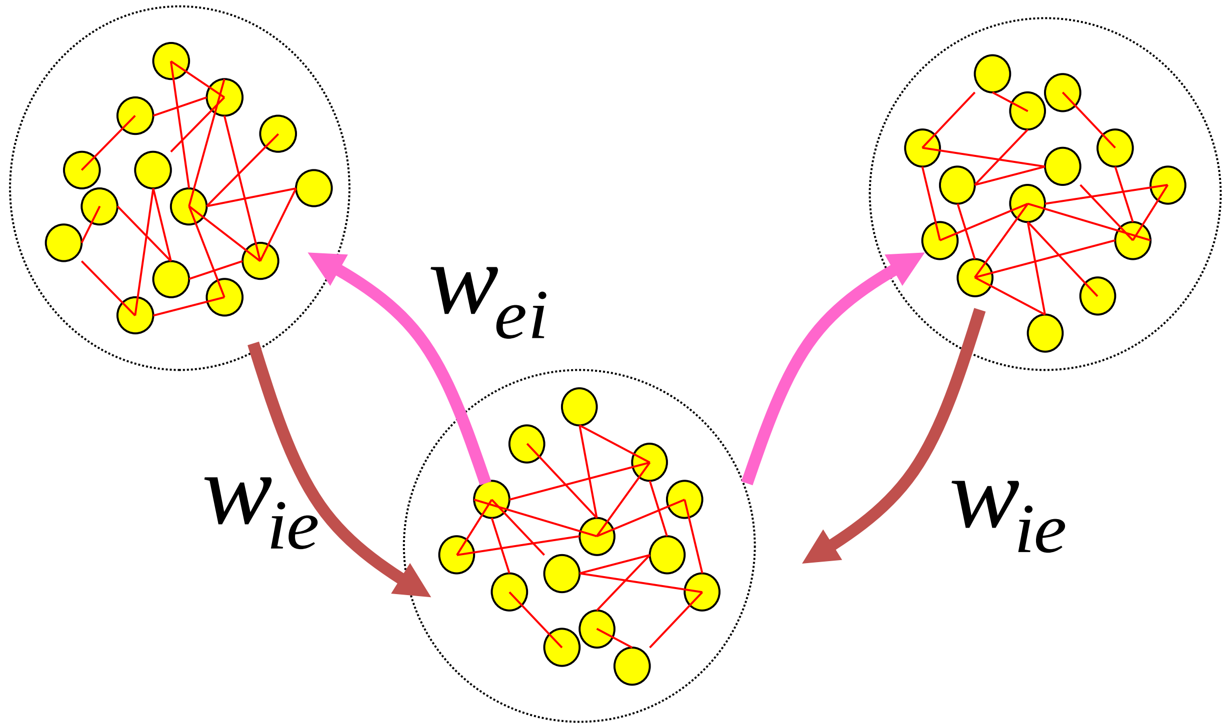
Popul. 2

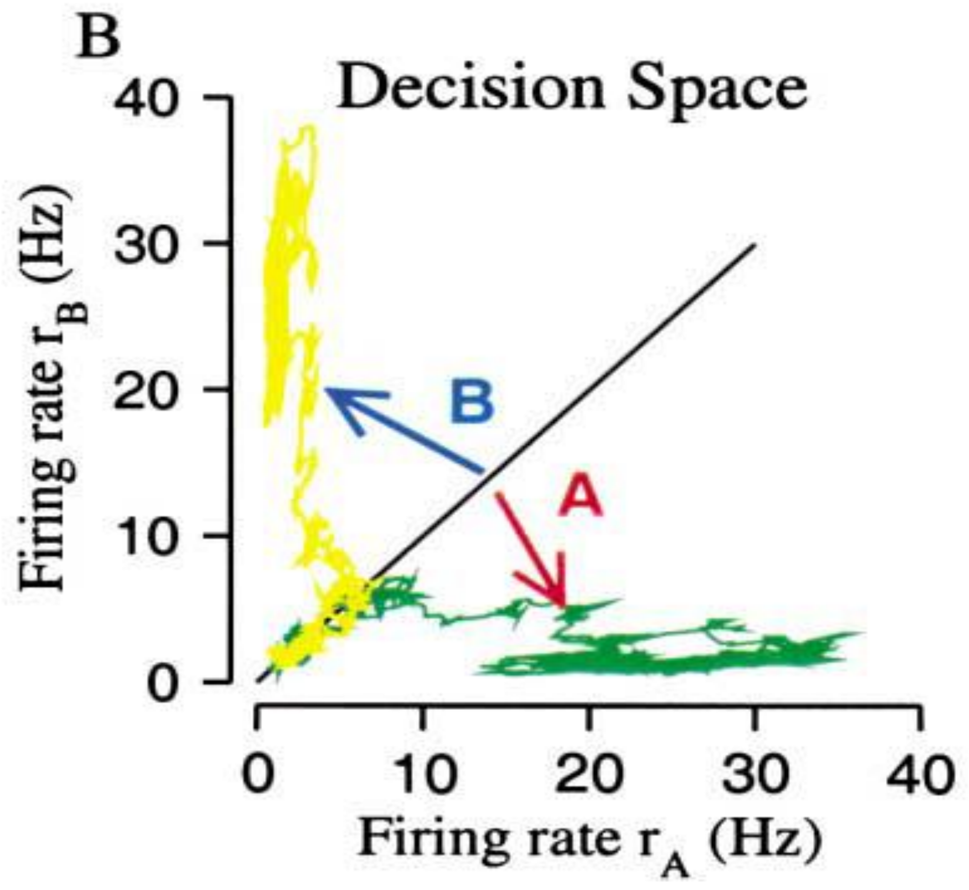
Popul.1

stimulus



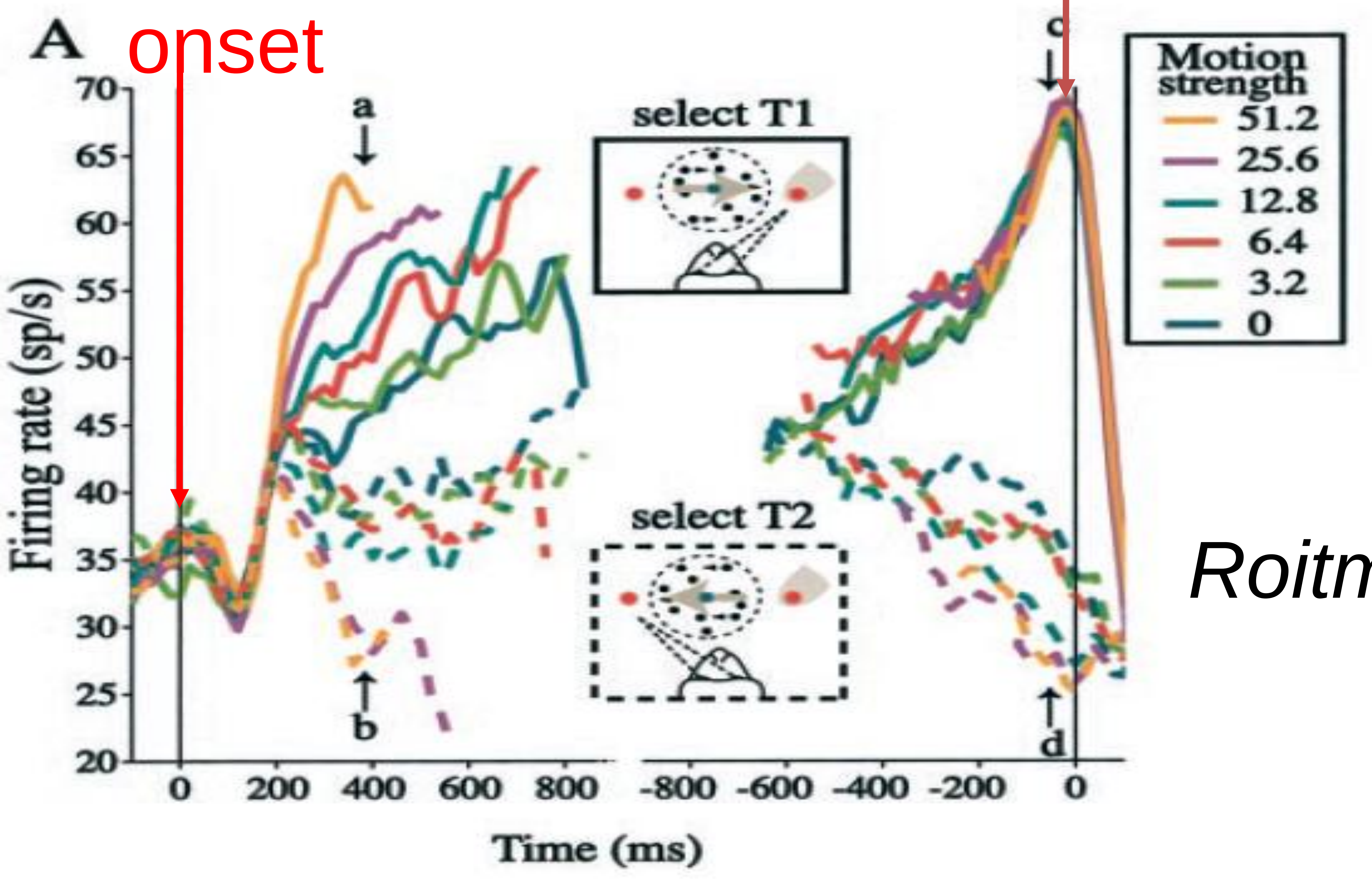
X.J. Wang, 2002
NEURON





saccade onset

Stimulus onset



Roitman and Shadlen 2002

Figure 7. Time course of LIP activity in the RT-direction-discrimination task. *A*, Average response from 54 LIP neurons. Responses are grouped by motion strength and choice as indicated by *color* and *line type*. The responses are aligned to two events in the trial. On the *left*, responses are aligned to the onset of stimulus motion. Response averages in this portion of the graph are drawn to the median RT for each motion strength and exclude any activity within 100 msec of eye movement initiation. On the *right*, responses are aligned to initiation of the eye movement response. Response averages in this portion of the graph show the buildup and decline in activity at the end of the decision process. They exclude any activity within 200 msec of motion onset. The average firing rate was smoothed using a 60 msec running mean. *Arrows* indicate the epochs used to compare spike rate as a function

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Biological Modeling of Neural Networks:

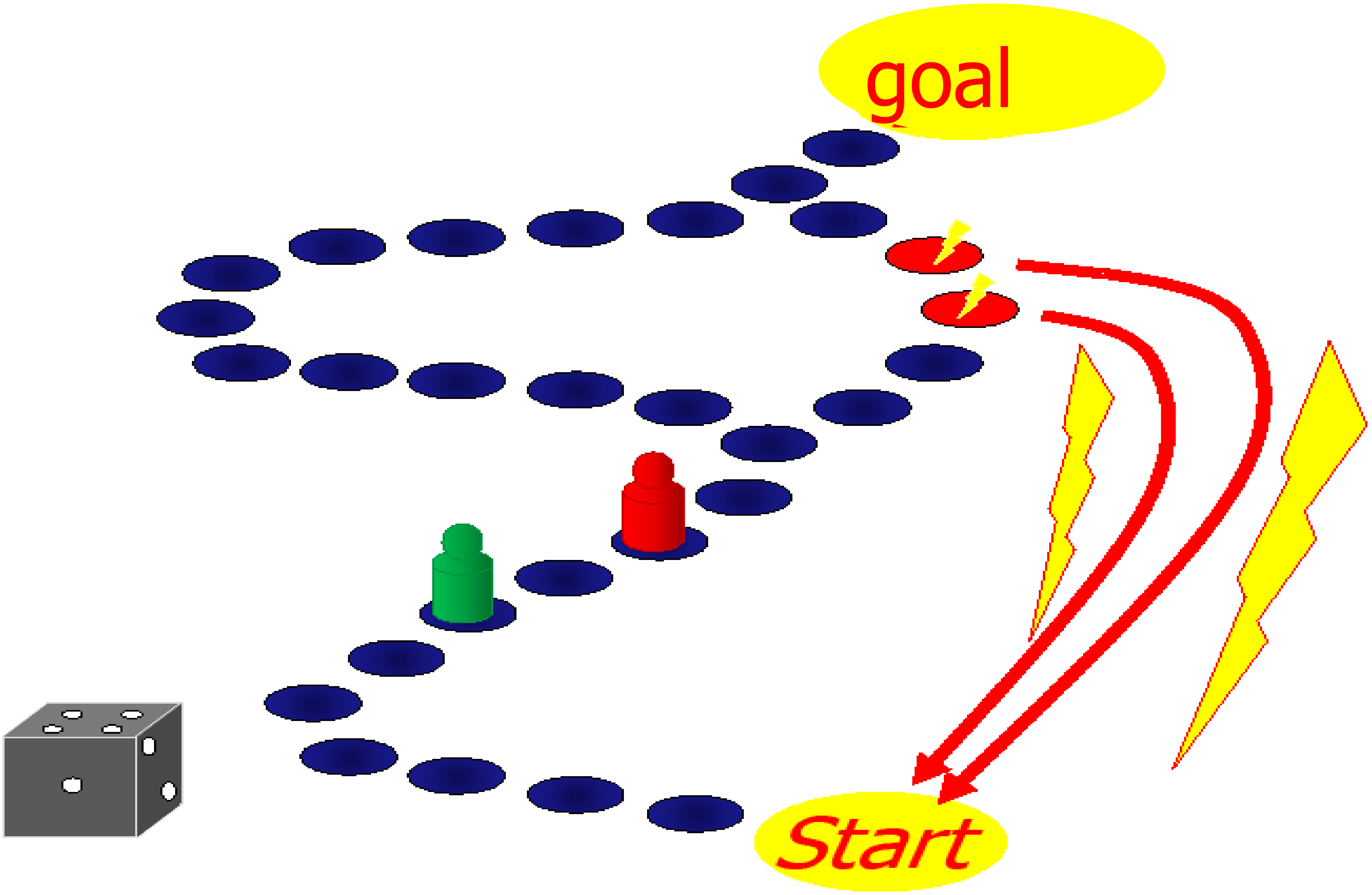
Week 12 – Decision models: Competitive dynamics

Wulfram Gerstner

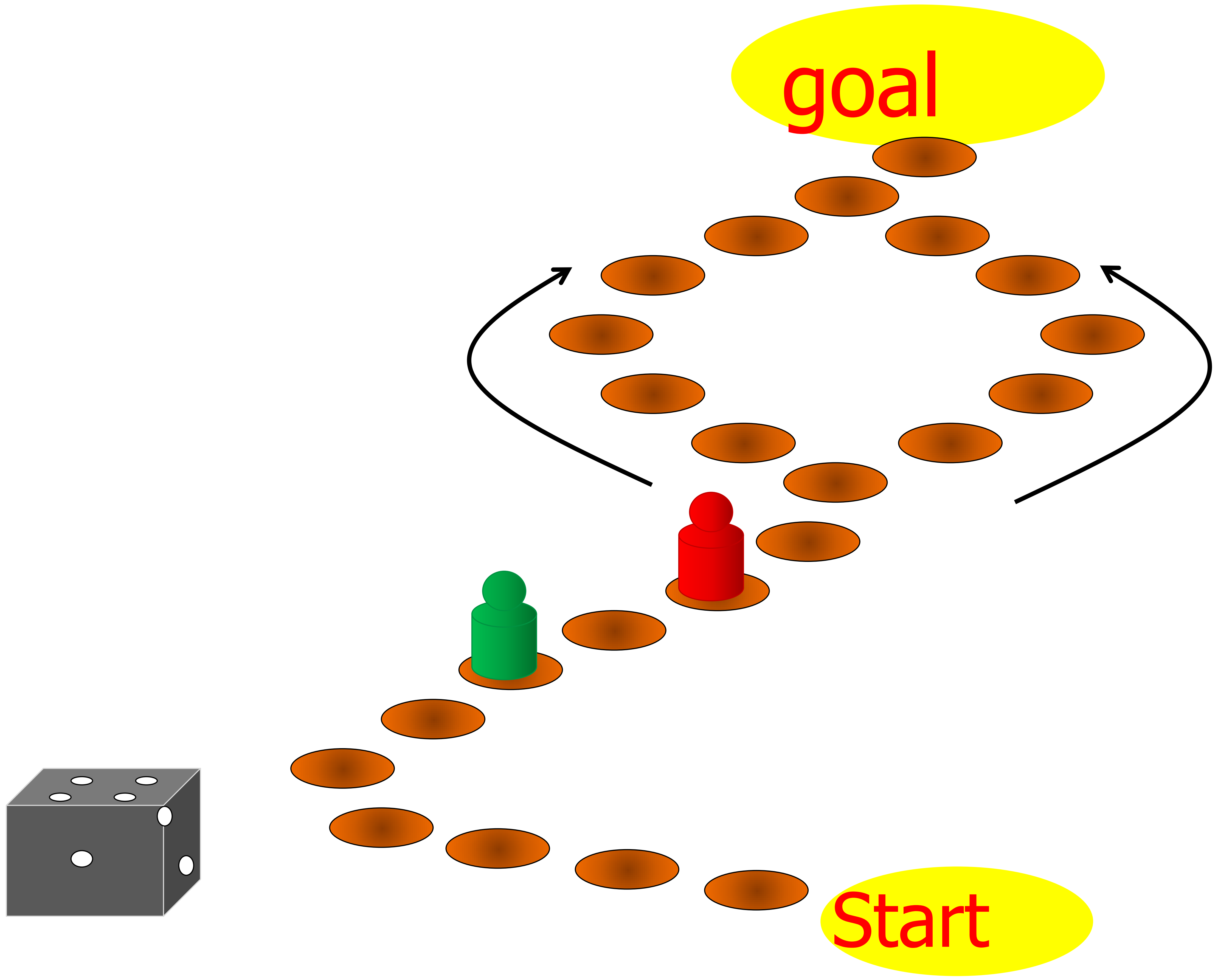
EPFL, Lausanne, Switzerland

Week 12-5: Decision: risky vs. safe

How would you decide?

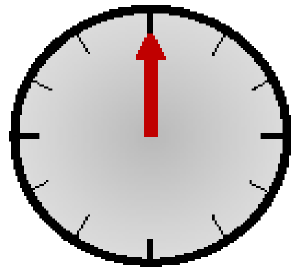


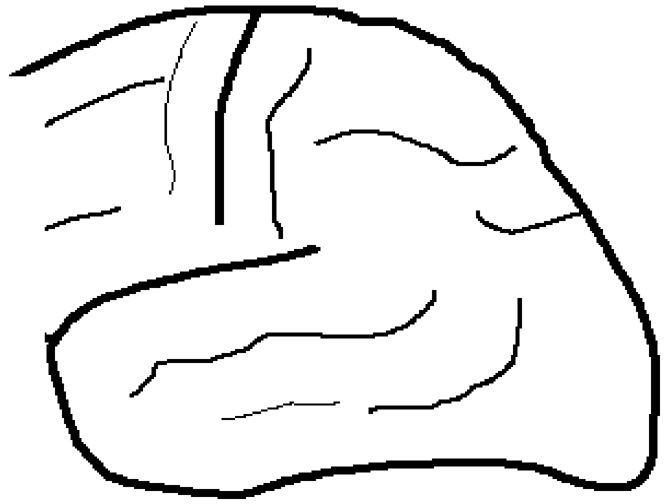
How would you decide?



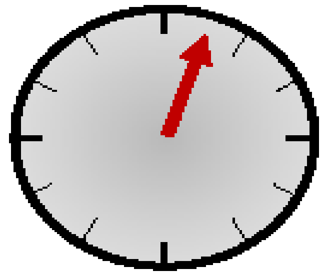
fMRI variant of Libet experiment

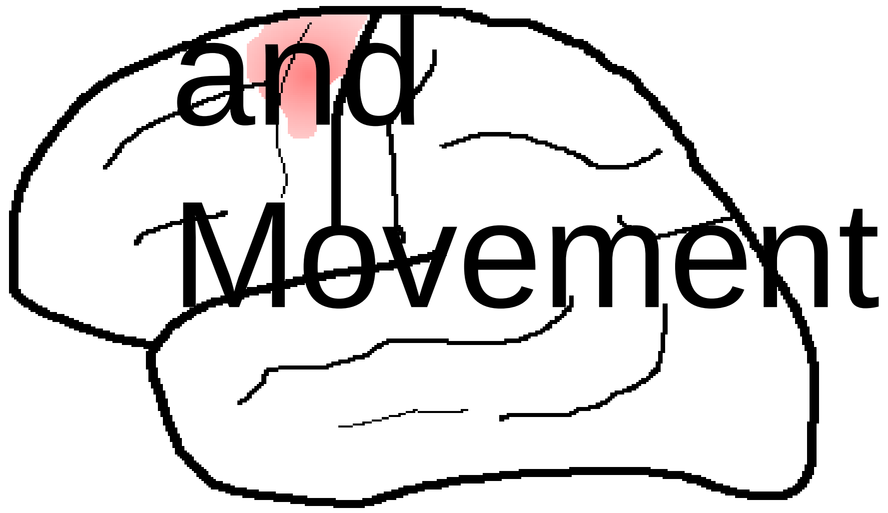
x a r h q e f g y t u



Preparation 

x a r h q e f g y t u





-Subject decides spontaneously
 to move left or right hand

- report when they made their decision

Libet, Behav. Brain Sci., 1985

Soon et al., Nat. Neurosci., 2008

What decides? Who decides?

'Your brain decides what you want or what you prefer … '

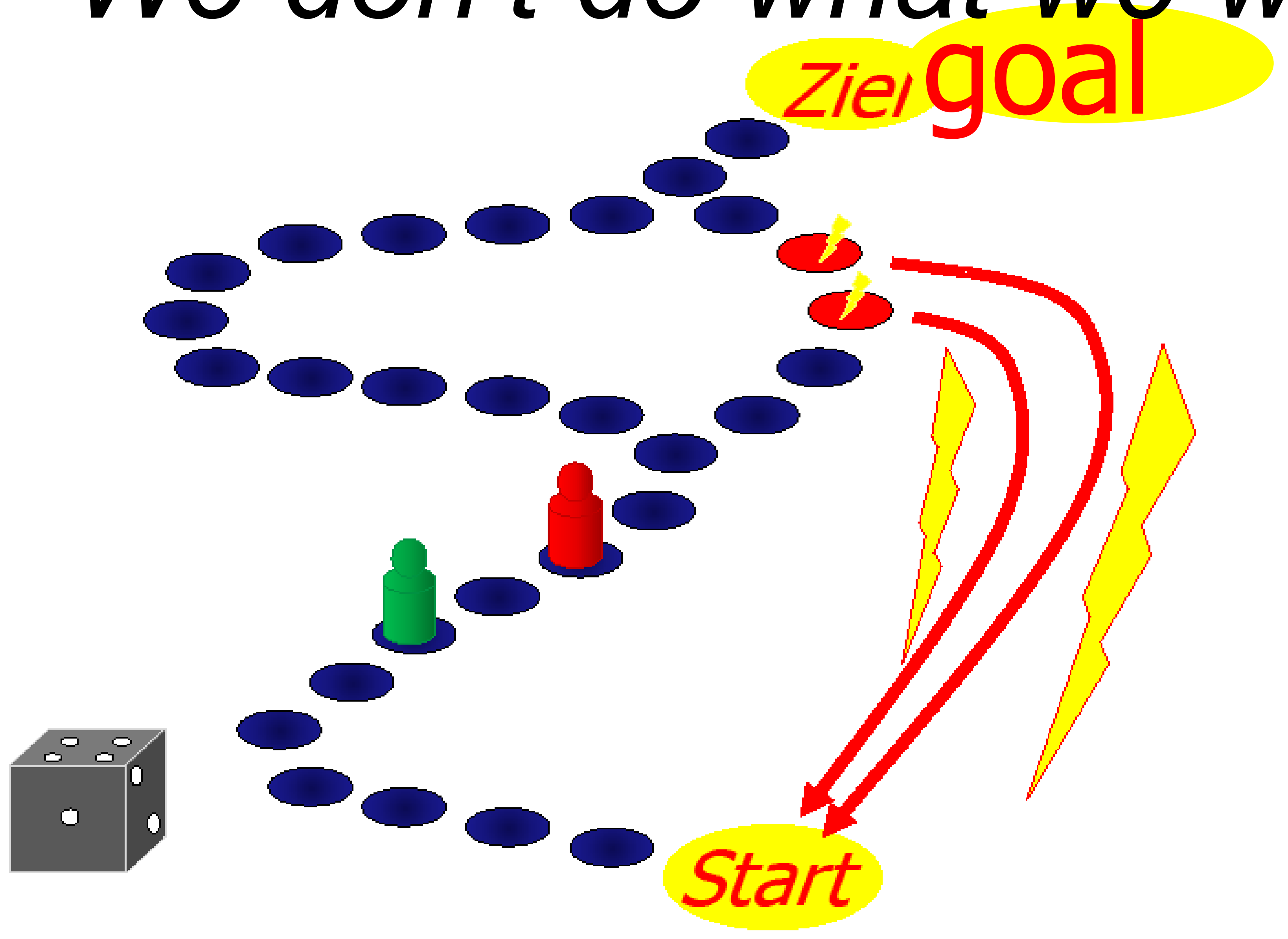
' … but your brain – this is you!!!'

-Your experiences are memorized in your brain

-Your values are memorized in your brain

-Your decisions are reflected in brain activities

'We don't do what we want, but we want what we do' (W. Prinz)



The problem of Free Will (see e.g. Wikipedia article)

Decision, Perception and Competition in Connected Populations

Wulfram Gerstner
EPFL

Suggested Reading:
- *Salzman et al. Nature 1990*
- *Roitman and Shadlen, J. Neurosci. 2002*
- *Abbott, Fusi, Miller: Theoretical Approaches to Neurosci.*
- *X.-J. Wang, Neuron 2002*
- *Libet, Behav. Brain Sci., 1985*
- *Soon et al., Nat. Neurosci., 2008*
- *free will, Wikipedia*

Chapter 16, *Neuronal Dynamics*, Gerstner et al. Cambridge 2014