Decision, Perception and Competition in Connected Populations

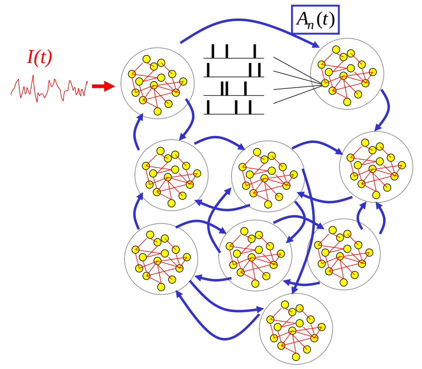
Lecture 13
Course: Neural Networks and Biological Modeling

Wulfram Gerstner
EPFL

-Review: Population Equations
-Motion Detection in Cortex (Area MT)
-Decision Dynamics - Areal LIP
-Decision Dynamics – Theory
-Human Decisions and Free Will

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

Microscopic vs. Macroscopic Description



High-noise activity equation

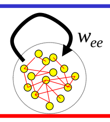
Population activity

$$A(t) = g(h(t))$$

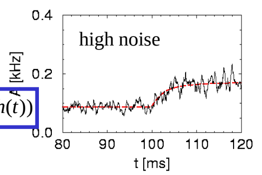
Membrane potential caused by input

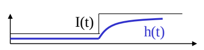
$$\tau \frac{d}{dt} h(t) = -h(t) + R\, I(t)$$

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



noise model A
(escape noise/fast noise)



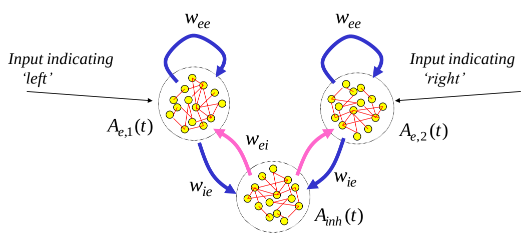


slow transient

$$A(t) = g(h(t))$$

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

Competition between two populations



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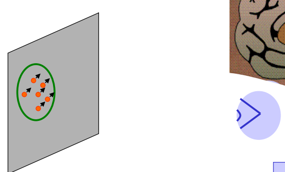
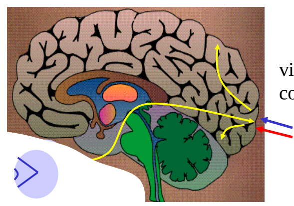
Detour: Receptive fields in V5/MT

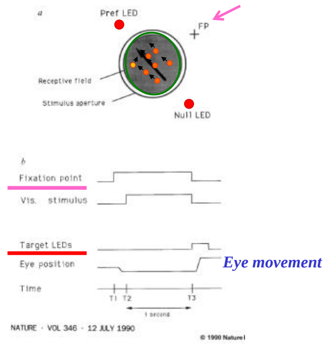




Blackboard:
Receptive Fields depend on direction of motion

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

Shadlen and Newsome: Moving dot stimuli (MT)



coherence 0.8=80%

coherence 0.5 = 50%

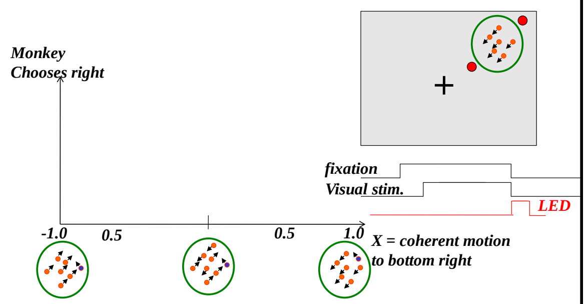
coherence 0.0

coherence -1.0

opposite direction

Salzman, Britten, Newsome, 1990

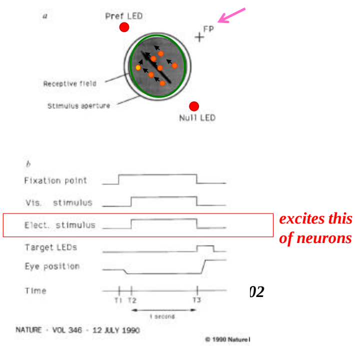
Monkey behavior w. or w/o Stimulation of neurons in V5/MT



Blackboard:
Motion detection and stimulation

Salzman, Britten, Newsome, 1990

Shadlen and Newsome: Moving dot stimuli (MT)



excites this group of neurons

coherence 0.8=80%

coherence 0.5 = 50%

coherence 0.0

coherence -1.0

Salzman, Britten, Newsome, 1990

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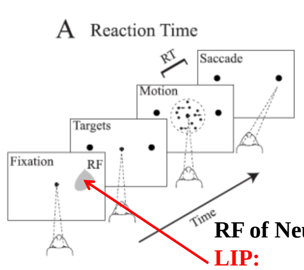
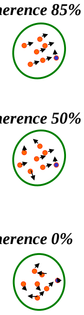
*Roitman and Shadlen 2002: moving dot stimuli (***LIP measurements***)*



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

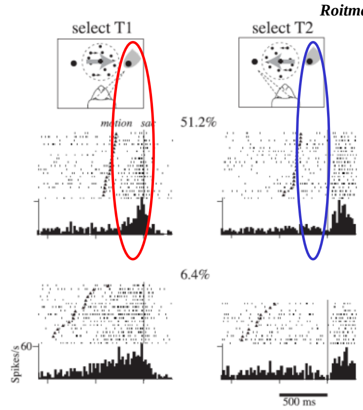


Figure 4. Response of an LIP neuron during the RT-direction-

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)

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- *X.-J. Wang, Neuron 2002*

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activity equations

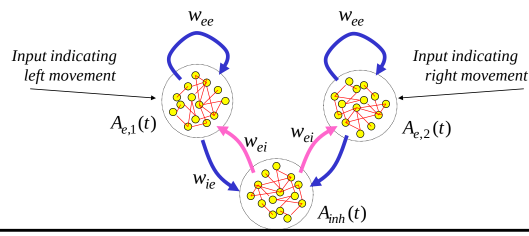
Population activity

$$A_n(t) = g(h_n(t))$$

Membrane potential caused by input

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

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



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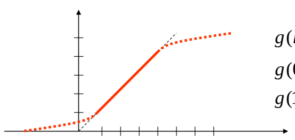
activity equations

Population activity

$$A_n(t) = g(h_n(t))$$



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

$g(0) = 0.1$

$g(1) = 0.9$

Inhibitory Population

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

Blackboard:
reduction from 3 to 2 equations

---

activity equations

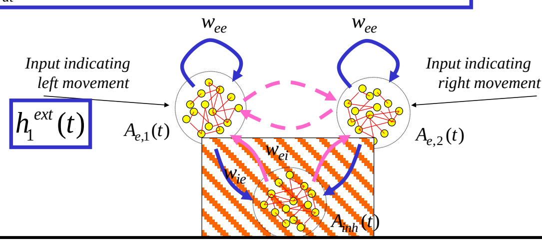
Population activity

$$A_n(t) = g(h_n(t))$$

Membrane potential caused by input

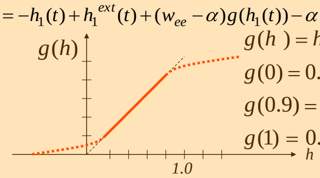
$$\tau \tfrac{d}{dt} h_1(t) = -h_1(t) + h_1^{ext}(t) + (w_{ee} - \alpha) g(h_1(t)) - \alpha\, g(h_2(t))$$

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



Exercise 1 now: draw nullclines and flow arrows

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



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

$g(0) = 0.1$

$g(0.9) = 0.85$

$g(1) = 0.9$

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

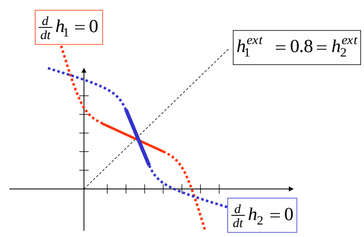
$\tfrac{d}{dt} h_1 = 0$	h_1	$g(h_2)$	h_2
	1.0		
	0.8		
	0.2		
	0.0		

$\tfrac{d}{dt} h_2 = 0$	h_2	$g(h_1)$	h_1
	1.0		
	0.8		
	0.2		
	0.0		

Next Lecture at 10:25

Phase plane, strong external input

Population activity



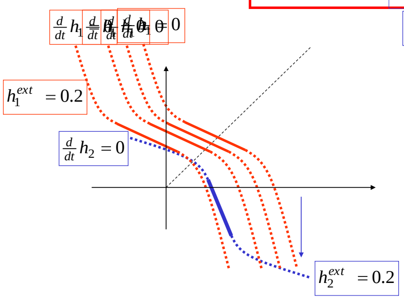
$g(h) = h$ for $0.2 < h < 0.8$

$g(0) = 0.1$

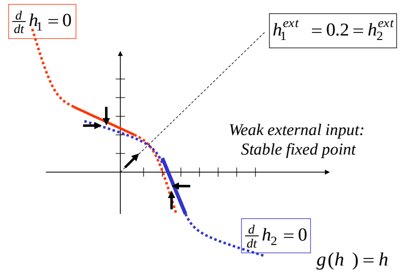
$g(1) = 0.9$

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

Population activity



Phase plane – symmetric but small input



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

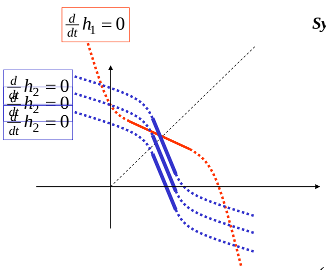
$g(0) = 0.1$

$g(1) = 0.9$

Phase plane

Population activity

Symmetric, but strong input



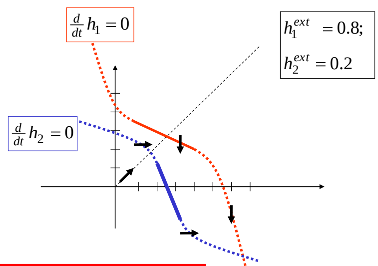
$g(h) = h \quad for \quad 0.2 < h < 0.8$

$g(0) = 0.1$

$g(1) = 0.9$

Phase plane

Population activity



Biased input = stable fixed point
→ decision reflects bias

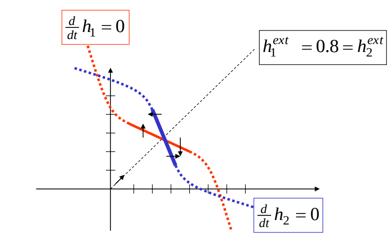
$g(h) = h \quad for \quad 0.2 < h < 0.8$

$g(0) = 0.1$

$g(1) = 0.9$

Phase plane

Population activity



Homogeneous solution = saddle point
→ decision must be taken

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

$g(0) = 0.1$

$g(1) = 0.9$

Exercise 2.1 now: stability of homogeneous solution

$A_n(t) = g(h_n(t))$

Membrane potential caused by input

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

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

Assume: $h_1^{ext} = h_2^{ext} = b$

a) Calculate homogeneous fixed point $h_1 = h_2 = h^*(b)$

b) Analyze stability of the fixed point h(b) as a function of b

Next Lecture at 11:15

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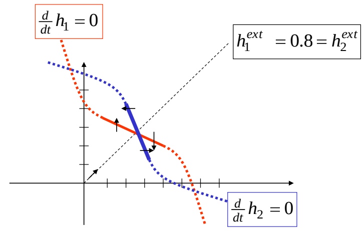
Suggested Reading:
- Abbott, Fusi, Miller: Theoretical Approaches to Neurosci.
- X.-J. Wang, Neuron 2002

Population activity

Phase plane



Homogeneous solution = saddle point
→ decision must be taken

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

$g(0) = 0.1$

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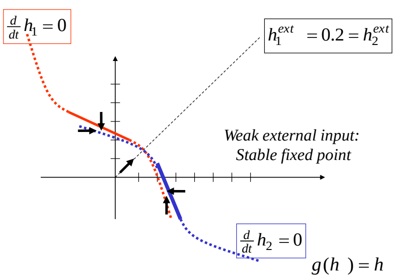
Phase plane



Weak external input:
Stable fixed point

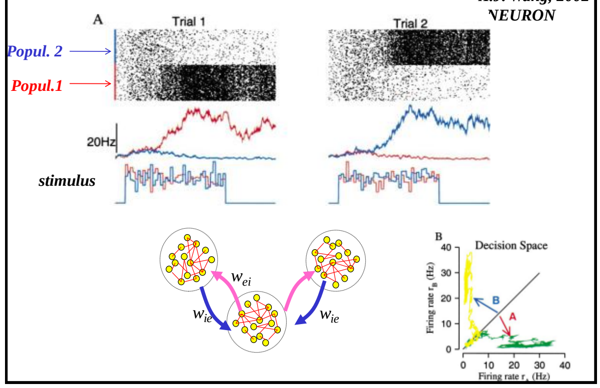
$g(h) = h \quad for \quad 0.2 < h < 0.8$

$g(0) = 0.1$

$g(1) = 0.9$

Simulation of 3 populations of spiking neurons, unbiased strong input

X.J. Wang, 2002 NEURON



Roitman and Shadlen 2002

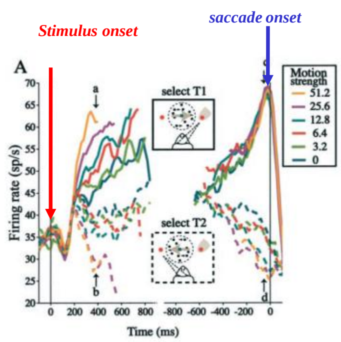


Figure 7. Time course of LIP activity in the RT-direction-discrimination task. *A*, Average response from 54 LIP neurons. Responses are grouped by motion strength and choice as indicated by *color* and *line type*. The responses are aligned to two events in the trial. On the *left*, responses are aligned 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

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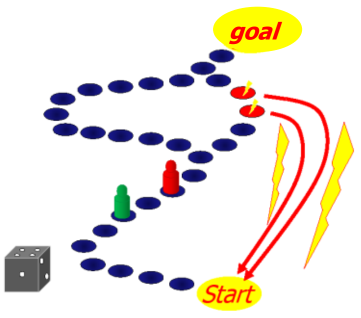
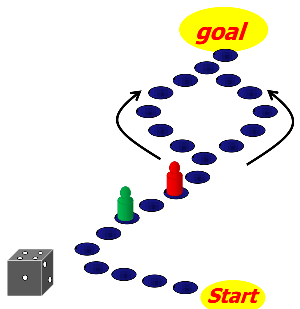
Suggested Reading: Soon et al., Nat. Neuroscience 2008

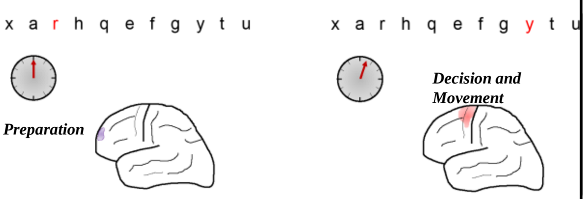
How would you decide?



How would you decide?



fMRI variant of Libet experiment



-Subject decides spontaneously
to move left or right hand
- report when they made their decision

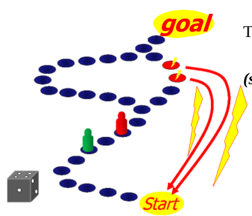
Libet, Behav. Brain Sci., 1985
Soon et al., Nat. Neurosci., 2008

What decides? Who decides?

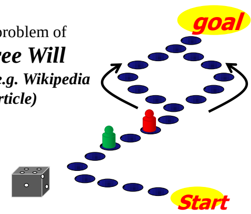
'Your brain decides what you want or what you prefer … '
'… but your brain – this is you!!!'

-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)



Last Lecture Next Week:
- prepare questions for discussion section

Exam:
- written exam 23. 06. 2011 from 8:15-11:00
- miniprojects counts 1/3 towards final grade

For written exam:
-bring 1 page A5 of own notes/summary
-HANDWRITTEN!

The end