Exam:
- written exam Wedn. 21. 06. from 8:15-11:15
- sample exams of previous years online
- miniproject counts 33 percent towards final grade

For written exam:
-bring 1 sheet A5 of own notes/summary
-HANDWRITTEN!
-no calculator, no textbook

LEARNING OUTCOMES
•Solve linear one-dimensional differential equations
•Analyze two-dimensional models in the phase plane
•Develop a simplified model by separation of time scales
•Analyze connected networks in the mean-field limit
•Formulate stochastic models of biological phenomena
•Formalize biological facts into mathematical models
•Prove stability and convergence
•Apply model concepts in simulations
•Predict outcome of dynamics
•Describe neuronal phenomena

Look at samples of past exams

Use a textbook, (Use video lectures) don't use slides (only)

Transversal skills
•Plan and carry out activities in a way which makes optimal use of available time and other resources.
•Collect data.
•Write a scientific or technical report.

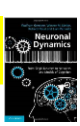
miniproject

Biological Modeling of Neural Networks:

Week 9 – Decision models: Competitive dynamics

Wulfram Gerstner
EPFL, Lausanne, Switzerland

Reading for week 9:
NEURONAL DYNAMICS
Ch. 16 (except 16.4.2)



Cambridge Univ. Press

9.1 Review: Population dynamics
- competition

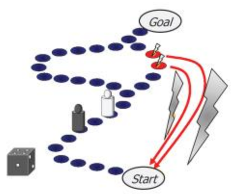
9.2 Perceptual decision making
- V5/MT
- Decision dynamics: Area LIP

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

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

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

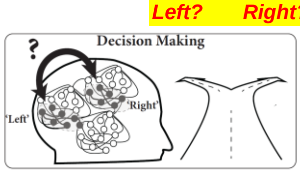
9.1: How do YOU decide?



9.1: Decision making

turn

Left? Right?

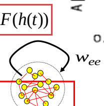


9.1: Review of week 8: High-noise activity equation

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

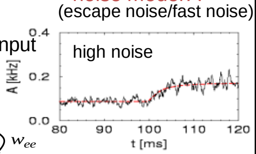
Membrane potential caused by input
$\tau \frac{d}{dt} h(t) = -h(t) + R\ I(t)$

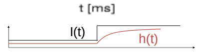
$\boxed{\tau \frac{d}{dt} h(t) = -h(t) + R I^{ext}(t) + w_{ee} F(h(t))}$



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

noise model A
(escape noise/fast noise)

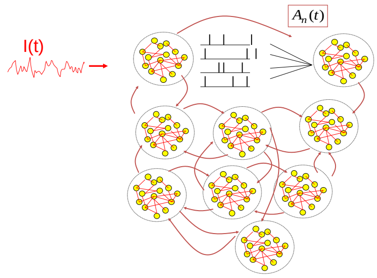




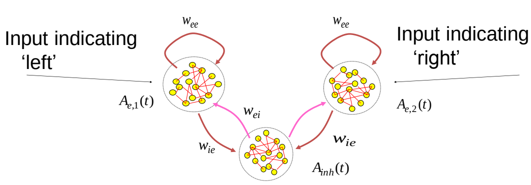
slow transient

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

9.1: Review: microscopic vs. macroscopic



9.1: Competition between two populations



9.1: How do YOU decide?

As selected EPFL student, pick your money at EPFL:

30CHF tomorrow / 100 CHF May first next year

90CHF tomorrow / 100 CHF May first next year

'Neuro-economics'

Biological Modeling of Neural Networks:

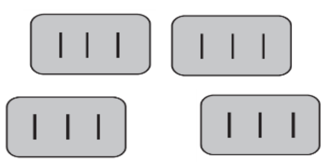
Week 9 – Decision models: Competitive dynamics

Wulfram Gerstner
EPFL, Lausanne, Switzerland

9.2: Perceptual decision making?

Bisection task:

'Is the middle bar shifted to the left or to the right?'



e.g., Herzog lab, EPFL

9.2: Detour: receptive fields in V5/MT

visual cortex

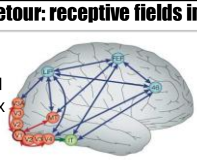
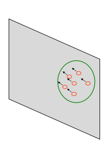


IMAGE Nature Reviews | Neuroscience



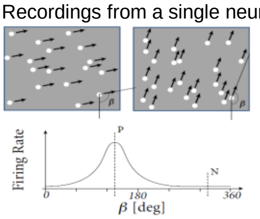
1) Cells in visual cortex MT/V5 respond to motion stimuli

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

Albright, Desimone,Gross, J. Neurophysiol, 1985

9. 2: Detour: receptive fields in V5/MT

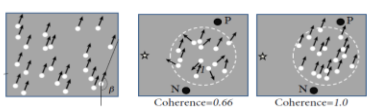
Recordings from a single neuron in V5/MT



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

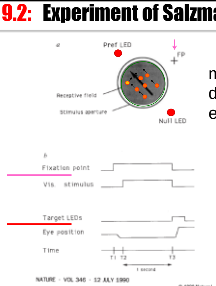
9.2: Detour: receptive fields in V5/MT



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

Image:
Gerstner et al. (2014),
Neuronal Dynamics

9.2: Experiment of Salzman et al. 1990

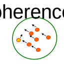


monkey indicates decision by eye movement

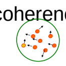
Eye movement

Image: Salzman, Britten, Newsome, 1990

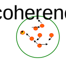
coherence 0.8=80%



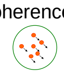
coherence 0.5 = 50%



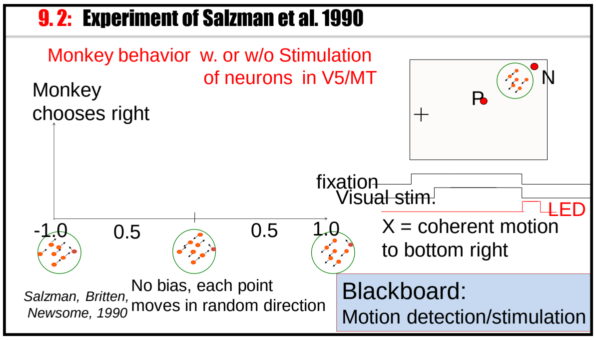
coherence 0.0

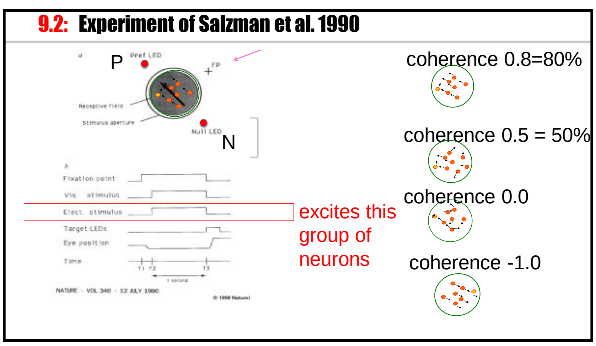


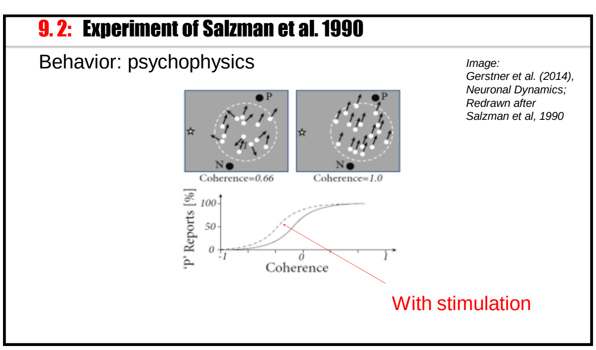
coherence -1.0



opposite direction


9. 2: Experiment of Salzman et al. 1990
Monkey behavior w. or w/o Stimulation
of neurons in V5/MT
Monkey
chooses right
P
N
fixation
Visual stim.
LED
-1.0
0.5
0.5
1.0
X = coherent motion
to bottom right
Salzman, Britten,
Newsome, 1990
No bias, each point
moves in random direction
Blackboard:
Motion detection/stimulation


9.2: Experiment of Salzman et al. 1990
P
N
excites this
group of
neurons
coherence 0.8=80%
coherence 0.5 = 50%
coherence 0.0
coherence -1.0

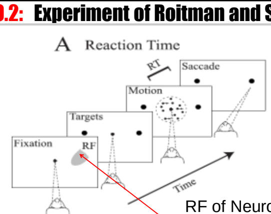

9. 2: Experiment of Salzman et al. 1990
Behavior: psychophysics
Image:
Gerstner et al. (2014),
Neuronal Dynamics;
Redrawn after
Salzman et al, 1990
Coherence=0.66
Coherence=1.0
'P' Reports [%]
Coherence
With stimulation

Biological Modeling of Neural Networks:

Week 9 – Decision models: Competitive dynamics

Wulfram Gerstner
EPFL, Lausanne, Switzerland

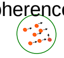
9.2: Experiment of Roitman and Shadlen in LIP (2002)



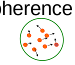
LIP is somewhere between MT (movement detection) and Frontal Eye Field (saccade control)

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

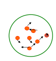
coherence 85%



coherence 50%



coherence 0%



Roitman and Shadlen 2002

9. 2: Experiment of Roitman and Shadlen in LIP (2002)

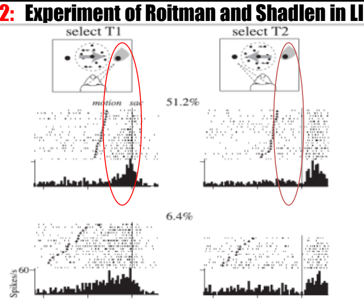


Figure 4. Response of an LIP neuron during the RT-direction-

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

Biological Modeling of Neural Networks:

Week 9 – Decision models: Competitive dynamics

Wulfram Gerstner

EPFL, Lausanne, Switzerland

9.3: Theory of decision dynamics

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

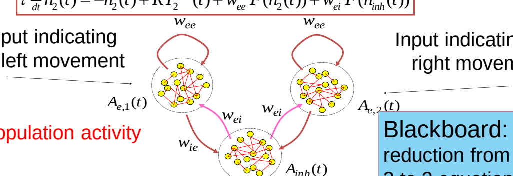
Membrane potential caused by input

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

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

Input indicating left movement

Input indicating right moveme



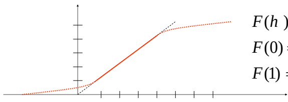
population activity

Blackboard: reduction from 3 to 2 equations

9.3: Theory of decision dynamics

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

activity equations



$F(h) = h \quad for \;\; 0.2 < h < 0.8$
$F(0) = 0.1$
$F(1) = 0.9$

Blackboard:
Linearized inhibition

Inhibitory Population

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

9.3: Effective 2-dim. model

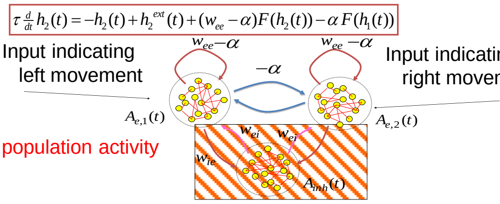
$A_n(t) = F(h_n(t))$

activity equations

Membrane potential caused by input

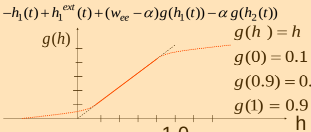
$$\boxed{\tau \tfrac{d}{dt} h_1(t) = -h_1(t) + h_1^{ext}(t) + (w_{ee} - \alpha) F(h_1(t)) - \alpha F(h_2(t))}$$

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



Exercise 1 now: draw nullclines and flow arrows

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



$g(h) = h \quad for \;\; 0.2 < h < 0.8$
$g(0) = 0.1$
$g(0.9) = 0.85$
$g(1) = 0.9$

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

$\boxed{\tfrac{d}{dt} h_1 = 0}$

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

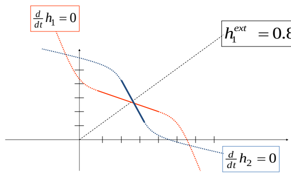
Next Lecture at 10:38

$\boxed{\tfrac{d}{dt} h_2 = 0}$

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

9.3: Theory of decision dynamics

Phase plane, strong external input



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

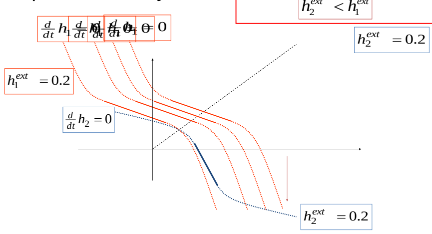
$g(0) = 0.1$

$g(1) = 0.9$

9.3: Theory of decision dynamics: biased input

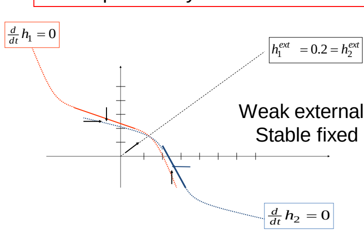
Population activity

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



9.3: Theory of decision dynamics: unbiased weak

Phase plane – symmetric but small input



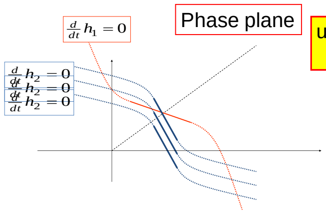
Weak external input:
Stable fixed point

9.3: decision dynamics: unbiased strong to biased

Symmetric, but strong input

Phase plane

unbiased strong input
= 2 stable fixed points

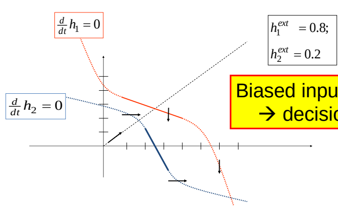


9.3: Theory of decision dynamics: biased strong

Population activity

Phase plane

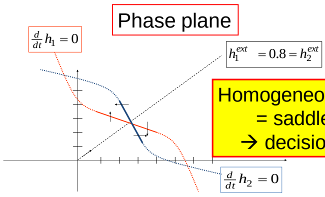
Biased input = stable fixed point
→ decision reflects bias



9.3: Theory of decision dynamics: unbiased strong

Phase plane

Homogeneous solution
= saddle point
→ decision must be taken



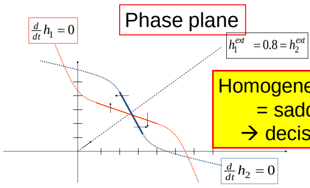
Biological Modeling of Neural Networks:

Week 9 – Decision models: Competitive dynamics

Wulfram Gerstner
EPFL, Lausanne, Switzerland

9.4: Review: unbiased strong

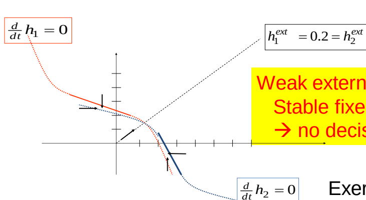
Phase plane



Homogeneous solution
= saddle point
→ decision must be taken

9.4: Review: unbiased weak

Phase plane – symmetric but small input

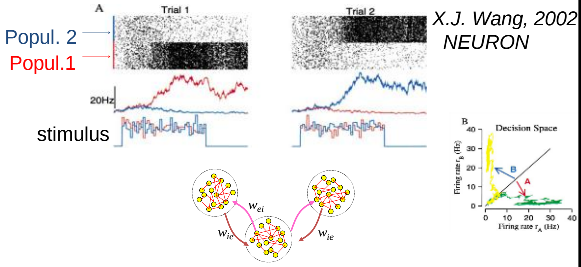


Weak external input:
Stable fixed point
→ no decision

Exercise 2 at home:
stability of symmetric solution

9.4: Decisions in populations of neurons: simulation

Simulation of 3 populations of spiking neurons, unbiased strong input

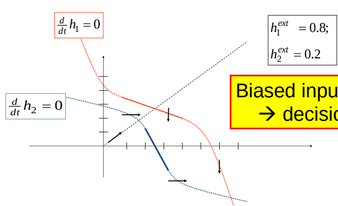


X.J. Wang, 2002 NEURON

9.3: Review: biased strong

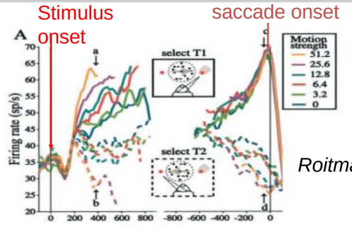
Population activity

Phase plane



Biased input = stable fixed point → decision reflects bias

9.4: Decisions in populations of neurons: LIP data



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

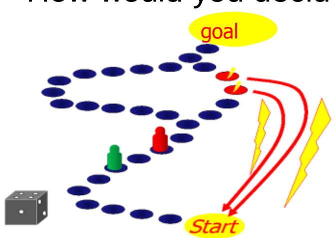
Biological Modeling of Neural Networks:

Week 9 – Decision models: Competitive dynamics

Wulfram Gerstner
EPFL, Lausanne, Switzerland

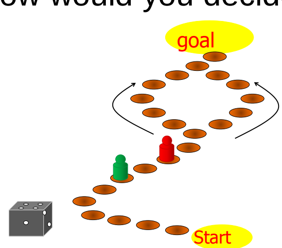
9.5: Decision: risky vs. safe

How would you decide?

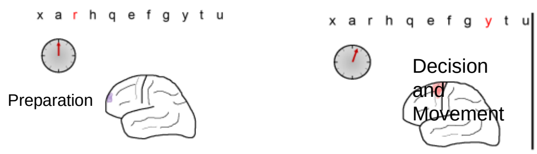


9.5: Decision: risky vs. safe

How would you decide?



9.5: fMRI variant of Libet experiment: volition and free will



-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

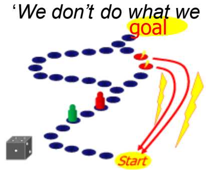
What decides? Who decides?

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

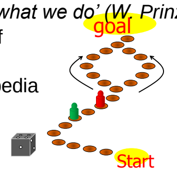
' … but your brain – this is you!!!'

-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

Exercise 2.1 now: stability of homogeneous solution

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

Membrane potential caused by input

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

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

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

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

Online course evaluation,
still open this week.
1 summary question per class
→ please do it
(for all your classes)