Biological Modeling of Neural Networks

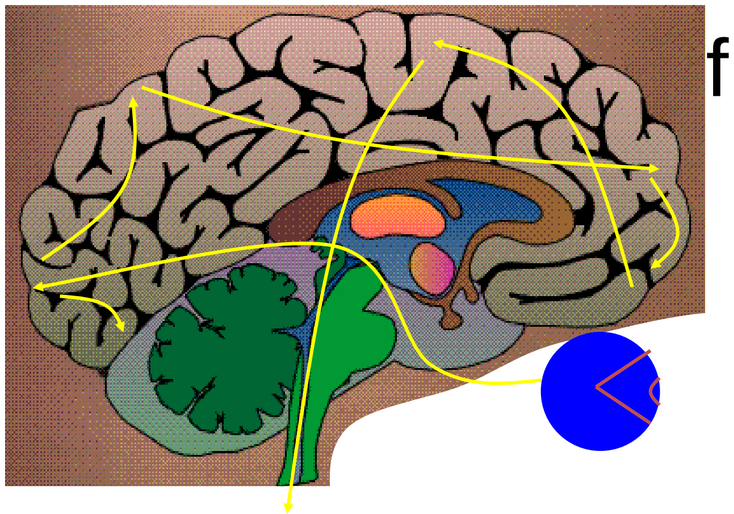
Welcome back to EPFL!!

Big question for this class:

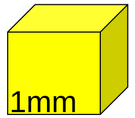
How does the brain work?

Biological Modeling of Neural Networks

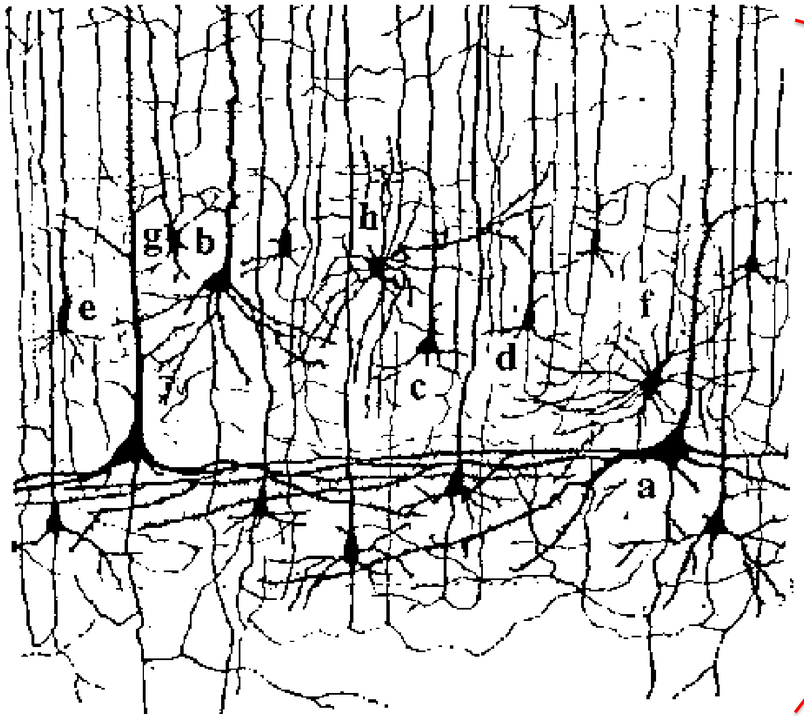
How do we recognize things?
Models of cognition
Weeks 5-10



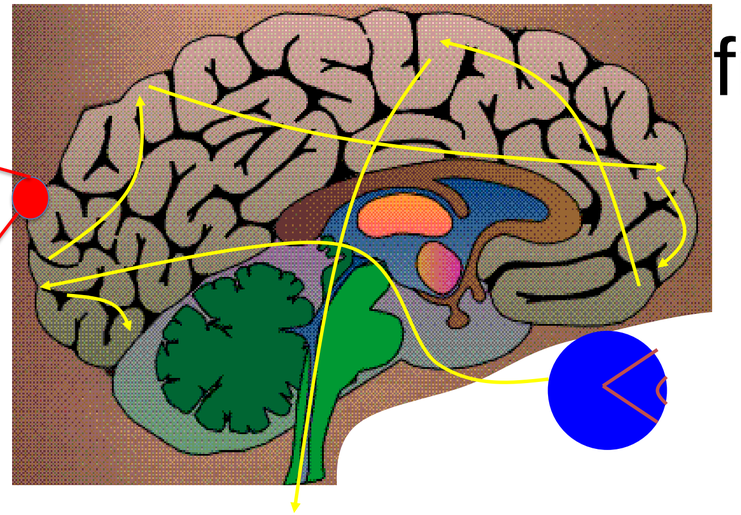
Biological Modeling of Neural Networks



10 000 neurons
3 km of wire



motor
cortex



frontal
cortex

to motor
output

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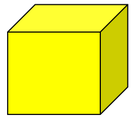
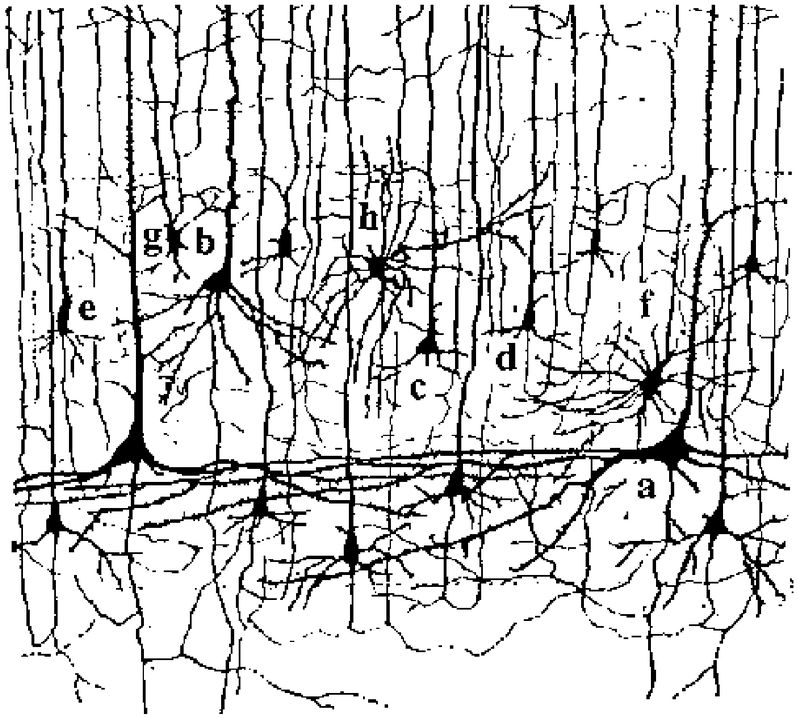


1mm

10 000 neurons

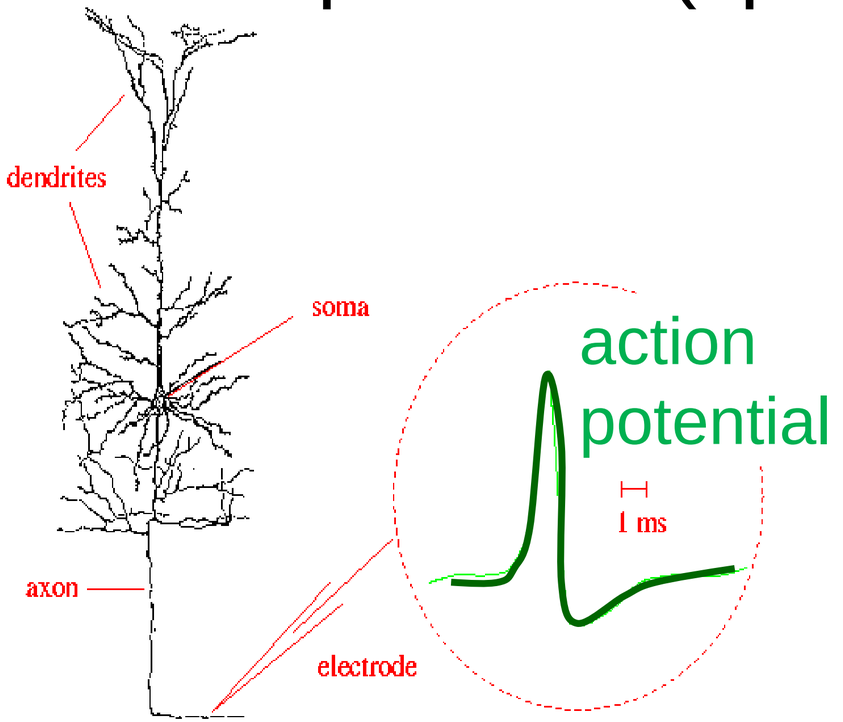
3 km of wire



Ramon y Cajal

Signal:

action potential (spike)

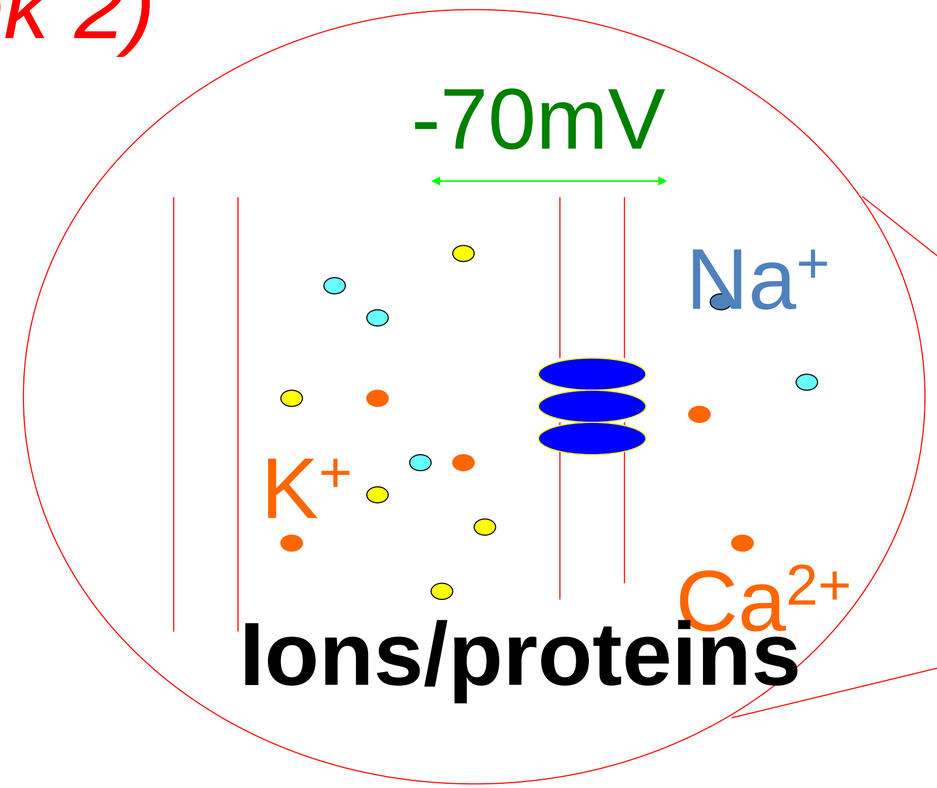


Biological Modeling of Neural Networks

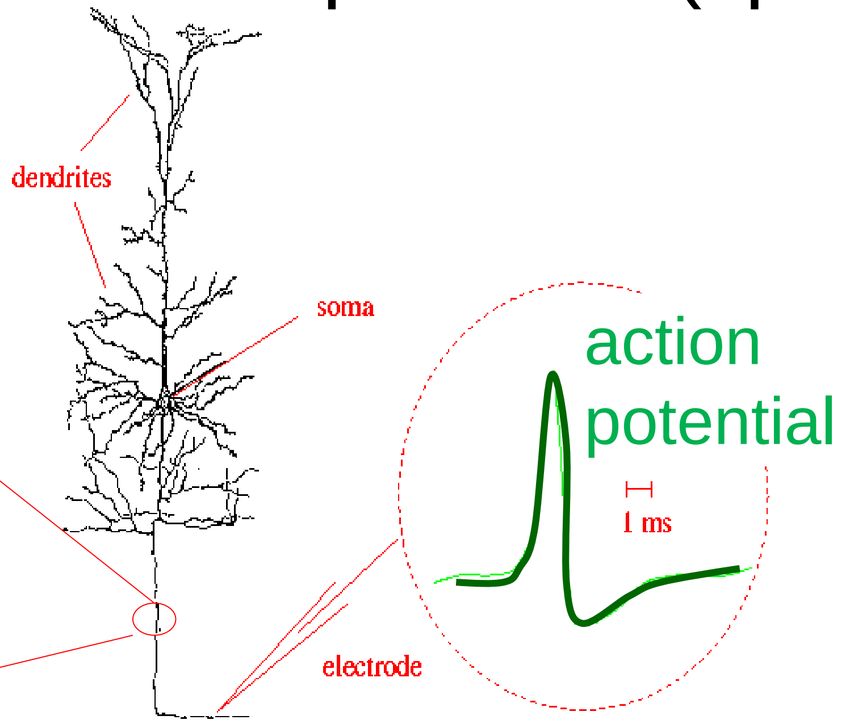
Hodgkin-Huxley type models:

Biophysics, molecules, ions

(week 2)

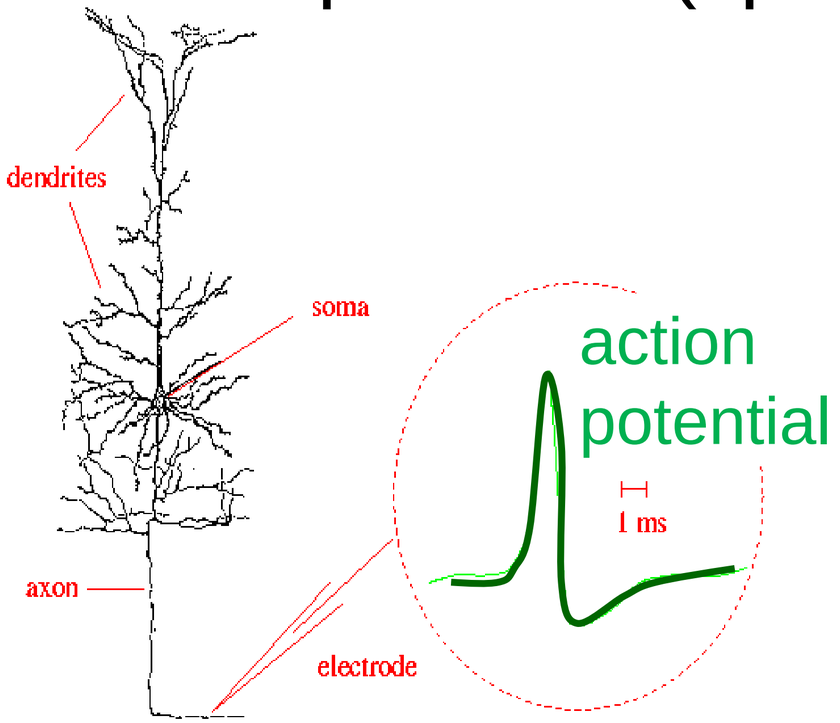


Signal:
action potential (spike)



Biological Modeling of Neural Networks

Signal:
action potential (spike)

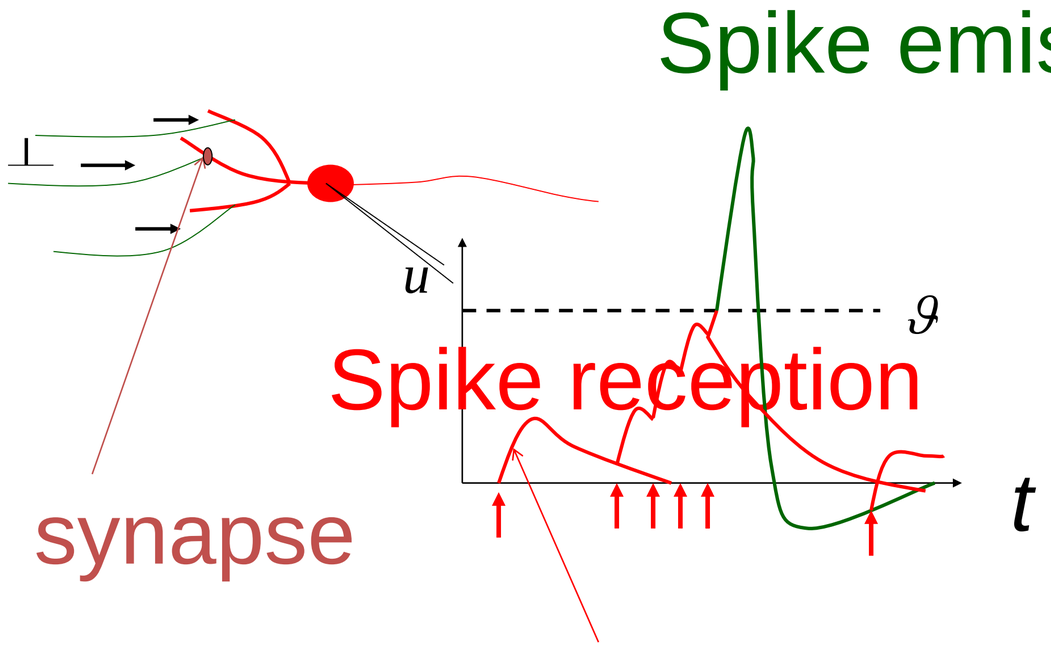


Biological Modeling of Neural Networks

Integrate-and-fire models:

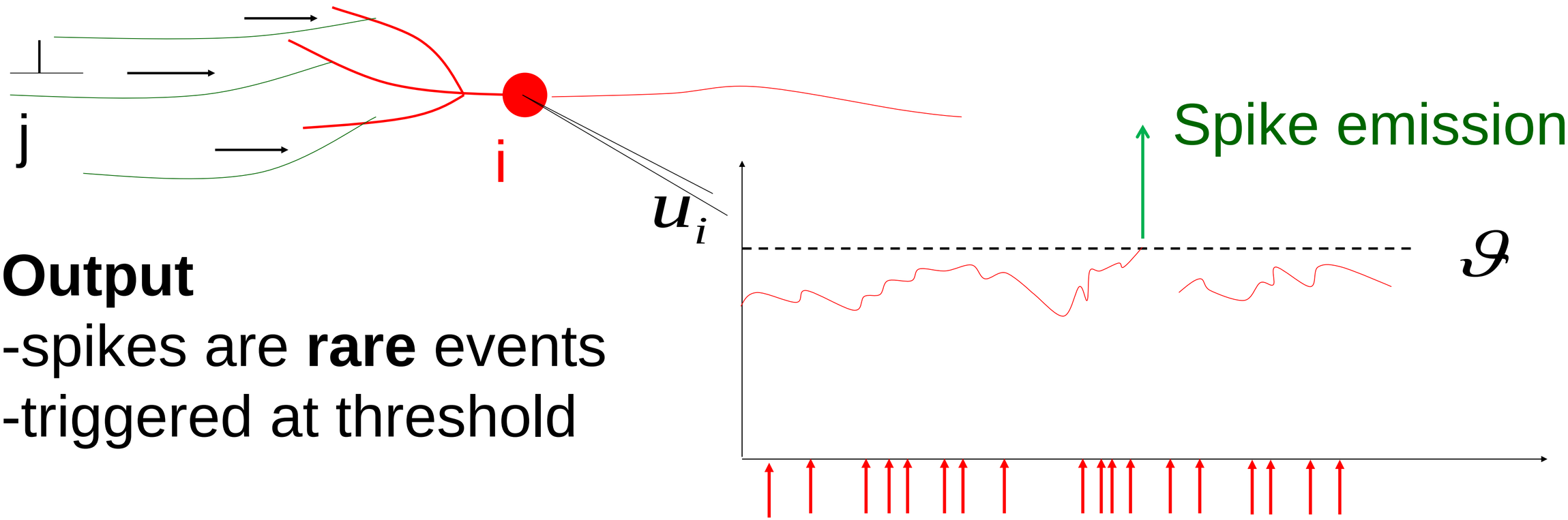
Formal/phenomenological

(week 1 and week 7-9)



-spikes are events
-triggered at threshold
-spike/reset/refractoriness

Biological Modeling of Neural Networks



Output

-spikes are **rare** events

-triggered at threshold

Subthreshold regime:

-trajectory of potential shows fluctuations

Biological Modeling of Neural Networks

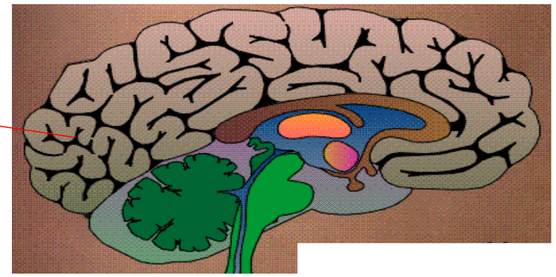
Spontaneous activity *in vivo*

What is noise?

What is the neural code?

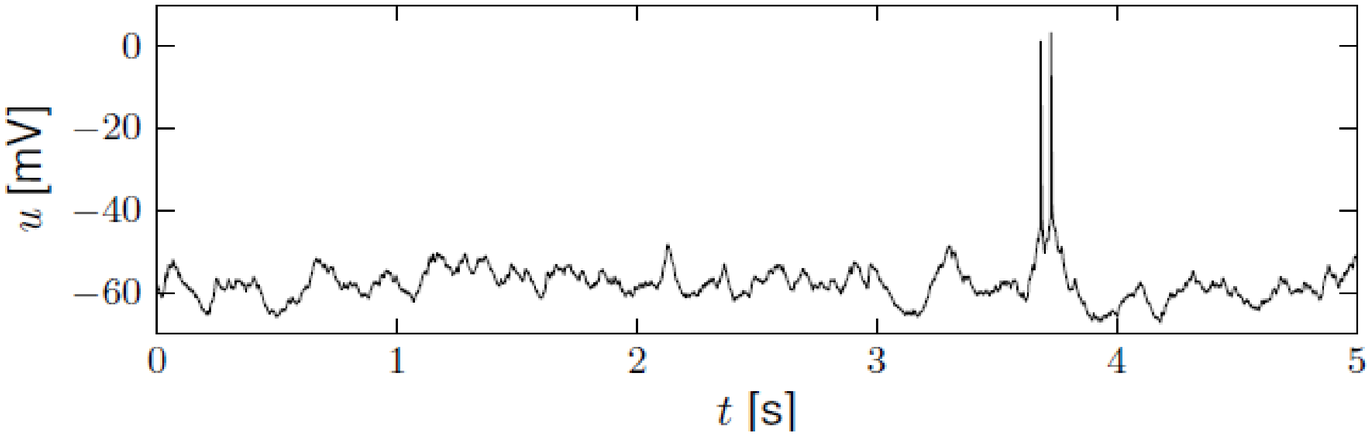
(week 11-13)

electrode



Brain

awake mouse, cortex, freely whisking,



Lab of Prof. C. Petersen, EPFL

Crochet et al., 2011

Biological Modeling of Neural Networks

Wulfram Gerstner

EPFL, Lausanne, Switzerland

TAs in 2021:
Valentin Schmutz (head)
Sophia Becker
Shuqi Wang
Christos Sourmpis

COURSE WEBPAGE:
Moodle.epfl.ch

Week 1: **A first simple neuron model/ neurons and mathematics**
Week 2: **Hodgkin-Huxley models and biophysical modeling**
Week 3: **Two-dimensional models and phase plane analysis**
Week 4: **Two-dimensional models (cont.), type I and type II models**
Week 5,6: **Associative Memory, Hebb rule, Hopfield**
Week 7-10: **Networks, cognition, learning**
Week 11,12: **Noise models, noisy neurons and coding**
Week 13: **Estimating neuron models for coding and decoding: GLM**
Week x: **Online video: Dendrites/Biophysics**

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)

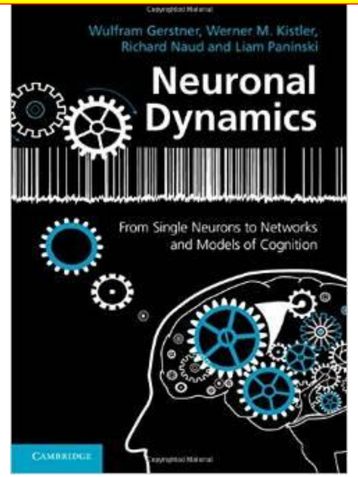
Transversal skills

- 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

Written Exam (70%)
+ miniproject (30%)



Miniproject consists of
2 extended computer exercises,
of which you have to hand in 1
(teams of two students

- handout March 30
- handin 2 options
  May 31 (fraud detection: June3/4)
  June 7 (fraud detection June 10/11)

Textbook:

http://neuronaldynamics.epfl.ch/
)

Video (two possibilities):

https://lcnwww.epfl.ch/gerstner/NeuronalDynamics-MOOCall.html

https://courseware.epfl.ch/

Milan Vojnovic (PhD 2003 with J-Y Le Boudec)

Biological Modeling of Neural Networks – Quiz 1.1

A cortical neuron sends out signals which are called:

- [ ] action potentials
- [ ] spikes
- [ ] postsynaptic potential

The dendrite is a part of the neuron

- [ ] where synapses are located
- [ ] which collects signals from other neurons
- [ ] along which spikes are sent to other neurons

In an integrate-and-fire model, when the voltage hits the threshold:

- [ ] the neuron fires a spike
- [ ] the neuron can enter a state of refractoriness
- [ ] the voltage is reset
- [ ] the neuron explodes

In vivo, a typical cortical neuron exhibits

- [ ] rare output spikes
- [ ] regular firing activity
- [ ] a fluctuating membrane potential

Multiple answers possible!

Biological Modeling of Neural Networks

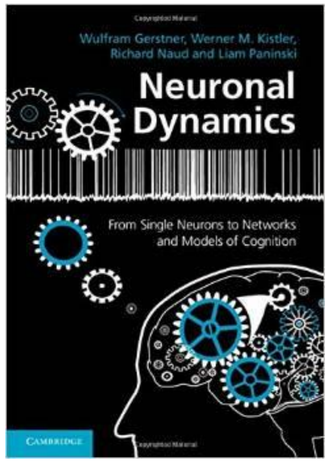
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Week 1 – neurons and mathematics: a first simple neuron model

Wulfram Gerstner

EPFL, Lausanne, Switzerland

Reading for week 1:
NEURONAL DYNAMICS
- Ch. 1 (without 1.3.6 and 1.4)
- Ch. 5 (without 5.3.1)



Cambridge Univ. Press

1.1 **Neurons and Synapses:**
Overview
1.2 **The Passive Membrane**
- Linear circuit
- Dirac delta-function

1.3 **Leaky Integrate-and-Fire Model**
1.4 **Generalized Integrate-and-Fire Model**
1.5. **Quality of Integrate-and-Fire Models**

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Wulfram Gerstner

EPFL, Lausanne, Switzerland

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Sophia Becker
Shuqi Wang
Christos Sourmpis

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Moodle.epfl.ch

PLAN FOR TODAY:
- Meet your TAs (now)
- Questions and Answers
- Sign up for Piazza
- Sign up for Wonder
- Watch videos
- Solve Paper-and-Pencil Ex.
- Install Python