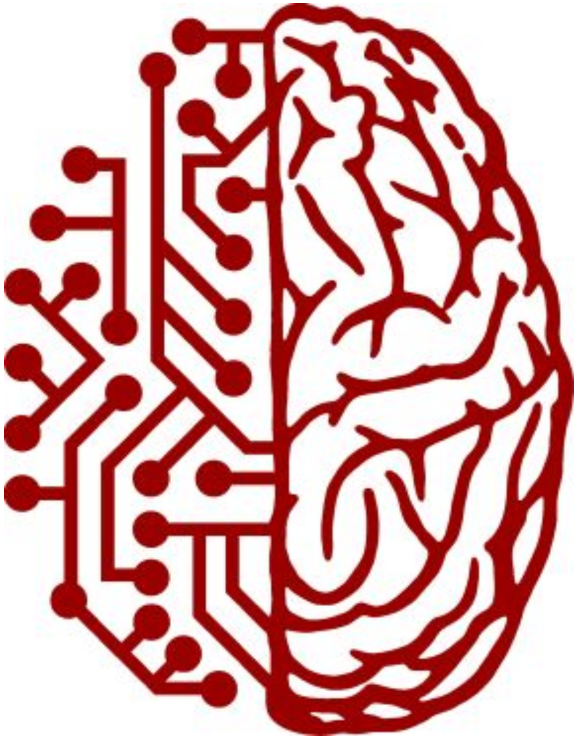
Welcome to:



Brain-**I**nspired
Computing
Summer 2019

Comparison: Brain vs. Traditional Computer

- Parallel
- Continuous time
- Self-tuning
- Processor + memory intermingled
- Robust computing

- Serial
- Centralized clock cycles
- Programmed
- Processor + memory separated
- Fragile computing

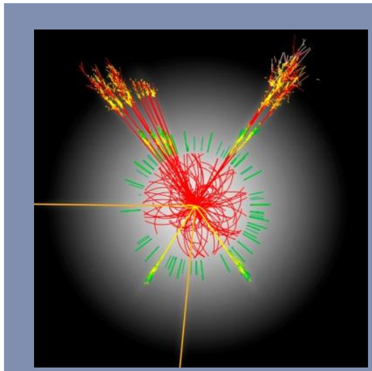
Typical tasks

1) 4711 x 0.815 = ?
2) For i in 0..10000: do ...
3) Copy array A to array B

1) Recognize mood from face expression
2) Retrieve old memory from small cue
3) Investigate brain computing

Neuroscience: a physicist's motivation

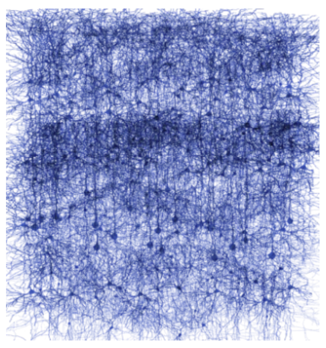
Planck length	$\sim 10^{-35}$ m
quark (upper bound)	$\sim 10^{-18}$ m
proton	$\sim 10^{-15}$ m
hydrogen atom	$\sim 10^{-11}$ m
protein	$\sim 10^{-9}$ m
cell	$\sim 10^{-5}$ m
human	$\sim 10^{0}$ m
Earth	$\sim 10^{7}$ m
the sun (Sol)	$\sim 10^{9}$ m
Milky Way galaxy	$\sim 10^{21}$ m
observable universe	$\sim 10^{26}$ m



The Very Small

simulated Higgs event

ATLAS @ LHC, CERN



The Very Complex

neocortex microcircuitry

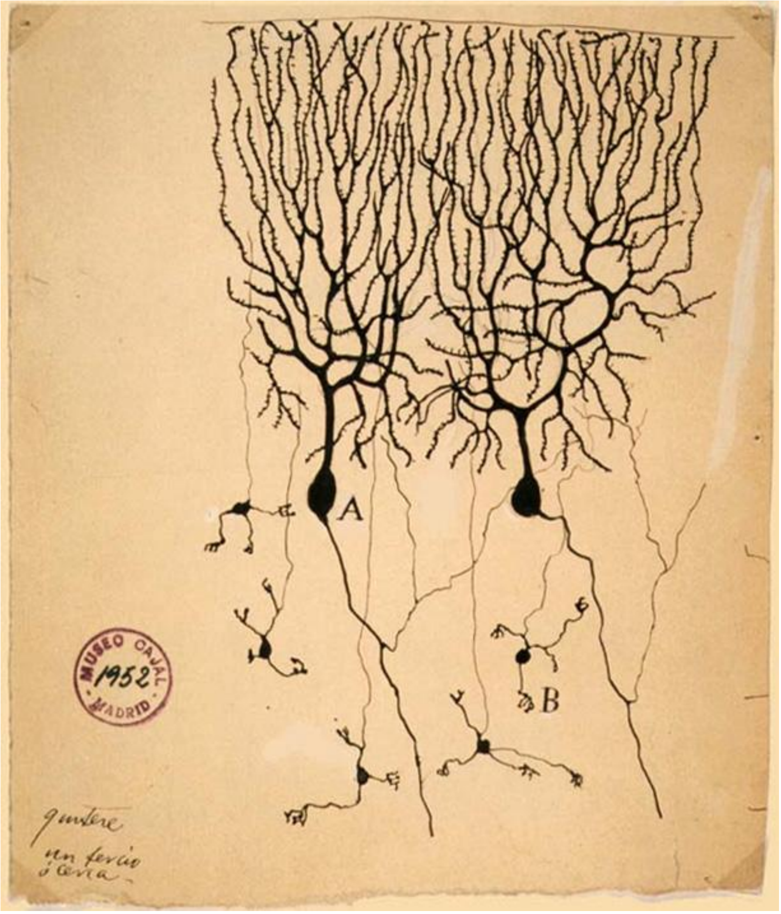
Blue Brain Project

EPFL Lausanne

The Very Large

Pillars of Creation

Hubble Telescope



A brief history
of neuroscience:
where are we now
and how did we get here
?

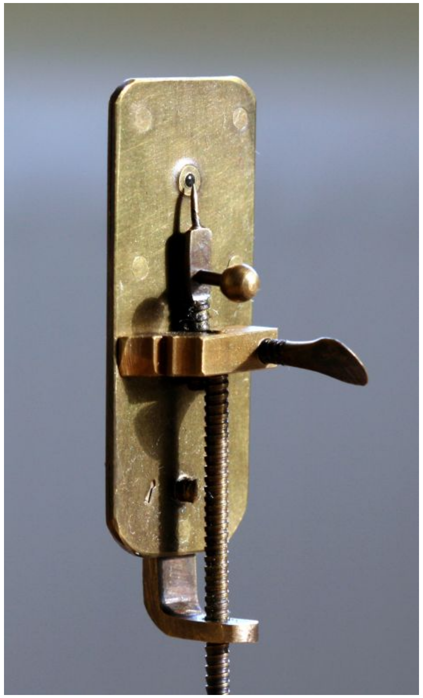
Ancient history

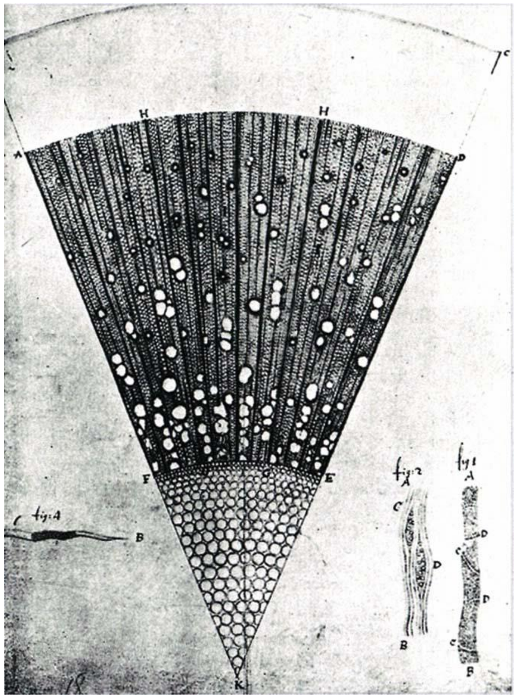
Trepanated skull, iron age

„The extraction of the stone of madness“
by Hyeronimus Bosch, ~1500

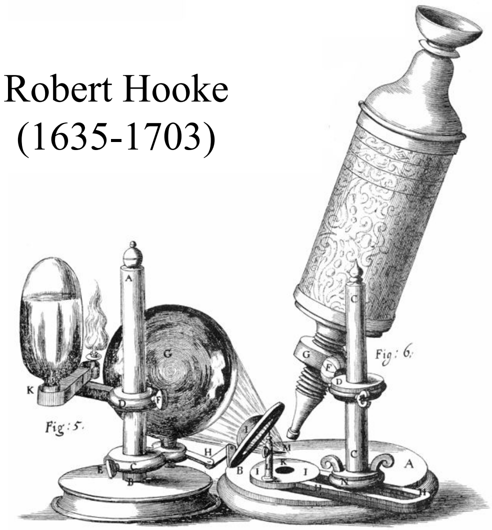
Discovery of the cell

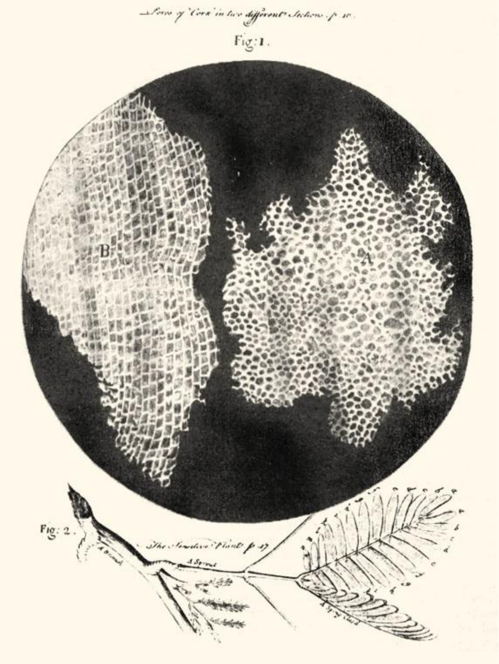
Antonie van
Leeuwenhoek
(1632-1723)





Robert Hooke
(1635-1703)



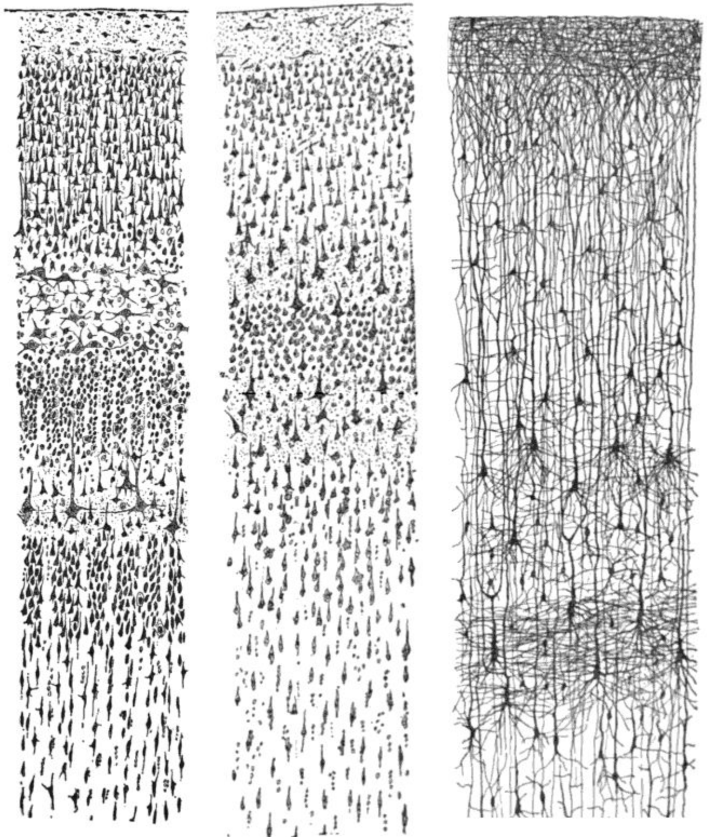


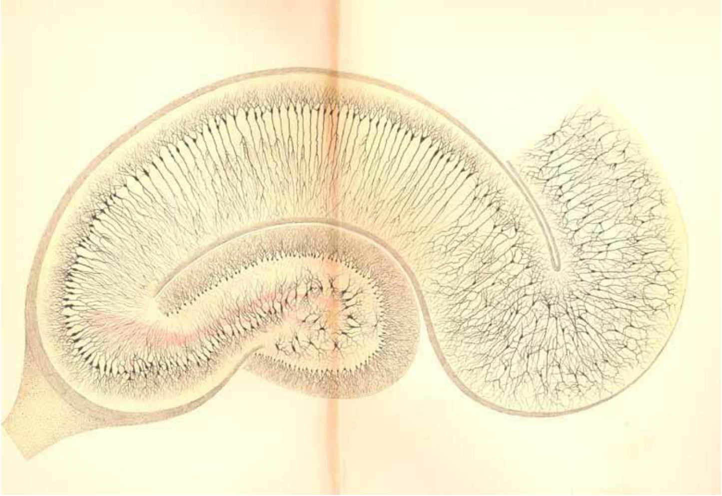
The “neuron doctrine”

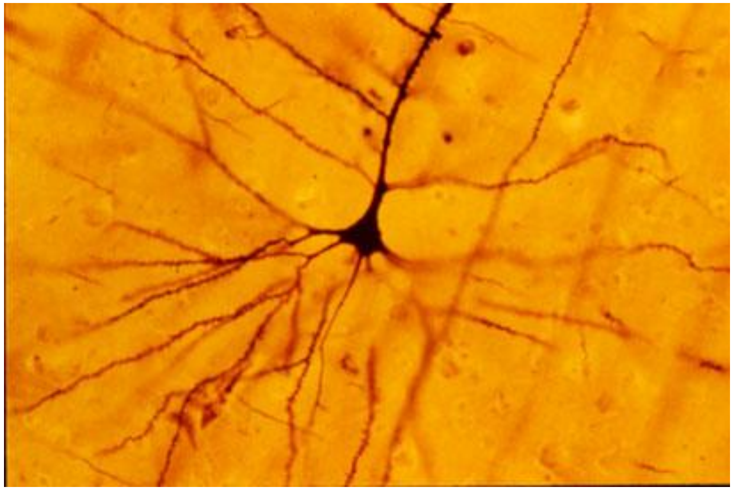
Santiago Ramón y
Cajal
(1852-1934)

Nobel Prize (1906):
"in recognition of their work on
the structure of the nervous
system"

Camillo Golgi
(1843-1926)





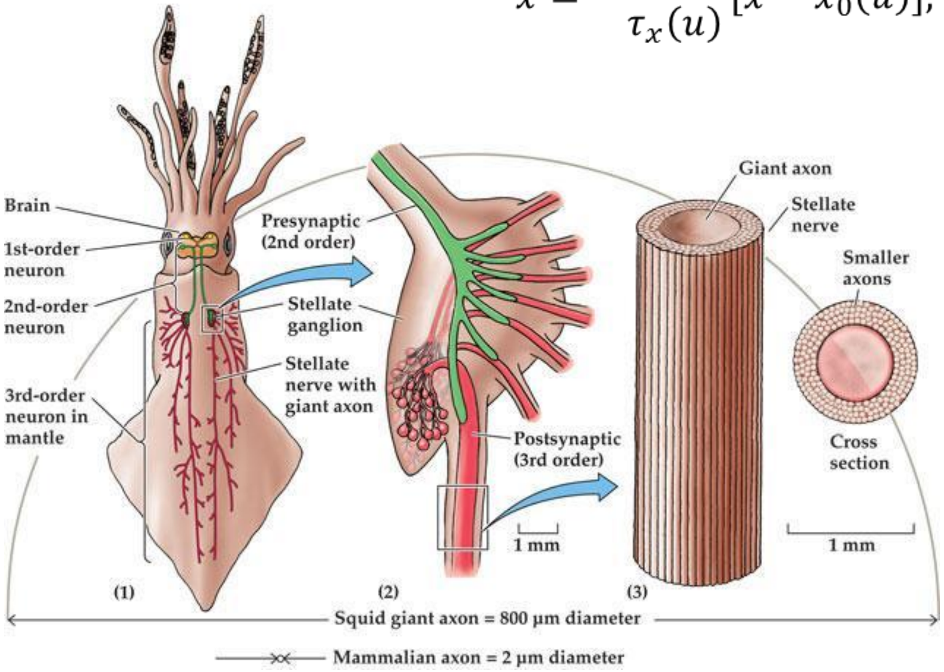


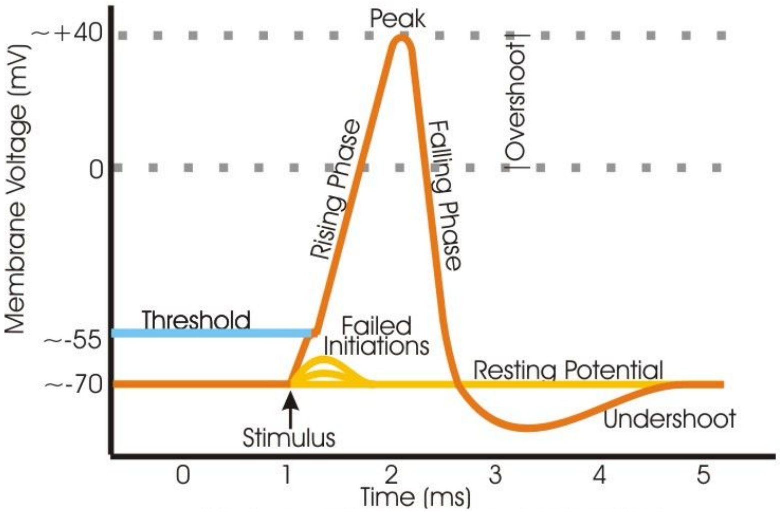
The Hodgkin-Huxley model

Alan Hodgkin and Andrew Huxley, 1952 (Nobel Prize 1963)

$$C_{\mathrm{m}}\,\dot{u} = -g_{\mathrm{Na}^+} m^3 h (u - E_{\mathrm{Na}^+}) - g_{\mathrm{K}^+} n^4 (u - E_{\mathrm{K}^+}) - g_{\mathrm{l}}\,(u - E_{\mathrm{l}}\,) + I$$

$$\dot{x} = -\frac{1}{\tau_x(u)}[x - x_0(u)], \qquad x \in \{m, h, n\}$$

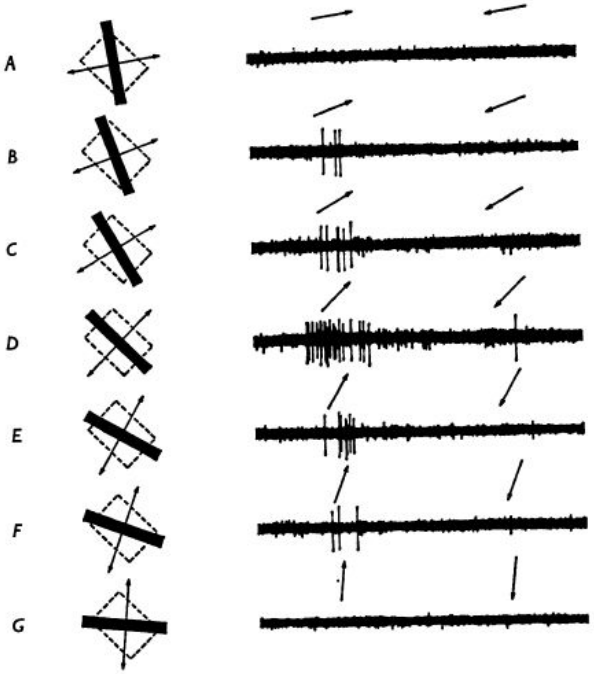


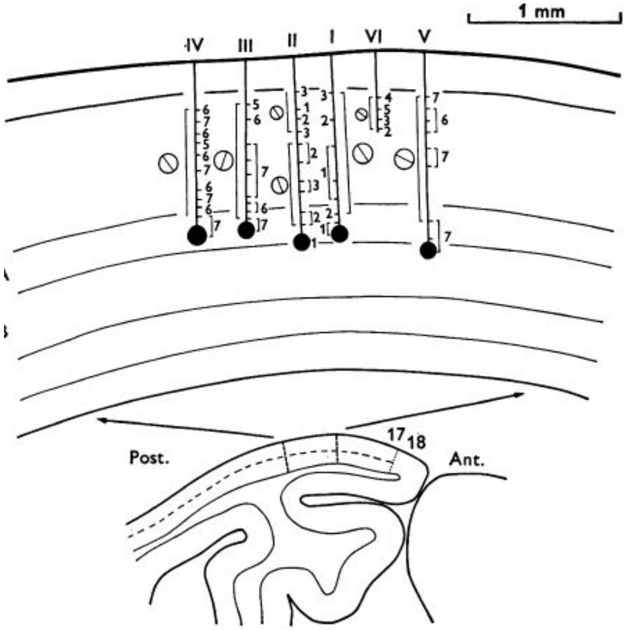


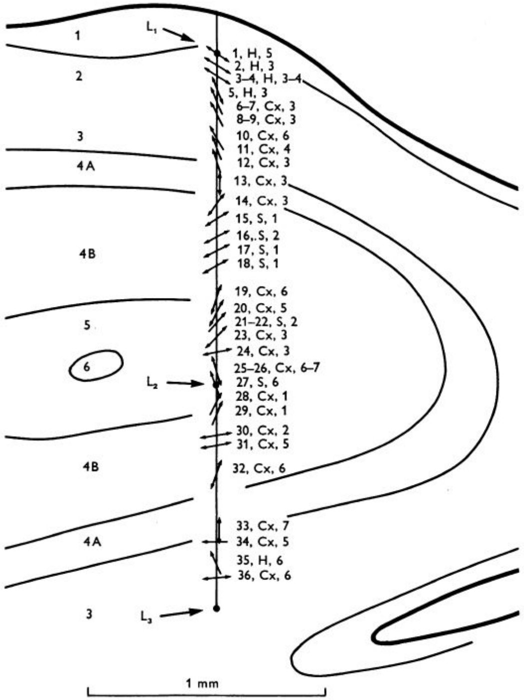
first complete mechanistic neuron model !

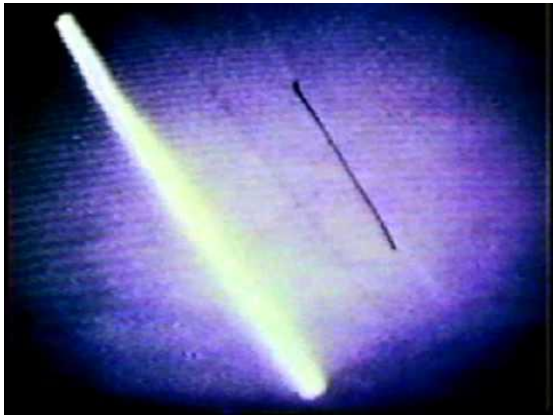
Columnar architecture of the cortex

David Hubel and Torsten Wiesel, 1968 (Nobel Prize 1981)



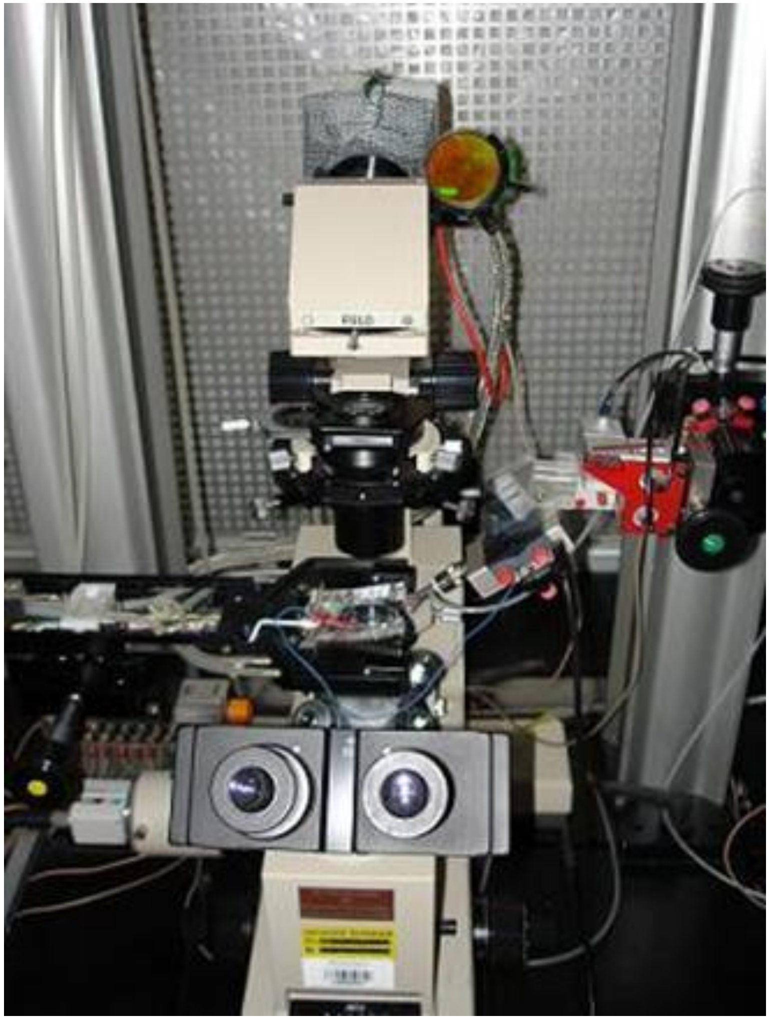


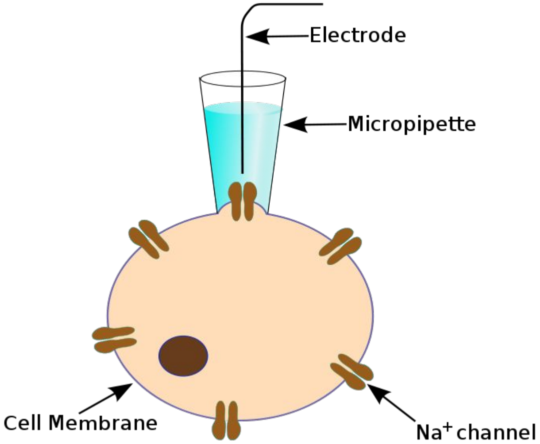




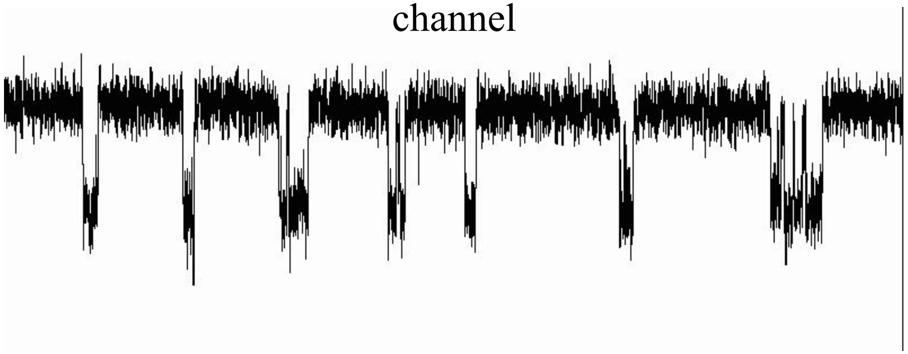
Patch clamping

Erwin Neher and Bert Sakmann 1970s (Nobel Prize 1981)

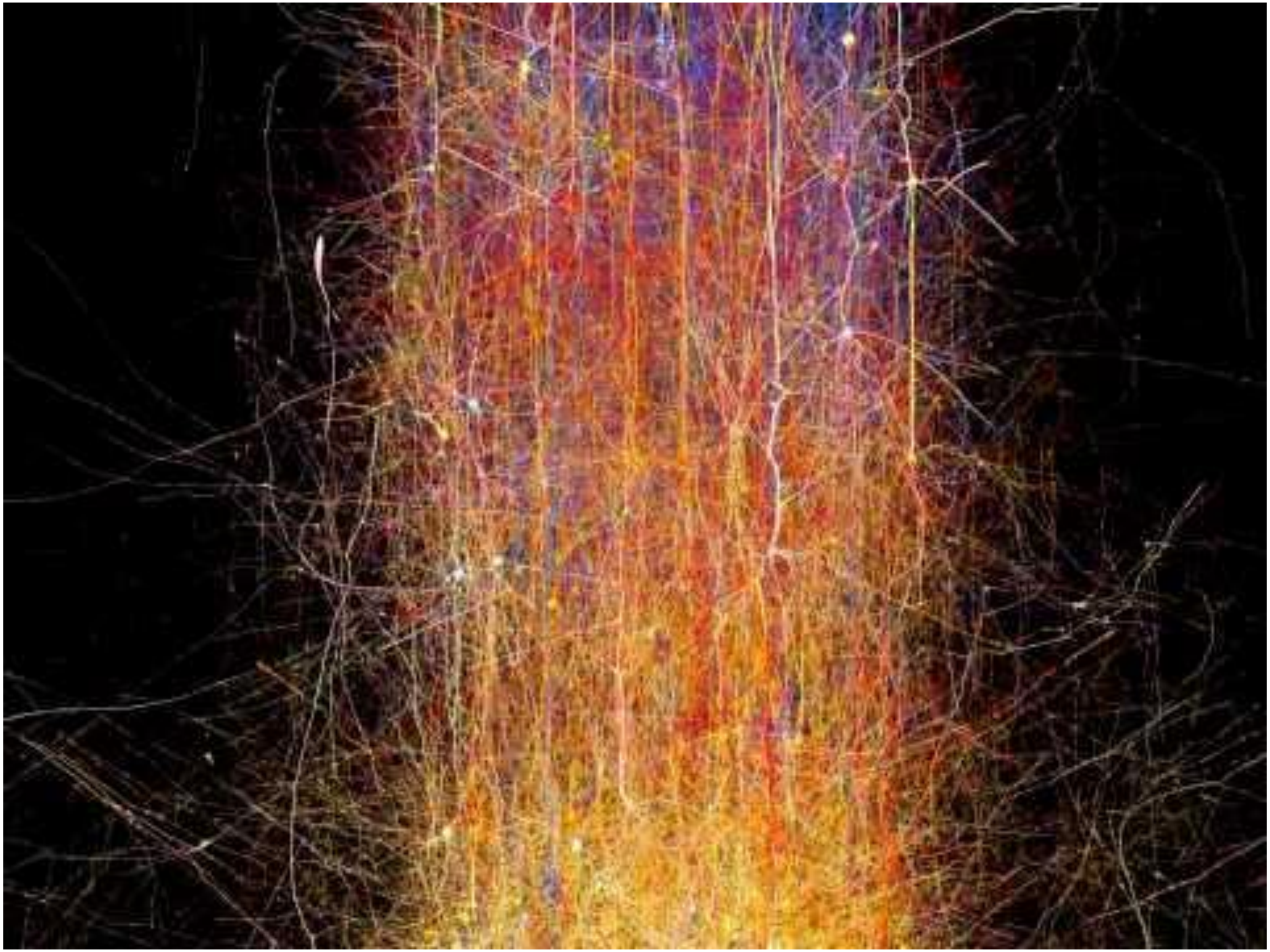




conductance of a single Na^+ channel

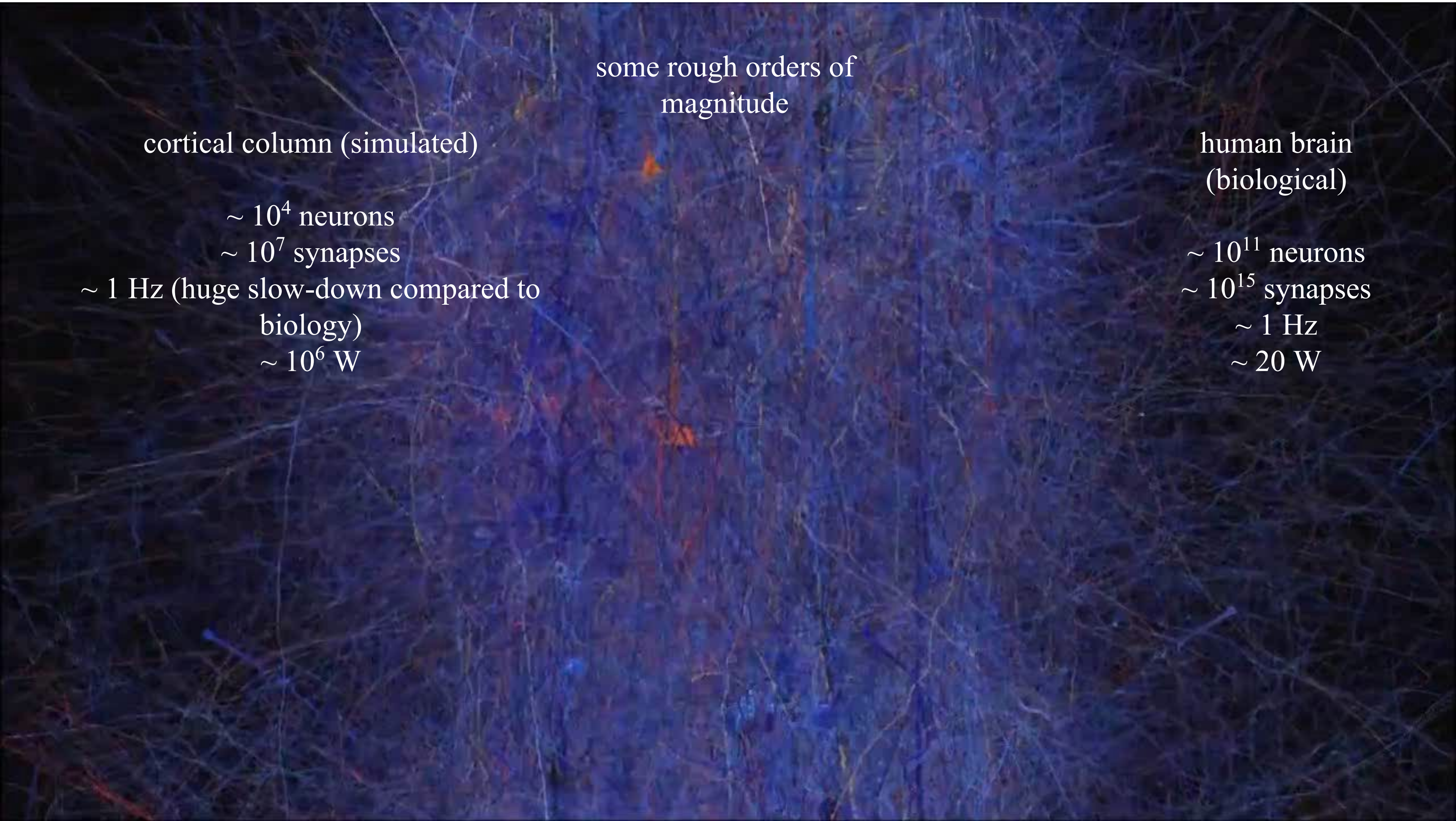


A glimpse at the Very Complex



A glimpse at the Very Complex

simulation of a cortical column, Blue Brain Project



some rough orders of magnitude

cortical column (simulated)

~ 10^4 neurons
~ 10^7 synapses
~ 1 Hz (huge slow-down compared to biology)
~ 10^6 W

human brain (biological)

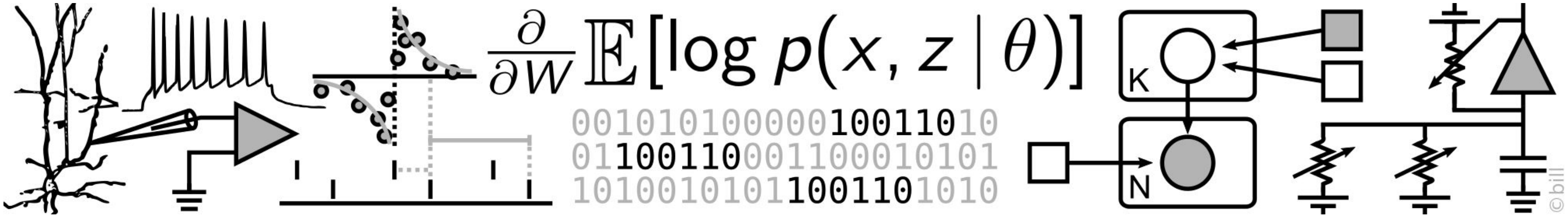
~ 10^{11} neurons
~ 10^{15} synapses
~ 1 Hz
~ 20 W

Overview “Brain-Inspired Computing”

Neurophysics
Biophysics of neurons
Biophysics of synapses

Theoretical analysis
Neural response, Statistics

Computational
neuroscience
Networks, Machine learning



Neural modeling
Simplified models of
neurons, synapses, plasticity

Simulations
Testing predictions
Beyond theoretical analysis

Neuromorphic engineering
Physical model networks

Understanding complex systems on multiple structural scales:

⟶ **Not one** universal mathematical description
⟶ But: switching between different **levels of abstraction**

Acknowledgements

Based on the script of
Mihai Petrovici and **Johannes Bill**

Sebastian Schmitt (Lecturer, Tutor)

BIC2019 team

Christian Mauch (Tutor)

Akos Kungl (Scientific Advisor)

Class material

Moodle name: BIC SS 2019

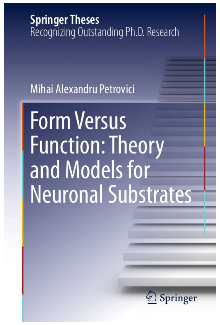
https://elearning2.uni-heidelberg.de/course/view.php?id=21281

Password: bic2019 ← write this down **now**

Here you can find:

- handwritten lecture notes and slides
- homework exercise sheets
- further material (links, code, excerpts from literature)
- announcements
- and discussion forums (not for sharing solutions)

Literature

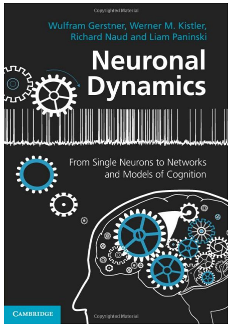


Mihai Petrovici

Form Versus Function:

Theory and Models for Neuronal Substrates

www.springer.com/de/book/9783319395517



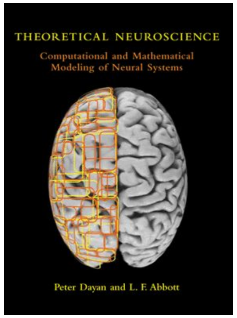
Gerstner, Kistler, Naud,

and Paninski

Neuronal Dynamics:

From single neurons to networks and models of cognition

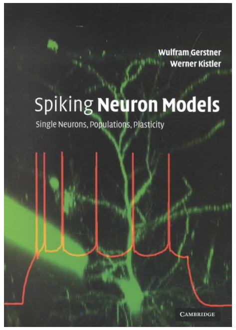
http://neuronaldynamics.epfl.ch/online/index.html



Dayan & Abbott

Theoretical neuroscience

http://www.gatsby.ucl.ac.uk/~dayan/book/



Gerstner & Kistler

Spiking neuron models

http://lcn.epfl.ch/~gerstner/SPNM/SPNM.html

Times and dates

Course: Wednesdays 11:15 – 13:00 (with a 15 minute break around 12:00)

Tutorials: Mondays 11:15 – 13:00 (Groups: Mauch and Schmitt)

→ start 29.4.19

final exam: most likely on end of July (2019)

if fail: second exam

(if you attend the exam you will get a mark)

⇒ we have a total of 14 courses

⇒ passing the exam will give you 4 ECTS points

Homework & exam

registration: https://uebungen.physik.uni-heidelberg.de/uebungen/liste.php?vorl=1012

opens today at 14:00

rules of engagement: collaborative work permitted, in groups of max. 3 people

schedule: nth Wednesday: nth exercise sheet

nth exercise group: solutions for the (n-1)st exercise sheet

discussion of the nth exercise sheet

general questions concerning the course

(n+1)st Wednesday: hand-in of nth sheet until 14:00

(boxes in front of KIP office 1.111)

60% of homework points required for admittance to the exam ! (this does not count towards the final grade)

30% of exam points required to pass the exam !

(most likely difficult without regularly attending both the course and the tutorials)

Programming Exercises

You can get additional 2 CP for completing the programming exercises.

For this you need to hand in your code (mostly python) by mail to the tutor.

How you run python is up to you. You may want to use google’s colab for this:

- https://colab.research.google.com

There will be no programming in the exam, however, solving the programming exercises might be helpful for a better understanding of the course material.