Motivation: How can we see this flower?
The Protagonists: Neurons

- $10^{11}$ neurons in brain
- $10^6$ km of ‘wires’ ($\approx 2.5 \cdot d_{Earth-Moon}$)
- $10^3 - 10^4$ synapses per neuron
- $10^2 - 10^3$ ion channels per neuron
Neurons: Electricity

- in cell:
  \( K^+ \), negative molecules, total: -
- outside cell:
  \( Na^+ \), \( Cl^- \), total: +
- voltage between in and out:
  'membrane potential' \( U_m \)
- in rest state:
  \( U_m = U_{rest} \approx -80 \text{mV} \)
- kept by:
  - membrane with
  - ion pumps (active)
  - ion channels
    (voltage or chemically gated)
Signal Generation and Transmission: Action Potential

- Voltage on input(s) over threshold
- $Na^+$ ion channels open
- $Na^+$ ions flow in
- $U_m$ increases further
- More channels open...
- All channels are open
- $U_m = 0$
- $K^+$ channel open
- $K^+$ ions flow out
- $U_m$ decreases
- End: $U_m < U_{rest}$
- Pumps recreate initial state
Action Potential Hops along an Axon

- generating action potential: 200ms → too slow
- in real: transmission faster: < 7ms
- energy saving
Junktions between Neurons: Synapses

- pulse
- voltage gated ion channels cause release of neurotransmitters
- these gate 'next' ion channels
- excite / inhibit new pulse
Biological Neuronal Networks: Signal Processing (Idea)

- each neuron couples to many other neurons → neuronal network
- excite or inhibit next neuron
- information: sequence of action potentials (?)
- idea: logical circuit

Example: Stone in front of me, if:
- eye 1: signal
- hand: signal
- nose: no signal

\[\text{eye 1} \overset{\text{AND}}{\longrightarrow} \text{hand} \overset{\text{AND}}{\longrightarrow} \text{stone}\]

\[\text{nose} \overset{\text{on}}{\longrightarrow} \]
How are Brains Wired?

We found:

- neurons are the protagonists for biological signal transmission and processing
- transmission: action potentials in axons
- processing: neuronal network

How does such a network look like? To investigate this (try):

Do: measure (and plot) electricity in the head
Greek:  

\[ \text{graphy electro en kephalikos} \]

\[ \rightarrow \text{Electroencephalography (EEG)} \]
EEG - Principle:

- measure voltage between (head close to) brain and reference (e.g. ear)
- plot voltage versus time

Figure: first EEG (1924): H. Berger, Über das Elektrenkephalogramm des Menschen, Archives für Psychiatrie. 1929; 87:527-70.
What Does EEG Measure?

- action potentials: change charge distribution in head
- measure potential differences
- each electrode: 'macroscopic output' (superposition) of action potentials of $10^8$ neurons
- consider each neuron as dipole: superposition of E-fields is not linear!
- resistance of skull, skin, ...
What Does EEG Measure?

**EEG:**
Differences in electric potentials on various positions on the head. These arise from a huge number of action potentials in a complex neural network (brain).

**Heuristic:**
We do not know exactly, what EEG measures, but it is still very useful.
EEG Recording, Epileptic Seizure
EEG: Applications

- levels of consciousness
- epilepsy
- sleep (disorders)
- ...

make appropriate choice of
- number of electrodes
- position of electrodes

example: 10-20 system
**microscopic, assume:**
network of neurons
each neuron transmits/processes
voltage signals (action potentials)

**macropscopic, measure:**
EEG - effective voltage signal
in/around head

inverse problem:
find (hidden) system
from set of observations (EEG)
Literature, Image Sources

Books:

Image Sources:
- slide-

4. Flower: http://cliparts.co/cliparts/kc8/ok9/kc8ok9LEi.png, 10.6.15
5. schematic: [Phillips]
7. action potential: http://www.dummies.com/how-to/content/understanding-the-transmission-of-nerve-impulses.html, 11.6.15
9. real neurons: http://www.alanturing.net/turing_archive/graphics/realneurons.gif, 11.6.15
11. EEG recording: http://en.wikipedia.org/wiki/Electroencephalography, 12.6.15
12. Cap: http://www.ternimed.de/WebRoot/Store2/Shops/62826360/4DE0/7D0E/09EC/0DBB/1F14/C0A8/2936/3EC3/Links-web.jpg, 14.6.15
13. 10-20 system: https://en.wikipedia.org/wiki/10-20_system_%28EEG%29, 14.6.15
14. potential: K. Lehnertz, Electroencephalography - An Introduction, lecture at the University of Bonn, Summer Term 2014
15. setup: [Lehnertz], see above.

All pictures cited before.
Thank you for your attention.

Questions?