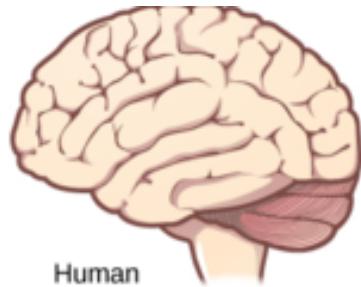


Cognitive Neuroscience for AI Developers

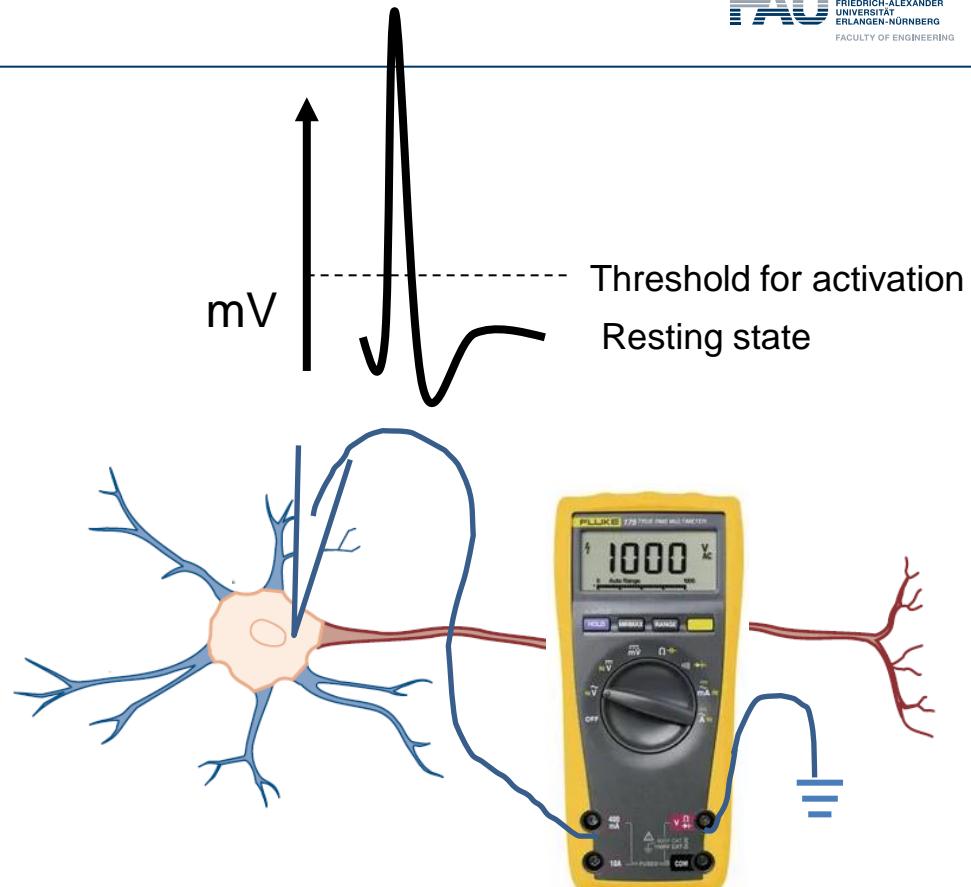
Week 07 – Measuring neural activity and connectivity



How do we actually know...?

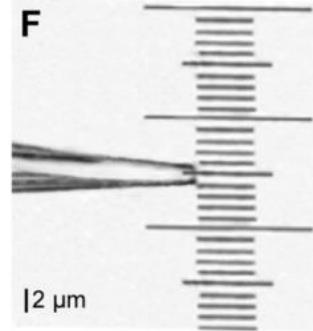
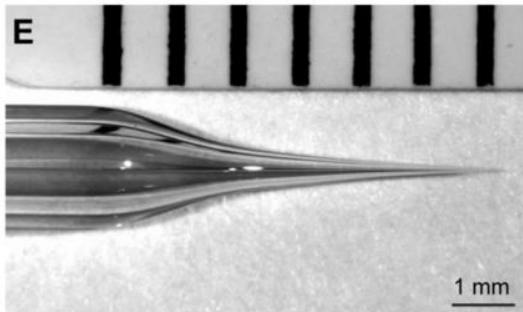
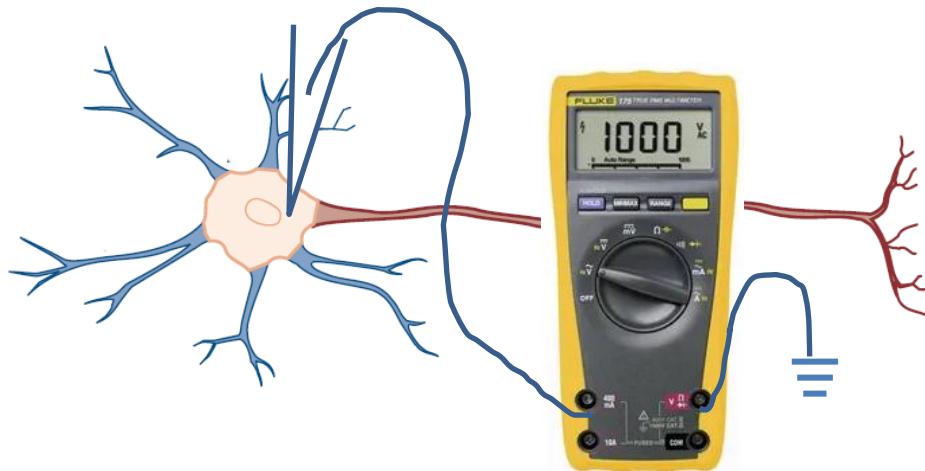


Human

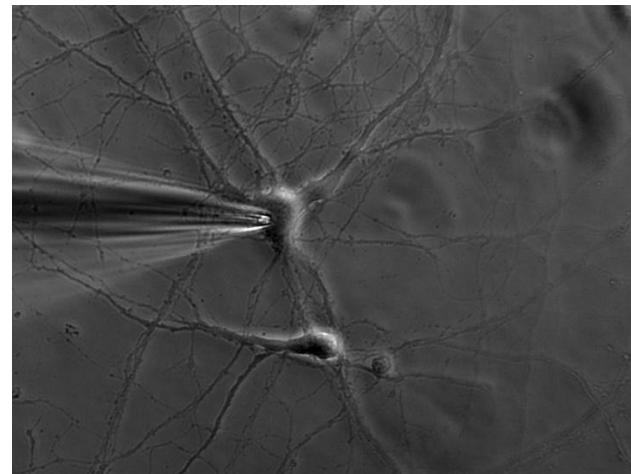


Voltage change → Electrical signal!

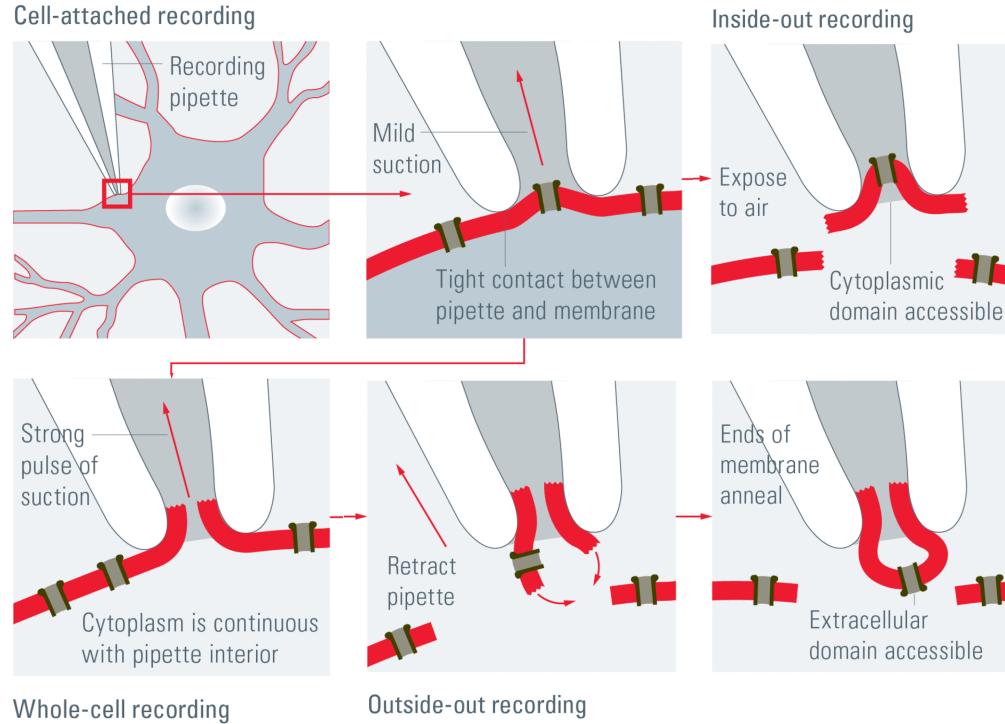
Measuring a potential across a cell



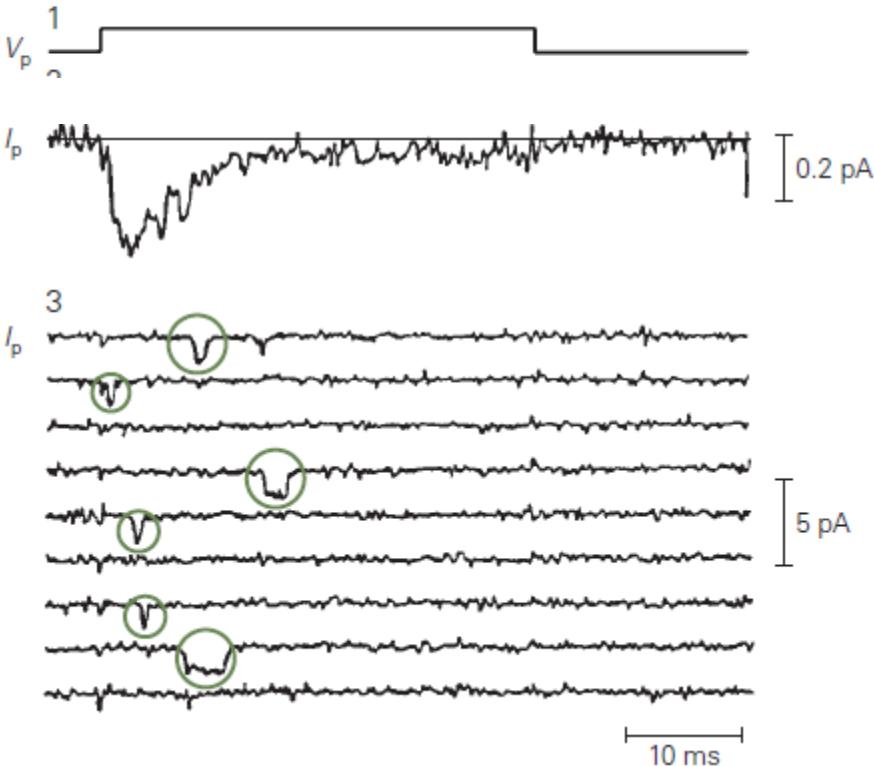
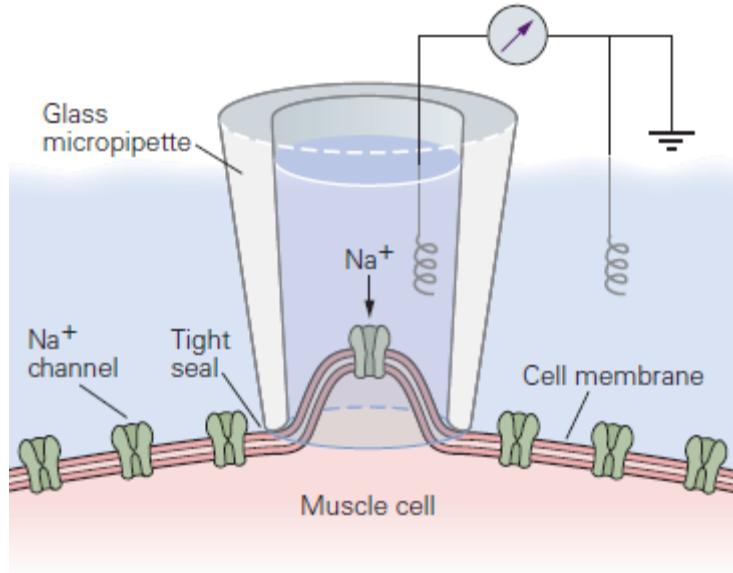
Jouhanneau, Poulet 2019



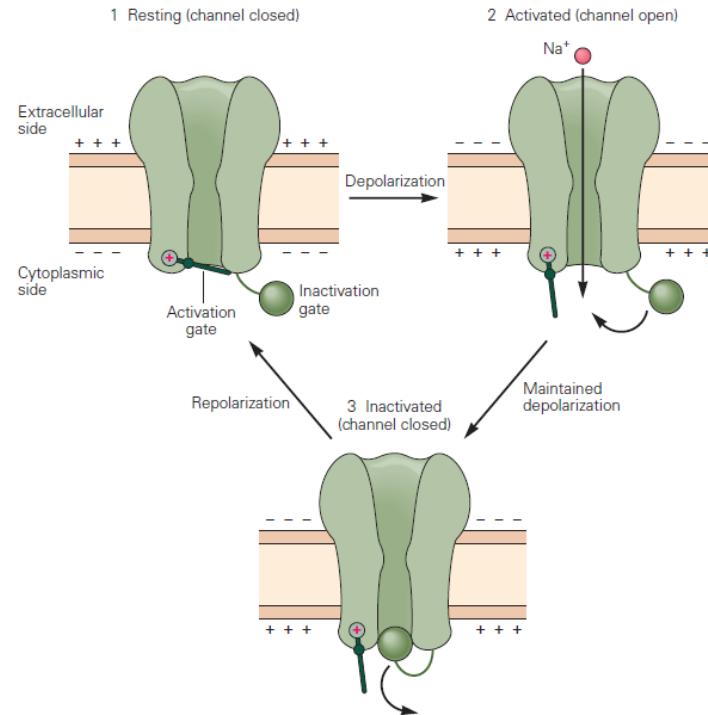
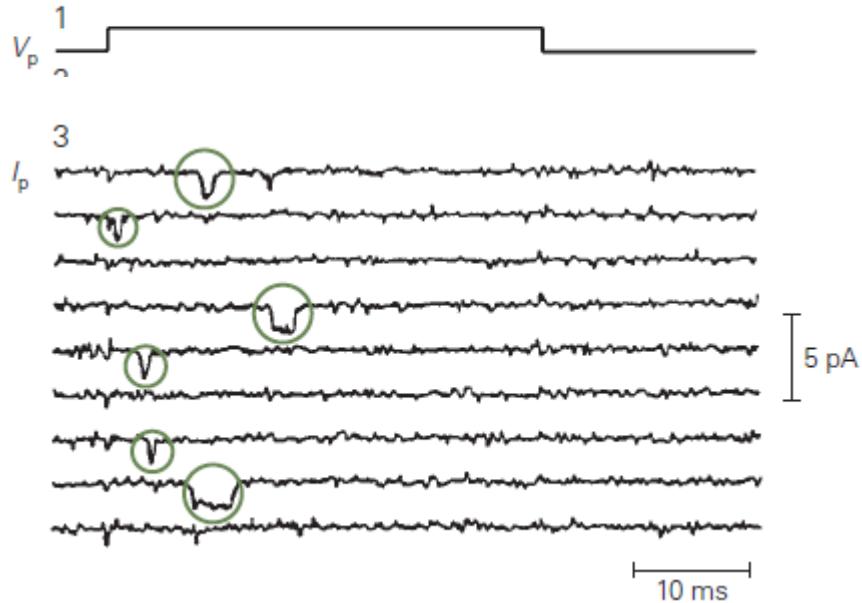
Accessing the cell



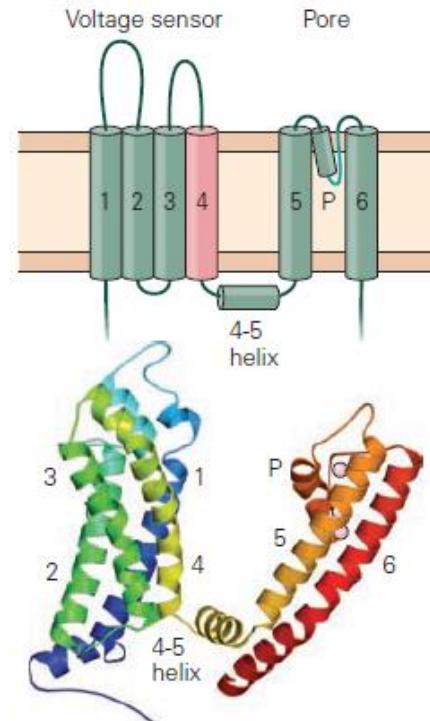
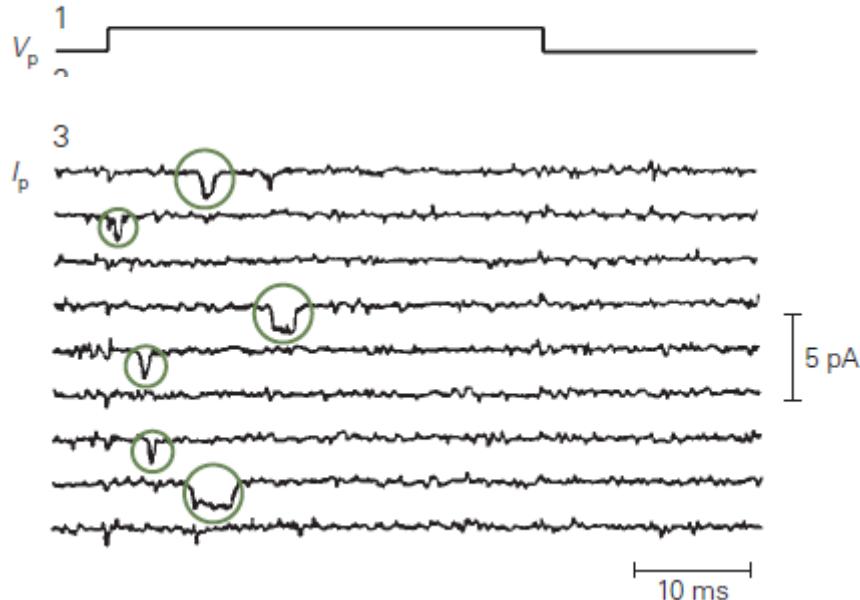
Measuring a single channel

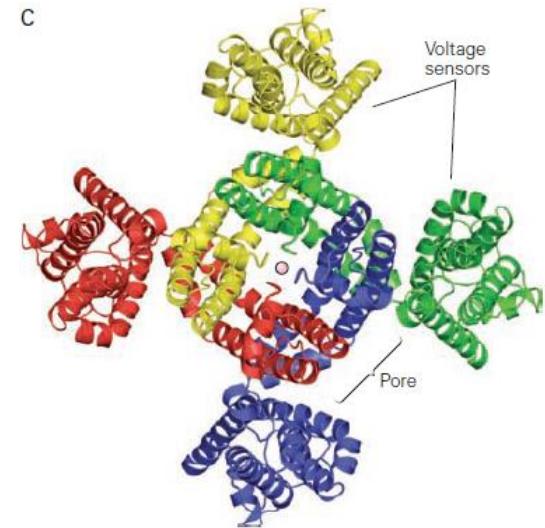
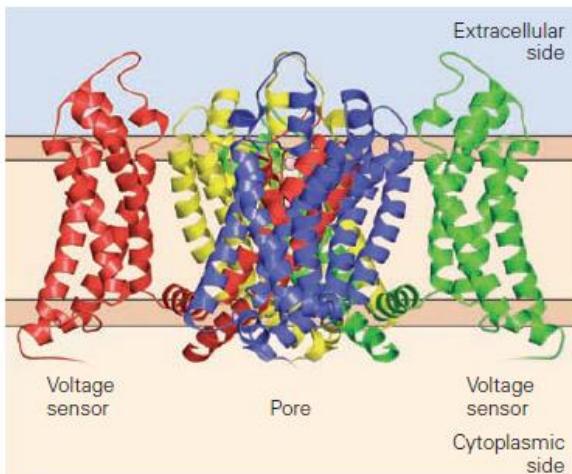
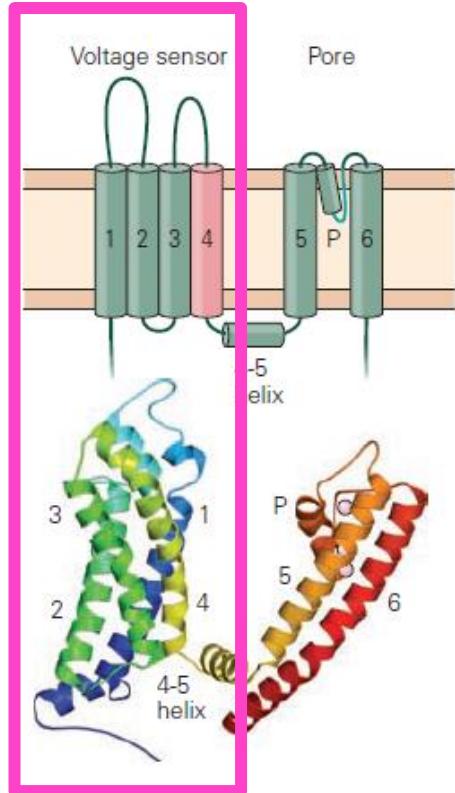


Ion channels

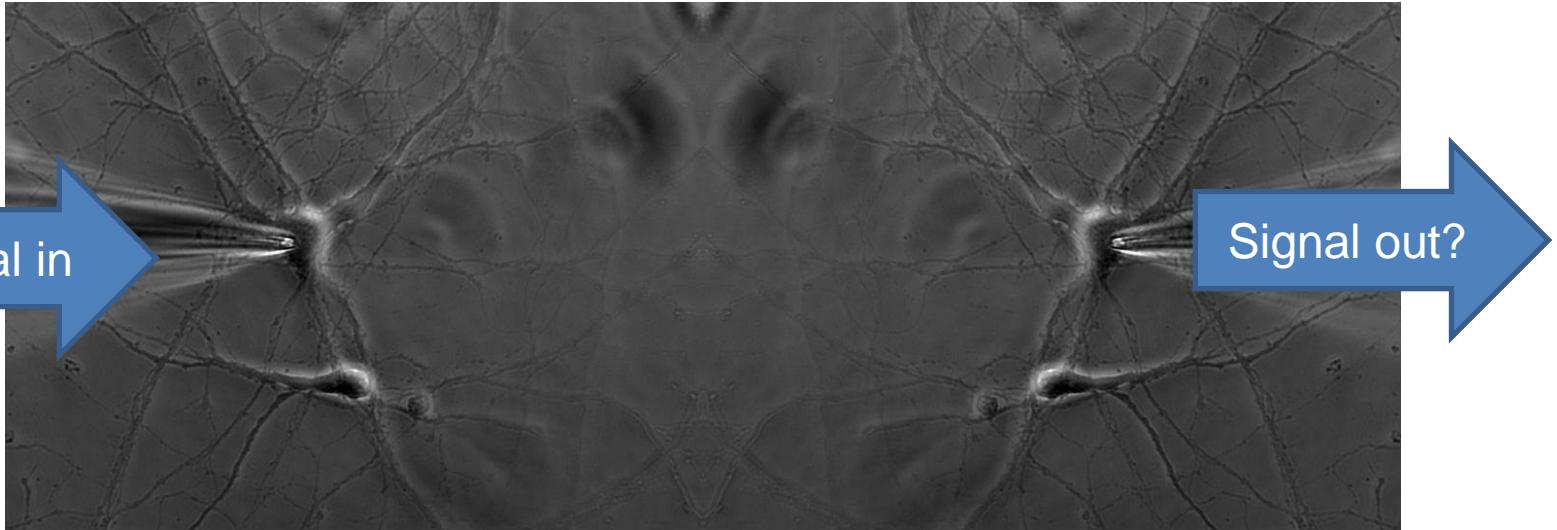


Sensing voltage





Measuring single neurons...?



Paired recordings → identification of functional circuitry

Electrophysiology methods

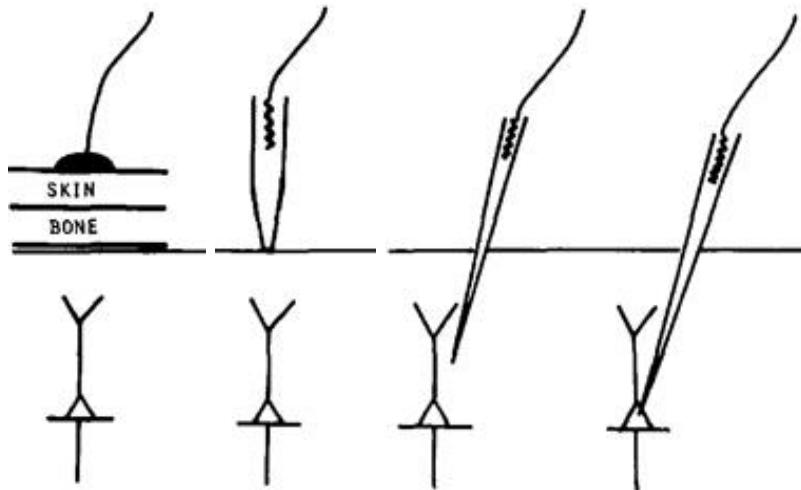
Localization

EEG

ECoG

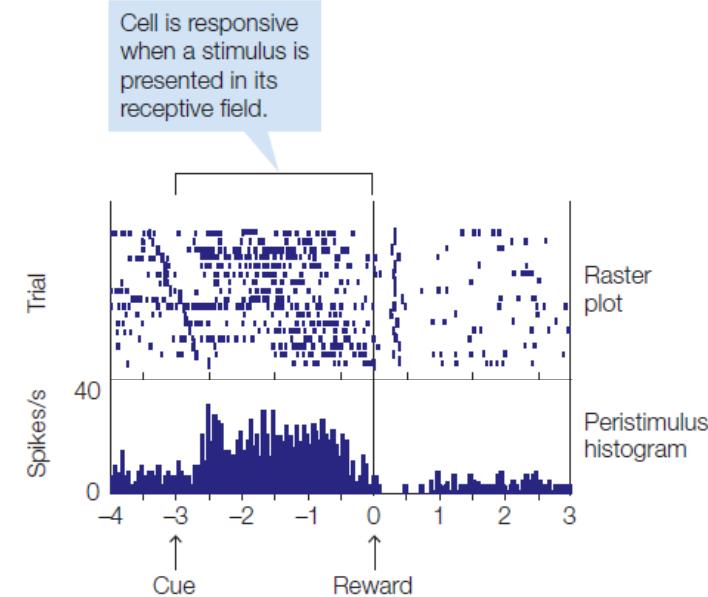
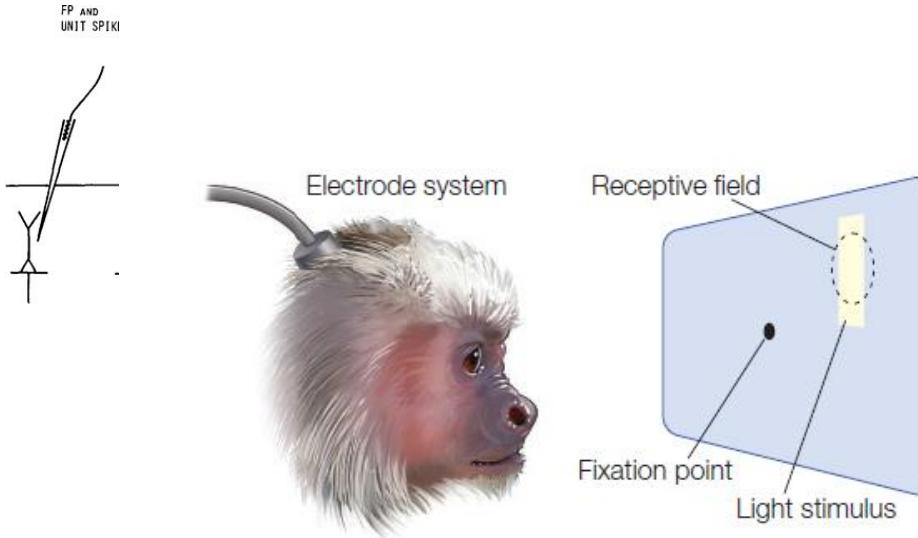
FP AND
UNIT SPIKES

**INTRA-
CELLULAR**

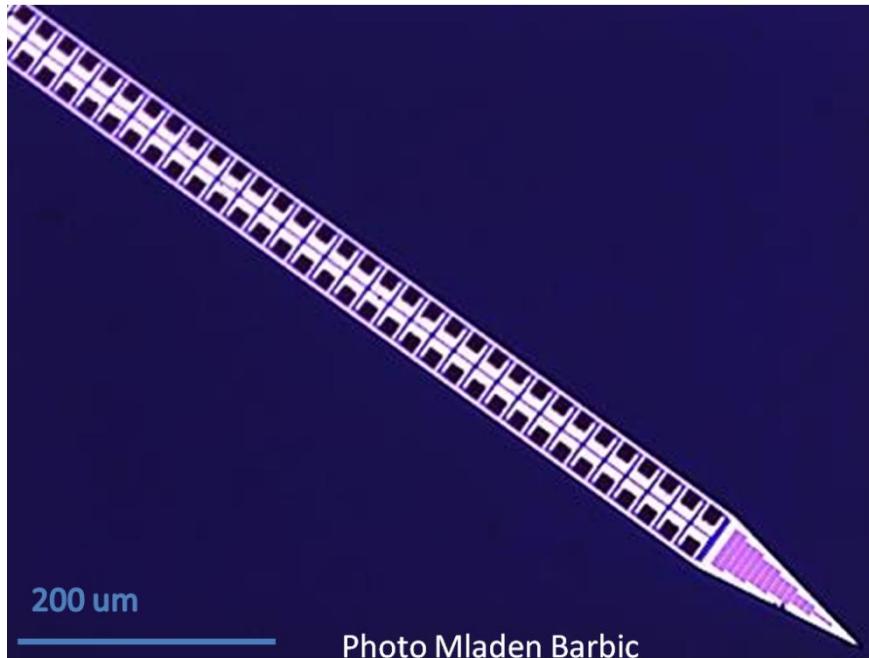


invasiveness

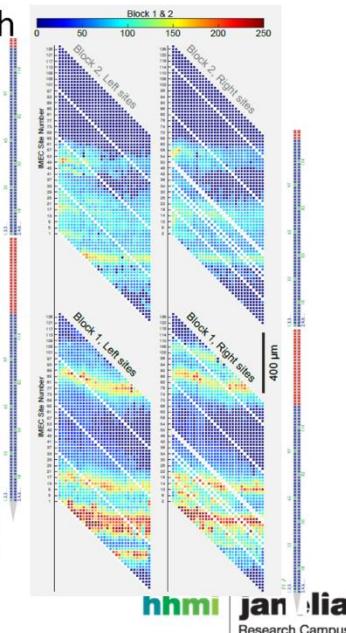
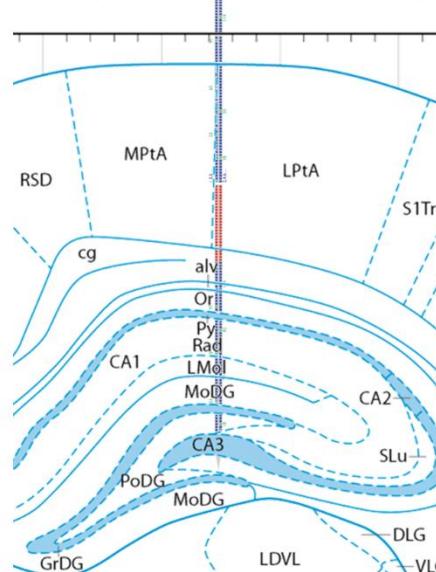
Local Field Potentials



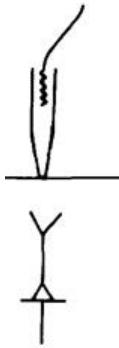
Multielectrodes



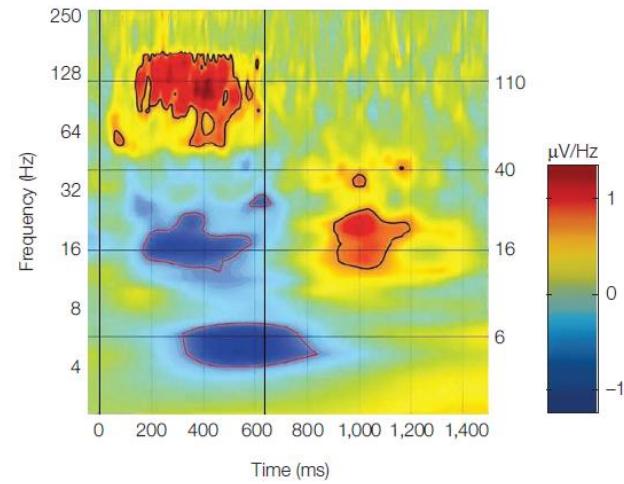
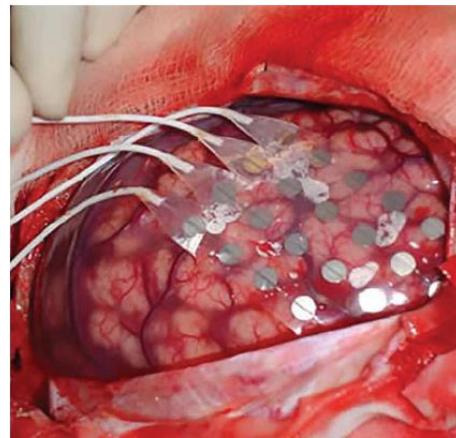
Spike Amplitude vs. Probe Depth

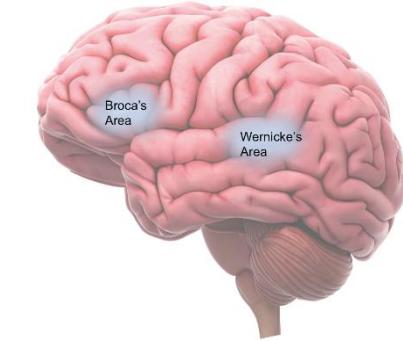
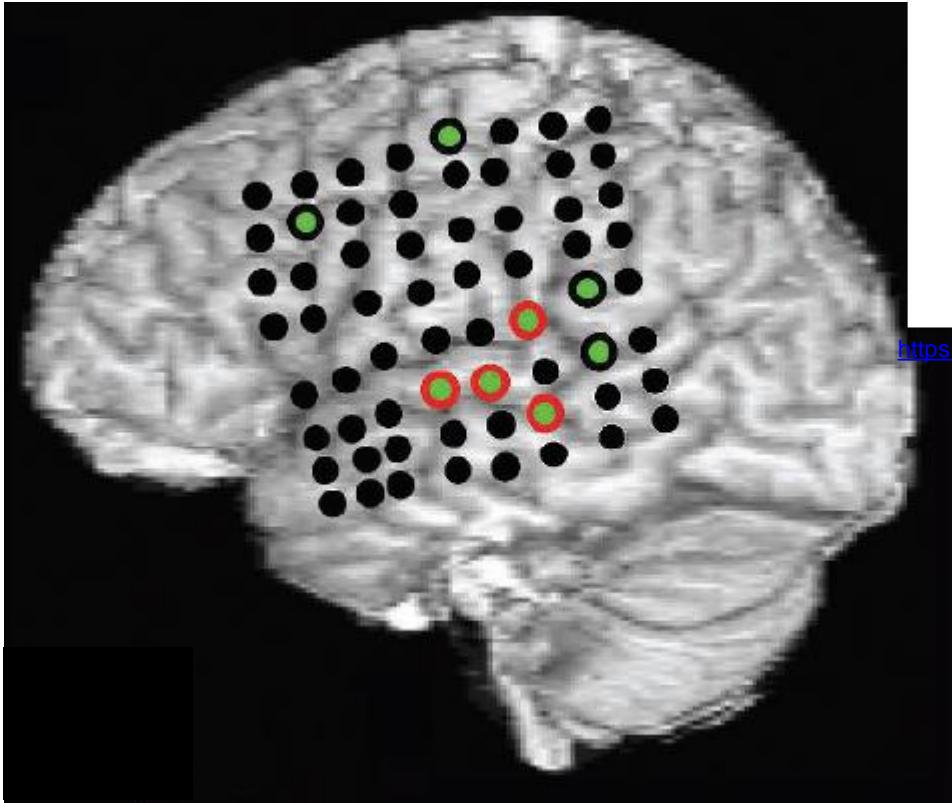


ECoG



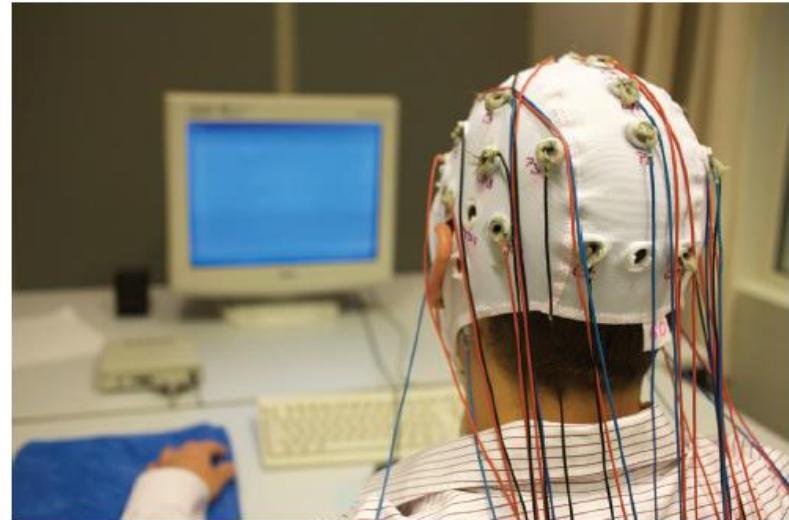
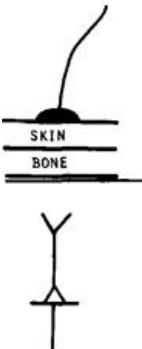
https://www.eurekalert.org/pub_releases/2016-10/uow-ftf102616.php





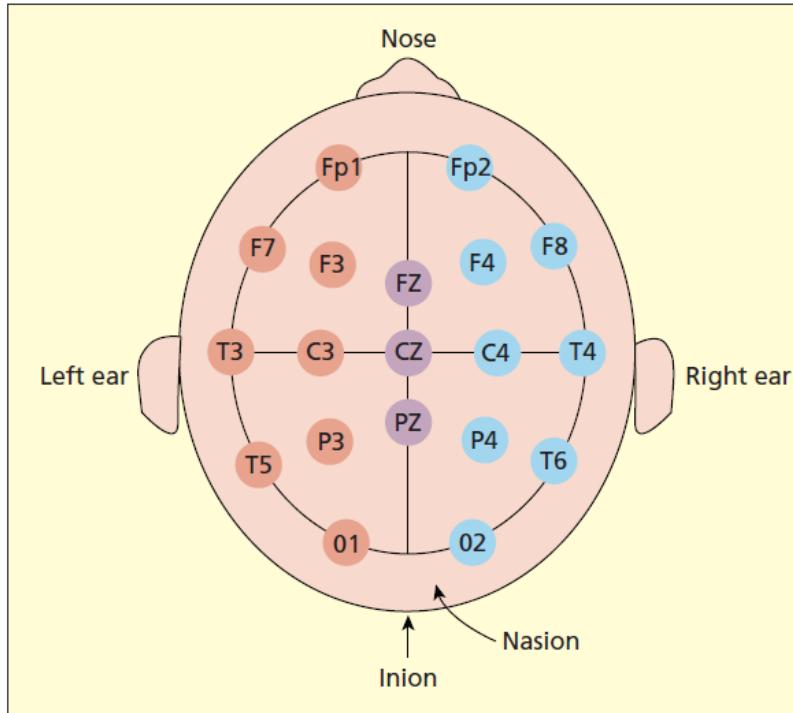
<https://sapienlabs.org/searching-the-brain-for-language/>

EEG

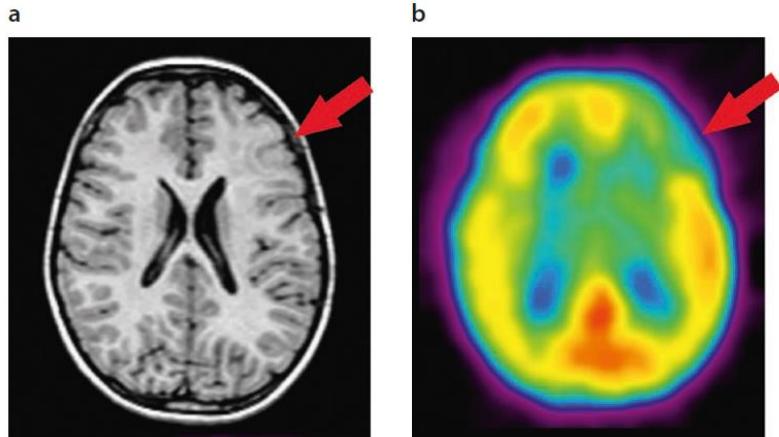
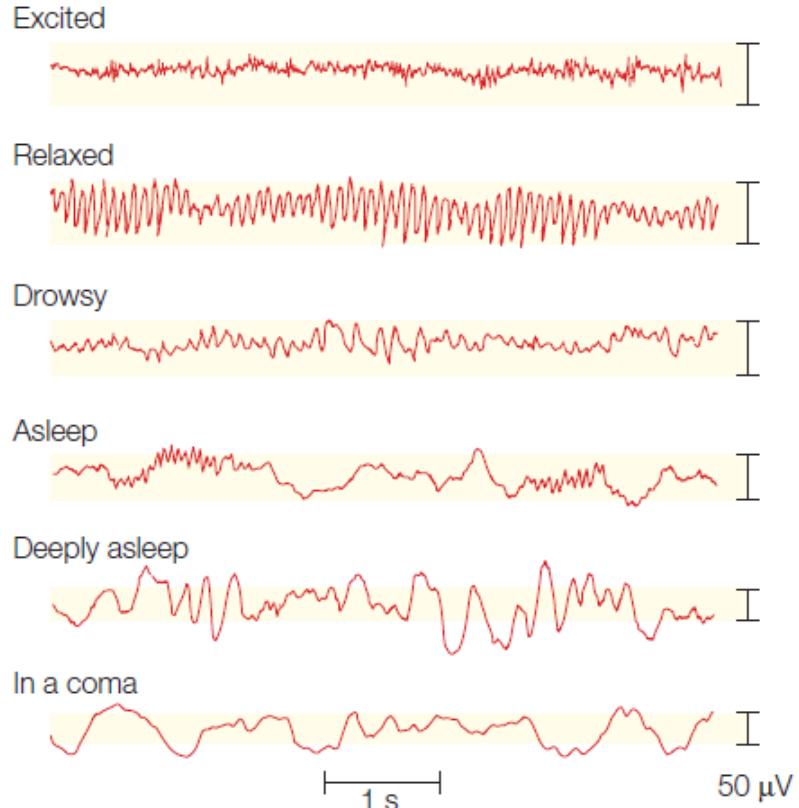


fotografixx/iStock

The 10-20 System



EEG signals



Event-related potentials

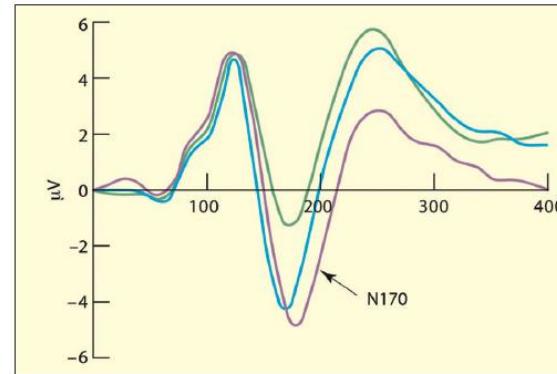
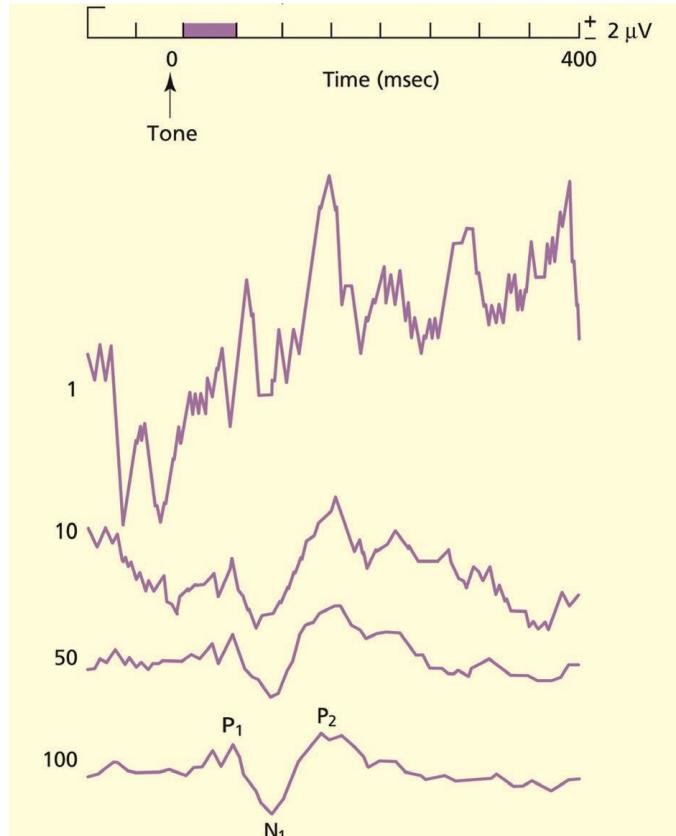


FIGURE 3.14: The N170 is observed for both human faces (purple) and animal faces (blue), but not other objects (green). From Rousselet et al., 2004. With permission of ARVO.

A single recording has a low signal-to-noise ratio.

Averaging over hundreds of trials reveals the tiny signal, as noise is canceling.

Other EEG signals are treated as being non-correlated to the stimulus

→ Serially uncorrelated random variable

→ 0 mean (!) and finite variance

→ No prior distribution is assumed

AVERAGING REMOVES THE NOISE

Python example

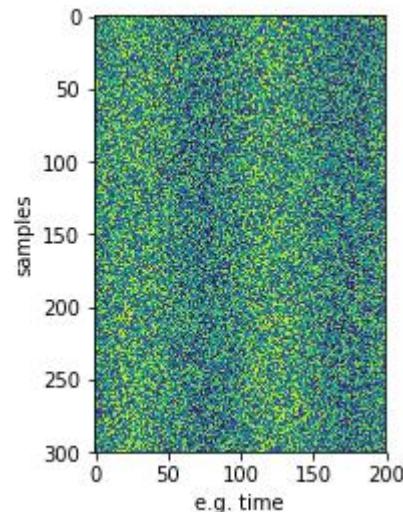
```
In [2]: 1 import numpy as np  
2 import matplotlib.pyplot as plt
```

Generate true signal

```
In [3]: 1 x = np.linspace(0, 4*np.pi, 200)  
2 y = np.sin(x)
```

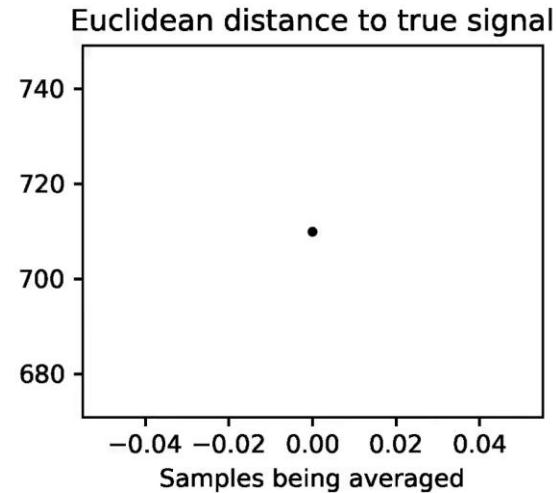
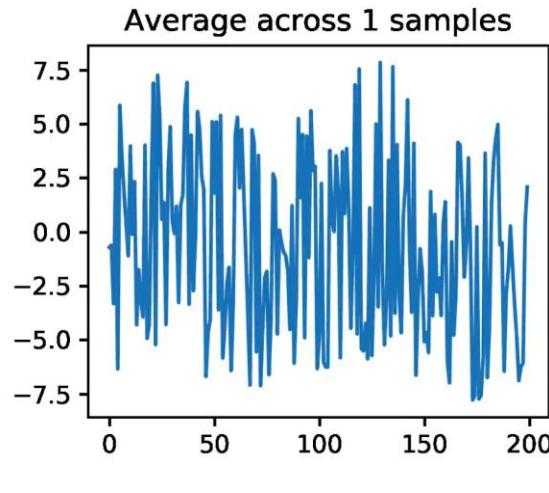
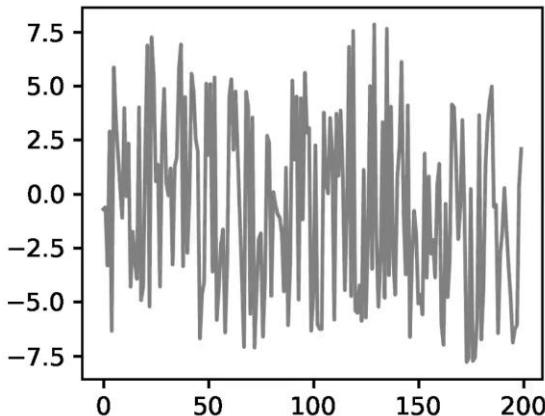
Generate samples from the true signal with added noise.

```
1 s = []  
2 factor=7  
3  
4 for _ in range(300):  
5     s.append(y + np.random.uniform(-factor, factor, y.size))  
6  
7 plt.imshow(s)  
8 plt.ylabel("samples")  
9 plt.xlabel("e.g. time")
```



Averaging over multiple samples

Sine signal with plenty of white noise (drawn from uniform distribution)



Noise2Noise and Noise2Void

For the L_2 loss $L(z, y) = (z - y)^2$, this minimum is found at the arithmetic mean of the observations:

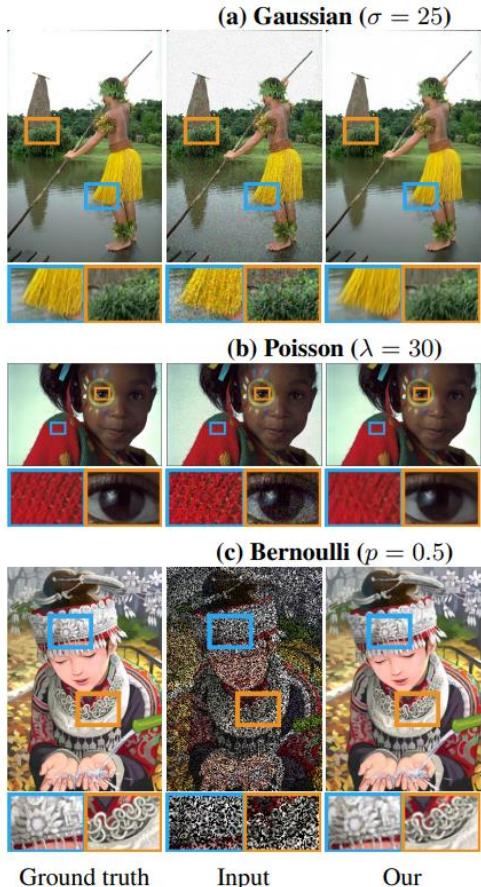
$$z = \mathbb{E}_y\{y\}. \quad (3)$$

The L_1 loss, the sum of absolute deviations $L(z, y) = |z - y|$, in turn, has its optimum at the median of the observations.

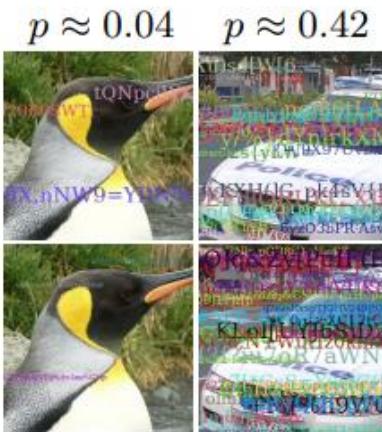
conditional expected values. *This implies that we can, in principle, corrupt the training targets of a neural network with zero-mean noise without changing what the network learns.* Combining this with the corrupted inputs from Equa-



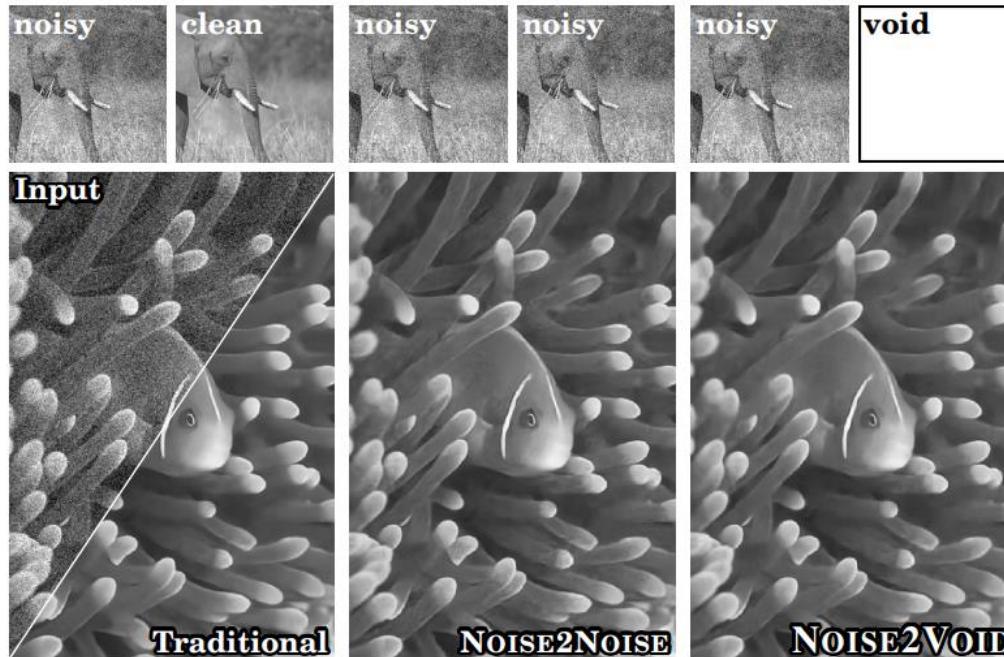
Lehtinen et al., 2018



Noise2Noise and Noise2Void

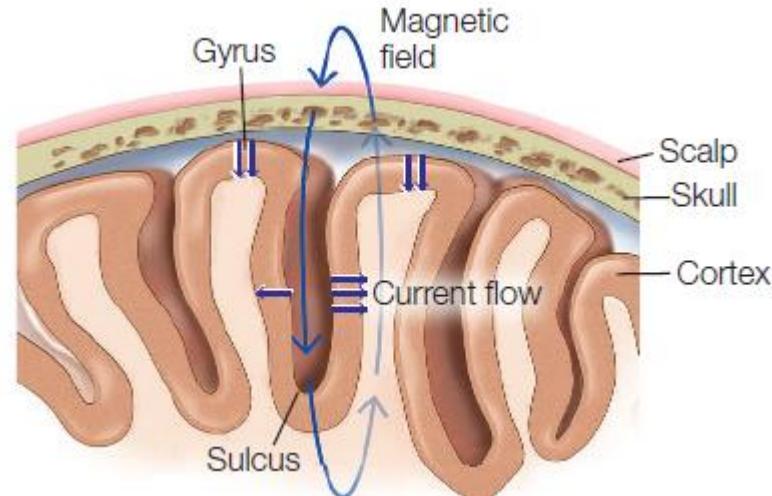
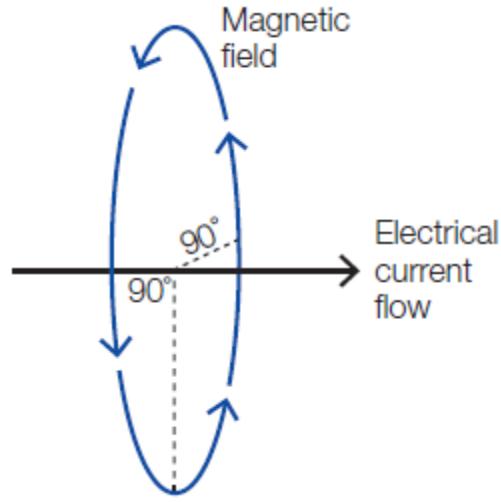


Example training pairs



Krull et al., 2019

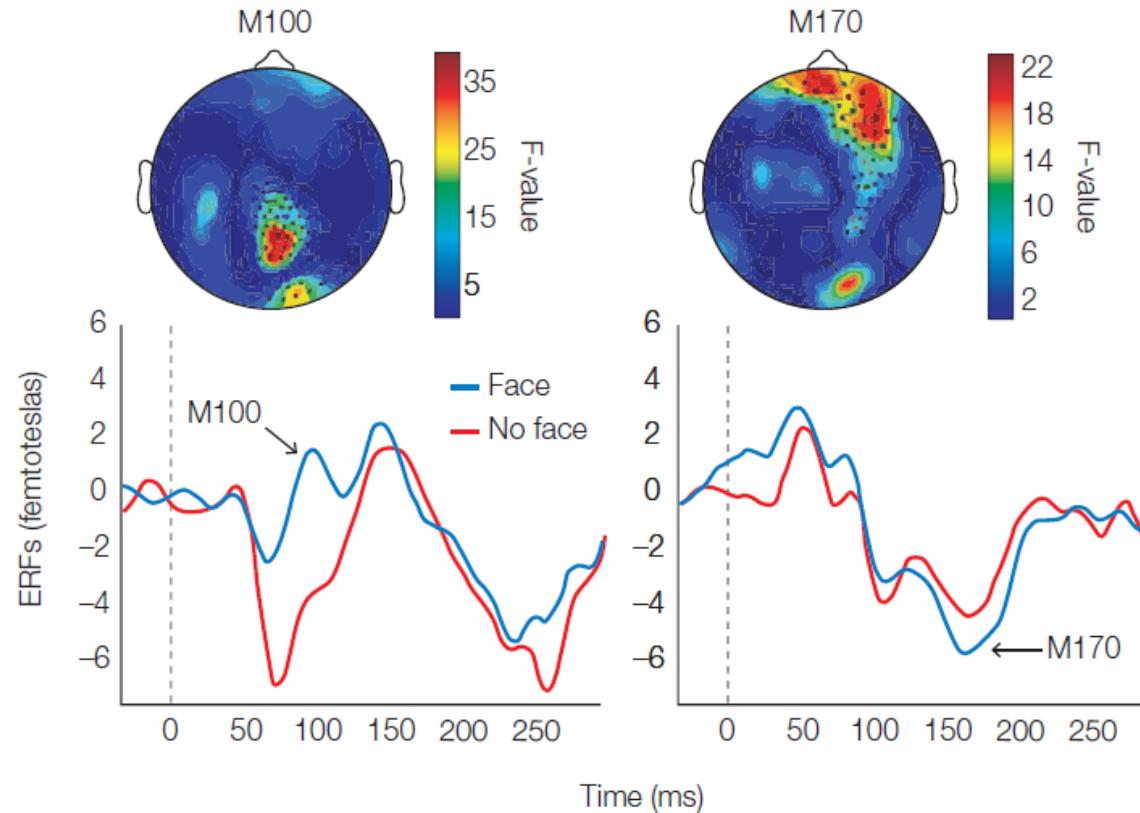
Magnetoencephalography (MEG)



MEG recording setting

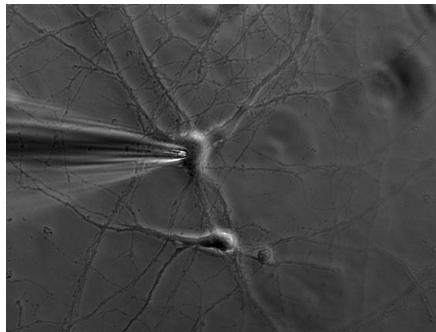
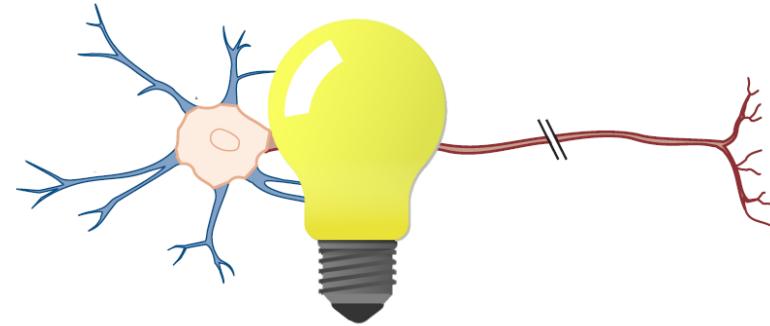
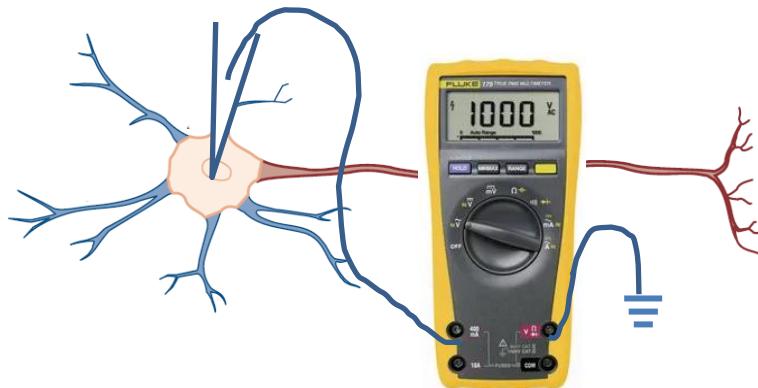


Topoplots



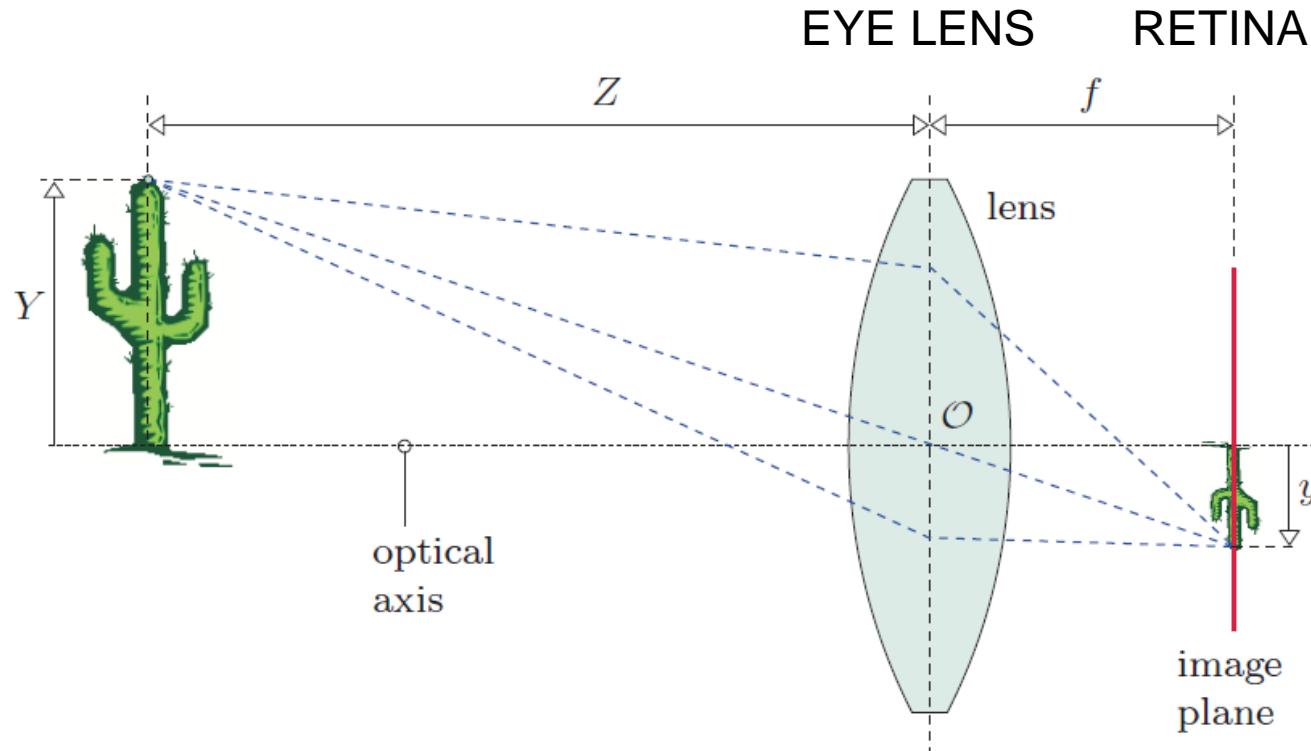
Optical approaches

Measuring neural activity

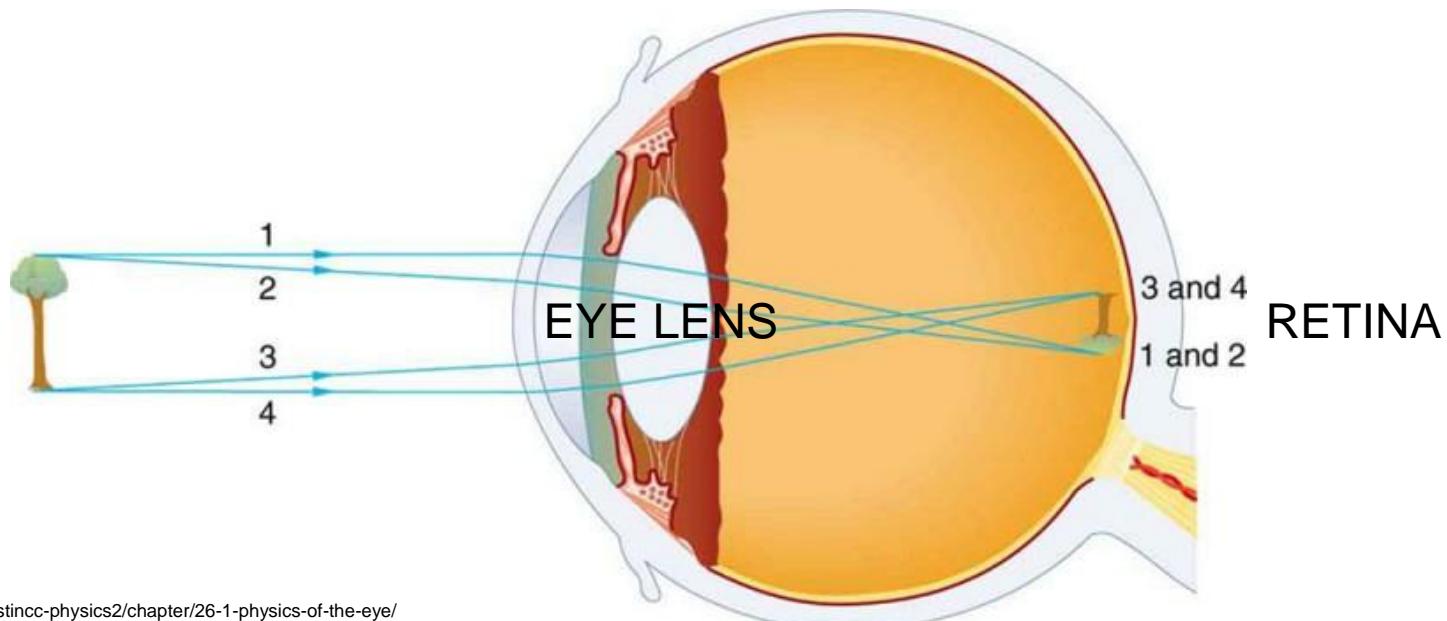
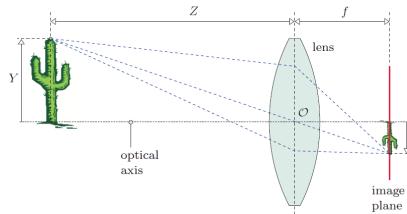


Optical approaches to measure
neural activity

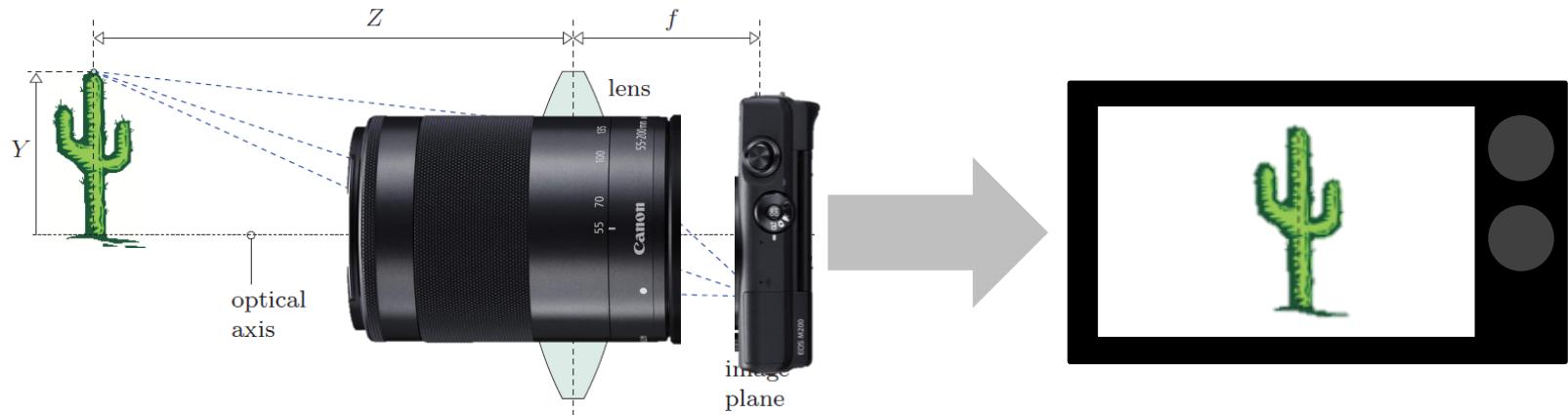
How does imaging work?

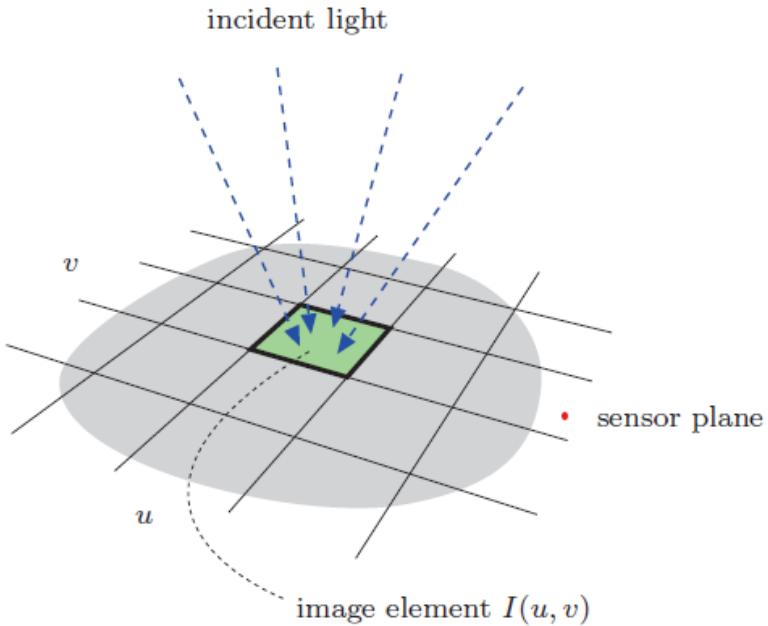
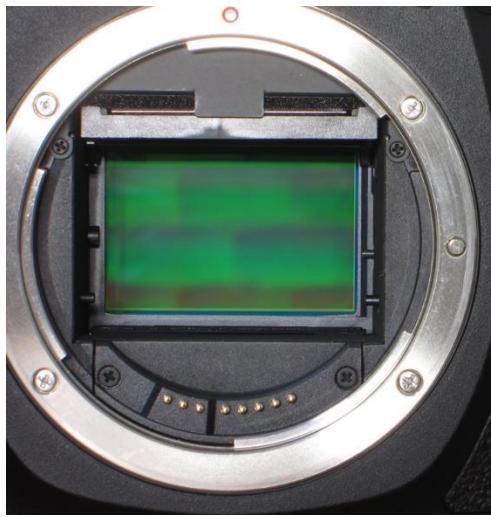


How does imaging work?

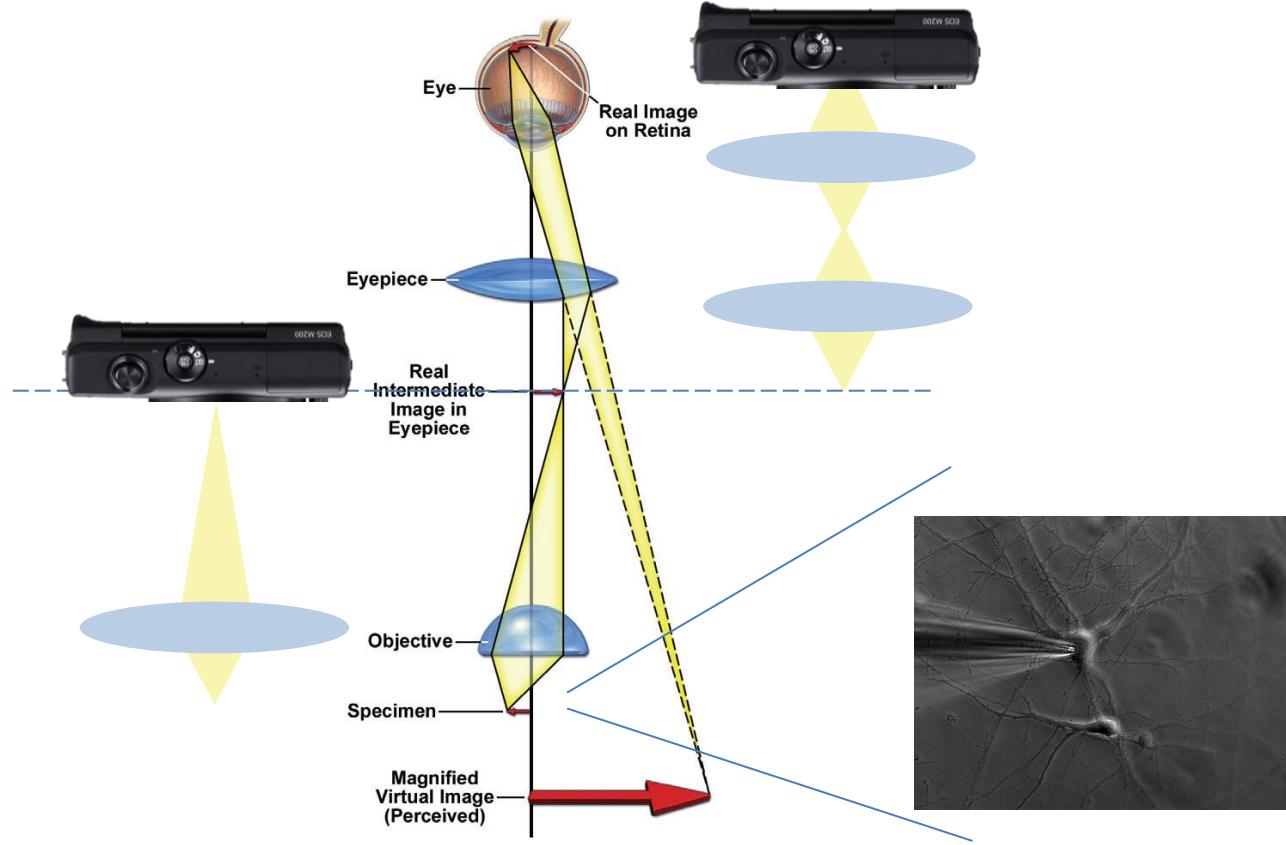


How does imaging work?

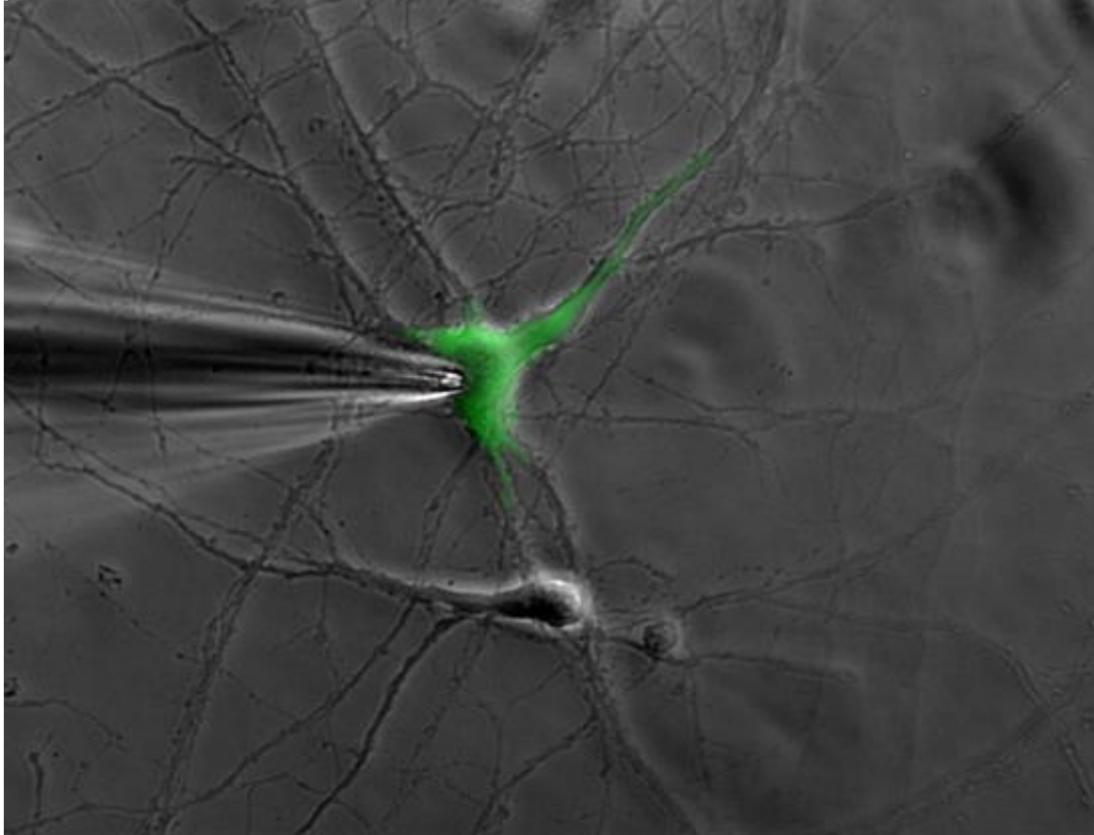




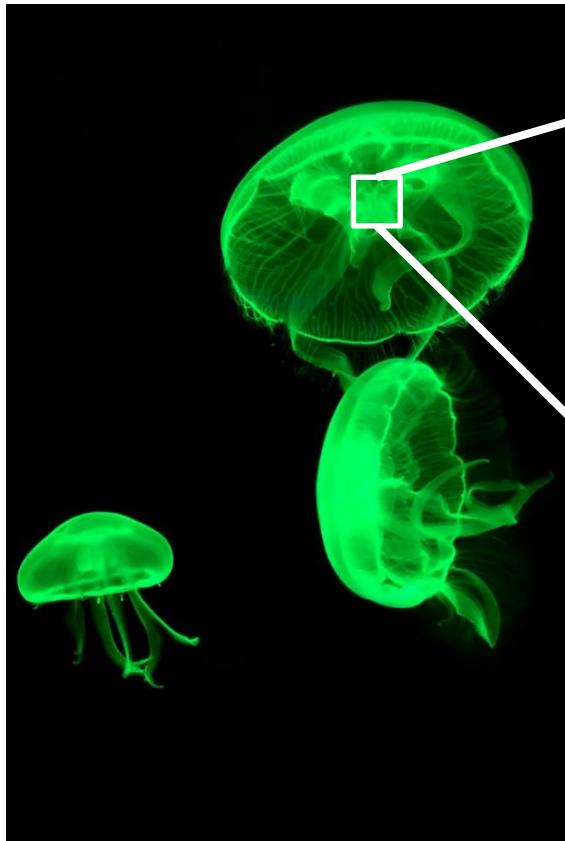
A basic microscopy setup



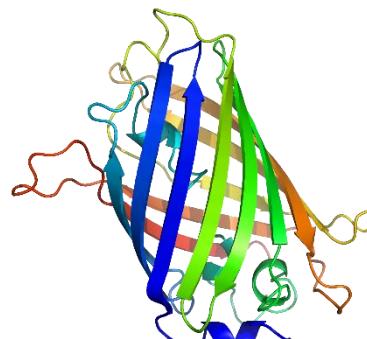
Making cells shine



Glowing jellyfish



Green fluorescent protein (GFP)



The Nobel Prize in Chemistry 2008



© The Nobel Foundation. Photo: U. Montan
Osamu Shimomura
Prize share: 1/3



© The Nobel Foundation. Photo: U. Montan
Martin Chalfie
Prize share: 1/3



© The Nobel Foundation. Photo: U. Montan
Roger Y. Tsien
Prize share: 1/3

The Nobel Prize in Chemistry 2008 was awarded jointly to Osamu Shimomura, Martin Chalfie and Roger Y. Tsien "for the discovery and development of the green fluorescent protein, GFP."

A protein that fluoresces

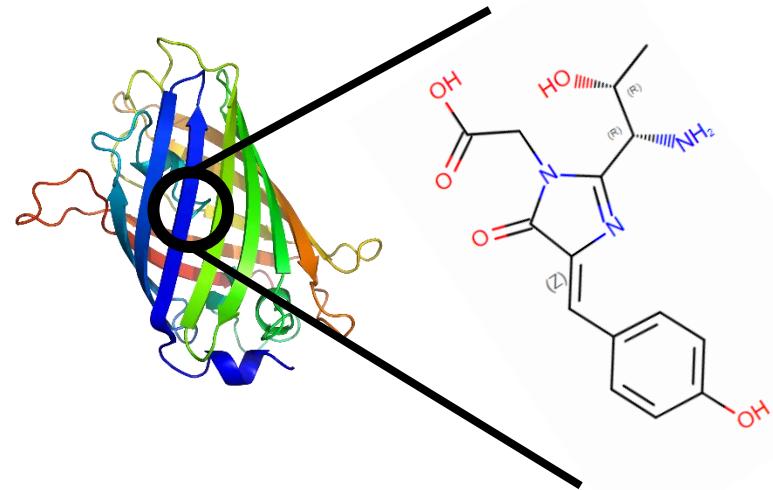
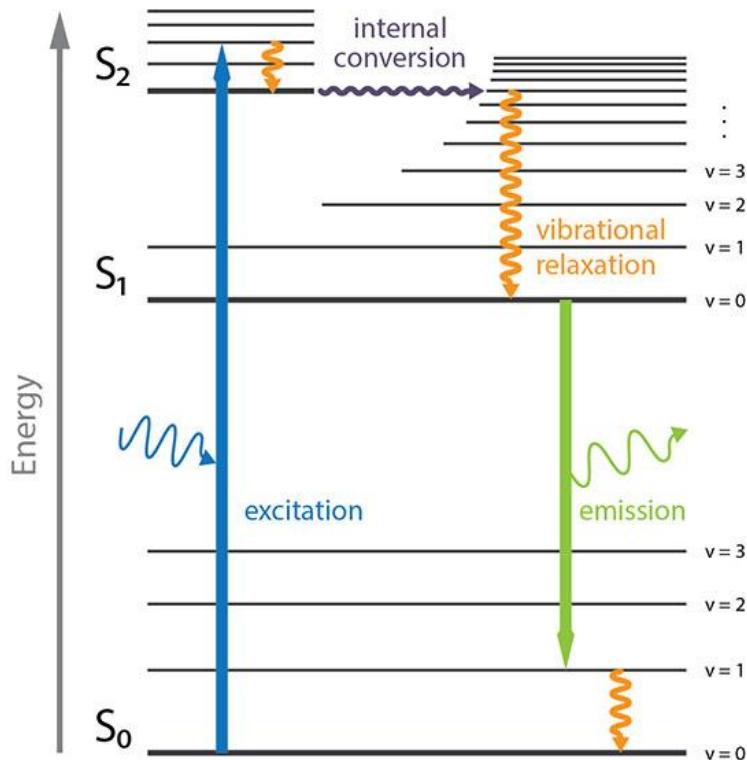
Bacteria expressing GFP



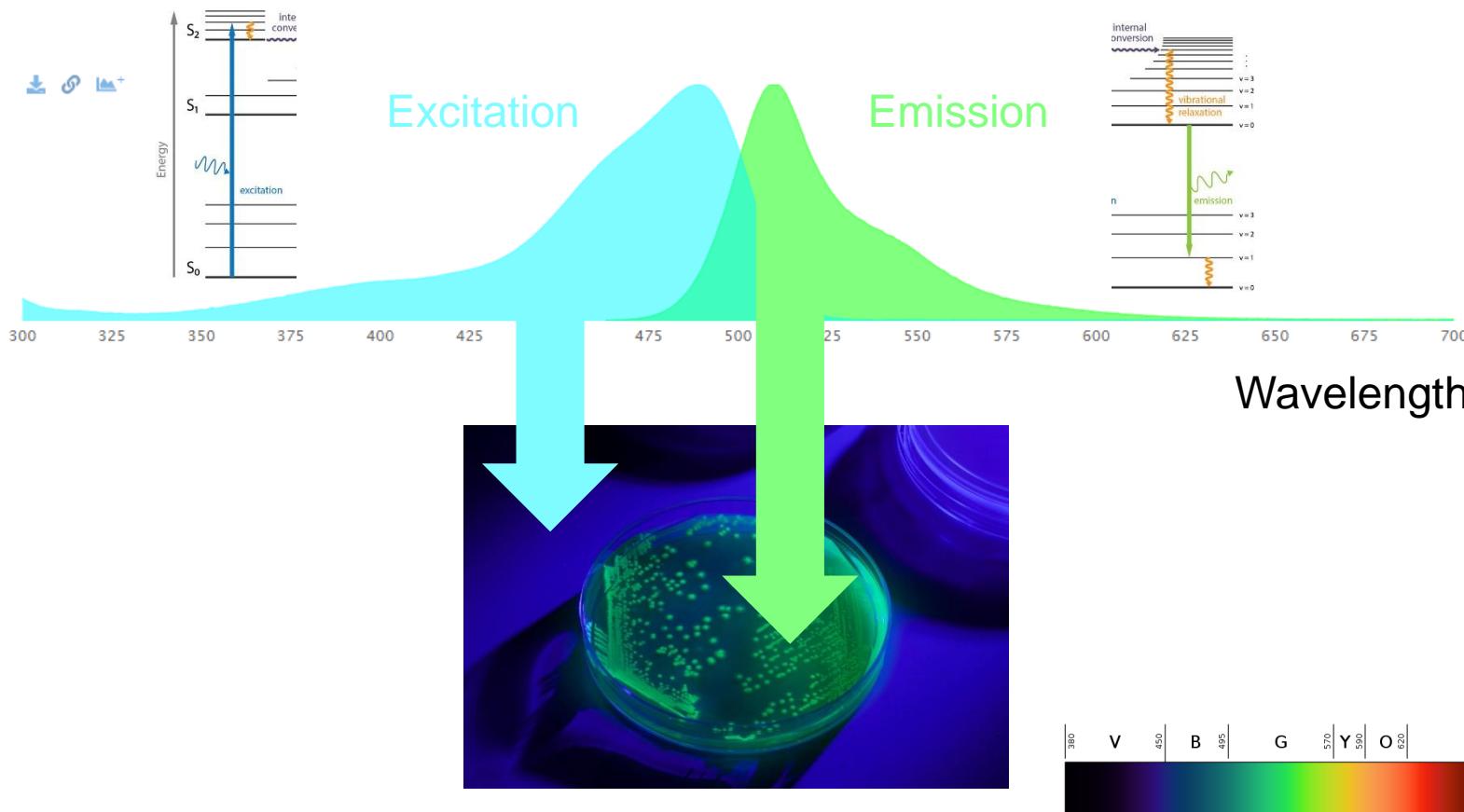
What is fluorescence?

Why is it useful?

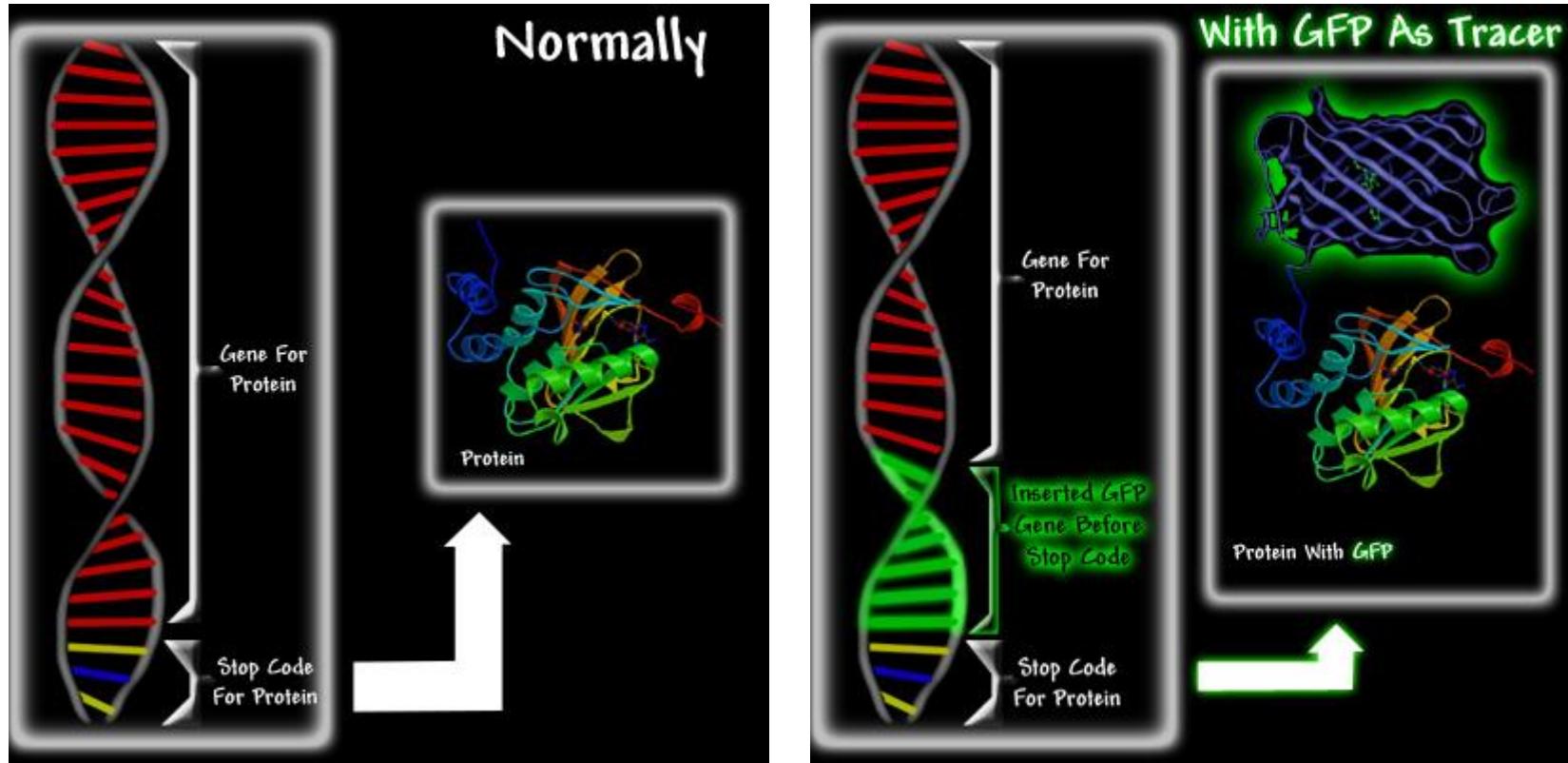
Fluorescence in essence



Spectral properties of GFP

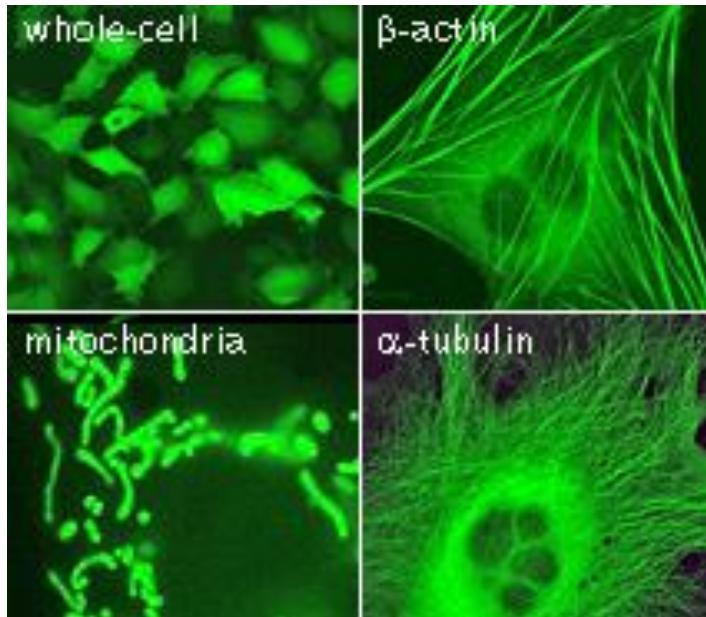


Why is it useful

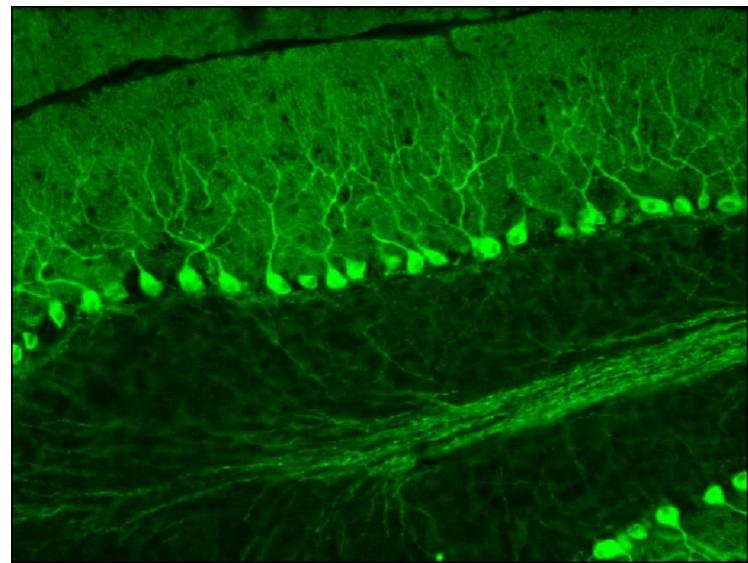


GFP tagging

GFP allows the visualization of cell structures,
when CELLS ARE ALIVE!

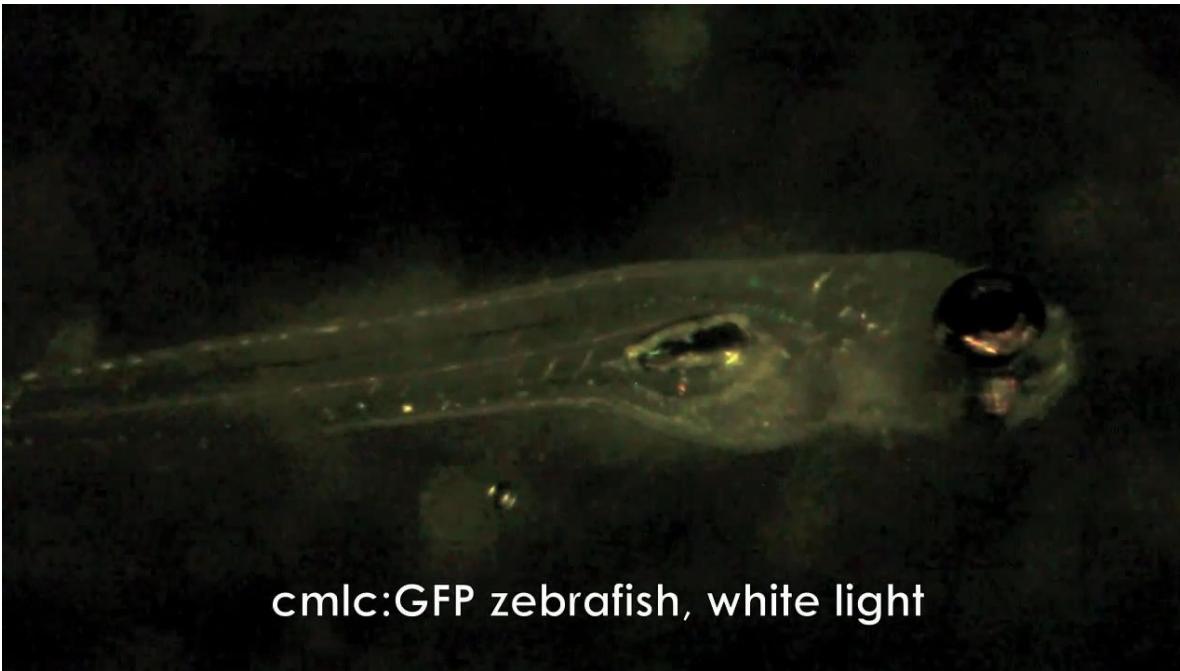


<https://www.biocat.com/proteomics/green-fluorescent-proteins-gfp-s>



https://www2.tmic.or.jp/Mn_B/English/GFP_in_Purkinje_cell.html

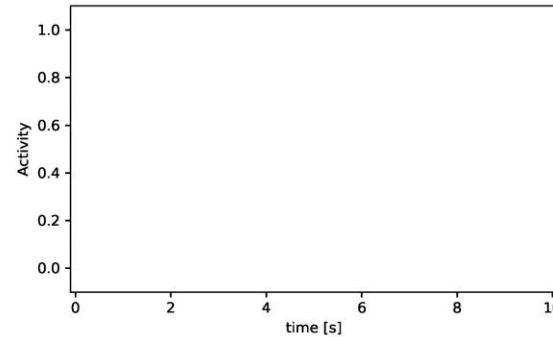
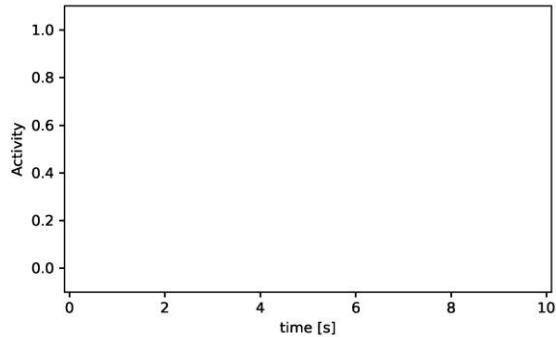
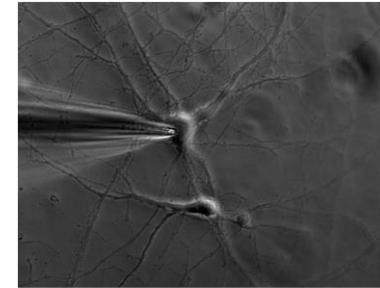
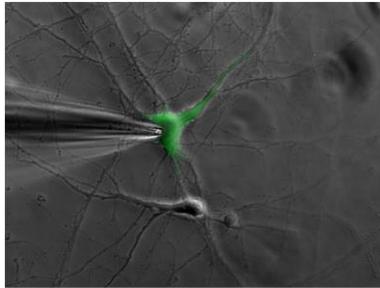
Larval zebrafish (ca. 5 days old)



cmlc:GFP zebrafish, white light

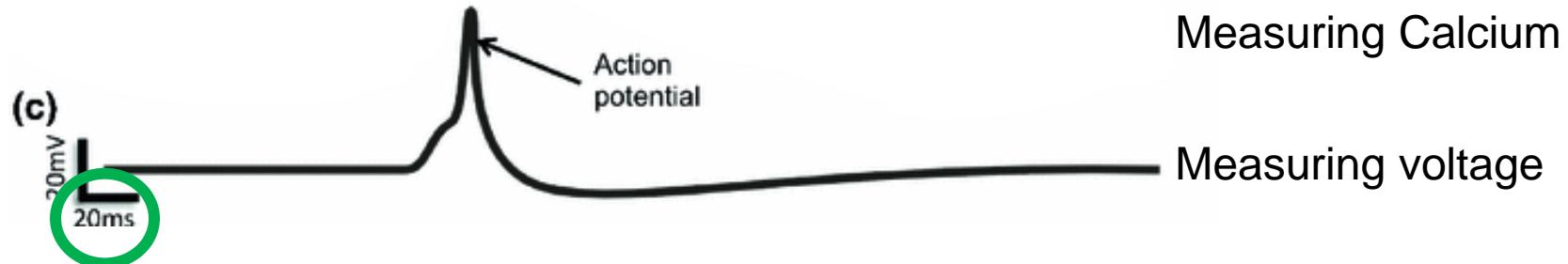
© Nightsea, <https://www.youtube.com/watch?v=fYMOEN7ANM>

How to track neural activity?

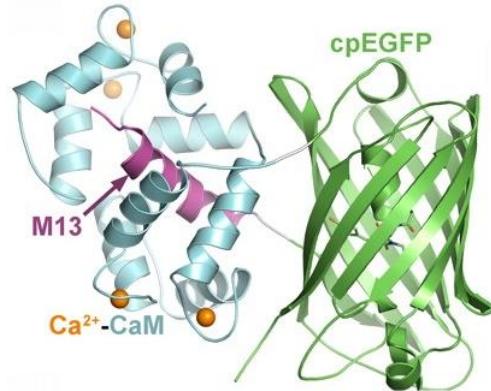


Activity-dependent fluorescence!

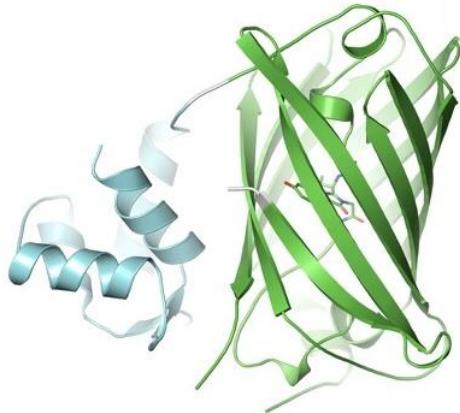
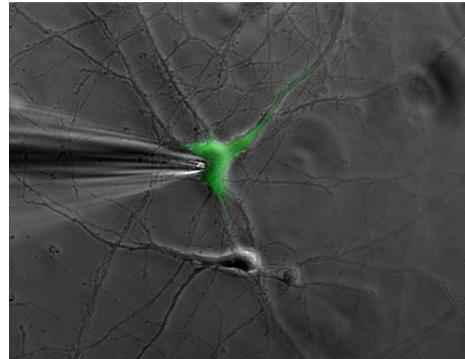
Activity dependent fluorescence



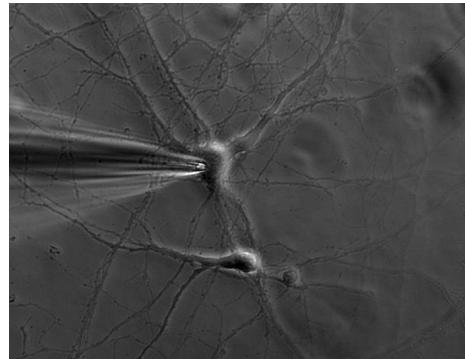
Calcium imaging



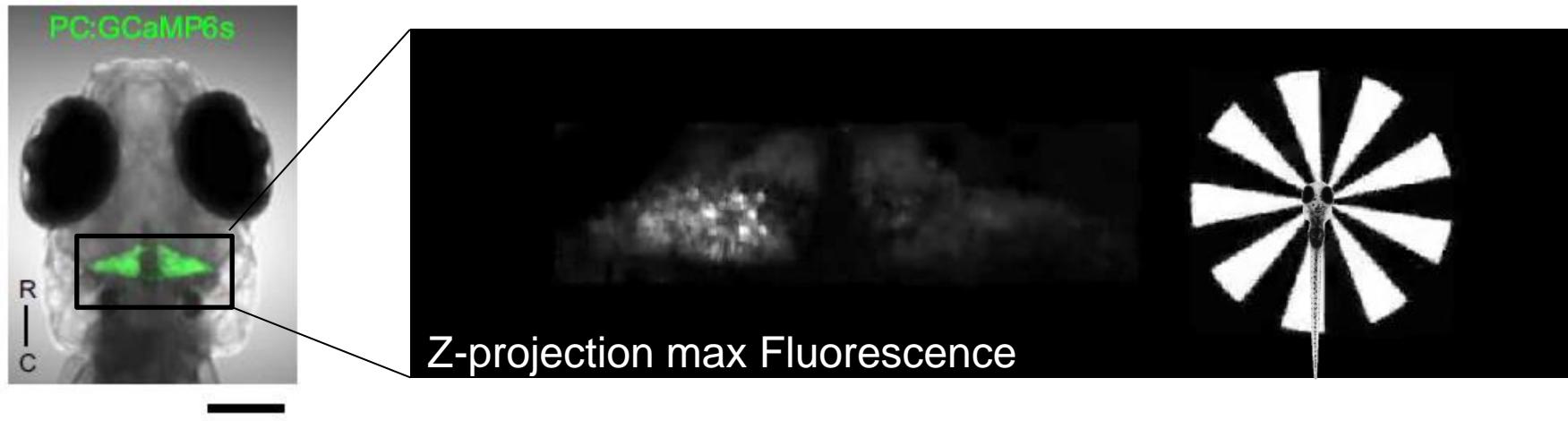
with Ca^{2+}



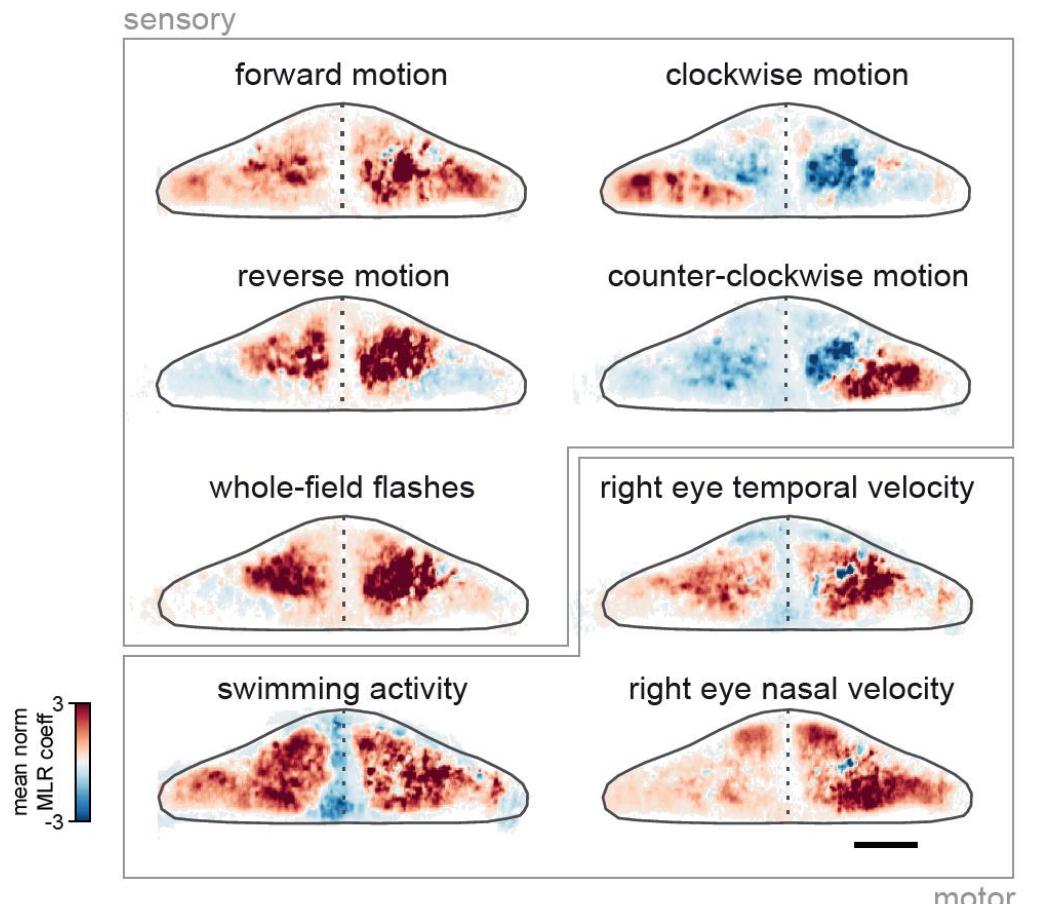
w/o Ca^{2+}



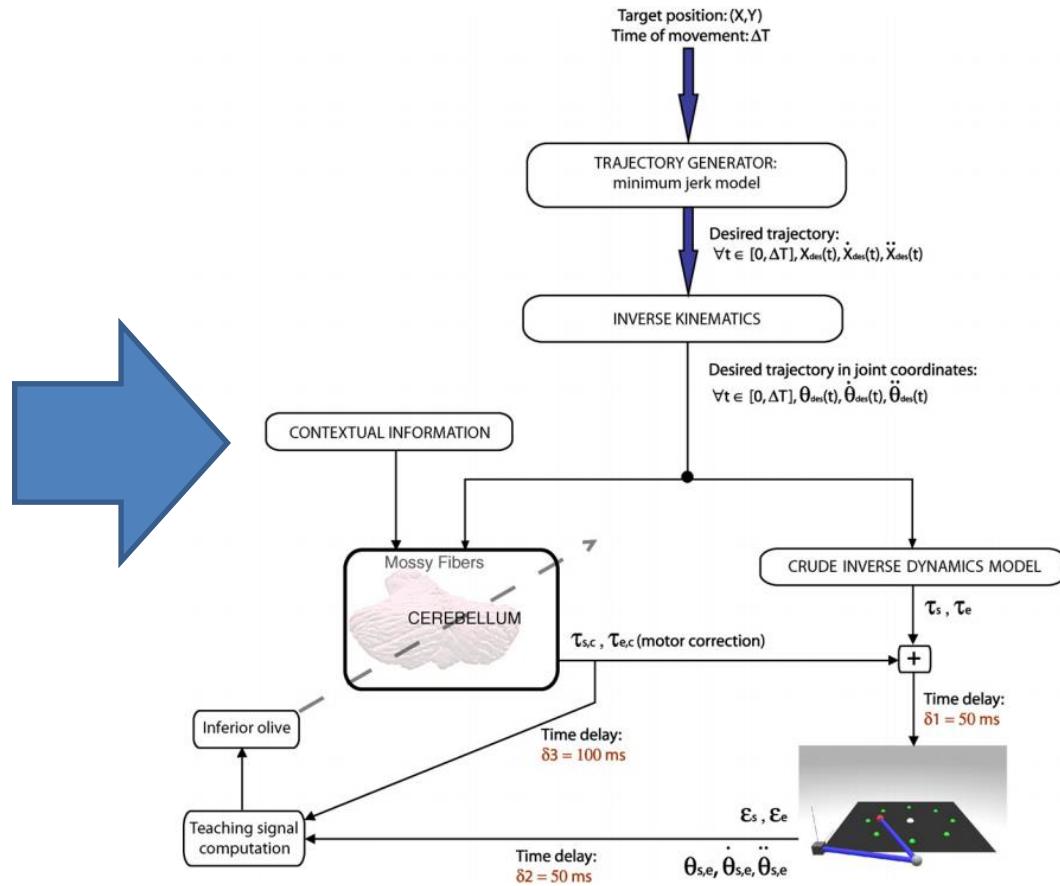
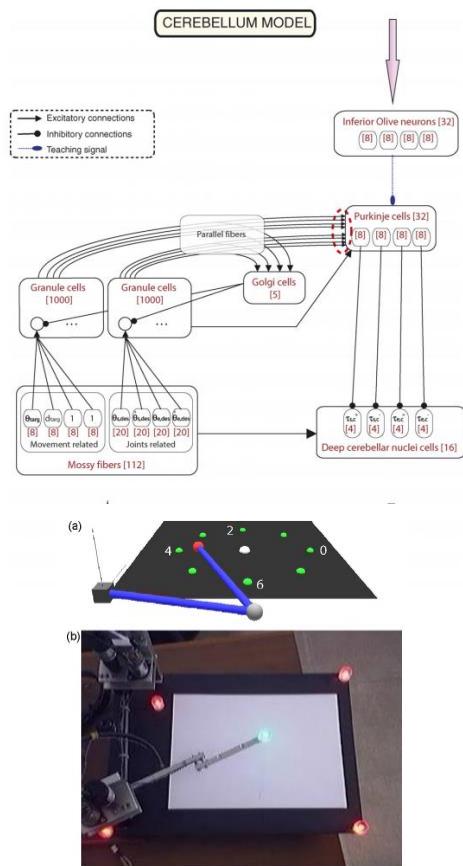
Imaging Purkinje cells in larval zebrafish



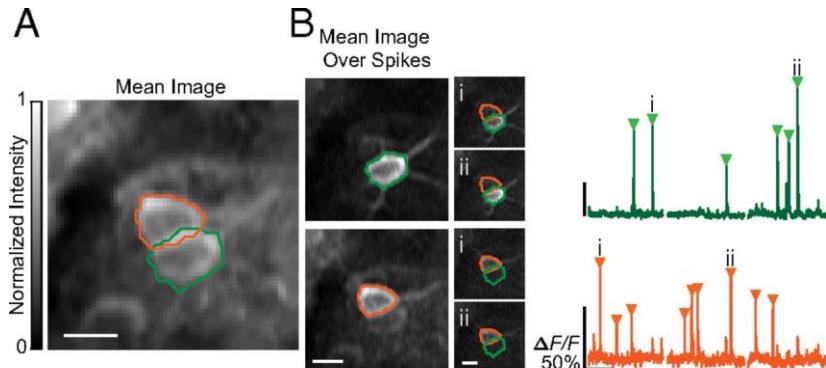
Calcium imaging reveals activity dependent on sensory stimuli



Why is this important to AI Developers?



Application of AI in life sciences



CalciumGAN: A Generative Adversarial Network Model for Synthesising Realistic Calcium Imaging Data of Neuronal Populations

Bryan M. Li¹
b.m.y.li@sms.ed.ac.uk

Theoklitos Amvrosiadis²
t.amvrosiadis@ed.ac.uk

Nathalie Rochefort^{2,3}
n.rochefort@ed.ac.uk

Arno Onken¹
arnonken@inf.ed.ac.uk

¹School of Informatics, University of Edinburgh

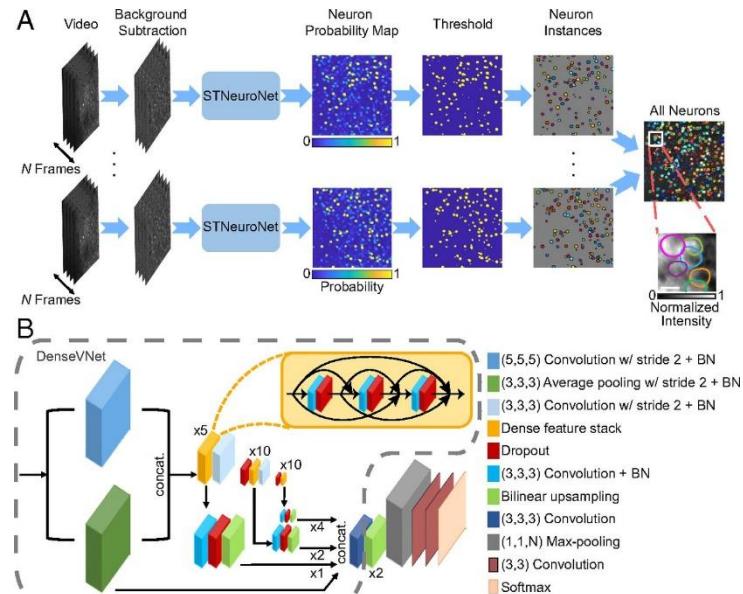
²Centre for Discovery Brain Sciences, University of Edinburgh

³Simons Initiative for the Developing Brain, University of Edinburgh

Fast and robust active neuron segmentation in two-photon calcium imaging using spatiotemporal deep learning

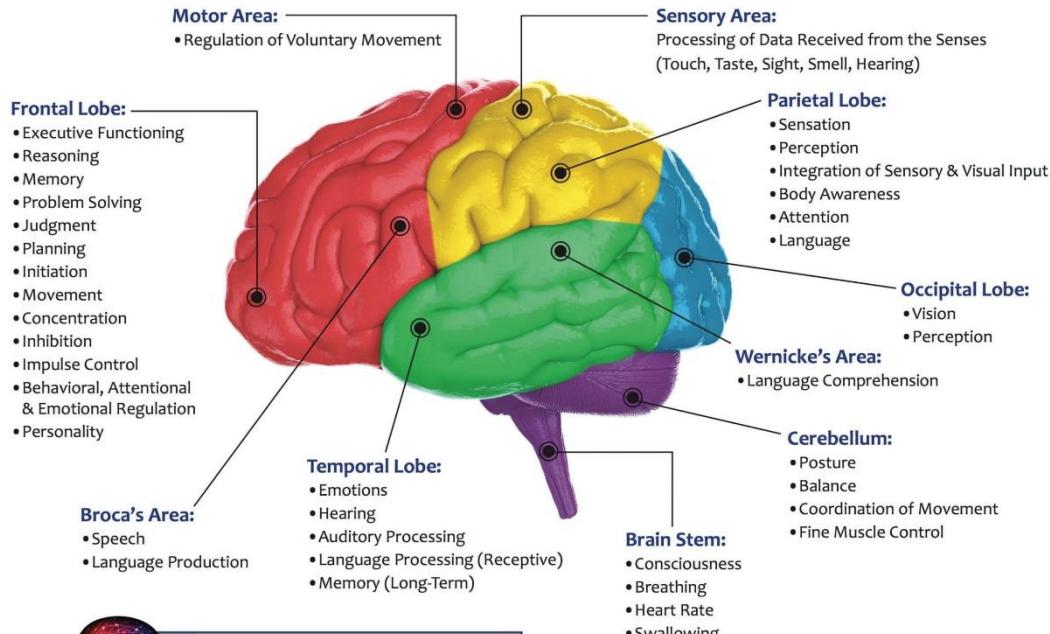
• Somayeh Soltanian-Zadeh, Kaan Sahingur, Sarah Blau, Yiyang Gong, and Sina Farsiu
+ See all authors and affiliations

PNAS April 23, 2019 116 (17) 8554-8563; first published April 11, 2019; <https://doi.org/10.1073/pnas.1812995116>



Connectivity

Brain Structure and Function



**Dr. Roseann Capanna-Hodge
& Associates**

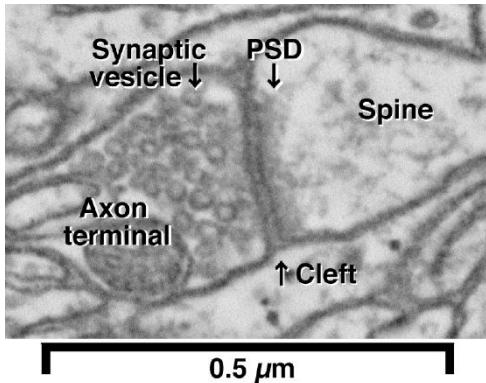
Neurofeedback, Evaluation & Therapy Services

www.drroseann.com

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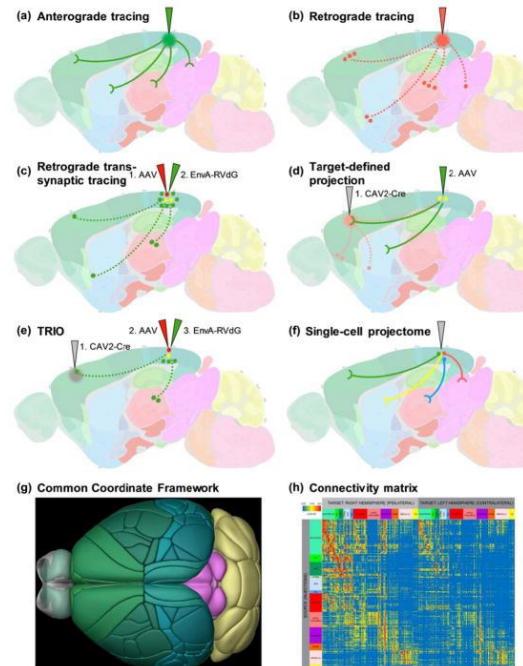
Connectivity analysis

Micro [μms]



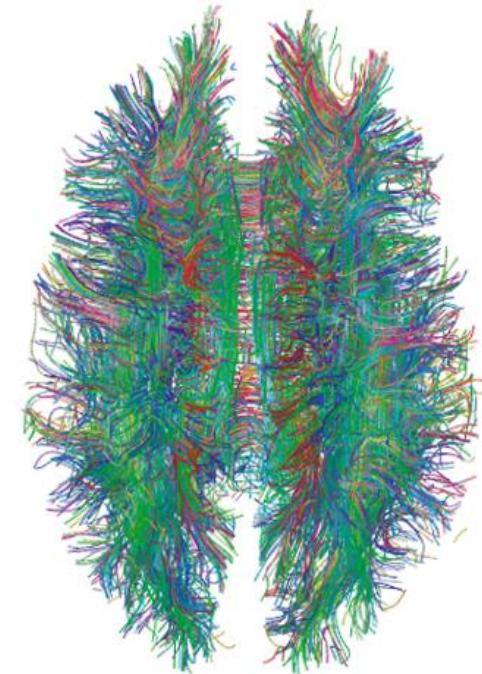
<https://blogs.zeiss.com/microscopy/en/brain-circuits/>

Meso [100 μms]



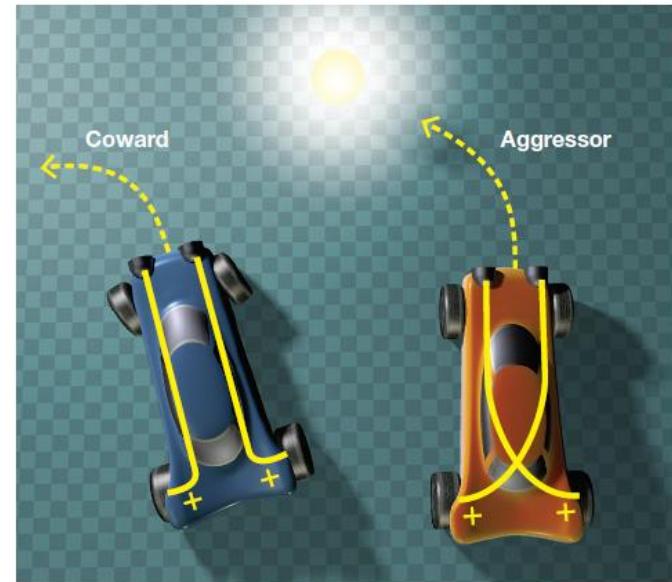
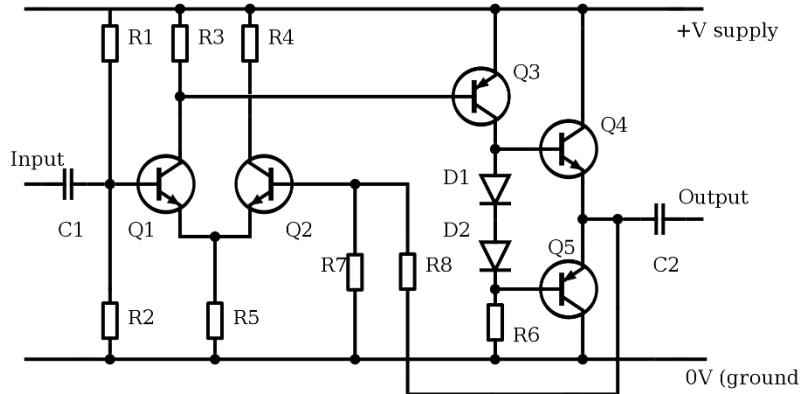
Zeng, Curr Opin Neurobiol 2018

Macro [mms]



Xavier Gigandet
et al., 2008

Why is it important?



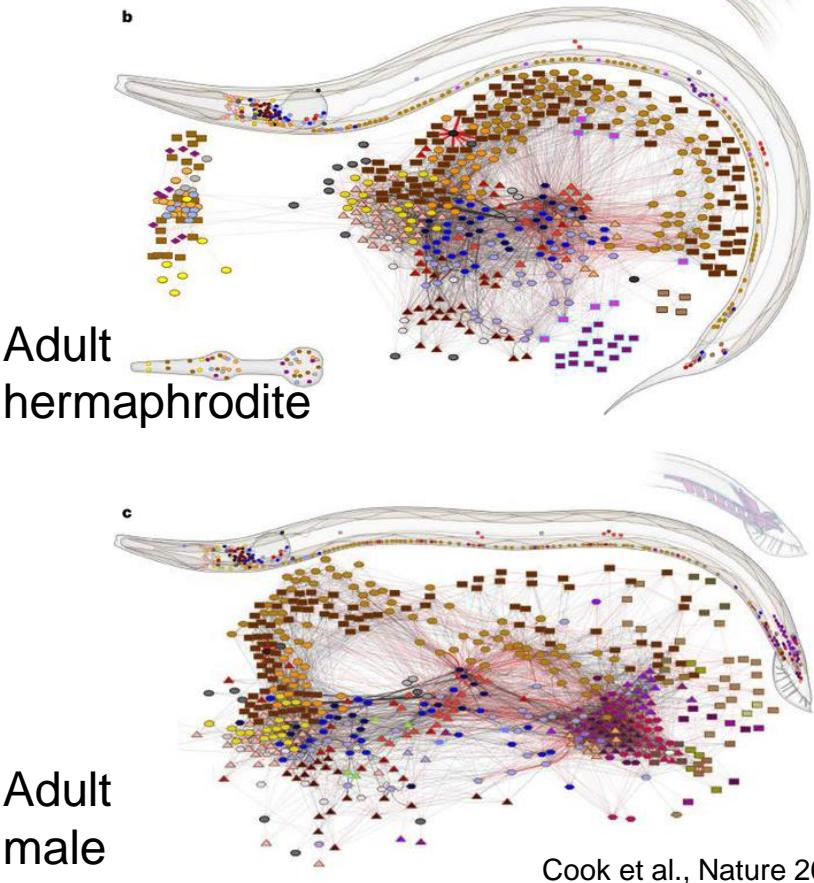
Knowing the circuitry helps in identifying the purpose

https://en.wikipedia.org/wiki/Amplifier#/media/File:Amplifier_Circuit_Small.svg

C. elegans connectome

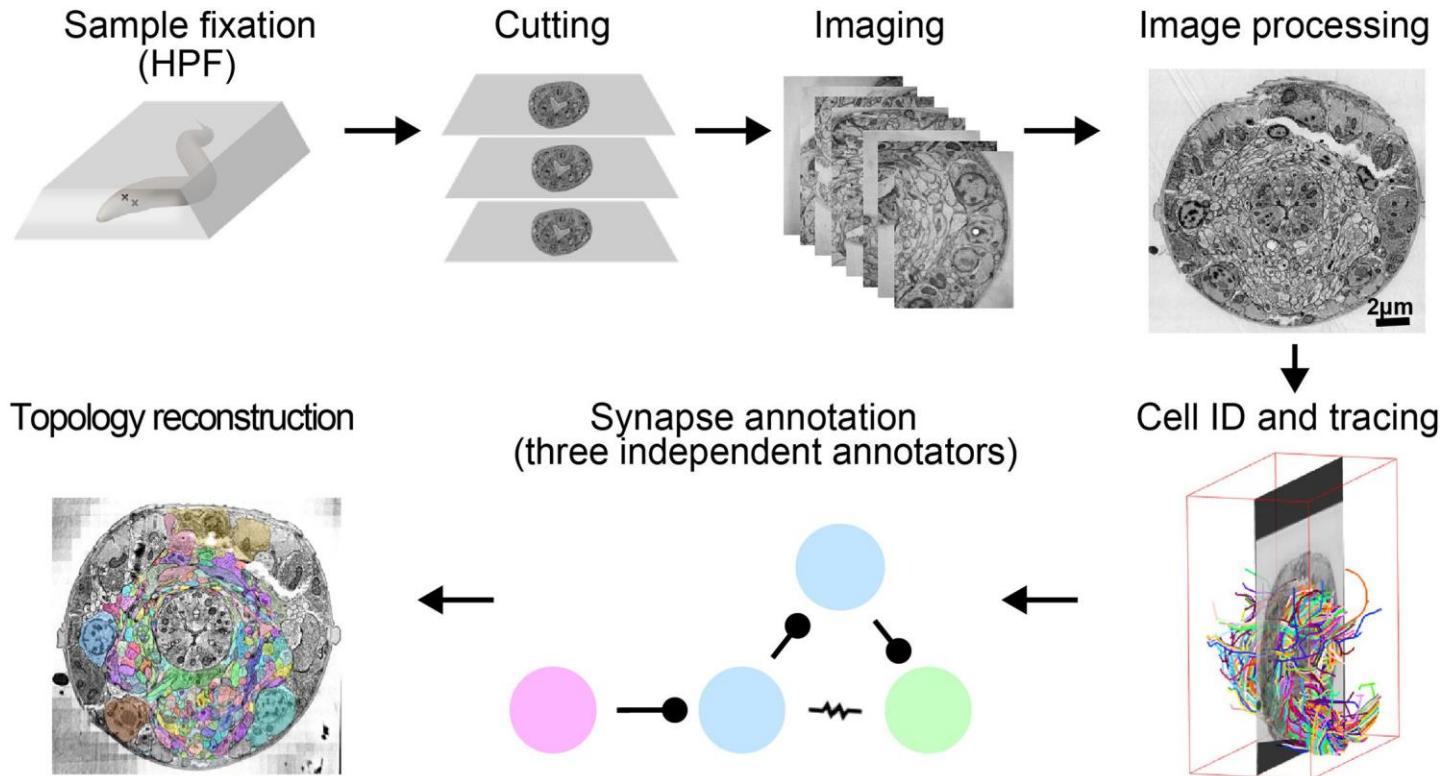


© Bob Goldstein



Cook et al., Nature 2019

Electron microscopy



Gamification of tasks



Using AI for connectomics analysis

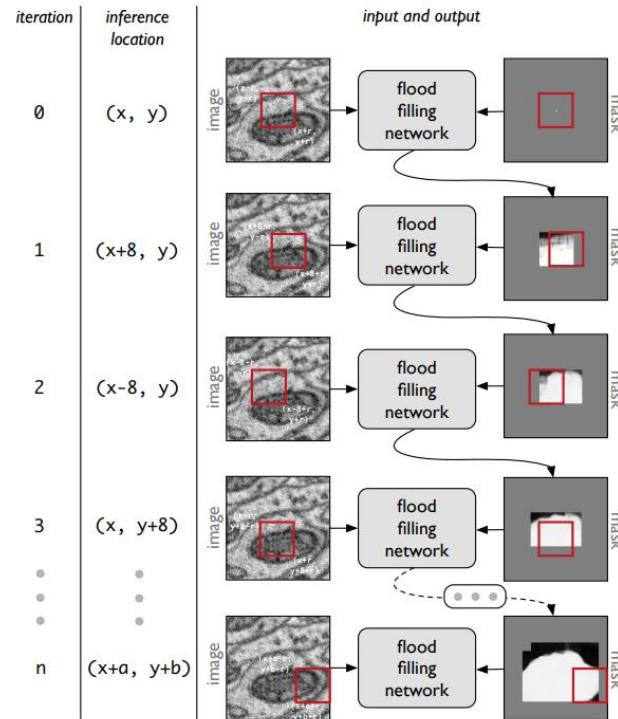
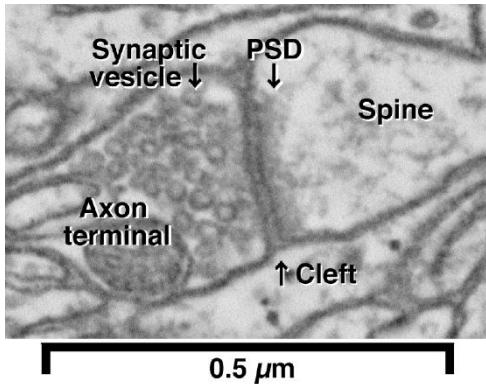


Figure 2: Schematic of multiple-field-of-view inference of a flood-filling network.

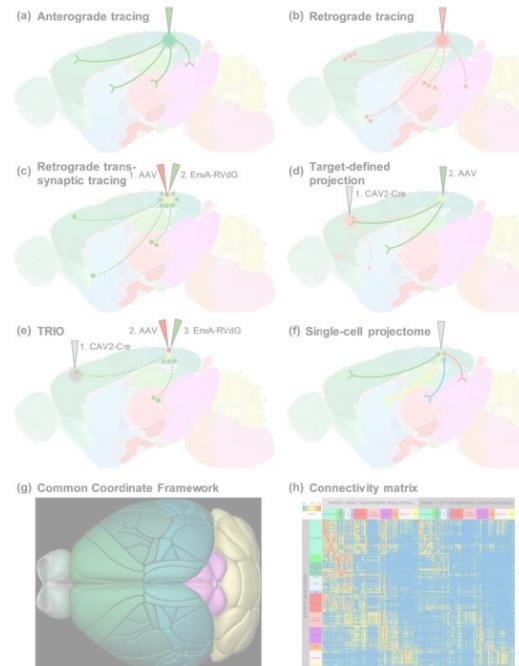
Connectivity analysis

Micro [μms]



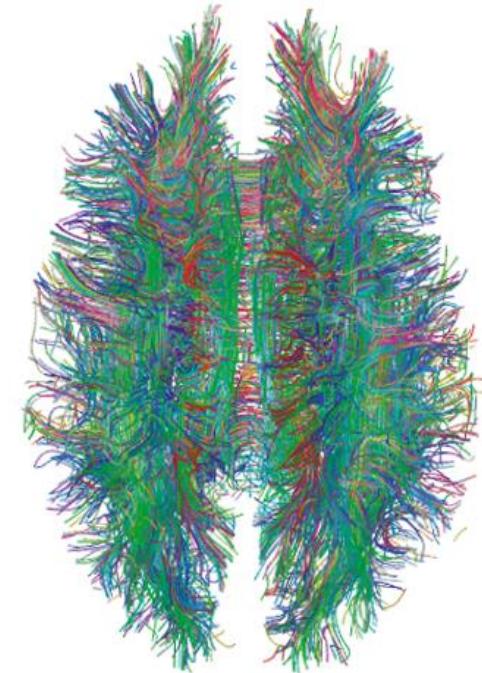
<https://blogs.zeiss.com/microscopy/en/brain-circuits/>

Meso [100 μms]



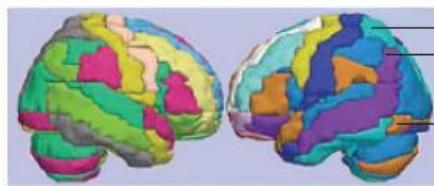
Zeng, Curr Opin Neurobiol 2018

Macro [mms]

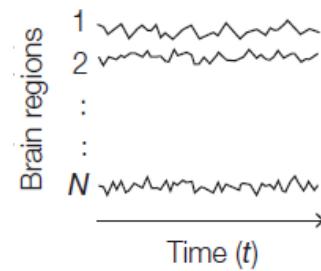


Xavier Gigandet
et al., 2008

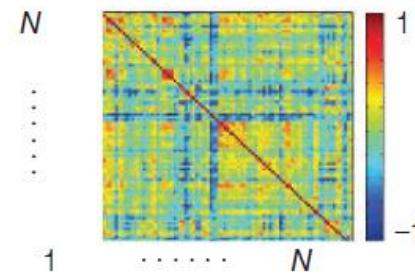
Construction a human brain network



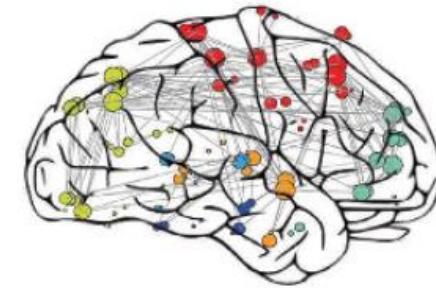
① Anatomical nodes



② fMRI time series



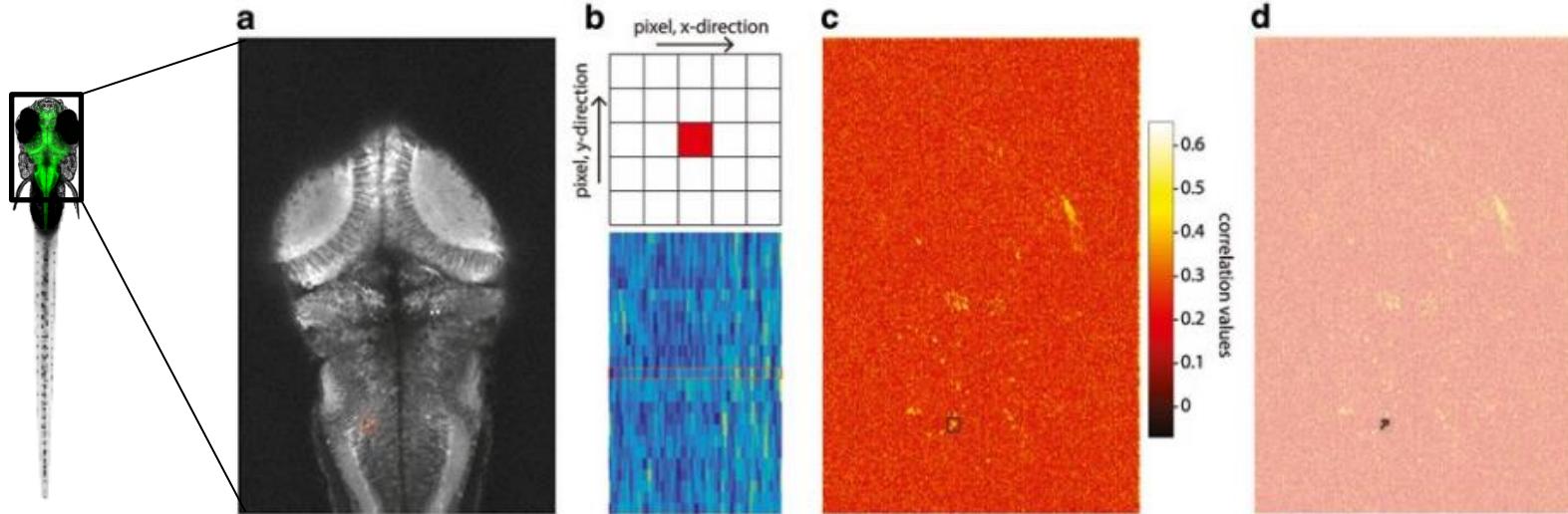
③ Association matrix



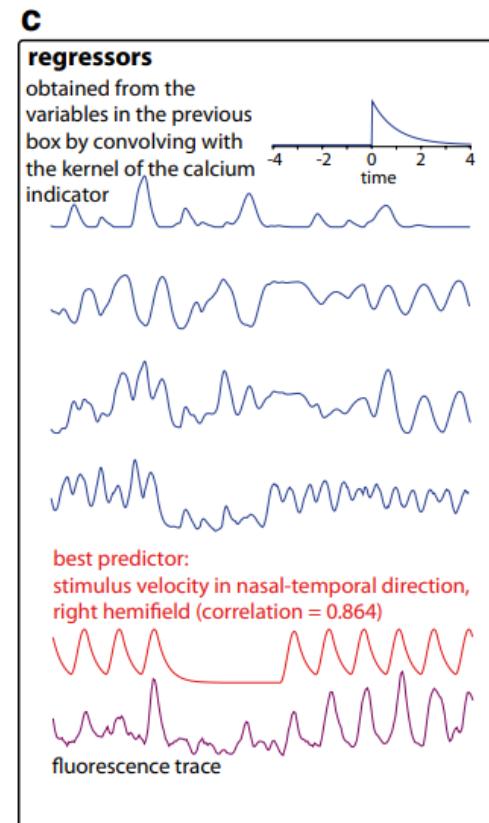
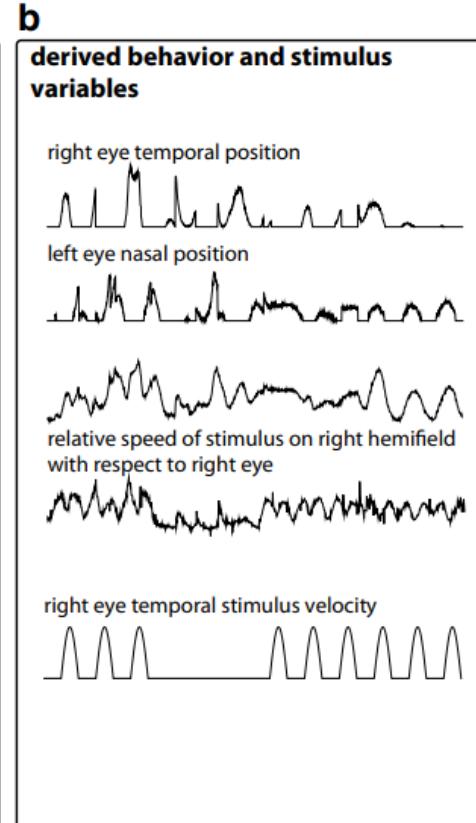
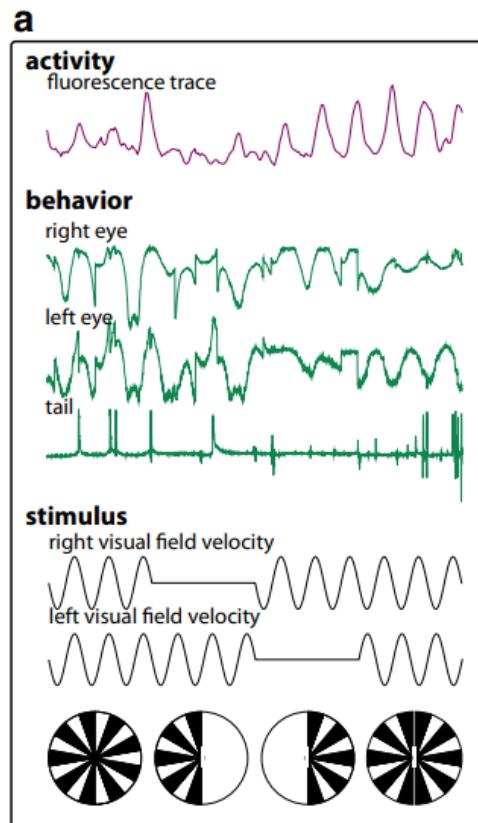
④ Connectivity map

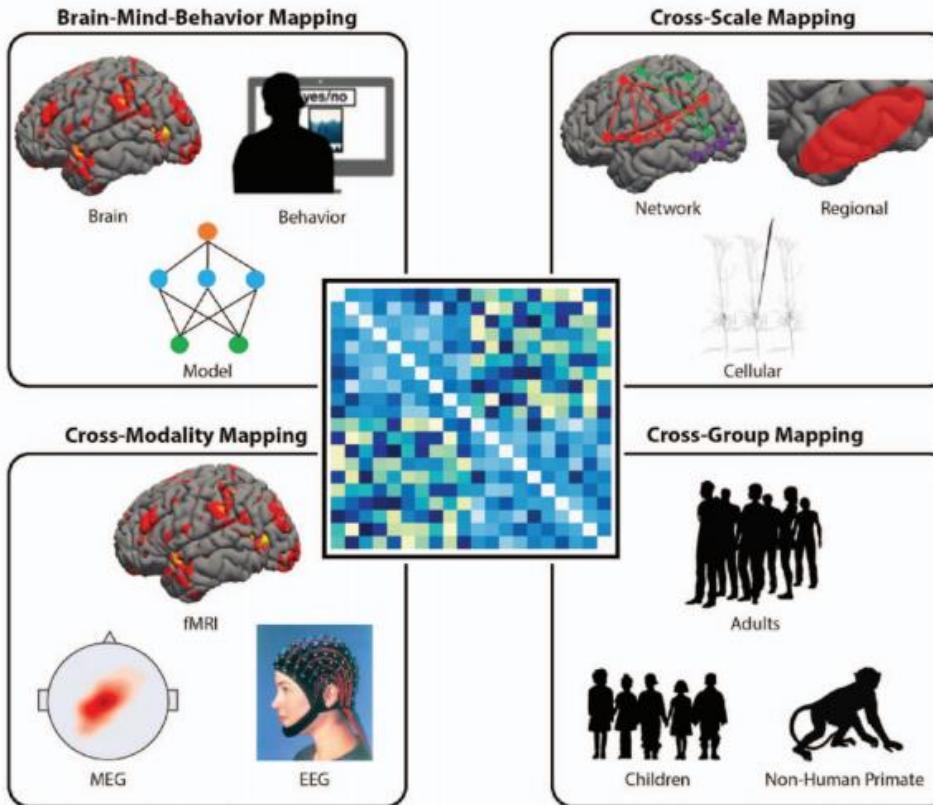
Voxel-based correlation map

Unbiased voxel-based self-correlation

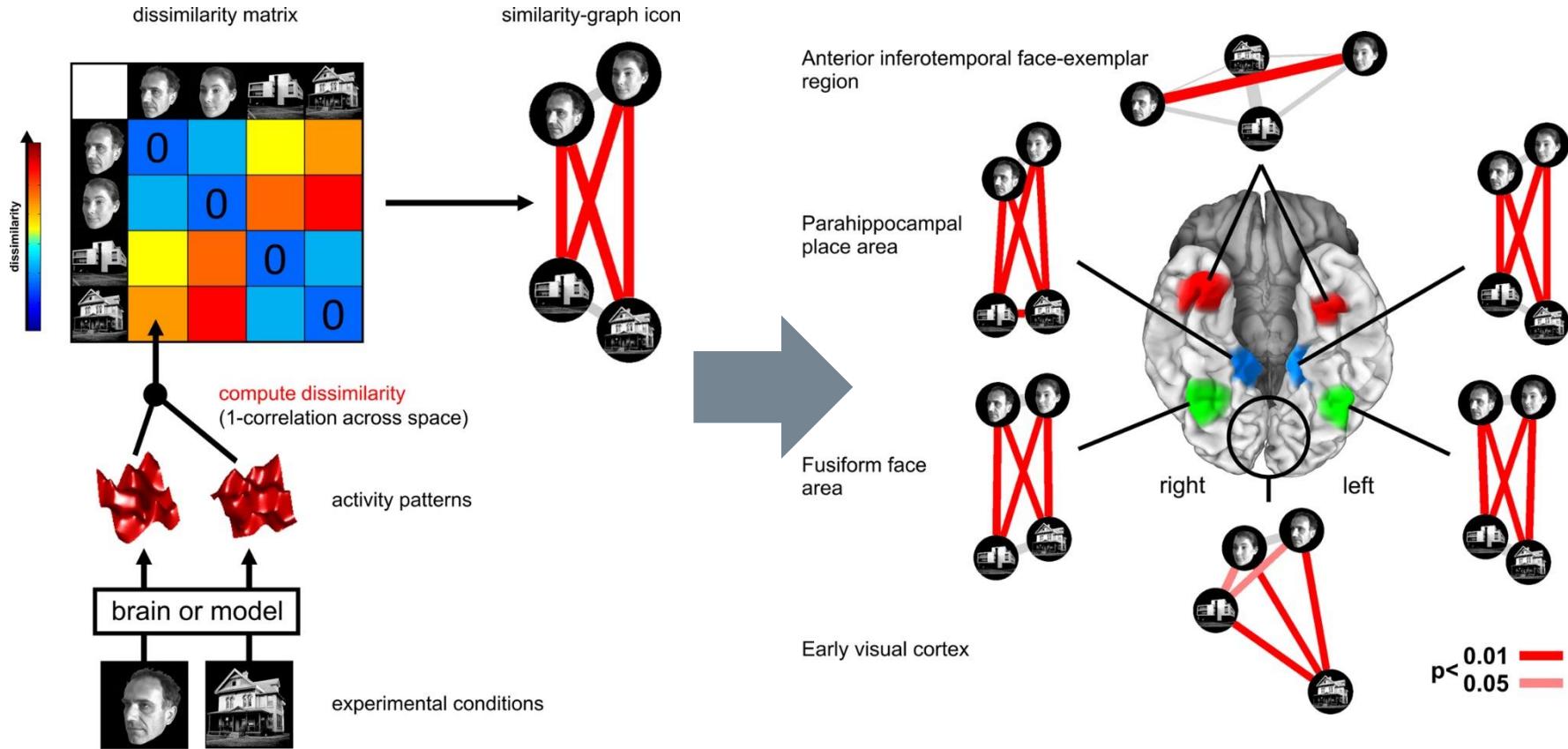


Voxel-based correlation maps



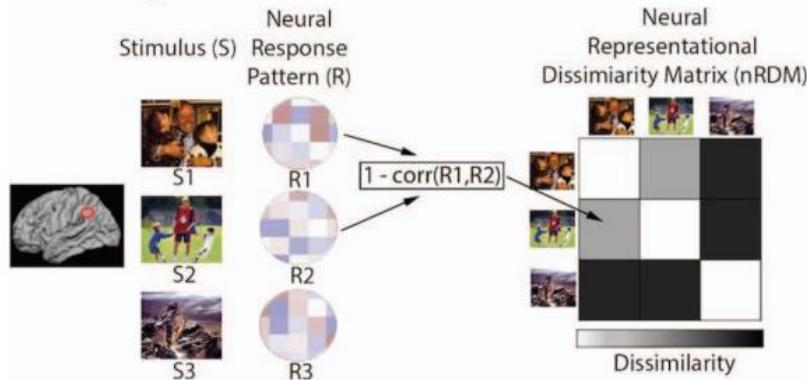


Representational Dissimilarity Matrices (RDMs)

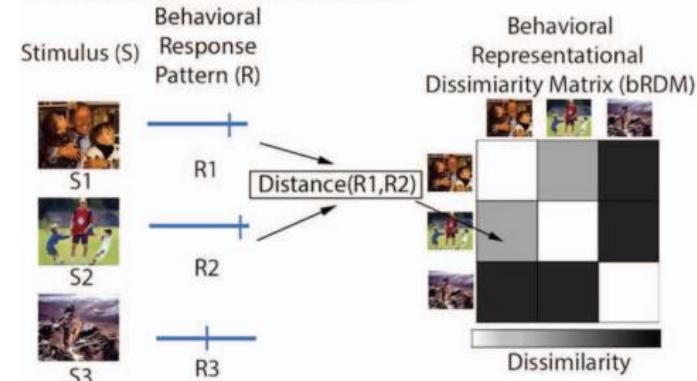


Creating RDMs

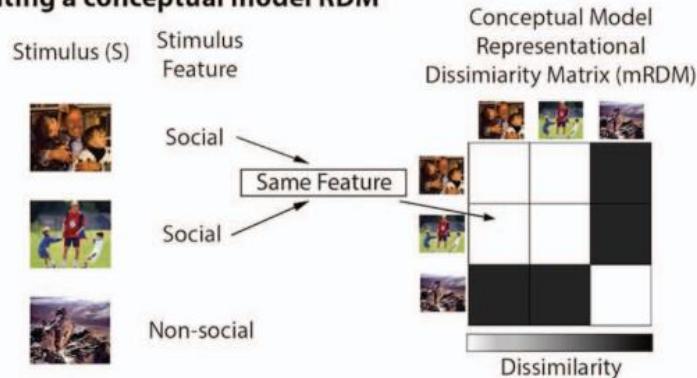
A. Creating a neural RDM



B. Creating a behavioral RDM



C. Creating a conceptual model RDM



RSA to uncover brain coding in humans and monkeys

