When machines look at neurons: learning from neuroscience time series

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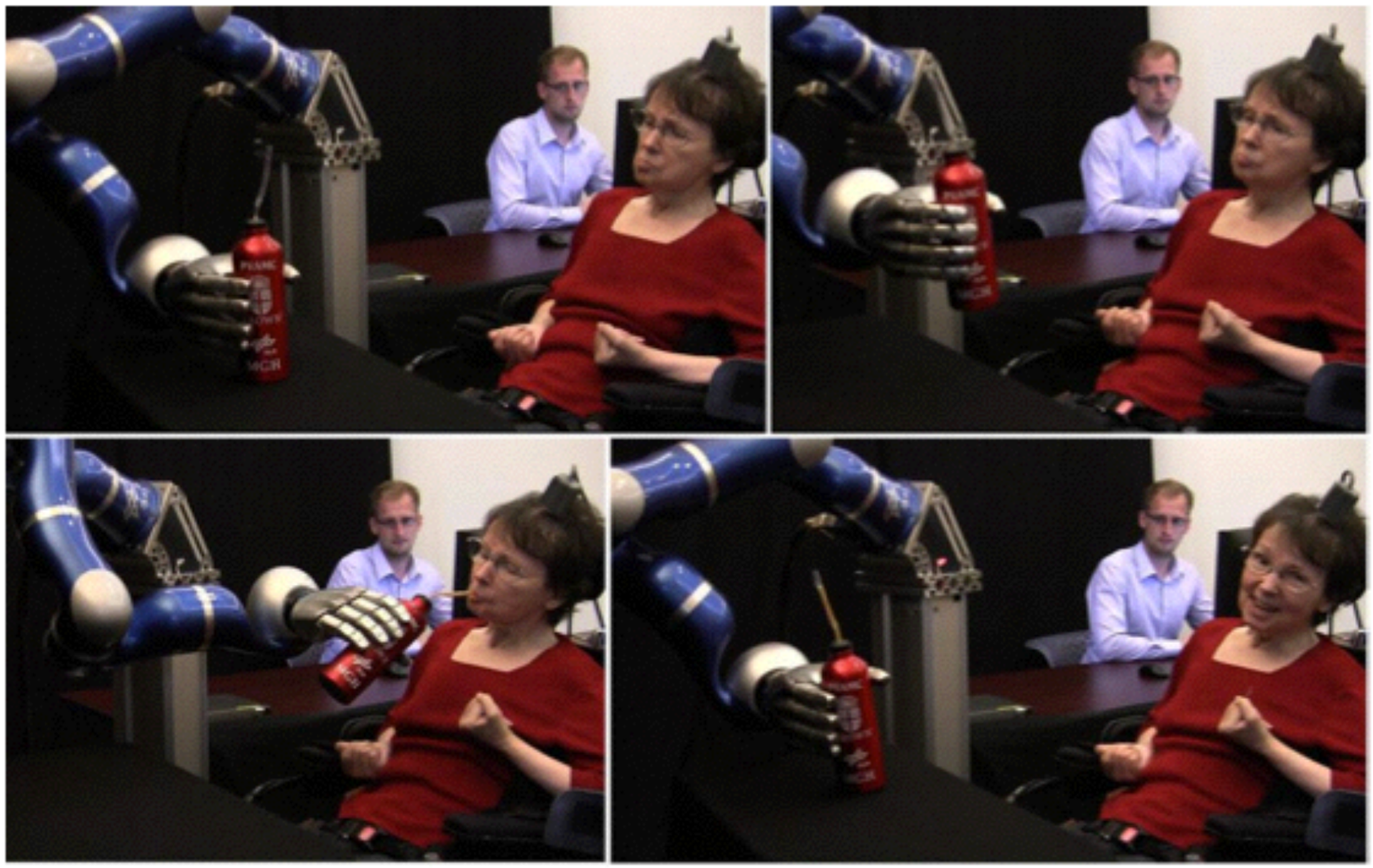
Paris-Saclay Center for Data Science

Digicosme Research Days - 12 Avril 2016

nature

Reach and grasp by people with tetraplegia using a neurally controlled robotic arm. 2012.

Leigh R. Hochberg[1,2,4,5], Daniel Bacher[2], Beata Jarosiewicz[1,3], Nicolas Y. Masse[3], John D. Simeral[1,2,4], Joern Vogel[6], Sami Haddadin[6], Jie Liu[1,2], Sydney S. Cash[4,5], Patrick van der Smagt[6], and John P. Donoghue[1,2,3]

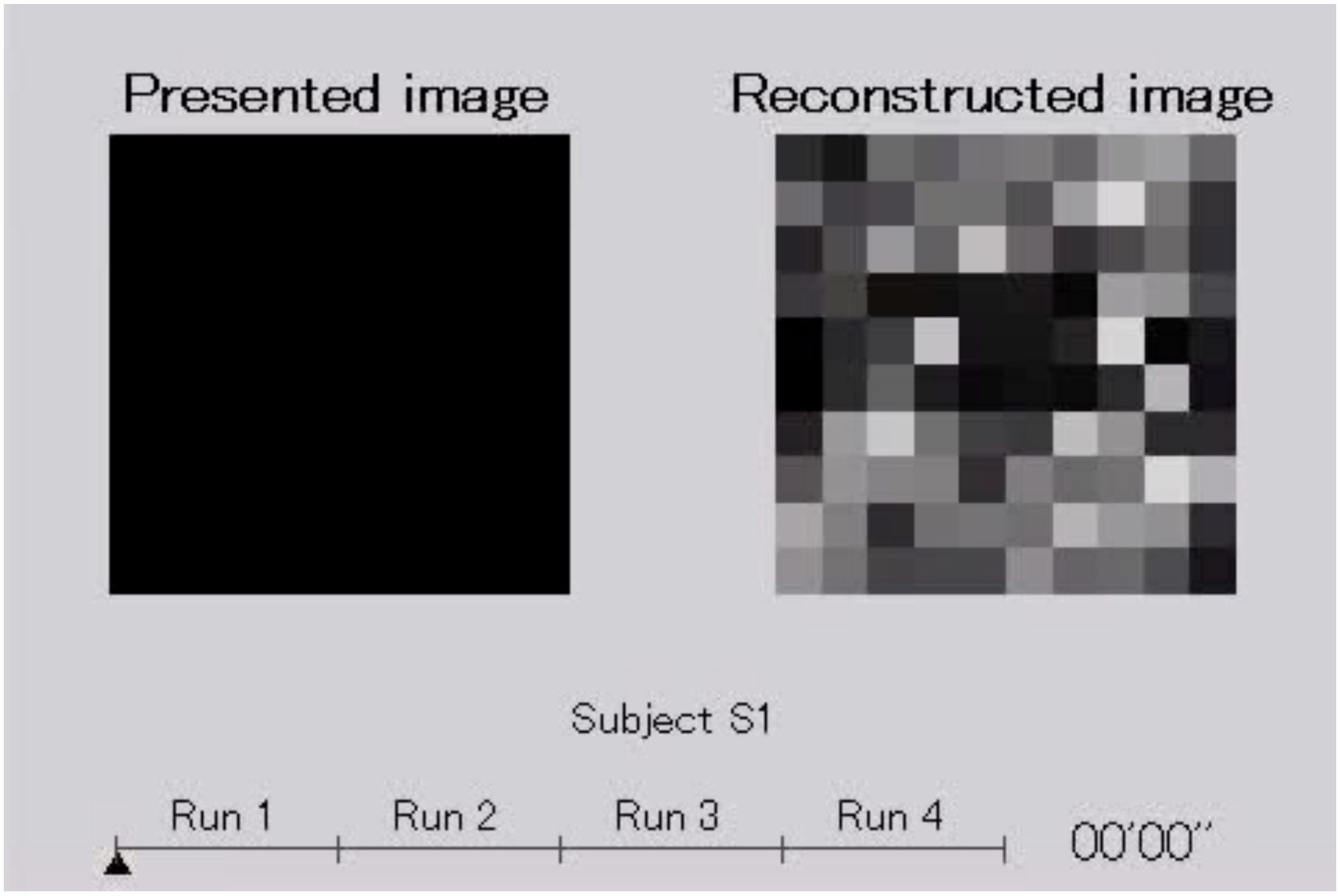


https://www.youtube.com/watch?v=QRt8QCx3BCo

Neuron
Article

Visual Image Reconstruction from Human Brain Activity using a Combination of Multiscale Local Image Decoders

Yoichi Miyawaki,[1,2,6] Hajime Uchida,[2,3,6] Okito Yamashita,[2] Masa-aki Sato,[2] Yusuke Morito,[4,5] Hiroki C. Tanabe,[4,5] Norihiro Sadato,[4,5] and Yukiyasu Kamitani[2,3,*]



http://www.youtube.com/watch?v=h1Gu1YSoDaY

Current Biology 21, 1641–1646, October 11, 2011 ©2011 Elsevier Ltd All rights reserved DOI 10.1016/j.cub.2011.08.031

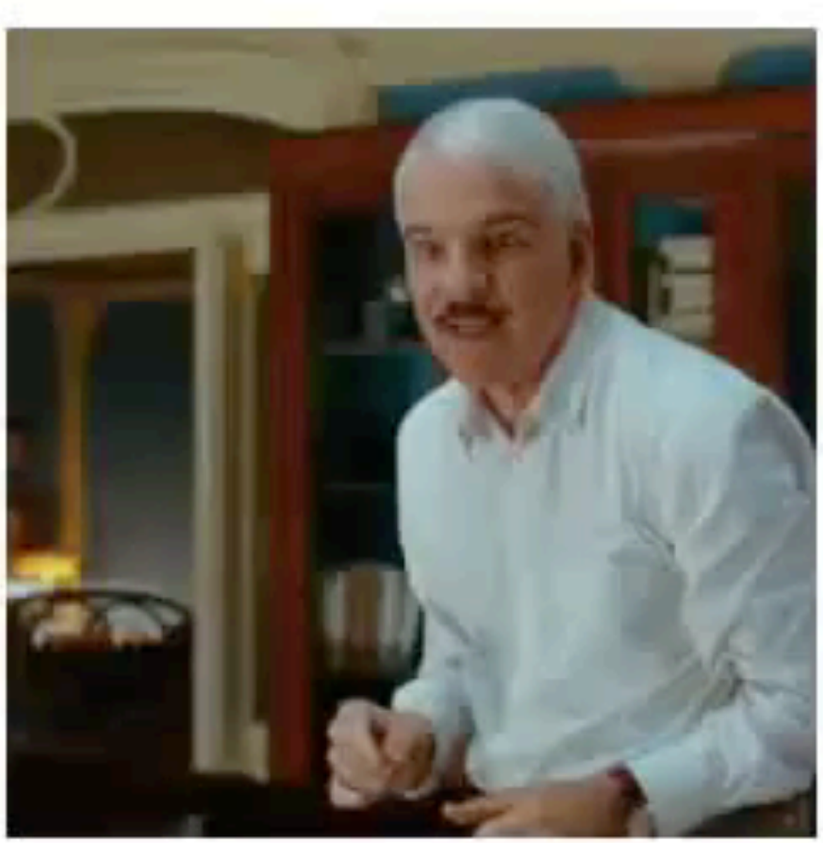
Report

Reconstructing Visual Experiences from Brain Activity Evoked by Natural Movies

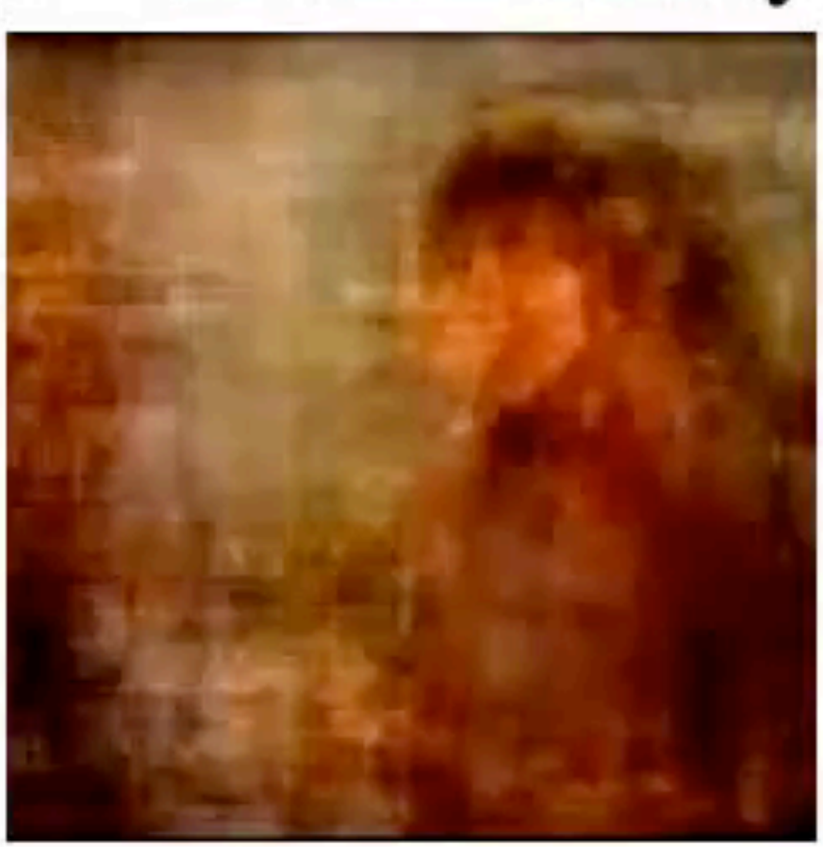
Shinji Nishimoto,[1] An T. Vu,[2] Thomas Naselaris,[1] Yuval Benjamini,[3] Bin Yu,[3] and Jack L. Gallant[1,2,4,*]

mental processes. It has therefore been assumed that fMRI data would not be useful for modeling brain activity evoked

Presented clip



Clip reconstructed from brain activity

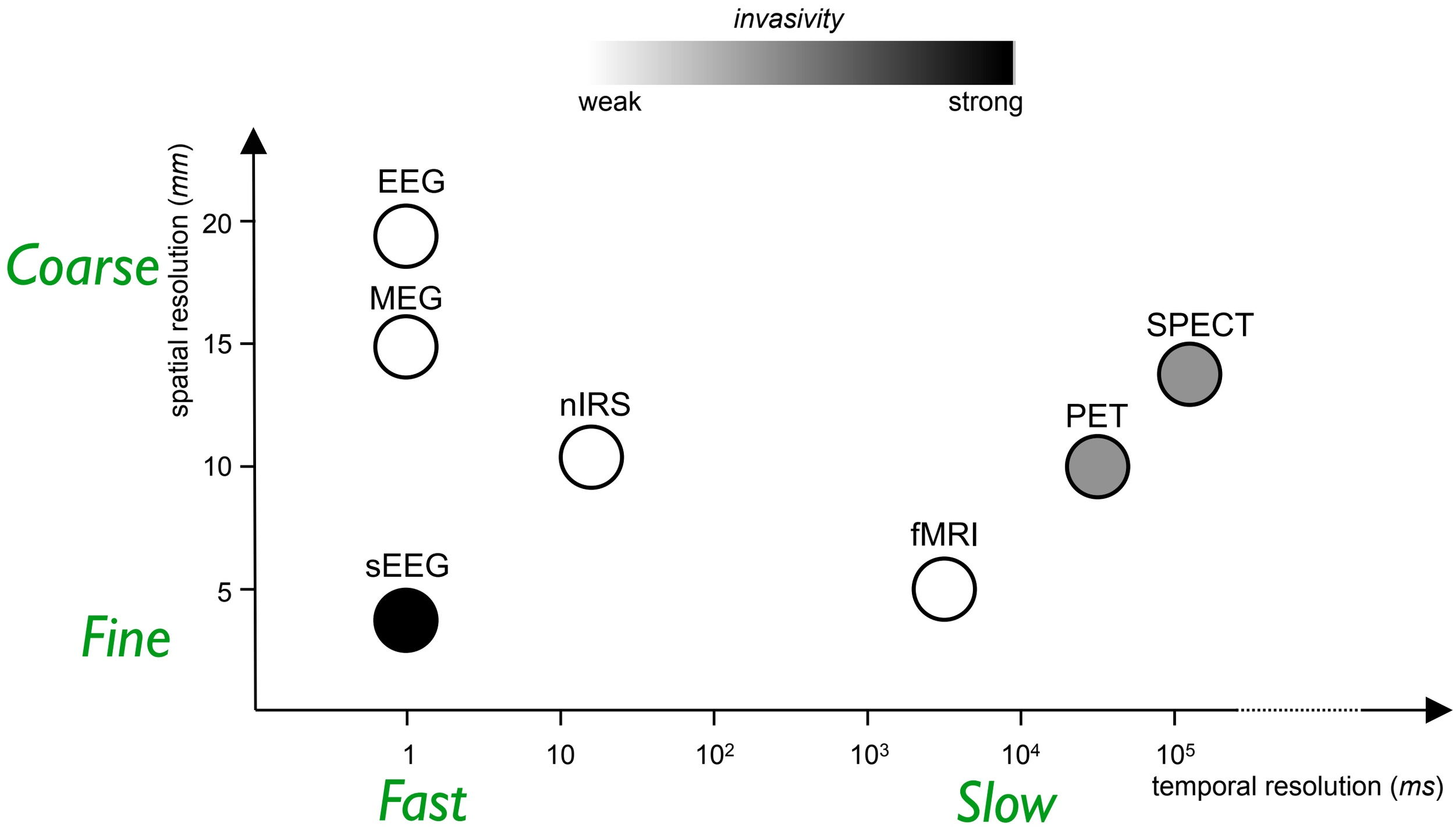


http://www.youtube.com/watch?v=nsjDnYxJ0bo

Some details on these data

- Some details about the data:
  - 30GB of stimuli (15 frames/s in .png for 3h)
  - about 4,000 volumes
  - about 10GB of raw data
  - 30,000 “good” voxels
  - > 3h in the scanner

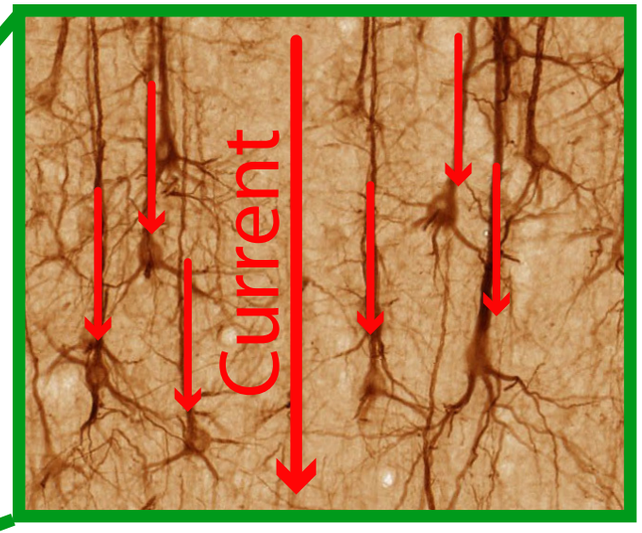
What is functional brain imaging?

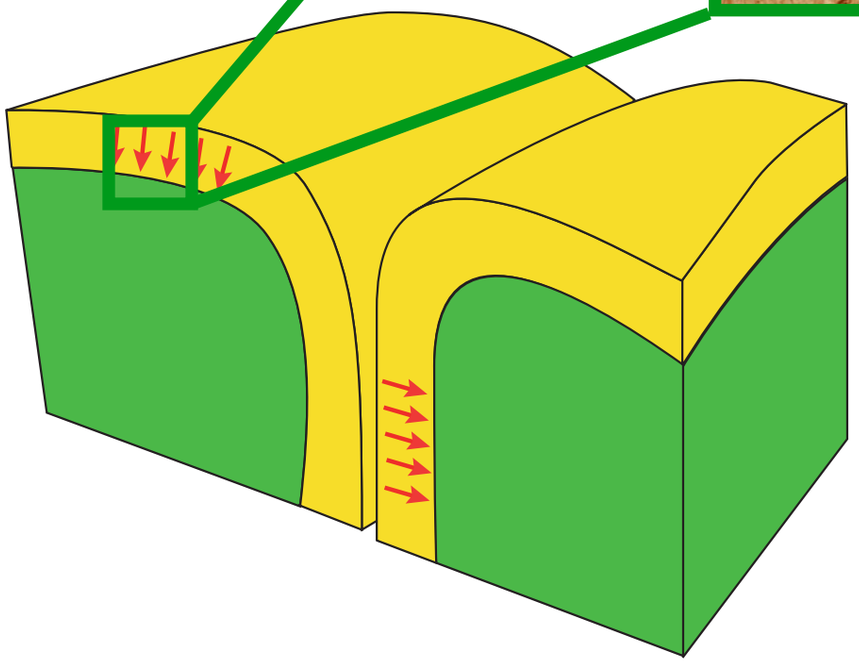


Neurons as current generators

Large cortical pyramidal cells organized in macro-assemblies with their **dendrites normally oriented to the local cortical surface**

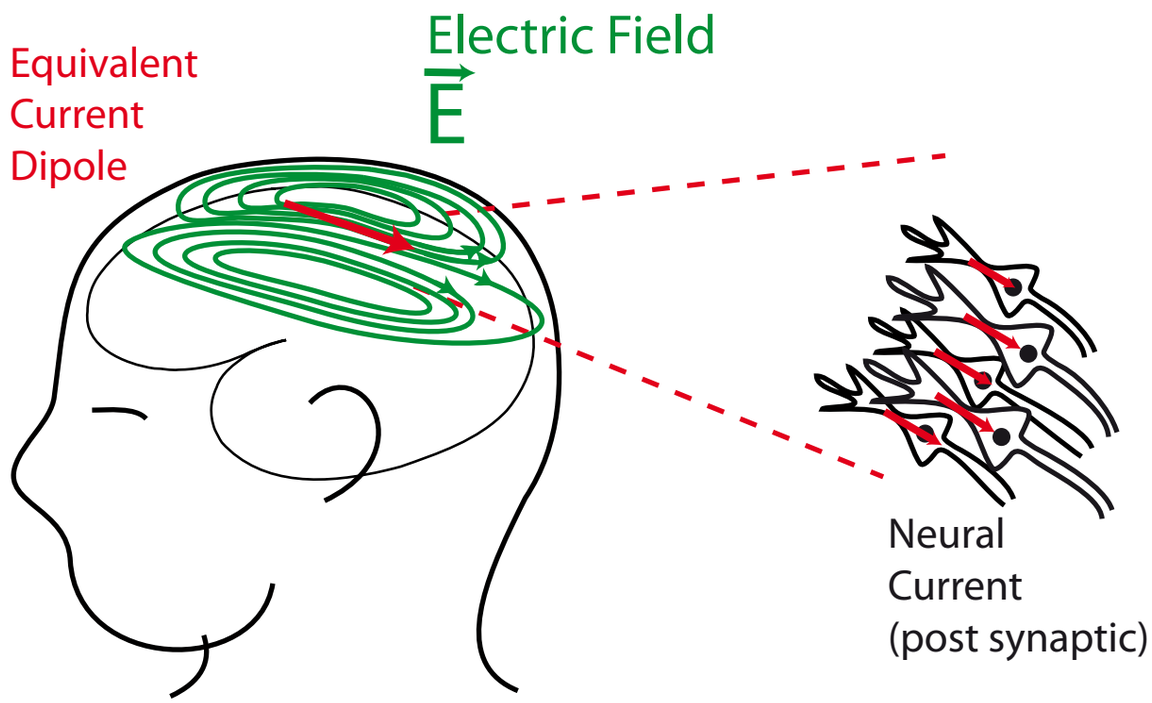
$Q = I \times d$
(10 to 100 nAm) with the equivalent current dipole (ECD) model

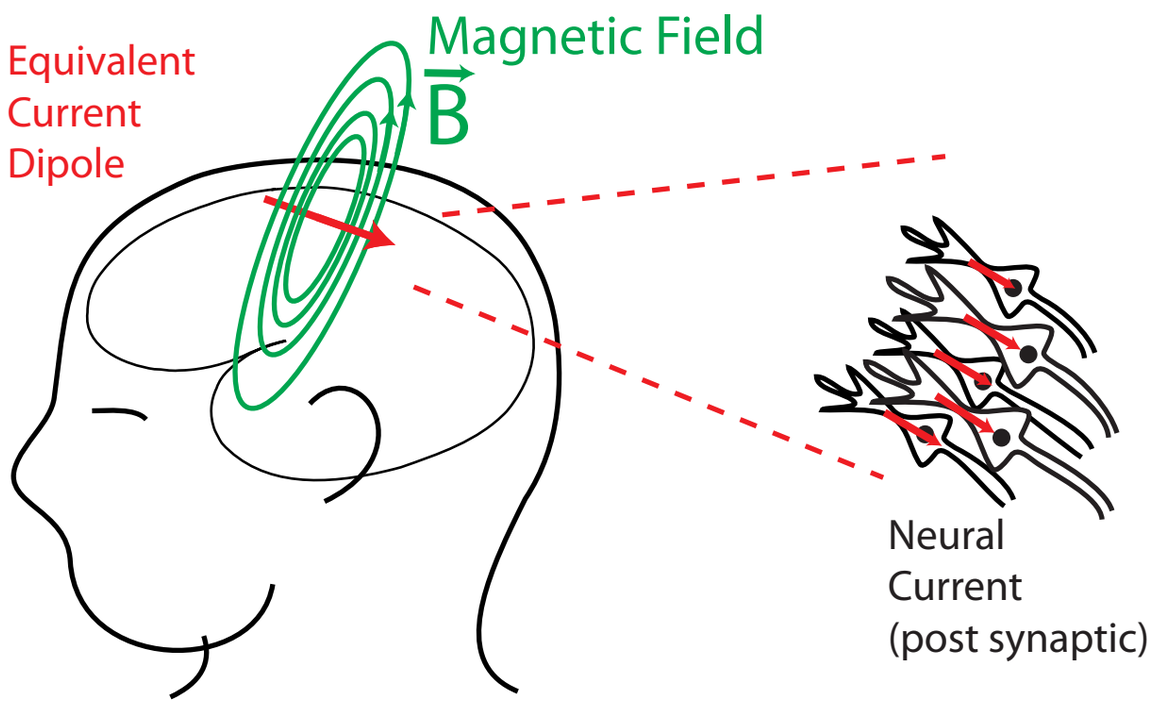




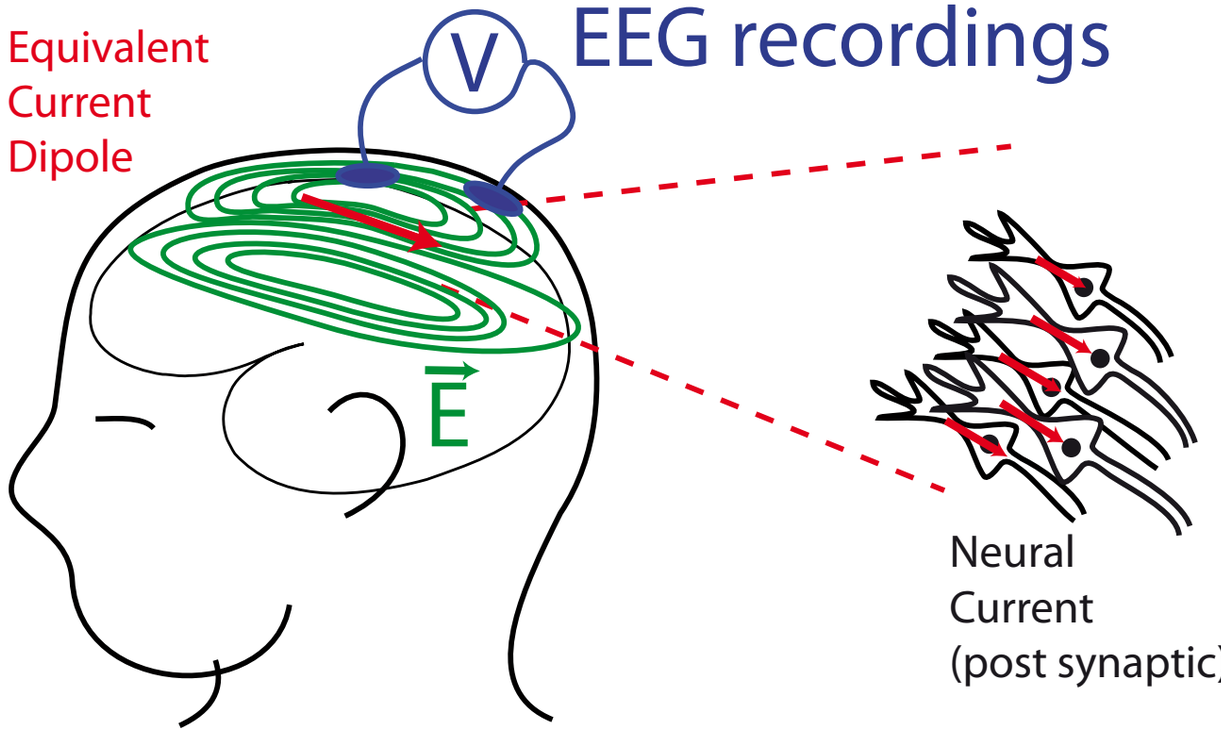
Gray matter

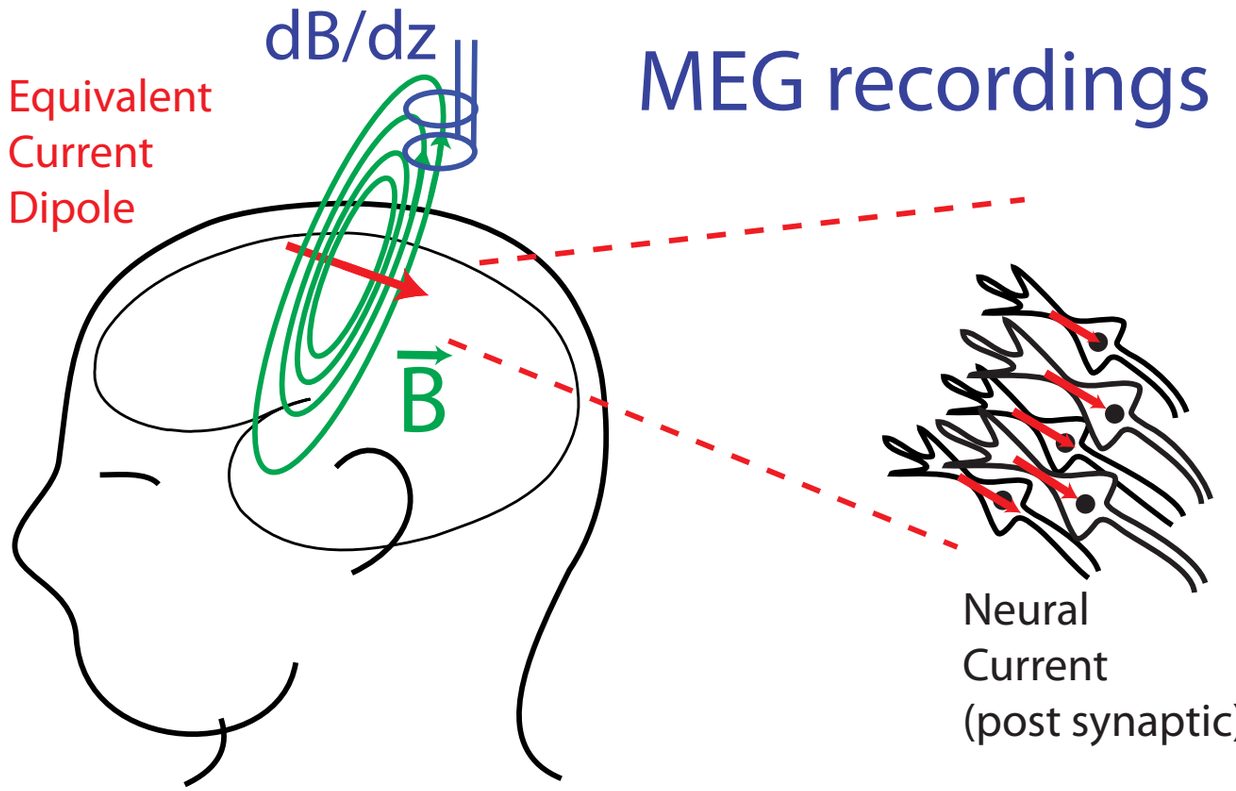
White matter





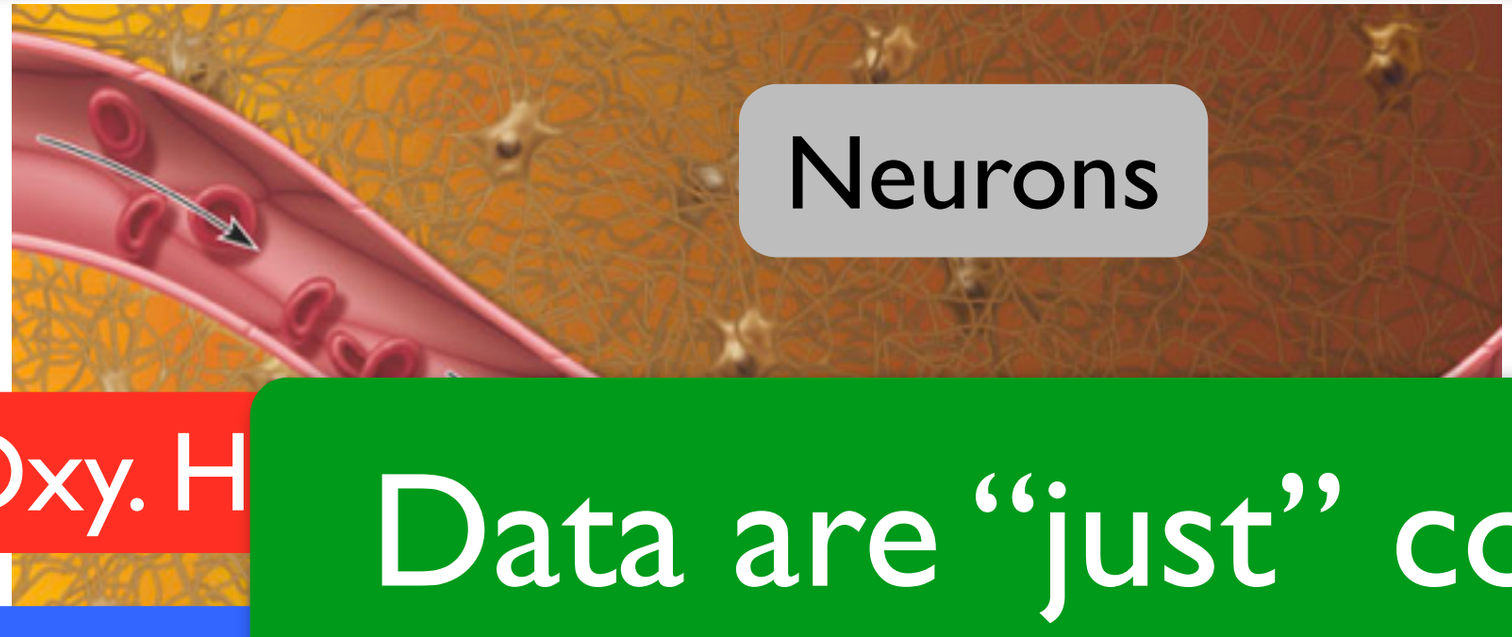
Electro- & Magneto-encephalography

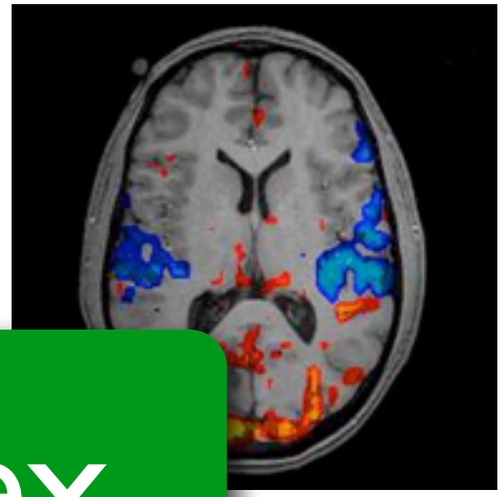




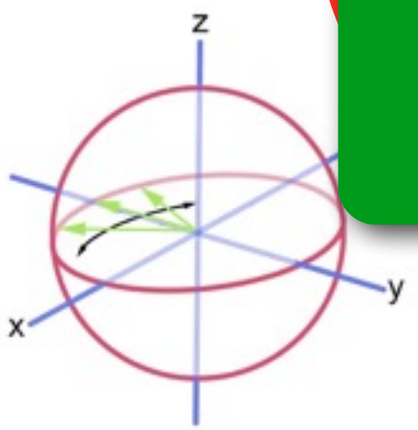
First EEG
recordings
in 1929
by H. Berger

Functional MRI (fMRI)

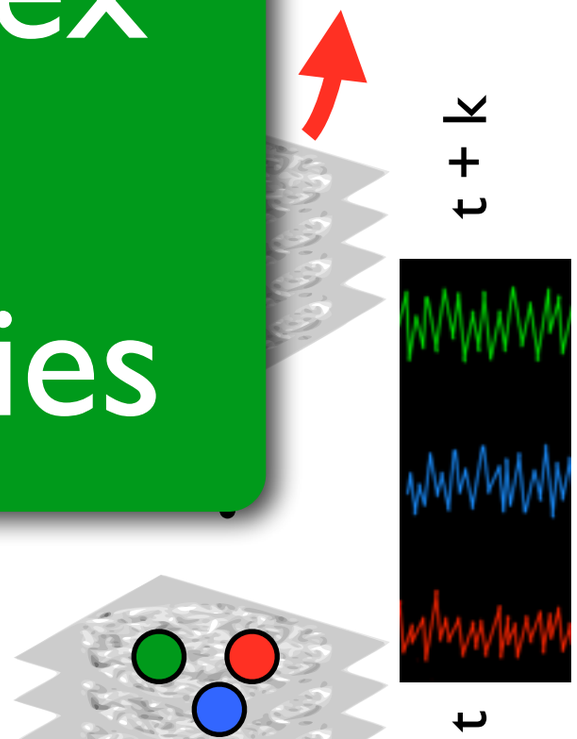




Data are "just" complex spatio-temporal multivariate times-series



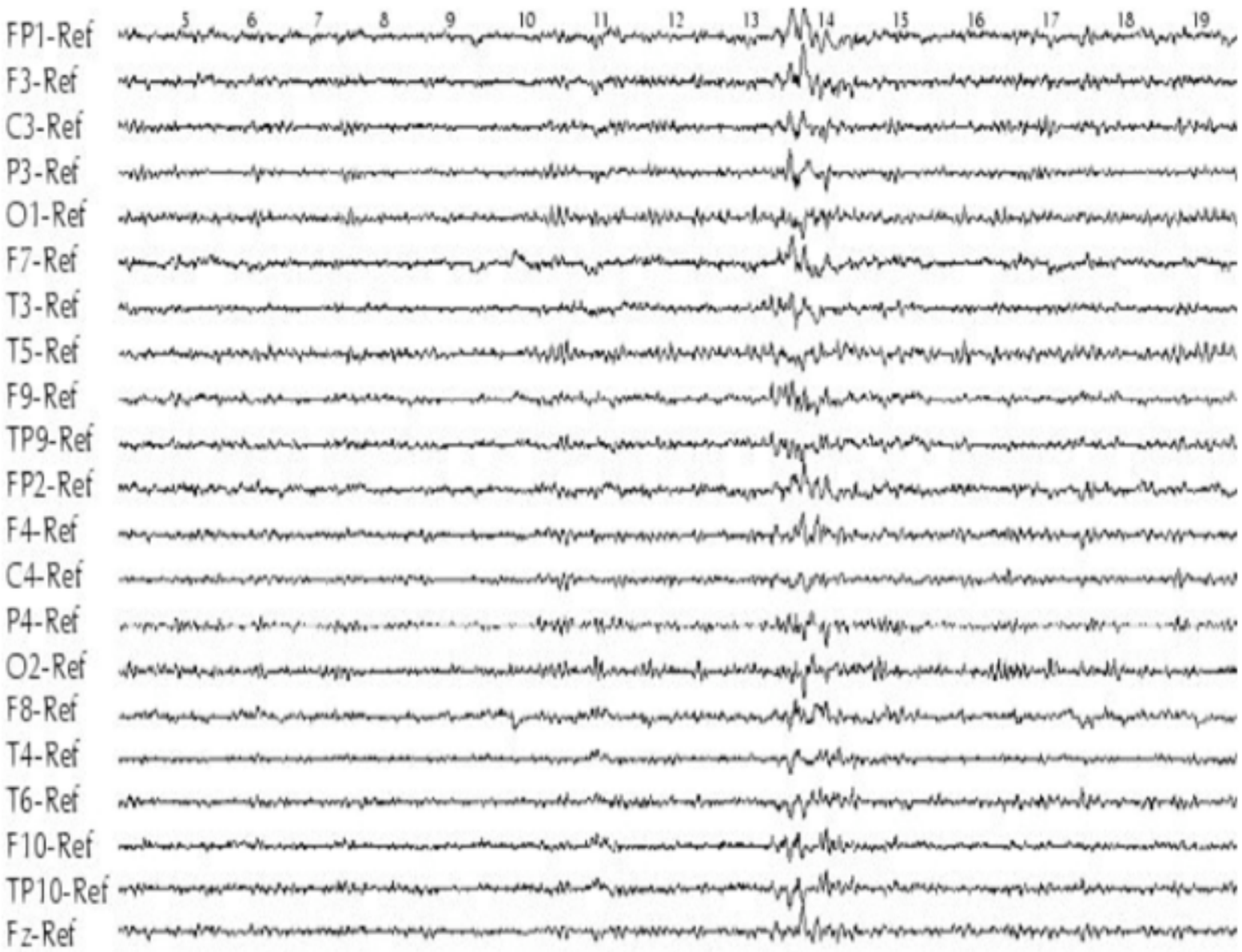
Magnetic resonance imaging



Imaging the brain at a millisecond time scale with MEG and EEG

Gramfort et al., Mixed-norm estimates for the M/EEG inverse problem using accelerated gradient methods, Physics in Medicine and Biology, 2012 *(Joint work with M. Kowalski at L2S U-PSud Supelec)*
Gramfort et al. Time-frequency mixed-norm estimates: Sparse M/EEG imaging with non-stationary source activations, NeuroImage, 2013 *(Joint work with M. Kowalski at L2S U-PSud Supelec)*
Strohmeier et al., MEG/EEG source imaging with a non-convex penalty in the time-frequency domain, Int. Workshop on Pattern Recognition in Neuroimaging (PRNI), 2015
Fercoq et al., Mind the duality gap: Safer rules for the Lasso, ICML, 2015
Ndiaye et al., GAP Safe screening rules for sparse multi-task and multi-class models, NIPS, 2015
Strohmeier et al., The iterative reweighted Mixed-Norm Estimate for spatio-temporal MEG/EEG source reconstruction, to appear in IEEE TMI.

M/EEG Measurements



EEG :

- ≈ 32 to 100 sensors

MEG :

- ≈ 150 to 300 sensors

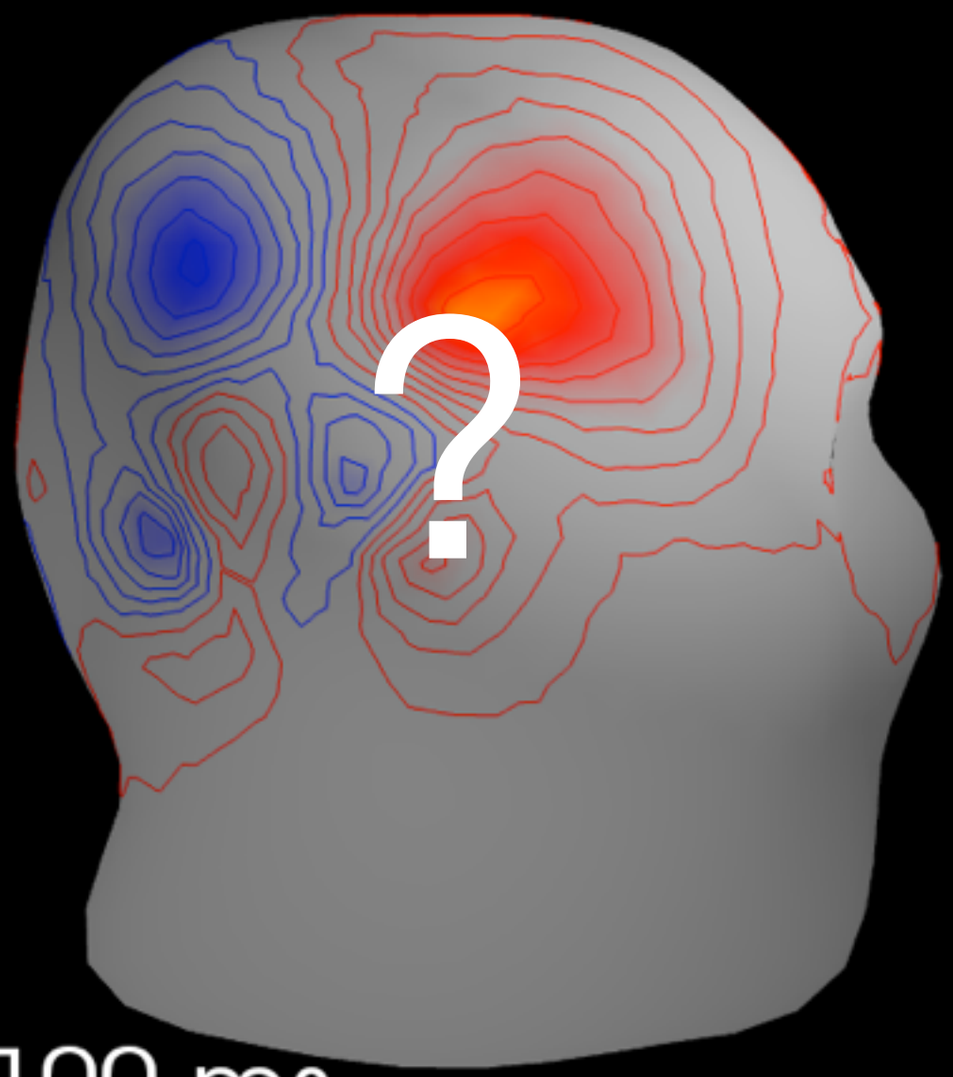
Sampling between 250 and1000 Hz

M/EEG measurements: Multivariate Time-Series

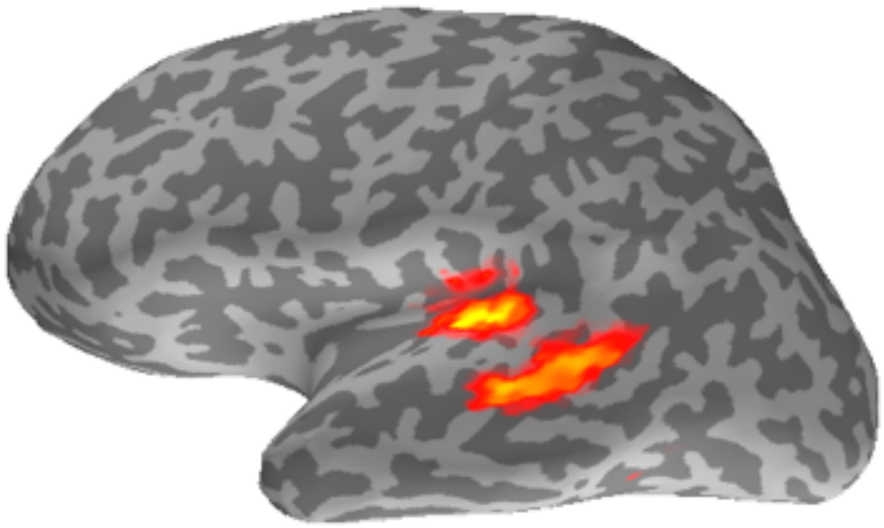
THM: High temporal resolution

Inverse problem: Objective

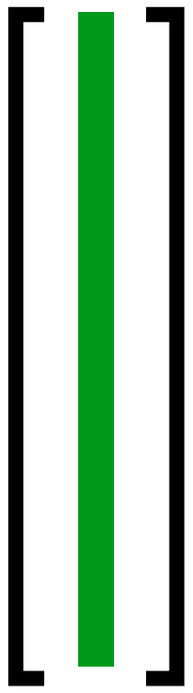
Find the current generators that produced the measurements



Model : Regression in high dimension



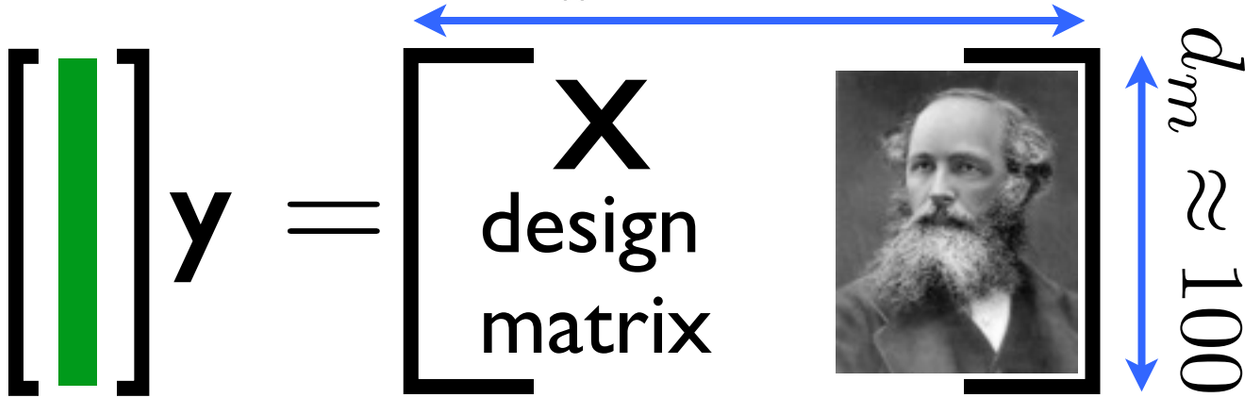
$d_x \approx 10000$



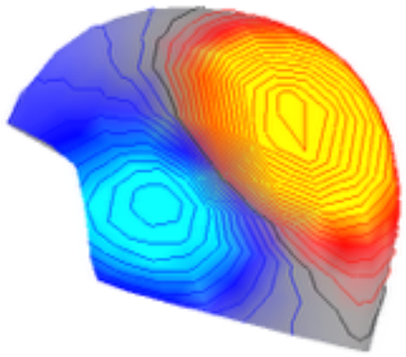
Standard statistics notations

w (or β)

regression coefficients

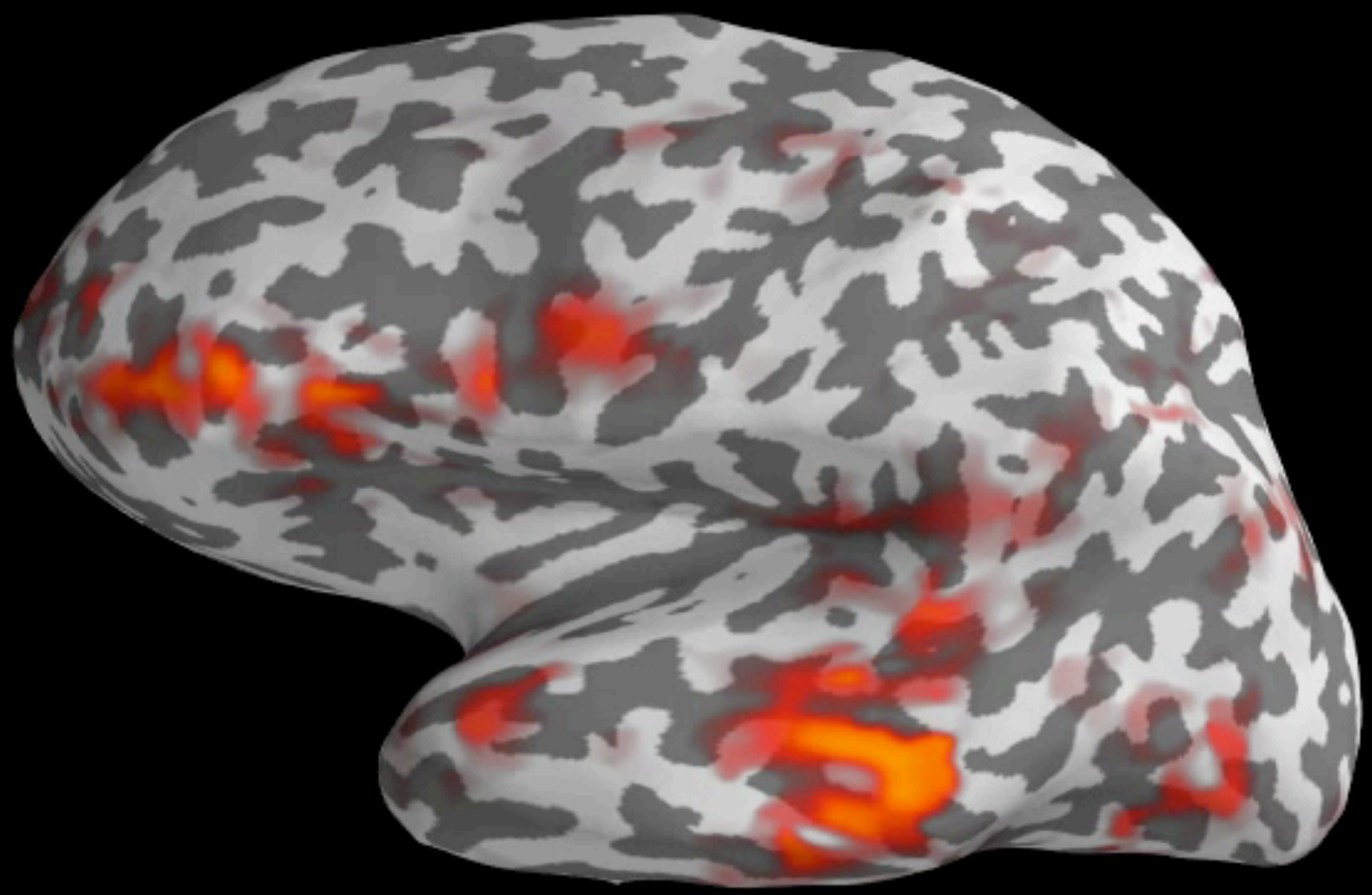


$+ \mathbf{E}$



- At **each time instant** the inverse problem is a **regression** with more variables than observations (ill-posed)
- **Statistics - optimization - algorithmic** challenges

Reconstruction with smooth L2 prior



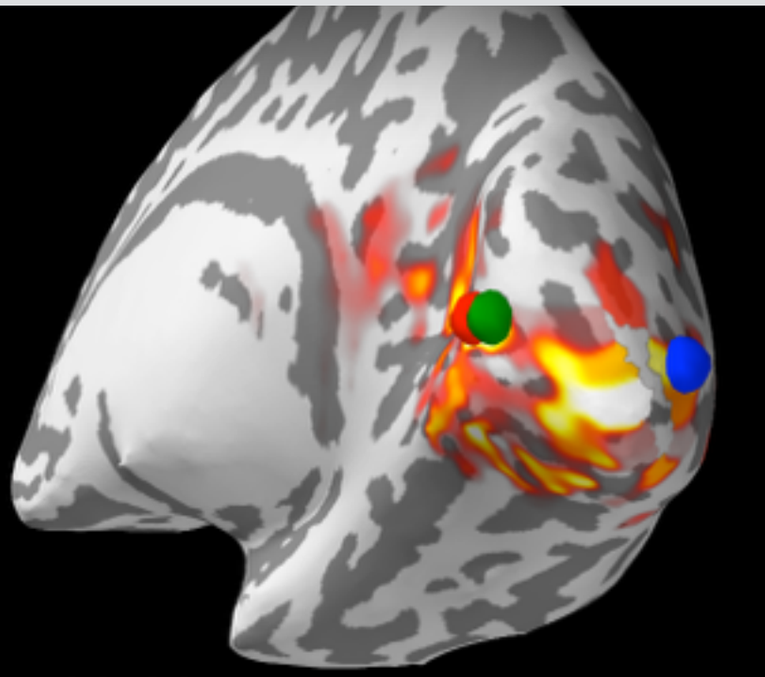
time=0.00 ms

http://youtu.be/Uxr5Pz7JPrs

Alexandre Gramfort, Telecom ParisTech, CEA/Neurospin

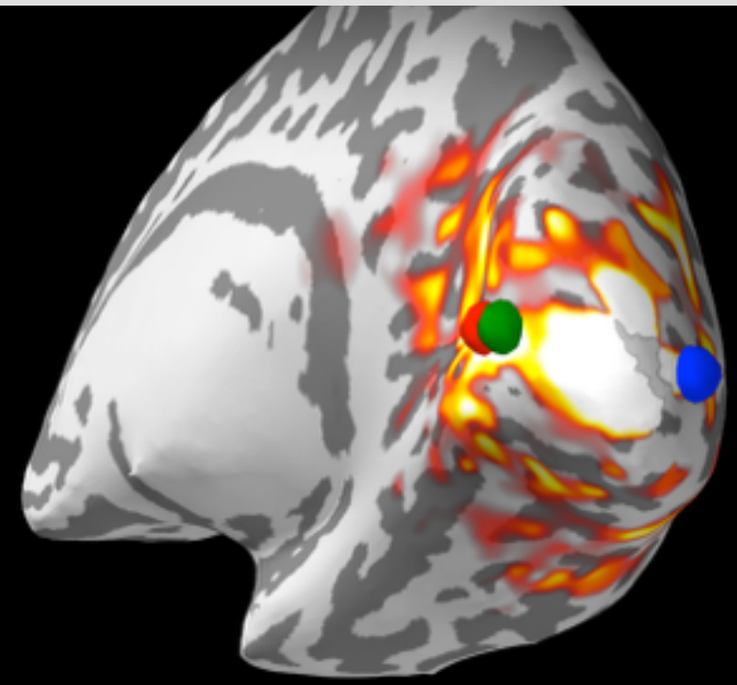
Reconstruction with sparse time-frequency priors

dSPM



time=83.88 ms

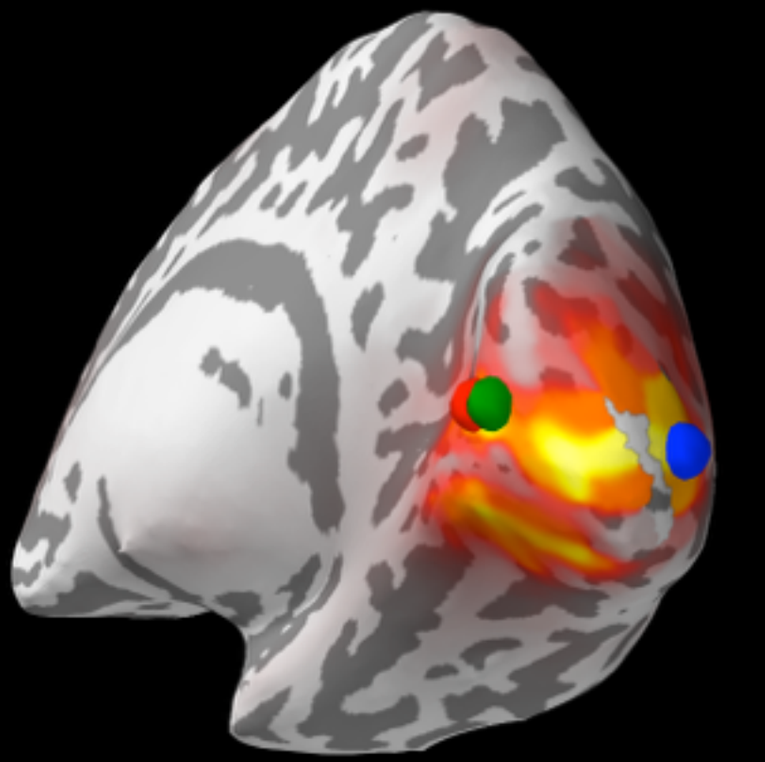
5.00 6.43 7.86 9.29 10.7 12.1 13.6 15.0



time=134.07 ms

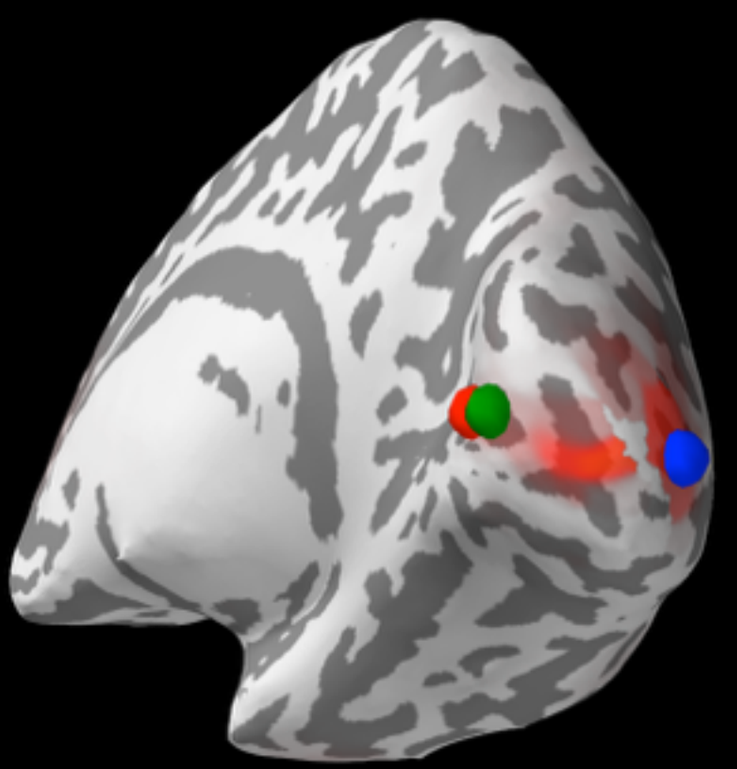
5.00 6.43 7.86 9.29 10.7 12.1 13.6 15.0

LCMV



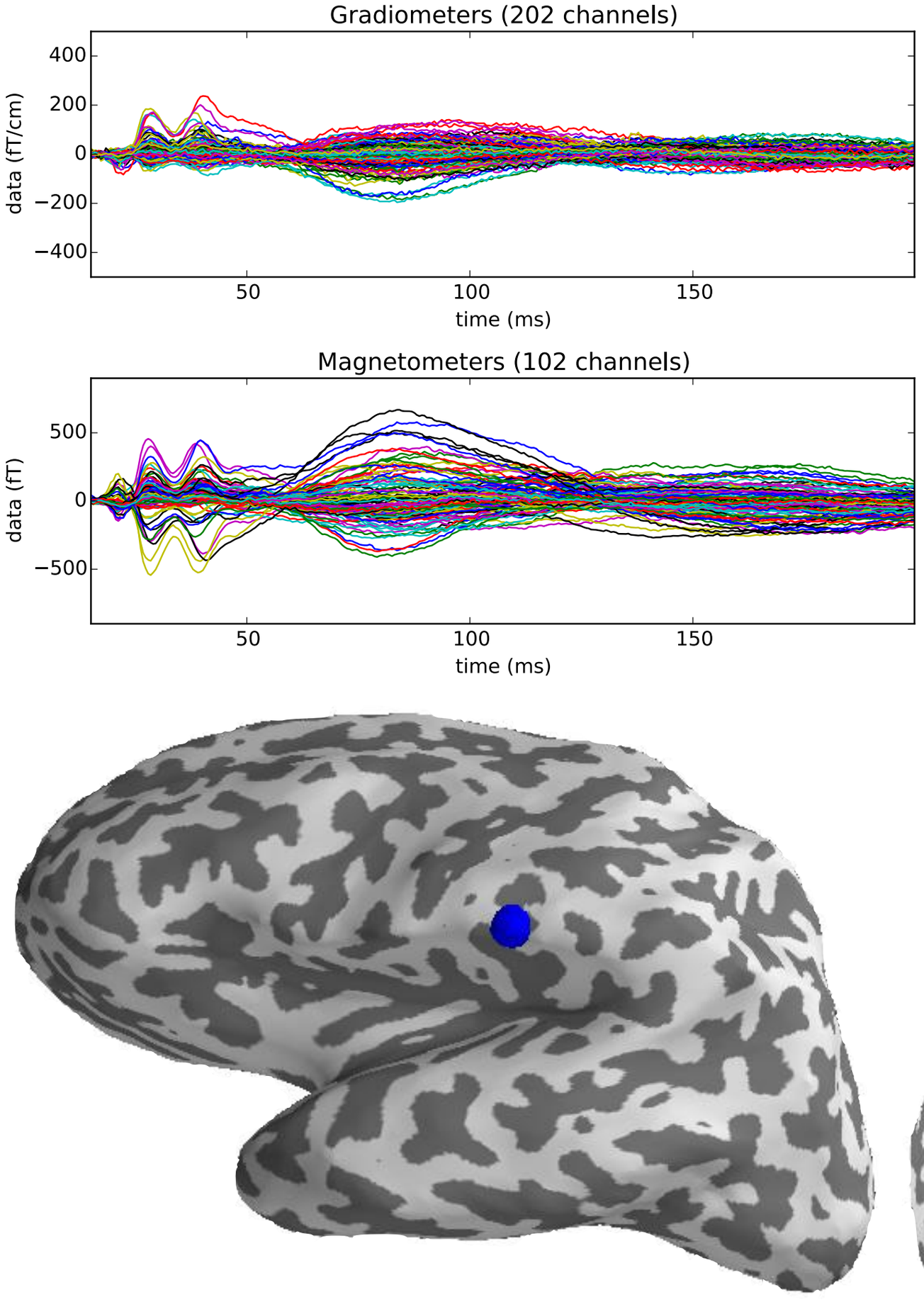
time=83.92 ms

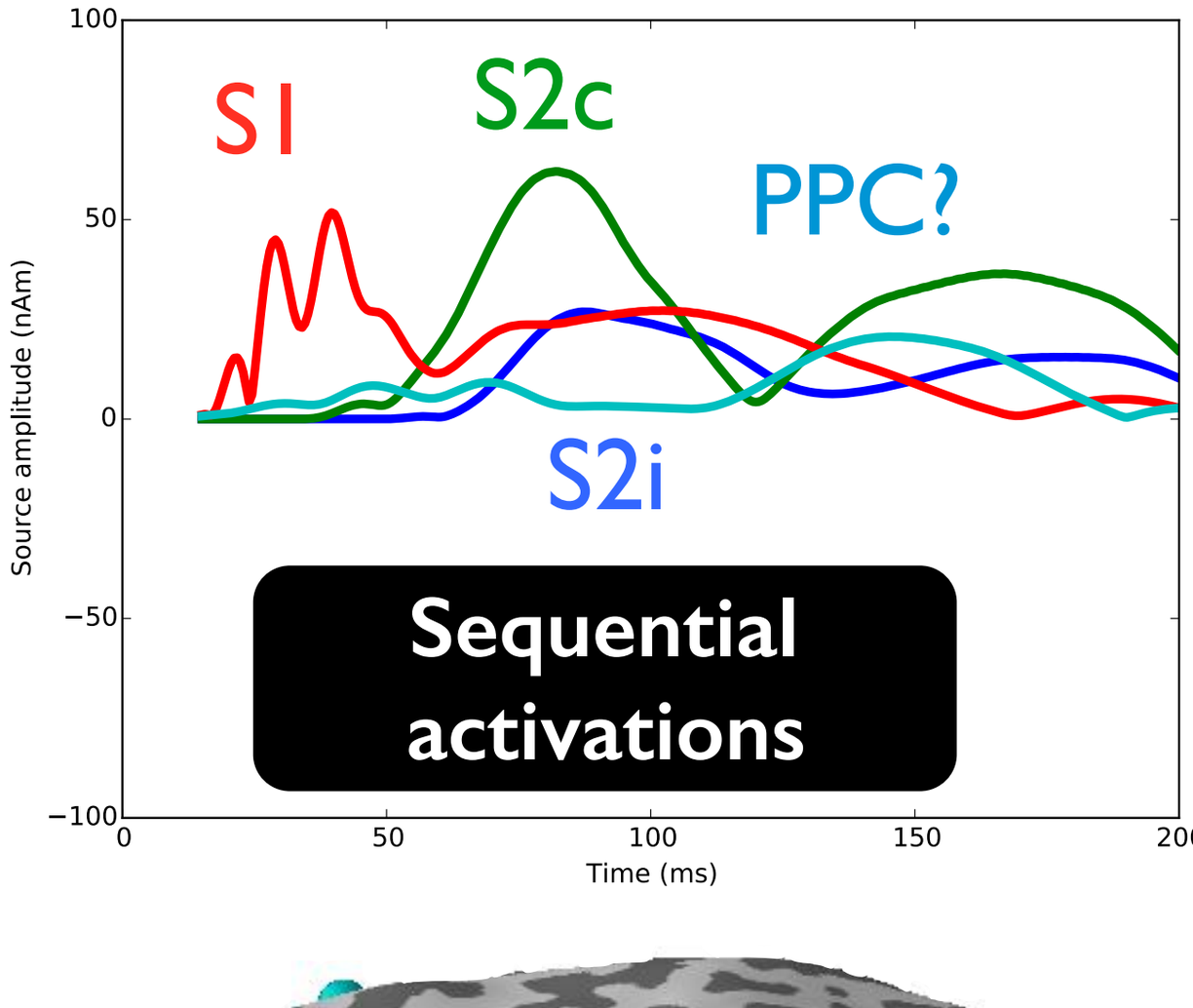
0.100 0.229 0.357 0.486 0.614 0.743 0.871 1.00



time=133.99 ms

0.100 0.229 0.357 0.486 0.614 0.743 0.871 1.00


Gradiometers (202 channels)
data (fT/cm)
time (ms)
Magnetometers (102 channels)
data (fT)
time (ms)


S1
S2c
PPC?
S2i
Sequential activations
Source amplitude (nAm)
Time (ms)

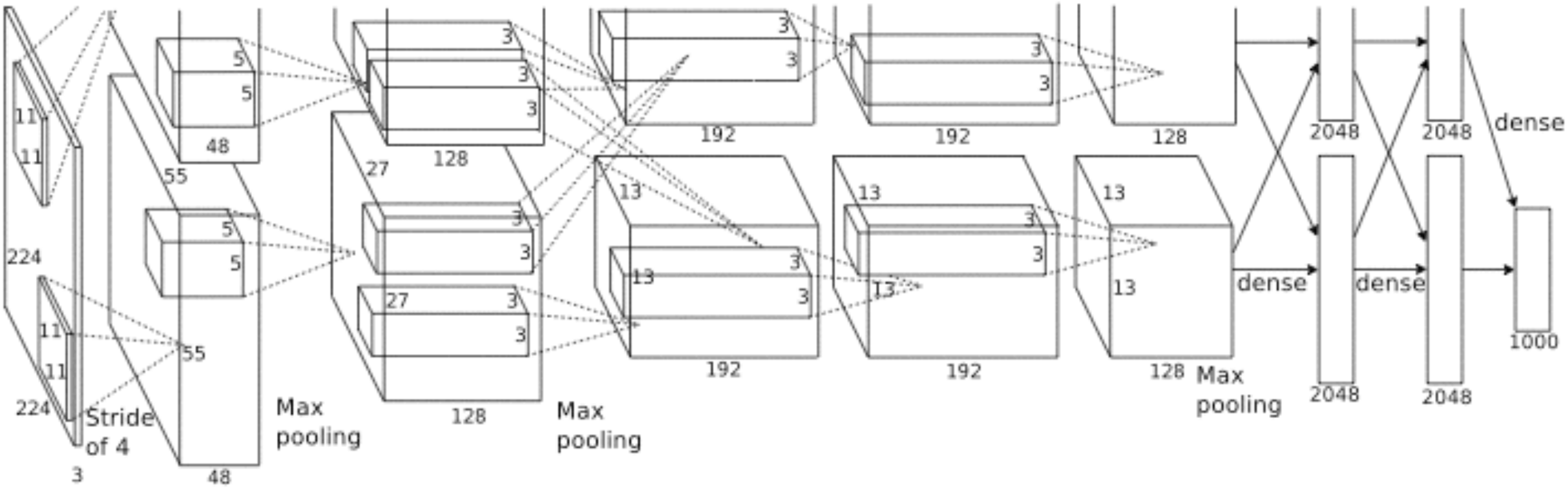
Convolutional Networks Map the Architecture of the Human Visual System

work of Michael Eickenberg

joint work with Bertrand Thirion and Gaël Varoquaux at INRIA Saclay

"Seeing it all: Convolutional network layers map the function of the human visual system"
Michael Eickenberg, Alexandre Gramfort, Gaël Varoquaux, Bertrand Thirion (submitted)

Convolutional Nets for Computer Vision

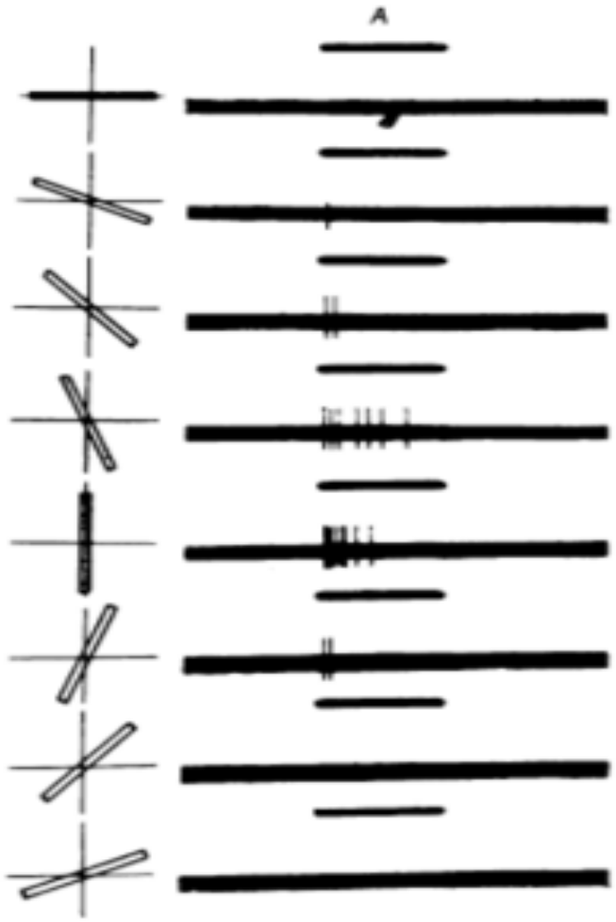


[Krizhevski et al, 2012]

Relating biological and computer vision

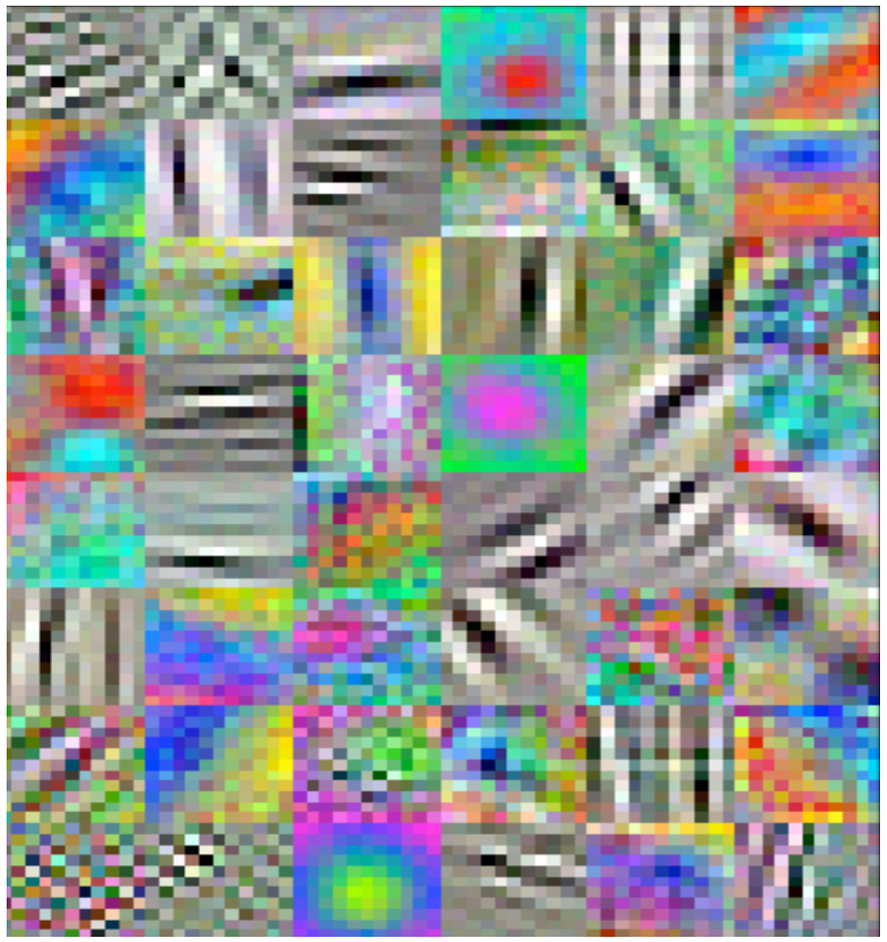
Low Level

Cat V1
orientation selectivity



[Hubel & Wiesel, 1959]

ConvNet Layer 1



[Sermanet 2013]

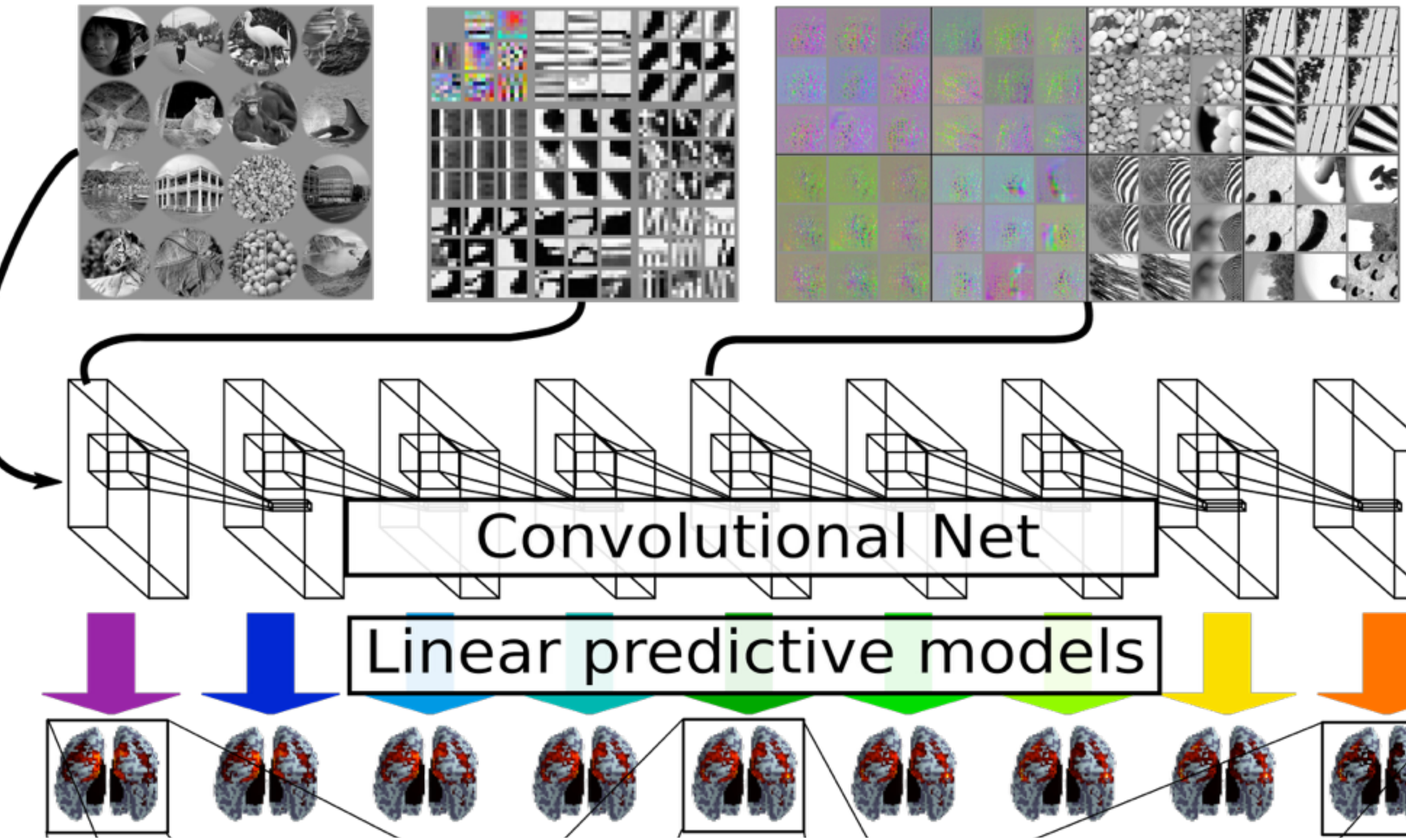
- V1 functionality comprises edge detection
- Convolutional nets learn edge detectors, color boundary detectors and blob detectors

Can we use computer vision models and a large fMRI data to better understand human vision?

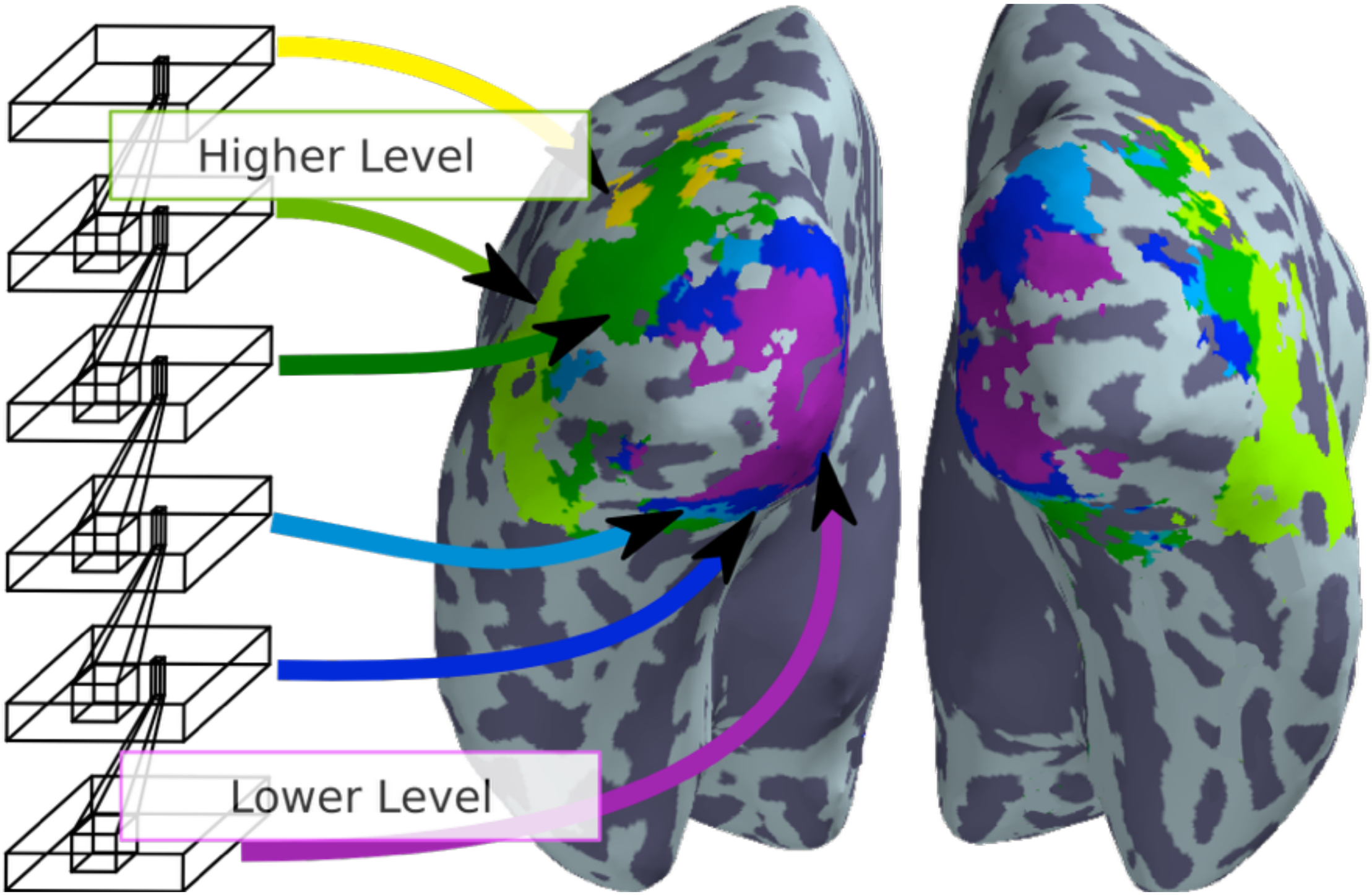
Input

Layer 1

Layer 5

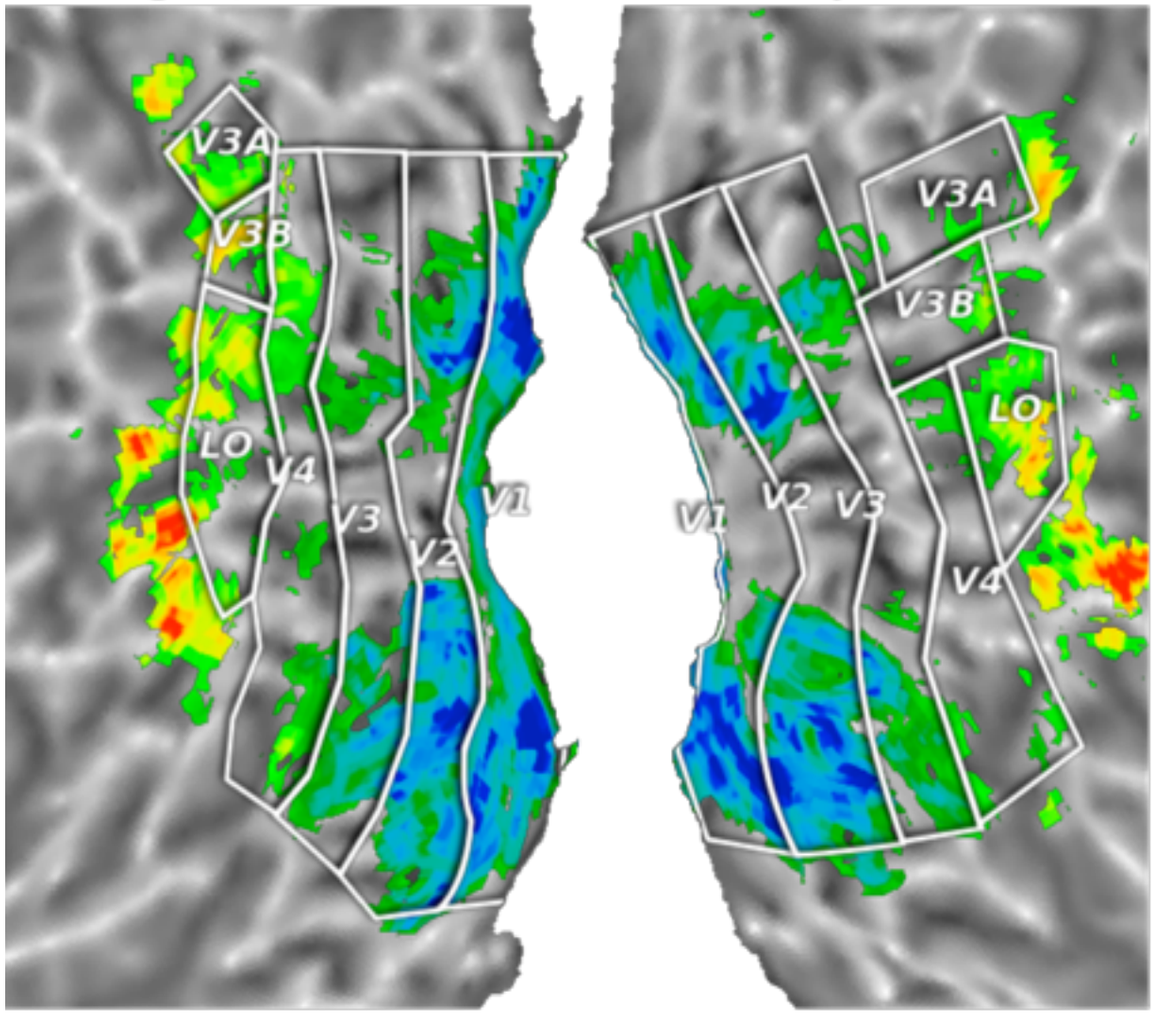


Best Predicting Layers per Voxel



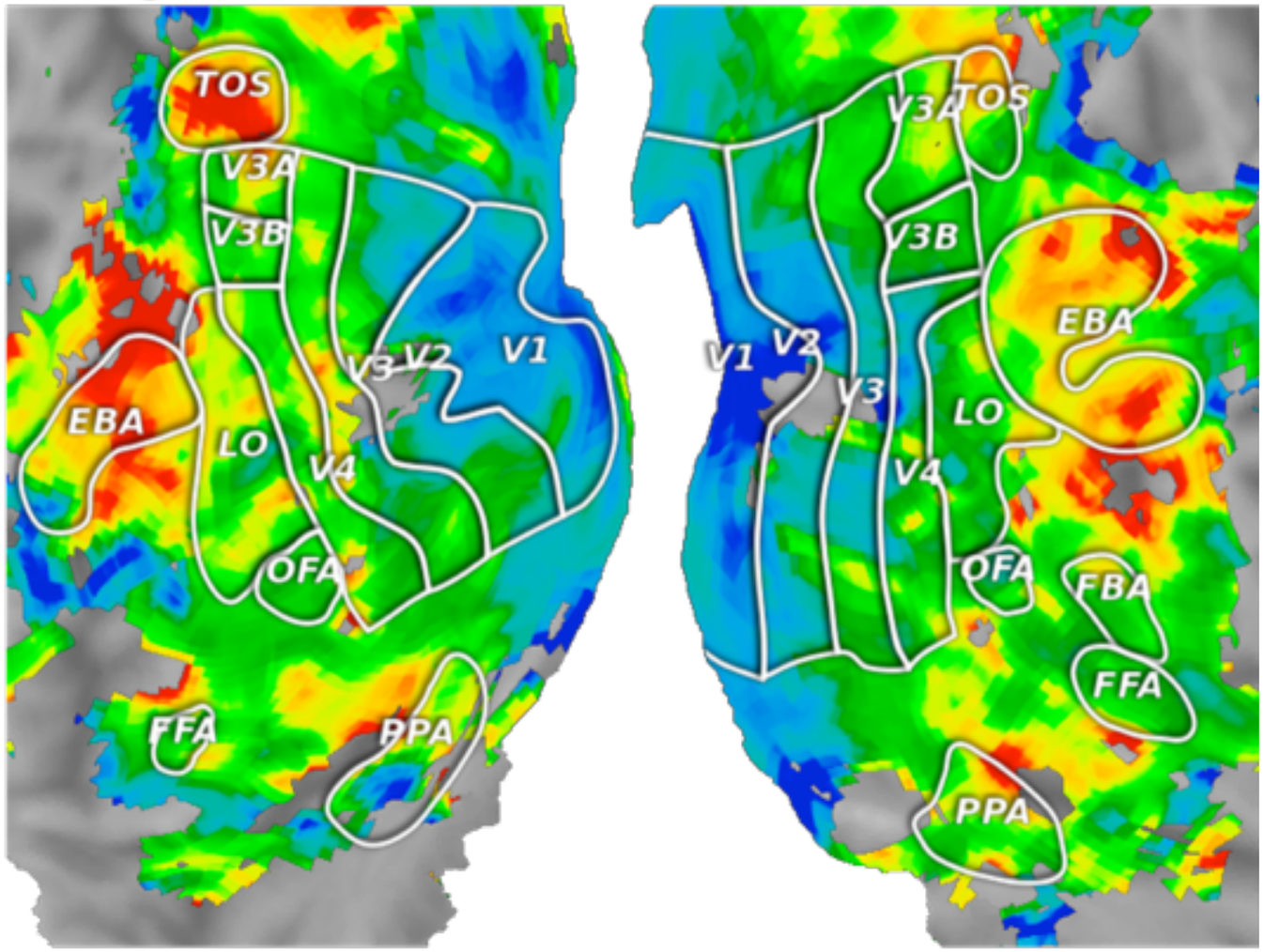
Fingerprints summary statistic

A Fingerprint summaries for Kay2008



Lower level — Higher level

B Fingerprint summaries for Huth2012



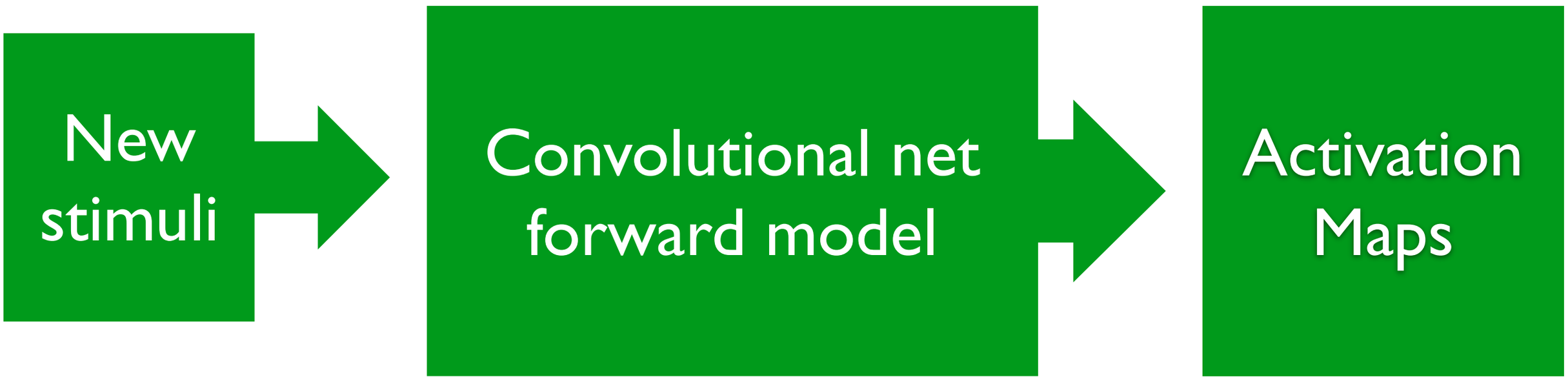
Lower level — Higher level

Photos

Videos

2 public datasets from UC Berkeley

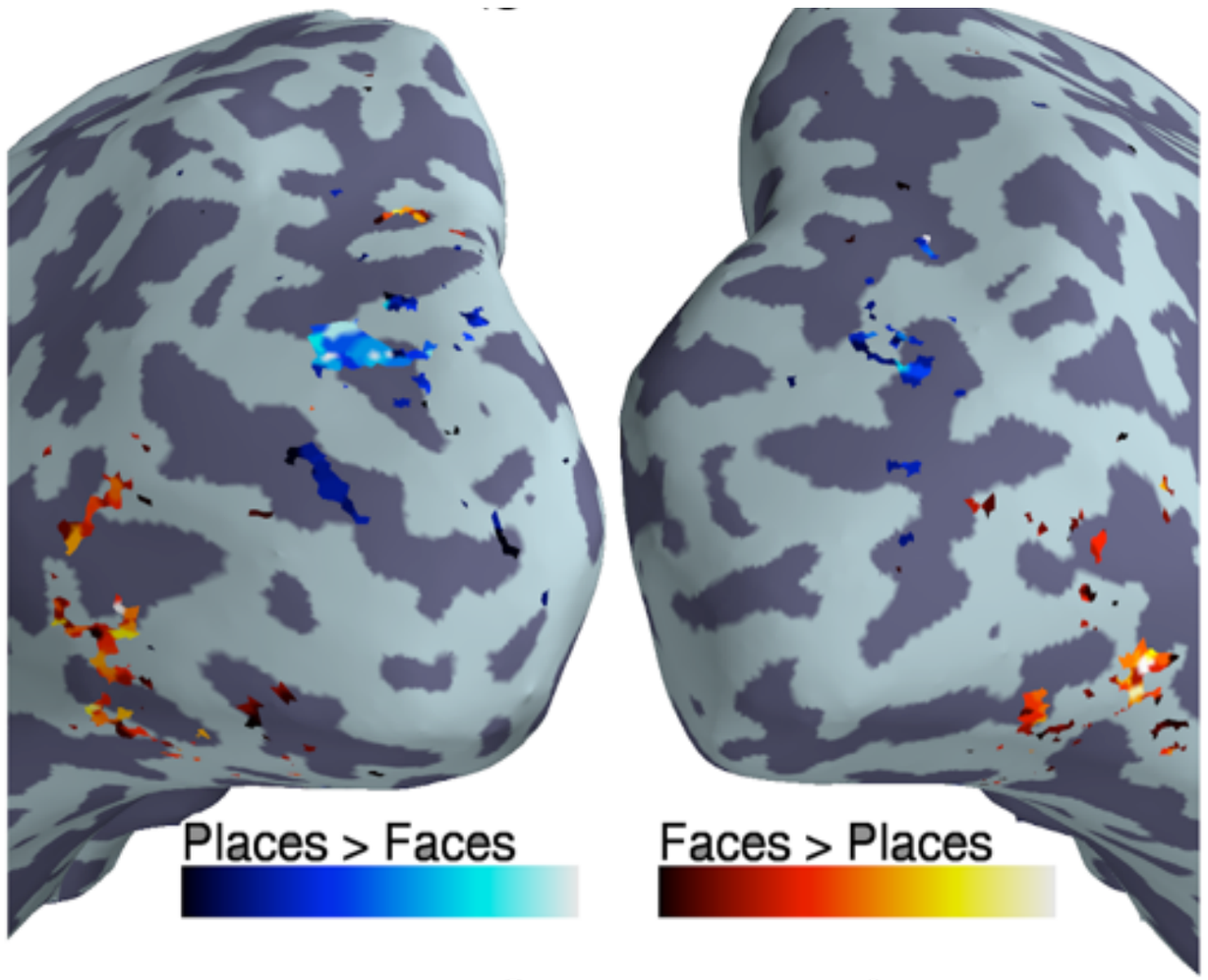
Synthesizing Brain activation maps



Question: Did we learn a good forward model of brain activation as seen with fMRI?

Faces vs Places: Ground Truth

Stimuli from [Kay 2008]
Close-up faces and scenes



Contrast of
stimuli from [Kay 2008]
Close-up faces and scenes

Let’s take a step back…

What is changing?

Volume (Computational issues)

- Standard MEG Study (25 subjects, 10 GB per subject)
- Human Connectome Project (18GB x1000 subjects), USA with first MEG data released in March 2015 (100 subjects)
- Human Brain Project, EU

Data variability (Computational issues)

- 7000 fMRI pipelines lead to different neuroscience findings [Carp 2012]

MNE

MEG + EEG ANALYSIS & VISUALIZATION

http://www.martinos.org/mne

MNE is a community-driven software package designed for for **processing electroencephalography (EEG) and magnetoencephalography (MEG) data** providing comprehensive tools and workflows for:

1. Preprocessing
2. Source estimation
3. Time–frequency analysis
4. Statistical testing
5. Estimation of functional connectivity
6. Applying machine learning algorithms
7. Visualization of sensor- and source-space data

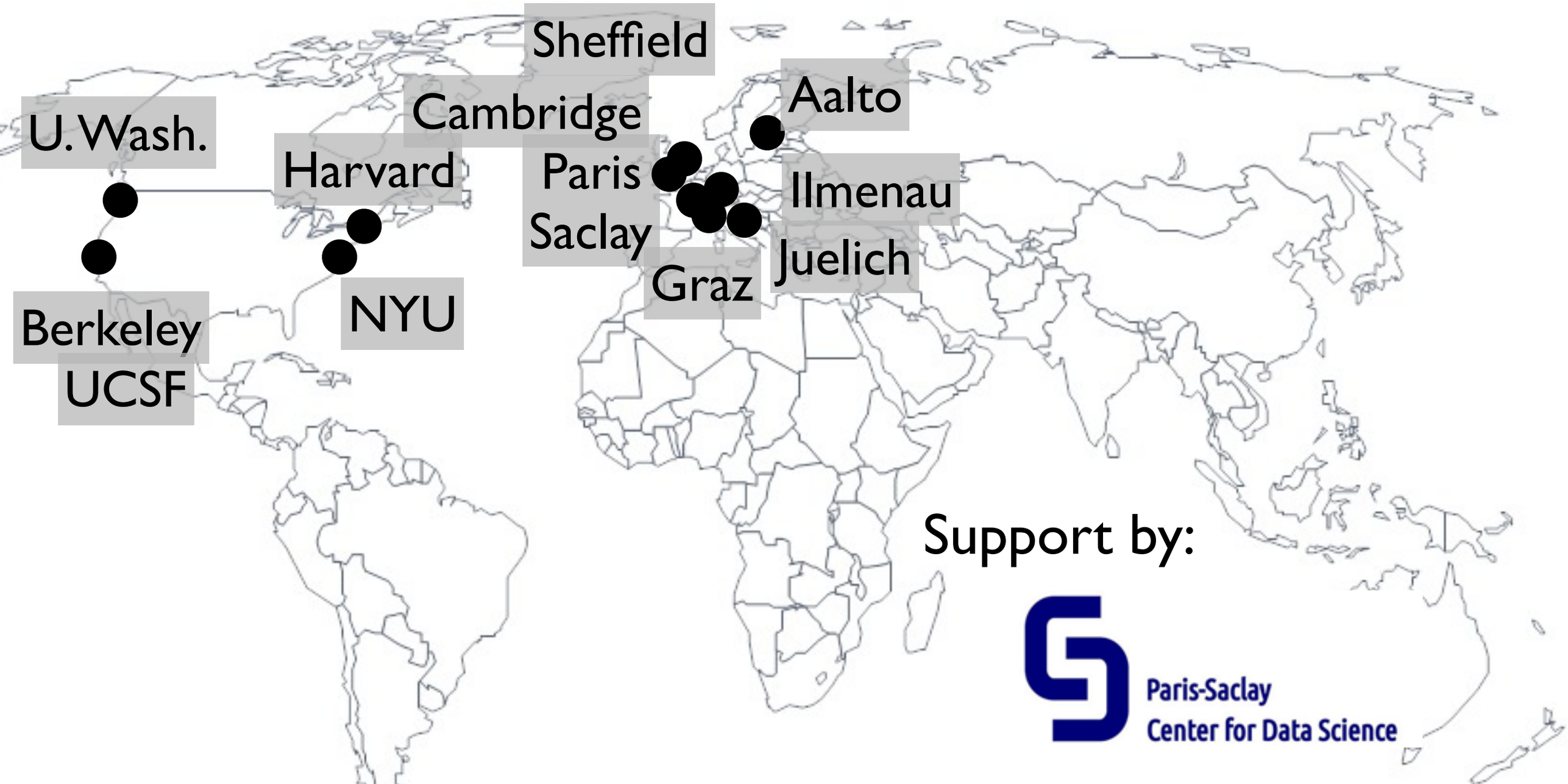
MNE includes a comprehensive Python package (provided under the simplified BSD license), supplemented by tools compiled from C code for the LINUX and Mac OSX operating systems, as well as a MATLAB toolbox.

Documentation

- Getting Started
- What's new
- Cite MNE
- Related publications
- Tutorials
- Examples Gallery
- Manual
- API Reference
- Frequently Asked Questions
- Advanced installation and setup
- MNE with CPP

MNE software for processing MEG and EEG data, A. Gramfort, M. Luessi, E. Larson, D. Engemann, D. Strohmeier, C. Brodbeck, L. Parkkonen, M. Hämäläinen, Neuroimage 2013

Development of the MNE software



Support by:

Paris-Saclay
Center for Data Science

http://martinos.org/mne/stable/contributing.html

Thanks !

Post-docs positions available !

Contact

http://alexandre.gramfort.net

GitHub : @agramfort

Twitter : @agramfort