Neuroimaging lecture 1:
Statistical parametric mapping (SPM)

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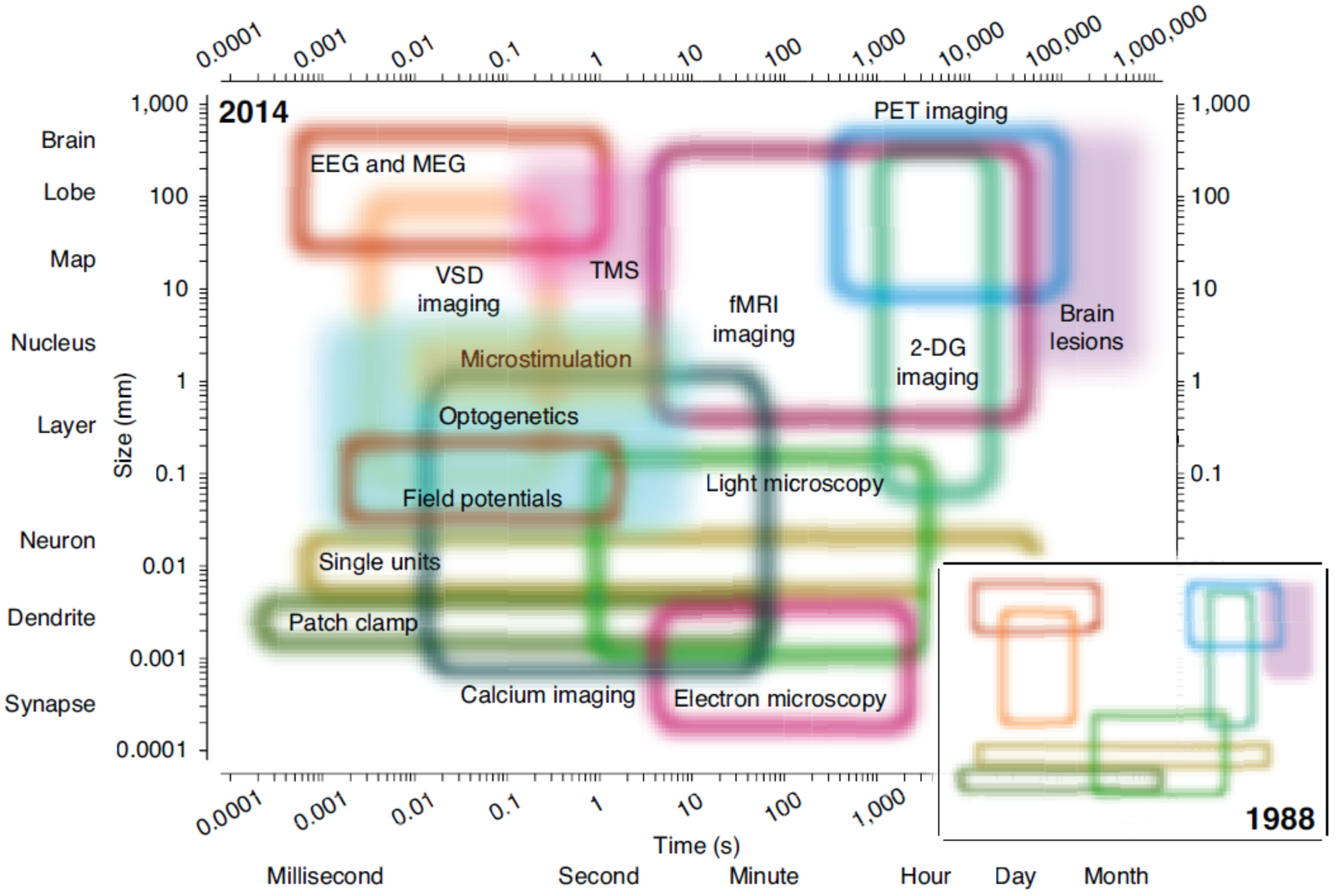
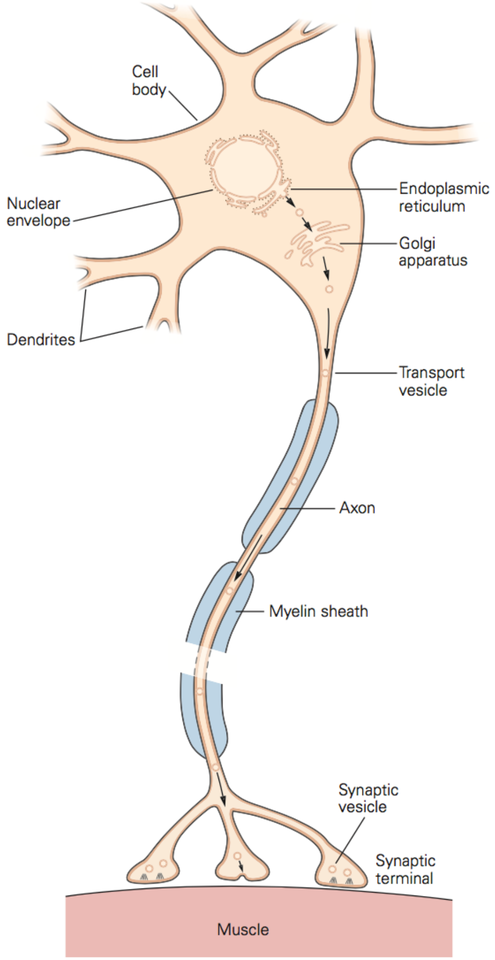
Contents

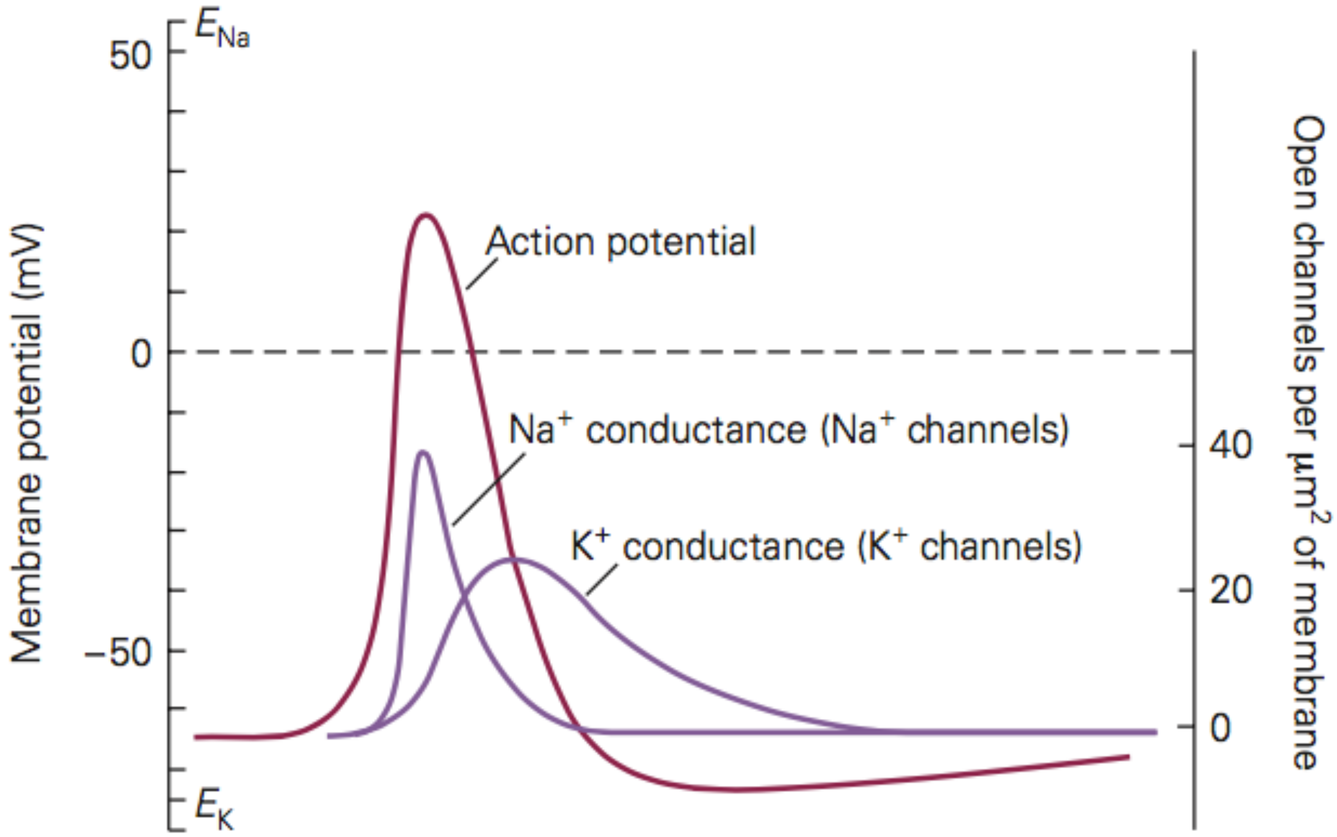
- Various neuroimaging techniques (EEG, MEG, PET)
- Functional magnetic resonance imaging (fMRI)
- Terminology and coordinates in neuroimaging study
- fMRI preprocessing steps

Experimental methods for cognitive and psychiatric neuroscience


2014
EEG and MEG
PET imaging
VSD imaging
TMS
fMRI imaging
Brain lesions
2-DG imaging
Microstimulation
Optogenetics
Light microscopy
Field potentials
Single units
Patch clamp
Calcium imaging
Electron microscopy
1988
Brain
Lobe
Map
Nucleus
Layer
Neuron
Dendrite
Synapse
Size (mm)
1,000
100
10
1
0.1
0.01
0.001
0.0001
0.0001
0.001
0.01
0.1
1
10
100
1,000
10,000
100,000
1,000,000
Time (s)
Millisecond
Second
Minute
Hour
Day
Month

Single Cell Recoding

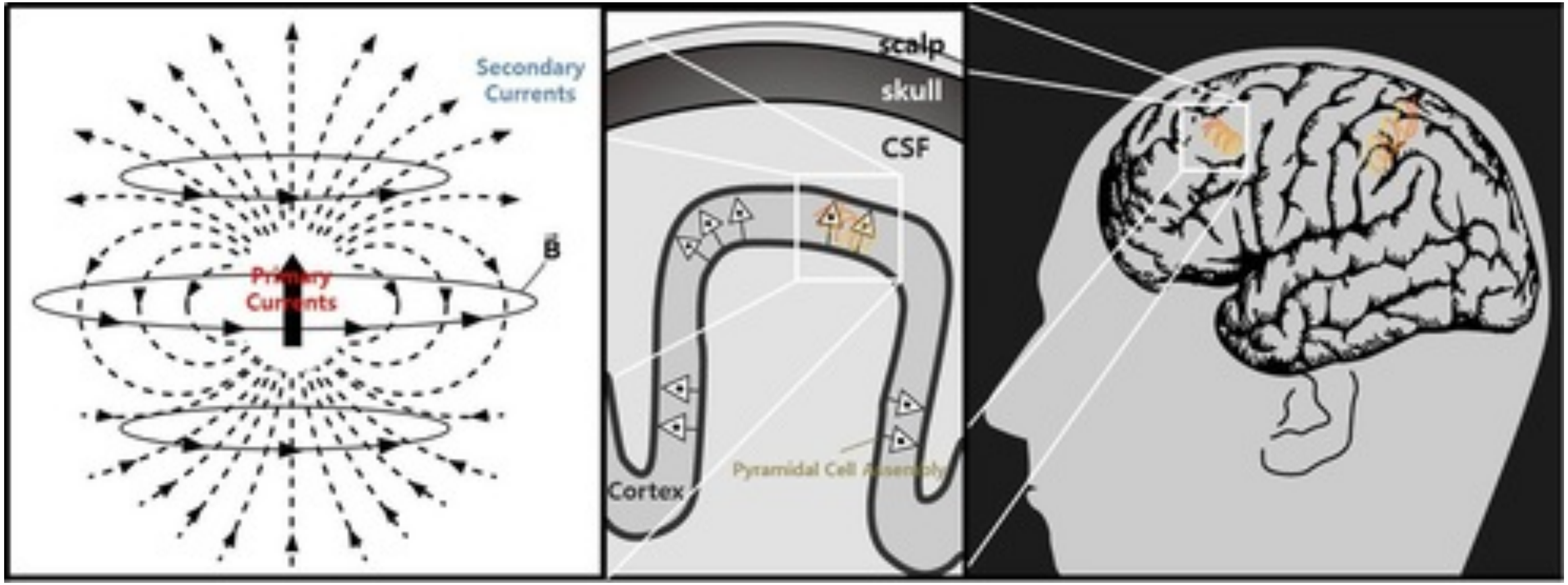




Principles of Neural Science, Kandel, 2013

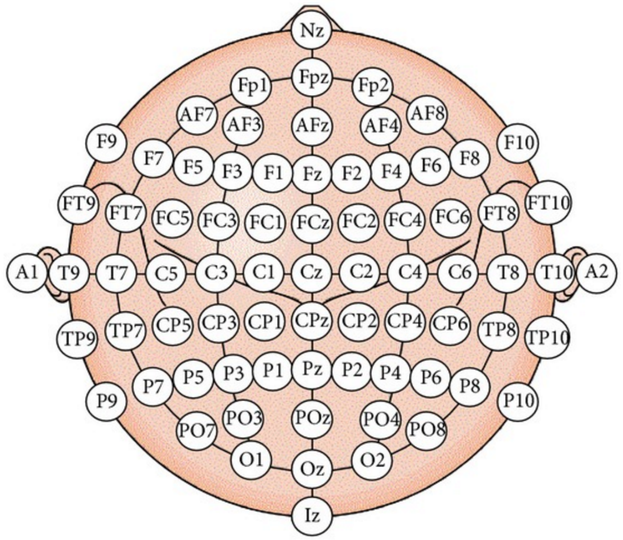
Electroencephalogram (EEG)

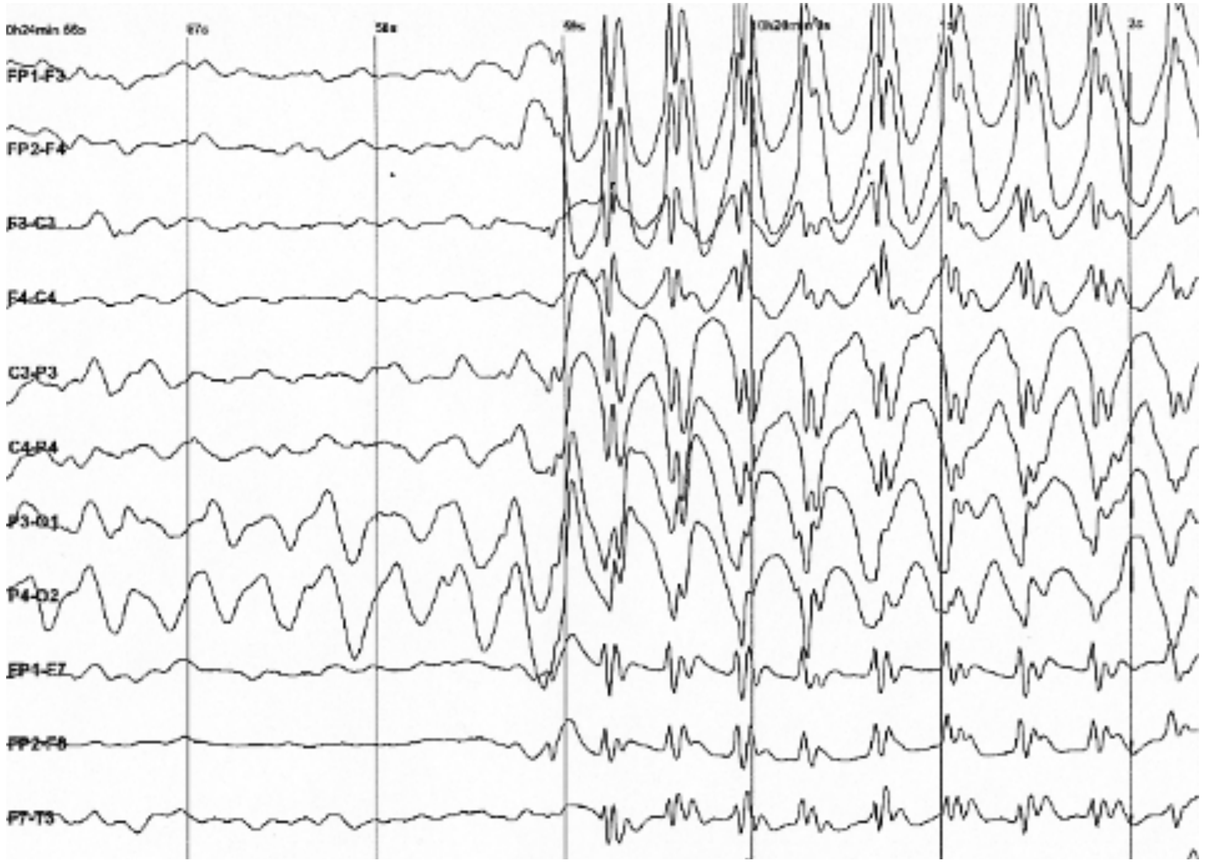
a direct measure of post-synaptic potential



http://bispl.weebly.com/

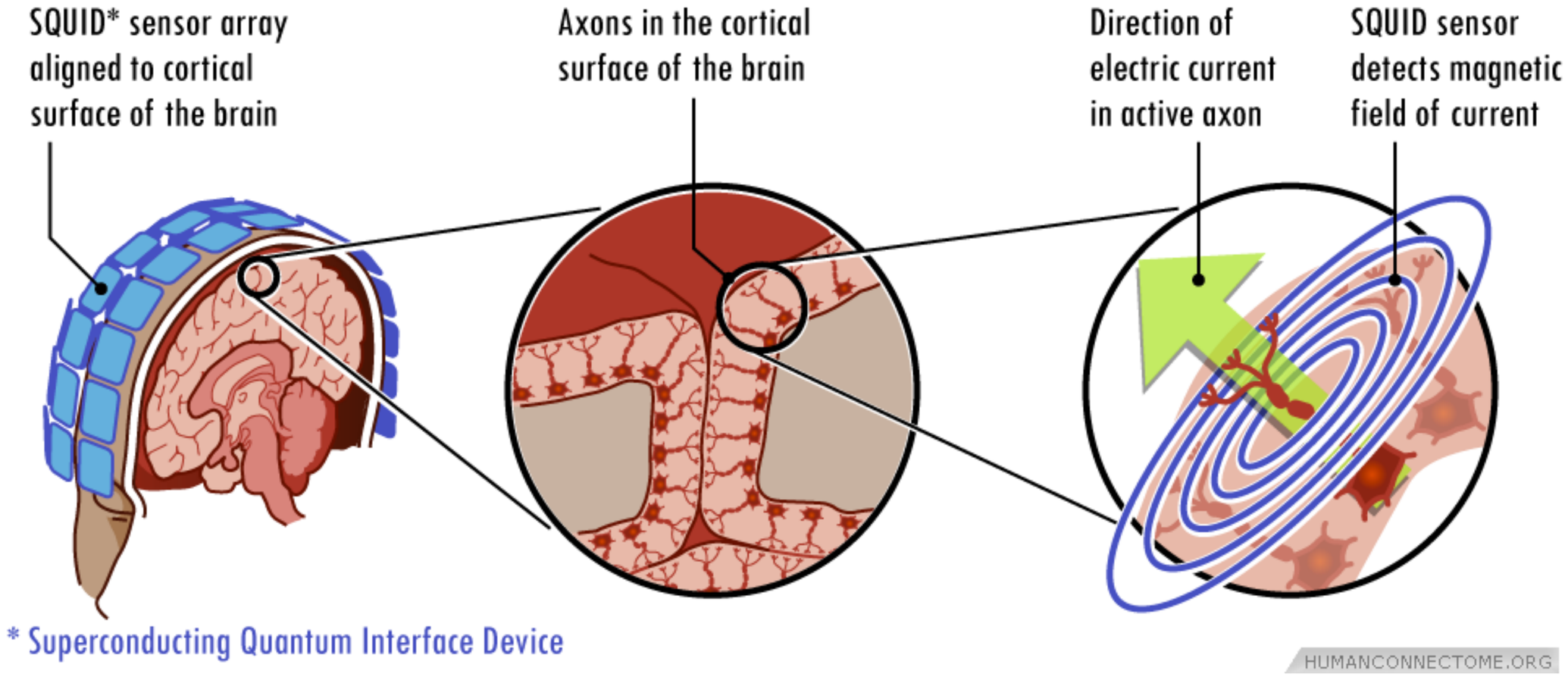
EEG recoding





psychology.uzh.ch
researchgate.org
https://en.wikipedia.org/

Magnetoencephalography (MEG)

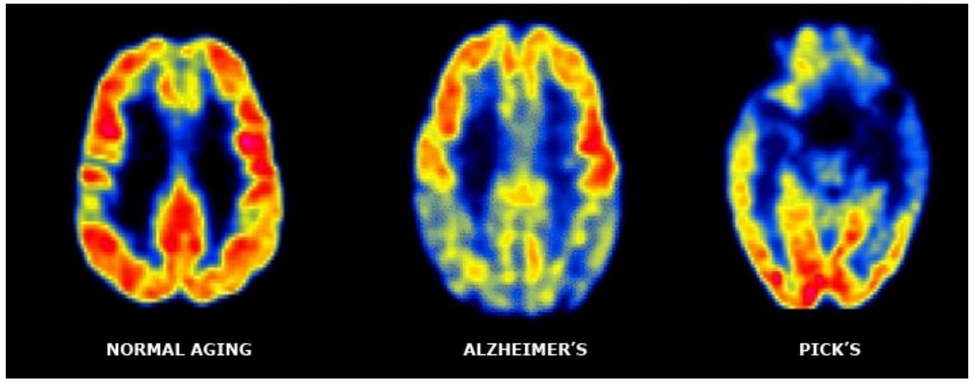


MEG

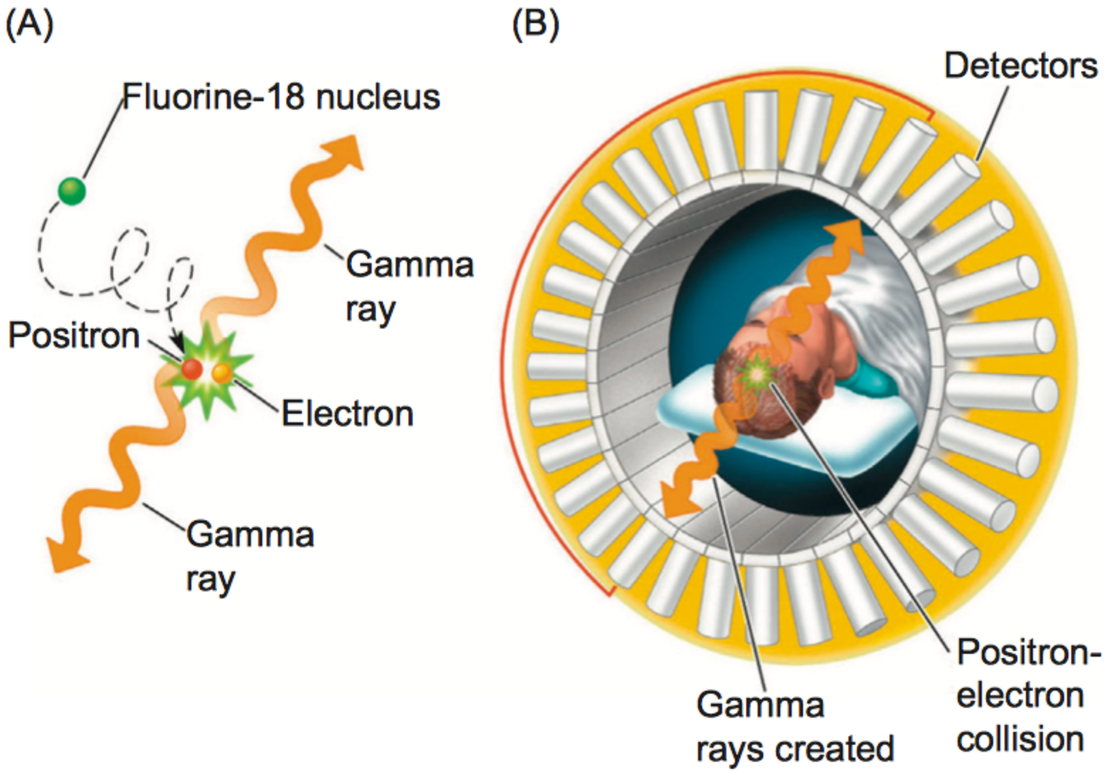
https://en.wikipedia.org/

Positron Emission Tomography:

Two photo detector



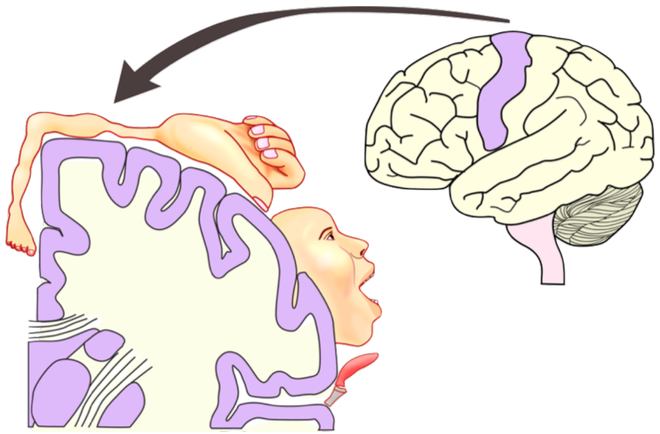
Positron Emission Tomography



Neuroeconomics, Glimcher et al., 2014
https://en.wikipedia.org/

Isotope in PET imaging

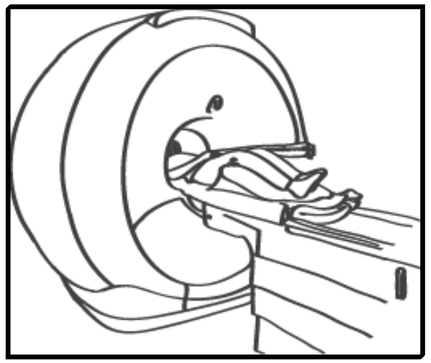
- Unstable positron-emitting isotopes are synthesised in a cyclotron by bombarding elements such as oxygen, carbon, or fluorine with protons.
- Isotopes : ^{15}O(half-life 2min), ^{18}F(110 min), ^{11}C(20min)
- When the radio-labeled compounds are injected into the blood stream, they distribute according to the physiological state of the brain, accumulating preferentially in more metabolically active areas.
- The structure of F-18-FDG is similar to the glucose, so it can used to diagnosis the abnormality of glucose metabolism.



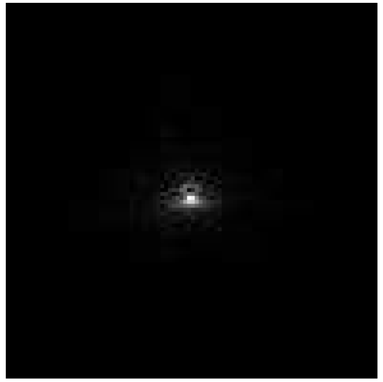
Blood Oxygen Level Dependent Signal for

functional MRI

fMRI Data Acquisition

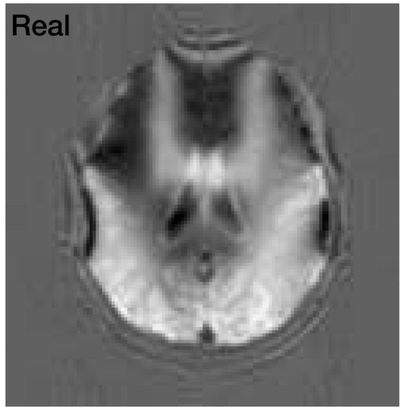


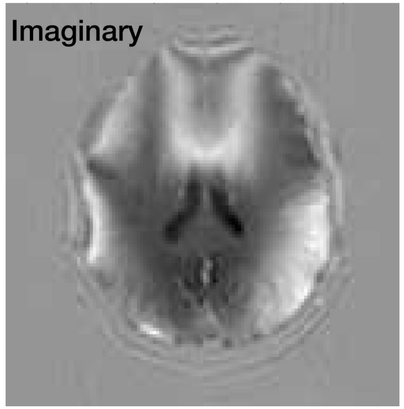
Raw Data



k-Space Image

2D *i*FFT





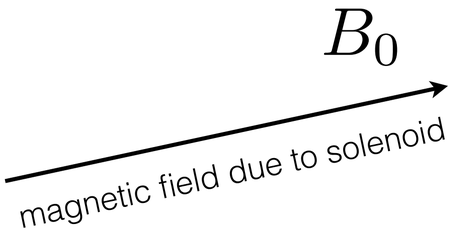
Complex Data in
Image Domain

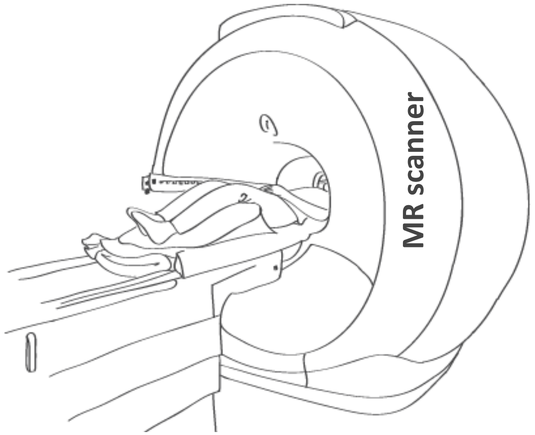
$$M = |R + iI|$$

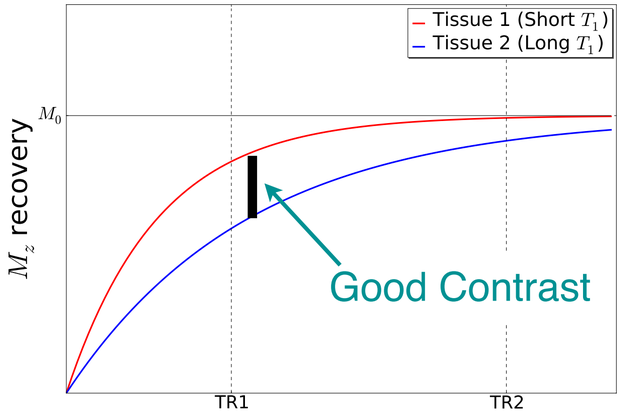
$$P = \tan^{-1}(I/R)$$

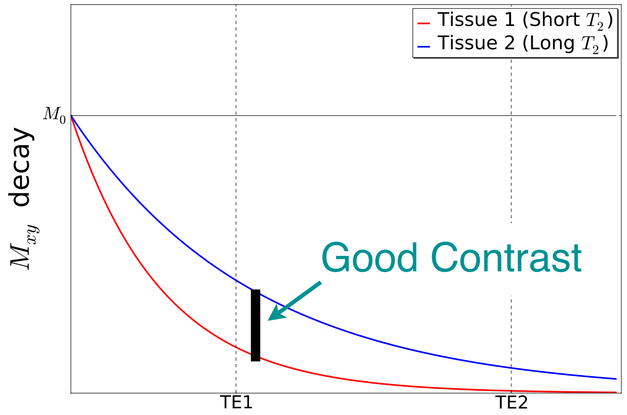
Detection of MRI Signal

- Applying RF pulse to tip down bulk magnetisation (*Mz*) to the transverse plane.
- *Mz* tends to align the external magnetic field as time goes on (*T1* recovery).
- *Mz* decays in the transverse plane as time goes on (*T2* decay).









Tissue Specific T1 and T2

- T1 recovery and T2 decay time ranges from tens to thousands of milliseconds for protons in human tissue over the main field. Typical values for various tissues are shown in following table.
- Applying the pulse sequences, we can discriminate brain tissues; The different sequences should be applied to obtain the specific image, for example, anatomic, functional, angio images.

Tissue	T_1 (ms)	T_2 (ms)
Gray matter (GM)	950	100
White matter (WM)	600	80
Muscle	900	50
Cerebrospinal fluid (CSF)	4500	2200
Fat	250	60
Blood	1200	100~300

obtained at

$B_0 = 1.5\ T$

$T = 37°C$

Detecting BOLD fMRI Signal

- The abbreviation BOLD fMRI stands for **B**lood **O**xygen **L**evel **D**ependent functional MRI.
- The ***BOLD*** contrast mechanism alters the *T*2* parameter mainly through neural activity–dependent changes in the relative concentration of oxygenated and deoxygenated blood.
- **Deoxyhemoglobin** is **paramagnetic** and influences the MR signal unlike oxygenated hemoglobin.

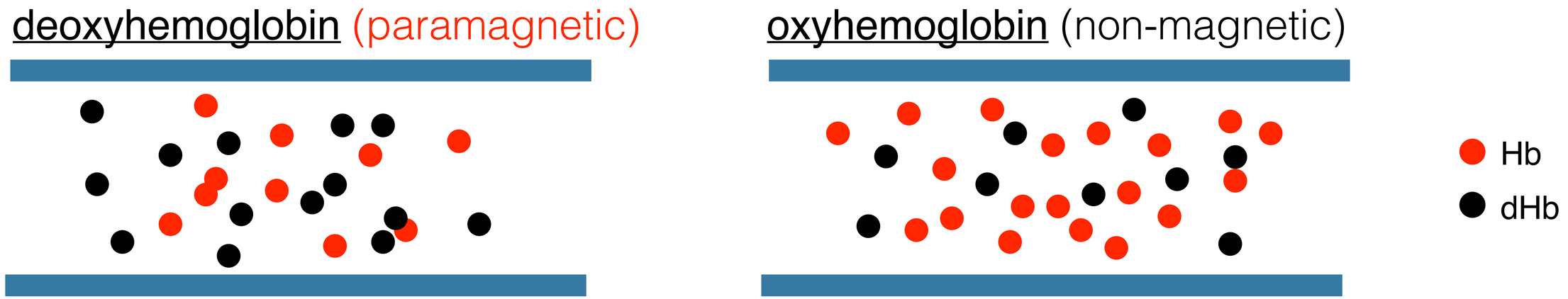
Contrast Agents for fMRI ?

- Definition : Substances that alter magnetic susceptibility of tissue of blood, leading to changes in MR signal
  - Affects local magnetic homogeneity: decrease in T2*
- Two types
  - Exogenous : Externally applied, non-biological compounds.
  - Endogenous : Internally generated biological compound (e.g., dHb)
- BOLD functional magnetic imaging method doesn't need the external contrast agents.

O_2 Ratios in Blood

$$\text{BOLD signal} = \frac{\text{HB}}{\text{dHB}}$$

- BOLD contrast measures inhomogeneities in magnetic field due to changes in the level of O_2 in the blood.



Normal blood flow

High ratio deoxy :
→ deoxygenated blood
→ fast decrease in MRI signal

High blood flow

Low ratio deoxy :
→ oxygenated blood
→ slow decrease in MRI signal

Mechanism of BOLD fMRI

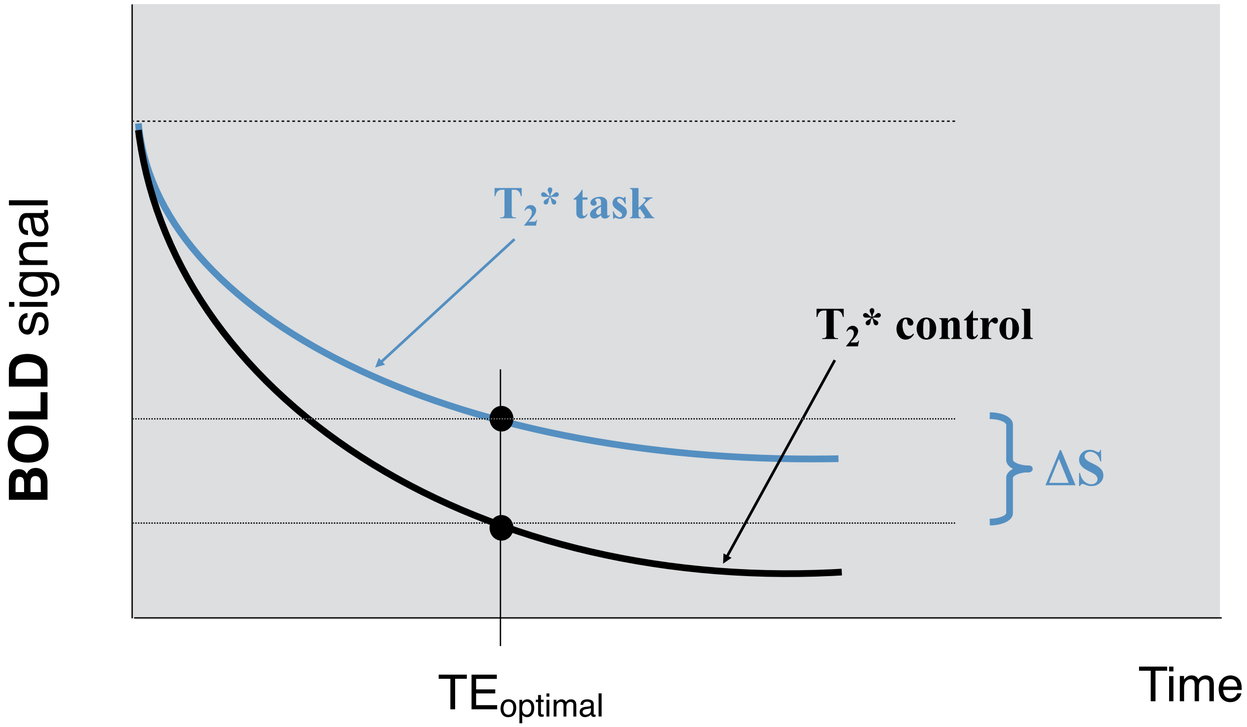
↑ Neural Activity → ↑ Blood Flow → ↑ Oxyhemoglobin

↓

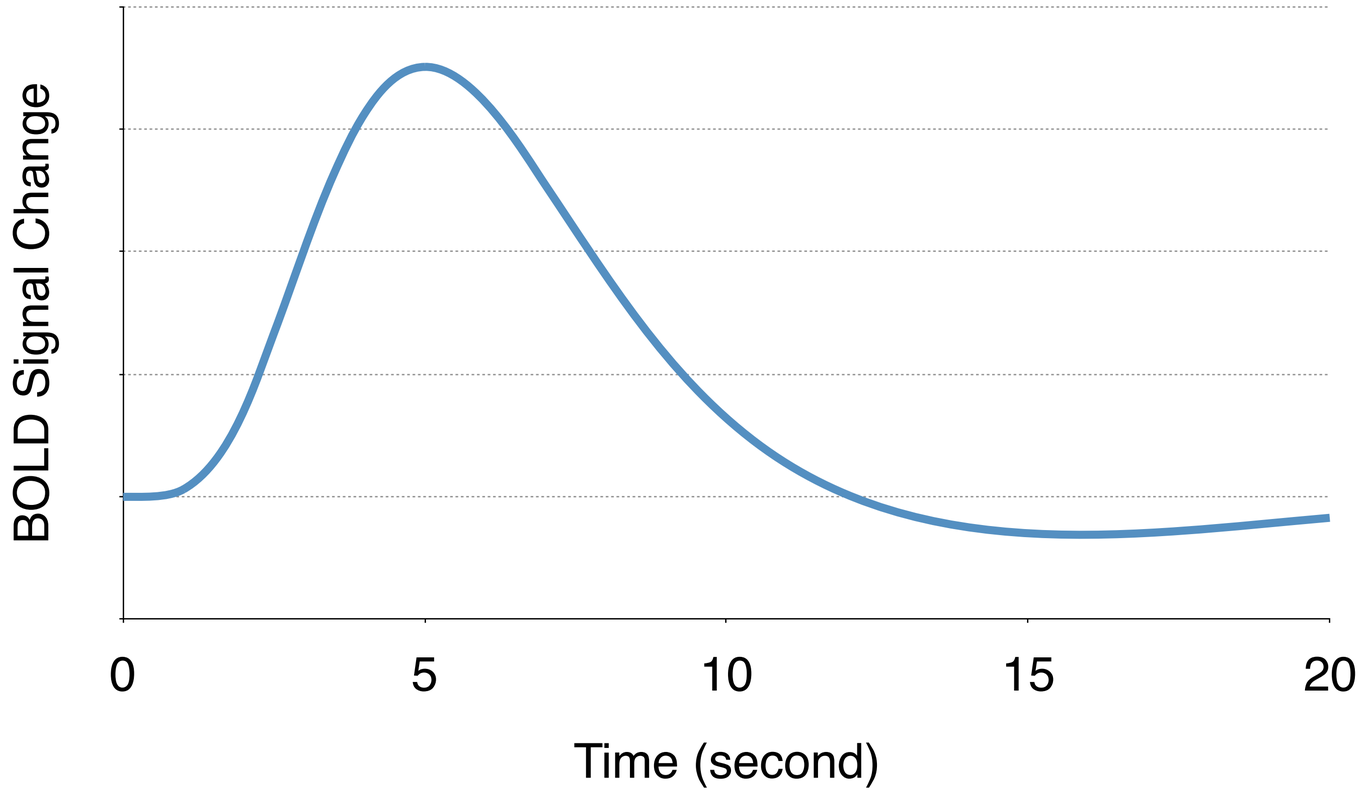
↑ T_2*

↓

↑ MR Signal



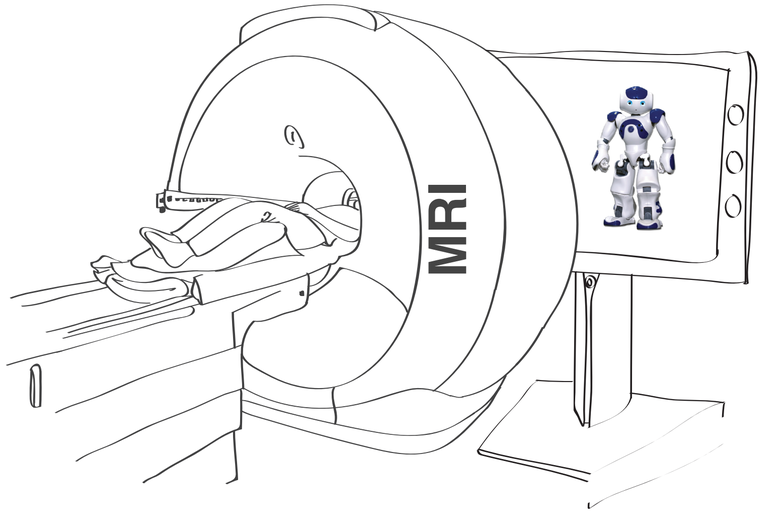
Hemodynamic Response

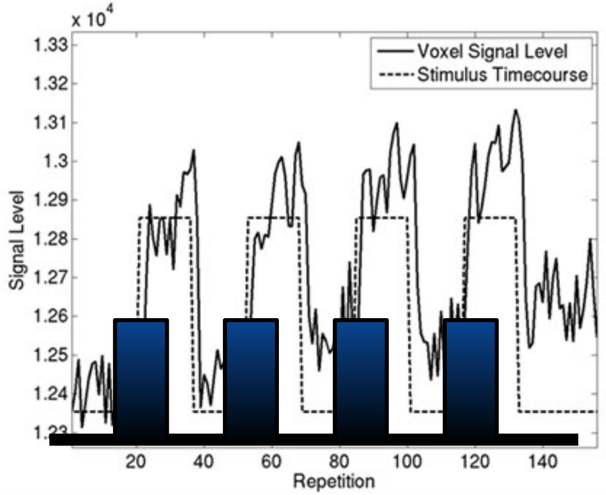


- BOLD signal은 자극이 제시되고 5~6초 후에 최대 반응을 보임
- Fast event related + jittered ISI is the optimal design

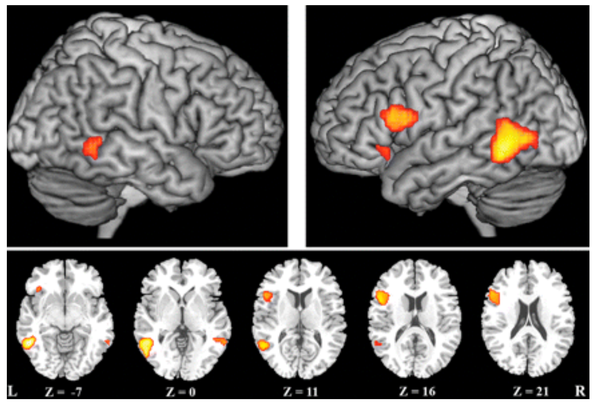
Reference for FMRI Experimental Design, http://afni.nimh.nih.gov/pub/dist/HOWTO/howto/ht03_stim/html/stim_background.html

Block Designed fMRI

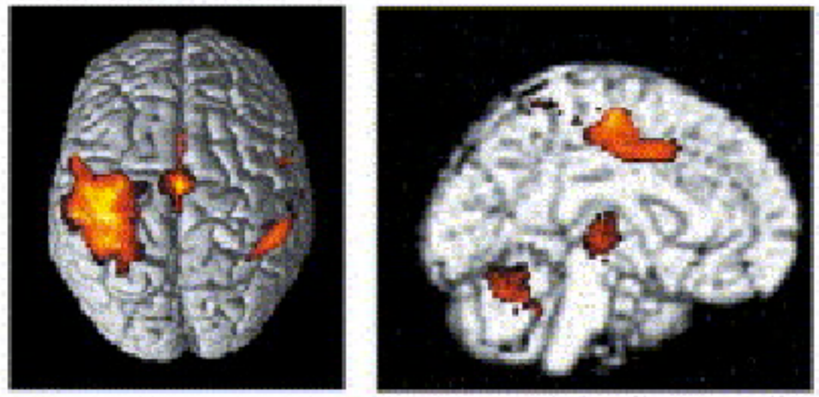




Language Area



Motor Area



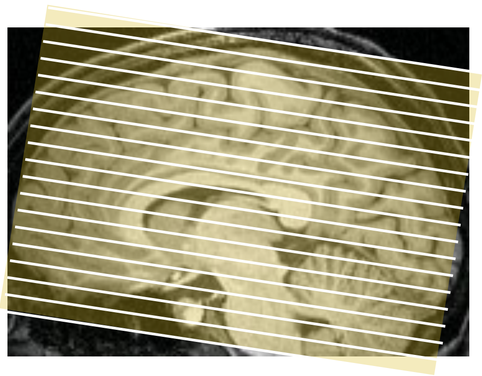
Resting State fMRI

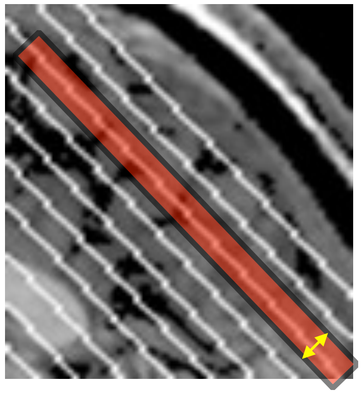
- Resting state fMRI measures “low-frequency (0.01~0.08 Hz)” slow oscillation.
- Resting state means “Keep eyes closed resting state but not sleep for several minutes”.
- Resting state functional connectivity considered as “intrinsic connectivity”.
- Modular structure in RSFC were found in many studies.
- Default mode network (DMN) alteration in Psychiatric patients (e.g. schizophrenia).

Terminology and Coordinates in neuroimaging study

Terminology of fMRI

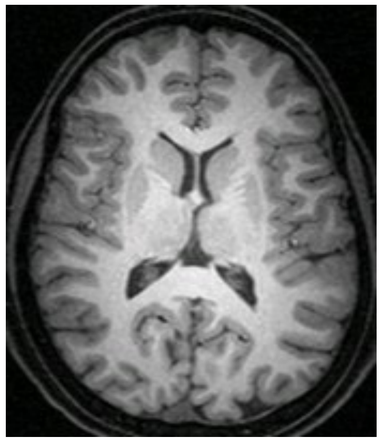
Scan Volume:
Field of View (FoV),
e.g. 192 mm





Slice thickness
e.g. 3mm

Matrix Size
e.g., 64 x 64

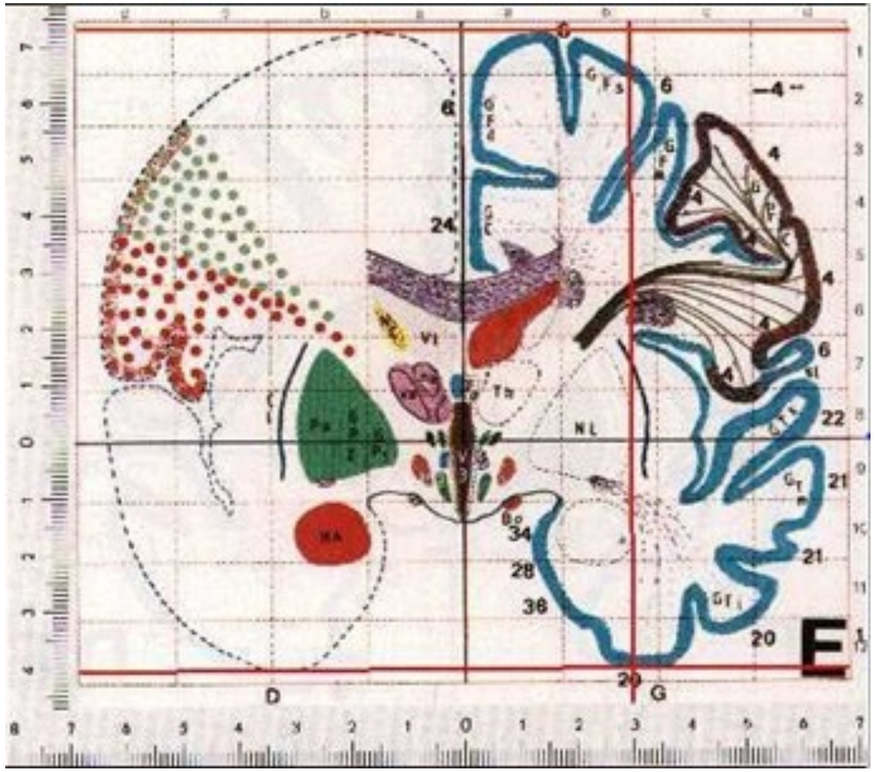


In-plane resolution
192 mm / 64 = 3 mm

Voxel size
(volumetric pixel)

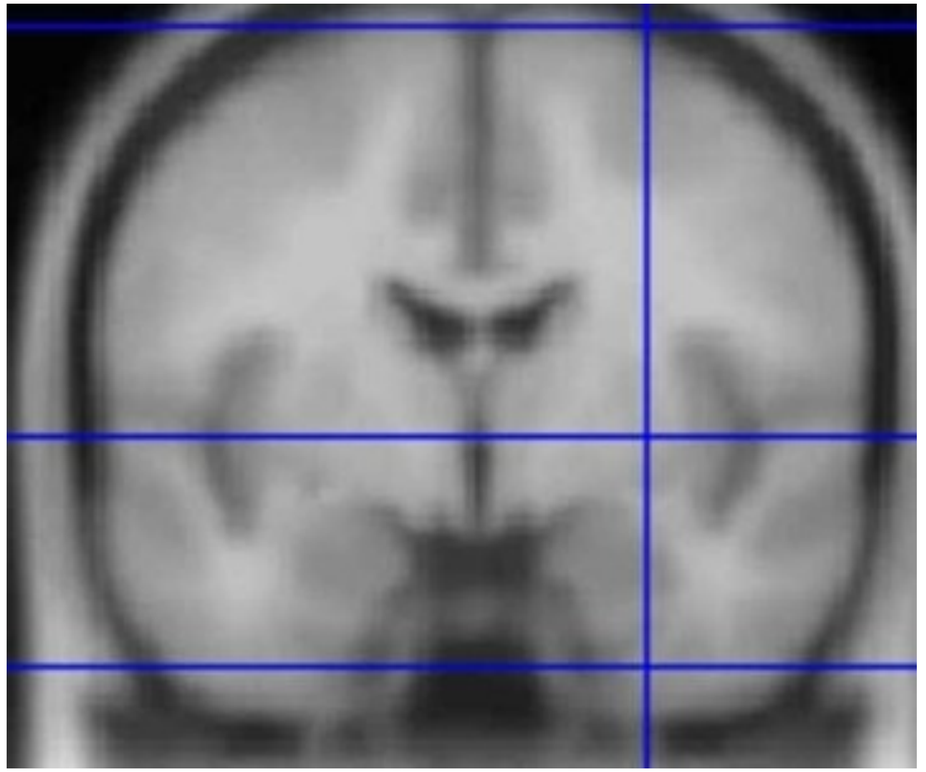
Two standard spaces

The Talairach Space



AFNI uses Talairach template

The MNI Space

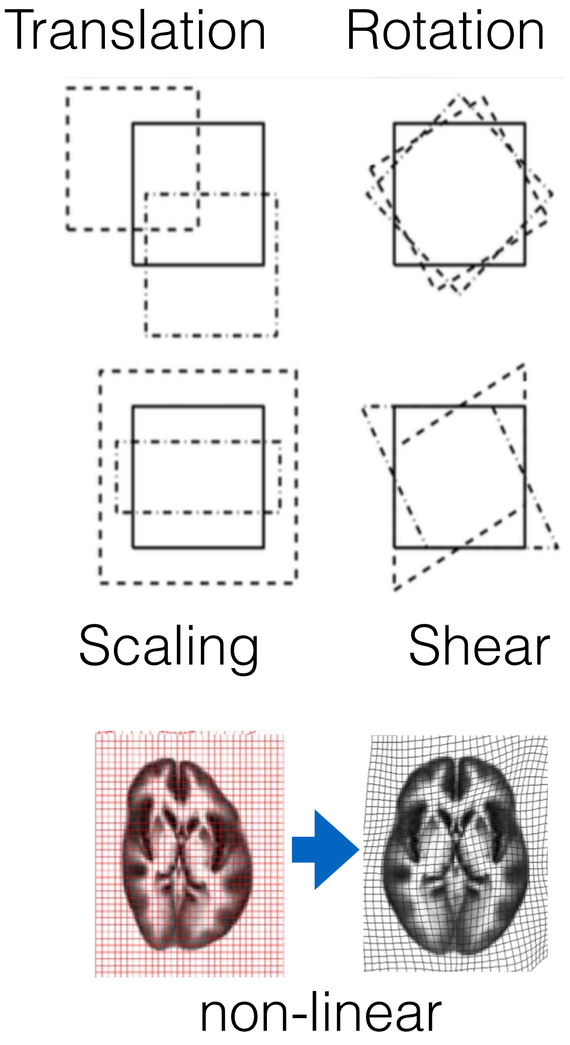


SPM & FSL use MNI template

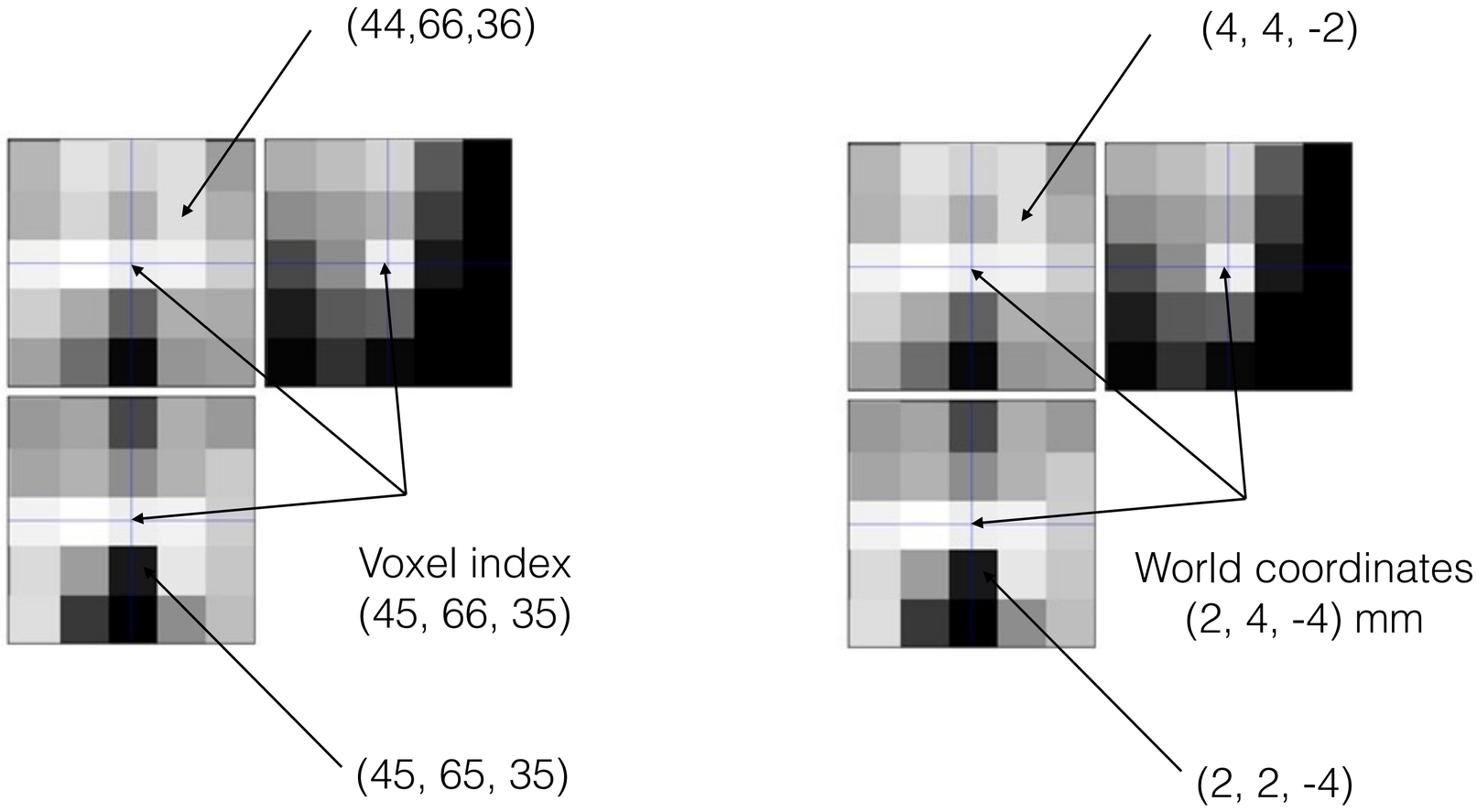
Types of transformations

- Transformations describe the mapping of all image voxels from one coordinate system into another

- Types of transformations
  - rigid body = translation + rotation
  - affine = rigid body + scaling + shear
  - non-linear = any mapping



World space & voxel space



Changing coordinate systems

$$x_W = -2x_V + 92$$
$$y_W = 2y_V - 128$$
$$z_W = 2z_V - 74$$

$$\begin{pmatrix} x_W \\ y_W \\ z_W \end{pmatrix} = \begin{pmatrix} -2 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 2 \end{pmatrix} \begin{pmatrix} x_V \\ y_V \\ z_V \end{pmatrix} + \begin{pmatrix} 92 \\ -128 \\ -74 \end{pmatrix}$$

By moving to 4D, one can include translations within a single matrix multiplication

$$\begin{pmatrix} x_W \\ y_W \\ z_W \\ 1 \end{pmatrix} = \begin{pmatrix} -2 & 0 & 0 & 92 \\ 0 & 2 & 0 & -128 \\ 0 & 0 & 2 & -74 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_V \\ y_V \\ z_V \\ 1 \end{pmatrix}$$

These 4-by-4 “homogeneous matrices” are the currency of voxel-world mappings, affine coregistration and realignment. In SPM5 & SPM8, they are stored in the .hdr files. In SPM2, they are stored in .mat files.

To find inverse mapping, or results of concatenating multiple transformations, we simply follow the rules of matrix algebra

Why does fMRI require spatial preprocessing?

- Head motion artefacts during scanning
  → realignment
- Problems of EPI acquisition: distortion and signal dropouts
  → Unwarping (using B0 fieldmap)
- Brain are quite different across subjects
  → Normalization (“Warping”)
  → Smoothing

fMRI preprocessing

steps in the spatial preprocessing

Neuroimaging analysis tools

by UCL group

win/mac/linux

fMRI/EEG/PET/VBM

Matlab

by NIMH group

mac/linux

fMRI/DTI/PET

Python/shell script

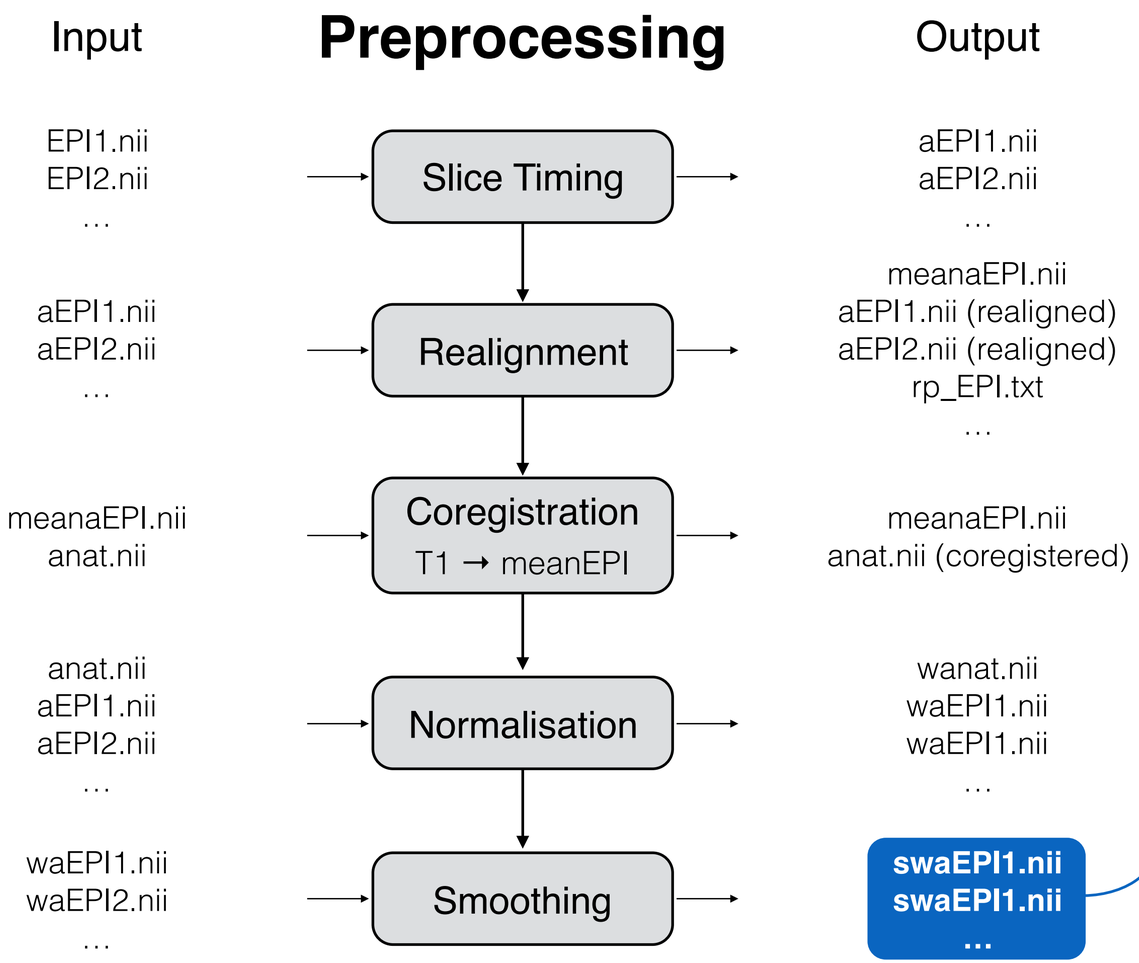
by Oxford group

mac/linux

fMRI/DTI/PET/Thickness

Python/shell script

Summary of Preprocess



Event related fMRI analysis

- **Specify 1st-level** in SPM
  Individual GLM with Stimulus onset and rp_EPI.txt as regressors
- **Specify 2nd-level** in SPM
  Group-wise GLM analysis
  one sample, two sample, factorial design, flexible design

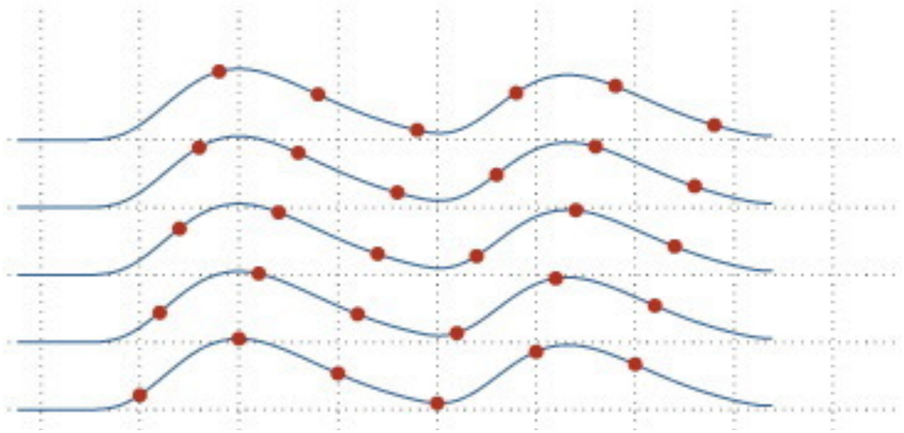
Resting state fMRI analysis

- Linear **detrending** of EPI time series at each voxel.
- **bandpass filtering** (0.009~0.08Hz) to capture Low-frequency fluctuation
- regression nuisance parameters such as head motion, white matter, ventricle, and global signal
- Functional connectivity analysis and Complex network analysis

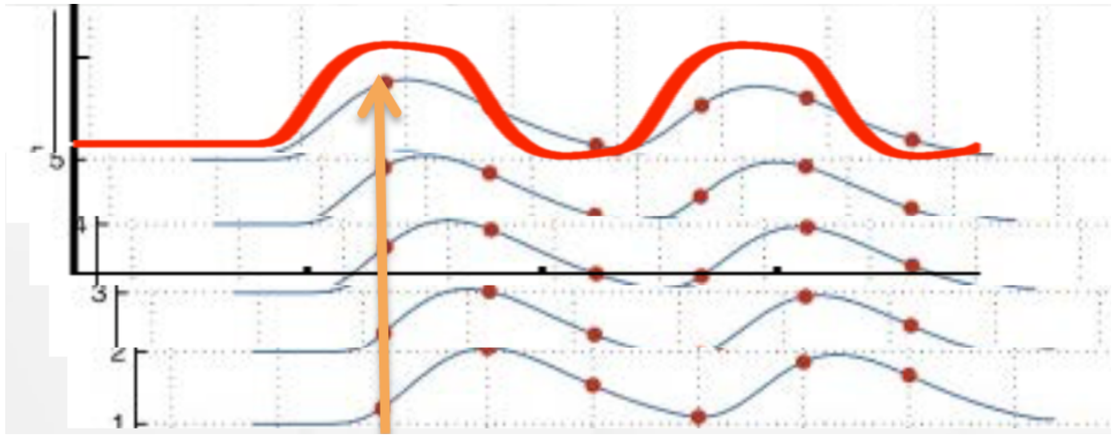
Slice-timing correction (STC)

- Slices of 1 scan volume are not acquired simultaneously (60 ms per slice)
- Creates shifts of up to 1 volume repetition time (TR), *i.e.*, several seconds
- Reduces sensitivity for time-locked effects (smaller correlation)

True 2D acquisition



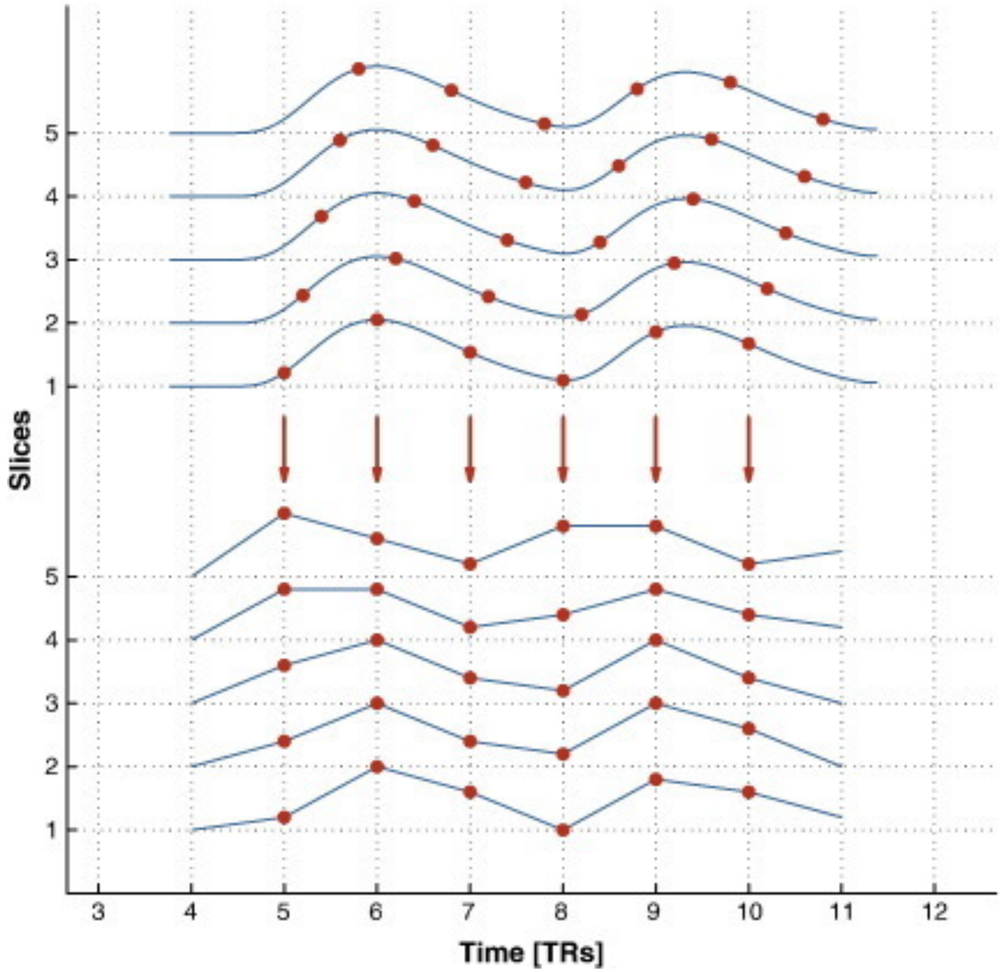
Same-Timepjoint Assumption



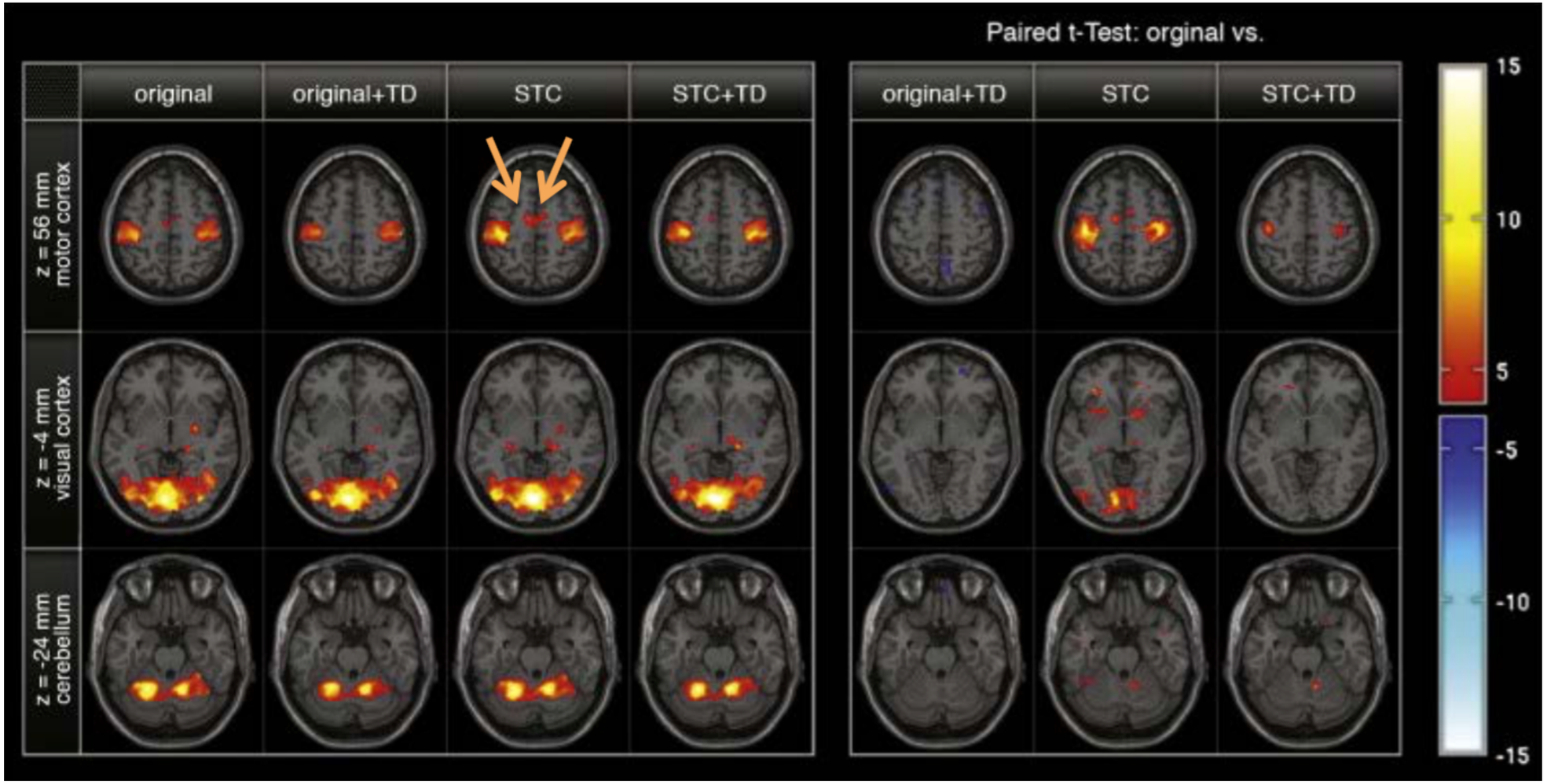
Slice-timing correction (STC)

- Slice-timing correction: All voxel time series are aligned to acquisition time of 1 slice

- Missing data is sinc-interpolated (band-limited signal)

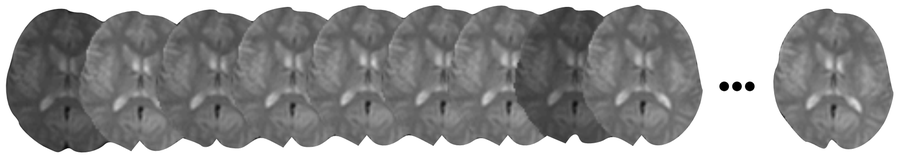


STC Results: Experiment



Sladky et al, NeuroImage 2011

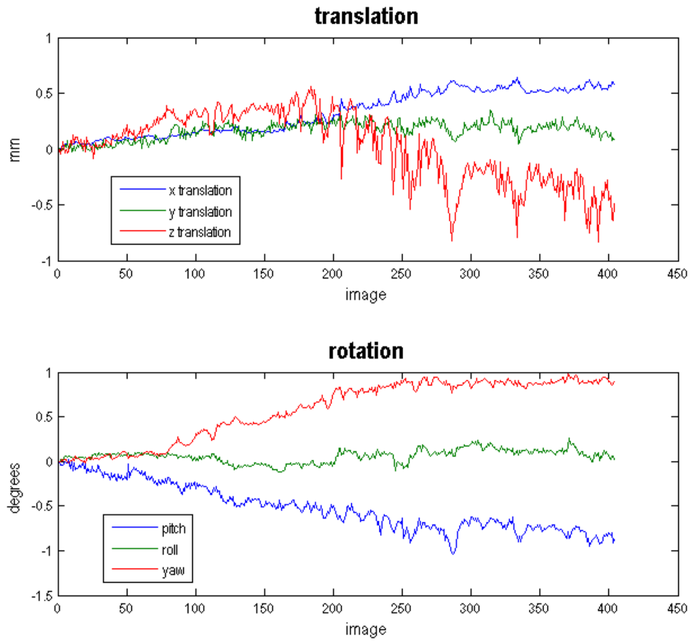
Realignment

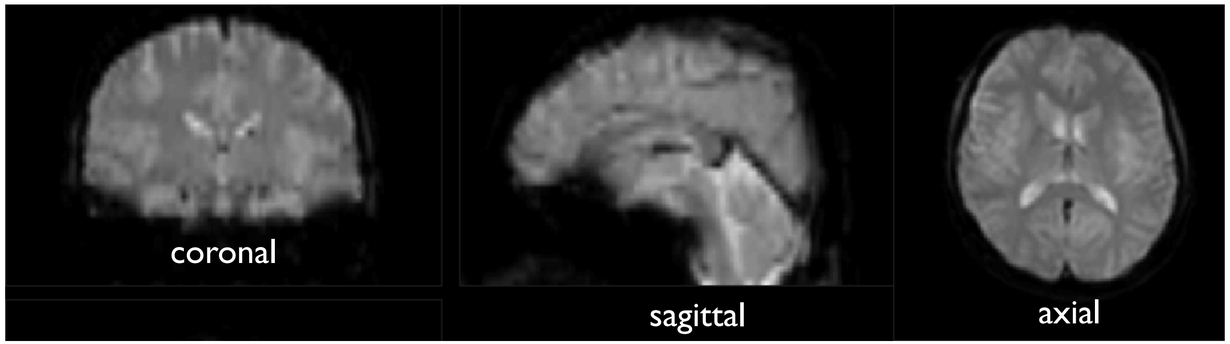


100 dynamic images

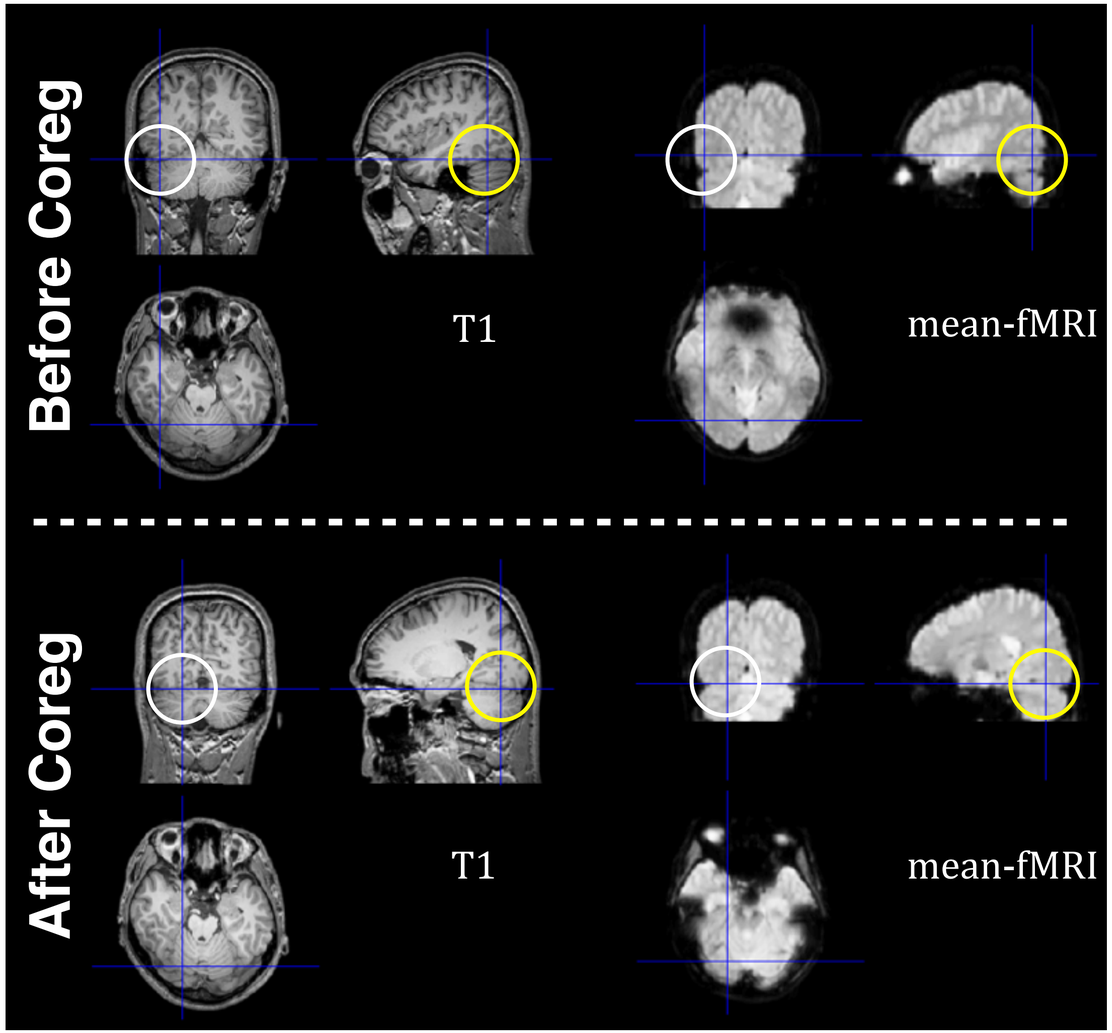
motion parameters

mean-fMRI





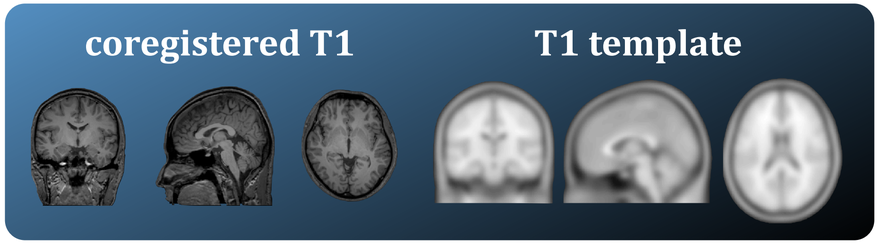
Coregistration



- High Resolution T1 data is registered to mean-fMRI
- Rigid-body transformation only (translation & rotation)

Normalisation and Smoothing

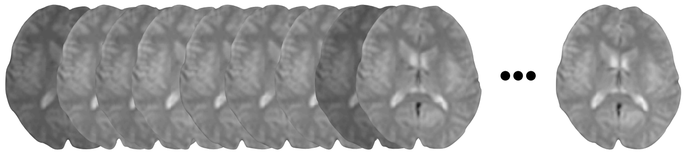
Nonlinear normalisation (T1→Template)



W

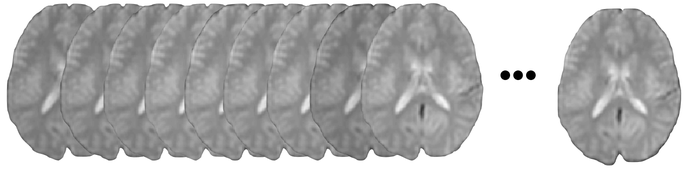
normalized T1 (**wT1**)

fMRI images



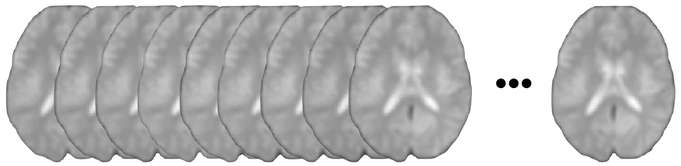
W

normalised fMRI (**wfMRI**) images



S

smoothed fMRI (**swfMRI**) images



spatial gaussian filter (FWHM=6 or 8mm)

Normalization options in practice

Conventional normalization:

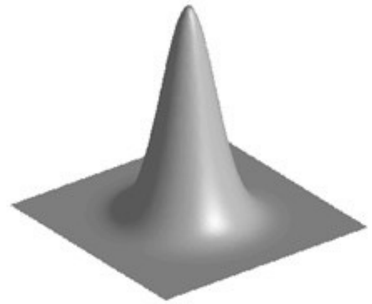
- either warp functional scans to EPI template directly
- or coregister structural scan to functional scans and then warp structural scan to T1 template; then apply these parameters to functional scans (“normalize: eat & write”)

Unified segmentation:

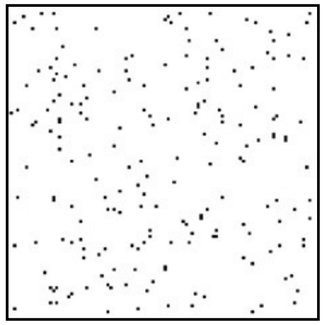
- coregister structural scan to functional scans
- unified segmentation provides normalization parameters
- apply these parameters to functional scans (‘normalize: write)”

Smoothing

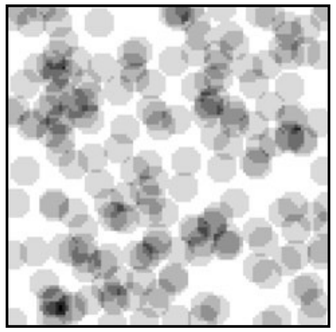
- Smoothing is done by convolving with a 3D Gaussian which is defined by its full width at half maximum (FWHM).
- Each voxel after smoothing effectively becomes the results of applying a weighted region of interest.



Before convolution



Convolved with a circle



Convolved with a Gaussian