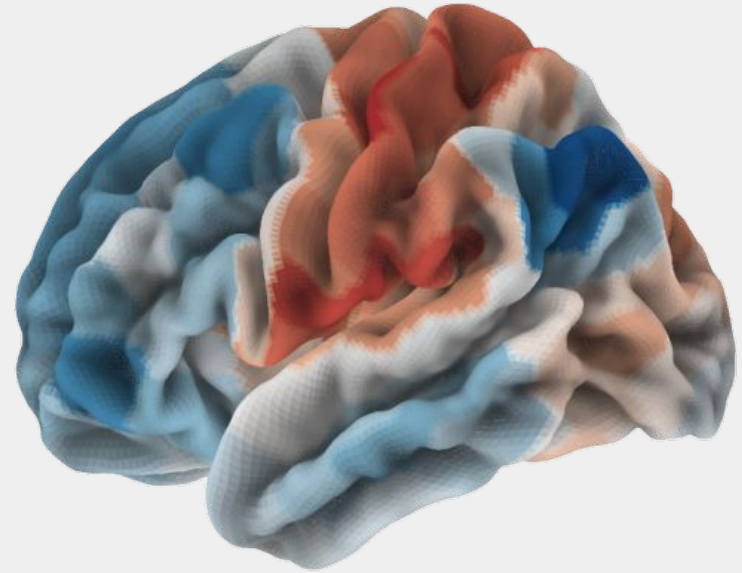


Fundamentals of fMRI data analysis

Karolina Finc

Centre for Modern Interdisciplinary
Technologies Nicolaus Copernicus University
in Toruń

PART #6: **Functional connectivity**



Study plan

Open science &
neuroimaging

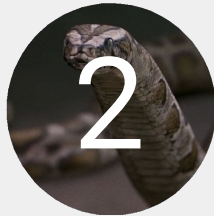


BEFORE

fMRI data
preprocessing



fMRI data manipulation
in python



Functional
connectivity



General
Linear Model



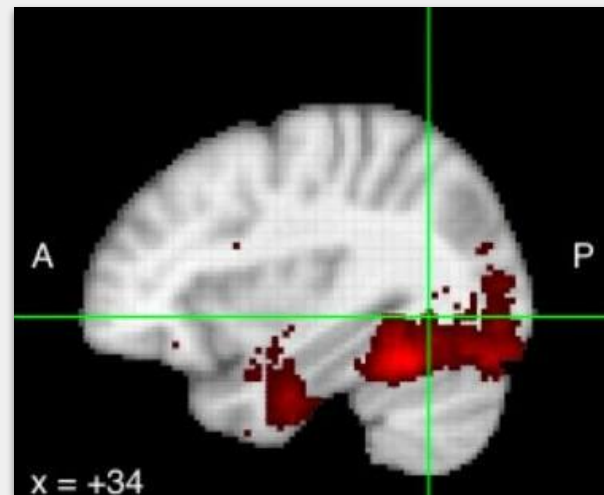
AFTER



Machine Learning
on fMRI data

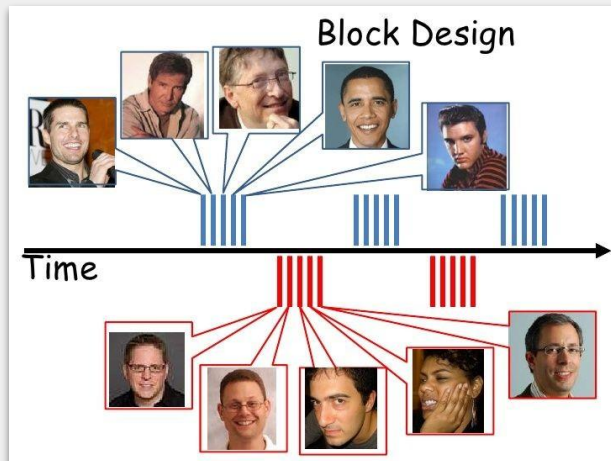
Goals of task-based fMRI

1. Induce in a study participant to do actions or experience cognitive states you're interested in.
2. You want to detect brain signals that are related to this cognitive states or actions.



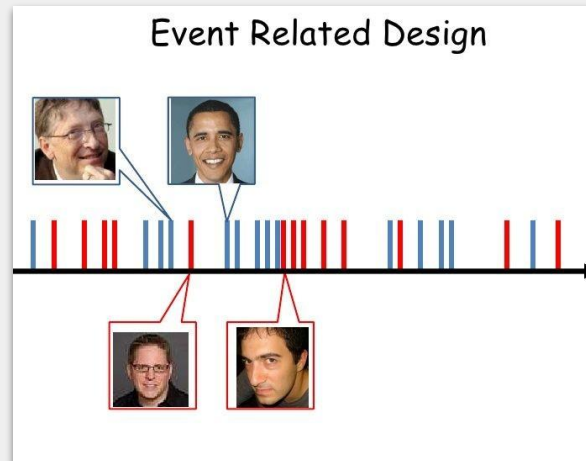
Task designs

Famous
people



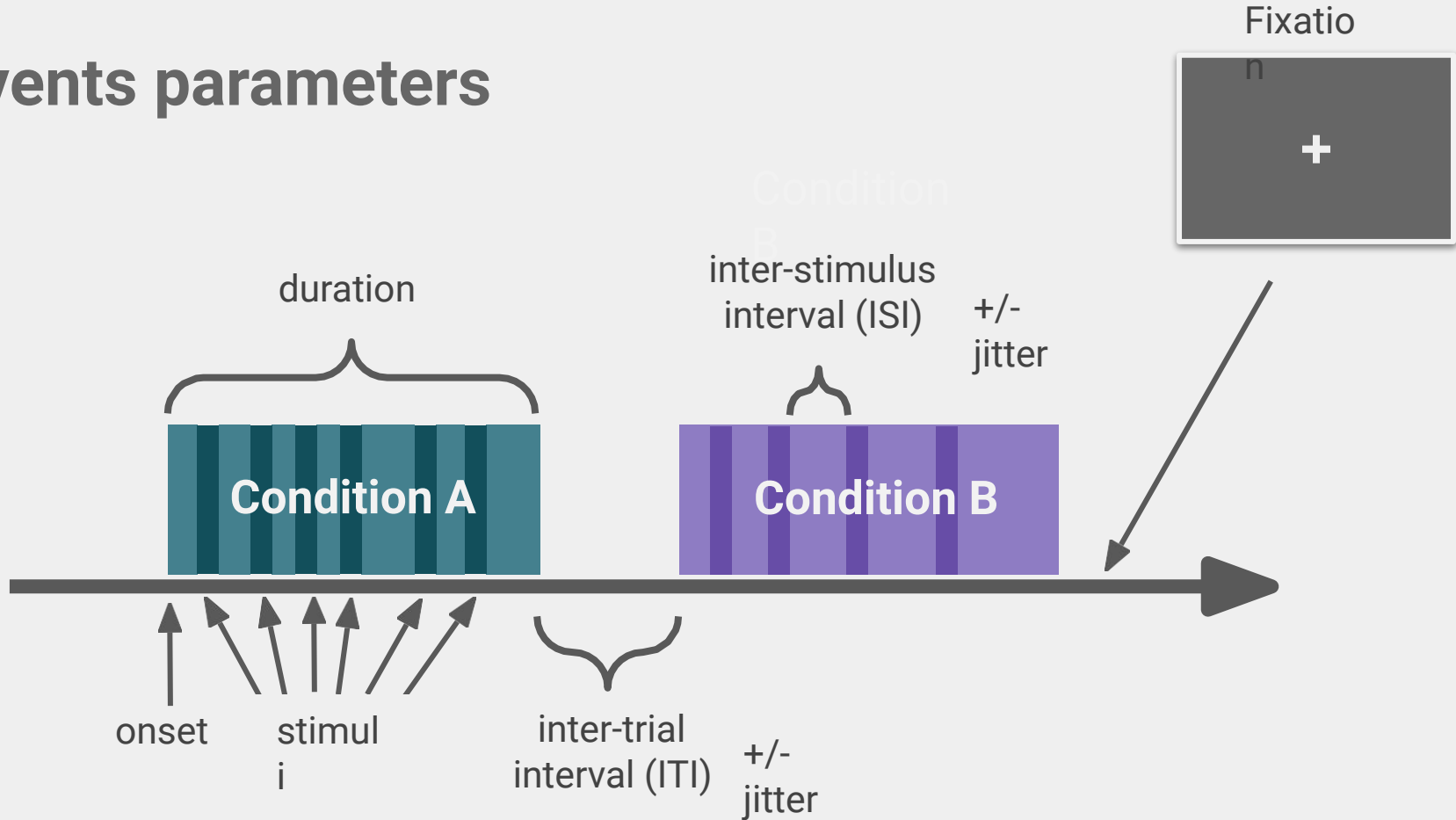
Non-famous
people

Block design
similar events are
grouped



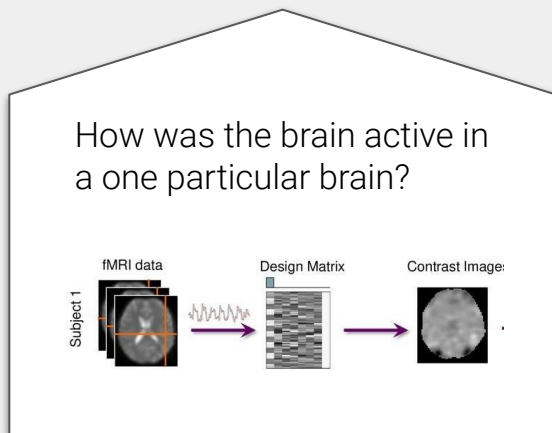
Event-related design
events are mixed

Events parameters

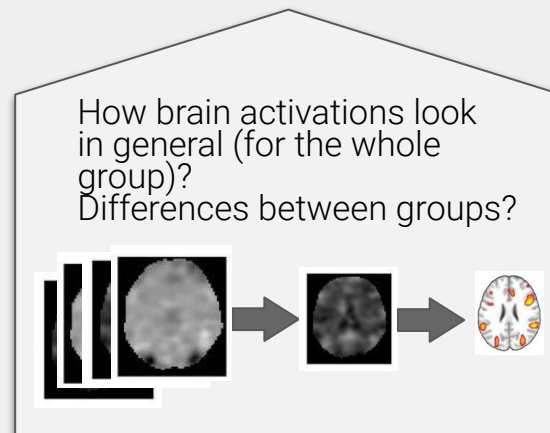


Analysis steps

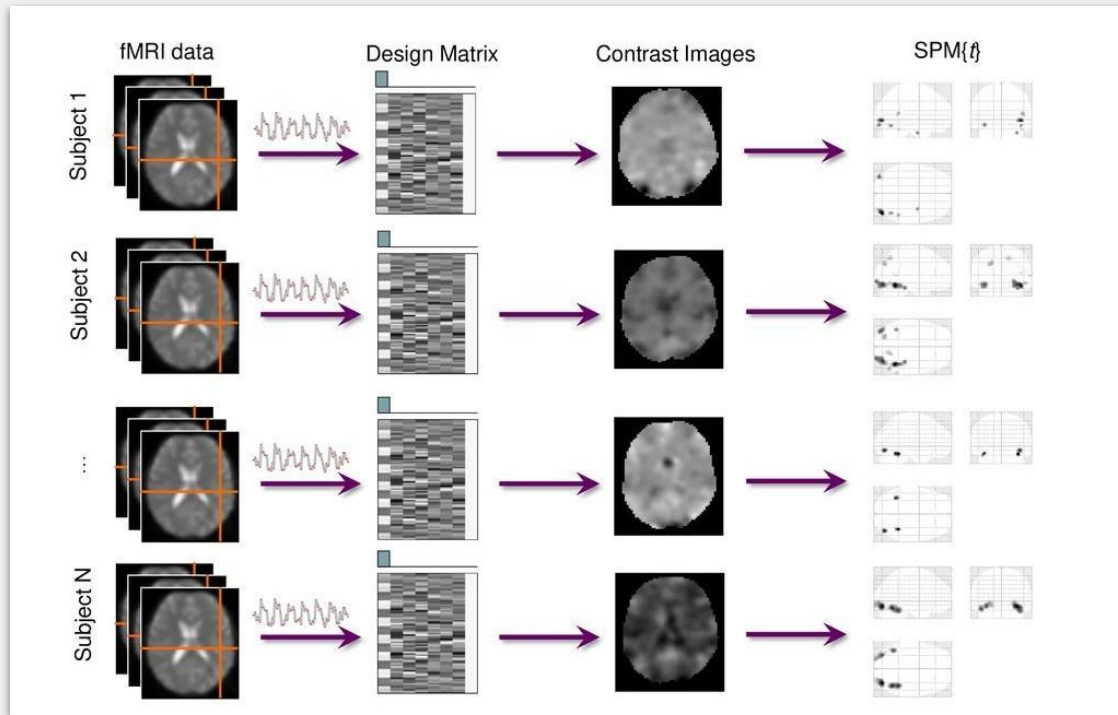
1-level analysis (within-subject; individual)



2-level analysis (across-subject; group)

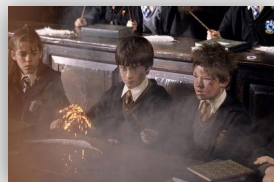


1-level analysis



Study plan

Open science &
neuroimaging



BEFORE

fMRI data
preprocessing



fMRI data manipulation
in python



Functional
connectivity



General
Linear Model



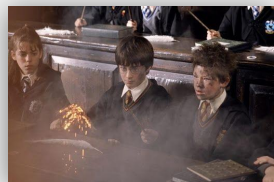
AFTER



Machine Learning
on fMRI data

Study plan

Open science &
neuroimaging



BEFORE

fMRI data
preprocessing



fMRI data manipulation
in python



Functional
connectivity



General
Linear Model

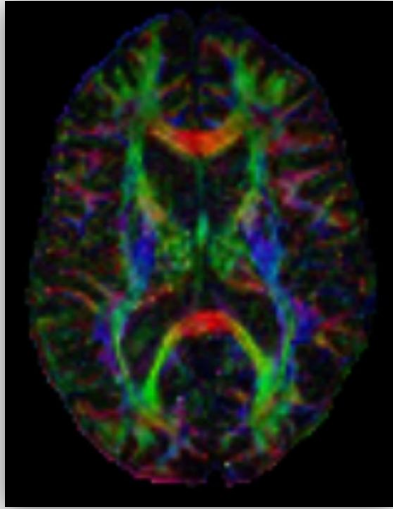


AFTER



Machine Learning
on fMRI data

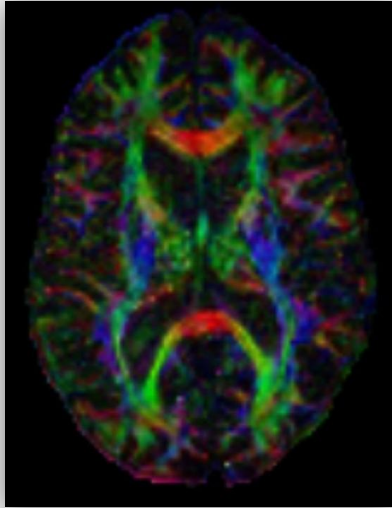
Structural connectivity



Diffusion MRI

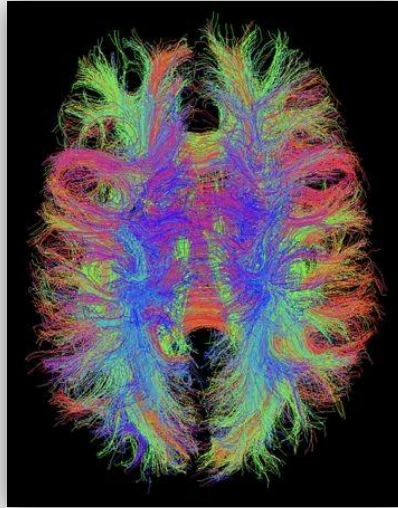
image contrast is determined by
the random microscopic motion
of water protons

Structural connectivity



Diffusion MRI

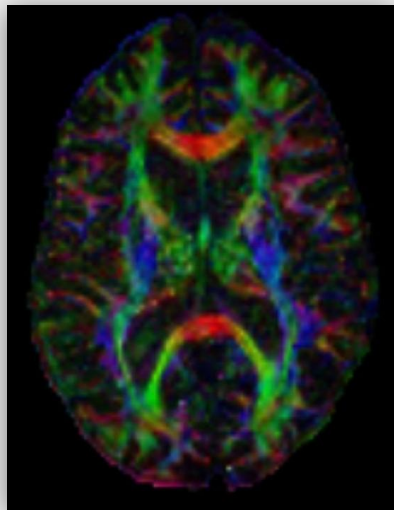
image contrast is determined by the random microscopic motion of water protons



Tractography

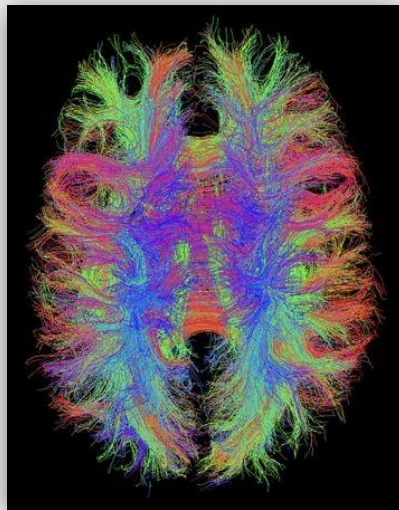
is a modeling technique used to visually represent nerve tracts using data collected by diffusion MRI.

Structural connectivity



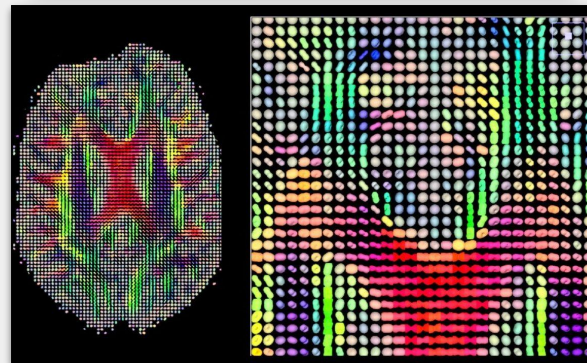
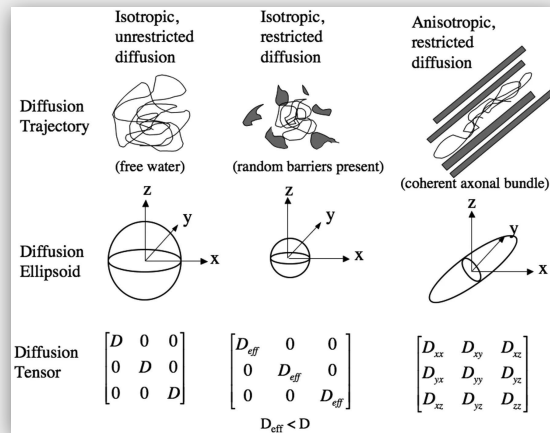
Diffusion MRI

image contrast is determined by the random microscopic motion of water protons



Tractography

is a modeling technique used to visually represent nerve tracts using data collected by diffusion MRI.

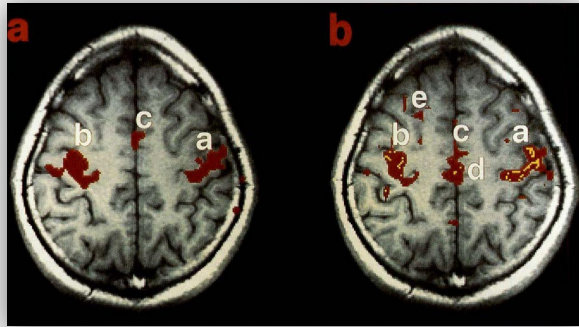


[Explore DTI animations](#)

Functional connectivity

Motor task

Resting state

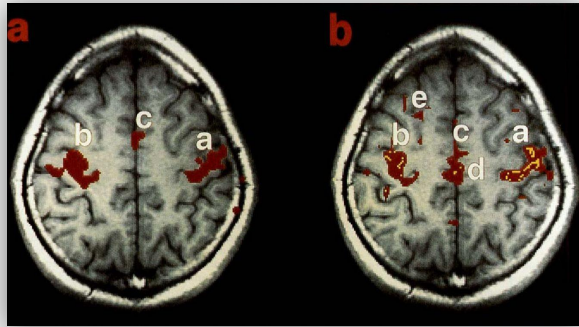


Biswal et al. (1995)

Functional connectivity

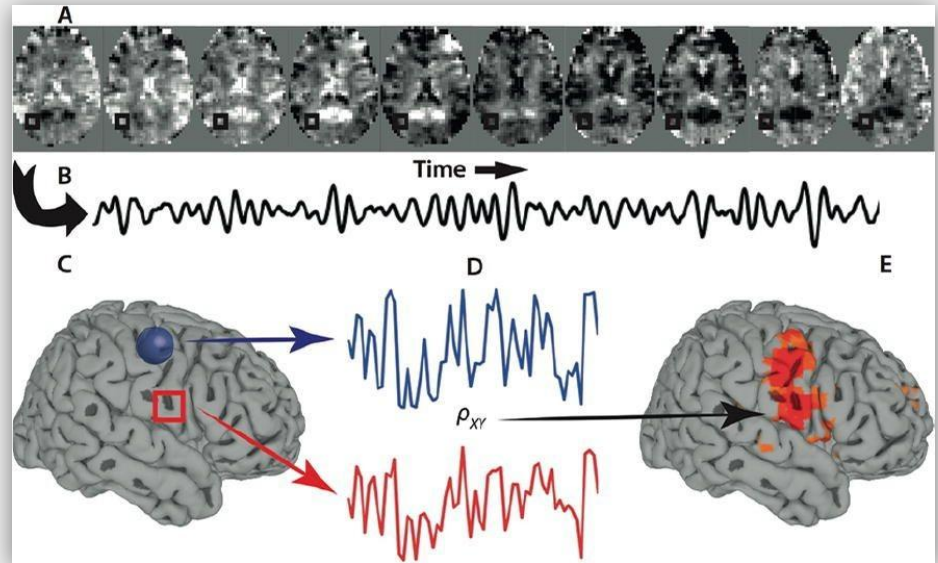
Motor task

Resting state



Biswal et al. (1995)

Seed-based approach

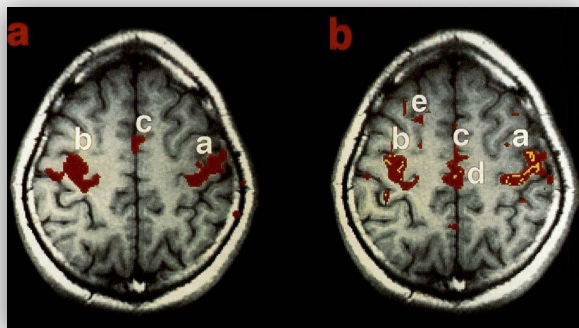


Hart et al. (2016)

Functional connectivity

Motor task

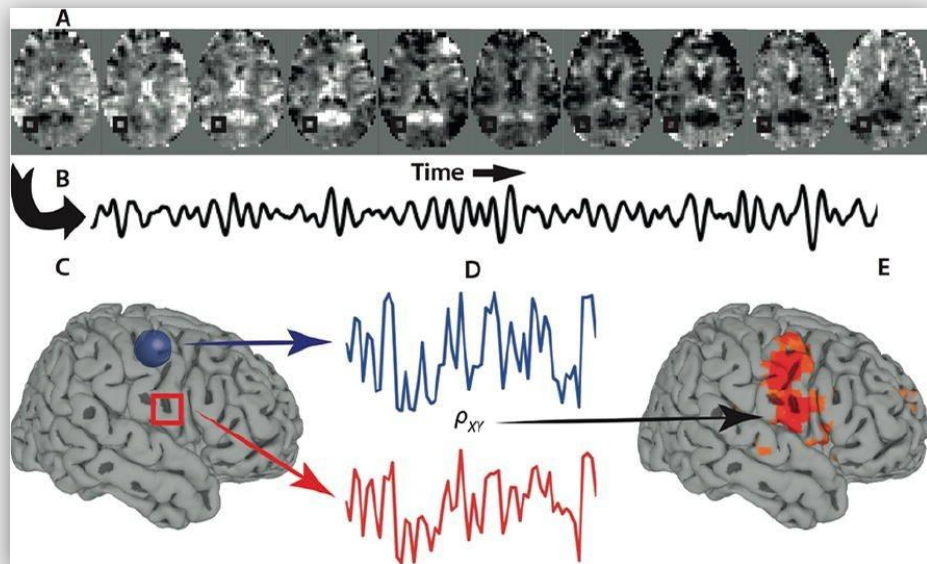
Resting state



Biswal et al. (1995)

Resting-state functional connectivity measures temporal correlation of spontaneous BOLD signal among spatially distributed brain regions, with the assumption that regions with correlated activity form functional networks

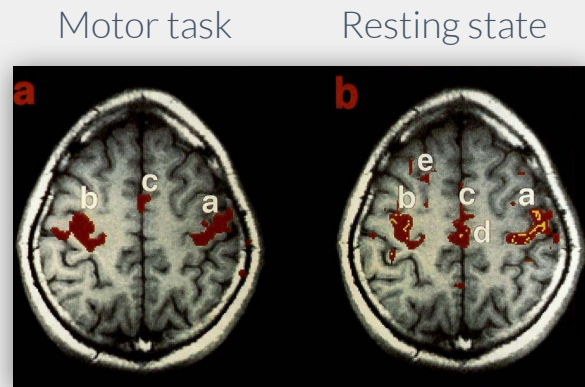
Seed-based approach



Hart et al. (2016)

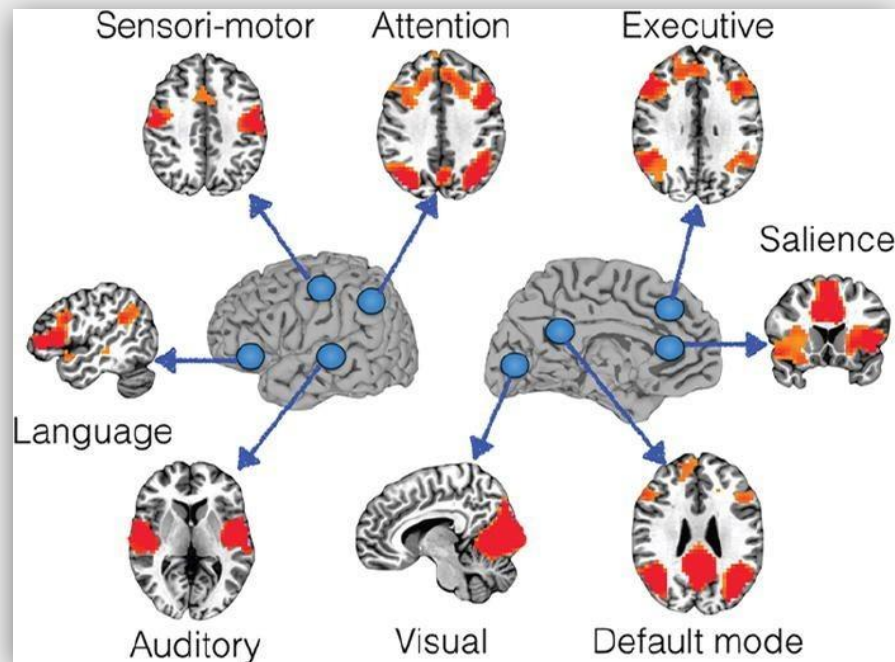
Functional connectivity

Resting-state networks



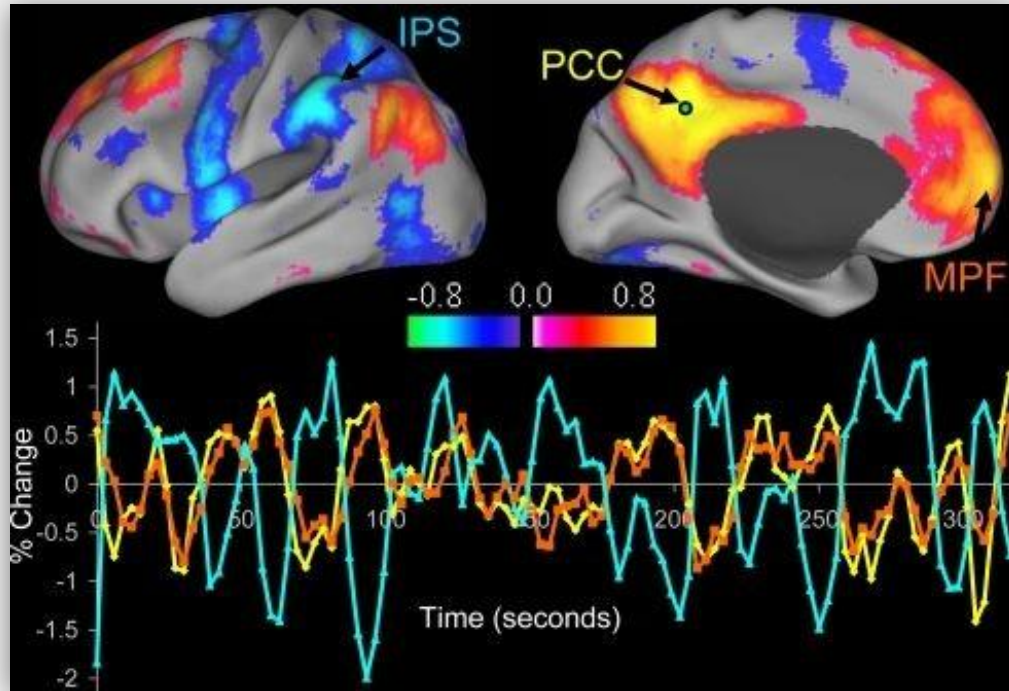
Biswal et al. (1995)

Resting-state functional connectivity measures temporal correlation of spontaneous BOLD signal among spatially distributed brain regions, with the assumption that regions with correlated activity form functional networks



Hart et al. (2016)

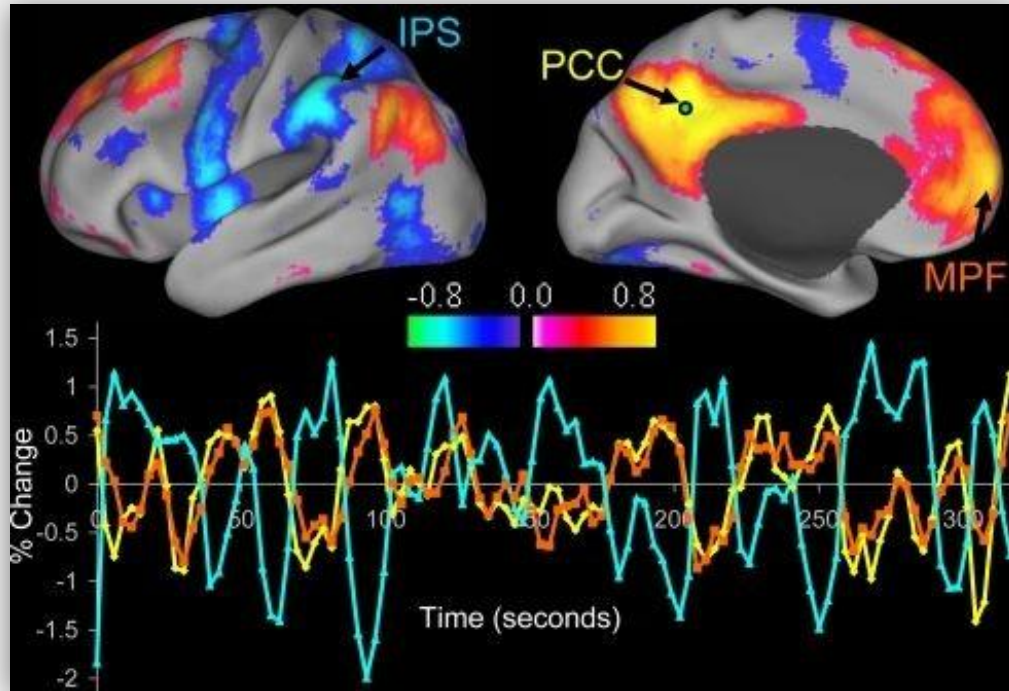
Anticorrelated networks



Fox et al. (2005)

Task-positive networks - networks that are active during cognitively demanding tasks (e.g. frontoparietal network, dorsal attention network).

Anticorrelated networks

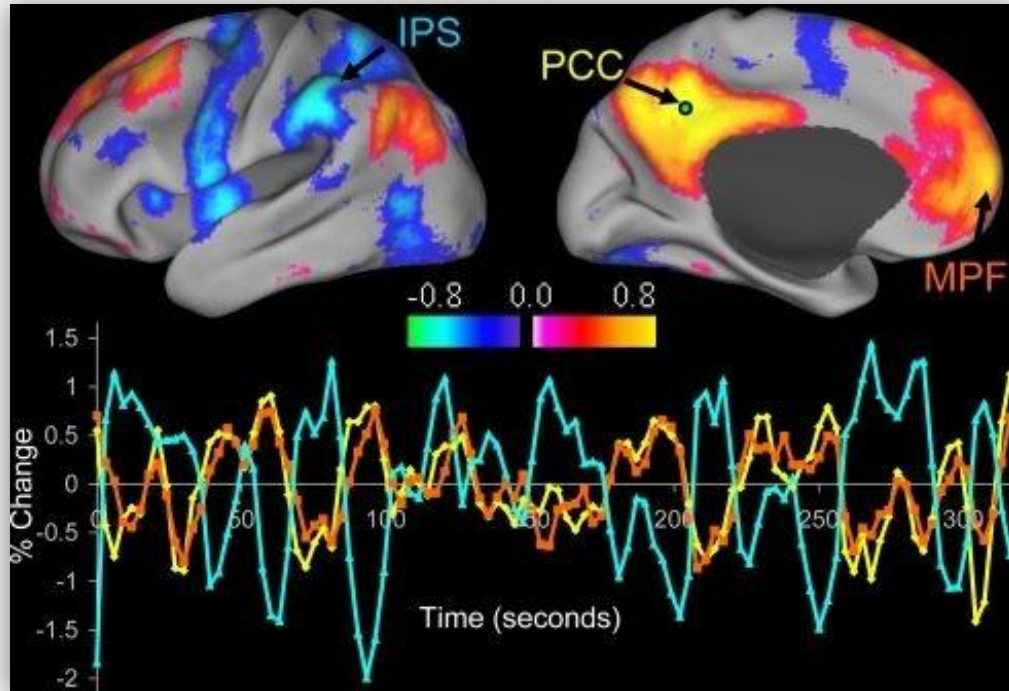


Fox et al. (2005)

Task-positive networks - networks that are active during cognitively demanding tasks (e.g. frontoparietal network, dorsal attention network).

Task-negative networks that are inactive during cognitively demanding tasks (e.g. default mode network).

Anticorrelated networks



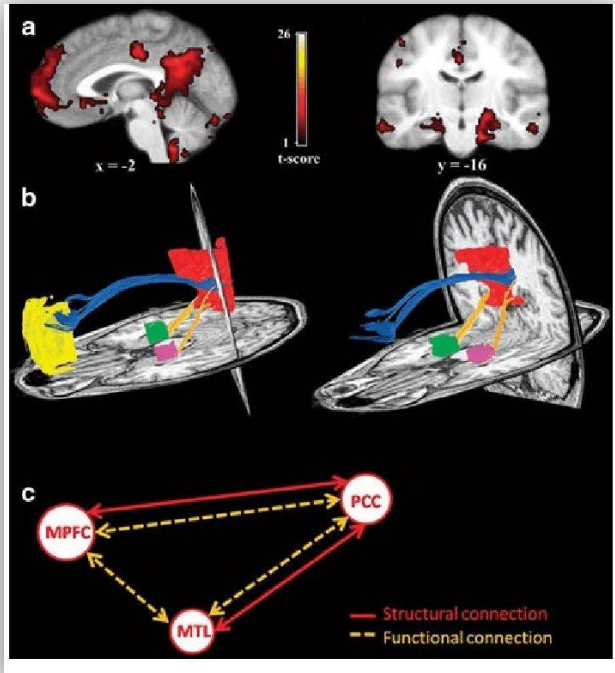
Fox et al. (2005)

Task-positive networks - networks that are active during cognitively demanding tasks (e.g. frontoparietal network, dorsal attention network).

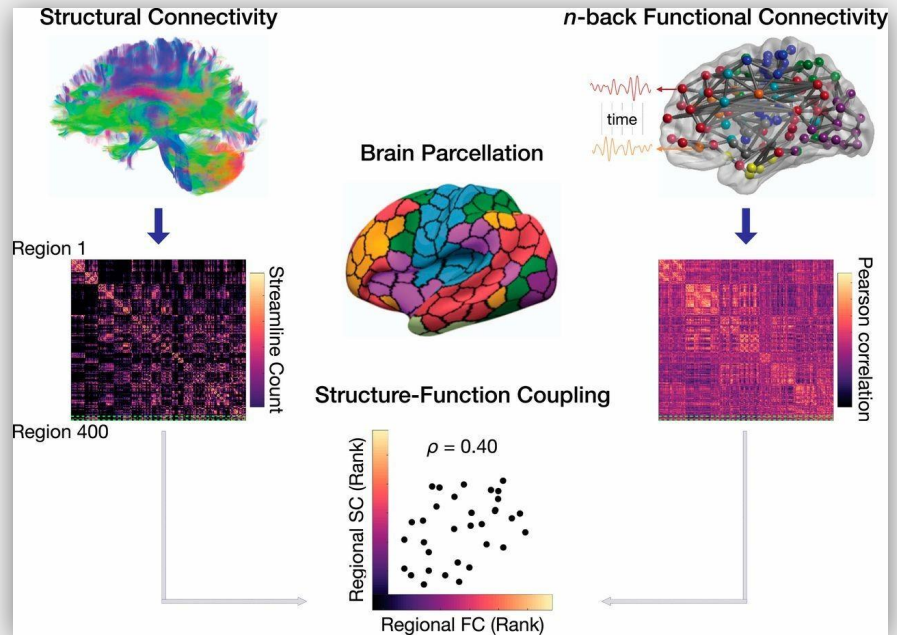
Task-negative networks that are inactive during cognitively demanding tasks (e.g. default mode network).

Task-positive and **task-negative** networks are *often* **anticorrelated** during task and rest.

Functional connectivity vs structural connectivity

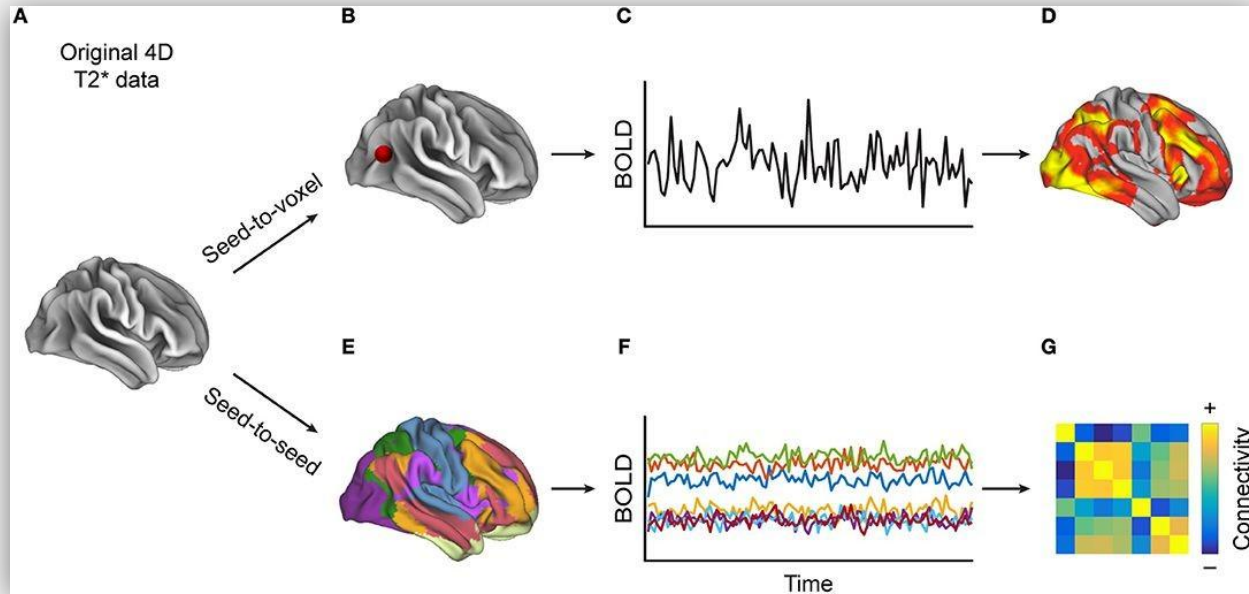


Greicius et al. (2009)



Baum et al. (2019)


Functional connectivity: methods



Seed - predefined region of the brain.

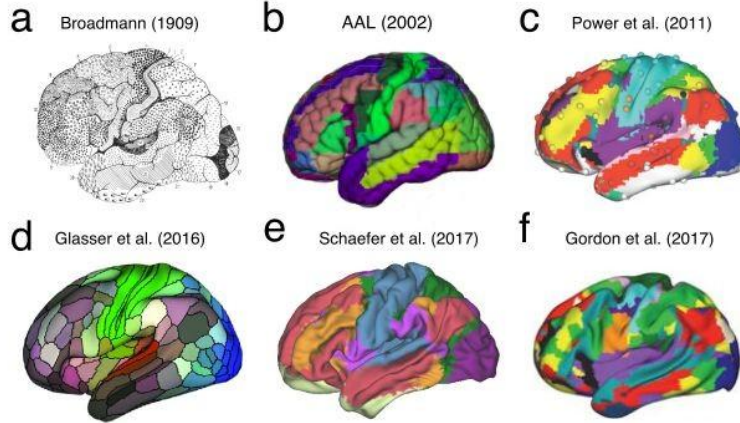
Seed-to-voxel - calculating correlations between seed and all voxels in the brain.

Seed-to-seed - calculating correlations between seed regions.

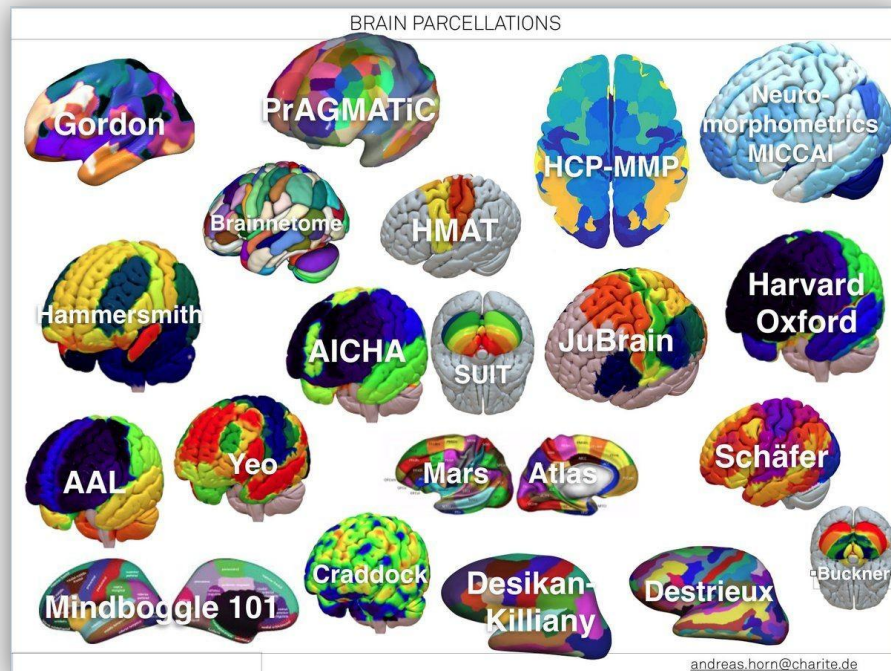
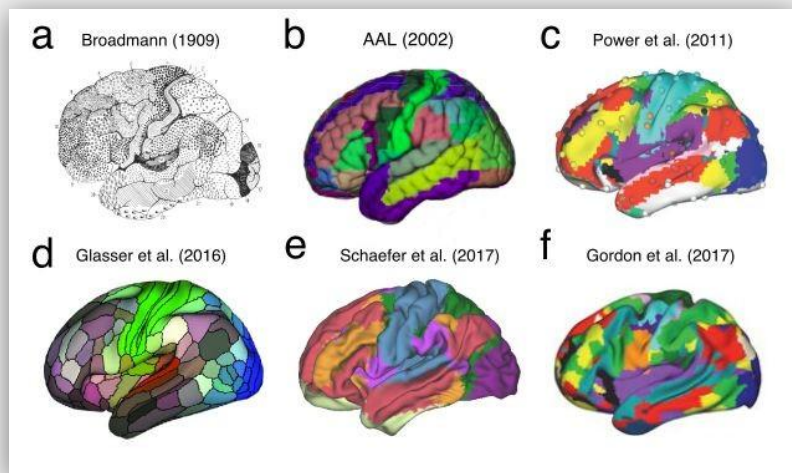
The background of the slide is a complex, overlapping grid of brain MRI scans. Each scan is accompanied by a block of technical data, including parameters like 'SP 1500.0', 'TR 90.0', 'TE 1.46', 'SL 5.0', 'FOV 173.250', 'SAG 41', 'W 12.50', 'C 503', 'M 33V', 'STUDY 1', '04-Feb-16', '09:54:47', '15-MAR-17/1'. The scans show various cross-sections of the brain, with some areas highlighted in red, possibly indicating lesions or areas of interest. The overall color scheme is a mix of teal, blue, and red, with white text for the technical data and the main title.

Where to get brain parcellation?

Brain parcellations



Brain parcellations



Correlation

Correlation is a statistic that measures the degree to which two variables are related to each other.

$$r = \frac{\sum (X - \bar{X})(Y - \bar{Y})}{\sqrt{\sum (X - \bar{X})^2} \sqrt{\sum (Y - \bar{Y})^2}}$$

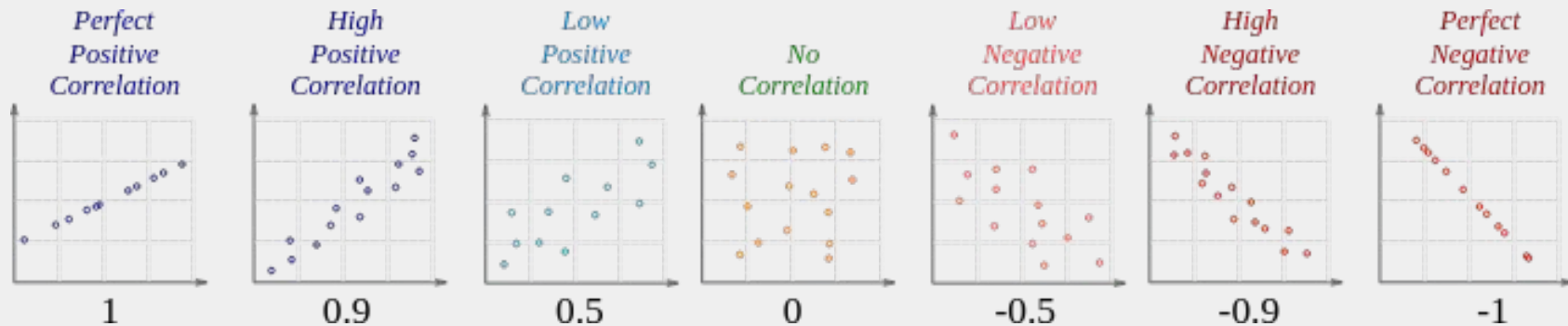
Where, \bar{X} = mean of X variable
 \bar{Y} = mean of Y variable



$$\text{Correlation} = \frac{\text{Cov}(x, y)}{\sigma_x * \sigma_y}$$

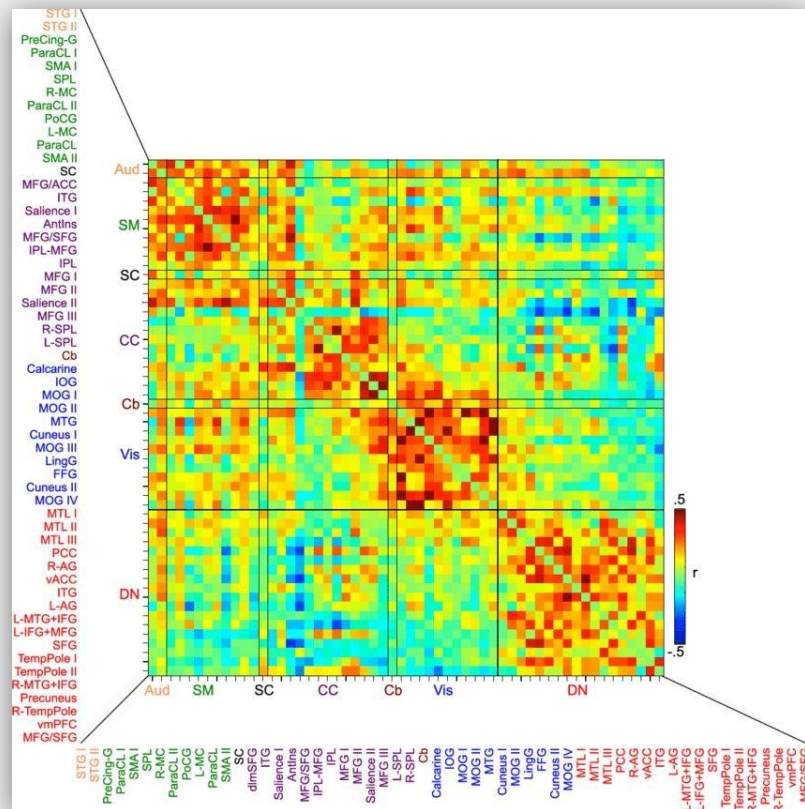
Covariance

Standard deviation



Correlation matrix

Each ij element of a matrix represent the **correlation coefficient** (functional connectivity strength) between two regions.

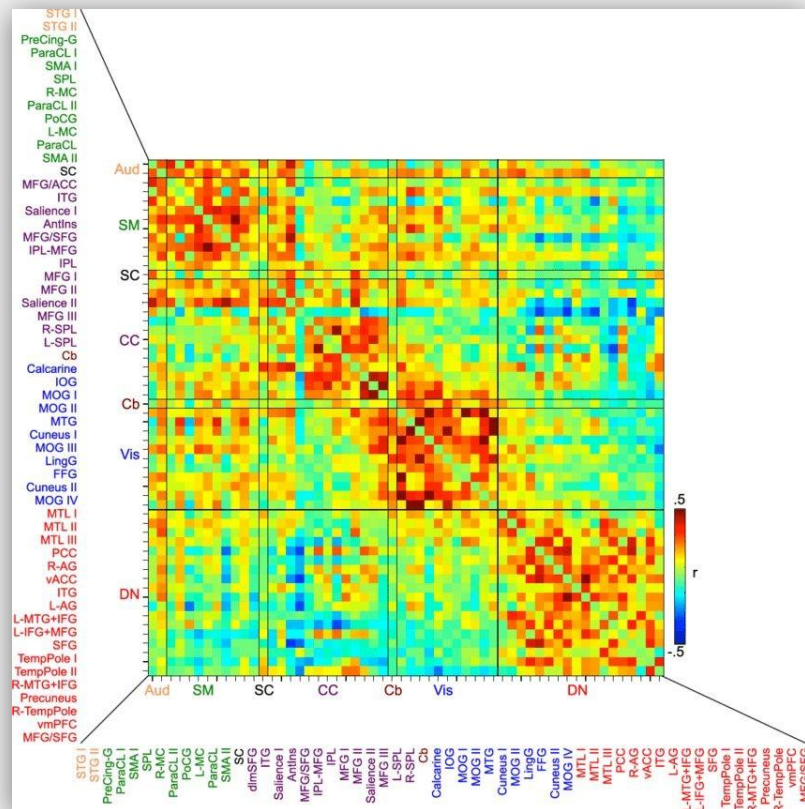


Hutchison & Morton, 2015

Correlation matrix

Each ij element of a matrix represent the **correlation coefficient** (functional connectivity strength) between two regions.

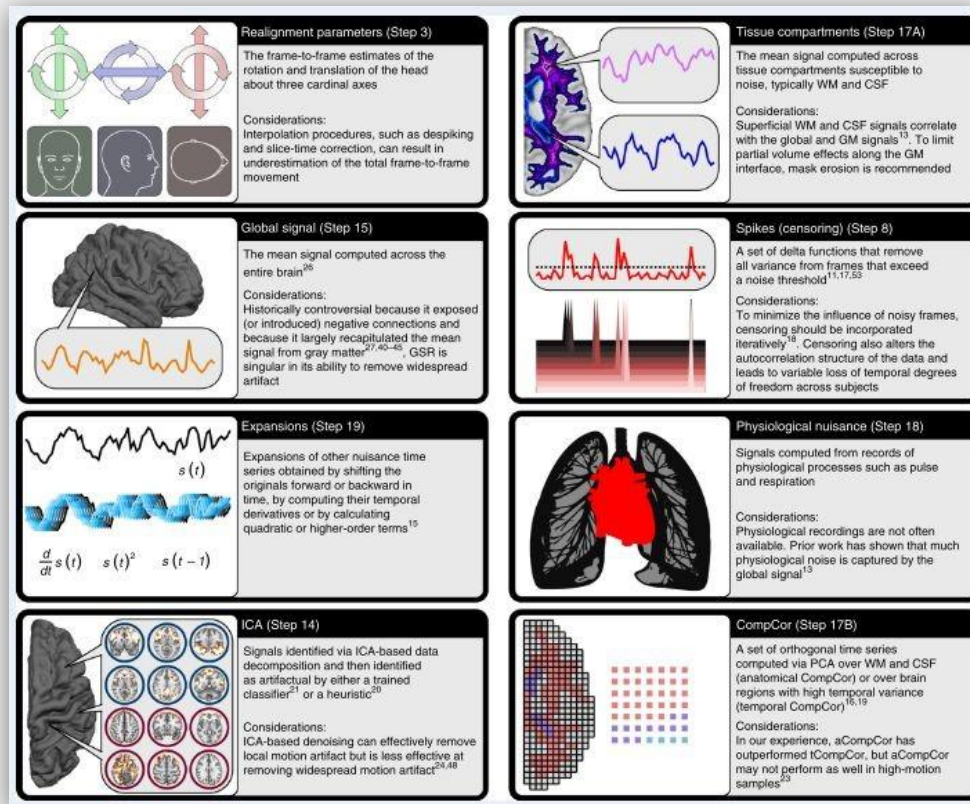
Clusters on a correlation matrix represents brain subnetworks (also known called **modules** or **large-scale systems**).



Hutchison & Morton, 2015

Spurious correlations

Signal of **non-neuronal origin**
(motion, physiological effects)
can pump the correlation values
between BOLD time-series.



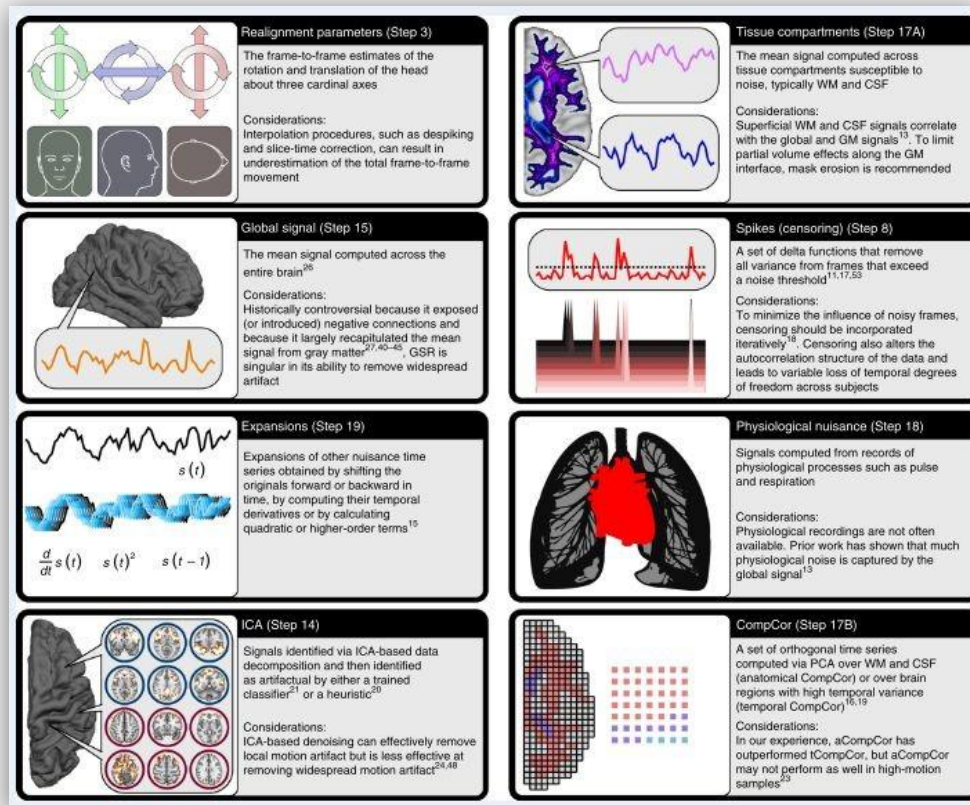
Ciric et al., 2018

Spurious correlations

Signal of **non-neuronal origin**
(motion, physiological effects)
can pump the correlation values
between BOLD time-series.

Denoising procedure -

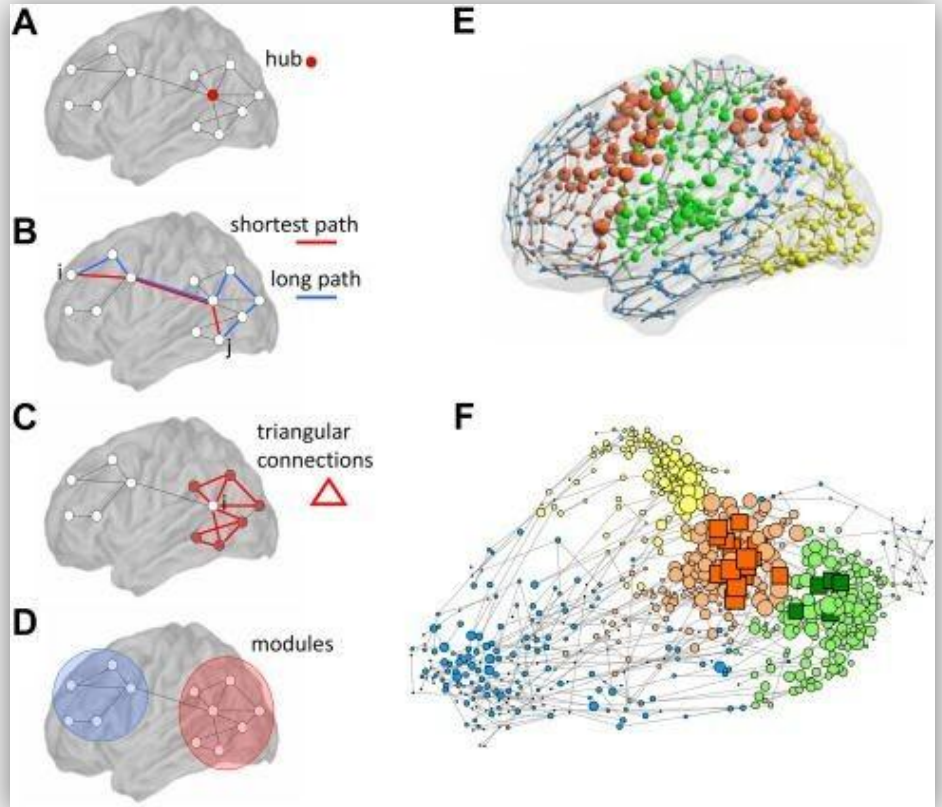
regressing out confounding
signals might minimise the level
of spurious correlations in
studies focused on functional
connectivity.



Ciric et al., 2018

Network neuroscience

The goal of the **network neuroscience** is to understand properties of brain network reorganization using **network science** tools.

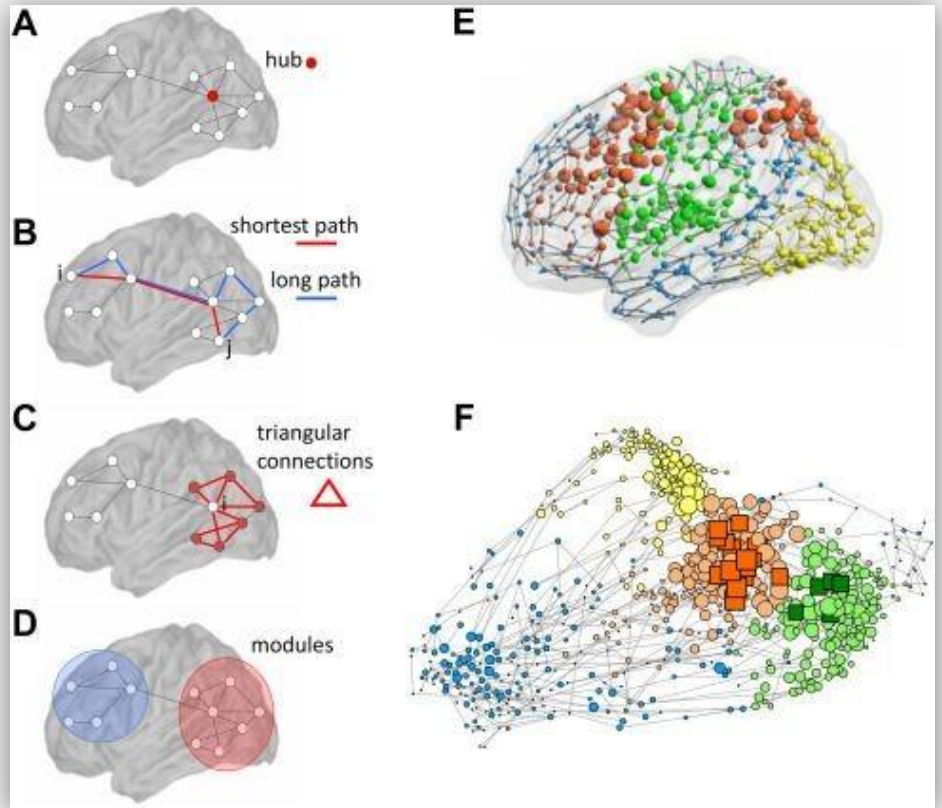


Morgan et al., 2018

Network neuroscience

The goal of the **network neuroscience** is to understand properties of brain network reorganization using **network science** tools.

Network science - field which studies complex networks, considering distinct elements represented by **nodes** (or vertices) and the **edges** (or connections) between them.

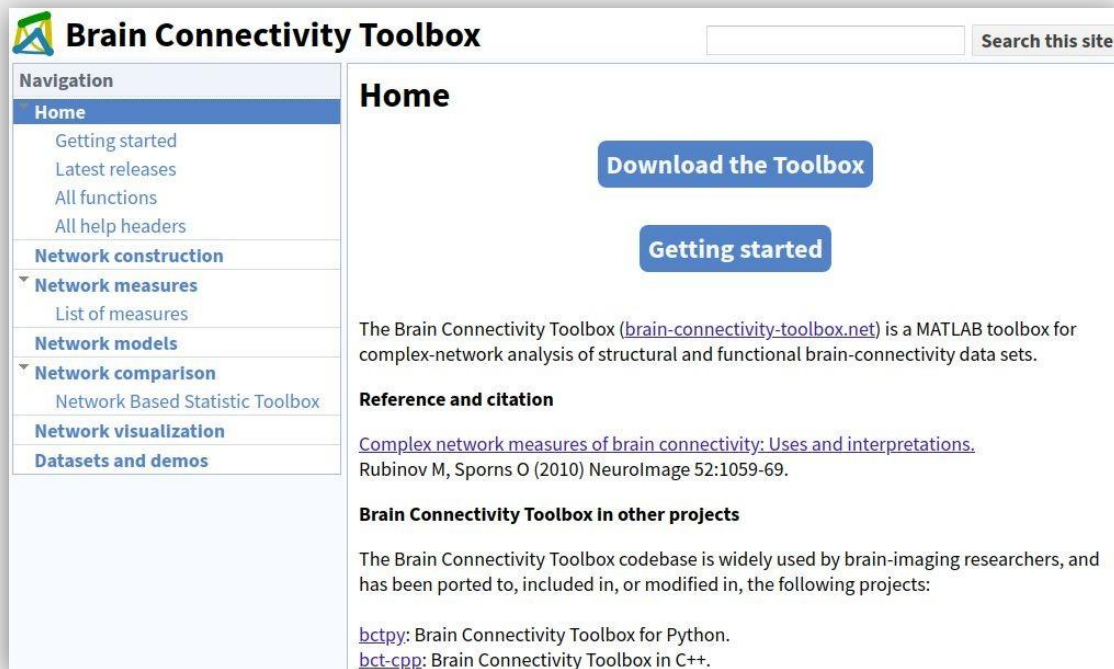


Morgan et al., 2018

Network neuroscience

The goal of the **network neuroscience** is to understand properties of brain network reorganization using **network science** tools.

Network science - field which studies complex networks, considering distinct elements represented by **nodes** (or vertices) and the **edges** (or connections) between them.



The screenshot shows the homepage of the Brain Connectivity Toolbox. It features a navigation menu on the left with links to Home, Getting started, Latest releases, All functions, All help headers, Network construction, Network measures, Network models, Network comparison, Network visualization, and Datasets and demos. The main content area includes a 'Home' heading, two prominent blue buttons for 'Download the Toolbox' and 'Getting started', and text describing the toolbox as a MATLAB tool for complex-network analysis. It also includes a 'Reference and citation' section with a link to a paper by Rubinov M and Sporns O (2010), and a 'Brain Connectivity Toolbox in other projects' section with links to Python and C++ versions.

Brain Connectivity Toolbox

Navigation

- Home
- Getting started
- Latest releases
- All functions
- All help headers
- Network construction
- Network measures
 - List of measures
- Network models
- Network comparison
 - Network Based Statistic Toolbox
- Network visualization
- Datasets and demos

Home

[Download the Toolbox](#)

[Getting started](#)

The Brain Connectivity Toolbox (brain-connectivity-toolbox.net) is a MATLAB toolbox for complex-network analysis of structural and functional brain-connectivity data sets.

Reference and citation

[Complex network measures of brain connectivity: Uses and interpretations.](#)
Rubinov M, Sporns O (2010) NeuroImage 52:1059-69.

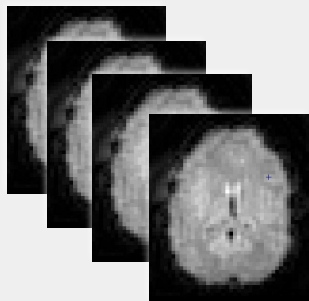
Brain Connectivity Toolbox in other projects

The Brain Connectivity Toolbox codebase is widely used by brain-imaging researchers, and has been ported to, included in, or modified in, the following projects:

[bctpy](#): Brain Connectivity Toolbox for Python.
[bct-cpp](#): Brain Connectivity Toolbox in C++.

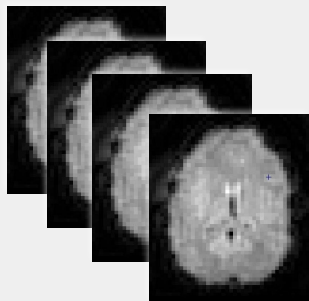
Workflow

fMRI data



Workflow

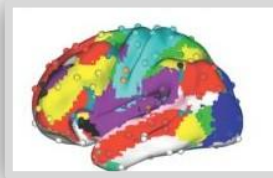
fMRI data



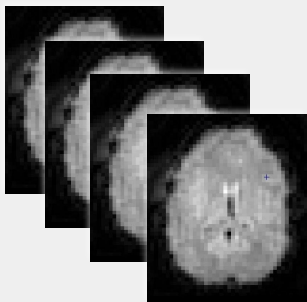
Denoising

Workflow

Definition of brain regions



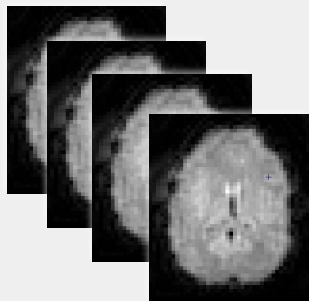
fMRI data



Denoising

Workflow

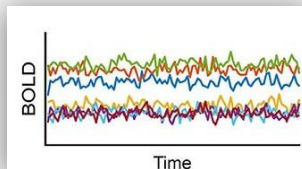
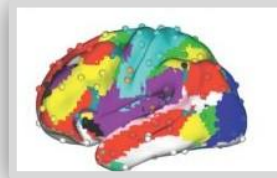
fMRI data



Denoising



Definition of brain regions

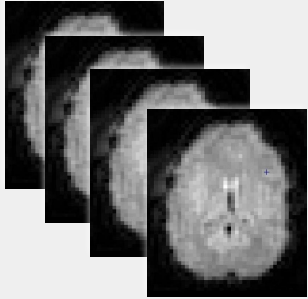


Time-series extraction

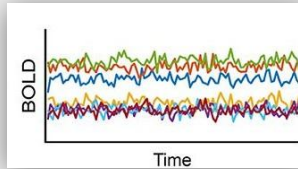
Workflow



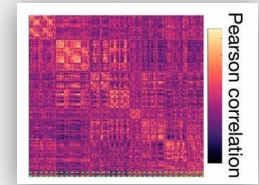
fMRI data



Denoising



Time-series extraction

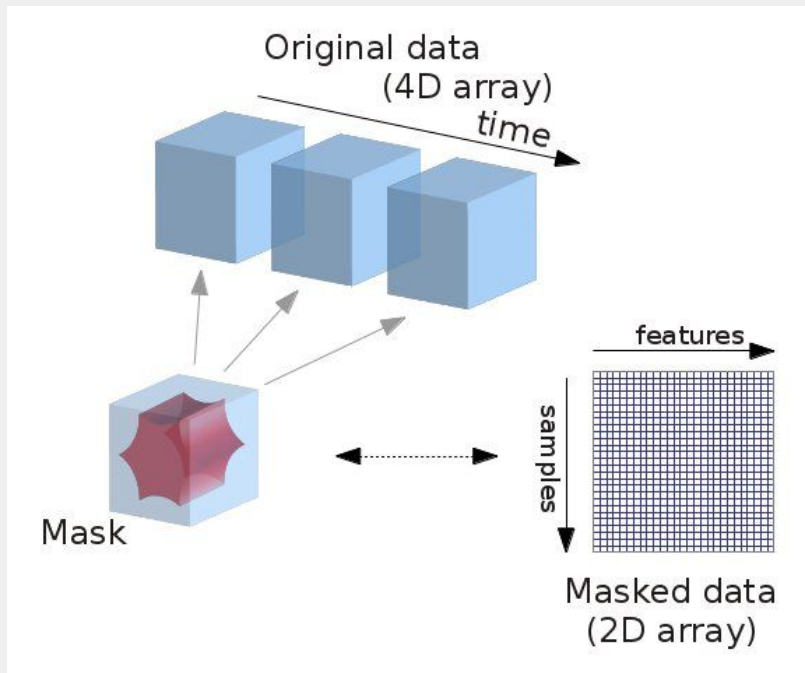


Connectivity estimation

Definition of brain regions



Masking data: from 4D to 2D



Homework

1. GitHub Classroom

Functional connectivity

Classroom for **GitHub**

Your course assignments on GitHub



Next



Machine learning