Big Data in Cognitive Neuroscience: Opportunities & Challenges

S. Bapi Raju

Cognitive Science Lab & IHub-Data, IIIT-H

Kamalaker Dadi

IHub-Data, IIIT-H

Neuroimaging Workshop: 10-Aug to 26-Oct-2024

A Peak into the ticking Brain

Functional Magnetic Resonance Imaging (fMRI) is a powerful imaging technique, which can be used to visualize both the Structure and Brain Function *in vivo*, when subjects perform specific task or are exposed to specific stimuli.

Neuroimaging

- Non-invasive or minimally invasive techniques that directly or indirectly image the structure or function of the brain in-vivo *e.g., EEG,* MRI, fMRI, MEG, PET, etc.

- Thousands of publications every year using neuroimaging techniques

- Interdisciplinary science unraveling the brain function:
in collaboration with Neurologists, Neuroscience, Psychologists, Psychiatrists, Physicists, Cognitive scientists and others

Neuroimaging techniques

Spatiotemporal domain of neuroscience methods

Biafra Ahanonu, based on Sejnowski, 2014
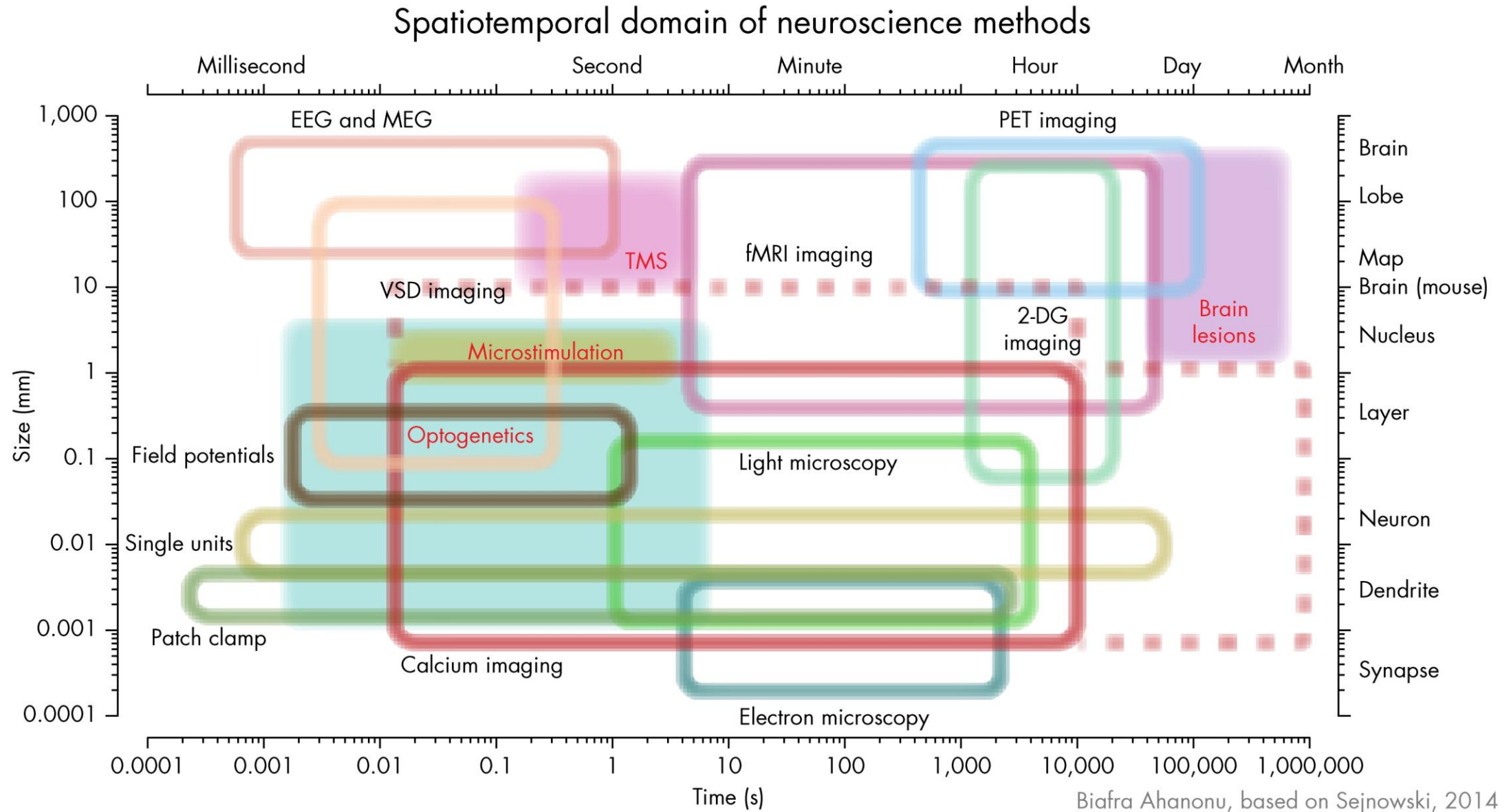
Sejnowski, T, Churchland, P & Movshon, J. Putting big data to good use in neuroscience. Nat. Neuroscience (2014).
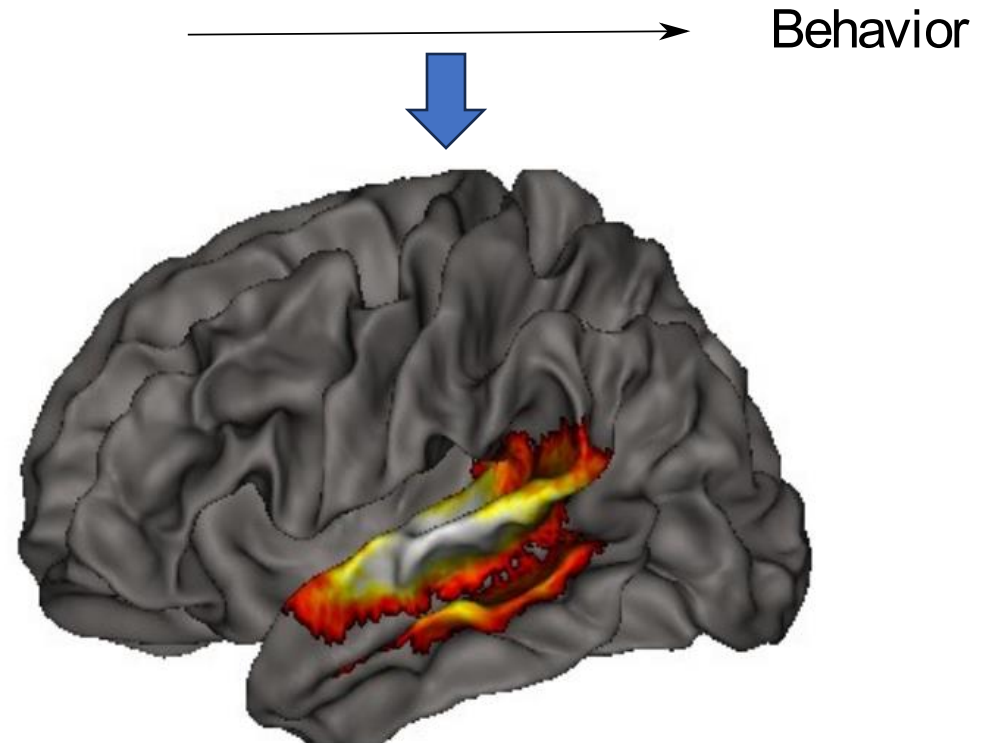
MRI and Cognitive Science

Cognitive Science: The study of mind and its relationships with the behavior
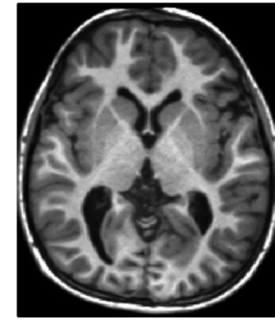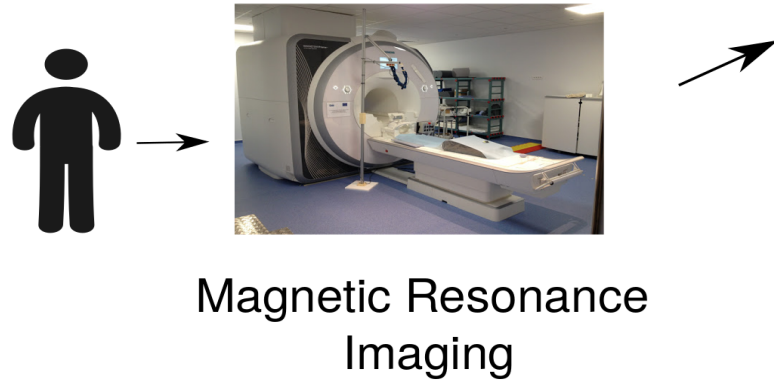
Mind

Sensation and Perception,

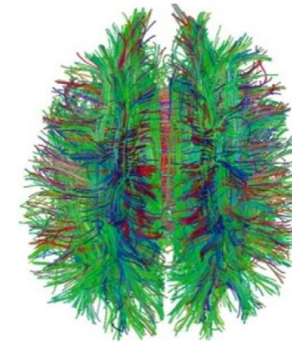Attention, Memory control,

Decision making

Behavior

Brain representations

MRI modalities

Magnetic Resonance
Imaging

Brain structures

Structural
Connectivity

MRI measures

Structural
Connectivity

Brain structures

Magnetic Resonance
Imaging

Motor

Parietal

Pre-frontal

Visual

Frontal

Temporal

Node ordering

Brain function
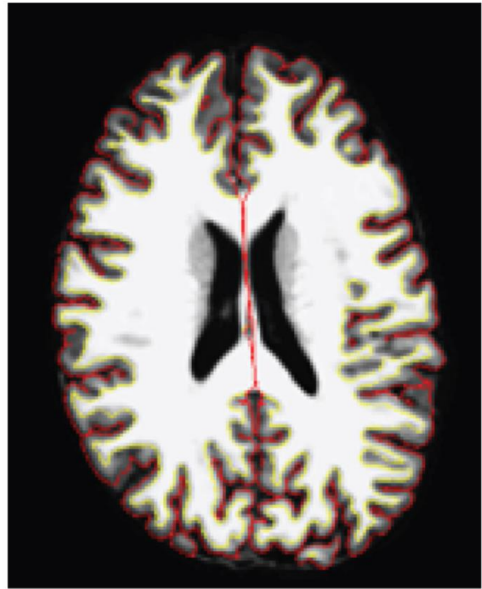
Cerebellum
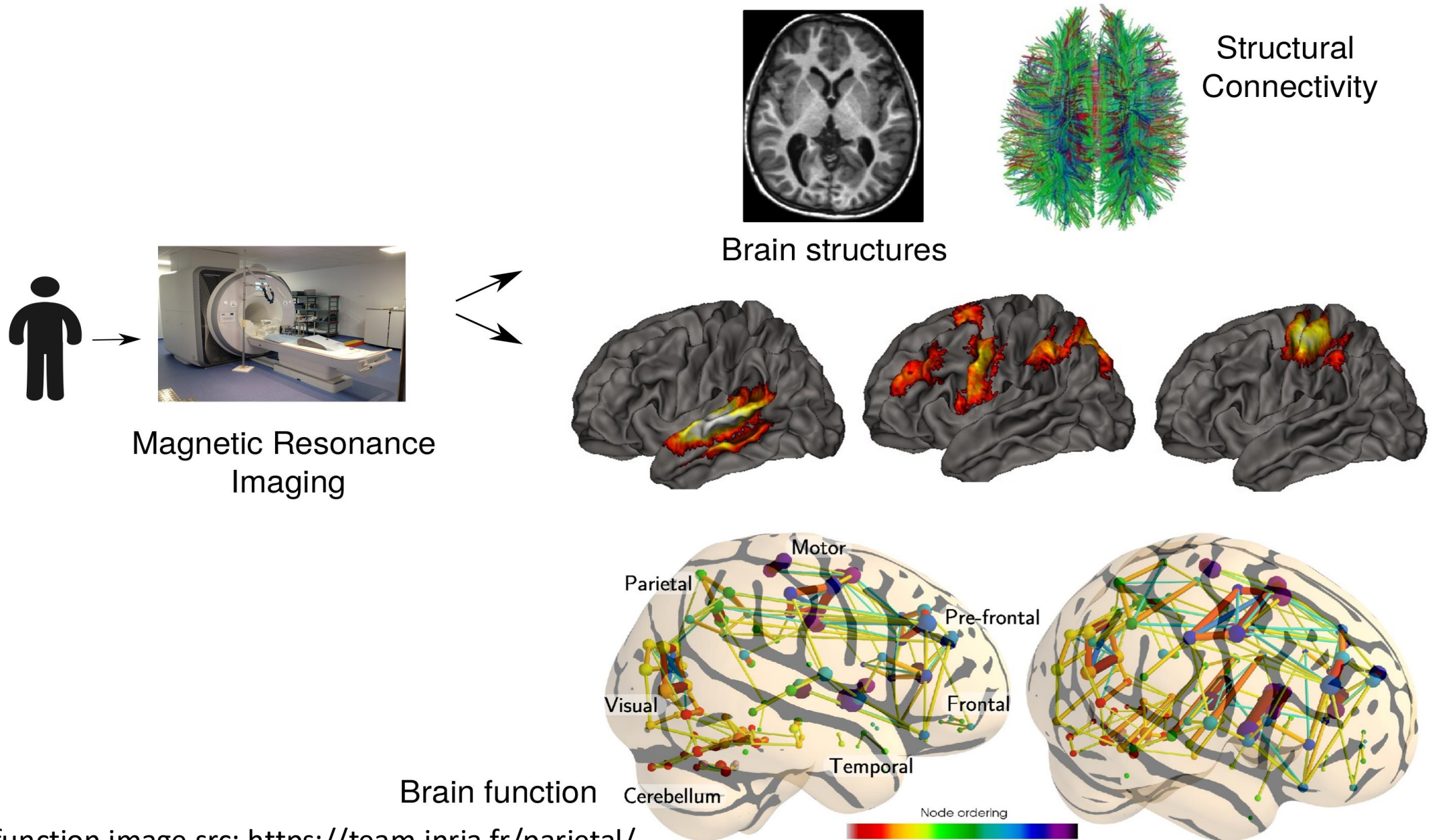
Brain function image src: https://team.inria.fr/parietal/
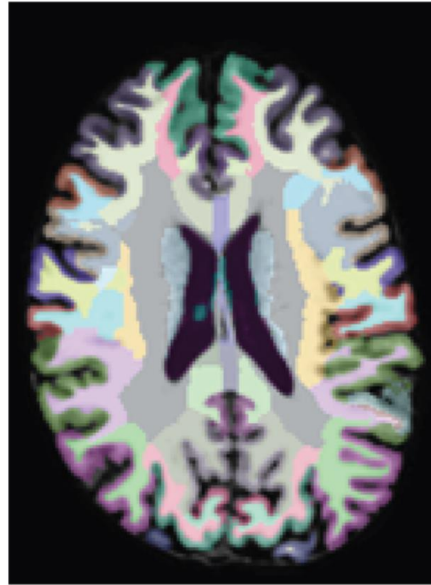
EEG
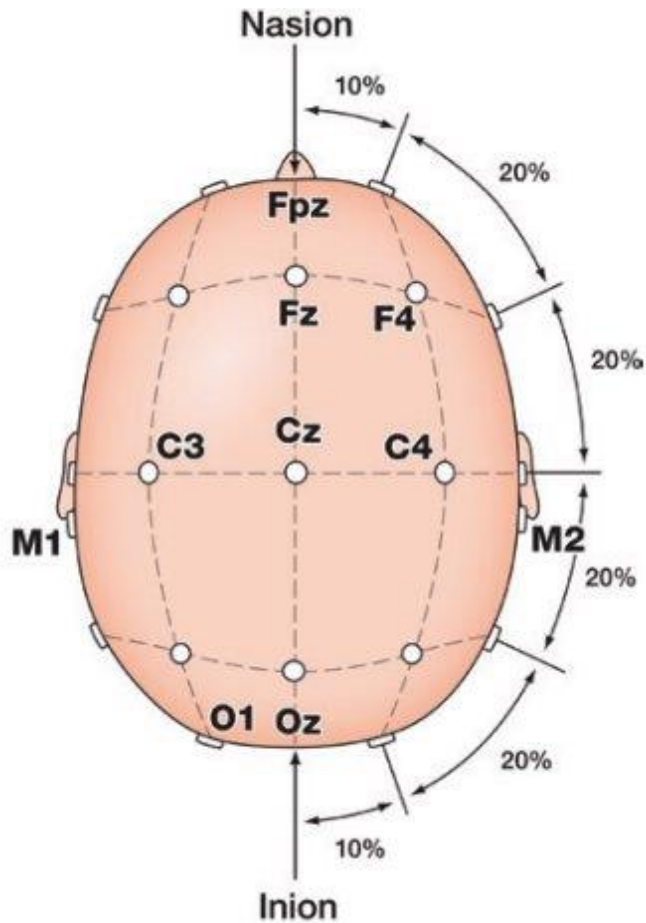
Placement of electrodes for electroencephalography (EEG) following the International 10-20 System.
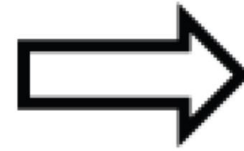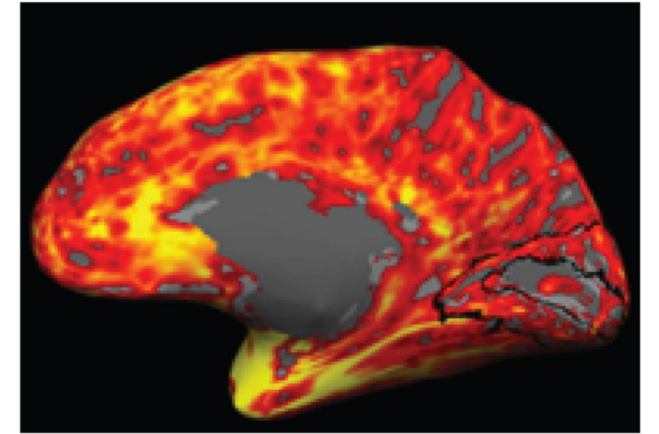
Outline of the workshop – T1-weighted

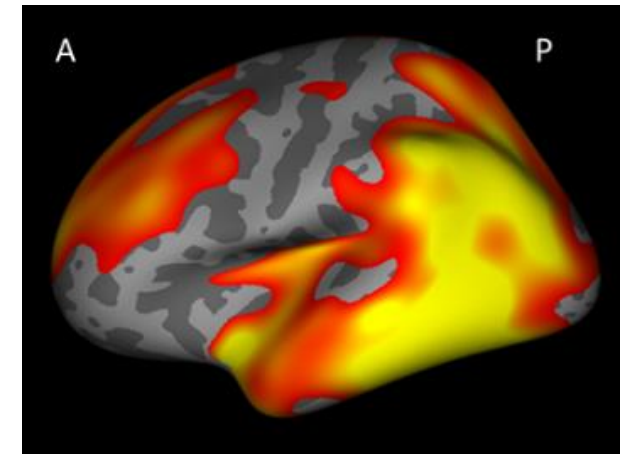skull stripping, intensity normalization, gray/white/CSF boundaries

Gray and white matter parcellation (Desikan Atlas)
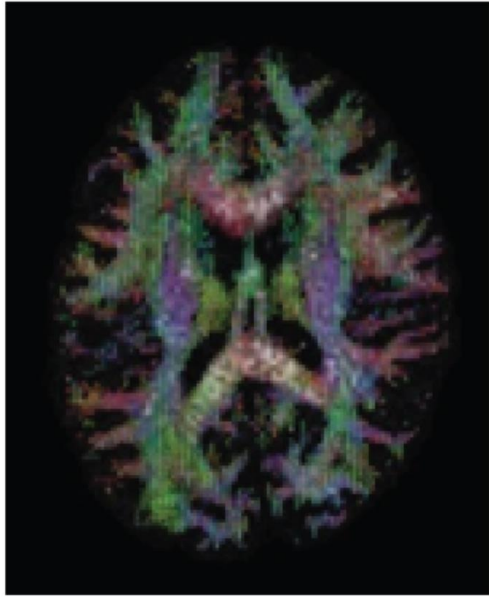
Surface-based Morphometry

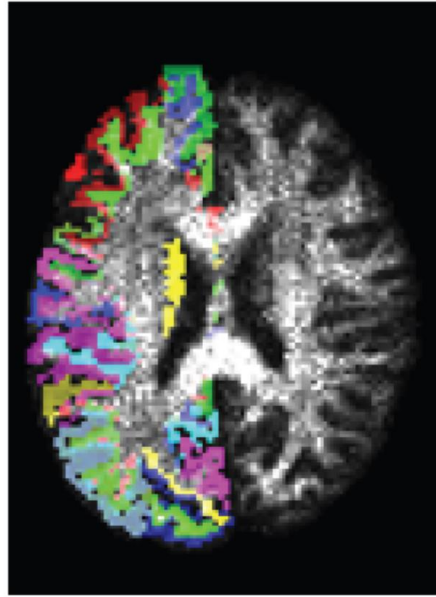Cortical thickness, gray matter volume, white matter volume. T-tests at each vertex
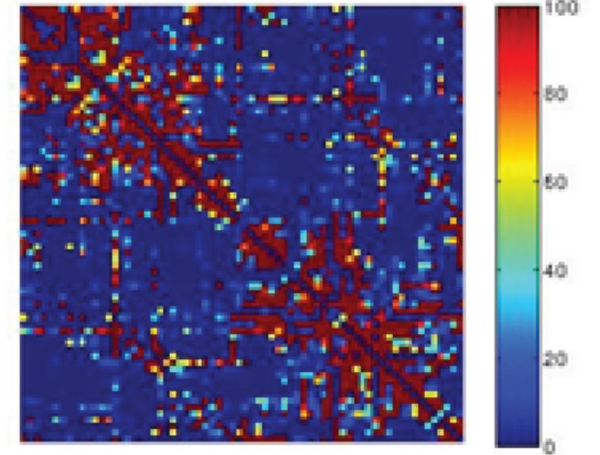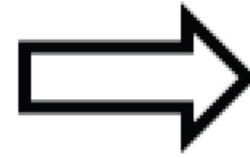
Disease vs Controls

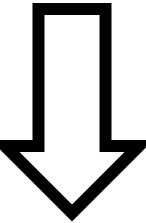# Outline of the workshop – Structural connectivity (DTI)

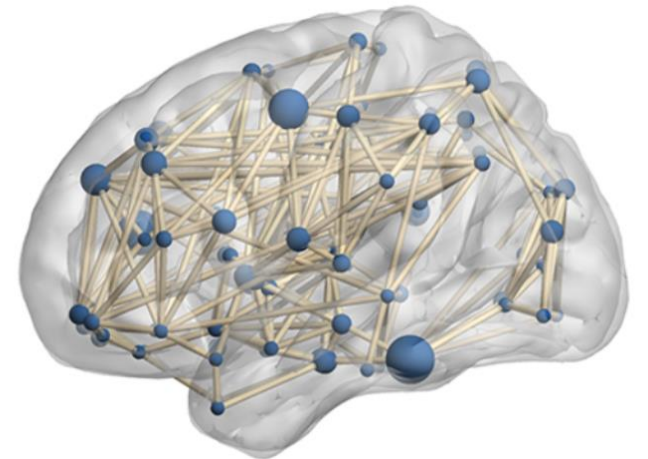eddy correction, BET, motion correction, ODF Reconstruction
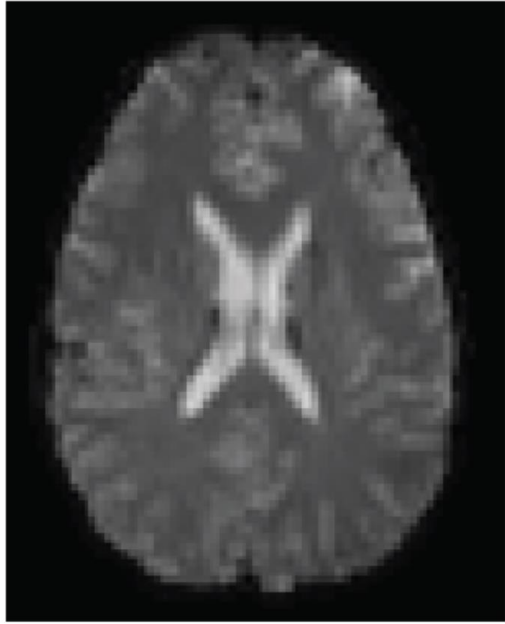
ROIs into subject specific space

ROI to ROI connectivity matrices of structural connectivity (fiber number and QA)
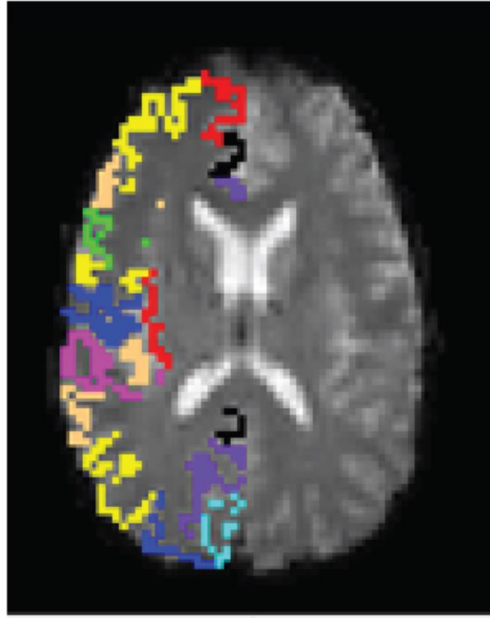
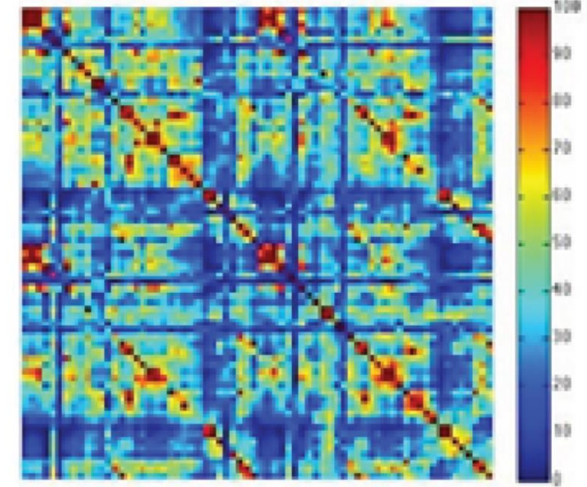Network based statistics

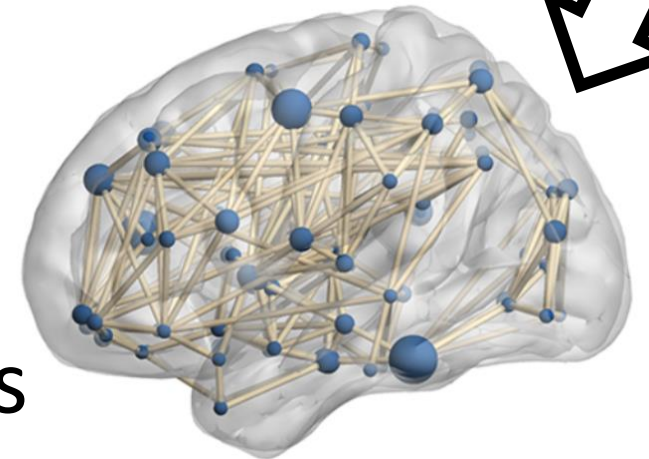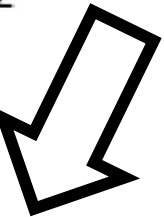# Outline of the workshop – Functional Connectivity

eddy correction, BET, motion correction, B0 field inhomogeneity correction

ROIs into subject-specific rsfMRI space

ROI to ROI connectivity matrices. Fischer's z-transformed partial correlations

Disease vs Controls

Outline of the workshop – EEG
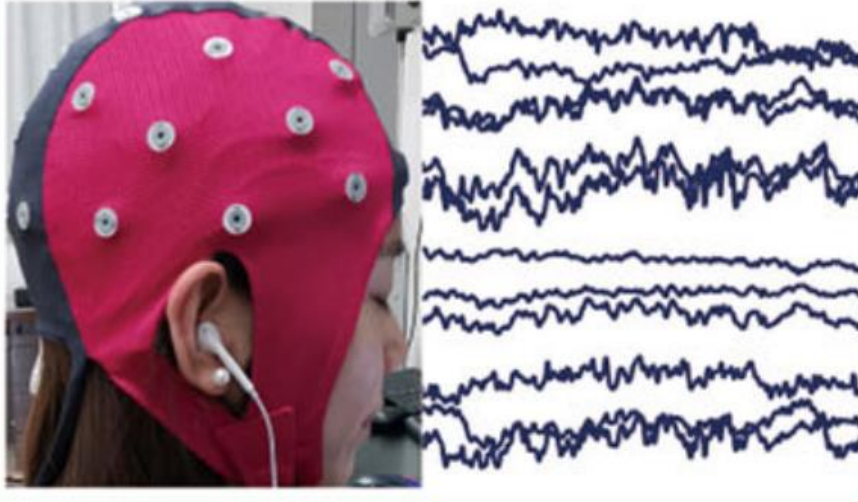
Raw EEG signals

Preprocessing & feature extraction
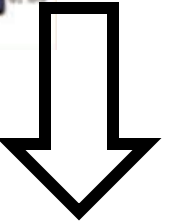
Sleep disorders

Cognitive brain imaging: fMRI for Cognitive Science

Cognitive theories

Sensory stimulus
Light, Sound, Smell, etc

Sensory receptors
Eyes, Ears, Nose, etc.

Perceptual /
Cognitive
processing

MR scanner

Task stimuli

Words

35-17

Brain response
to the
cognitive task
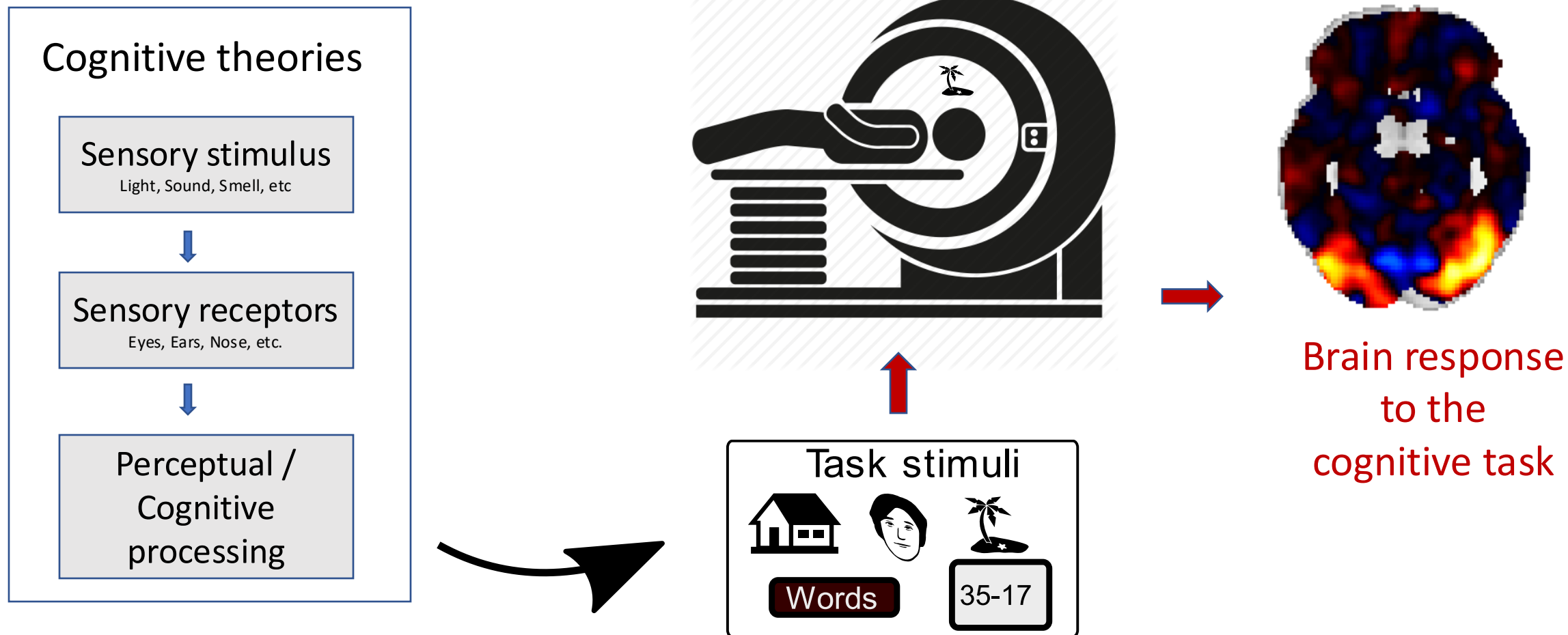
Cognitive Neuroscience is becoming data-intensive

- The Human Connectome Project (adult, *N=1200*)

  - T1, DTI, resting-state fMRI, task-fMRI

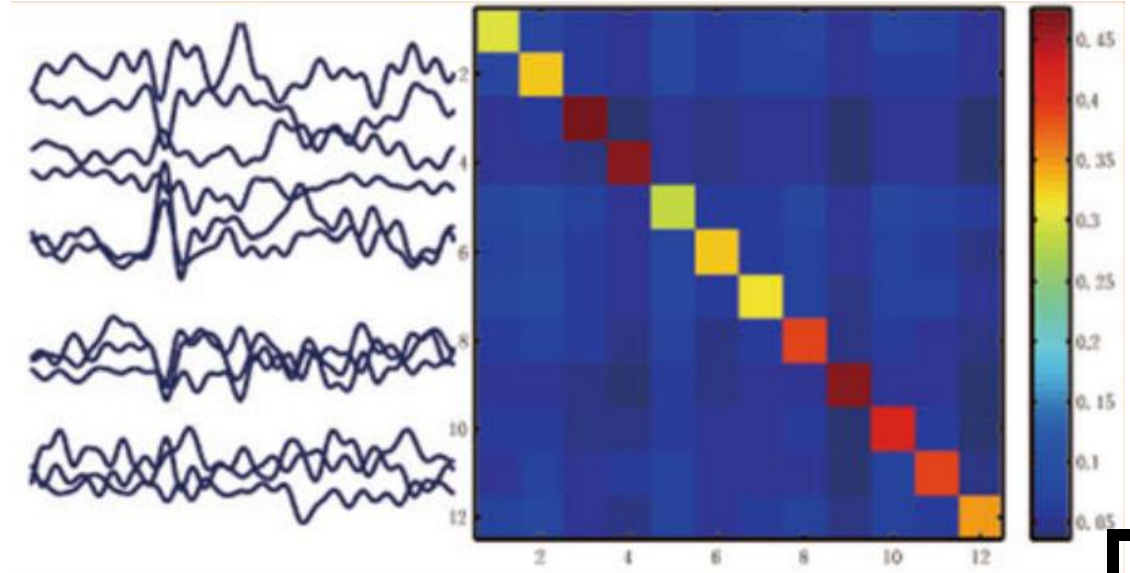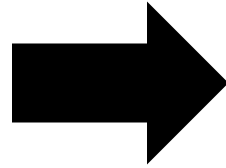- Cambridge Centre for Ageing Neuroscience (healthy aging, *N=700*)

  - T1, DTI, resting-state & task-fMRI and MEG

- Alzheimer's Disease Neuroimaging Initiative (aging, *N=1600*)

  - T1, DTI, resting-state fMRI

- The UK Biobank (early aging, *N=100,000*)

  - T1, DTI, resting-state fMRI, task-fMRI
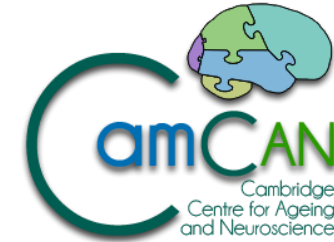
Cognitive Neuroscience is becoming data-intensive: Data consortium

ENIGMA is organized as a set of 50 WGs, studying 26 major brain diseases

- Disease working groups
- Genomics
- Healthy variation
- Methods & Development

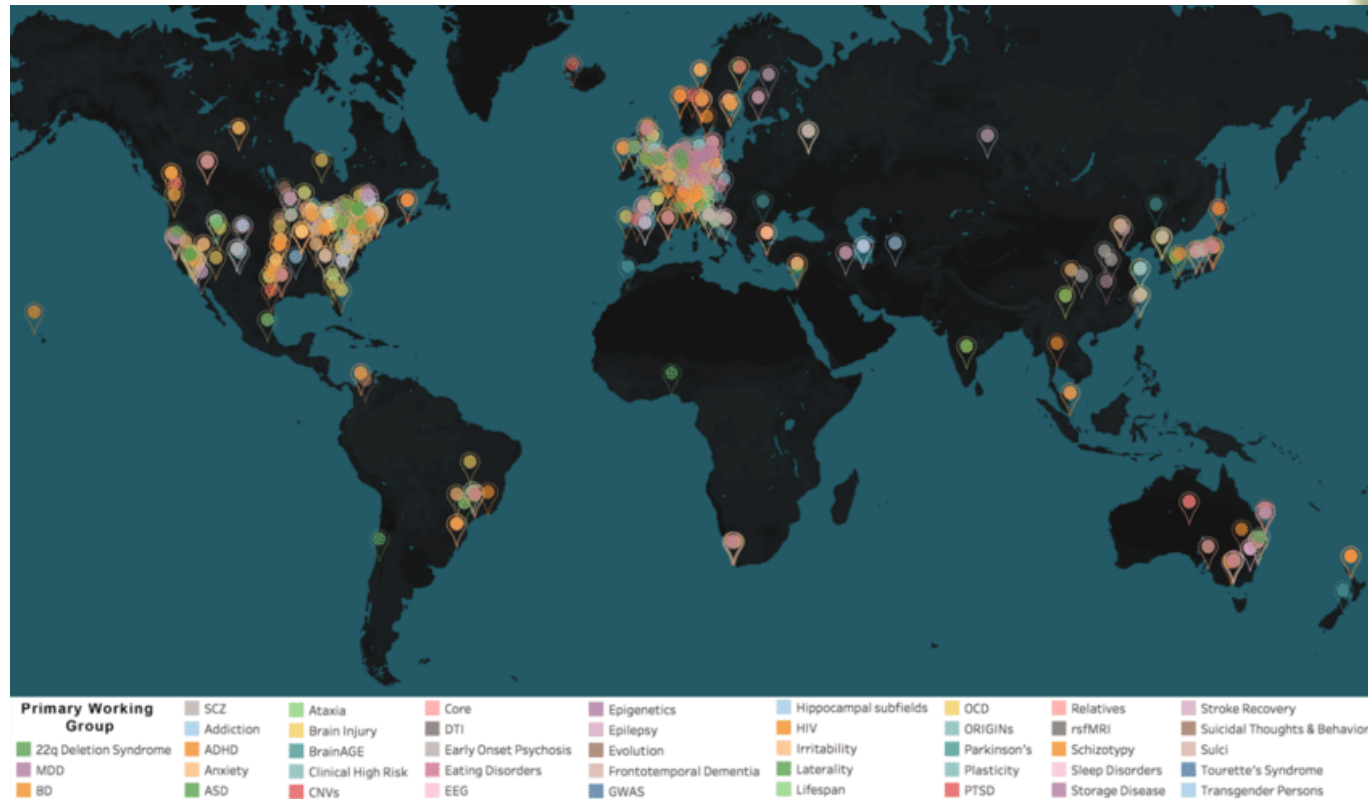Thompson, P.M., *et al.* ENIGMA and global neuroscience: A decade of large-scale studies of the brain in health and disease *across* more than 40 countries. *Transl Psychiatry* (2020)

Challenges

- Neuroimaging data is more complex, noisy as compared to classical datasets used by ML/DL researchers
  - Individual variability is the norm in neuroimaging data!
  - Confounding factor: spurious associations
- Ethical, computational and privacy law issues with regard to data sharing
- No harmonization in neuroimaging and clinical data collection, site-effects
- Unavailability of deeply characterized phenotypes and longitudinal data
- Big data demands new methods that are scalable

Opportunities

- Exciting times: publicly accessible neuroimaging data of various tasks starting to be available now!

- Data ahead of theory, so it's an open field for theoretical and methodological innovation!

- ML/DL are helpful in uncovering patterns in brain responses and may lead to theories of information organization in the brain.

Summary

- Glimpse of Cognitive Neuroscience Datasets

- Tools for meta-analysis (NeuroQuery)

- Three Case Studies:
  - Population imaging study (UK Biobank)
  - Brain Encoding (Listening and Reading datasets)
  - SC-FC Mapping (HCP Dataset)

- Challenges and Opportunities