Analysis of Functional Magnetic Resonance Imaging (fMRI)

Course Overview

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Syllabus 1/2

Week	Topic
1 (2/19)	Course Introduction and Overview
2 (2/26)	Principles of BOLD fMRI
3 (3/5)	Experimental Design of BOLD fMRI
4 (3/12)	Neuroanatomy and Image Atlas
5 (3/19)	**17:00-18:00 Visit of YM 3T-MRI Facility - Data Acquisition**
6 (3/26)	Image Preprocessing of fMRI
7 (4/2)	Brain Activation - General Linear Model: Part I
8 (4/9)	Brain Activation - General Linear Model: Part II
9 (4/16)	Amplitude of Low-Frequency Fluctuation

Syllabus 2/2

Week	Topic
10 (4/23)	Brain Decoding - Multivariate Pattern Analysis: Part I
11 (4/30)	Brain Decoding - Multivariate Pattern Analysis: Part II
12 (5/7)	Brain Network - Independent Component Analysis
13 (5/14)	**No class during ISMRM annual meeting**
14 (5/21)	Brain Network - Functional Connectivity
15 (5/28)	Brain Network - Effective Connectivity
16 (6/4)	Brain Network - Dynamic Functional Connectivity
17 (6/11)	Brain Network - Graph Theory and Topological Properties
18 (6/18)	**Final Report**

Teaching Materials

http://www.ym.edu.tw/~cflu/CFLu_course_fMRIana.html

Evaluation

- **Attendance (10%)**
  - Attendance of at least one-third lectures is required.
- **Participation of hands-on practice and discussion (40%)**
- **Final reports (50%)**
  - Seminar of relevant fMRI literatures.

Answers to the Questions

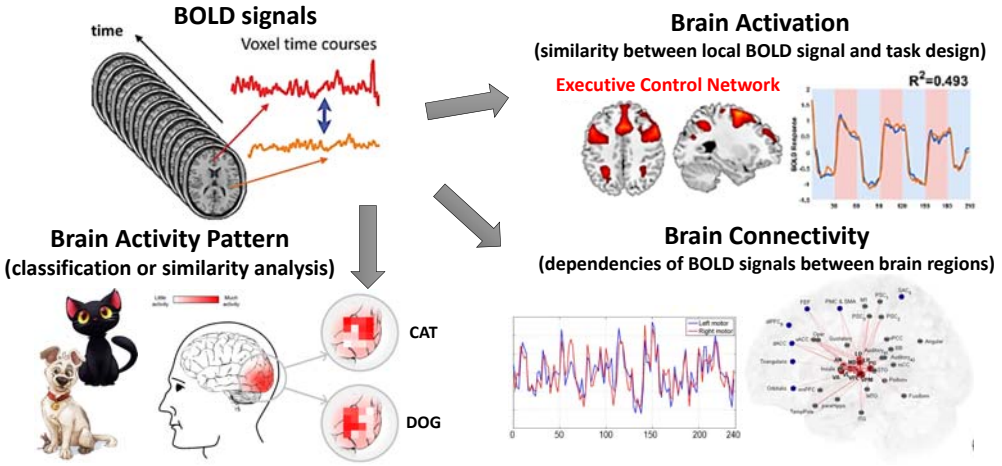
Specialization
Representation
Integration

Brain activation to the corresponding task.
- Where is the motion area?
- Where is the face recognition area?

Brain encoding to the representation of stimulus classes.
- What are the varying brain states in an area?
- How do brain cortices encode different types of information?

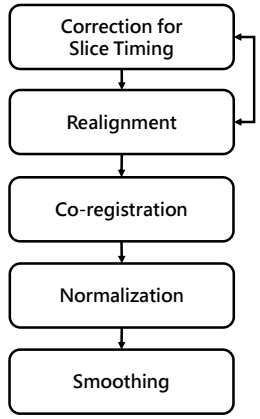
Brain connectivity to the integration of neural networks.
- How do neurons and neural networks process information?

fMRI Analysis



BOLD-fMRI Preprocessing

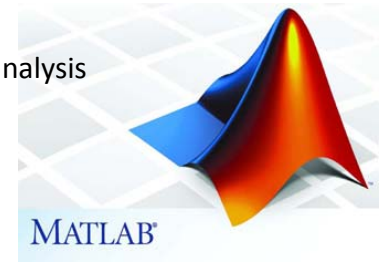
- Standard preprocessing steps for fMRI
  - Slice timing
  - Realignment
  - Co-registration (with anatomical images)
  - Normalization
  - Smoothing
  - Segment (tissue classification; optional)



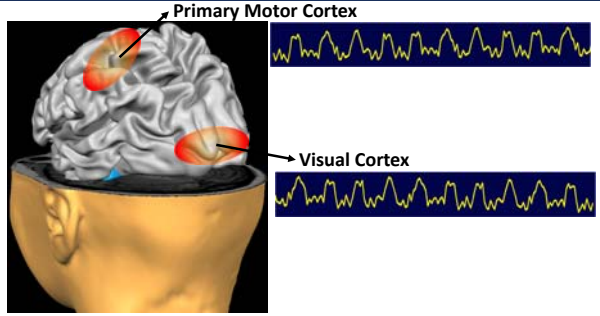
SPM
https://www.fil.ion.ucl.ac.uk/spm/

fMRI Analysis

- **Brain Activation Analysis**
  - General Linear Model (GLM)
- **Brain Decoding:**
  - Multivariate Pattern Analysis (MVPA)
  - Classifier-based MVPA, pattern similarity analysis
- **Brain Connectivity:**
  - Statistical dependency
  - Independent Component Analysis (ICA)
  - Network analysis



Data Acquisition



Block Design

10 tasking blocks (duration = 20s) with resting interval (20s)

MRI

- 3D MPRAGE (3D T1W)
- BOLD fMRI:
  10 blocks in one task run
  (visual stimuli)

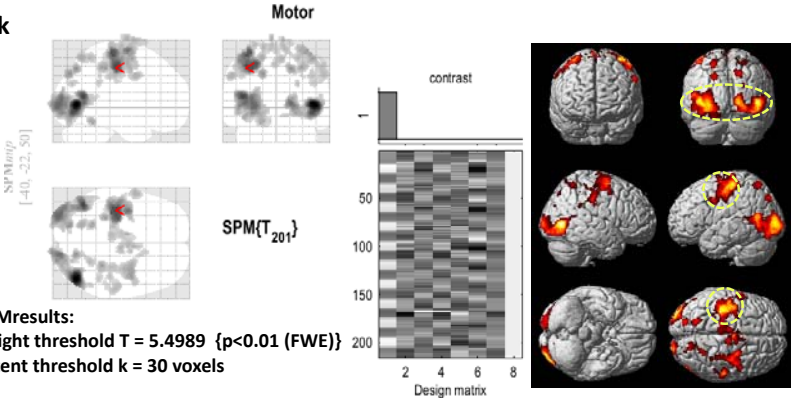
SPM T-test

Right hand grasping task

Q: activation during grasping?

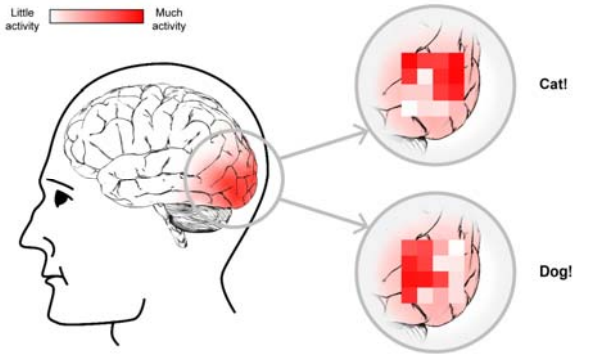
Null hypothesis: $\beta_1 = 0$

$$t = \frac{c^T \hat{\beta}}{Std(c^T \hat{\beta})}$$



SPMresults:
Height threshold T = 5.4989 {p<0.01 (FWE)}
Extent threshold k = 30 voxels

Decoding Activity Pattern of Brain



Looking at the pattern of activation within a brain area allows us to answer what the person is seeing.

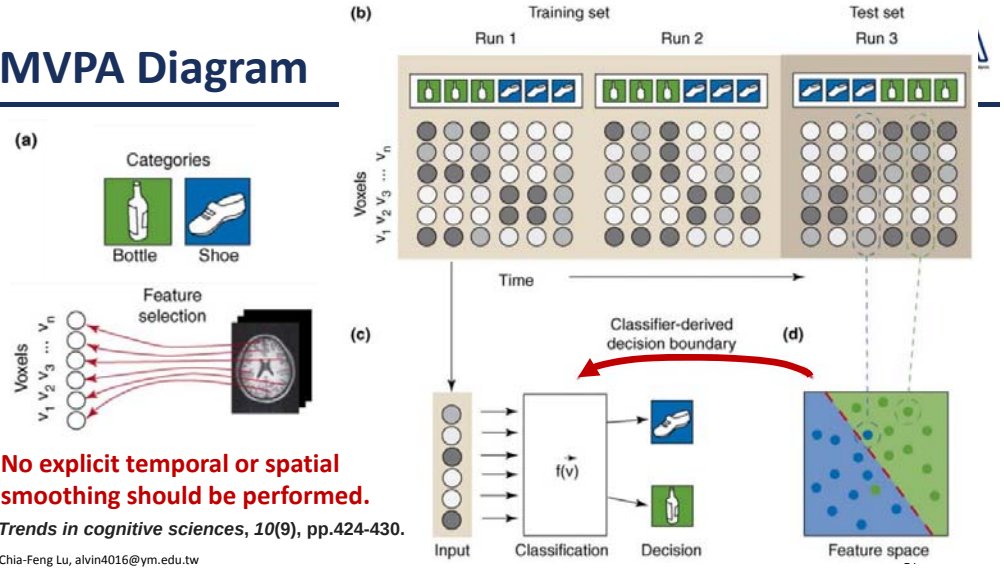
Illustration by Pim Mostert http://blog.donders.ru.nl/?p=4361&lang=en

MVPA: A Classification Problem

- Classification consists in determining a decision function f that takes the values of various "features" in a data "example" x and predicts the class of that "example."

- An "**example**" may represent a given trial in the experimental run.
- The "**features**" may represent the corresponding fMRI signals in a cluster of voxels.
- The experimental conditions may represent the different "**classes**".

MVPA Diagram

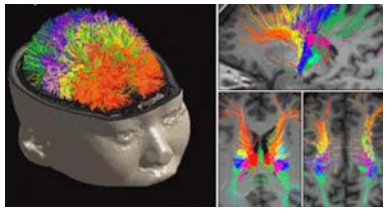


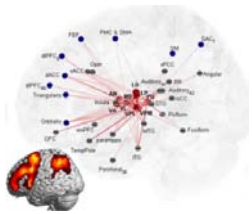
No explicit temporal or spatial smoothing should be performed.

***Trends in cognitive sciences*, *10*(9), pp.424-430.**

Brain Connectivity

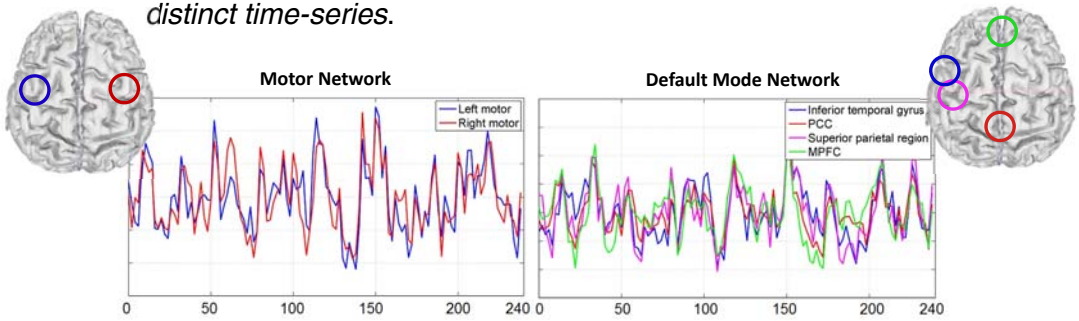
- **Structural connectivity**
  - Anatomical links (neuronal fibers)
- **Functional connectivity**
  - Statistical dependency
- **Effective connectivity**
  - Causal interactions between distinct units





Functional connectivity

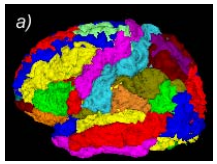
- Functional connectivity (FC) is defined as the statistical association or dependency *among two or more anatomically distinct time-series*.

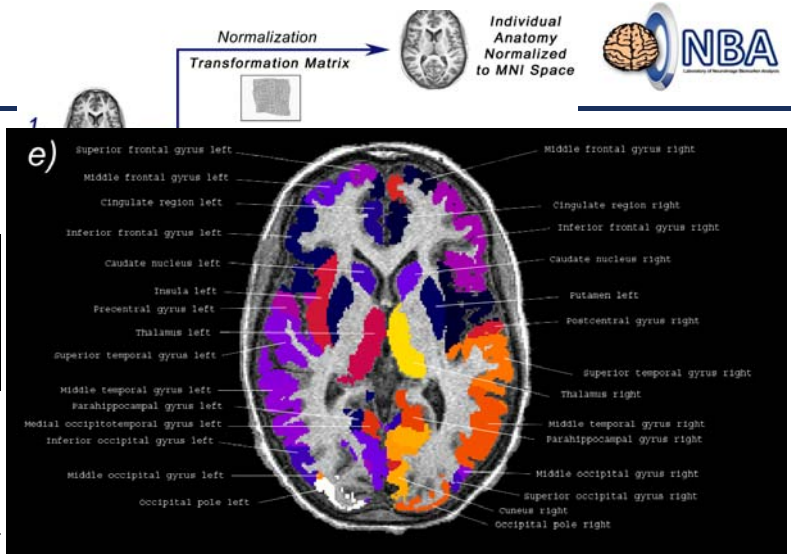


(Friston 1994, HBM 20, 56-78 & Friston et al., 1996,Cereb Cortex, 60 156-164)

IBASPM

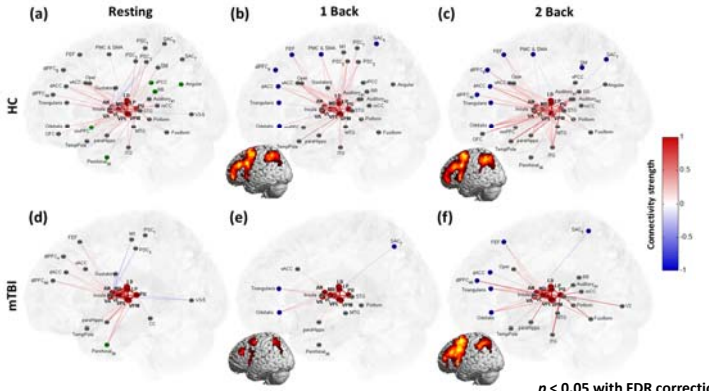
- Individual atlas flowchart





Tzourio-Mazoyer et al.
Neuroimage 15: 273-289. 2002.

Concussion-related alterations of FC



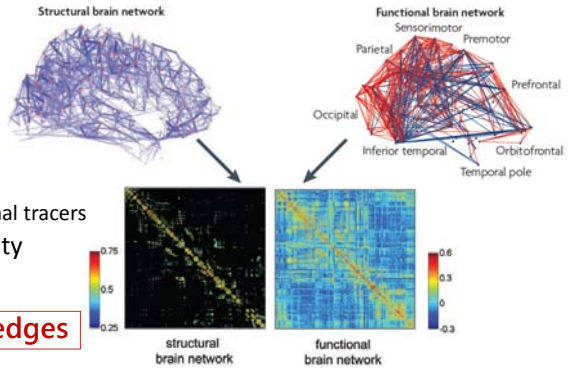
Lu et al., 2017 ISMRM.

***p* < 0.05 with FDR correction**

Network construction

- **Nodes**
  - Cortical regions
- **Edges**
  - Cortical thickness correlations
  - Fiber connections
    - DSI, DTI, transneuronal tracers
  - Functional connectivity
    - fMRI, EEG, MEG

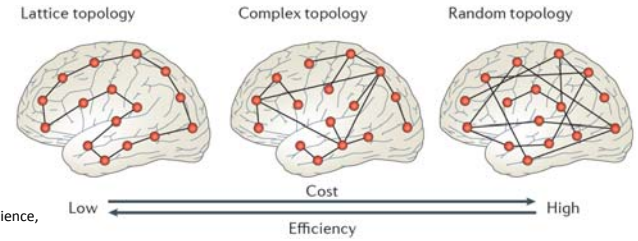
Network = nodes + edges



Human brain networks

Wiring costs ⇔ efficiency

- Clusters of lattice-like short-distance connections between spatially neighboring nodes
- Topologically direct interconnections between spatially remote brain regions → increase efficiency of information processing
- Nodes aggregated topologically and anatomically as modules → minimize wiring cost

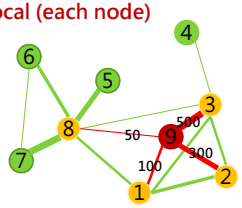


Nature Reviews Neuroscience, 13: 336-349, 2012.

A small-world architecture

Graph theory: topological properties

Local (each node)

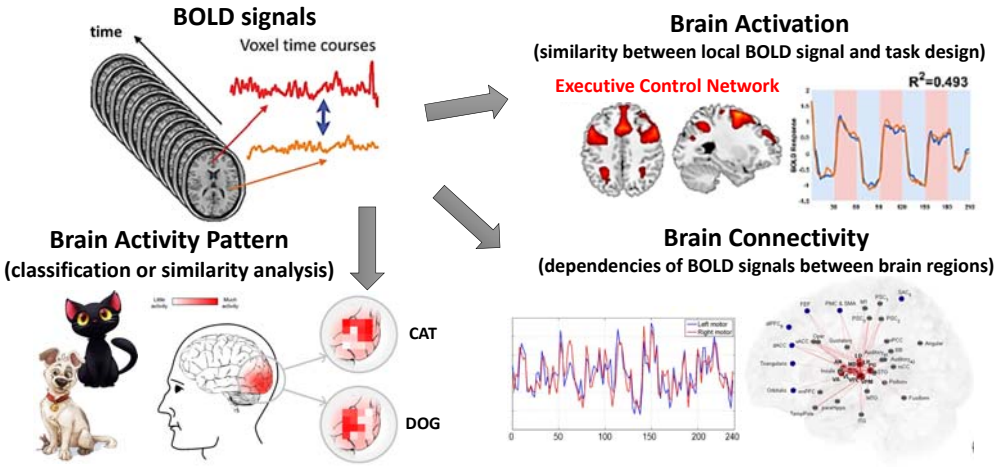


Global (average over all nodes)

- **degree** (the number of neighbors)
  e.g. degree of node 9 = 4
- **strength** (the connected fiber number*FA)
  e.g. strength of node 9 = (50+100+300+500)/4 = 237.5
- **clustering coefficient** (the connection between neighbors, [0~1])
  e.g. clustering coefficient of node 9 = 5/6 = 0.83
- **path length (separation)** (the minimal steps for connection)
  e.g. path length from node 9 to node 6 = 2 steps (9 → 8 → 6)

Philos Trans R Soc Lond B Biol Sci, 360, 937-946, 2005

fMRI Analysis



THE END

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