Analysis of Functional Magnetic Resonance Imaging (fMRI)

Brain Network – Graph Theory

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Teaching Materials

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

- ***Week 14: Brain Network – Graph Theory***
- ＜***Handout***＞*Lesson14_slides.pdf*

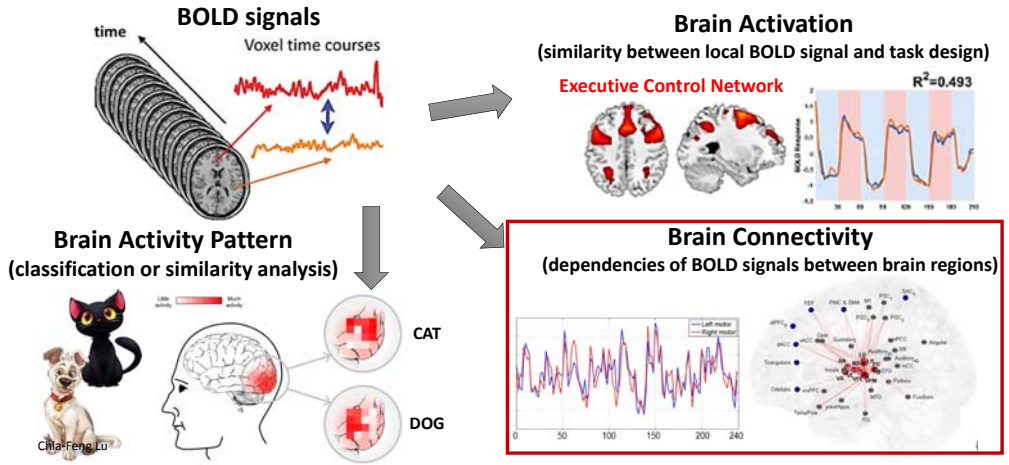
  ＜***Materials***＞*fMRIana14_materials.zip*

Employed Software

- **MRIcro**
  - https://people.cas.sc.edu/rorden/mricro/mricro.html#Installation
- **Statistical Parametric Mapping (SPM 12)**
  - http://www.fil.ion.ucl.ac.uk/spm/
- **GRETNA Toolbox**
  - https://www.nitrc.org/projects/gretna/
- **BrainNet Viewer Toolbox**
  - https://www.nitrc.org/projects/bnv/

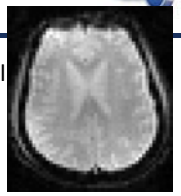
[Caution] File name\path contains Chinese character or space may cause error!

fMRI Analysis

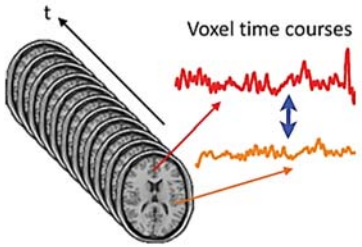


fMRI Protocol

- Siemens 3T MAGNETOM Trio Scanner @ NYMU, 32-channel head coil
- Single-Shot 2D EPI (GRE-EPI), T2* weighting
- Repetition Time = 2000 ms
- Echo Time = 20 ms
- Flip Angle = 70~90°
- NEX = 1
- Slice thickness = 3.4 mm
- Field of View = 220 x 220 mm²
- Matrix size = 64 x 64
- Slice number = 40
- Volume number **(depends on experiment design)**



3.44 x 3.44 x 3.40 mm³

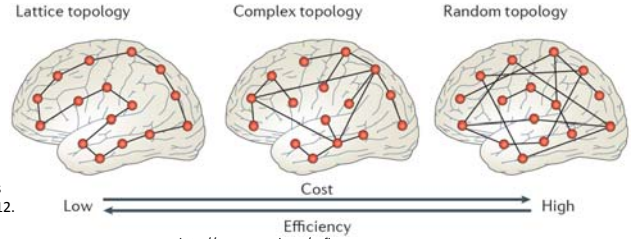


Graph Theory

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

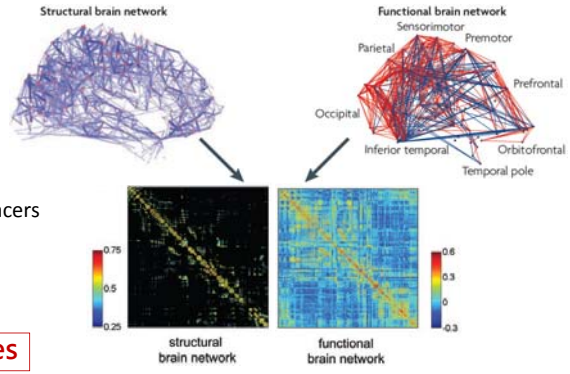


Bullmore et al., Nature Reviews Neuroscience, 13: 336-349, 2012.

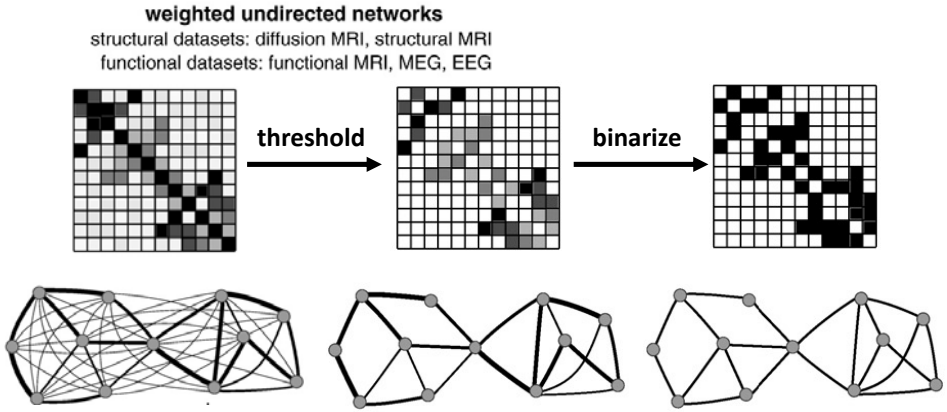
Network construction

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

Network = nodes + edges

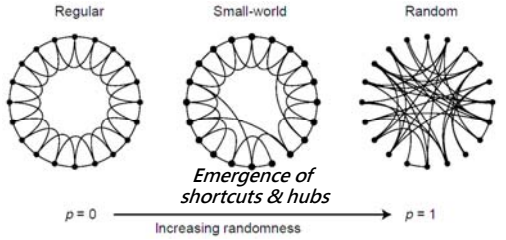


Network Construction

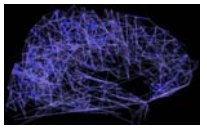


Complex networks

- Brain have a small-world architecture.



Complex networks
- Social network
- WWW internet
- Biological system
- Brain network



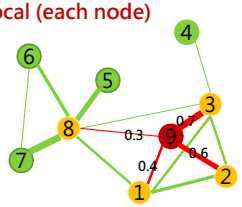
➢ *High local clustering* ➢ *Local segregation*
➢ *Low separation* ➢ *Global integration*

high signal-propagation speed, computational power, and synchronizability

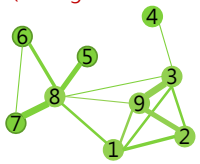
Watts DJ, Strogatz SH, *Nature* 393:440-442, 1998.

Graph theory: topological properties

Local (each node)



Global (average over all nodes)

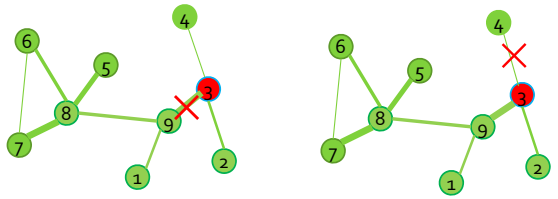


- **degree** (the number of neighbors)
  e.g. degree of node 9 = 4
- **strength** (the connected correlation coefficient)
  e.g. strength of node 9
  = (0.3+0.4+0.6+0.7)/4 = 0.5
- **clustering coefficient**
  (the connection between neighbors, [0~1])
  e.g. clustering coefficient of node 9
  = 5/6 = 0.83
- **shortest path length (separation)**
  (the minimal steps for connection)
  e.g. path length from node 9 to node 6
  = 2 steps (9 → 8 → 6)

Salvador et al, *Philos Trans R Soc Lond B Biol Sci*, 360, 937-946, 2005

Network properties

- The topological observations can reveal a "hidden" or "high-level" relations between nodes.



Brain Connectivity Toolbox


NeuroImage 52 (2010) 1059–1069

Contents lists available at ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Complex network measures of brain connectivity: Uses and interpretations

Mikail Rubinov [a,b,c], Olaf Sporns [d,*]

[a] Black Dog Institute and School of Psychiatry, University of New South Wales, Sydney, Australia
[b] Mental Health Research Division, Queensland Institute of Medical Research, Brisbane, Australia
[c] CSIRO Information and Communication Technologies Centre, Sydney, Australia
[d] Department of Psychological and Brain Sciences, Indiana University, Bloomington, IN 47405, USA

More than 5000 citations till 2019.

Topological Measurements

Basic Measures
- degree, strength, shortest path length

Measures of integration
- global efficiency

Measures of segregation
- Clustering coefficient, local efficiency, modularity

Measures of centrality
- Betweenness, within-module degree, participation coefficient

Network motifs

Measures of resilience
- Degree distribution, neighbor degree, assortativity coefficient

Network small-worldness

GRETNA and BrainNet Toolbox

Relevant Publications

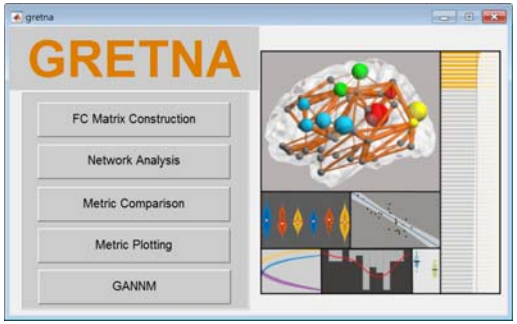
- Wang J, Wang X, Xia M, Liao X, Evans A, **He Y**. GRETNA: a graph theoretical network analysis toolbox for imaging connectomics. **Frontiers in human neuroscience. 2015** Jun 30;9:386.

- Xia M, Wang J, **He Y**. BrainNet Viewer: a network visualization tool for human brain connectomics. **PloS one. 2013** Jul 4;8(7):e68910.

GRETNA Toolbox

Include GRETNA-2.0.0_release path and key in **gretna** in MATLAB command window

- The GRETNA toolbox has been designed for the graph-theoretical network analysis of fMRI data.
  - fMRI preprocessing
  - Network construction
  - Calculation of network metrics
  - Statistical analysis

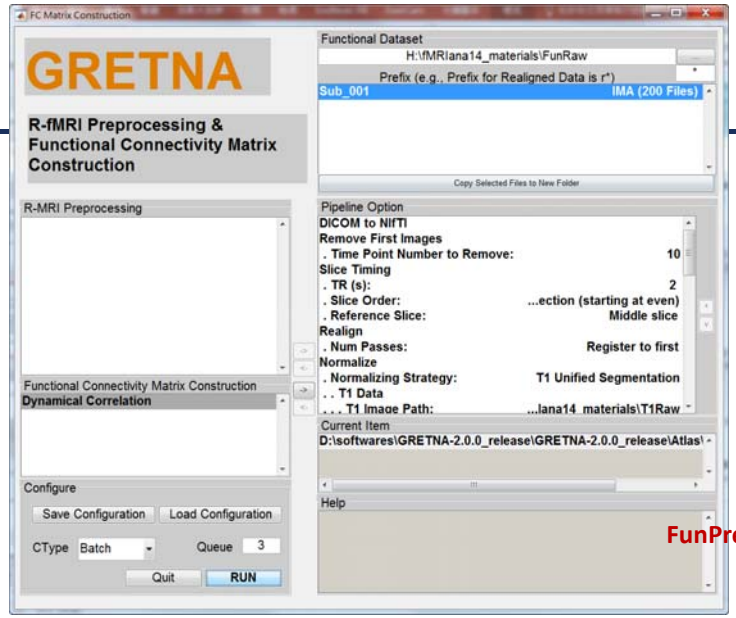


GRETNA Toolbox

- Error debug when importing Siemens DICOM images

- open gretna_GUI_PreprocessInterface.m
- line 1949: D=dir(fullfile(Path, [Prefix, '.ima'])); % DCM
- line 1959: D=dir(fullfile(Path, [Prefix, '.IMA'])); % DCM
- line 1853: D=dir(fullfile(Path, [Prefix, '.IMA'])); % DCM

- An * before .ima or .IMA should be removed.



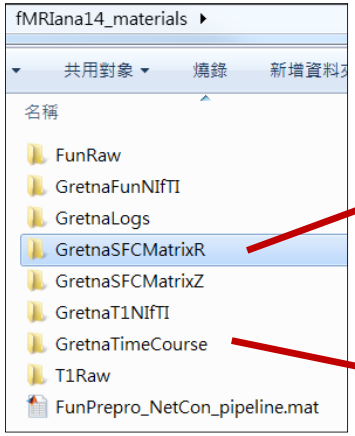
Step 1: FC Matrix Construction

~10 minutes for each subject

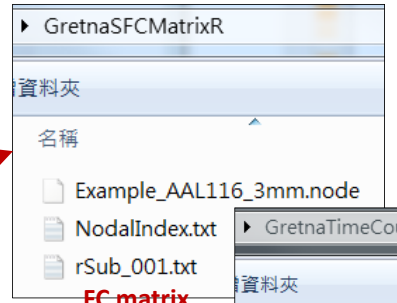
Static/dynamical Correlation
- Only support 3mm or 1mm atlas

FunPrepro_NetCon_pipeline.mat

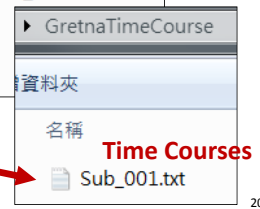
Step 1: FC Matrix Construction



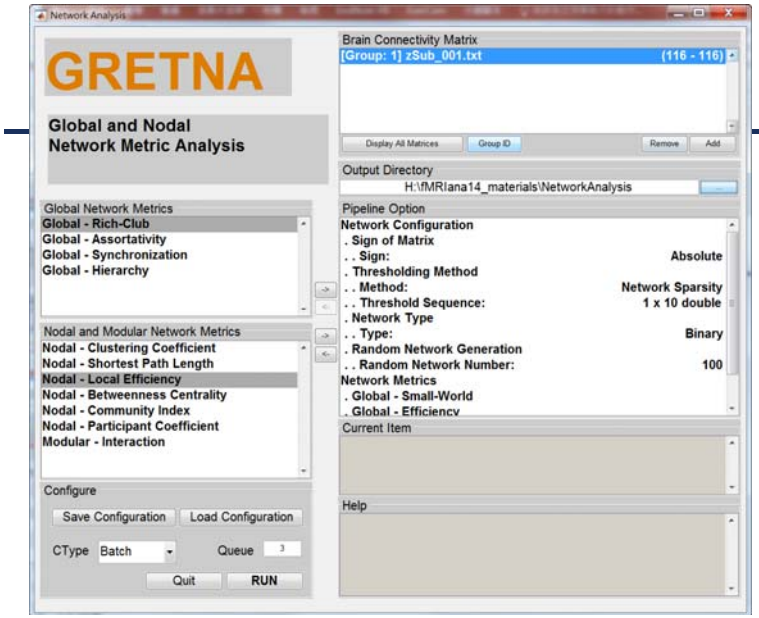
All jobs have been successfully completed.



FC matrix



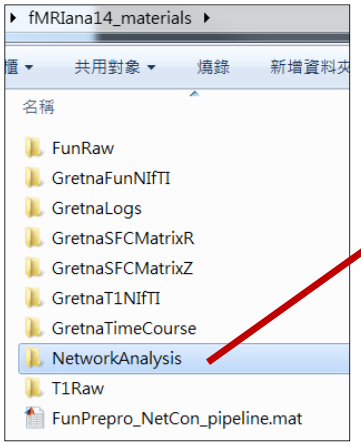
Time Courses



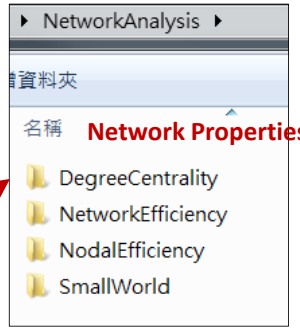
Step 2: Network Analysis

Global network properties

Step 2: Network Analysis



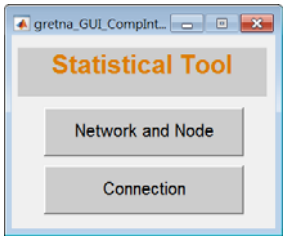
All jobs have been successfully completed.



Results *.mat files

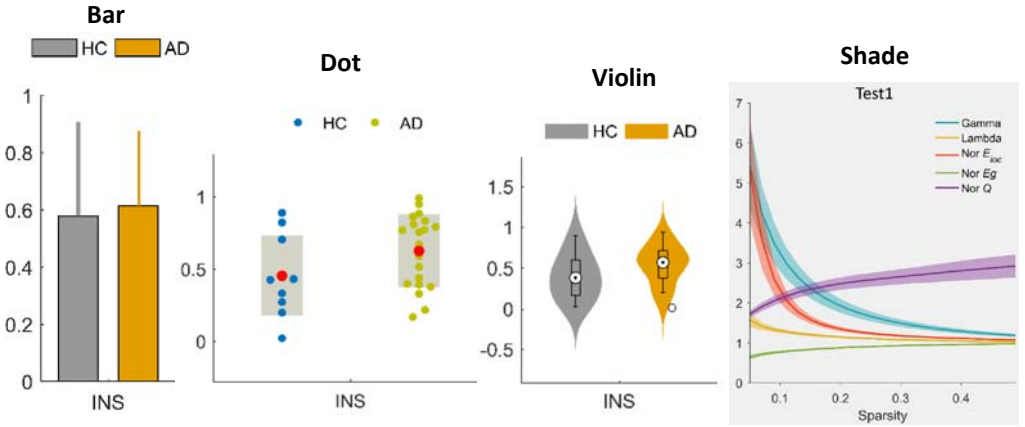
Page 38-47 of the GRETNA user manual

Step 3: Metric Comparison/Statistical Analysis



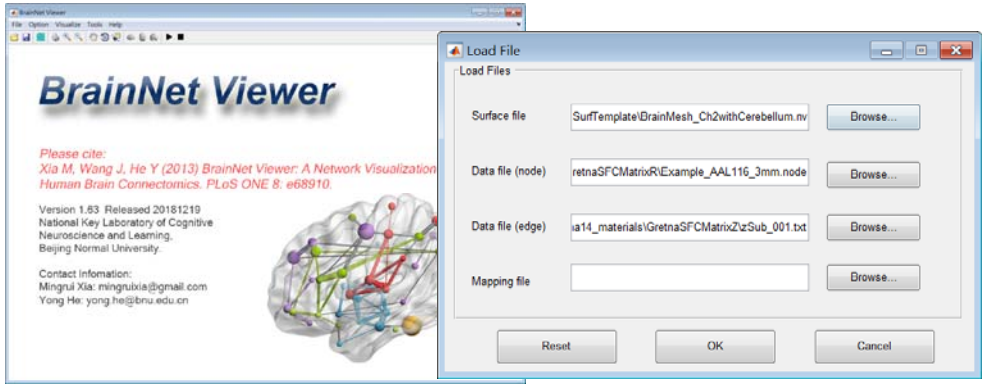
- Network and Node
  - One sample t-test
  - Two sample t-test
  - Paired t-test
  - ANOVA
  - Repeated ANOVA
  - Correlation analysis
- Connection
  - Perform statistical analysis on the FC matrices
  - One sample/two sample t-test

Step 4 (optional): Metric Plotting

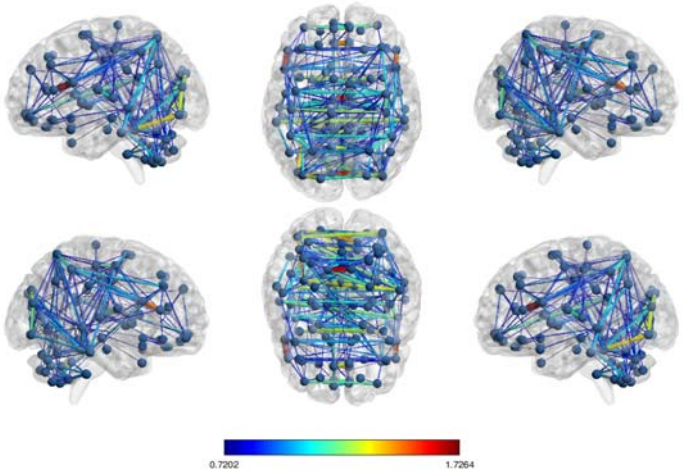


BrainNet Toolbox

Include BrainNetViewer_20181219 path and key in **BrainNet** in MATLAB command window



BrainNet Display



THE END

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