Network Analysis of Functional Connectivity

Jan Fousek

Faculty of Informatics, Masaryk University

Outline

Introduction and Theory

Networks of the Brain

Group Comparison

Software

Complex network analysis

Graph theory

- part of mathematics studying graphs
- graph: structure consisting of discrete entities and their pairwise relations

Network analysis

- networks as a way of looking at a complex systems
- nodes as parts of the system edges as interactions
- numerous applications (sociology, epidemiology, biology, ...)

Brain as a Network: Scales

Microscopic

- particular neurons and synaptic connections

Mesoscopic

- cortical columns and local structures

Macroscopic

- cortical areas and their interconnections

On the *whole brain* we can reach the macroscopic scale with current modalities: fMRI, DTI, EEG, etc.

Brain as a Network: Connectivity

Anatomic

- physical connections of neuronal populations
- DTI, cortical thickness correlations

Functional

- statistical relations between area activity
- fMRI, M/EEG + e.g. cross-correlation

Network Construction

Input: imaging modality data

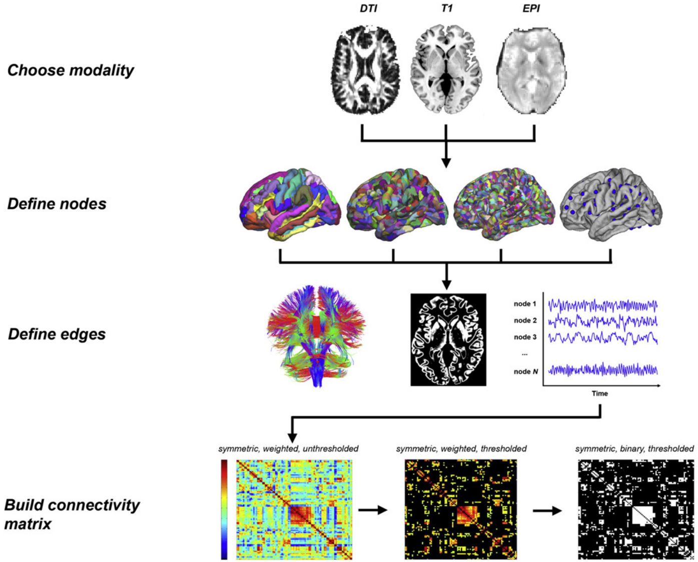
Node definition

- (anatomical) parcellation of grey matter
- particular voxels

Edge definition:

- axonal connections
- correlations, synchronization, ...

Output: network, e.g. as a adjacency matrix



Fornito et al. 2012

Resting State fMRI Pipeline

1. apply preprocessing steps (e.g. motion correction)
2. parcellate with an anatomical atlas
3. for each area, compute the representing signal (average or 1. principal component)
4. cross-correlate $\rightarrow$ correlation matrix
5. threshold to desired density
6. binarize

Steps 4 and 5 are optional.

Basic Properties: Segregation

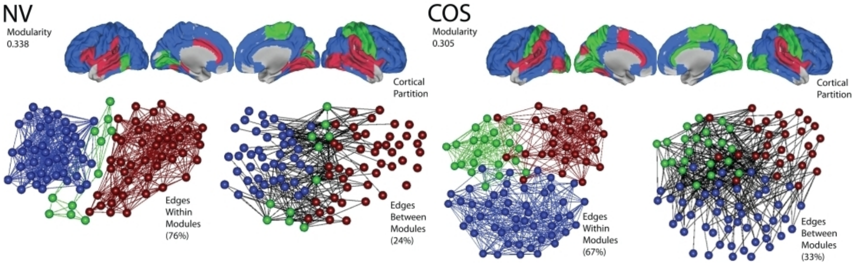
How well are the nodes connected *locally*.

Measures of segregation:

- clustering coefficient – density of connections between neighbours
- topological motives – repeated local topologies
- modularity – densely connected subgraphs

Segregation Application: Schizophrenia

- increased global and decreased local efficiency (Fornito et al. 2012)
- decreased modularity (Alexander-Bloch et al. 2010)



Basic Properties: Integration

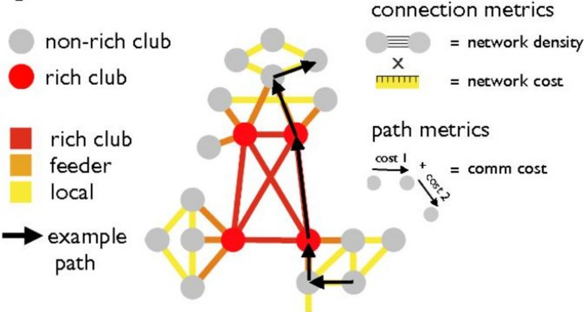
How well is the network connected *globally*.

Measures of integration:

- characteristic path length
- global efficiency – average inverse shortest path length
- rich-club – densely interconnected hubs

Integration Application: Rich-Club

- anatomic connectivity has a highly connected and highly central backbone (Heuvel et al. 2012)
- includes e.g. precuneus, cingulate cortex, superior frontal a parietal cortex, insula



Basic Properties: Centrality

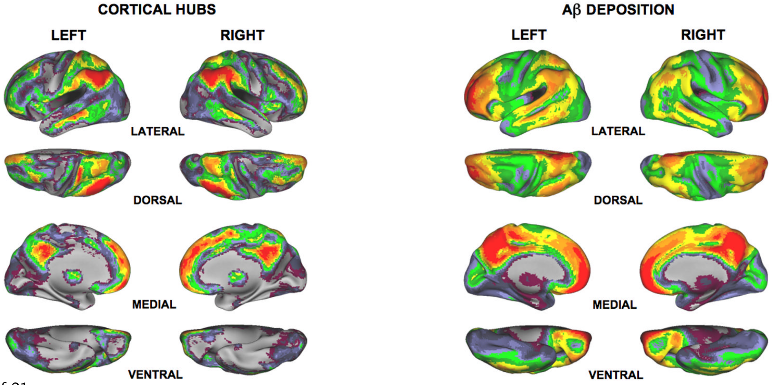
Which nodes are *important* in the network.

Measures of centrality:

- node degree – number of neighbours
- betweenness centrality – number of shortest paths passing through a node
- eigenvector centrality – influence of a node to a network

Centrality Application: Alzhaimer d.

- degenerative changes affect hubs (Buckner et al. 2009, Tijms et al. 2013)



Group Comparison

Both groups need to have:

- same parcellation scheme (node correspondence)
- same density

Edge-level group differences:

- Network Based Statistics (Zalesky, Fornito, and Bullmore 2010)
- Partial Least Squares
- Sum of Powered Score (Kim et al. 2014)

Software

MATLAB

- Brain Connectivity Toolbox – library of measures
- GraphVar – GUI for BCT
- from 2015b can plot networks and has `graph` structure

Gephi

- interactive complex network exploration tool

Many packages in R and Python.

Summary

- complex network analysis is a useful formalism for describing connectivity
- various measures capture functional/structural segregation and integration
- centrality measures pinpoint important nodes (areas) in the network

Thank you for your attention.

References (1)

Alexander-Bloch, Aaron F et al. (2010). "Disrupted modularity and local connectivity of brain functional networks in childhood-onset schizophrenia". In: *Frontiers in systems neuroscience* 4.

Buckner, Randy L et al. (2009). "Cortical hubs revealed by intrinsic functional connectivity: mapping, assessment of stability, and relation to Alzheimer's disease". In: *The Journal of Neuroscience* 29.6, pp. 1860–1873.

References (2)

Fornito, Alex et al. (2012). “Schizophrenia, neuroimaging and connectomics”. In: *NeuroImage* 62.4, pp. 2296–2314. ISSN: 1053-8119. DOI: 10.1016/j.neuroimage.2011.12.090. URL: http://www.sciencedirect.com/science/article/pii/S1053811912002133.

Heuvel, Martijn P van den et al. (2012). “High-cost, high-capacity backbone for global brain communication”. In: *Proceedings of the National Academy of Sciences* 109.28, pp. 11372–11377.

References (3)

Kim, Junghi et al. (2014). "Comparison of statistical tests for group differences in brain functional networks". In: *NeuroImage* 101, pp. 681–694.

Tijms, Betty M et al. (2013). "Alzheimer's disease: connecting findings from graph theoretical studies of brain networks". In: *Neurobiology of Aging*.

Zalesky, Andrew, Alex Fornito, and Edward T Bullmore (2010). "Network-based statistic: identifying differences in brain networks". In: *Neuroimage* 53.4, pp. 1197–1207.