Connectivity and Networks in the Brain

Mgr. Beáta Špiláková

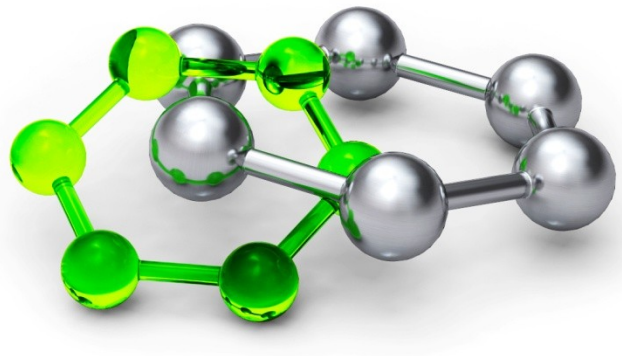
Selected topics from contemporary neuroscience

16.11.2017

beata.spilakova@ceitec.muni.cz

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
INVESTING IN YOUR FUTURE

2007–13
OP Research and Development for Innovation



Overview

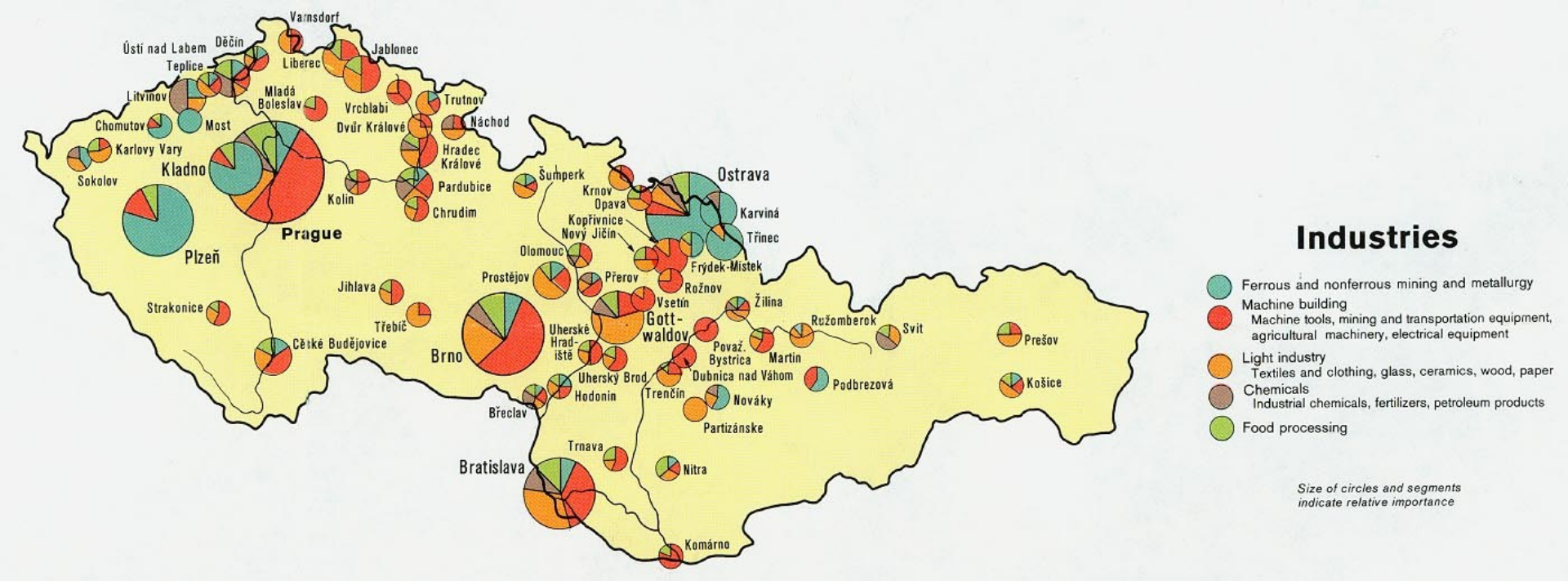
- Historical perspective
- Motivation
- Levels and types of connectivity
- Methods
- Graph theory and network elements
- Selected brain networks in humans
- Altered connectivity

Historical perspective

- Phrenology (up until 1808)
- Lesion studies, electrical stimulation experiments
  - Fritsch, Hitzig (1870), and Ferrier (1873-75)
  - Broca, Wernicke
- Localization of Function in the Cortex Cerebri (1881)
- Golgi & Ramón y Cajal (1888-)
- Early applications of network science to the brain (90’s-00’s)

Motivation

- Segregation & functional localisation approach is reductionistic



https://legacy.lib.utexas.edu/maps/czech_republic.html

Levels and types of connectivity

- Three basic levels:
- MICROSCALE
- MESOSCALE
- MACROSCALE
- Specific techniques for each of them

MICROSCALE

- Single neurons and synapses
- Electron or light microscopy
- Optogenetics
- https://www.youtube.com/watch?v=I64X7vHSHOE

MESOSCALE

- Neuronal populations and their interconnecting circuitry
- Tracing of axonal projections, histological sectioning

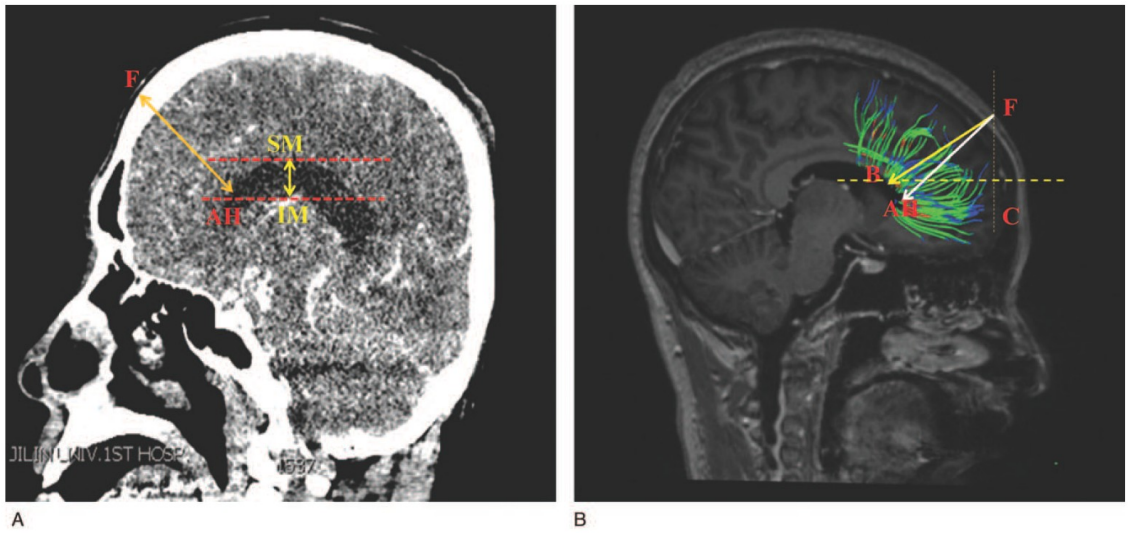
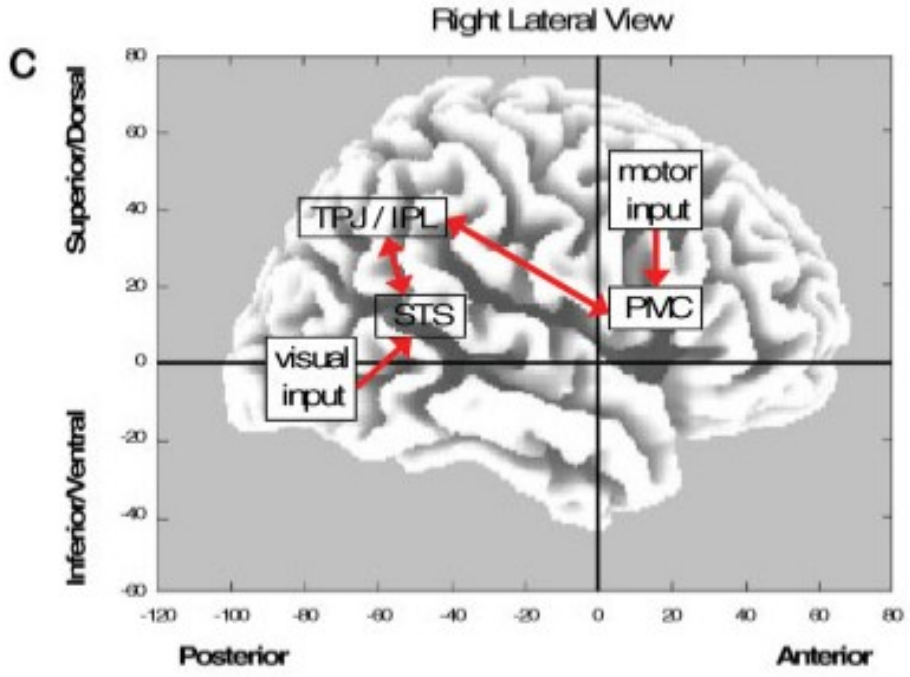


Figure 1. (A) The data and the puncture point from frontal lobe in computed tomography image. (B) The puncture point and angle in diffusion tensor image.

Zhong *et al.*, 2018

MACROSCALE

- Anatomically distinct brain regions and pathways
- Non-invasive, whole brain imaging techniques



Van Overwalle, 2009

Types of Connectivity

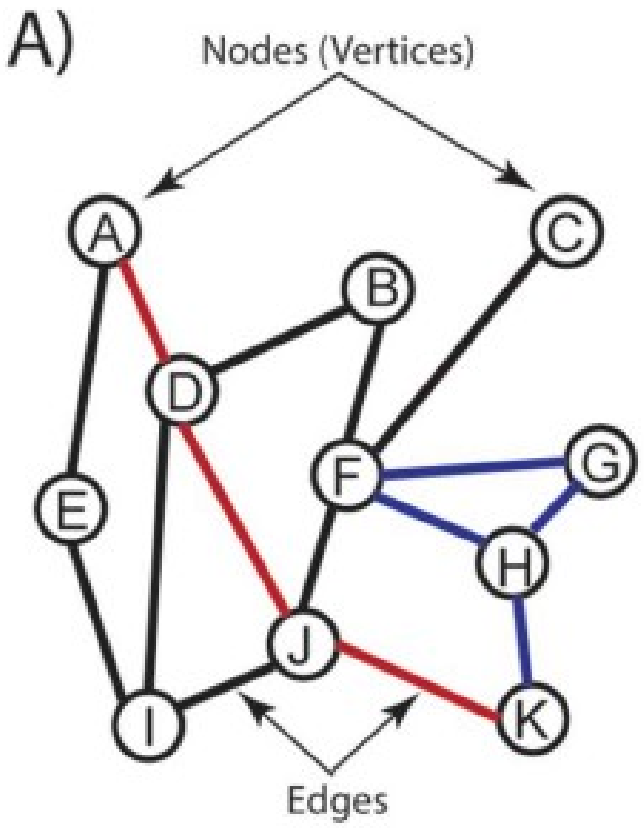
- Structural
- Functional
- Effective

Methods

- Histology
- DTI
- Functional imaging + subsequent analysis:
  - Correlations/coherence
  - ICA, gICA
  - Phase-locking value
  - PPI, DCM
  - …

Graph theory

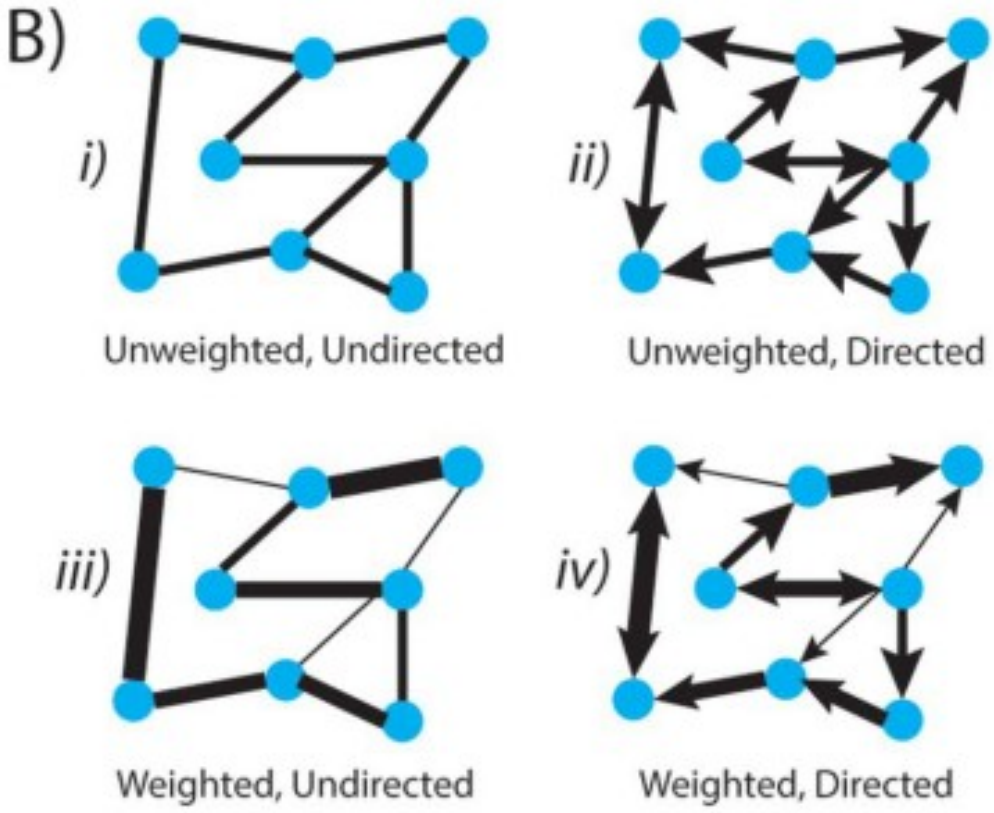
- Need to describe the network
- Graphs=models of real systems, their elements and their links
- Elements → NODES
- Links → EDGES



Mears and Pollard, 2016

Graph theory

- Edges:



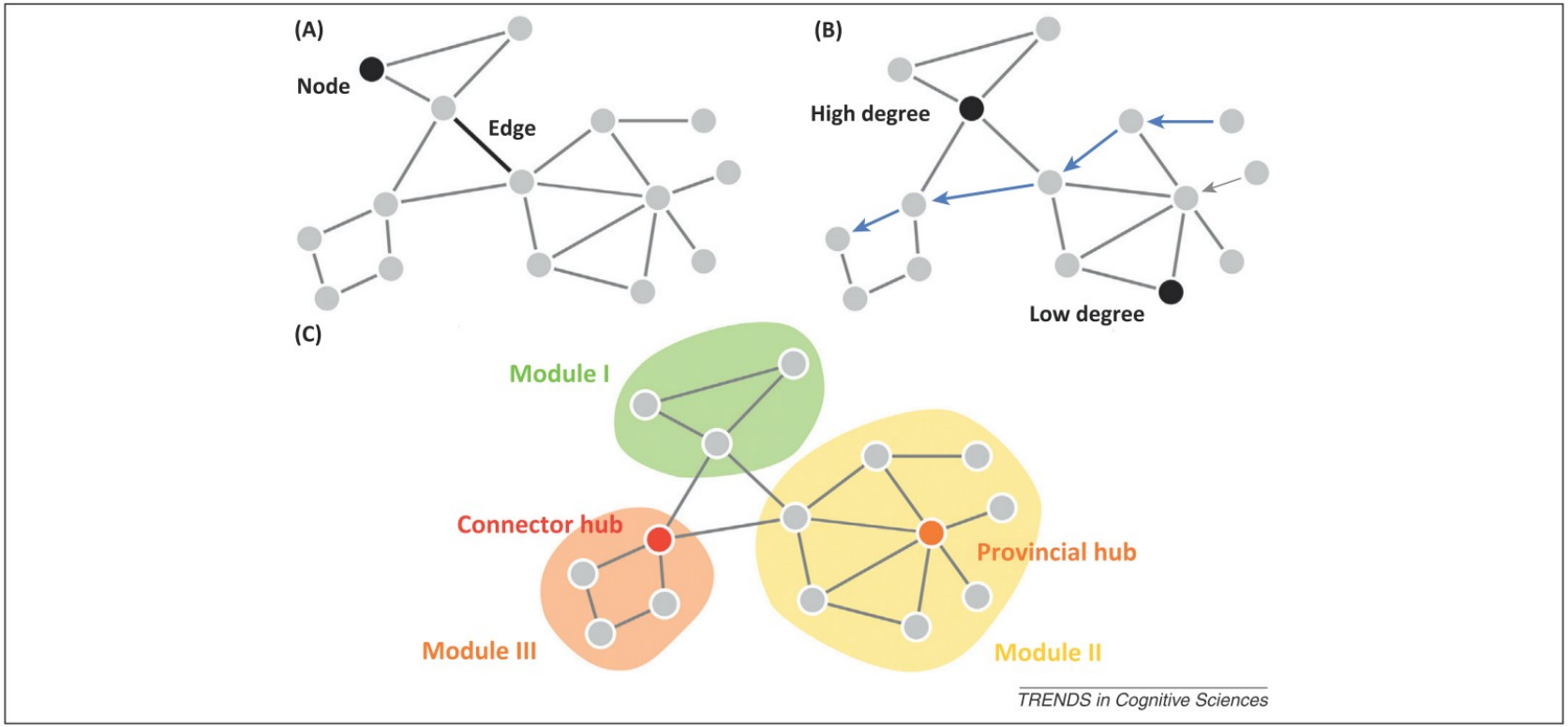
Mears and Pollard, 2016

Graph theory

- Local metrics
  - Degree
  - Clustering coefficient
  - Path length
  - …
- Global metrics
  - Rich club

Graph theory

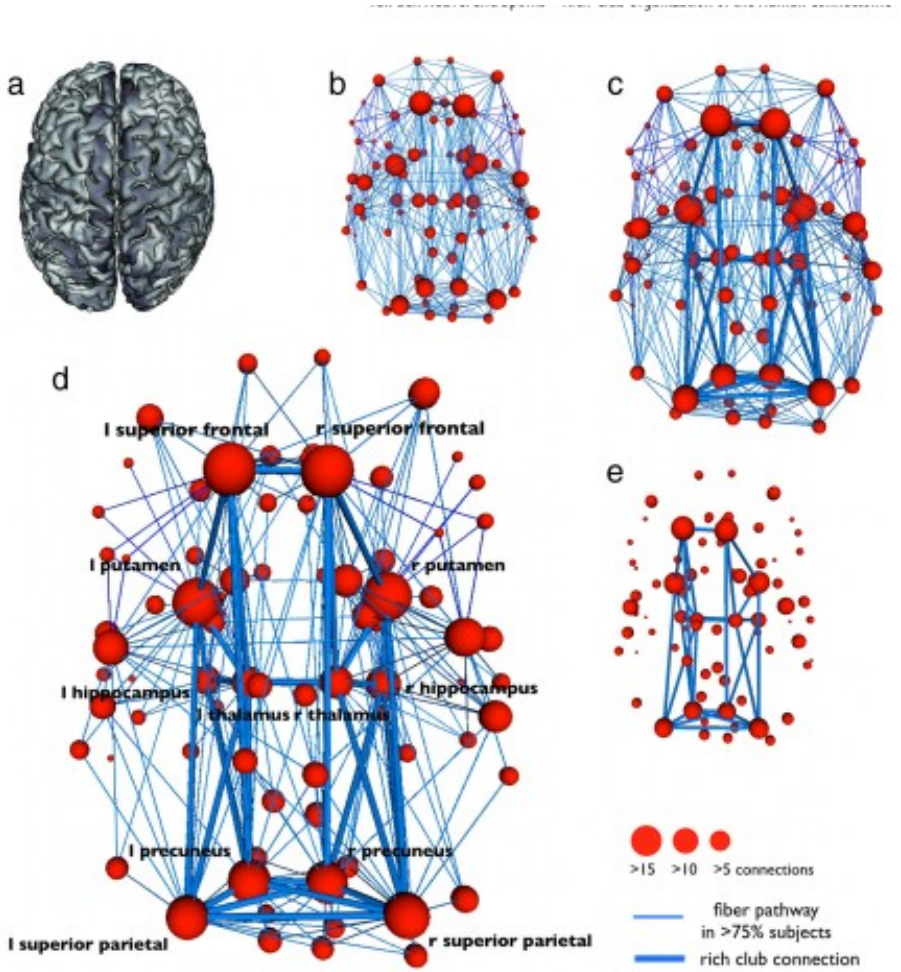
- Nodes:



van den Heuvel and Sporns, 2013

Graph theory

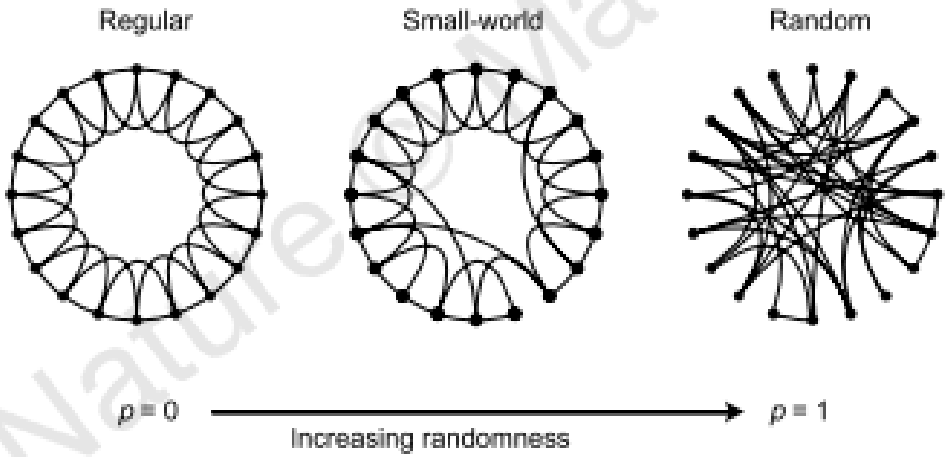
- Rich club:



van den Heuvel and Sporns, 2011

Graph theory

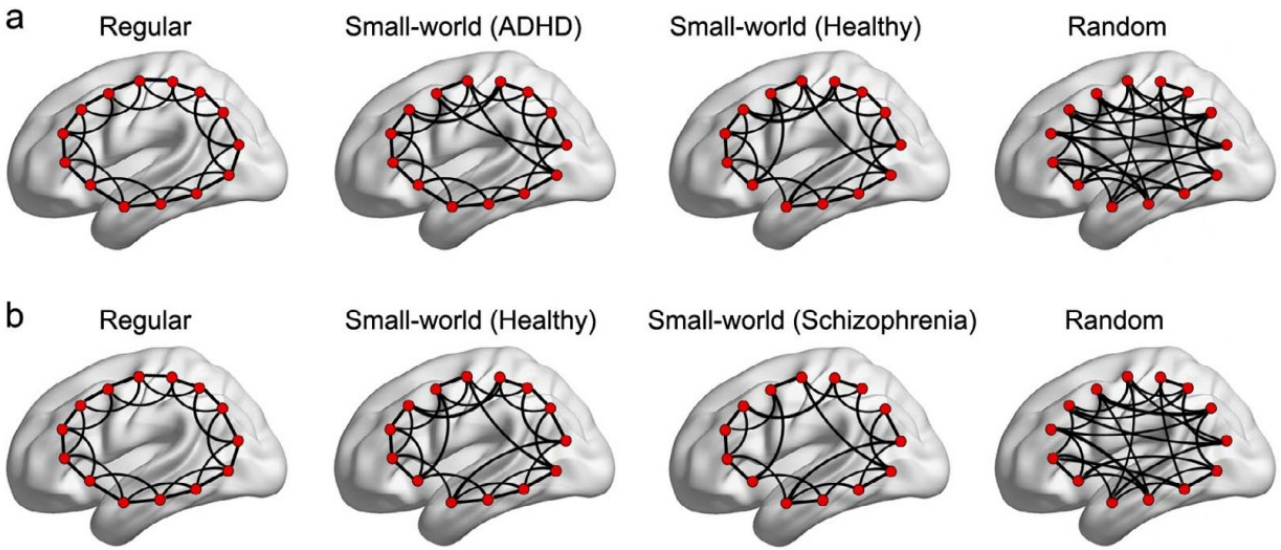
- Small world networks:
- High clustering coefficients, similar to regular graphs, and short average path lengths, similar to random graphs



Watts and Strogatz, 1998

Graph theory

- Milgram's experiment (no, not THAT one)
- Many real world phenomena (social, biological, technological)
- …and in brain as well



Liao *et al.*, 2017

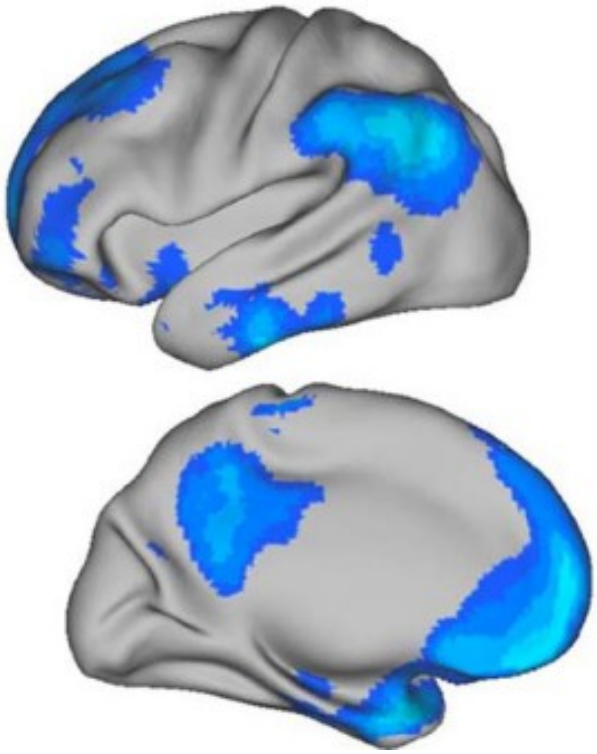
Selected brain networks

- Default mode network
- Salience network
- Reward network

Default mode network

- Freethinking, remembering the past, envisioning future events…
- Consistent set of regions in different methodologies
- Brain areas:

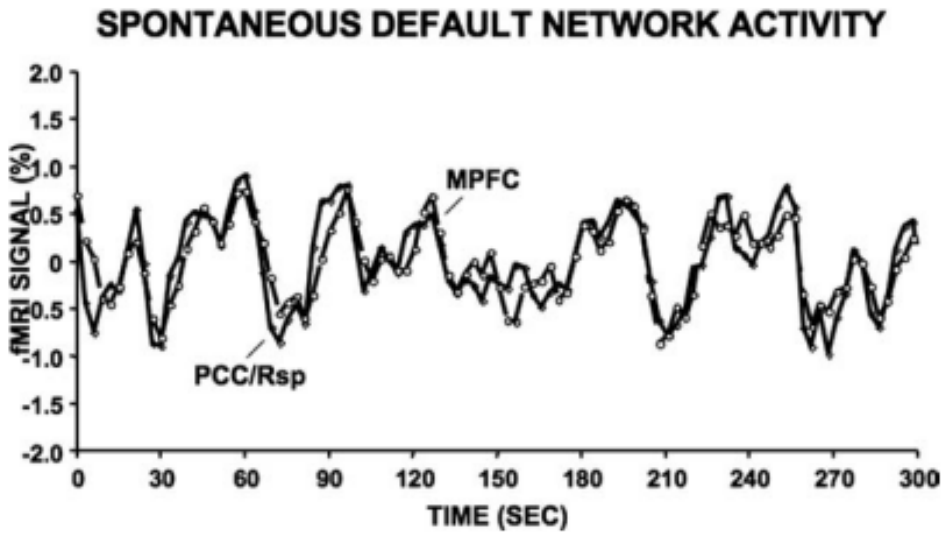
- Ventral medial prefrontal cortex
- Posterior cingulate cortex
- Inferior parietal lobule
- Lateral temporal cortex
- Dorsal medial prefrontal cortex
- Hippocampal formation



Buckner *et al.*, 2008

Default mode network

- Infants do not show the structured interactions between the default network regions
- Disrupted in autism, schizophrenia, and Alzheimer's disease and at old age



Buckner *et al.*, 2008

Default mode network

- **Function?**

- Constructing dynamic mental simulations based on personal past experiences
- Supporting exploratory monitoring of the external environment when focused attention is relaxed

Buckner *et al.*, 2008

Salience network

- Anterior insulae ventrolateral prefrontal cortex, dorsal anterior cingulate cortex
- Responds to behaviourally important events
- Identifies the most relevant stimuli to guide behaviour
- Switching between the CEN and the DMN

Yuan *et al.*, 2012; Goulden *et al.*, 2014; Chand and Dhamala, 2016

Salience networok

- Connected to IQ
- Disrupted in fronto-temporal dementia

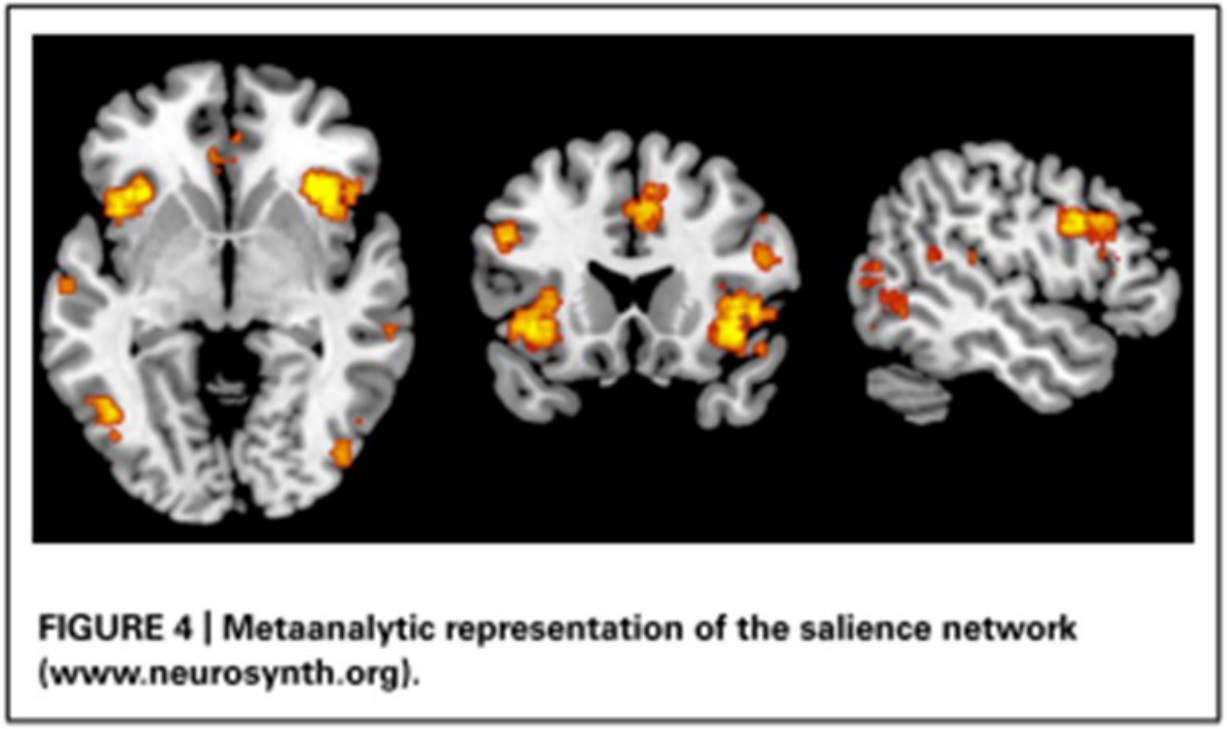
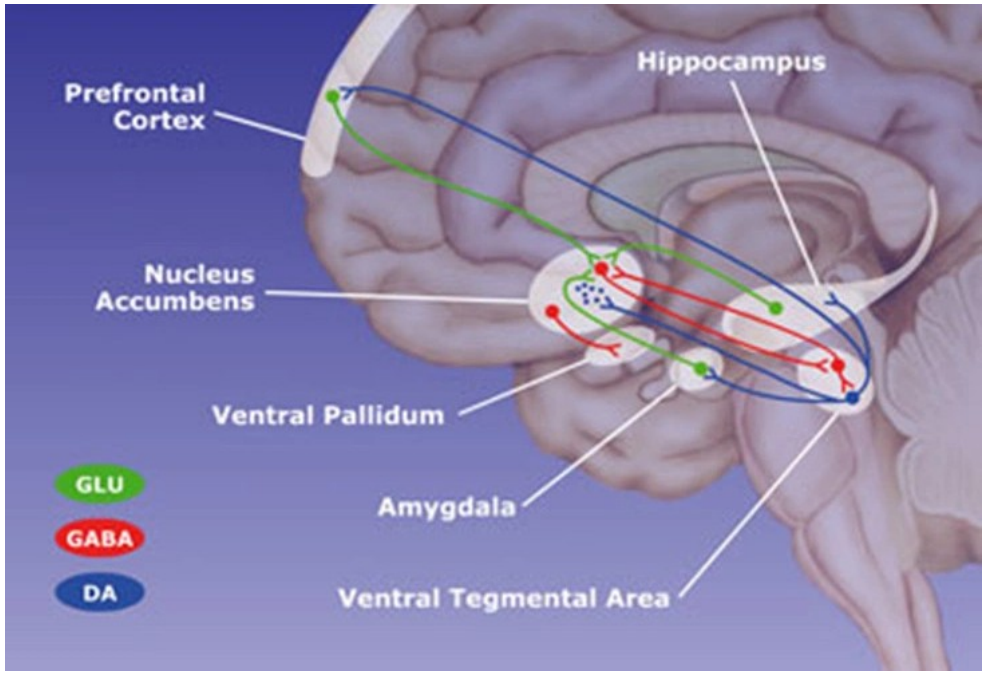


FIGURE 4 | Metaanalytic representation of the salience network (www.neurosynth.org).

Reward system

- Driving incentive-based learning, appropriate responses to stimuli, and the development of goal-directed behaviours



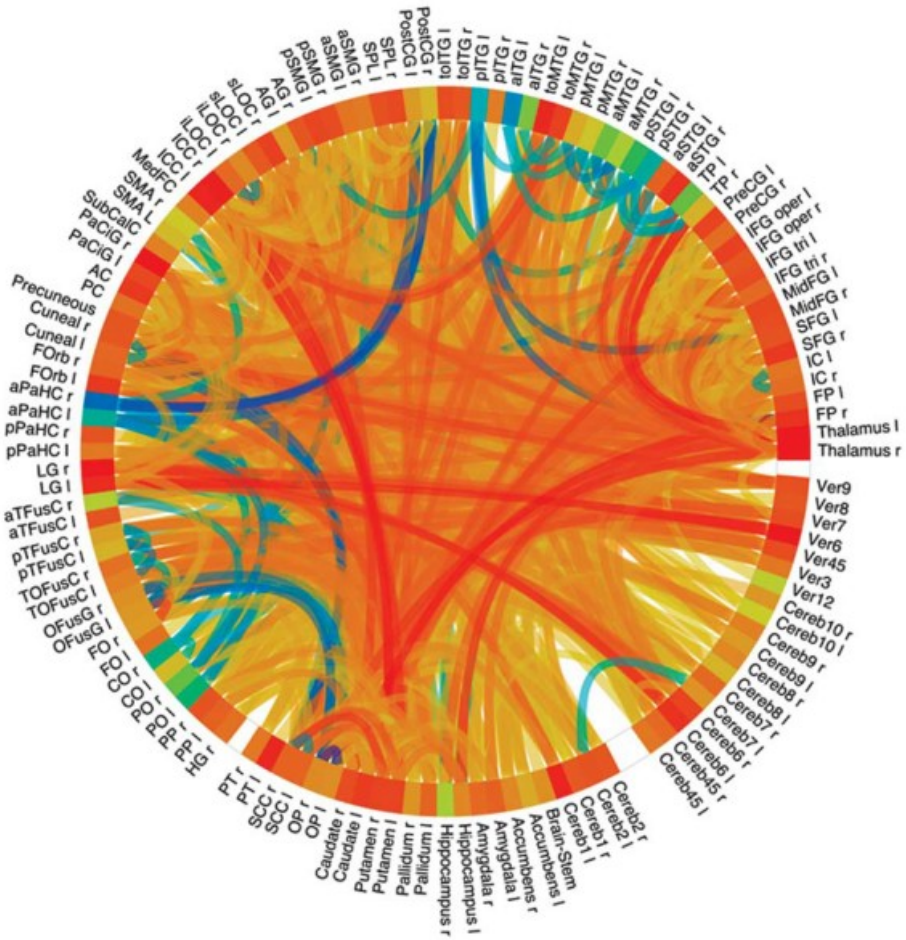
https://brainstates.org/tag/reward-circuitry/,

Reward system

- Dopamine neurons
- Linked to addiction
- Schizophrenia
- Mood disorders

Smith *et al.*, 2009; Haber and Knutson, 2010; Krill and Platek, 2012, Cooper *et al.*, 2017; Keren *et al.*, 2018; Vanes *et al.*, 2018

Altered connectivity in LSD



Liechti, 2017; Müller *et al.*, 2018

Thank you for listening!
Questions?

Sources

- Buckner, R.L., Andrews-Hanna, J.R., Schacter, D.L. (2008). The brain's default network: Anatomy, function, and relevance to disease. *Annals of the New York Academy of Sciences*, **1124**, 1–38
- Chand, G.B., Dhamala, M. (2016). The salience network dynamics in perceptual decision-making. *NeuroImage*, **134**, 85–93
- Cooper, S., Robison, A.J., Mazei-Robison, M.S. (2017). Reward Circuitry in Addiction. *Neurotherapeutics*, **14**, 687–97
- Goulden, N., Khusnulina, A., Davis, N.J., et al. (2014). The salience network is responsible for switching between the default mode network and the central executive network: Replication from DCM. *NeuroImage*, **99**, 180–90
- Haber, S.N., Knutson, B. (2010). The Reward Circuit: Linking Primate Anatomy and Human Imaging. *Neuropsychopharmacology*, **35**, 4–26
- van den Heuvel, M.P., Sporns, O. (2013). Network hubs in the human brain. *Trends in Cognitive Sciences*, **17**, 683–96
- van den Heuvel, M.P., Sporns, O. (2011). Rich-Club Organization of the Human Connectome. *Journal of Neuroscience*, **31**, 15775–86
- Keren, H., O'Callaghan, G., Vidal-Ribas, P., et al. (2018). Reward Processing in Depression: A Conceptual and Meta-Analytic Review Across fMRI and EEG Studies. *American Journal of Psychiatry*, appi.ajp.2018.1
- Krill, A.L., Platek, S.M. (2012). Working together may be better: Activation of reward centers during a cooperative maze task. *PLoS ONE*, **7**, 1–7
- Liao, X., Vasilakos, A. V., He, Y. (2017). Small-world human brain networks: Perspectives and challenges. *Neuroscience & Biobehavioral Reviews*, **77**, 286–300
- Liechti, M.E. (2017). Modern Clinical Research on LSD. *Neuropsychopharmacology*, **42**, 2114–27
- Mears, D., Pollard, H.B. (2016). Network science and the human brain: Using graph theory to understand the brain and one of its hubs, the amygdala, in health and disease. *Journal of Neuroscience Research*, **94**, 590–605
- Müller, F., Dolder, P.C., Schmidt, A., et al. (2018). Altered network hub connectivity after acute LSD administration. *NeuroImage: Clinical*, **18**, 694–701
- Van Overwalle, F. (2009). Social cognition and the brain: A meta-analysis. *Human Brain Mapping*, **30**, 829–58
- Smith, K.S., Tindell, A.J., Aldridge, J.W., et al. (2009). Ventral pallidum roles in reward and motivation. *Behavioural Brain Research*, **196**, 155–67
- Sporns, O. (2011). The human connectome: a complex network. *Annals of the New York Academy of Sciences*, **1224**, 109–25
- Vanes, L.D., Mouchlianitis, E., Collier, T., et al. (2018). Differential neural reward mechanisms in treatment-responsive and treatment-resistant schizophrenia. *Psychological Medicine*, **48**, 2418–27
- Watts, D.J., Strogatz, S.H. (1998). Collective dynamics of 'small-world' networks. **393**, 440–42
- Yuan, Z., Qin, W., Wang, D., et al. (2012). The salience network contributes to an individual's fluid reasoning capacity. *Behavioural Brain Research*, **229**, 384–90
- Zhong, S., Li, W., Wang, B., et al. (2018). Selection of the best point and angle of lateral ventricle puncture according to DTI reconstruction of peripheral nerve fibers. *Medicine*, **97**, e13095