Summary

Complex brain networks: graph theoretical analysis of structural and functional systems

by Bullmore2009

Keywords: brain network, graph theory, complex network, structural network, functional network

The paper reviews a number of investigations and researches about modeling the brain system as a complex network depending on graph theory.

Background:

Graph theory is a branch of mathematics that deals with the formal description and analysis of graphs. A graph is defined as a set of nodes linked by connections or edges. A graph provides an abstract representation of the elements and their interactions of a real-world system.

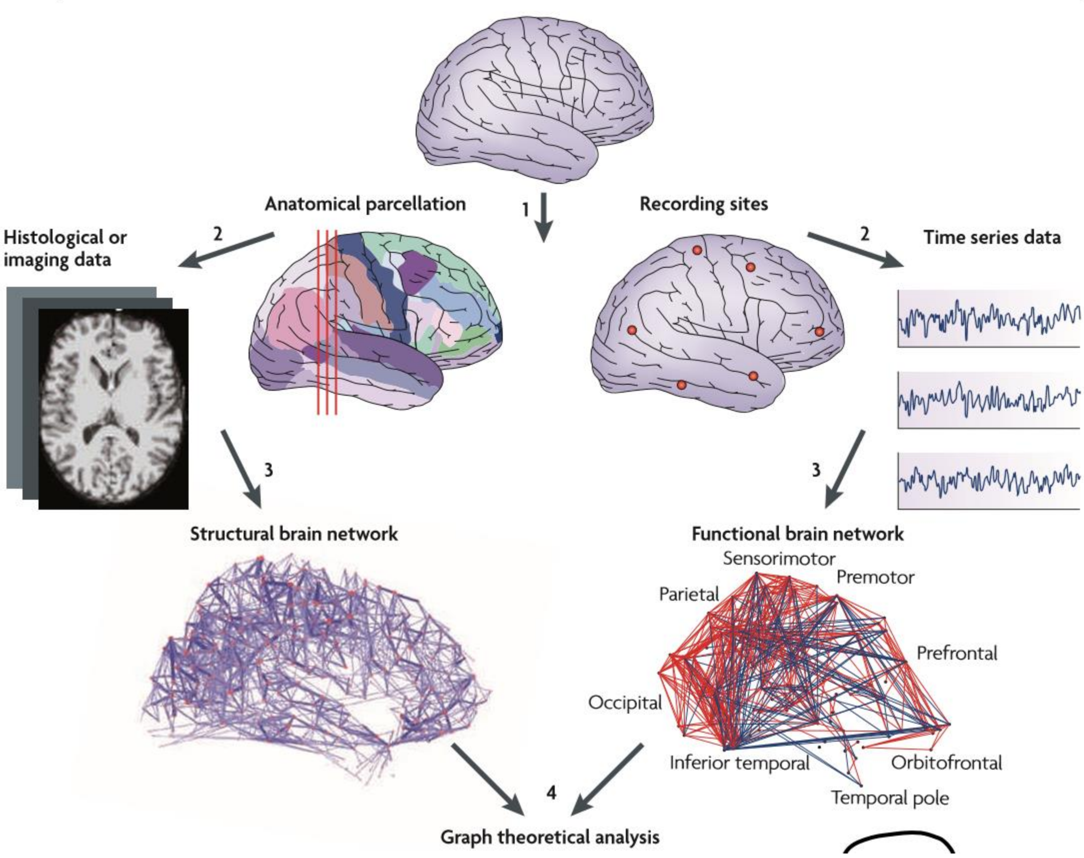
That's exactly what they apply to the brain systems, since the brain's structural and functional systems have features of complex networks like small-world topology and highly connected hubs and modularity.

General ways:

Brain networks can be explored using graph theory through **four** steps:

1. Define the network nodes (MRI is a kind of method to help define).
2. Estimate a continuous measure of association between nodes.
3. Generate an association matrix by compiling all pairwise associations between nodes and apply a threshold to each element of this matrix to produce a binary adjacency matrix or undirected graph.
4. Calculate the network parameters of interest in this graphical model of a brain network and compare them to the equivalent parameters of a population of random networks.

Box 1 | **Structural and functional brain networks**



Structural brain networks:

That's where the **diffusion MRI** method works. A study [54, 55] into the 70-90 cortical and basal brain grey matter areas was using DTI--diffusion tensor imaging and using analytical methods from graph theory.

DTI has difficulty detecting crossing fiber bundles (topology term). **Diffusion spectrum imaging** can overcome this limitation by reconstructing multiple diffusion directions in each voxel [57] and was used to build cortical connection matrices between 500–4,000 homogeneously distributed regions of interest[58].

We use anatomical parcellation to analyze and model the structural brain networks. According to graph theory, structural brain networks can be described as graphs that are composed of nodes denoting neural elements (neurons or brain regions) that are linked by edges representing physical connections. Mapping structural networks of animal models has already been studied and currently(2009), the only nervous system to have been mapped at a cellular resolution is the nematode Caenorhabditis elegans. In larger animals' brains, someone studied the patterns in neuronal connections and led to developing neuronal microcircuits and the formulation of probabilistic connection rules. Data sets have already been created and network analyses of such data sets can tell us a lot about the how related functional areas of those brains are connected.

Studies of human brains are also in progress like Human Connectome[50], which is mapping the structural networks of the human brain at the scale of brain regions.

Functional brain networks:

That's where the functional MRI method works.

Structural network analysis helps us to understand the fundamental architecture of interregional connections, while functional networks directly elucidate how this architecture supports neurophysiological dynamics. Most of these studies are based on functional MRI, electroencephalography (EEG), magnetoencephalography (MEG) and multielectrode array (MEA) data.

Relevant terms:

Small-world: A **small-world** network is a type of mathematical graph in which most nodes are not neighbors of one another, but the neighbors of any given node are likely to be neighbors of each other and most nodes can be reached from every other node by a **small** number of hops or steps.

Hubs: Hubs are nodes with high degree, or high centrality. The centrality of a node measures how many of the shortest paths between all other node pairs in the network pass through it.

Modularity: Each module contains several densely interconnected nodes, and there are relatively few connections between nodes in different modules.

Fiber bundles:

Useful references:

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