Dissertation: Background and Literature

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1 Brain Formation and structure

1.1 Parsimonious principles

These reach back very far to as Ramon y Cajal (1899).

1.1.1 Network wiring cost

There is overvelwheling evidence in favor of this hypothesis (Bullmore and Sporns 2012):

- Cost of building and maintaining axonal connections and speed of transmission increase in wiring volume which is proportional to length (D)
- White matter grows faster than grey-matter as function of brain size, driven by increase in axonal diameter and number synapses per neuron
- Fraction of grey matter neurons that send myelinated axons into white matter slowly reduces with brain size
- The probability distribution of connection distances is skewed towards short distances that will be relatively parsimonious in wiring cost

Factors which potentially explain the deviations from this simple wiring principle (Bullmore and Sporns 2012):

- Volume exclusions = Due to the limited size of the brain, axonal projections must perturbate from the straight line connection
- Functional properties = Example: Monosynaptic vs. Polysynaptic nerves, when you need low latency you would build a high cost long axonal connection

1.1.2 Network running cost

Not part of Cajal's initial principal's, but metabolic cost of running the brain has become an increasingly important principle for network formation.

- Bigger brains are metabolically more expensive, with a rate increasing faster than overall body oxygen increase as function of weight
- The cost attributable to maintenance of electrochemical gradients across membranes
- Cost increases in overall neuronal membrane size as well as axonal length and diameter, this controlling length also limits energy requirements
- Limitation: Networks often functionally configured to be less expensive than possible within the anatomical constraints (network formation), e.g., through sparse coding

1.2 Topological characteristics

1.2.1 Small-world architecture

- Watts and Strogatz analyses nervous system of C. Elegans as binary graph and found both high clustering and short path-length
- Brains posses the small-world properties of high clustering and global efficiency, a modular community structure and a heavy tailed degree distribution, that indicate high connected nodes or hubs
- High clustering and efficiency is attractive to allow for segregation of process (e.g., visual analysis) and integration (distributed process, executive functions)
- IQ negatively correlated with paht lengths, which supports workspace theory, that effortful tasks depend on oscillations in ensembles of anatomically distributed regions
- Topological modularity might also be helpful to evolution, making it more robust to rewiring
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2 Generative network models

These models were first developed and applied to connectome data by Betzel et al. (2016).

2.1 Evaluation

$$E = max(KS_k, KS_c, KS_b, KS_e)$$

to quantify the difference between the synthetic and observed data using the Kolmogorov-Smirnov statistic. The corresponding statistic is computed for every vertex, and then the distributions are compared.

- KS_K Nodal degree = Number of edges that are incident to a vertex
- KS_C Clustering (coefficient) = Measure of the degree to which nodes in a graph tend to cluster together, proportion of possible connections realized among the neighbors of a vertex (Where the neighbor of a vertex are all the other connected vertices)
- KS_b Betweenness centrality = Measures the centrality of a vertex by investigating the number of shortest paths that pass through the vertex (For every pair of vertices there exists a shortest path between them minimizing either the number of edges or the summed weights of the edges)
- KS_e Edge length = Sum off al the edge length that are incident to a vertex

2.2 Optimization

2.3 Rules

2.3.1 Geometric

- Promotion of low cost connections is promoted, but forming only the shortest connections, produces lack of long distance connections, which increases path length, and reduces efficiency
- Problems in reproducing clustering and edge length distributions simultaneously (KS_c, KS_e), this is because strong distance penalty required to make high clustering but then lacking long distance connections

2.3.2 Degree

2.3.3 Clustering

2.3.4 Homophilic

2.3.4.1 Matching index

- Normalized measure of the overlap in two vertexes neighborhoods
- that eta and gamma seem to trade offer with each other, such that a connectome is either shaped by geometry or non-geometric constraints

3 Graphs

3.1 Rich clubs

- Measure the extent by which well connected nodes are connected to each other
- Networks of high rich-club coefficients have many connections between nodes of high degree

4 Random dictionary

- Gray matter = Composed of the neurons (appears darker due ot higher levels of melanin)
- White matter = Mainly made up of myelinated axons also called tracts (light appearance through the lipid content of myelin)
- Monosynaptic reflex = There is only one synapse between the afferent nerve and the efferent nerve (slow latency)
- Polysnaptic reflex = There are more than one synapse between the nerves, such that there is higher latency
- Sparse coding = Neural coding that represents the information by activation of small subset of the available neurons
- Small-world = Combine random and regular topological properties, i.e., high efficiency (short path length) and high clustering
- Community structure = Sub-global organization of a complex network, an example is modular organization
- Heavy-tailed degree distributions = Proportion of high degree nodes is larger than in random graphs (so that they can be hubs)

References

Betzel, Richard F., Andrea Avena-Koenigsberger, Joaquín Goñi, Ye He, Marcel A. De Reus, Alessandra Griffa, Petra E. Vértes, et al. 2016. "Generative Models of the Human Connectome." *NeuroImage* 124 (January): 1054–64. https://doi.org/10.1016/j.neuroimage.2015.09.041.

Bullmore, Ed, and Olaf Sporns. 2012. "The Economy of Brain Network Organization." *Nature Reviews Neuroscience* 13 (5): 336–49. https://doi.org/10.1038/nrn3214.