Analysis of connectivity of gray matter regions using DTI and graph theory

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Introduction: The connectivity of gray matter regions in the brain via white matter tracts has recently become an area of wide interest due to the advances in imaging techniques that can measure structural connections via white matter (Diffusion Tensor Magnetic Resonance Imaging - DTI) and functional connectivity via correlation of functional activation (functional Magnetic Resonance Imaging- fMRI). The information that can be extracted from these modalities has not yet been harvested fully due to their relative novelty; however some studies have proven its potential [1,2,4]. We propose a computational methodology that utilizes DTI and structural MR images of the brain, graph theory, and clustering algorithms to explore the regions of high connectivity and importance to overall connectivity in normal brains.

Data and Methods: In the project, we will use diffusion tensor imaging (DTI) data from 5 normal brains and graph theoretic methods to explore clusters of highly connected gray matter regions and quantify these regions' role in overall brain connectivity. We proceed via the following steps: 1) co-register structural (T1) MRI brain volumes against diffusion (DTI, 30 directions) volumes, 2) fully reconstruct the orientation distribution function (ODF) of raw DTI data, 3) parcellate T1 volumes into 116 cortical structures, using Statistical Parametric Mapping (SPM) software and standard 116-region anatomic atlas, 4) use parcellated structures from T1 volume to seed corresponding regions in DTI volume, and perform tractography, 5) probabilistically "count" all tracts originating and terminating in any pair of cortical regions, and use this to build a connectivity matrix and therefore the connectivity graph, as in [3]. This process is repeated for each normal patient, and the collection of connectivity graphs will be averaged to create a graph that is more robust to error in data acquisition and processing. After this average connectivity graph has been created, we use max-flow algorithms that essentially give a measure of the amount of information that can flow between any two nodes directly or indirectly via routes through other nodes. A measure of overall connectivity of the graph can be found by summing all of the pair wise connectivities in this max-flow graph. We then successively delete one node at a time and recompute the max-flow graph and the corresponding overall connectivity measure. This will give us a quantification of each node's importance in global brain connectivity.

Results: First, we performed clustering on the brain connectivity graph and found that the frontal and temporal regions are more closely connected to regions in their respective hemispheres, but the occipital and parts of the parietal region seems to be more connected bi-laterally, as they are grouped into the same cluster (shown in the two left panels of Figure 1). Performing clustering using 6 groups does not change this bi-lateral tendency. Further insight is gained if we calculate the effect of node deletion on overall connectivity of the max-flow graph of the brain. The right panel gives the 116 regions in the brain each plotted with color that indicates the change in brain connectivity of the max-flow graph (green- large change, yellow- small change). It is interesting to note that the left hemisphere is much more important as far as connectivity than the right, possibly because it is the location of the language center in most people. Among the most important regions for overall brain connectivity were the left and right precuneus and the right cuneus, which are centers dealing with sensory-based functions. This methodology can be extended to explore the importance in overall brain connectivity of various white matter regions, with possible application to assessment of stroke severity or traumatic brain injury.

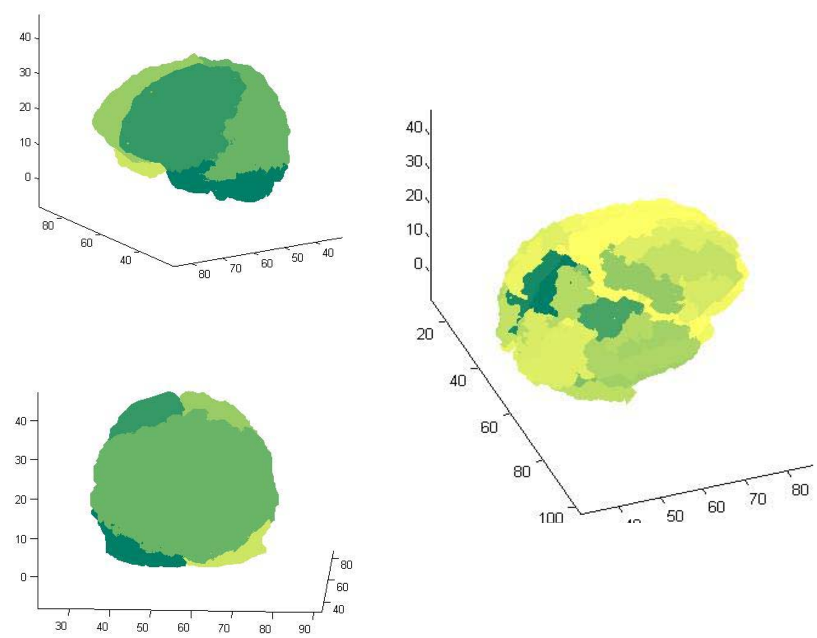

Figure 1: (left two panels) Clusters of gray matter regions with high inter-connectivity, note the bilateral tendency of the occipital and parietal regions. (right panel) The amount of change in overall brain connectivity (green-high, yellow-low) in the max-flow graph when that particular gray matter region and all of its connections are removed. Note the higher disruptions in overall brain connectivity when gray matter regions in the left hemisphere are removed, possibly because it is the location of the language center in most normal patients.

[1] Achard S, Salvador R, Whitcher B, Suckling J, and Bullmore E. (2006) *A Resilient, Low-Frequency, Small-World Human Brain Functional Network with Highly Connected Association Cortical Hubs.* Journal of Neuroscience, 26(1): 63-72.
[2] Bowman FD, Derado G, and Chen S. (2009). *Evaluating Functional Connectivity using fMRI Data with Diffusion-Based Anatomical Weighting.* Poster presentation at the 15th annual meeting of the Organization for Human Brain Mapping, San Francisco , CA.
[3] Iturria-Medina Y, Sotero R, Canales-Rodríguez E, Alemán-Gómez Y, and Melie-García L. (2008) *Studying the human brain anatomical network via diffusion-weighted MRI and Graph Theory.* NeuroImage. 40(3): 1064–1076.
[4] Sporns O, Zwi JD. (2004) *The small world of the cerebral cortex*. Neuroinformatics 2: 145–162.