Global Quantification of Structural Brain Connectivity

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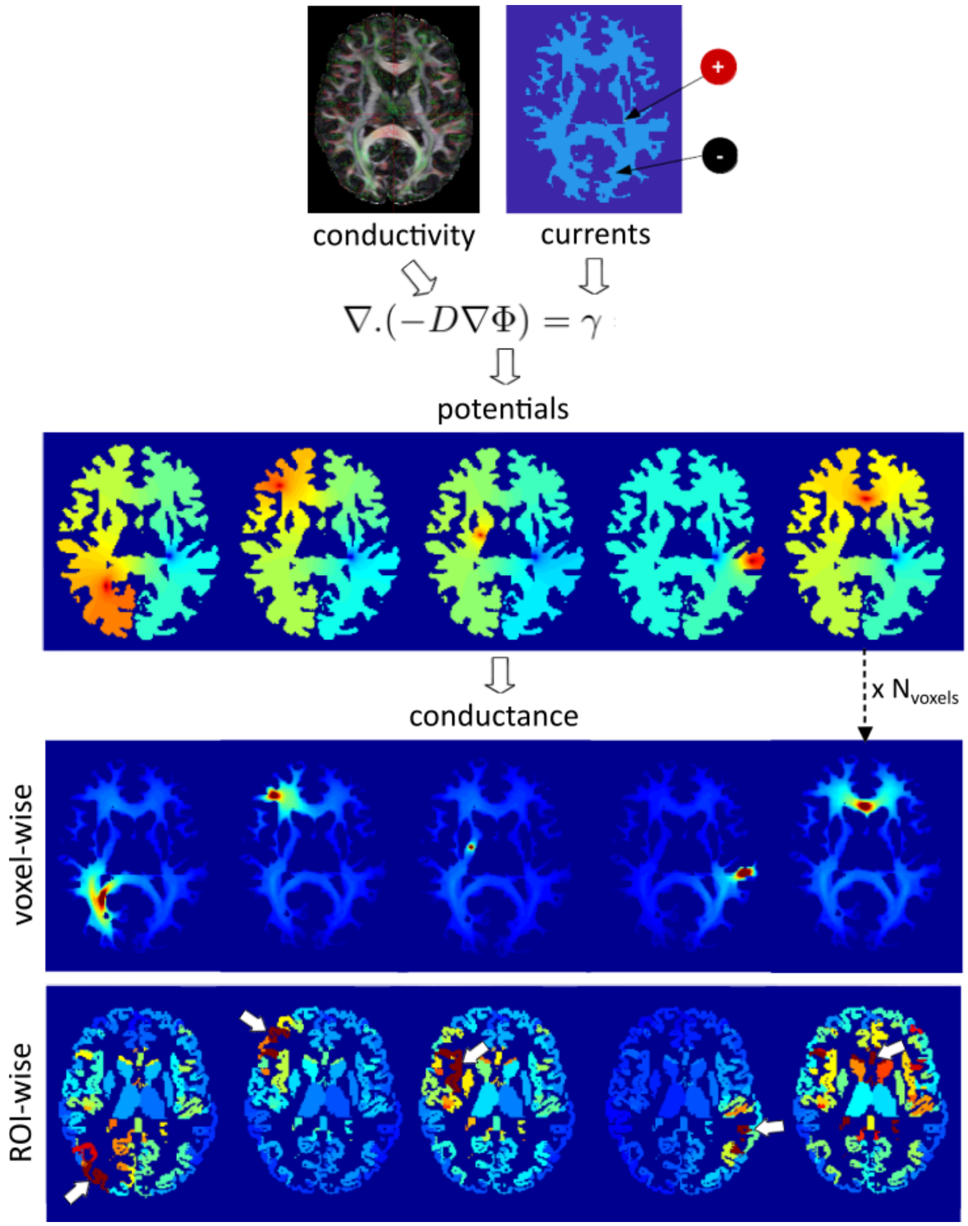
Introduction:

Connectomics has proved promising in quantifying and understanding the effects of development and certain diseases on the brain. However, existing literature on brain functional and structural connectivity is not fully consistent: while several studies have shown functional connectivity to be correlated with structural connectivity [1], strong functional connections have also been commonly observed between regions with no direct structural connection [2]. Some of this variance has been linked to the impact of indirect structural connections, usually not considered in modeling [2,3]. Such connections have been successfully accounted for via graph theory [2-4], with a limitation in the amount considered.

The information that is hidden in these indirect connections could be critical for the quantification of brain connectivity and for the discovery of new imaging biomarkers that might help us better understand clinical data, and predict the development of diseases such as Alzheimer's from connectivity patterns [5-7]. The use of new and more accurate biomarkers could improve prognosis, diagnosis, and treatment, as well as deepen our understanding of the human brain and how it is affected by disease, through imaging.

Methods:

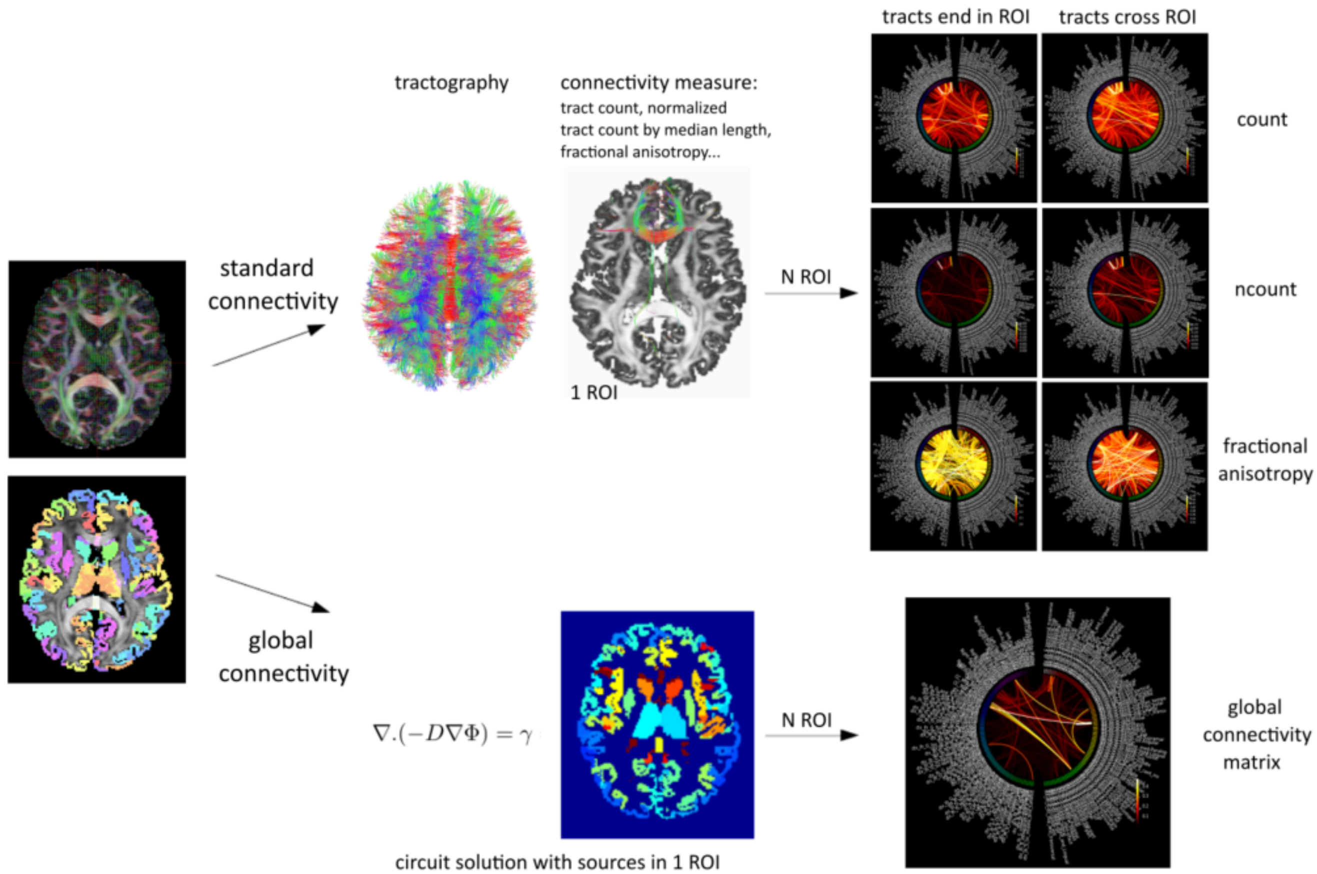
Brain connectivity has been modeled with the help of the established mathematical framework of electrical circuits [5-7]. In this work, we model brain connectivity globally by using a combination of differential Maxwell's equations and Kirchhoff's circuit laws, resulting in an equation similar to the heat equation proposed in [8,9]. As depicted in Fig.1, we assign local anisotropic conductivity values D, which are functions of the diffusion tensors computed from diffusion MRI [10,11], to N image voxels. By solving the partial differential equation $\nabla\cdot(-D\,\nabla\Phi)=\gamma$ for a certain current γ between a pair of voxels, we find the potential map Φ for that specific source/sink configuration. Contrary to [8,9], we then obtain a measure of conductance between each pair of voxels from all the potential maps (N potential maps by exploiting the superposition property). This measure is computed globally, by considering all diffusion paths between them. The same measure can be computed ROI-wise, by distributing the currents γ among the ROI voxels.



·Modelling of brain connectivity globally using a combination of differential Maxwell's equations and Kirchhoff's circuit laws, with DTI tensors computed from DWI using DSI Studio as input.

Results:

We tested our approach on the diffusion-weighted images of a subject from the publicly available Human Connectome Project (HCP) data set. As shown in Fig.1, we computed voxel-wise conductance maps from a single point (in red) to all the rest when using a white-matter mask, and parcel-wise conductance maps from a single ROI (in red, indicated with an arrow) to all the other ROIs. Note that all the ROIs are at least weakly connected, given that all indirect connections are considered. These maps could then be thresholded to constrain the amount of connectivity that we want to consider. Similar to standard approaches, we then compute a connectivity matrix from these ROI-to-ROI connectivity measures, as shown in Fig.2. Using a standard connectivity approach, we performed tractography [11,12] and computed a tract-count measure of connectivity between ROIs: plain count, normalized by the median length, or weighted by fractional anisotropy. All these measures gave us different connectivity matrices. In our case, we produce a single connectivity matrix that is only dependent on the input conductivity values.



·Comparison of connectivity matrices of the proposed method with state of the art connectivity.

Conclusions:

Our global approach allows us – without relying on other processing steps such as tractography – to account for indirect brain connections that would not otherwise be considered by standard techniques. This modeling of brain connectivity enables the computation of voxel-wise (and thus parcellation-independent), and global ROI-wise connectivity matrices. Future work will be dedicated to the assessment of this method and its potential use in the better understanding of the variance between structural and functional connectivities, as well as in the discrimination of healthy and diseased populations.

Imaging Methods:

Diffusion MRI

Modeling and Analysis Methods:

Diffusion MRI Modeling and Analysis [1]
Methods Development [2]

Keywords:

WHITE MATTER IMAGING - DTI, HARDI, DSI, ETC
Other - Brain connectivity

[1|2]Indicates the priority used for review

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Please indicate which methods were used in your research:

Structural MRI
Diffusion MRI

For human MRI, what field strength scanner do you use?

3.0T

Which processing packages did you use for your study?

Free Surfer
Other, Please list - DSI Studio

Provide references using author date format

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