MultiXplore: Multimodal Exploration Platform for Collocated Functional and Structural Connectivity

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Introduction

Functional and Diffusion Tensor Imaging are two established brain imaging modalities are generally used to explore the functional correlates and anatomical connections. MultiXplore is a 3D interactive tool that facilitates the visualization of the links between functional connectivity and structural connectivity. An intuitive framework has been developed to define brain network nodes (cf. Kaiming 2012) interactively. We compare and contrast our work to a recent multifunctional interactive unit, implemented in FATCAT, in which feedback from DTI assists user to modify anatomical regions of Interest (ROI) (Taylor 2016).

Integrating data from multiple modalities is a necessary component of a viable solution for brain connectome navigation. However, information overload is one of the drawbacks of current software interfaces. In MultiXplore, users are given the freedom to adjust inputs from different channels based on the current criteria of interrogation, while observing current selection in a 3D space that belongs to brain anatomy.

Methods

Representation of functional and structural connectivity matrices in a 3D brain context provides user with an interactive tool to investigate connectomics, and facilitates scientific enquires of functional-structural relationships in behavioural datasets. This feature has been the main consideration in MultiXplore design. This toolchain has been implemented within Slicer, which is the open source, cross platform ecosystem. Slicer allows biomedical researchers to implement medical image computing algorithms, while accessing to required libraries that are built-in to Slicer and offers a great deal of functionality, flexibility and extensibility to the developer, as well as end user (Fedorov 2012).

MultiXplore operates on the following classes of data:

1- Functional connectivity matrix along with names of regions

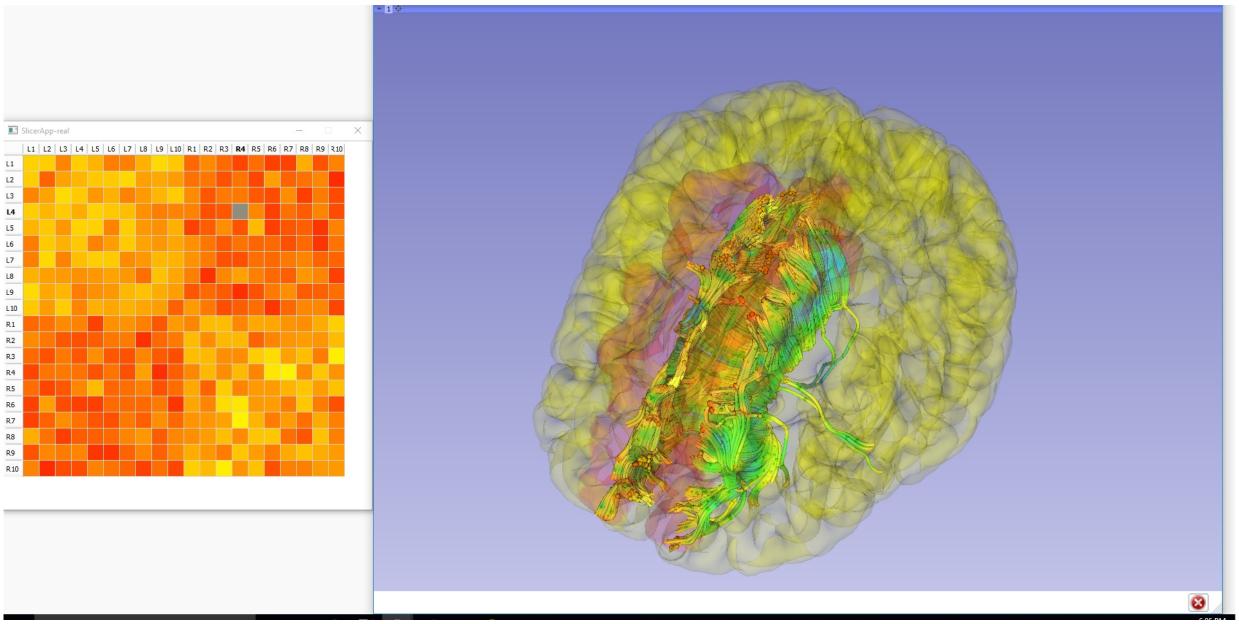
2- Subject registered brain atlas, surface meshes and regional labels

3- DTI images for generating full brain deterministic tractography

A fiber bundle extraction algorithm searches through lines and points of imported tractography file, while checking for the existence of any given point within an ROI and saves lines that cross through. Next, desired lines and assigned tensors are copied to a new VTK file.

Results

MultiXplore is composed of two major units, an interactive input matrix, and a 3D canvas. The input matrix accepts an N×N matrix of connectivity graph and represents nodes as N rows or columns labeled by names of regions. Edges are cells of the matrix and a color map indicates link strength. Cells can be selected or deselected individually or as a group, based on user's preference. In the canvas, surface models of right and left hemispheres are displayed with color label overlays to localize graph nodes that will turn on, once corresponding nodes are selected. Simultaneously, fiber streamlines crossing from corresponding regions will appear. Also, user can manipulate this 3D view by rotating and zooming in and out. MultiXplore allows user to visually inspect anatomical location of functional connection nodes and compare existing structural links. Usability study involves metrics on the speed and accuracy with which this tool can be used to perform interactive visualization tasks involving the 3D dataset.



Linked Input Matrix and 3D view of Slicer: upon user's selection, a pair of regions from left and right hemisphere is highlighted in both units and existing fiber tracts become visible.

Conclusions

The initialization of the interface is established by running the Python script through Slicer. The input matrix is displayed within a user-friendly graphical interface to support interaction with the traditional connectivity graph. The resulting unified representation of two main neuroimaging modalities can be a valuable tool for experts in visual examining of hypothesis in discovering physiological basis of functional connections. Moreover, extracting brain pathways based on user selected ROIs is a promising approach to examine validity of parameters and current methods of deterministic tractography. We present a case study of this use case, based on our behavioural imaging studies.

References

Li, Kaiming, et al. "Visual analytics of brain networks." *NeuroImage* 61.1 (2012): 82-97.

Taylor, Paul A., et al. "Open Environment for Multimodal Interactive Connectivity Visualization and Analysis." *Brain connectivity* 6.2 (2016): 109-121.

Fedorov, Andriy, et al. "3D Slicer as an image computing platform for the Quantitative Imaging Network." *Magnetic resonance imaging* 30.9 (2012): 1323-1341.

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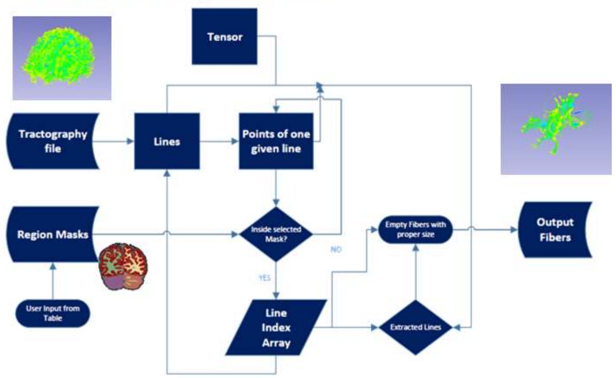
Motivation

- Functional and Diffusion Tensor Imaging (two established brain imaging modalities) are generally used to explore the functional correlates and anatomical connections.
- Human Brain Connectome studies leads to major advances in our understanding of brain functionality and future treatments of many neurological and psychiatric disorders.
- In order to save and further understand functional hubs, related anatomical links need to be identified and preserved.
- Currently, no method or tool exists that can allow for multimodal exploration of brain networks
- We compare and contrast our work to a recent multifunctional interactive unit, implemented in FATCAT, in which feedback from DTI assists user to modify anatomical regions of Interest (ROI) [1,2].

Methods

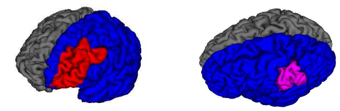
fMRI driven filtering of streamlines

- A fiber bundle extraction algorithm searches through lines and points of imported tractography file while checking for the existence of any given point within an ROI and saves lines that cross through.
- A "Line Index Array" stores indices of the selected lines and sends them to the unit that generates new tracts.
- Next, desired lines and assigned tensors are copied to a new VTK file that represents tracts and colored segments to indicate underlying tensor information.



Merging of Brain Grey Matter Masks in 3D Slicer

- Primarily, 3D Slicer doesn't allow to load more than one mask (scalar overlay) for each brain volume (model).
- Using a new developed script, any number of isolated brain masks can be combined and displayed simultaneously.
- As a result, new integrated masks can be created and updated easily and frequently.



Objectives

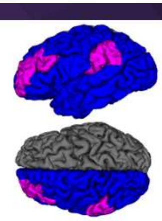
Integrating data from multiple modalities is a necessary component of a viable solution for brain connectome navigation. However, information overload is one of the drawbacks of current software interfaces. As such, our objective is: *Giving the users freedom to adjust inputs from different channels based on the current criteria of interrogation, while observing current selection in a 3D anatomical environment.*

Methods

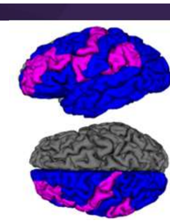
Creation of Patient-Specific visualization Scene

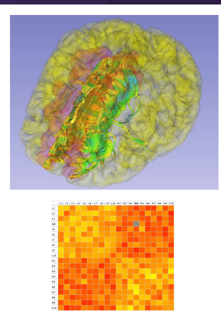
- List of functional regions/maps and functional connectivity matrix will be imported by user.
- Each patient's Grey Matter mask and functional labels can be generated by FSL and FreeSurfer and added to the platform.
- Whole brain tractography are computed prior to user's interaction by 3D Slicer and loaded to the platform.

Results

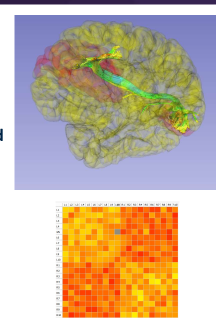


- *Left:* Sagittal and axial views of Single brain mask created by combining supramarginal and rostralmiddlefrontal grey matter masks (registered by FSL) for the left hemisphere.
- *Right:* This procedure can also accept 3 or more input brain masks and generate an integrated single mask. New mask (in comparison to the left figure) is precentral gyrus of left brain hemisphere.





- Selected pair of regions are highlighted in red to contrast with the rest of the brain cortex with yellow color. User's selection from functional connectivity matrix (imported by user) is painted in gray. User can select single (or multiple) cells (equivalent to a pair of region) from the matrix and group of deterministic fiber tracts that intersect both volumetric regions of the selected pair(s) will be displayed in the 3D scene.
- *Left:* Selected pair of regions from left and right hemispheres are both superiorfrontal gyrus which depicts a part of corpus callosum fiber bundle.
- *Right:* Selected pair is from left hemisphere consisting of lateral orbitofrontal and fusiform gyrus and extracted fiber bundle.



Discussion

- A Novel visualization method has been designed and developed to visualize deterministic white matter fiber tracts (structural connections) and functional connectivity hubs at the same environment.
- Interactive connectivity matrix allows user to select pairs of predefined functional regions and visualize underlying connective fiber tracts.
- The resulting unified representation of two main neuroimaging modalities can be a valuable tool for experts in visual examining of hypothesis in discovering physiological basis of functional connections.
- Current implementation of the system is by Python scripting in command line of 3D Slicer, future work will be translation to a user friendly GUI.
- Interactive filtration of brain white matter fiber bundles is a promising approach to inspect tractography results and tune it's parameters iteratively. This is due to less cluttered view [3] that is a result of user's selection.

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References

1. Li, Kaiming, et al. "Visual analytics of brain networks." *NeuroImage* 61.1 (2012): 82-97.
2. Taylor, Paul A., et al. "Open Environment for Multimodal Interactive Connectivity Visualization and Analysis." *Brain connectivity* (2015).
3. Tax, Chantal MW, et al. "Seeing More by Showing Less: Orientation-Dependent Transparency Rendering for Fiber Tractography Visualization."*PloS one* 10.10 (2015): e0139434.

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