**Neuronavigator: Structural and functional connectivity tool for mobile devices**

Abstract: Neuronavigator is a mobile application for visualizing and exploring structural and functional connectivity in the human brain. The app features five separate modalities 1) diffusion MRI (DWI), 2) structural t1-weighted MRI (T1), 3) functional MRI (BOLD), 4) susceptibility-weighted MRI (SWI) and 5) time-of-flight MRI (TOF). Employing research-level processing pipelines on the modalities results in vascular (veins, arteries), cortical/subcortical segmentations, probabilistic white matter bundle tractography, and interactive functional connectivity maps. The app is an accessible resource and comprehensive visualization tool for MRI-based human neuroimaging results.

Introduction: Increases in software and mobile device hardware allows for millions of vertices to be rendered at high frames per second (fps) on common devices such as the iphone and Samsung galaxy. High resolution human neuroimaging datasets acquired with magnetic resonance imaging (MRI) reveal detailed maps of human brain structure and function and the opportunity for interactive exploration. In particular, diffusion weighted MRI (DWI) images allow for interaction with fiber pathways using selection objects, and functional MRI (BOLD) images allow for interactive functional connectivity probing based on regions of interest (ROIs). These interactive brain visualization techniques are valuable tools for educators, basic research (Ref), and even clinicians are increasingly using more advanced versions to plan surgery (ref).

The brain is an integrated system of gray matter processing centers connected by white matter pathways with energy managed by venous/arterial vasculature. The brain is compartmentalized, with different regions performing different functions (Broca, Freesurfer maps). White matter connections between functionally distinct regions for information processing (ref). Today, MRI-based neuroimaging techniques allow us to map the brain’s systems non-invasively, providing a detailed functional and structural ‘connectome’ for every individual. The functional and structural connectomes are though to be related (ref) but to what extent is still a matter of debate (ref). The structural connectome is constructed by defining a set of gray matter ROIs, and plotting the connections between them using the adjacency matrix representation of a graph. Graph theory is then applied to the matrix, to derive measures such as hubness, degree, and centrality, informing theories of human brain organization (ref). Functional connectivity defines connections between the set of ROIs as the temporal correlation of their BOLD signal, regions with high functional connectivity being highly correlated in time. Similar graph-theoretic approaches are applied to functional connectivity matrices.

The ability to map an individual’s functional and structural connectome is already yielding major advances in theory of human brain organization (refs). However, the general public is still not aware of the precision and accuracy with which human brain can be mapped. Increased awareness of these maps is critical, as they are already being used to inform treatment and predict behavior.

Materials and Methods:

One healthy human male 33 years old underwent T1-weighted (params), Diffusion weighted (params), SWI, time of flight angiogram (params) and resting state BOLD (params).

Diffusion weighted images were corrected (all correction steps) and tractograms computed (params) which were subsequently bundled (params). Bundles were sub-sampled to improve performance (figure, bundles with different sub-sampling). Unity rendering uses OpenGL and speed increases can be obtained using mesh instead of drawing all lines. Due to the 64000 vertex limit for Unity meshes, bundles were composed of multiple mesh. The basic Unlit shader was used to render points from bundles. To allow for interaction with the tractography, a quad tree was implemented over 3d space and populated with tractography points. A user-controlled spherical selection object sampled 3d space and the quad tree was queried every frame to define ‘currently selected tracks’ (figure). In this manner, the user can precisely control which fiber bundles to display.

SWI phase and magnitude images were combined and the resulting image filtered using VED to enhance vesselness. The VED image was enhanced further (bernier) and segmented, then hand-trimmed to remove spurious clusters of non-venous tissue. An iso-surface of the 3d VED filtered voxel data was created and imported to Unity. A similar procedure was employed on TOF images, to yield arterial iso-surface in Unity.

T1 gray matter was parcellated into subcortical and cortical ROIs using Freesurfer (ref). Freesurfer labels were converted to 3d volumes and then an iso-surface constructed based on the 3d volume which was imported into Unity. High vertex count anatomical ROIs were included for visualization, and lower vertex count iso-surfaces of the same ROIs were also included for fast collision detection using raycasting. The cortical ROIs were from the X atlas, 68 total cortical regions (34 per hemi) and 27 subcortical ROIs including ventricles. A skull-stripped T1 was also imported into unity and each slice converted to a texture for display along xyz axes. Left and right surfaces of the entire cortex were also added to the scene, to allow for semi-opaque rendering of the entire brain surface.

BOLD images were motion corrected, bandpass filtered (0.005-1Hz) and the timeseries in each voxel was linearly sub-sampled from 800 points (8 minutes) to 80 points to speed up the resting state connectivity analysis. Voxels size was interpolated (increased to 4mm isotropic from 3mm isotropic) and 3d smoothing was performed on each volume. Four-dimensional FMRI niftis were imported to Unity. A second quad tree was instantiated to track the location of a functional connectivity selection object which the user could move in 3d space to examine the functional connectivity across different brain areas in an interactive fashion.

Three additional cameras were added to the scene to allow for slice scrolling in x, y, and z dimensions. The camera clipping planes were narrowed, to only show a thin slab at the same level as the plane.

Results:

The app achieved good performance on a wide range of devices and platforms. Six separate device/platforms were tested 1) Samsung galaxy S5 2) Windows 10 laptop 3) ipad 4) google pixel 2 5) webgl. Fps as a function of number of vertices are shown in Figure 1. FPS as a function of number of different modes (tractography interaction, functional connectivity interaction) is shown in Figure 2. Surprisingly, the Ipad outperformed all other devices for fps rendering as well as fps during interaction, followed by the PC, webgl, google pixel, and android S5. No appreciable performance deficit was observed due to any of the cortical/subcortical surfaces, but the high vertex count vascular surfaces did result in significant FPS decrease.

Most of the functional networks including visual, motor, auditory, executive control, and default mode networks were easily obtained using the FCT.

Surface

rendering

Raycasting

Discussion:

Sharing of datasets is becoming increasingly common in the neuroimaging community (ref), but human neuroimaging datasets are often difficult to process, requiring operating system and platform specific