Exploring geometrical sheet-like structures in real-time

Maxime Chamberland[1], Chantal M. W. Tax[2], David Fortin[3], Kevin Whittingstall[4] and Maxime Descoteaux[1]
[1]Sherbrooke Connectivity Imaging Lab, Sherbrooke, Québec, Canada
[2]CUBRIC, School of Psychology, Cardiff University, United Kingdom
[3] Divison of neurosurgery and neuro-oncology, University of Sherbrooke, Québec, Canada
[4]Department of diagnostic radiology, University of Sherbrooke, Québec, Canada

Target audience: Researchers who are interested in the so-called "*sheet or no sheet*" debate and who are looking to explore path neighborhoods in their own data in a real-time fashion.

Purpose: Conventional streamline tractography algorithms infer connectivity by following directions which are maximally aligned at every voxel. Recently, tremendous attention has been given to the investigation of the brain's geometrical structure[1-4]. In their 2012 work[1], Wedeen and colleagues suggested that the cerebral fiber pathways form a well-organized, 3D grid consisting of sheets of fibers by exploring different path neighborhoods. In their approach, streamline generation and streamline visualization are done separately in two steps; first streamlines are reconstructed using a fixed set of parameters (Diffusion Toolkit[5]). Subsequently, the resulting pathways are visualized offline (TrackVis[5]). However, to the best of our knowledge, there exists no publicly available tool for the diffusion community to generate and visualize patch-like structures on the fly. In order to facilitate the interpretation of the sheet-structure hypothesis, we provide a fully interactive tool for the exploration of grid-like structures using the Fibernavigator[6], available online at: `chamberm.github.io/fibernavigator_single.html`.

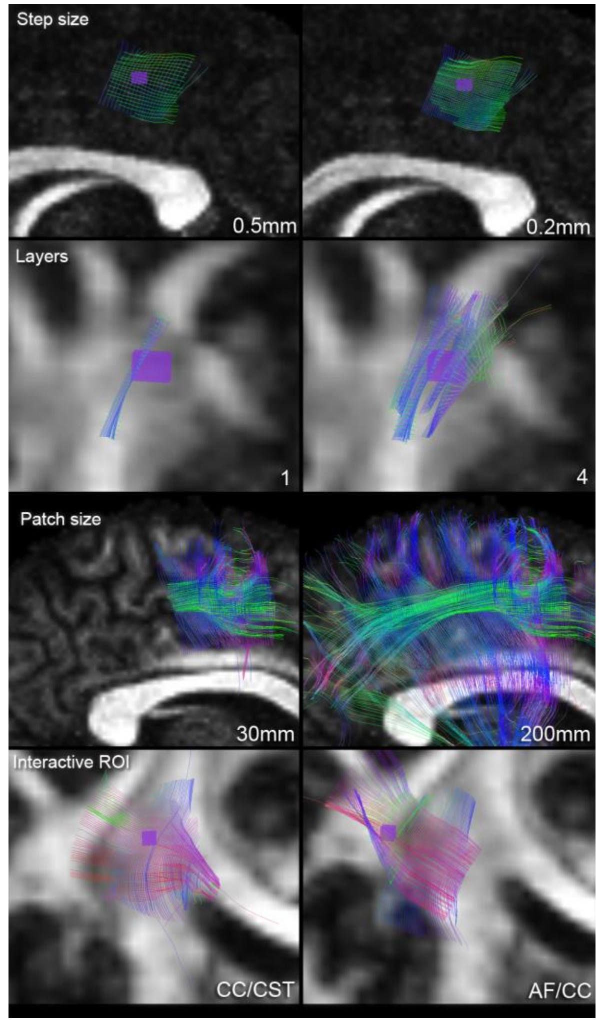

Fig.1: Illustration of the different geometrical parameters.

Methods: A single shell (90 directions, b=3000s/mm^2) of a Human Connectome Project[7] dataset was extracted (voxel size: 1.25mm). Constrained spherical deconvolution[8, 9] (CSD, $l_{max} = 8$) was used to generate and extract up to 3 main peaks per voxel. A white matter mask served as tracking domain. Tractography is initialized from a single seed inside a sizeable cubic-ROI that can be moved across the whole brain volume. Multiple "layers" of sheets can be obtained by increasing the number of seeds per axis of the ROI. Streamline generation is inspired by the method described in Wedeen et al. 2014[10]. First, two peaks are chosen at random to initiate tractography along the "backbones" of the patch. Next, for each point along the first backbone, seeds are re-initiated in the direction of the second backbone and vice-versa. Most importantly, pairs of peaks have to be appropriately matched when stepping along a pathway to account for curvature of pathways. Thus, instead of only considering the peaks that are maximally aligned at each step, we consider the whole *frame*[4] within each voxel (i.e. by minimizing the sum of the dot products between all possible pair of peaks). Peaks are thus matched according to the previously obtained permutation. Finally, if a voxel contains only one peak, propagation is resumed like in conventional streamline tractography. Multiple conventional tractography parameters can be adjusted in real-time to instantly reflect their effect on the streamlines[6], such as the angular threshold and stopping mask criterion. In addition, geometric parameters such as the grid spacing (i.e. step size), # of layers (i.e. # of seeds), patch size (i.e. max length) and ROI positioning are also tunable. Here, instead of using the classical rejection rule: `if streamlines < max_length, discard`; streamlines are simply "cut" once they reached the desired patch-length.

Results: Fig. 1 shows the influence of real-time parameter tuning using the interactive tool. Although parameter showcase was focused in the centrum semiovale region, multiple sheet-like structures where fluidly generated in other areas of the brain such as at the junction of Cingulum (Cg)/Corpus Callosum (CC), Arcuate Fasciculus (AF)/Optic Radiations (OR) and AF/CC (not shown here).

Discussion & Conclusion: The real-time part is at the heart of this method, meaning that the user never has to request streamlines to be updated since they are automatically recomputed and rendered on the fly. Note that the proposed tool is not limited to only explore sheet-forming structures, but rather the whole path neighborhood environment. We believe that having the ability to interactively navigate along these interwoven paths will allow for a better understanding of the sheet structure hypothesis.

References: [1] Wedeen et al., Science 335: 1628-1634, 2012; [2] Catani et al., Science 337: 1605, 2012; [3] Wedeen et al., Science 337: 1605, 2012; [4] Tax et al. Proc Soc. Mag. Reson. Med. 24 #0791, 2016; [5] Wang et al. Proc Soc. Mag. Reson. Med. 15 #3720, 2007; [6] Chamberland et al. Front. Neuroinf. 8: 59, 2014; [7] Van Essen et al. NeuroImage 80: 62-79, 2013; [8] Tournier et al., NeuroImage 35: 1459-1472, 2007; [9] Tax et al., NeuroImage 86: 67-80, 2014; [10] Wedeen et al. Proc. Intl. Soc. Mag. Reson. Med. 22 #0803, 2014.