Atlas-based multi-direction tractography using tensor registration and orientation statistics

Abstract Submission No:

2281

Authors:

Ryan Cabeen[1], David Laidlaw[2], Mark Bastin[3]

Institutions:

[1]Brown University, Providence, RI, United States, [2]Department of Computer Science, Brown University, Providence, RI, [3]University of Edinburgh, Edinburgh, United Kingdom

Introduction:

Atlas-space reconstruction of white matter tracts offers a way to understand consistency of anatomy across a population; it also provides a reference for anatomically specific comparisons in clinical study [1,2]. Two important steps in this process are spatial normalization and population statistics. Spatial normalization may be based on scalar measures or richer models of local diffusion [3,4]. Population statistics of anatomical structures in atlas space may be computed from shape models of pathways, or more locally with tensors or ODFs [5]. This study investigates the use of tensor registration and orientation statistics of a multi-direction diffusion model. To evaluate this approach, we examine angular dispersion of the registration and reconstruct pathways in atlas space.

Methods:

Acquisition: An IRB-approved diffusion MRI protocol was used to acquire data from 80 (39 male) healthy volunteers uniformly distributed in age from 25 to 64 years. Imaging was conducted on a GE 1.5T scanner with 2x2x2mm voxels, 64-directions, b=1000s/mm2, and resolution 128x128x72.
Per-subject analysis: Volumes were corrected for motion and eddy current artifacts and were skull stripped with FSL [6]. Two-direction stick-and-ball diffusion models were fit using FSL, a model consisting of a single isotropic tensor, multiple infinitely anisotropic tensors and volume fractions for each component [7].
Group analysis: A population-specific template was computed by diffeomorphic tensor registration using DTI-TK [3]. Diffusion models for each subject were deformed to template space, with fiber orientation rotation by the finite strain method [8]. Two mean fiber orientations were computed per voxel using an iterative process to minimize the angular dispersion across the subjects, accounting for swaps and inversions in their vector representation. For both fiber compartments, angular dispersion was measured by the average angle to the mean fiber, weighted by each fiber's volume fraction. Custom streamline deterministic tractography was used to account for multiple directions, with the following tracking parameters: step size 1.5mm, two seeds/voxel, angle threshold 35 degrees, minimum length 20mm, Runge-Kutta integration, and fiber volume fraction 0.15. Major pathways were manually segmented by spherical ROIs using TrackVis.

Results:

Figure 1 shows whole brain tractography derived from the mean fiber orientation in atlas space, in comparison to a single tensor atlas and the NTU-90 DSI atlas [9.10]. We found a number of crossing fiber configurations present in the multi-direction reconstruction that were not present in the others. Figure 2 shows major pathways and those not present in the single tensor atlas (shown) or the NTU-90 atlas (not shown), most notably the two dorsal fronto-occipital pathways. In general, we found decreasing dispersion with increased volume fraction. We also found an overall greater dispersion for the smaller volume fiber compartment. Angular dispersion was found to be 13.43 +- 5.06 for voxels with a single fiber. For voxels with two fiber orientations, the angular dispersions were 13.57 +- 3.37 and 20.56 +- 7.74 degrees for the larger and smaller components, respectively.

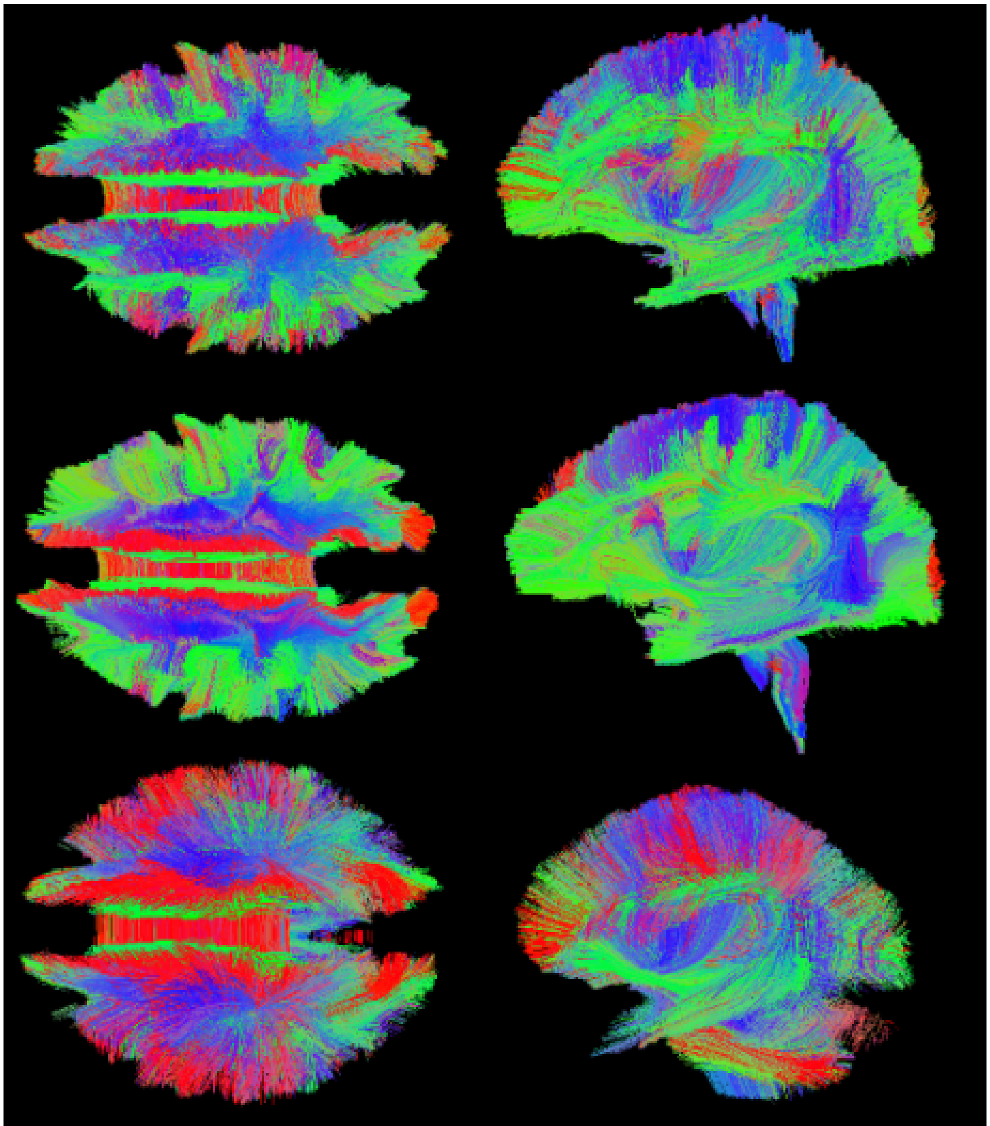

Figure 1: Whole brain tractography reconstructed from multi-direction (top), single tensor (middle), and q-space (bottom) models. The top and middle were constructed from our collected data, and the bottom is the NTU-90 atlas.

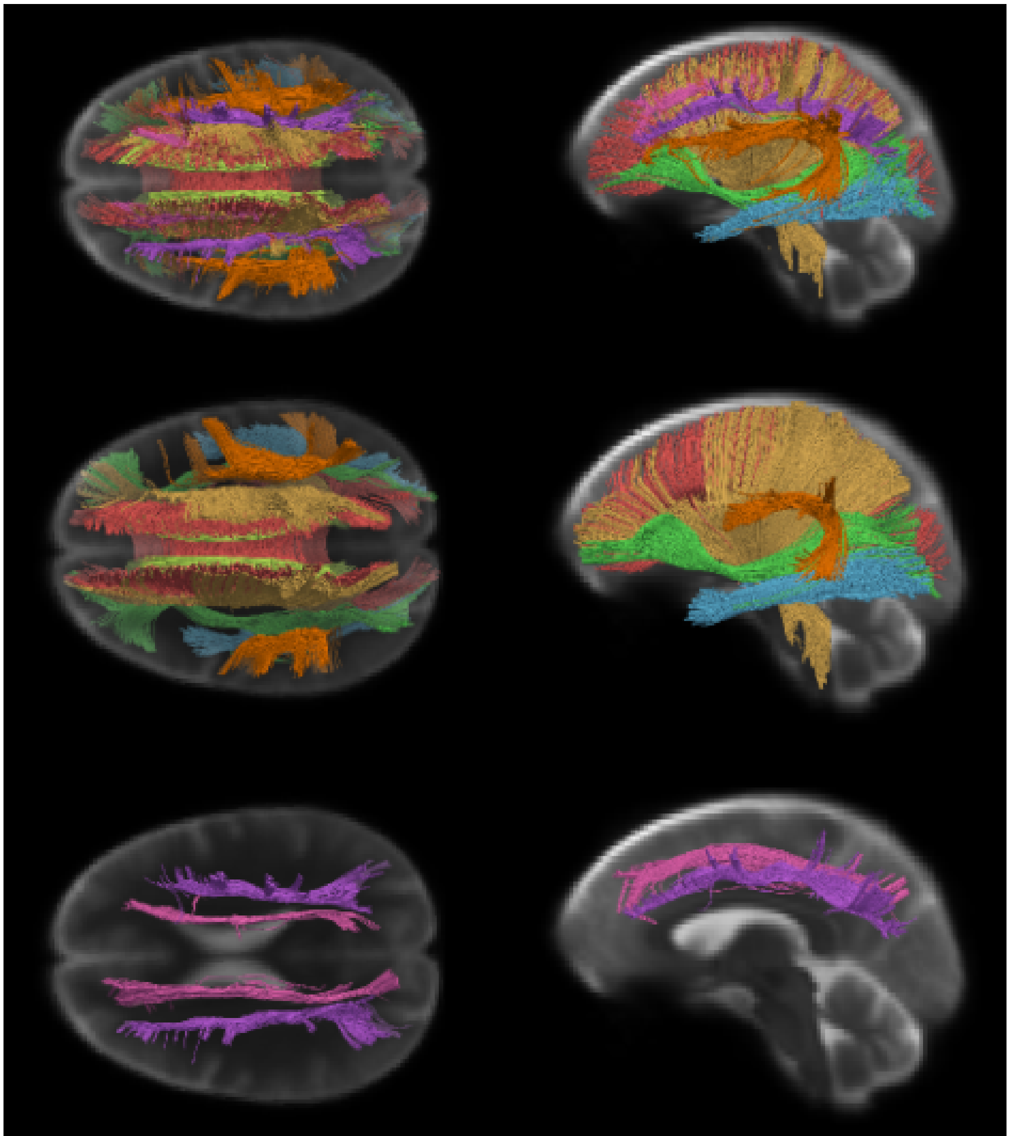

Figure 2: Major pathways reconstructed from the multi-direction (top) and single tensor (middle) models are shown. The bottom shows pathways absent in the single tensor reconstruction, which are dorsal fronto-occipital pathways.

Conclusions:

Our results suggest that fiber orientation statistics are an effective way to construct a diffusion atlas that represents more complex configurations than described by single tensors. While tensor registration may not explicitly match configurations such as crossings, the spatial continuity of the deformation is a plausible explanation for the fiber orientation consistency found in our data. Our observed angular dispersions agree with previous results and are considerably lower than the expected dispersion of 60 degrees from uniformly random orientations [2]. In conclusion, our results indicate that tensor-based registration and multi-direction orientation statistics provide a means to reconstruct white matter structures that are otherwise challenging to map across a population.

Modeling and Analysis Methods:

Diffusion MRI Modeling and Analysis

[1] Cook, P.A. et al (2008), “Atlas-guided probabilistic diffusion-tensor fiber tractography”,

International Symposium on Biomedical Imaging, 2008

[2] Yap P.T. et al (2011), “PopTract: population-based tractography”, IEEE Transactions Medical Imaging, vol 30, no. 10, pg. 1829-40, 2011

[3] Zhang H. et al (2005), “Deformable registration of diffusion tensor MR images with explicit orientation optimization”, Medical Imaging and Computer Assisted Intervention, 2005

[4] Forkel S.J. et al (2012), “The anatomy of fronto-occipital connections from early blunt dissections to contemporary tractography”, Cortex Sept. 2012

[5] Adluru N. et al (2012), “Spatial Normalization of DTI Preserves Tract Reconstruction of Major White Matter Pathways”, Annual Meeting of the Organization for Human Brain Mapping, 2012

[6] Jenkinson M. et al (2012), “FSL”, NeuroImage, vol 62, pg 782-790, 2012

[7] Behrens T.E.J. et al (2007), “Probabilistic diffusion tractography with multiple fibre orientations: What can we gain?”, NeuroImage, vol. 34, no. 1, pg 144-55, 2007

[8] Alexander D.C. et al (2001), Spatial transformations of diffusion tensor magnetic resonance images”, IEEE Transactions on Medical Imaging, vol 20, no. 11, pg 1131—9

[9] Yeh F.C. (2011), “NTU-90: A high angular resolution brain atlas constructed by q-space diffeomorphic reconstruction”, NeuroImage, vol. 58, no. 1, pg. 91-99, 2011

[10] Zhang, H. (2010) “A computational white matter atlas for aging with surface-based representation of fasciculi” In International Workshop on Biomedical Image Registration, volume 6204 of Lecture Notes in Computer Science, pages 83-90, July 2010.