Towards a Global Tractography-based Model of FA

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A global tractography-based model of white matter derived from DTI has many potential applications in the study of aging. We present a method for optimizing a set of paths integrated within WM so that their density correlates with fractional anisotropy (FA) values globally. The optimization scheme improves the correlation between fiber density and FA.

Methods

We build on the assumption that regions where paths are denser will produce relatively higher FA values than regions where the paths are sparser. We also assume a linear relationship between path density and FA. Our approach modifies the set of paths so that their density better matches FA globally.

We use our streamtube algorithm [1] to track paths in the DTI data set. A path stops when it would go out of the data boundary or into a region of low anisotropy. We also cull paths that do not project into gray matter. This culling is based of classification using FAST [2].

The optimization takes the following steps:

1.) Generate an initial set of pathways using a uniform set of seed points throughout the data volume (see Fig. 1 left).

2.) Calculate the fiber density (FD) on a regular grid. Fiber density is calculated by counting the number of fibers running through a voxel and normalizing by the maximum fiber count within any voxel. Calculate $G = \sum(\mathrm{FD} - \mathrm{FA})$ over the whole brain. G is the goal function we optimize.

3.) For each voxel, compare the fiber density with the FA value. If the fiber density is lower than the FA value, generate a new pathway with a seed point within the voxel, calculate G again, if the new pathway lowers the G value keep it, otherwise discard it. If the fiber density is higher than the FA value, delete a pathway though this voxel, calculate G again, if the deletion lowers the G value leave the path deleted, otherwise put it back.

4.) Iterate step 3 until the decrease on G is less than a threshold.

Results

Fig. 1 right shows the set of fiber pathways after four steps of iteration. Note that the paths becomes denser in areas of higher FA, e.g., some gaps in corpus callosum in the original model are filled in the optimized model.

Fig. 2 shows a section of fiber density map before and after the optimization. Note that after the optimization, the fiber density map more closely resembles the FA map.

Discussion and Conclusion

A number of the assumptions that we make are simplistic, in particular the linear relationship between FD and FA, the relationship between integral curves and fiber tracts, the sufficiency of the editing operation on the set of paths, and the efficacy of the greedy optimization algorithm. Nonetheless, the results suggest that a global optimization has the potential to improve the match between data and an underlying model of WM structure. Such a model has the potential to lead to measures of WM integrity with important applications to the quantification of brain changes associated with aging.

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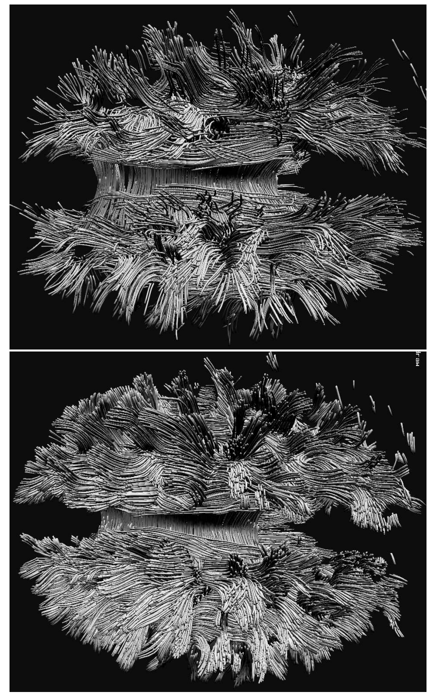

Figure 1: Fiber tracts before (left) and after (right) optimization to match imaging data. The placement of thousands of paths is optimized to improve the resulting FA volume image; a single slice of the FA volume is shown in Fig. 2. Note that the paths become denser in areas of higher FA.

Figure 2: One section of fiber density maps before (left) and after (center) optimization to match the acquired section (right). The region of FA is masked to include only the WM regions identified by classification using FAST [2].

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References

[1] Zhang et al. TVCG , 9(4):454-462, 2003

[2] Zhang et al. TMI, 20(1):45-57, 2001.