Probabilistic Fiber Tractography Using Neighborhood Information

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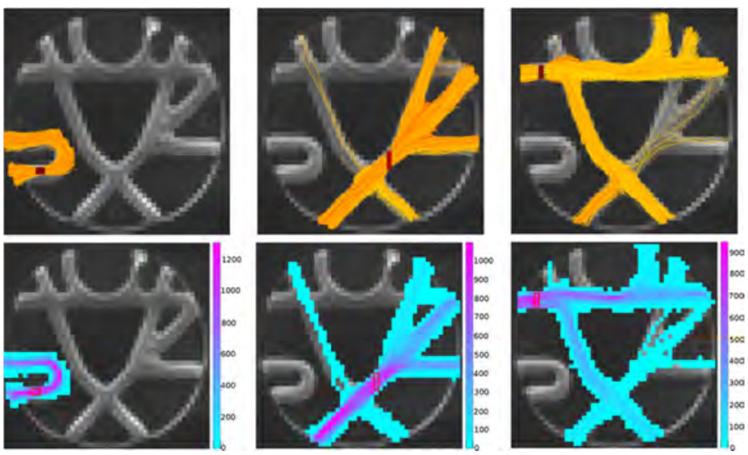
TARGET AUDIENCE: This abstract is intended for researchers in diffusion MRI working on tractography methods.

PURPOSE: Local deterministic streamline-based tractography constructs fiber pathways by performing successive steps in the direction of principle diffusion derived from diffusion tensor (DT) or orientation distribution function (ODF) at the current voxel. Though being fast with respect to computation time, these algorithms suffer from noise and artifacts present in the diffusion data. Probabilistic methods[1,2], on the other hand, establish the representation of uncertainty introduced by noise and artifacts, as well as underlying critical regions such as crossing or fanning structures. We present an ODF based semi-local probabilistic approach including diffusion information of neighboring regions to reduce accumulation of errors in the probabilistic fiber tracks.

METHODS: The algorithm presented here uses ODFs to perform probabilistic fiber tracking. We tested our algorithm on ODF data obtained from HARDI data using constrained spherical deconvolution (CSD) with spatial regularization similar to the method described by Reisert and Kiselev[3]. Starting with an initial tracking direction d_0 pointing towards one of the ODF maxima in the seed voxel, the following steps are executed for each iteration k: (1) A new fiber path point is computed as $x_{k+1} = x_k + \lambda d_k$ with constant step length λ. (2) A guiding direction d_{extr} is determined either by extrapolation of a certain number (N) of previously tracked points $x_{k-(N-2)}, \dots, x_{k+1}$ or, if $k < (N-2)$, as the former tracking direction d_k. (3) We consider a set of candidate directions $d^{(1)}, \dots, d^{(n)}$ in a small, cone-shaped region around d_{extr}. A weight $w^{(i)}$, $i = 1, \dots, n$, is assigned to each candidate direction based upon the corresponding ODF values. To explore the region ahead, the procedure is repeated for a preset number of times for the candidate directions, respectively. The candidate weights are updated according to the outcome of the forward search. (4) From the candidate directions, a direction $d_{cand} \in \{d^{(i)}\}_{i=1}^{n}$ is chosen with probability $P(d^{(i)} | x_{k+1}) = w^{(i)} / \sum_{i=1}^{n} w^{(i)}$. (5) The new tracking direction is calculated as a weighted sum $d_{k+1} = (d_{cand} + \beta\, d_{extr})/(1+\beta)$, where the second term regulates smoothness of the tracks.



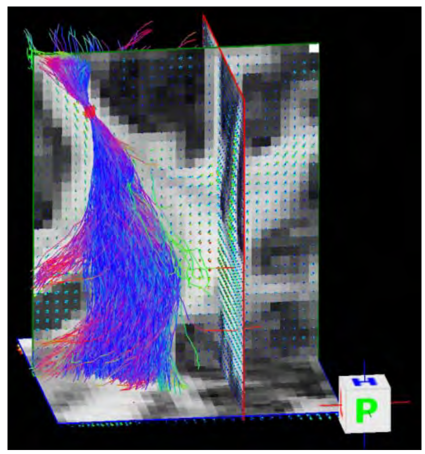


Fig. 1 *(left):* Probabilistic tractography on the fiber phantom.
Fig. 2a *(middle)*: Some probabilistic tracks in the semioval center.
Fig. 2b *(right/above)*: Coronal section showing number of fibers passing through each voxel.

DATA AND RESULTS: We tested our method on data of a diffusion phantom[4] that was also used for the *Fiber Cup*[5], and on data provided by the MGH-USC Human Connectome Project[6] (www.humanconnectome.org). We chose the diffusion phantom data set with a resolution of 3x3x3 mm^3 acquired at b=1500 s/mm^2. The *in vivo* data consists of 18 scans at b=0 s/mm^2, diffusion weighted scans on 3 shells (3x90 gradients at b=1000 s/mm^2, b=2000 s/mm^2 and b=3000 s/mm^2) and has a voxel size of 1.25x1.25x1.25mm^3. For ODF reconstruction with CSD we select the b=2000 s/mm^2 (and b=0 s/mm^2) scans. Fiber tracking with λ = 1, N = 5 and β = 1 is performed starting at the ROIs highlighted in red in Figures 1 and 2. As candidate directions (step (3)) we choose all vectors from a finite set of vectors evenly distributed on the unit sphere, which do not deviate from d_{extr} by more than 45°. The number of steps the algorithm explores the region ahead is set to 2. Regarding the phantom data, we consider 20 seed points in each of the three ROIs, from which 100 tracks are generated, respectively. The resulting tracks are visualized in the upper row of Figure 1. Correspondingly, the images below illustrate the number of fibers passing through each voxel. From the *in vivo* data we regard an area of the semioval center shown in Figure 2. 100 tracks are generated from each of the 9 selected seed points in the seed voxel. The tracks are shown in a three dimensional view in Figure 2a. In Figure 2b, the voxels of a coronal section are colored according to the number of visiting fiber tracks.

DISCUSSION: Regarding the diffusion phantom, the majority of tracks correctly pass the sharp bending while negligible number gets lost in the surrounding isotropic region. Likewise, at the 90° -crossing only about 15% of the tracks are wrongly deflected. At the more challenging 70° -crossing, at least more than half of the tracks correctly pass through and about 35% correctly proceed along the entire path. We attribute this increase in false positives to the fact that up to 45° difference between guiding direction and candidate directions is allowed. Figures 2a and 2b illustrate that our algorithm also yields reasonable results when applied to *in vivo* data.

CONCLUSION: We proposed a method for probabilistic fiber tracking exploiting information of neighboring ODFs to improve guidance at critical regions.

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