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RAY-BASED AND GRAPH-BASED METHODS FOR FIBER BUNDLE BOUNDARY ESTIMATION

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Introduction:

Diffusion-Tensor-Imaging

- non-invasive MR-imaging technique
- allows estimation of location and course of white matter tracts in the human brain in vivo

Reconstruction of white matter tracts

- knowledge about the course is important in neurosurgical context to prevent postoperative neurological deficits after tumor resection
- 3D-reconstructed white matter tracts can be intraoperatively visualized in the operating microscope
- commonly used fiber tracking delivers no border information and generation of borders is very sensitive to tracking errors

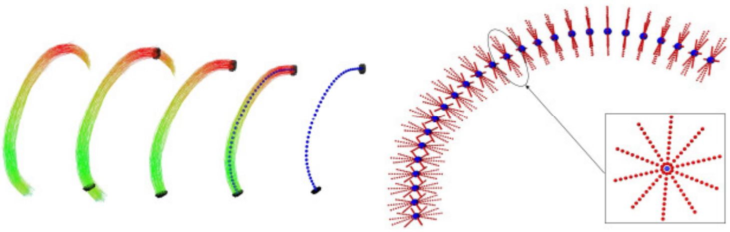


Figure 1: Principle of preprocessing for ray-based and graph-based method (fiber tracking, cropping, centerline calculation, plane calculation, sending out rays, sampling of rays)

Methods:

Preprocessing (Fig. 1)

- initial fiber tracking and cropping to select fiber tract of interest, followed by centerline calculation
- creation of planes along the centerline, sending out rays within each plane and sampling along every ray

Ray-Based Method [1,2]

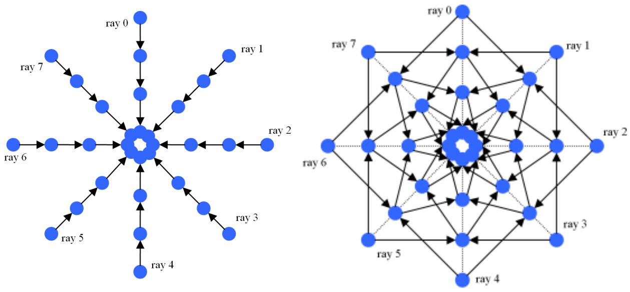
- parameter calculation for every point including fractional anisotropy (FA) and angles between main direction of the centerline, the actual point and the previous point
- application of threshold criteria for local evaluation area along each ray to determine a boundary point per ray, resulting in a point cloud

Graph-Based Method [3] (Fig. 2)

- set up weighted and directed graph $G(V,E)$, with the sampled points as nodes $n \in V$ plus virtual source $s \in V$ and sink $t \in V$ and a set of edges $e \in E$
- ∞-weighted edges connecting point along one ray (type 1), points of neighbored rays within one plane (type 2) and points of the same ray of neighbored planes (type 3)
- FA-dependent weights for edges connecting the evaluation points with source s or sink t
- polynomial time s-t-cut delivers optimal segmentation (min-cut) given by a point cloud

Postprocessing

- triangulation of point cloud ⇨closed surface



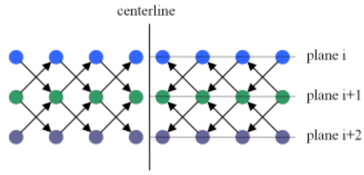


Figure 2: Graph-based approach: construction of ∞-weighted edges of different types

Type 1: edges connecting points along each ray of each plane

Type 2: edges connecting points of neighbored rays of the same plane ($\Delta x = 1$)

Type 3: edges connecting points of the same ray of neighbored planes ($\Delta y = 1$)

Results:

The methods were implemented in C++ within MeVisLab development environment [4].

- data: torus-shaped software phantom and anatomical software phantom with modeled right corticospinal tract (Fig. 3) [6,7]
- tract parameters: 50 centerline points, 20 rays per plane, 30 points per ray (distance 0.5mm)

Segmentation results

- ray-based approach: the average Dice Similarity Coefficient (DSC) [5] for phantom 1 was 88.462%±4,438% and for phantom 2 it was 81.538%±4,918%
- graph-based approach: the average DSC for phantom 1 was 74.171%±3.999% and for phantom 2 (Fig. 4) it was 73.731%±5.119%

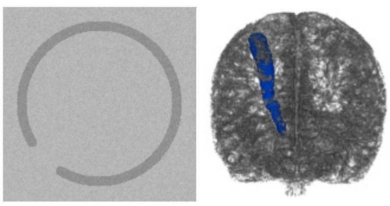


Figure 3: Used software-phantoms for evaluation of both approaches: Torus-shaped phantom (left) and anatomical phantom with modeled right cortico-spinal tract (right)

phantom 1	ray-based approach	graph-based approach
min DSC(%)	74.721	68.330
max DSC(%)	91.532	78.138
average DSC(%)	88.462	74.171
standard deviation	4.438	3.999

phantom 2	ray-based approach	graph-based approach
min DSC(%)	75.321	63.142
max DSC(%)	88.502	80.747
average DSC(%)	81.538	73.731
standard deviation	4.918	5.119

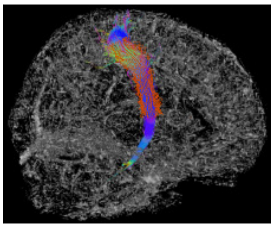


Figure 4: Results (point cloud) of both approaches for the two software phantom (left) and resulting point cloud of the graph-based segmentation approach applied to the anatomical software phantom (right).

Conclusion:

In this work, two approaches for determination of the fiber bundle boundary of major white matter tracts were introduced and compared to each other. The presented methods are based on an initial fiber tracking with centerline calculation, resulting in several planes along the centerline with rays within each plane and points along each ray. The ray-based approach determines the boundary stepwise for each ray using threshold criteria, the graph-based approach sets up a directed and weighted graph and calculates a min cut, separating the fiber bundle from the surrounding. There are several areas of future work. For example, the ray-based approach can be enhanced by other parameters describing directed diffusion. An extended cost function would be a possible extension of the graph-based approach.

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