Cleaning output of tractography via fiber to bundle coherence, a new open source implementation

Stephan Meesters[1,2], Gonzalo Sanguinetti[1], Eleftherios Garyfallidis[3], Jorg Portegies[1], Pauly Ossenblok[2] and Remco Duits[1]

1) Eindhoven University of Technology, The Netherlands; 2) Academic Center for Epileptology Kempenhaeghe, The Netherlands; 3) University of Sherbrooke, Canada

Purpose

The output of tractography algorithms often contains spurious fibers, which are isolated and poorly aligned with the surrounding bundle of fibers. The fiber to bundle coherence (FBC) [1] provides us with a quantitative measure of fiber alignment and is therefore useful in pruning the results of tractography algorithms by removing spurious fibers that are identified by a low FBC. Here we propose a novel open-source module included in the DIPY (Diffusion Imaging in Python) library [2].

Fiber to Bundle Coherence measures

Fibers resulting from tractography are lifted to 5D curves by including the local orientation of the tangent to the fiber. In order to include a notion of alignment between neighboring fiber tangents, we embed the 5D domain with the non-flat differential structure of the rigid body motion Lie Group SE(3) together with a sub-Riemannian metric that takes into account that the angular components are determined by the tangent to the fiber.

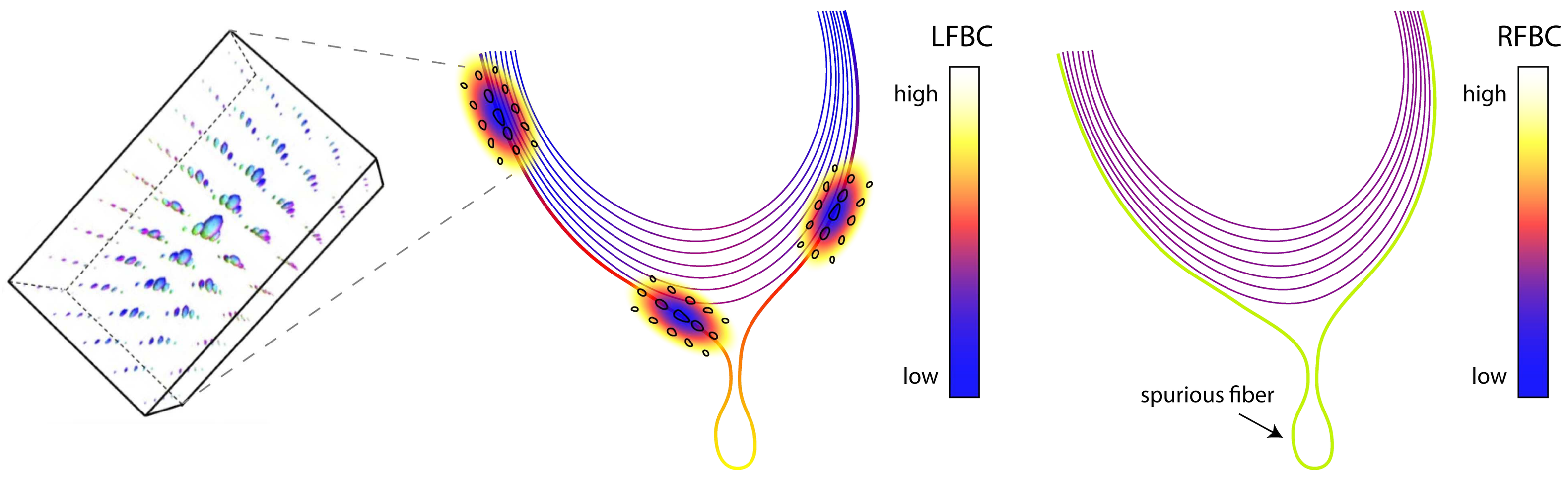

Figure 1: The local fiber to bundle coherence LFBC is obtained from the sum over all such locally aligned kernels on the 5D space of positions and orientations (depicted via 3D glyph field visualization, left). The contribution of fiber points to the kernel density estimator is depicted in 2D for simplicity (middle) and is shown color-coded for each fiber. The relative FBC or RFBC (right) provides a scalar measure for each fiber and successfully identifies the spurious fiber.

The FBC measures are implemented based on kernel density estimation in the non-flat 5D domain. First we compute the kernel density estimator induced by the full lifted output of the tractography. Then, the Local FBC (LFBC) results from evaluating the estimator along each element of the lifted fiber (Fig. 1, left). The Relative FBC (RFBC) is a whole fiber measure that is calculated by the minimum of the moving average LFBC along the fiber. (Fig. 1, right).

Implementation details

- Implemented in the DIPY framework using the Cython language, including multithread processing via the OpenMP library.
- Fiber tractograms are obtained from the 'LocalTracking' probabilistic tractography algorithm in DIPY.
- Considerable speedup of the kernel density estimation is achieved by computing lookup-tables, inspired by [3], containing rotated versions of the contour enhancement kernel sampled over a discrete set of orientations.
- In order to apply the lookup table, it is required to match each tangent orientation with the discrete orientation that is closest. Efficient orientation matching is achieved with a KD-tree to minimize the number of angular distance computations.

Probabilistic interpretation of the kernel

The kernels used in the kernel density estimation have a probabilistic interpretation: they are the limiting distributions of random walkers which randomly move forward or backward, randomly change their orientation, but cannot move sideways. For details see [4]. An analytic Gaussian approximation [5] of the contour enhancement kernel was used for kernel density estimation. For a comparison to recently derived exact solutions see [6].

Results

An example illustrating the method is performed on the Stanford HARDI dataset [8] (160 orientations, b=3000s/mm^2). Constrained Spherical Deconvolution [9] is used to create the fiber orientation density function, after which probabilistic tractography is applied. The optic radiation is reconstructed by tracking fibers from the calcarine sulcus (visual cortex V1) to the lateral geniculate nucleus. The initial output of tractography has a large number of incoherent fibers (Fig. 2, top row). The spurious fibers identified by a low RFBC are removed (Fig. 2, bottom row) by setting a threshold.

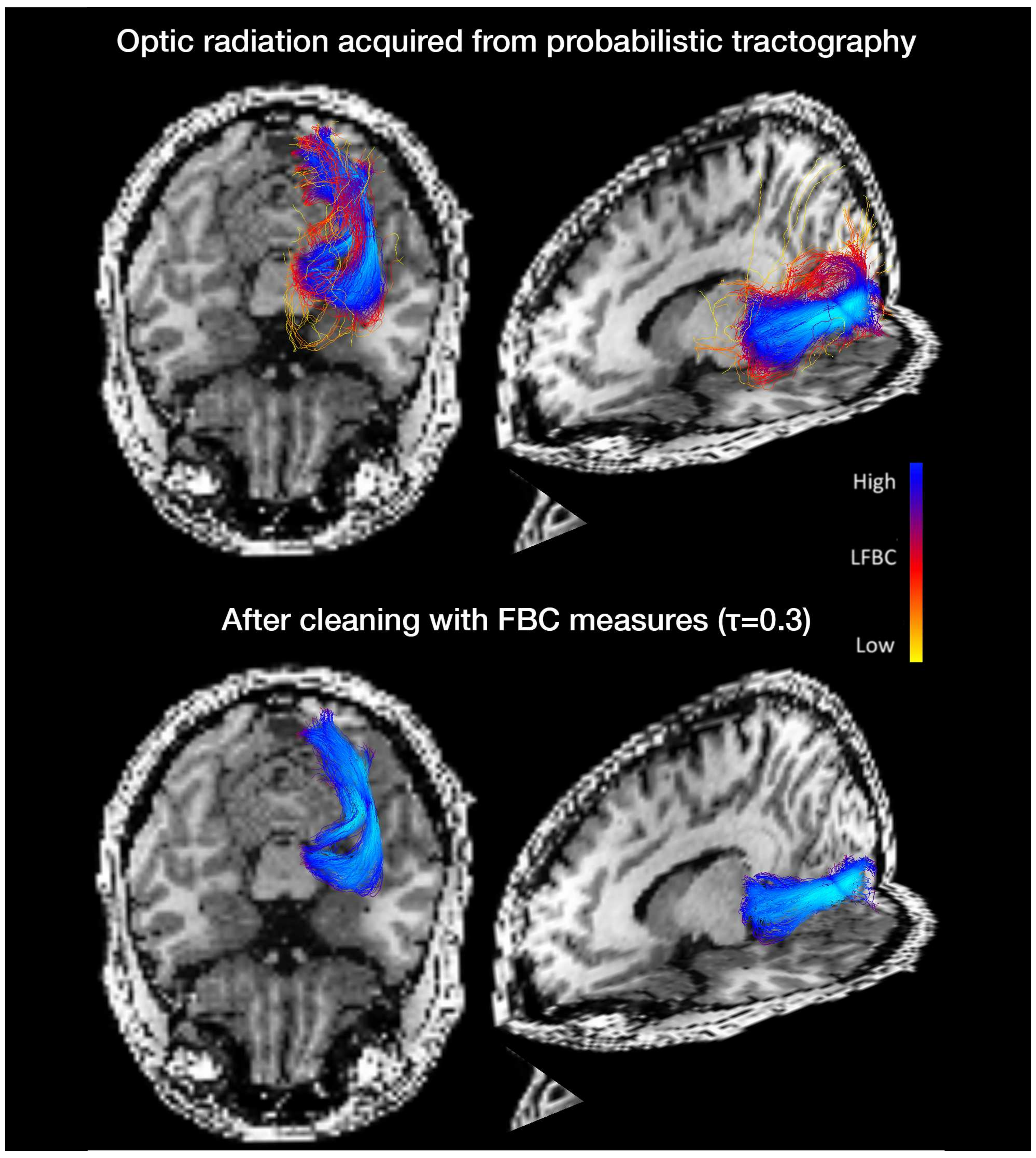

Figure 2: The fibers of the reconstruction of the optic radiation are color-coded by the Local FBC value (LFBC). The tractography result is cleaned (shown in bottom) by removing fibers with a Relative FBC (RFBC) lower than 0.3 (30%).

Discussion

A tool is presented to quantify and remove spurious fibers from any tractography result. Our new module in DIPY makes this method widely available to the neuroimaging community and can readily be included within a processing pipeline. The fast implementation via KD-trees, multithreading and lookup-tables allow for large scale experiments.

Acknowledgements

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S. Meesters(1,2), G. Sanguinetti (1), E. Garyfallidis (3), J. Portegies (1), P. Ossenblok (2), R. Duits (1)

1) Department of Mathematics & Computer Science, Eindhoven University of Technology, Den Dolech 2, 5612 AZ Eindhoven, The Netherlands;
2) Academic Center for Epileptology Kempenhaeghe & Maastricht UMC+, Sterkselseweg 65, 5591 VE Heeze, The Netherlands
3) Computer Science Department, University of Sherbrooke, Sherbrooke, QC, Canada

Introduction

The output of tractography algorithms often contains spurious fibers, which are isolated and poorly aligned with the surrounding bundle of fibers. The fiber to bundle coherence (FBC) [1] provides us with a quantitative measure of fiber alignment and is therefore useful in pruning the results of tractography algorithms by removing spurious fibers that are identified by a low FBC. Here we propose a novel open-source module, included in the DIPY (Diffusion Imaging in Python) library [2], implemented efficiently using multithreading and pre-computed lookup tables.

Methods

Fibers resulting from tractography are lifted to 5D curves by including the local orientation of the tangent to the fiber. In order to include a notion of alignment between neighboring fiber tangents, we embed the 5D domain with the non-flat differential structure of the rigid body motion Lie Group SE(3) together with a sub-Riemannian metric that takes into account that the angular components are determined by the tangent to the fiber. This framework extends classical models of visual perception and integration of contours [3, 4, 5], which was proven to be powerful in diffusion-weighted MRI applications [1, 6, 7]. We implement FBC measures based on kernel density estimation in the non-flat 5D domain. First we compute the kernel density estimator induced by the full lifted output of the tractography. Then, the Local FBC (LFBC) results from evaluating the estimator along each element of the lifted fiber (Fig 1). A whole fiber measure, the relative FBC (RFBC), is calculated by the minimum of the moving average LFBC along the fiber. The kernels used in the kernel density estimation have a probabilistic interpretation: they are the limiting distribution of random walkers which randomly move forward or backward, randomly change their orientation, but cannot move sidewards. For details see [1,7].

The FBC measures are implemented inside DIPY using the high-speed Cython language and are executed with multithreading via the OpenMP library. To speed up the kernel density estimation, lookup-tables are computed containing rotated versions of the kernel rotated over a discrete set of orientations, which are equally distributed over a sphere to ensure rotationally invariant processing. Fiber tractograms are obtained from the 'LocalTracking' probabilistic tractography algorithm in DIPY. To be able to use the lookup table, each tangent orientation is matched with the discrete orientation that is closest. For efficient implementation of orientation matching, a KD-tree is used, which is a multi-dimensional (K=3) binary space partitioning, to minimize the number of angular distance computations.

Results

An example illustrating the method is performed on the Stanford HARDI dataset [8] (160 orientations, b=3000s/mm^2). Constrained Spherical Deconvolution [9] is used to create the fiber orientation density function, after which probabilistic tractography is applied. The optic radiation is reconstructed by tracking fibers from the calcarine sulcus (visual cortex V1) to the lateral geniculate nucleus. The initial tractogram has a large number of incoherent fibers (Fig 2 top). The spurious fibers identified by a low RFBC are removed (Fig 2 bottom) by setting a threshold (τ=0.3). Regarding computation time, after a one-time computation of the lookup-table (taking several minutes) the fiber tracking took 76 seconds followed by 194 seconds for the FBC computation on a Mac Pro (2008 model).

Conclusions

A tool is presented to quantify and remove spurious fibers from any tractography result. Our new module in DIPY makes this method widely available to the neuroimaging community and can readily be included within a processing pipeline. The fast implementation via KD-trees, multithreading and lookup-tables allow for large scale experiments.

Acknowledgements

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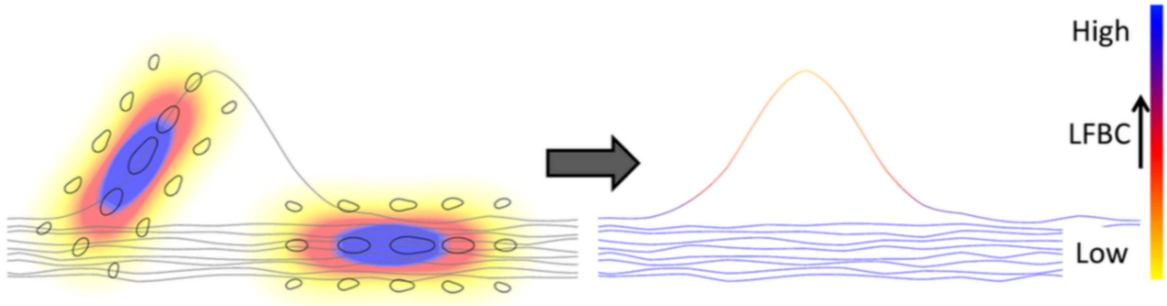

Fig. 1: On the left this figure illustrates (in 2D) the contribution of two fiber points to the kernel density estimator. The kernel density estimator is the sum over all such locally aligned kernels. The local fiber to bundle coherence shown on the right color-coded for each fiber, is obtained by evaluating the kernel density estimator along the fibers. One spurious fiber is present which is isolated and badly aligned with the other fibers, and can be identified by a low LFBC value in the region where it deviates from the bundle. Figure adapted from [1].

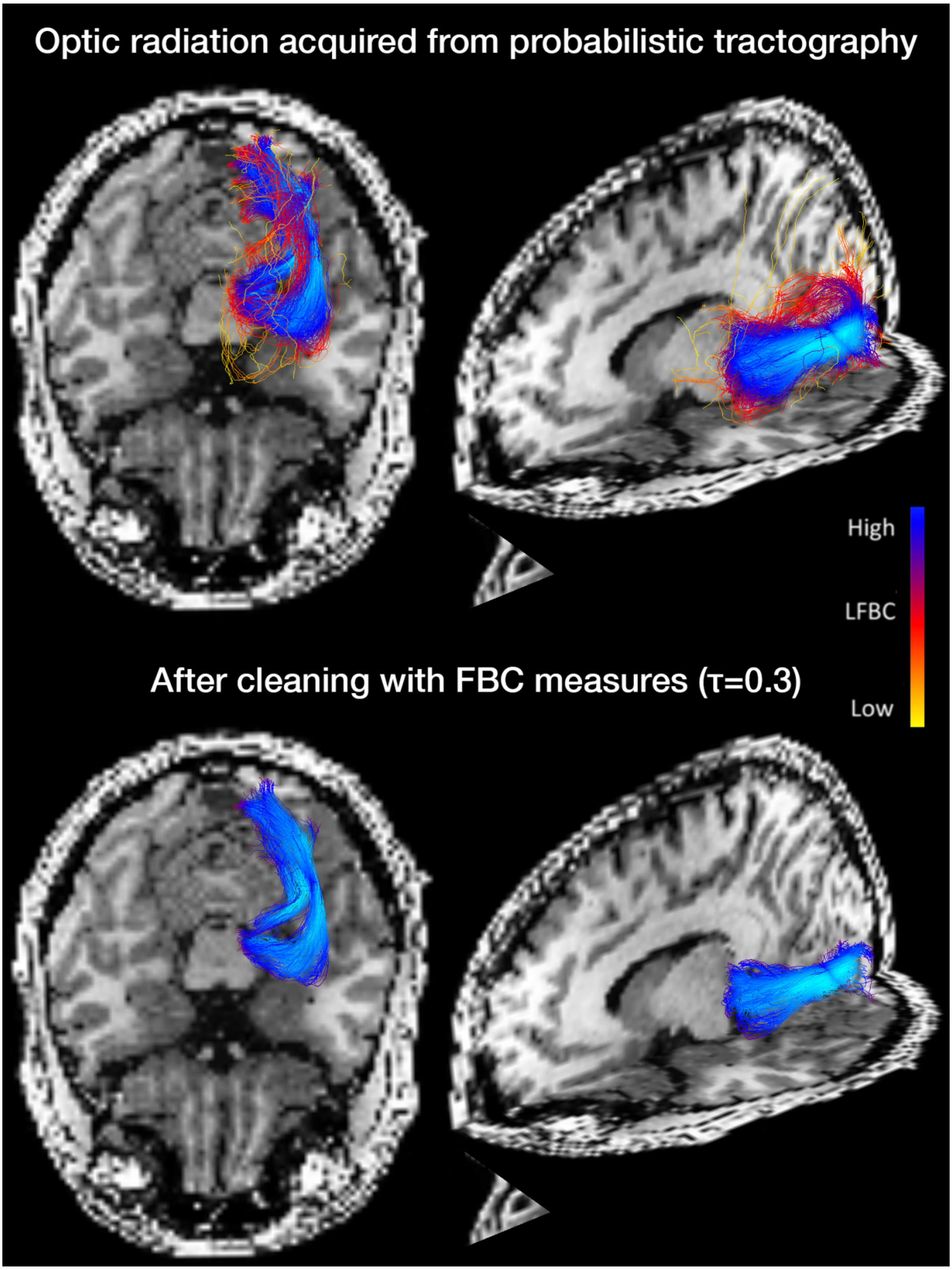

Fig 2: The fiber to bundle coherence (FBC) measures are demonstrated on the reconstruction of the optic radiation (OR). The OR can be obtained through probabilistic tractography by tracking fibers from the calcarine sulcus to the lateral geniculate nucleus (shown in top). The fibers are color-coded by the local FBC value (LFBC). The tractography result is cleaned (shown in bottom) by removing fibers with a relative FBC (RFBC) lower than the threshold τ=0.3.