Extraction of Structural Metrics from Crossing Fiber Models

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Dissertation

Abstract

Diffusion MRI (dMRI) measurements allow us to infer the microstructural properties of white matter and to reconstruct fiber pathways in-vivo. High angular diffusion imaging (HARDI) allows for the creation of more and more complex local models connecting the microstructure to the measured signal. One of the challenges is the derivation of meaningful metrics describing the underlying structure from the local models. The aim hereby is to increase the specificity of the widely used metric fractional anisotropy (FA) by using the additional information contained within the HARDI data.

A local model which is connected directly to the underlying microstructure through the model of a single fiber population is spherical deconvolution. It produces a fiber orientation density function (fODF), which can often be interpreted as superposition of multiple peaks, each associated to one relatively coherent fiber population (bundle). Parameterizing these peaks one is able to disentangle and characterize these bundles. In this work, the fODF peaks are approximated by Bingham distributions, capturing first and second order statistics of the fiber orientations, from which metrics for the parametric quantification of fiber bundles are derived. Meaningful relationships between these measures and the underlying microstructural properties are proposed. The focus lies on metrics derived directly from properties of the Bingham distribution, such as peak length, peak direction, peak spread, integral over the peak, as well as a metric derived from the comparison of the largest peaks, which probes the complexity of the underlying microstructure. These metrics are compared to the conventionally used fractional anisotropy (FA) and it is shown how they may help to increase the specificity of the characterization of microstructural properties.

Visualization of the micro-structural arrangement is another application of dMRI. This is done by using tractography to propagate the fiber layout, extracted from the local model, in each voxel. In practice most tractography algorithms use little of the additional information gained from HARDI based local models aside from the reconstructed fiber bundle directions. In this work an approach to tractography based on the Bingham parameterization of the fODF is introduced. For each of the fiber populations present in a voxel the diffusion signal and tensor are computed. Then tensor deflection tractography is performed. This allows incorporating the complete bundle information, performing local interpolation as well as using multiple directions per voxel for generating tracts.

Another aspect of this work is the investigation of the spherical harmonic representation which is used most commonly for the fODF by means of the parameters derived from the Bingham distribution fit. Here a strong connection between the approximation errors in the spherical representation of the Dirac delta function and the distribution of crossing angles recovered from the fODF was discovered.

The final aspect of this work is the application of the metrics derived from the Bingham fit to a number of fetal datasets for quantifying the brain's development. This is done by introducing the Gini-coefficient as a metric describing the brain's age.