Global Fiber Tracking becomes practical

M. Reisert[1], I. Mader[2], C. Anastasopoulus[2], S. Schnell[1], and V. Kiselev[1]
[1]Medical Physics, University Hospital Freiburg, Freiburg, Baden-Wuerttemberg, Germany, [2]Section of Neuroradiology, University Hospital Freiburg

Introduction: Fibre tracking algorithms follow two paradigms: Local tracking approaches are based on the 'walker' principle, the fibres are reconstructed path-by-path by small successive steps along the tracts. On the other hand global ideas try to reconstruct all fibres at once by optimizing a certain global objective. Local algorithms are fast but suffer from accumulated errors. Global methods have a more sound foundation but are very complex to optimize. Recent approaches need weeks (2) up to one month (3) for optimization. This abstract presents an approach, which fuses both ideas while keeping their advantages (based on (1)). The key idea to make the algorithm practical is to use local methods within the optimization process to approach the global optimum efficiently. The experiments show that the approach is orders of magnitude faster than recent global approaches while improving the detection performance.

Methods: The algorithm is based on a Bayesian approach. The objective is to find the fibre configuration, which maximizes the a-posteriori probability. The fibre configuration is built of a set of small fibre segments, which make connections with each other. Using an exponential model the posterior can be decomposed into an internal energy reflecting the prior knowledge and an external energy evaluating the model with respect to the DTI measurement: $P(\mathcal{M}|D) \propto \exp(-E_{\text{int}}(\mathcal{M}) - E_{\text{ext}}(\mathcal{M}|D))$. The internal energy controls that connected segments stay together and have similar orientations. The external energy is just the distance between a model-predicted signal and the measured signal. Each segment contributes to the prediction by a usual stick-model in orientation space and with a Gaussian in position space. The optimization is based on a Metropolis-Hastings sampler. The main innovation of our approach is that the connections between the segments are established by a 'usual' tracking algorithm. In each step a random segment is chosen and a tracking algorithm is started at this segment. The tracker performs a 'hopping' on the already present segments to propose new connections. This idea reduces reconstruction times for the whole brain to minutes (for sparse reconstructions) and hours (dense reconstructions) on standard PCs. The important parameters of the algorithm are the width of the Gaussian of a single segment and the 'mass' of the segment. The width of the Gaussian controls the fiber density, i.e. the average number of fibers crossing a volume element, while the mass is acting like a kind of threshold where fibres are generated at all.

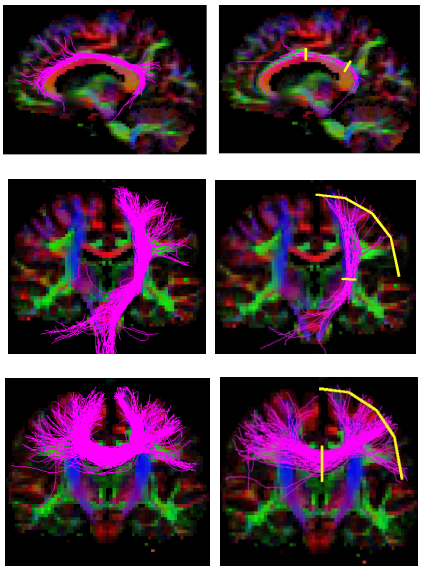

Figure 1: Comparison of our approach (left) with the Gibbs tracker (2) (right) for the cingulum, cortical spinal tracts and callosal fibres (from top to bottom). ROIs used for selection shown in yellow.

Results: The diffusion measurements were acquired on a Siemens 3T TIM Trio using an SE EPI sequence, with a TE of 95 ms and a TR of 8.5 s. The whole brain was covered with contiguous 2-mm slices in an in-plane resolution of 2x2 mm^2. The diffusion encoding was performed in 61 directions with an effective b-value of 1000 s/mm^2. We compared our approach with the Gibbs tracker (2). Both methods were used to compute a whole brain reconstruction. Our approach needs 6 hours while the Gibbs tracker (2) needed 1 month. In Figure 1 we show three selected fibre bundles (Cingulum, Tractus Corticospinalis, Callosal fibres), each of them were selected by finding the fibres passing two ROIs (in yellow) simultaneously. Differences are apparent for the cingulum fibres: the algorithm is able to find much more fibres than (2), which is in particular because the Gibbs tracker (2) uses as prior knowledge that fibres are stopping and ending in the cortex (just by placing seeds in the cortex). This might also explain the differences for the callosal fibres: for our approach there are much more fibres following the superior axis than for the Gibbs tracker (2). For Gibbs the superior seeds are already captured by the very dominant cortical-spinal tracts. This problem gets even more apparent for the optical tracks (Figure 2) that were not found by the Gibbs tracker (2) in the whole-brain optimization but by our algorithm. In Figure 3 one can see a 3D plot of fibres crossing the corpus callosum: again more fibre surrogates were found than by the Gibbs tracker. The proposed fibre tracking algorithm is made public available within the *DTI&FiberTools* toolbox (4).

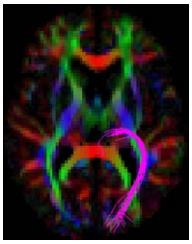

Figure 2: The Optical Track

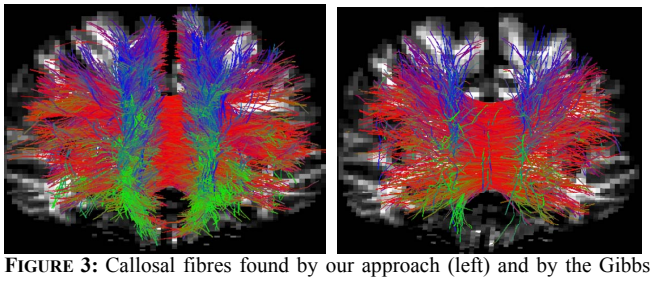

Figure 3: Callosal fibres found by our approach (left) and by the Gibbs tracker (2) (right). For the Gibbs tracker fibres going superior seem to be missing. Also the frontal fibres are underrepresented.

Discussion and Outlook: We proposed a practical global fibre tracking algorithm. The reconstruction times are reasonable for clinical practice. Besides the DTI measurement the only other requirement for running the algorithm is a rough white matter mask. Compared with (2) our method is faster and more accurate. Nevertheless there are still several open problems and challenges. The DTI measurement is only providing relative orientation densities rather than absolute fibre densities. For global reconstruction algorithms this is a major problem, because they need to derive absolute densities. At the moment our algorithm infers these absolute densities implicitly from the local context, which works somewhat sufficiently but complicates the optimization. The approaches in (2,3) circumvent this problem by placing seeds on the cortex, which causes other additional problems as explained above. Another challenge is a deeper understanding of the parameters and their influences on the result. Besides the two mentioned above there are other fudge factors that have to be carefully chosen.

References

- M. Reisert, I. Mader, V.G. Kiselev: *Global Reconstruction of Neuronal Fibers*, MICCAI, Workshop DMFC, 2009, pp. 70-82
- B. Kreher, I. Mader, V.G. Kiselev: *Gibbs Tracking: A Novel Approach for the Reconstruction of Neuronal Pathways.* Proceedings of ISMRM 16th Annual Meeting, Toronto, Canada, 2008
- P. Fillard, C. Poupon, J.-F. Mangin: *A Novel Global Tractography Algorithm Based on an Adaptive Spin Glass Model*. MICCAI (1) 2009: 927-934
- B. Kreher, J. Hennig, K. Il'yasov: *DTI&FiberTools: A Complete Toolbox for DTI Calculation, Fiber Tracking, and Combined Evaluation*. Proceeding of ISMRM 14th International Scientific Meeting, Seattle, USA, 2006

Acknowledgements: Thanks to B. Kreher for providing the Gibbs tracker. This work is supported by OVOC project, ERC Advanced Grant #23290.