Probabilistic fibre tracking through regions containing crossing fibres

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Introduction: Diffusion-weighted MRI based tractography techniques aim to delineate the path of white matter fibres in the brain *in vivo*, and have recently generated extensive interest in the literature. Many of the techniques currently in use are based on the diffusion tensor model, which is known to be unreliable in regions containing crossing fibres. We have recently proposed a novel method for the estimation of the fibre orientation distribution (FOD) directly from high angular resolution diffusion-weighted data, using the concept of spherical deconvolution [1]. This technique was shown to adequately estimate the FOD even in regions containing multiple fibre populations, which cannot be characterised by a single diffusion tensor. In this study, we propose a probabilistic fibre-tracking technique that uses the information provided by the spherical deconvolution technique, to enable tracking through regions containing multiple fibre populations.

Methods: Diffusion-weighted data were acquired from a healthy 26-year old volunteer on a 1.5T Siemens Vision system using a twice-refocused EPI sequence [2] (b = 2971 s/mm^2, TE = 140 ms, FOV = 384 × 384 mm, matrix size 128 × 128 zero-filled to 256 × 256, slice thickness 3 mm, 40 contiguous slices, 60 directions, 6 b=0 images, 3 repeats). The spherical deconvolution technique [1] was used to estimate the FOD at any given point of interest, using the diffusion-weighted intensities calculated by trilinear interpolation from the nearest voxels. The response function and filter parameters used for the spherical deconvolution were estimated from the data themselves using a minimum entropy principle.

Fibre tracking was performed using a probabilistic streamlines method [3]. Starting from an initial seed point, the direction of the next step was determined by drawing a random orientation from the FOD estimated at the current point, using the rejection sampling technique [4]. The next point along the track was then given by stepping along this direction by a user-specified step size (0.2 mm in this study). Each track was generated by repeating this step until a termination criterion was reached: tracks were terminated either when they ventured outside of the brain, or when the amplitude of the FOD at the peak nearest to the current direction of tracking fell below a user-specified threshold. To avoid biologically unlikely changes in direction, additional constraints were applied on the angle between the current direction of tracking and the direction of the next step, using a prior distribution on track curvatures: given the step size and a desired radius of curvature, the angle between successive steps along the track can be defined. The prior distribution used in this study was a simple Gaussian over that angle, truncated at a maximum angle of 45°. In this study, the standard deviation used in the prior corresponded to a radius of curvature of 4 mm. 2000 tracks were generated for each seed point, to ensure that the most likely paths had been properly sampled.

Results & Discussion: Three seed points were used, the first placed in the corticospinal tract at the base of the pons, the second in the body of the corpus callosum, and the third in the superior longitudinal fasciculus, in the anterior occipital periventricular white matter. The tracks generated are displayed in figure 1, and can be seen to correspond well with the known anatomy. Note that the different bundles intersect over a significant proportion of the brain, in the region of the centrum semiovale. In particular, there is a region where all three fibre bundles can be seen to intersect, where the commissural fibres from the corpus callosum (in purple) project through both the corona radiata (in yellow) and the superior longitudinal fasciculus (in cyan).

Conclusion: We have proposed a tractography technique that can make use of the information provided by the spherical deconvolution technique to track through regions containing multiple fibre populations. The method is fast (a set of 2000 tracks can be generated in approximately 2½ minutes), and requires no pre-computation, since the FOD is estimated directly from the diffusion-weighted data. This technique may be used to generate more reliable estimates of the probability of connection between different structures in the brain than can currently be produced using diffusion tensor based techniques.

References: [1] Tournier JD *et al.* NeuroImage 23:1176 (2004). [2] Reese TG *et al.* MRM 49:177 (2003). [3] Behrens TEJ *et al.* MRM 50:1077 (2003). [4] Mackay DJC *Information Theory, Inference and Learning Algorithms*, Cambridge University Press, page 364 (2003).

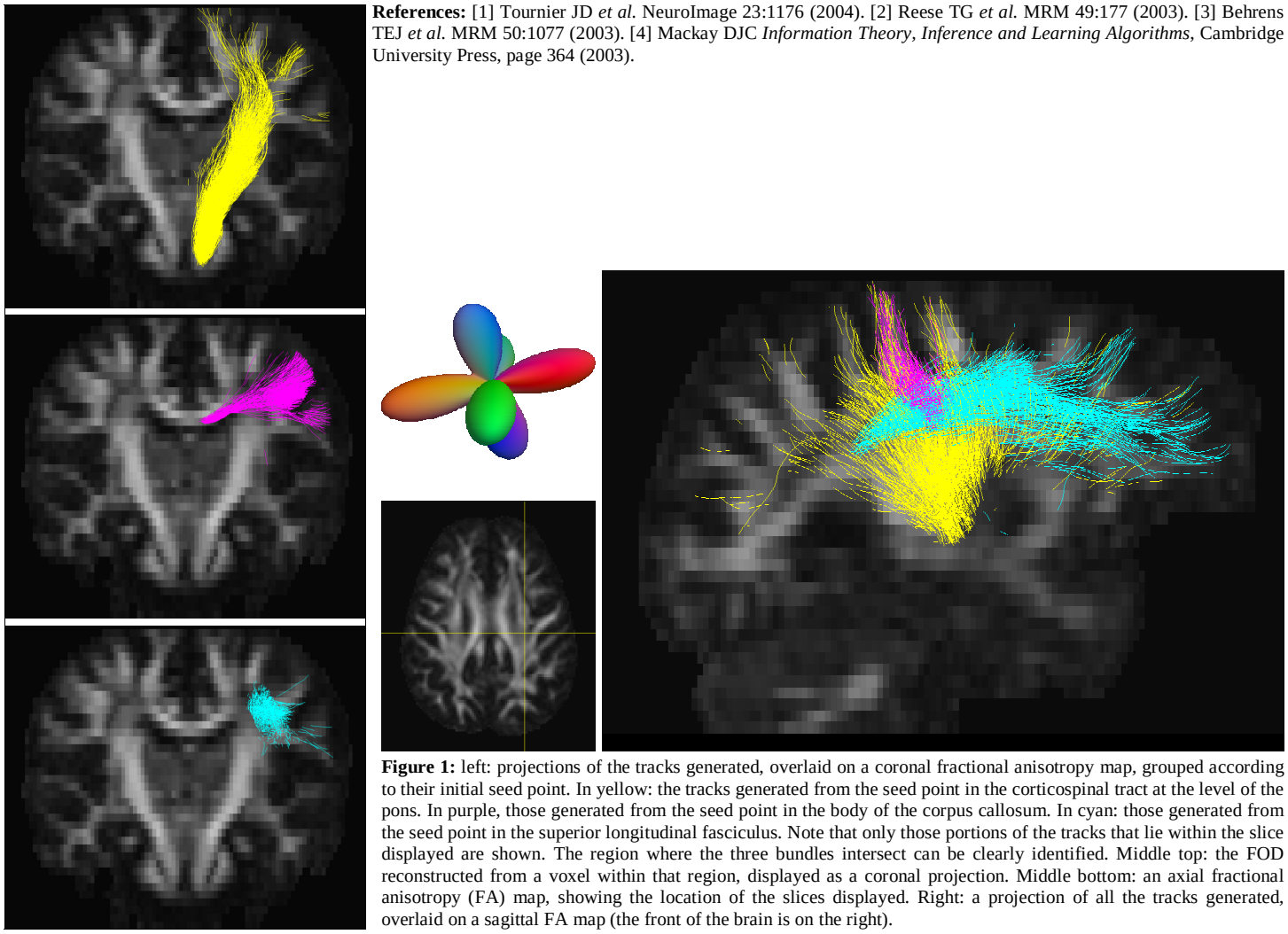

Figure 1: left: projections of the tracks generated, overlaid on a coronal fractional anisotropy map, grouped according to their initial seed point. In yellow: the tracks generated from the seed point in the corticospinal tract at the level of the pons. In purple, those generated from the seed point in the body of the corpus callosum. In cyan: those generated from the seed point in the superior longitudinal fasciculus. Note that only those portions of the tracks that lie within the slice displayed are shown. The region where the three bundles intersect can be clearly identified. Middle top: the FOD reconstructed from a voxel within that region, displayed as a coronal projection. Middle bottom: an axial fractional anisotropy (FA) map, showing the location of the slices displayed. Right: a projection of all the tracks generated, overlaid on a sagittal FA map (the front of the brain is on the right).