Random effects modelling of crossing fibre voxels in diffusion MRI

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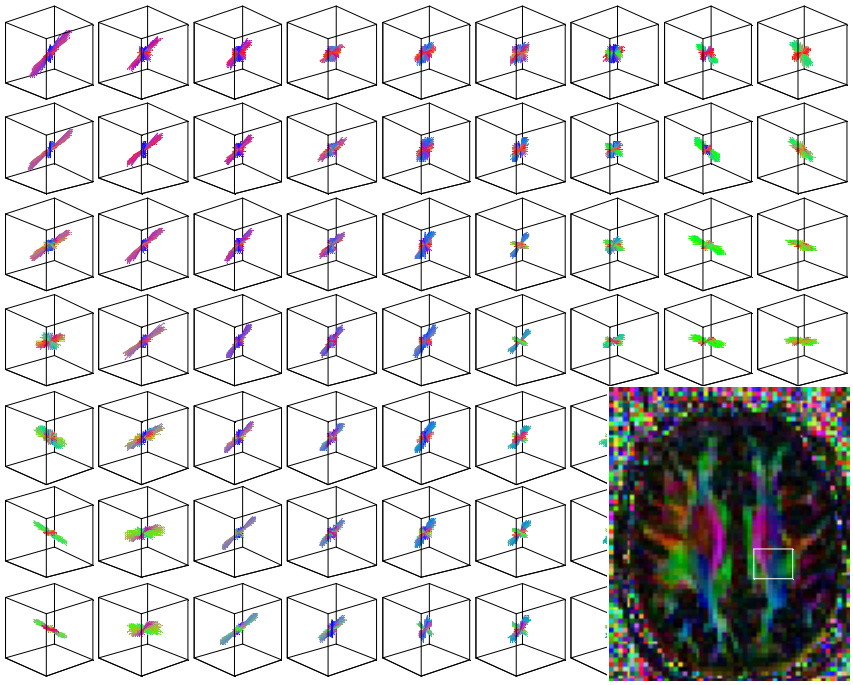
Introduction Diffusion tractography has rapidly become a prominent MRI technique, one that is used both as a neurosciences research tool and as an aid to clinical decision making. Nevertheless, several problems remain to be resolved in order to achieve better performance in terms of false positive tracts and false negatives (a failure to generate established pathways). This abstract examines one avenue of potential improvement, namely the application of random effect (RE) models, implemented using Markov chain Monte Carlo (MCMC) simulation.
A common feature of the tractography algorithms used to date is the voxel-by-voxel approach that is adopted. RE models are a category of regression model in which one, or more, of the regression coefficients is a random variable. They provide a formal procedure for modelling 'clusters' of voxels. We have investigated a number of RE models including a spatial (Markov Random Field) model, an exchangeable model and an independent RE model. The Besag-York-Mollie[1] model, which includes both spatial and exchangeable RE terms, was also examined. Each has a potential to improve parameter estimation.

Methods Diffusion weighted images were collected using a b-value of 1000 s mm^{-2} and 20 directions. Each RE model incorporates the 'mixture model' proposed by Behrens et al.[2]. The exchangeable model was specified using standard uninformative prior probability distributions, except for the imposition of various physical constraints. Gibbs sampling was performed using WinBUGS (http://www.mrc-bsu.cam.ac.uk/bugs). Spatial models were based on the spatial prior provided by the car.proper function in the GeoBUGS addon to winBUGS. Programs were written using the WinBUGS development interface[3]. Various convergence tests were performed using an R-Plus implementation of the CODA set of 'diagnostic' functions (http://www.mrc-bsu.cam.ac.uk/bugs).



Results The figure consists of an array of vector cluster plots obtained for a crossing-fibre region, as obtained using the BMY model. It was generated by taking 100 samples from the spherical coordinate posterior distribution and plotting the resulting vectors, scaled by their respective volume fractions. It shows structures attributable to lateral projections of the corpus callosum (red), the anterior-posterior projections of the superior longitudinal fasciculus (green) and the inferior-superior projection of the corona radiata (blue). Similarly, results obtained for the pons were entirely consistent with established structure (results not shown).

Discussion An RE MCMC modelling approach to the crossing fibre problem offers several advantages over some of the alternatives outlined in the MR tractography literature. A major advantage is the manner in which probabilistic information (including bounds on the accuracy of each quantile estimate, not shown) is provided by MCMC. Given a satisfactory model and convergence, the posterior distributions generated with MCMC provide a direct measure of uncertainty, subject only to simulation error. The latter may be reduced, as required by the application.

Validity of the MCMC posterior distribution requires convergence to a stationary distribution. Convergence assessment is, therefore, essential. Unfortunately, label switching, which occurs in mixture model applications due to symmetry in the posterior distribution caused by invariance to permutation of the mixture model labels, prevents the direct application of standard tests. Rudimentary convergence monitoring was performed in the present study, sufficient to show that subtle differences between models are reproducible, and not attributable to convergence failure and a resulting poor coverage of parameter space. Nevertheless, label switching and convergence monitoring are among the issues requiring more attention. The vector cluster plots shown in this abstract are, however, unaffected by label switching. Questions arise in this RE smoothing application regarding the necessity to detect highly localized effects arising from abrupt changes in spatial pattern. The results indicate that RE models can be applied to regions in which neighbouring voxels differ markedly in structure, and that the underlying spatial heterogeneity in orientation is maintained.

Conclusion Behrens et al.[2] have demonstrated the power of the MCMC approach to tractography. We have combined their 'delta function' mixture model with several RE models. Our results demonstrate that an MCMC RE modelling approach to the crossing fibre problem provides a useful alternative to published methods.

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