

# Selecting the number of fibers in a Multi-Fiber Model from CUbe and SPHERE (CUSP) Diffusion Imaging

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## E-Poster

### Introduction:

Multi-tensor models enable the assessment of complex fiber structure but are known to provide a less accurate description of the underlying white matter microstructure for voxels containing a single fiber bundle. In this work, we propose a novel acquisition-based approach to select between the one- and the two-tensor models at each voxel. It is based on characterizing the diffusion signal at multiple diffusion scales by considering multiple b-values. We employ the recently proposed CUbe and SPHERE (CUSP) acquisition scheme which achieves multiple non-zero b-values without increasing artifacts such as the geometric and intensity distortion. We show that our approach enables the selection of the number of tensors at each voxel. It is to our knowledge the first model selection approach taking into account the underlying properties of the diffusion signal generation.

### Methods:

Increasing the b-value in a diffusion weighting experiment is known to probe the diffusion signal at a smaller diffusion scale. In voxels containing multiple fiber bundles, it leads to a sharper diffusion profile in the space between the fiber bundles. In contrast, the diffusion profile in voxels containing a single fiber bundle is more homogeneous among different b-values. We propose to characterize the voxel complexity by assessing the homogeneity of the estimated diffusion profile at low and high b-value measurements. More precisely, we first consider each voxel to be composed of a single fiber bundle; we estimate the one tensor solution D1T from the low b-values with a least square fitting. Second, we evaluate the prediction performance (PP) of this estimate for the higher b-value measurements. It is done by computing the mean square difference  $\tau$  between the signal predicted by D1T and the measured signal for the high b-values (Eq 1). With this formulation, a large value of  $\tau$  ( $\tau > \tau_{\text{one fiber}}$ ) indicates heterogeneity of the measured signal among different diffusion scales, indicating that a two-tensor model should be selected.

The multiple b-values were introduced by considering the CUSP acquisition scheme (20xx). It combines cubic and spherical sampling in q-space. It enables the acquisition of b-values up to three times larger than the nominal b-value while achieving the same low TE as a single-shell HARDI scheme, and thus does not increase the geometric and intensity distortion.

### Results:

We evaluated our novel CUSP-based MODEL SElection (CUSP-MOSE) on clinical data (35 DWI).  $\tau$ [one fiber] was determined by averaging the PP in the body of the corpus callosum, primarily composed of single fiber bundles. The tensors were estimated with CUSP-MFM (20xx). Fig1 shows the voxels where two fibers were detected by CUSP-MOSE and shows the resulting multi-tensor field. It shows consistent results with the known brain anatomy. Fig2 compares tractography results when using a single-fiber model and the combination of CUSP-MOSE and CUSP-MFM. CUSP-MOSE+MFM better represents the true brain connectivity, particularly the fiber bundle tips.

### Conclusions:

Previous model selection approaches were based on analyzing the diffusion data without taking into account the properties of the signal generation: (2002a) compares the spherical harmonic expansion of the ADC truncated at different orders; (2005a) performs Bayesian model selection which involves fitting every candidate model; (2007a) used a Bayesian Automatic Relevance Determination (ARD) approach which starts with the more complex model and gradually prune the unnecessary variables. In contrast, with CUSP-MOSE, we demonstrated that assessing the homogeneity of the diffusion signal among multiple diffusion scales provides information about the voxel microstructural complexity. Consequently, the use of multiple b-values, which is required to fully estimate multi-tensor models (2010a), can also be employed for the model selection. Future works will include a detailed evaluation and comparison of various model selection approaches including CUSP-MOSE.

### Modeling and Analysis Methods

Diffusion MRI Modeling and Analysis

$$\tau = \frac{1}{\#H} \sum_{k/b_k \in H} \left[ S_0 e^{-b_k \mathbf{g}_k^T \mathbf{D}_1 \mathbf{T} \mathbf{g}_k} - y_k \right]^2 \quad (\text{Eq 1})$$

- H: Set of high b-values, #H: Number of high b-values
- S0: Signal with no diffusion gradient applied
- gk: gradient direction associated with the b-value bk
- yk: measured signal

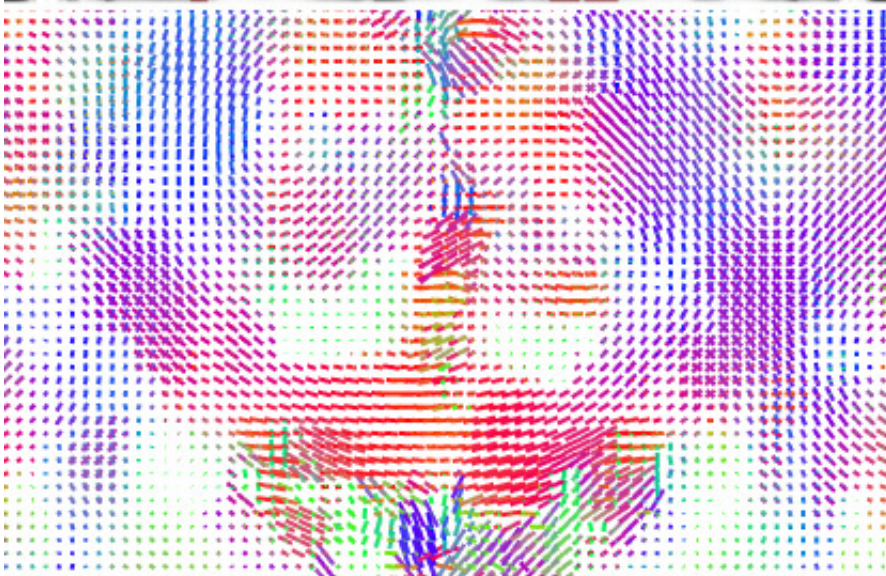
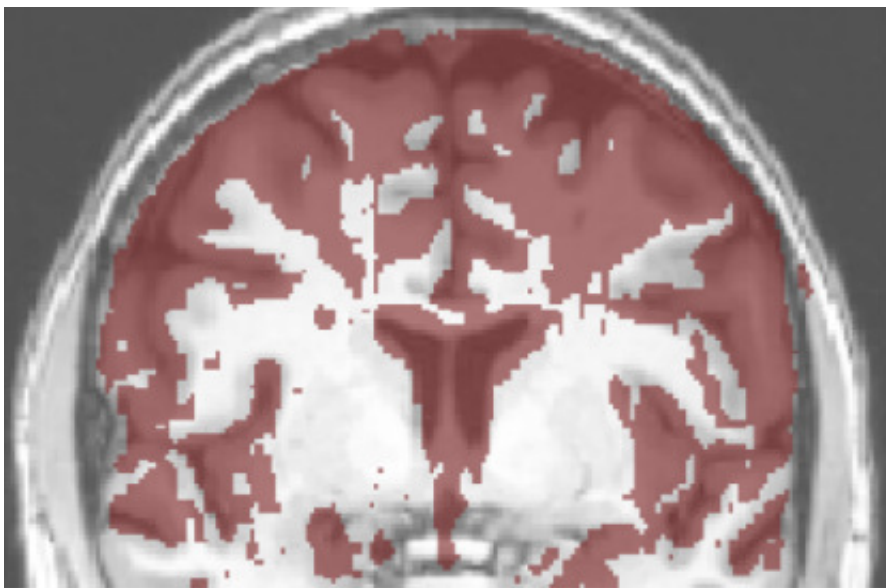


Fig 1: Voxels where two fibers were detected (top) and resulting multi-tensor field estimated (bottom)

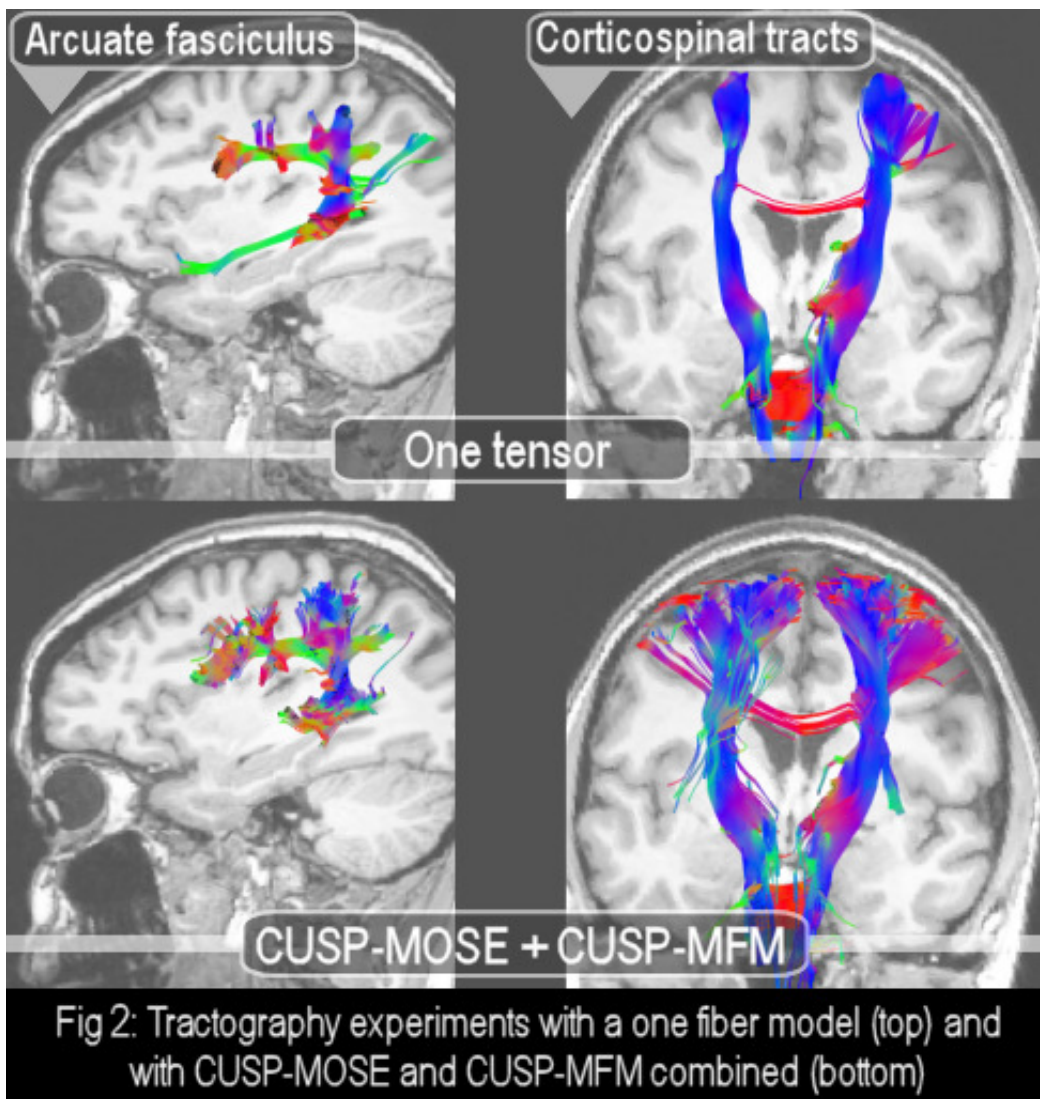


Fig 2: Tractography experiments with a one fiber model (top) and with CUSP-MOSE and CUSP-MFM combined (bottom)

### Abstract Information

### References

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- Behrens, T.E (2007a), 'Probabilistic diffusion tractography with multiple fibre orientations: What can we gain?', *Neuroimage*, 34(1), 144-155
- Hosey, T (2005a), 'Inference of multiple fiber orientations in high angular resolution diffusion imaging.', *Magnetic Resonance in Medicine*, 54(6), 1480-1489
- Scherrer, B (2010a), 'Why multiple b-values are required for multi-tensor models. Evaluation with a constrained log-Euclidean model', *ISBI*, 1389-1392
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