# A tensor based approach to crossing fibers using the Wild Bootstrap

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**Introduction**

The field of tractography has produced a number of multiple-fiber reconstruction algorithms that are often mathematically and computationally intensive (Q-ball [1], Spherical Deconvolution [2], PAS-MRI [3]). Here we present a simple, alternative method of delineating crossing structures using the Wild bootstrap and the diffusion tensor (DT) model to produce distributions of principal eigenvectors which are classified as belonging to one of two clusters. Our method provides comparable fiber reconstructions to Q-ball, particularly in the frontal pericallosal region (FPC).

**Method**

Two healthy adult males were scanned on a 1.5T Siemens Avanto MRI system with a double refocused pulsed diffusion-weighted EPI sequence, maximum gradient strength = 40mT $m^{-1}$ in 60 diffusion sensitised directions with b = 3000s $mm^{-2}$ and with three b = 0s $mm^{-2}$. TR/TE/NEX = 4100ms/112ms/2, voxel resolution = 2.5 x 2.5 x 5mm and 19 axial slices were acquired in the brain. The Wild bootstrap [4] was performed 2000 times on the dataset on which the DT was fitted for all bootstraps in each voxel between the interval b0-3000. Polar coordinates ($\theta$, $\varphi$) were calculated for the 2000 DT principal eigenvectors, $\boldsymbol{\varepsilon_1}$, and were then classified into two populations using k-means clustering. The two centroid vectors found represent the two points of greatest concentration of bootstrapped $\boldsymbol{\varepsilon_1}$ in a voxel. For visualisation, the polar coordinates were binned into a 3D frequency histogram of $\theta$ against $\varphi$ (75 bins each), giving the direction concentration of $\boldsymbol{\varepsilon_1}$ on a sphere. Q-Ball with a fourth-order spherical harmonics was also performed on the dataset using Camino [5].

**Results**

Fig 1 shows histograms of nine FPC voxels (from the 3x3 ROI magnified in Fig 2) of the frequency of bootstrapped $\boldsymbol{\varepsilon_1}$ against $\theta$, where $\theta$ ranges from 0-$\pi$. Fig 2a shows plots of the two centroid vectors found from our Wild-tensor method and Fig 2b is the Q-Ball output as given by Camino, overlaid on the fractional anisotropy map. It can be observed that for voxels potentially containing multiple fibers, the bootstrap histograms can reveal dual distributions (Fig 1a and Fig 1b). This is represented in the centroid plots in Fig 2a as increasing angular separation between the two centroid vectors. In contrast, Q-Ball analysis produces crossings with a greater angle between fiber populations.

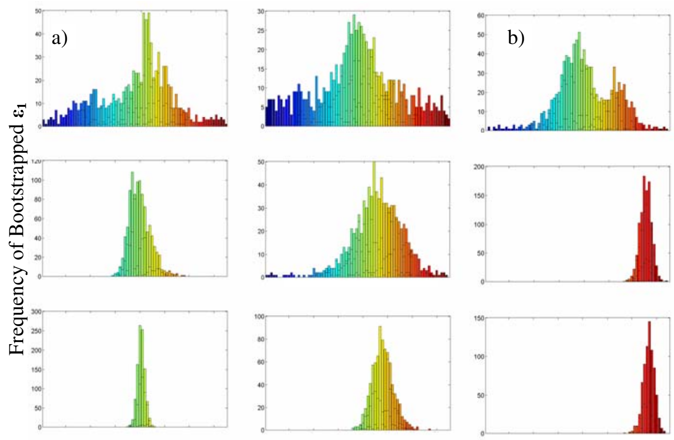


**Figure 1 – XZ-axis views of 3D polar histograms of 9 FPC voxels in Fig 2, plotting the frequency of 2000 bootstrapped $\varepsilon_1$ versus polar coordinate $\theta$, where $\theta$ ranges from 0- $\pi$.**

**Discussion**

The Wild bootstrap is a nonparametric technique where no assumptions of the underlying signal distribution are made. It can allow outliers with significance the potential to be included in the distribution of bootstrapped $\boldsymbol{\varepsilon_1}$ in Fig 1, perhaps explaining the dual distributions. The Wild-tensor method tends to give smaller crossing angles between centroids when compared with Q-Ball. Upon visual inspection of Fig 2, the Wild-tensor method also gives a more plausible trajectory of streamlines, particularly in the FPC region highlighted where the coronal radiata meets the corpus callosum. Further investigations of histogram shapes with respect to b-value range and the number of bootstraps calculated are warranted. The method we have presented shows promise for discerning multiple-fiber orientations in a voxel that is simple by using the diffusion tensor model with the Wild bootstrap. The availability of many replicates of the data also allows the calculation of a variety of statistics and indices of distributions and distances within and between clusters. The Q-Ball algorithm requires a higher angular resolution than 60 directions for optimal reconstruction; our initial results indicate an alternative to Q-Ball with sensible trajectories, using only 60 directions.

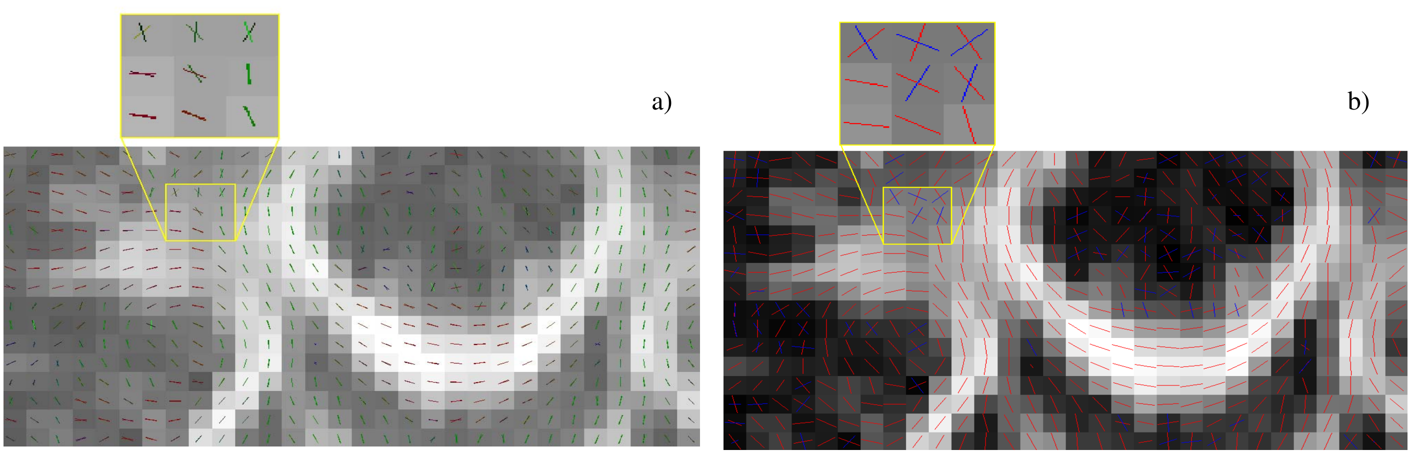


**Figure 2 – Prefrontal region with principal orientations from centroid vectors as found by our Wild-tensor approach a), and with Q-Ball b) plotted against FA. Magnified FPC regions are chosen as examples of voxels with multiple fibers for further inspection.**

References: [1] Tuch DS, MRM, 2004, 52:1358-1372, [2] Tournier JD et al., NeuroImage, 2004, 23:1176-1185 [3] Jansons KM and Alexander DC, Inverse Problems, 2003, 19:1031-1046 [4] Davison AC, Hinkley DV, Bootstrap Methods and their Application, Cambridge University Press, 1997 [5] Cook PA, Alexander DC et al., 14th ISMRM, 2006, #2759. Sponsored by Research Into Ageing, Grant number 256. The authors wish to thank MD King and KK Seunarine for helpful discussions.