Brain White Matter Tractography from DT Images Using Global Coverings and Maximal Likelihood Connectivity

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Introduction

Most fibre tracking techniques are based on successive tracking through a discrete vector field representing the principal eigenvectors of diffusion tensors [1]. The tendency of these algorithms to focus on local interactions and the principal orientation of the diffusion tensor, make them sensitive to noise and partial volume effects and producing confusion in regions of fibre crossings. Furthermore, their results tend to be dependent on the specific voxel selected as the initial seed point. The method presented here allows for wider potential interactions among individual voxels in the vector field, and considers both the principal and orthogonal diffusion orientations and magnitudes. These interactions are integrated into a *global covering* map [2] at sub-voxel scales, and the fibre tracks along this covering map are calculated as the maximally likely paths, using a modification of Dijkstra's shortest-path algorithm [3].

Methods

Diffusion tensor parameters were computed from diffusion images acquired on a 1.5T GE Signa scanner, using a standard diffusion-weighted-EPI sequence (1 NEX; 10 gradient orientations; b value = 1000 [s mm^{-2}], scan time=1.5 min) . Twenty-two 4-mm axial slices were collected (in-plane resolution 1.8 mm^2). Only white matter was analyzed, based on a segmented T1-weighted image [4] corresponding to the diffusion image. At each voxel, an oriented 3D region of influence, or covering, was computed, which overlaps a number of neighbouring voxels and reflects continuity with neighbouring voxels. We assumed displacement probability is a 3D-Gaussian with variance proportional to the tensor's 3 eigenvalues (ADC's), with orientation corresponding to the eigenvector. Highly anisotropic voxels generated long, thin regions of influence oriented in the primary diffusion direction and highly isotropic voxels were more spherical. The present results have a maximal overlap of 3 voxels in each direction. Overlap is accumulated in a *global covering* map (Fig 1), which is the sum of all the oriented coverings applied at each voxel.

We propose that the local ridges in the global covering map correspond to the integrated fibre paths and the intensity of the ridge at each point is proportional to the degree of support, or likelihood, that a fibre crosses that voxel. A modification of Dijkstra's shortest-path algorithm redefines the shortest path between any 2 locations as the path of maximal likelihood, based on global covering ridge heights. The algorithm also computes a quantitative measure of goodness-of-fit or probability for the calculated paths.

Results

Figure 2 shows the paths (green lines) from a source region-of-interest in inferior frontal cortex (magenta line) to the temporal lobe (left1, right1), and occipital cortex (left2, right2). Path probabilities (not adjusted for path length) for the frontal-temporal paths were similar (left1=0.237, right1=0.208), as were those for the frontal-occipital paths (left2=0.101, right2=0.084). Importantly, the paths were anatomically consistent: the frontal-temporal path coursed through the faciculus uncinatus, and the frontal-occipital path was primarily along the longitudinal fasiculus.

Discussion

The presented approach to fibre tracking has a number of advantages. Because the paths are based on the global covering map, initial seed points are not required, and the paths are unbiased. It is inherently noise insensitive since the directed coverings effectively smooth the data over local variations. Finally, coverings can be computed and applied at arbitrary sub-voxel resolutions, allowing similar resolution of the fibre paths. The ability to obtain unbiased estimates of connections between regions and their probability will be of great utility in studies of functional and effective connectivity in the nervous system.

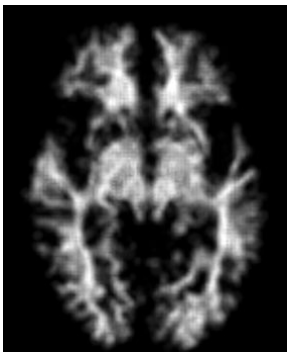

Fig 1

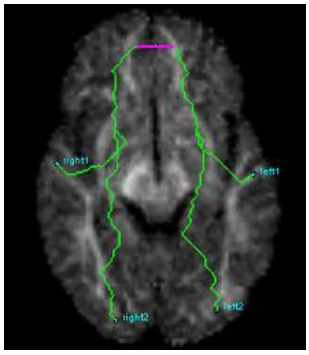

Fig 2a

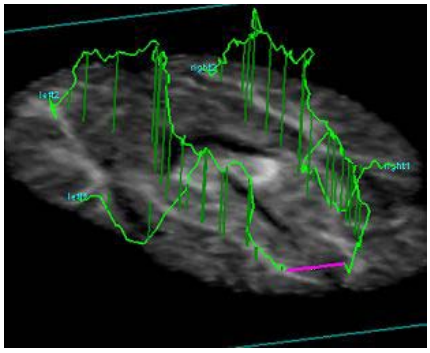

Fig 2b

Figure 1: Axial slice of global covering map. Figure 2: (a) Axial FA slice with overlaid fibre tracks (green) from 4 image points to source (magenta). (b) Same axial slice tipped off plane to show the 3 dimensional fibre paths.

[1] Mori et al. NMR Biomed. 2002;15:468-480. [2] David et al. Int J. Comp Vis. 1990; 5:3, 219-238.
[3] Cormen et al. Intro. to Algorithms; 1990 MIT Press, 527-531. [4] Kovacevic et al. Neuroimage, 2002, 17:1087–1100