Gibbs Tracking: A Novel Approach for the Reconstruction of Neuronal Pathways

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INTRODUCTION

Fibre tractography based on diffusion weighted MRI is a powerful method to extract the anatomical connectivity in white matter *in vivo*. The main idea of the currently available methods of fibre tracking is the reconstruction of long neuronal pathways in small successive steps by following the local, voxel-defined fibre direction. Starting from local information on the diffusivity, long-distance connections are determined. This method is inherently prone to instability, since a mistake at a single crossing affects radically the final result. In this paper we present a method based on a new principle. Instead of walking successively through the volume all neuronal pathways and the totality of the signal is taken into account at the same time. This novel approach is capable to reconstruct crossing and spreading fibre configuration.

METHODS

The method includes the following main steps: Creation of a trial fibre configuration, calculation of the corresponding diffusion-weighted signal and adjusting the trial configuration to the experimentally measured signal to minimise the difference [1]. This process can be explained using a close analogy to the chemical reaction of polymerisation as follows. The building elements of reconstructed fibres are **small straight cylinders** whose length, position and orientation can vary continuously. They can be compared with chemical monomers. The reconstruction begins at very **high temperature** where such cylinders are randomly distributed in the space occupied by white matter (Fig. 1 **a**) analogously to a solution of monomers. The interaction between them results in building long polymer chains with **decreasing temperatures** (Fig. 1 **b, c**). The chains, that represent the neuronal fibres, can start and end on **predefined surfaces**, for example at the boundary with the grey matter. Each cylinder **contributes a signal** typical for parallel fibres to all voxels it crosses [2]. The sum of such contributions is the anisotropic part of the signal. The requirement of **similarity** between this simulated signal and the measurement is analogous to an external field acting on the monomers and forcing them to take locally specific orientations and densities. We term the described method the **Gibbs Tracking**, keeping in mind its close analogy to statistical physics. On the other hand, the described simulation can be considered as a **Bayesian approach** based on spatial point processes. The interactions between the cylinders represent the a **priori probability** and the **likelihood function** represents the similarity the measured signal and simulated signal. Note that similar ideas are implemented in the so-called **Candy-Model** [3], that has been successfully used for road recognition in remotely acquired terrain images.

The *in vivo* diffusion-weighted measurements were performed on a Siemens 3T TIM Trio using a DW SE EPI sequence with automatic distortion correction [4], a voxel size of 2x2x2mm^3, 61 diffusion-encoding directions, and an effective b-value of 1000 s/mm^2. Additional a 3D T1 MPRAGE dataset with a resolution of 1 mm^3 was acquired. The T1 weighted dataset was segmented in CSF, white matter, and gray matter by SPM [5]. The transitions between white and gray matter are used to extract the predefined surfaces, specifying the ends of the fibres. The Gibbs Tracking was applied to the whole acquired diffusion-weighted dataset with respect to an exponential temperature schedule reaching the final temperature after 5x10^9 iteration.

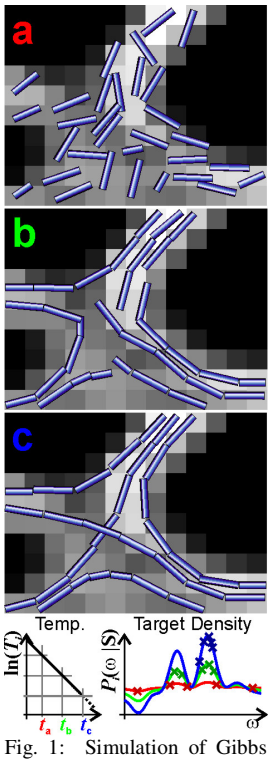

Fig. 1: Simulation of Gibbs process during decreasing temperature of the system (**a** for high, **b** medium, and **c** for low temperature). Temp. schedule and density functions are shown at the bottom.

RESULTS AND DISCUSSION

Specific neuronal pathways were selected form all reconstructed fibre tracks by assigning regions of interests (ROI) they should cross. In Fig. 2 the following neuronal pathways are visualized: Part of callosal fibres coming from the motor cortex (CF), the corticospinal tract (CST). the cingulum (CG), the arcuate fasc. (AF), and the inferior fronto-occipital fasc. (IFO). The capability of the Gibbs Tracking to resolve fiber crossing is pointed out in Fig. 2 **c** and **d**.

The callosal fibres reconstructed by the DTI-based FACT [6] method and by Gibbs Tracking are shown in Fig. 3. Caused by the projective pathways, nearly all fibres reconstructed by FACT are redirected into the vertical plane. In contrast, the Gibbs Tracking method was able to resolve the crossing: The callosal fibres pass the crossing region and spread out contacting nearly the whole cortex. The colouring in Fig. 3 indicates that the fibres keep track of the position at which they cross the corpus callosum.

The proposed method shows the ability to reconstruct neuronal pathways containing crossing and spreading fibre configurations without interpolation or strong a priori constraints. A reduction of computation time is imperative for clinical applications. This can be achieved by optimising the annealing schedule, using the parallel computing, and by using an optimisation method based on gradient descent.

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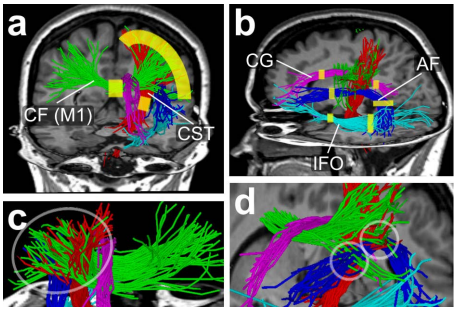

Fig. 2: Reconstructed fibre bundles. Part of callosal fibres coming from motor cortex (green), corticospinal tract (red), cingulum (magenta), arcuate fasc. (blue), and inferior fronto-occipital fasc. (cyan). ROIs used for fibre selection indicated in yellow.

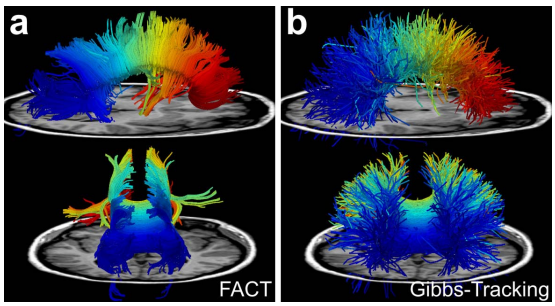

Fig. 3: Callosal fibres reconstructed by FACT and Gibbs Tracking. The colouring depends to the position at which the fibre is passing the corpus callosum. **a** FACT method: Nearly all fibres are redirected in the vertical plane. **b** Gibbs Tracking method: Fibres spread out and connect the cortex evenly.