

## Fiberfox: A novel tool to generate software phantoms of complex fiber geometries

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**Purpose:** Over the last years an abundance of new techniques for diffusion weighted image (DWI) processing like novel modeling or fiber tractography methods have been introduced. Quantitative evaluation of such methods requires an appropriate gold standard. One commonly used approach to this task is the employment of synthetic data because of its unique property of providing the ground truth together with the data itself. Hardware phantoms can provide ground truth information due to their well defined configuration, but their capabilities to model complex fiber geometries are limited and their construction is labor intensive. Existing openly available tools to synthesize diffusion data are command line based and either restricted to generate local diffusion profiles using complex modeling<sup>1,2</sup> or to simulate whole image volumes but with a very limited simulated fiber complexity<sup>3</sup>. We present an intuitive graphical tool, Fiberfox, for the interactive synthesis of DWI data of arbitrary fiber configurations combining the local domain of diffusion modeling and the global domain of synthetic fibers in one generic framework. All methods introduced here are integrated into MITK Diffusion<sup>4</sup>, which is part of the open source medical imaging interaction toolkit.

**Methods:** We divided the phantom generation process in two steps. Firstly, the fiber geometry is interactively defined and secondly, DWIs are generated from these fibers. In the first step, several elliptical ROIs that are later used as fiducials for the fiber generation are interactively positioned in 3D space. Waypoints for the fibers are equally distributed in the first ROI and propagated to the succeeding ones belonging to the same bundle. The ellipses are defined by three control points that allow for an easy adjustment of the position and shape of the ROI as well as a fourth point enabling the introduction of fiber twistings. In this way one can easily add multiple fiber bundles containing any number of straight, bended, crossing, kissing, twisting and fanning fibers. Interpolation between the waypoints is implemented using Kochanek-Bartels splines.

In the second step, the diffusion weighted signal  $S$  in direction  $g$  and each voxel  $v$  is calculated as the linear combination of an arbitrary number of compartments, weighted according to their volume fraction  $w$ . In our experiments we used a two compartment model simulating the isotropic diffusion of free water and the anisotropic diffusion in the fiber tissue. Using a second rank diffusion tensor model, the artificial signal is calculated to:

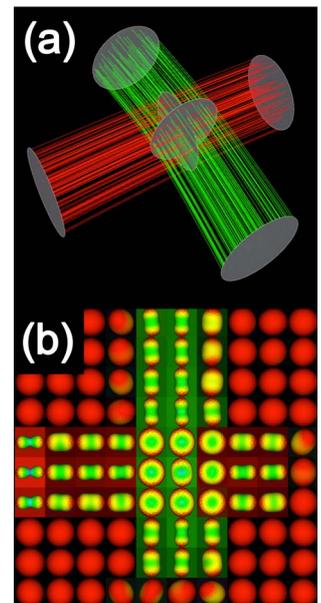
$$S_v(g) = wS_{Fiber} + (1-w)S_{Water} = wS_0^F \sum_{f \in F} \int e^{-bg^T M_x D_f M_x^T g} dx + (1-w)S_0^W e^{-bD_w}$$

where  $S_0$  is the tissue specific baseline signal,  $F$  is the set of all fiber paths  $f$  present inside  $v$ ,  $D_f$  is the second order tensor defining the anisotropic diffusivity in the fiber compartment,  $D_w$  is the scalar diffusivity in the free water compartment and  $M_x$  is the matrix rotating the largest eigenvector of  $D_f$  into the direction of the fiber tangent at position  $x$  along  $f$ . To gain a realistic measurement, rician noise is added to the simulated signal intensities.

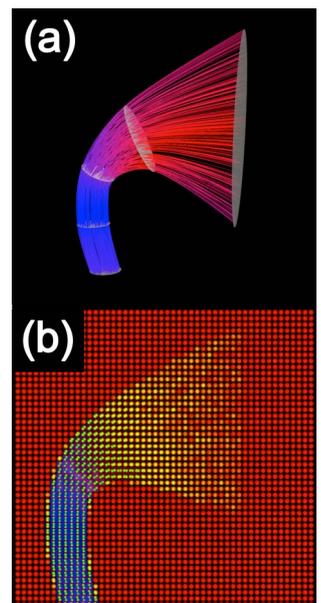
**Results:** To demonstrate the capabilities of Fiberfox we generated several commonly discussed fiber configurations and the corresponding phantom images. Fig. 1a shows the artificial fibers for a 90° crossing. The tensor reconstruction of the according DWI generated with a b-value of 1000 s/mm<sup>2</sup>, 60 gradient directions, SNR of 15 and a fiber FA of 0.7 is depicted in Fig. 1b. Figures 2 to 5 illustrate examples of fanning, kissing, twisting and highly curved bundles as well as some of the corresponding tensor images.

**Discussion and Conclusion:** We proposed Fiberfox, an open source tool that allows for the easy and intuitive generation of diffusion weighted fiber phantoms and illustrated its capabilities to simulate a wide range of complex fiber configurations. The tensor based two-compartment model used to generate the artificial signal can be easily extended by employing a higher order signal representation and more complex compartment models, e.g. as described in Panagiotaki *et al.*<sup>1</sup>, to incorporate the concepts of kurtosis and hindered and restricted diffusion. Fiberfox is integrated into MITK and will also be available as free and ready to use application in the next release of MITK Diffusion<sup>4</sup> ([www.nitrc.org/projects/mitk-diffusion/](http://www.nitrc.org/projects/mitk-diffusion/)).

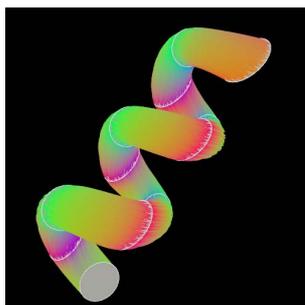
**References:** [1] Panagiotaki *et al.*, NeuroImage 2012, 59(3):2241-54 [2] <http://www.nitrc.org/projects/mcftool> [3] tend helix; <http://teem.sf.net> [4] K. H. Fritzsche *et al.*, Meth Inform Med, in press



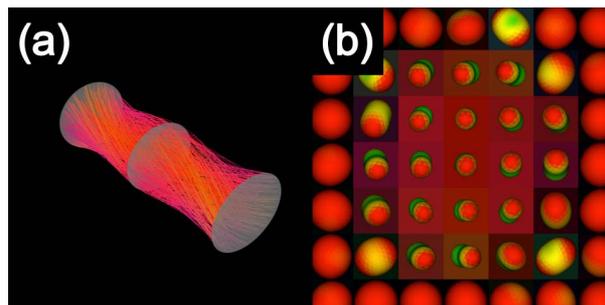
**Fig. 1** Crossing fiber configuration (a) and tensor reconstruction (b).



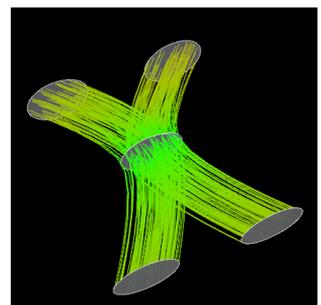
**Fig. 2** Fanning fiber bundle (a) and tensor reconstruction (b).



**Fig. 5** Helix shaped fiber bundle.



**Fig. 4** Fibers with two 90° twists (a) and corresponding tensors (b).



**Fig. 3** Kissing fiber configuration.