(This submission has an accompanying video)

Streamtubes and Streamsurfaces for Visualizing Diffusion Tensor MRI Volume Images

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In biological tissues water is ubiquitous and constantly in motion. This motion of water within biological tissues is called diffusion. The diffusion of water is constrained by, and correlated with, micro-structure of the tissues. Volume images of diffusion rate measurements can be acquired with magnetic resonance imaging [1].

We produce geometric models from diffusion tensor volume images. The models illustrate the connectivity and other micro-structural information in the nervous system. We provide the user with interactivity so that he/she can explore the geometry from different perspectives. We also include in the models anatomical landmarks, which have proven essential for understanding the diffusion information.

In the literature, researchers have successfully designed visualization methods for 2D slices of diffusion tensor fields. These include ellipsoids [1], as well as a normalized version of the ellipsoids and a painting-motivated method [2]. Directly extending these methods to volumes would not only be expensive but would also result in self-obscuring geometry. Two approaches have been explored for visualization of 3D second-order tensor fields. One uses a volume rendering approach [3], the other uses a geometric representation [4]. We extend the latter approach, originally applied to tensors related to fluid flow instead of diffusion, to visualize micro-structural information in biological tissues.

We distinguish between structures exhibiting linear anisotropy and those exhibiting planar anisotropy. Streamtubes and streamsurfaces, respectively, represent these two types of diffusion. Streamtubes represent linear structures, where diffusion is much faster in one direction. The trajectory of each tube sweeps along the principal direction of diffusion, and the cross-section shape is an ellipse representing the diffusion rates in the directions perpendicular to the trajectory. We normalize the maximum radius of the ellipse to a constant value so that the size of the streamtube is predictable while its aspect ratio is preserved. The color of the streamtube shows how anisotropic the diffusion is. Streamsurfaces represent surface structures, where diffusion is faster within a plane than perpendicular to the plane. The surface we generate is an approximation of the integral surface perpendicular to the direction of slowest diffusion. Colors are mapped to the surfaces to show how anisotropic the diffusion is.

Our algorithm begins by generating many streamtubes and streamsurfaces and then culls those down to a representative subset. Initially, every voxel with a linear or planar anisotropy value greater than a threshold has a representative streamtube or a streamsurface. The criteria for selecting the subset to display includes the size of the geometry, the average anisotropy in the region containing the geometry, and the similarity of the geometries. Geometries with low scores on these criteria are discarded. A representative subset of geometries are kept and displayed in the final image.

Based on feedback from preliminary results, we found that biologists were able to explore the models more effectively when they could identify familiar landmark structures, like the eyes or ventricles. For this reason, we also provide anatomical landmarks in our image. The final models are 2D surface geometries that can be imported into many interactive environments.

Figs. 1 and 2 and the accompanying video illustrate results of our method applied to data acquired from a human brain (data courtesy Dr. Susumu, Johns Hopkins). Many gross features are readily apparent in the results; several are identified in the figures and video. We are continuing to investigate the more subtle features that may be visible and the tradeoffs among the several selection criteria we use to choose streamtubes and streamsurfaces for display. Early results show promise for understanding connectivity in a volume and suggest that more anatomical context and additional interactivity will help make exploration more effective.

References

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[4] T. Delmarcelle and L. Hesselink. *Visualization of second order tensor fields and matrix data.* In IEEE Visualization 92 Proceedings, pages 316-323, 1992.

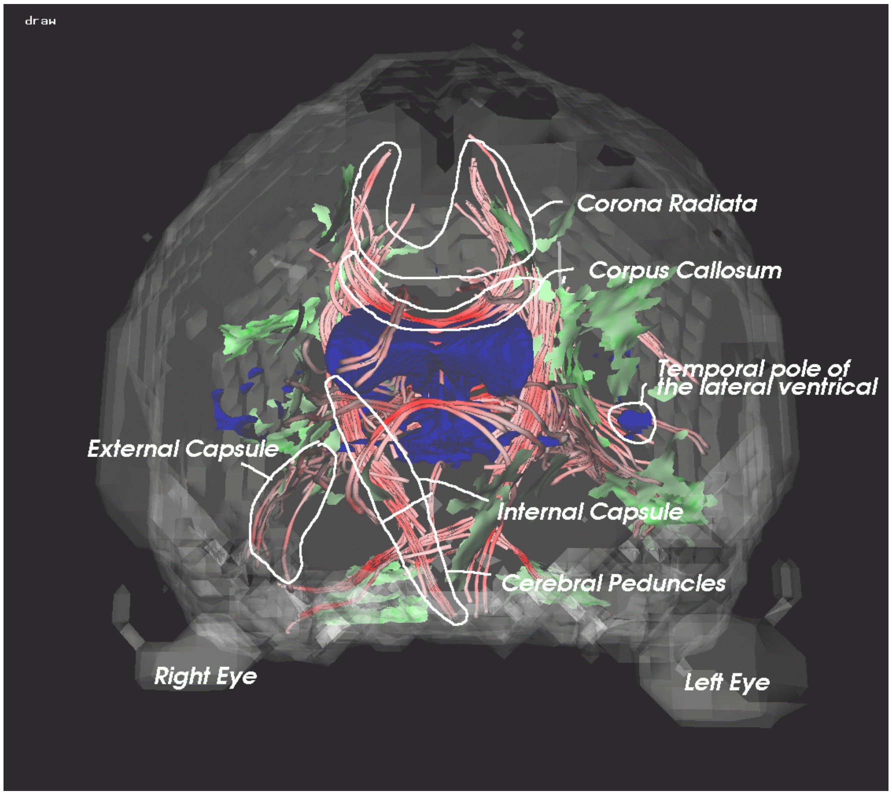

Fig. 1. A front view of the human brain image using streamtubes (red), streamsurfaces (green), and anatomical landmarks (blue and transparent white). Anatomical features, including the corpus callosum and corona radiata are clearly visible in the models.

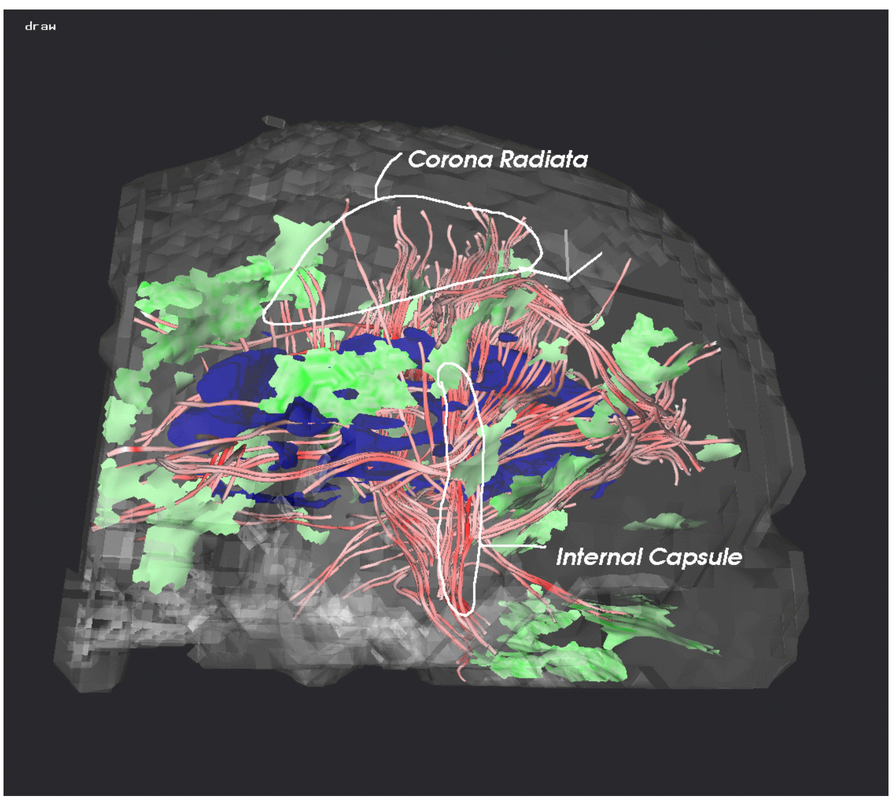

Fig. 2. A side view of the human brain image using streamtubes, streamsurfaces, and anatomical landmarks. The internal capsule and corona radiata are labeled.