

Visualizing the Differences between Diffusion Tensor Volume Images

M. J. da Silva, S. Zhang, Ç. Demiralp, D. H. Laidlaw*
Brown University Computer Science, Providence, RI, USA.

1 Introduction

We present a technique for visualizing the differences between two Diffusion Tensor Magnetic Resonance Imaging (DT-MRI) volumes. Our technique registers two DT-MRIs and then produces a 3D model that allows a user to simultaneously view structure in both volumes. The geometric model is based on one developed to visually represent a single volume with a carefully chosen set of streamtubes [6,7]. In the new model, we choose corresponding tubes from both volumes and show how they differ. Collectively, this illustrates the differences between the volumes. Saturation is used to indicate the magnitude of the difference between corresponding points on streamtubes. Streamtubes follow the orientation of the principal eigenvector of the diffusion tensor at each point in the volume. The cross-section at each point of the streamtube is an ellipse determined by the second and third eigenvectors and eigenvalues of the diffusion tensor.

We apply the method to three types of cases. In the first, we compare the streamtubes generated with different integration methods to show how the choice of method can lead to different streamtubes. In the second case, we show difference models for two volumes that are identical except for noise. In the third case, we show differences between two volumes acquired from the same human subject but at different orientations. Differences are shown in all the cases and they are easily identifiable from the color coding.

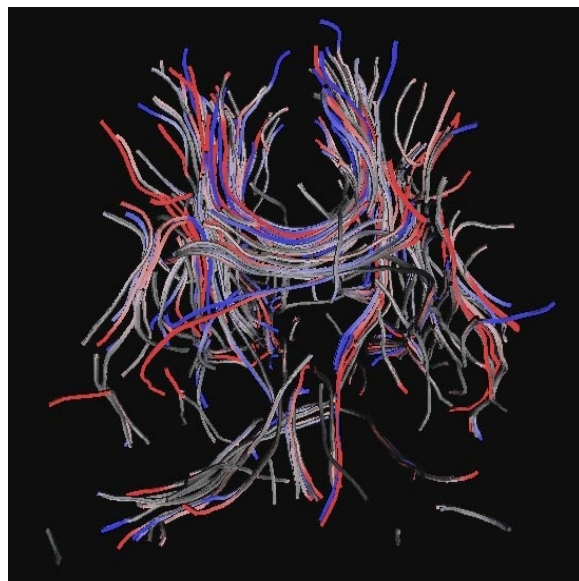
2 Methods

The technique used to generate the difference models presented in this paper consists of four steps. First, two DT-MRIs are resampled to the same isotropic resolution. The resampling is done using tricubic interpolation of each of the six diffusion tensor components. Basser *et al.* showed that such component-wise interpolation was sufficient in several experiments [1].

Next, if not already registered, the two volume data sets are registered semi-automatically using the gradient-based methods described in [2] to align T2-weighted images. This approach works best when the difference in orientation between the two images is small enough that most voxels need move less than eight voxels. Therefore, an initial estimate of the transformation matrix is applied to one of the original images, and this image is then used by the automatic image registration program. Once the transformation matrix is calculated, it is applied to one of the DT-MRI volumes. It is important to realize that the diffusion tensors must also undergo a transformation to reflect the change in coordinates. To achieve this, we apply the linear transform to the diffusion tensor.

Once the volumes are aligned, the third step is to generate corresponding streamtubes in each image. We first generate a model for one of the volumes. This is described in more detail in [6,7]. A streamtube is analogous to the streamline in fluid flow visualization. It follows the principal direction of water diffusion. This is accomplished by integrating the principal eigenvector field (as discussed in [1]) both forward and backward starting at a particular point. We choose many seed points on a jittered grid. Streamtubes that are similar to previously generated streamtubes are culled, as are short streamtubes and streamtubes with low average linear anisotropy (less than 0.2).

The numerical integration is carried out by either Euler, Runge-Kutta, or Adams integration using Numerical Algorithms Group [8] or Numerical Recipes [9] software. Diffusion tensor values at non-



(a)

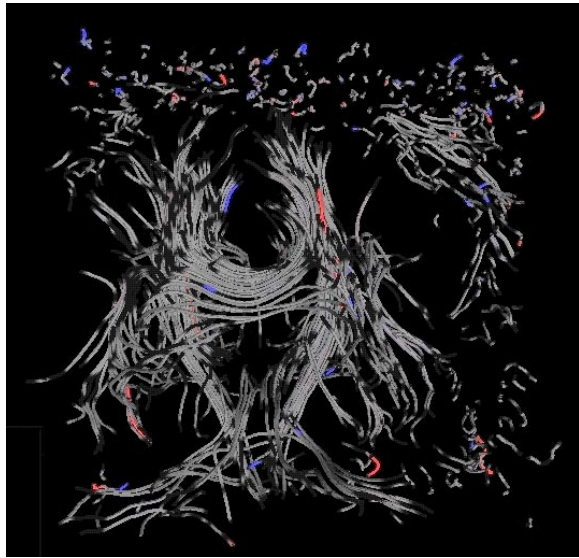


(b)

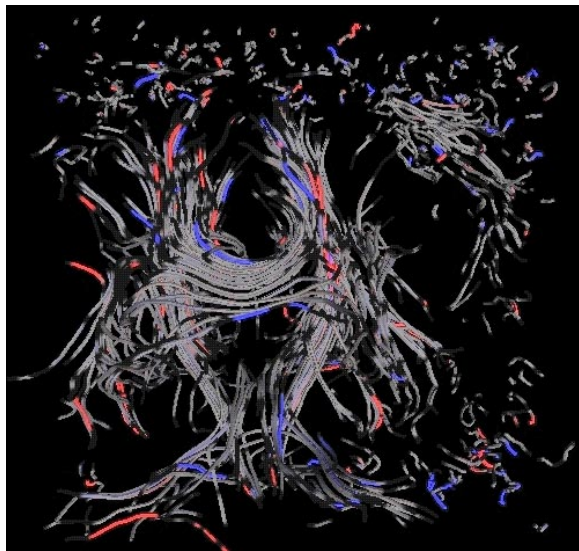
Figure 1: (a) Runge-Kutta vs. Euler. (b) Adams vs. Runge-Kutta. Frontal view of streamtube difference images of human brain data. For reference, note that the large left-to-right bundle of tubes near the center is the corpus callosum and the ascending connections from that bundle the corona radiata. (a) is a difference image between a model generated with Runge-Kutta (in blue) and Euler (in red) integration (see [10] for a color version of the paper). (b) is a difference image between Adams (in blue) and Runge-Kutta (in red) integration. In this case, we started with a smaller number of tubes. Note that (b) is almost entirely gray, in contrast with the color in (a), indicating that the Adams and Runge-Kutta integration schemes produce paths that are much more similar to each other than to paths generated by Euler integration.

grid coordinates are calculated by tricubic interpolation of the six component values.

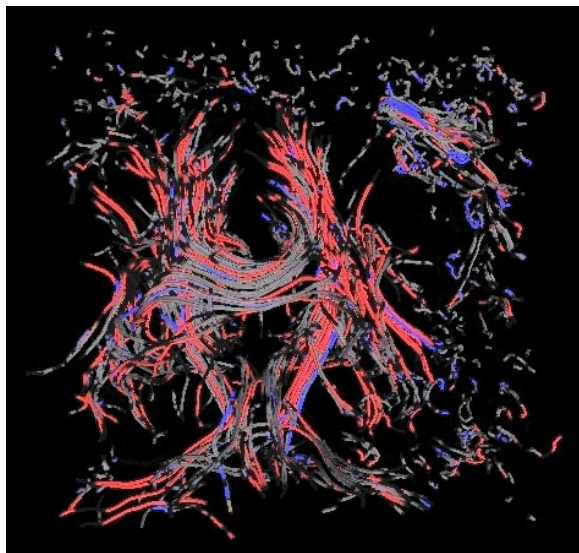
* {mds, sz, cad, dhl}@cs.brown.edu



(a)



(b)



(c)

Figure 2: Difference images of the data used in figure 1 with noise added. Gaussian noise was used, with different standard deviation σ , which affects the signal-to-noise ratio. (a) $\sigma = 0.0000001$, $\text{SNR} \sim 1000$ (b) $\sigma = 0.000001$, $\text{SNR} \sim 100$ (c) $\sigma = 0.00001$, $\text{SNR} \sim 10$. The SNR of a real dataset is typically between 10 and 30. Note that the differences in streamtubes increase as σ value increases.

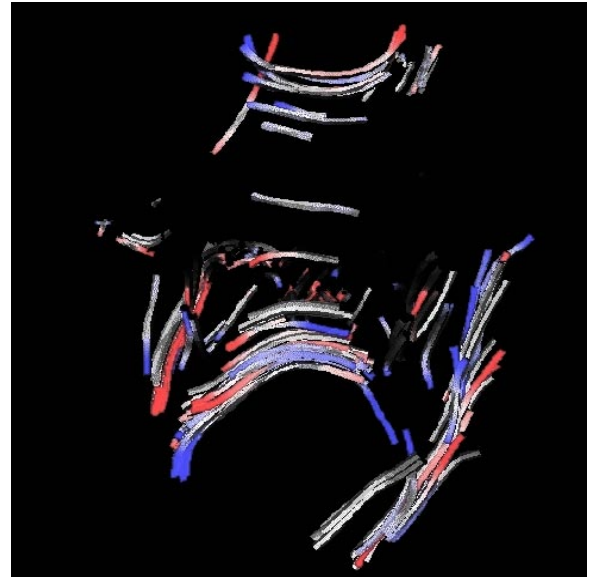


Figure 3: A different image between two acquisitions of the same brain. The acquisitions were taken at different orientation and the datasets registered before the different image was created.

With the seed points for the representative tubes for one volume, we generate corresponding tubes in the second volume. The second and third eigenvectors of the diffusion tensor at each sampled point of a streamtube are stored as well as that point's distance to its corresponding streamtube in the other data set. The distance is defined to be the minimum distance between the current point and all points on the other streamtube.

The fourth and final step is the rendering of the difference model. Each streamtube is rendered as a tube. At each sampled point of the tube the second and third eigenvectors are used to construct an elliptical cross-section. The color assigned to each point on the cross-section is defined to be $(\max_d - d)/\max_d$, where d is the distance found and stored in the previous step and \max_d is an arbitrary voxel distance that can be represented. The elliptical cross-sections are stitched together to produce a continuous tube and output as a VRML mesh file, which can then be viewed in standard viewing applications.

3 Results and Discussion

The first type of comparisons we examined were those between numerical integration algorithms. Figure 1 shows that results can vary depending on the integration scheme chosen. In particular, Euler integration with a large step size leads to significant differences compared to other more accurate integration methods. Note that Figure 1b show some slight differences between two very accurate methods. We believe that these are caused by threshold effects at the boundaries of the regions of anisotropy: different integration methods have different choices about where to put the next foothold, and some of them may stride over a region of low anisotropy where others walk into it and stop.

We then used the same integration techniques to compare different DT-MRIs. First, we assessed the effect of noise on our technique. Gaussian noises with different standard deviations were added to the original dataset, and comparisons were made between the noisy datasets and the original dataset. Figure 2 shows that the differences increase as the standard deviation σ increases, and suggests that our technique is moderately sensitive to noise. The noise changes the boundary of the anisotropic region a little amount, and threshold effects, again, are likely to be responsible for significant portions of the colored tubes.

We then evaluated the effect alignment has on our technique in Figure 3. The significant amounts of gray are consistent with data collected from the same subject. The color that is present is consis-

tent with the differences we see due to noise in Figure 2. It is also possible that the color is due to errors in registration, although it is not noticeably greater than would be expected from noise alone.

Streamtubes are well suited for showing changes in the orientation of the principal direction of diffusion, but poorly suited for depicting changes in anisotropy. While the second and third eigenvectors are encoded in a streamtube, it is difficult to determine by sight the differences in these values between corresponding streamtubes.

4 Conclusions

This extended abstract describes a method designed to help investigators visualize differences between DT-MRIs, specifically, the differences between the tracts generated in linear anisotropy regions. The images show differences that are difficult to see.

Acknowledgments

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