Visualizing Spatial Relations Between 3D-DTI Integral Curves Using Texture Patterns

Doria Jianu* Wenjin Zhou* Çağatay Demiralp* David H. Laidlaw*

Brown University

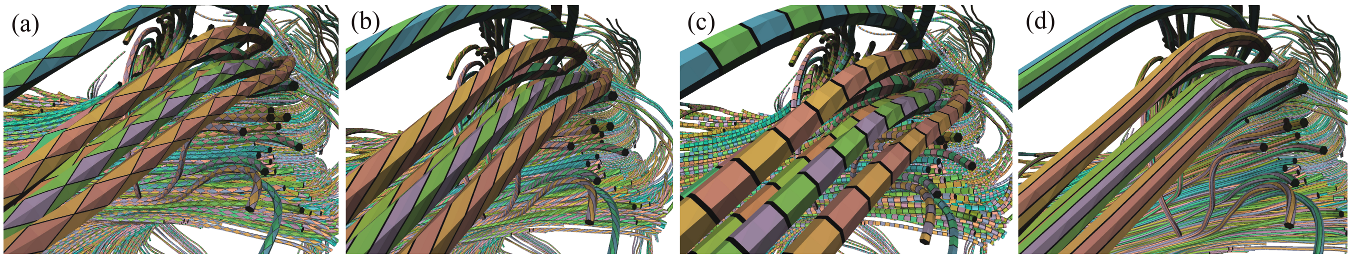

Figure 1: Four different patterns applied on corpus callosum streamtube model: (a) Diamond Pattern, (b) Diagonal Pattern (c) Vertical Pattern (d) Horizontal Pattern

Abstract

We present a new method for visually differentiating integral curves obtained from DTI volumes. The goal of our method is to reflect the spatial relations between visualized integral curves. This will enable the user to group similar curves together while differentiating dissimilar curves that may lie near one another. To this end, we first define a similarity measure and compute the similarities between the curves according to that measure. Then we encode this similarity information onto the streamtube representations of the curves as stripe texture patterns. We present examples of visualizations using four different pattern styles. We evaluate our method with help of neuropsychologists; initial feedback suggests that our method can be useful in understanding the underlying connectivity of integral curves.

1 Introduction

Diffusion-Tensor Magnetic Resonance Imaging (DTI) estimates Brownian motion of water in tissues enabling the exploration of fibrous structures such as white matter in the brain noninvasively. Understanding the white matter structure in the human brain is crucial for studying and understanding various neurological disorders. DTI tractography methods calculate a set of integral curves estimating neural fibers in the brain. These curves are generated by tracking the principal eigenvector of the underlying diffusion tensor field in both directions. They are often visualized with streamlines or variations of streamlines (streamtubes and hyperstreamlines) in 3D.

Densely sampled integral curves tend to be visually cluttered hindering the exploration of the underlying structures. This limitation highlights the need for better data mining and visualization techniques. In this paper we present a new method for visualizing integral curves obtained from DTI volumes that encodes spatial relations between curves with texture patterns.

2 Related Work

There is a vast amount of work done on visualization of DTI data (for a review see [5]), Here, we only discuss examples of previous work incorporating the spatial relations of DTI integral curves into their visualization.

The standard method used for coloring streamtubes according to spatial relations is to map the normalized absolute values of the x, y, and z components of the vector defined by the end points of the streamtubes, to R, G, and B color values. This method obviously suffers from mirror symmetries [4]. We will refer to this coloring technique as the RGB method hereafter. Recently, several coloring methods based on non-linear dimensionality reduction techniques have been proposed. Brun et al [1] apply the laplacian eigenmaps algorithm, a spectral embedding method, to embed the endpoint distances of integral curves in RGB space. Similarly, Zhou et al. [7] use another spectral method [2] to embed "anatomically-motivated dissimiliarites" between the curves into the L*a*b* color space , which is approximately perceptually uniform, such that each difference between the colors of the curves corresponds to the distance (or dissimilarity) between the curves.

We build on the body of previous work using non-linear dimensionality reduction techniques, and extend it by encoding the relations in the low-dimension (i.e., in the embedding plane) with a more flexible coloring scheme and texture patterns.

3 Methods

We create our visualizations in three steps: First, we generate integral curves from a DTI volume using a fiber-tracking algorithm [6]. Second, we adopt the flat-torus coloring scheme proposed by Demiralp et al. to obtain pairs of colors for all the integral curves [3]. We, however, modify the proposed method in two ways: In one, we initialize the "distance fitting" algorithm described by the authors with 2D points obtained by applying a spectral dimensionality reduction on the curves [2]. In the other, we get pairs of colors (instead of a single color) for each point by mapping the u, v and s, t components of the (u, v, s, t) flat-torus coordinates to two different iso-luminant planes of the L*a*b* color space, respectively. Third, we apply the obtained color pairs, as textures with four different styles, onto streamtube representations of the curves. Using the obtained color pairs we generate three texture patterns: horizontal, vertical and diagonal. If the color pair is orange and purple, we can see the resulted textures represented in Figure. 3. In each texture, the two colors are separated by a dark line as shown. This dark line is used to help the viewer visually distinguish the two colors when they are perceptually similar. Using different combinations of the texture and coordinate mapping, we obtain and apply four different

*e-mail: {doria, wzhou, cad, dhl}@cs.brown.edu

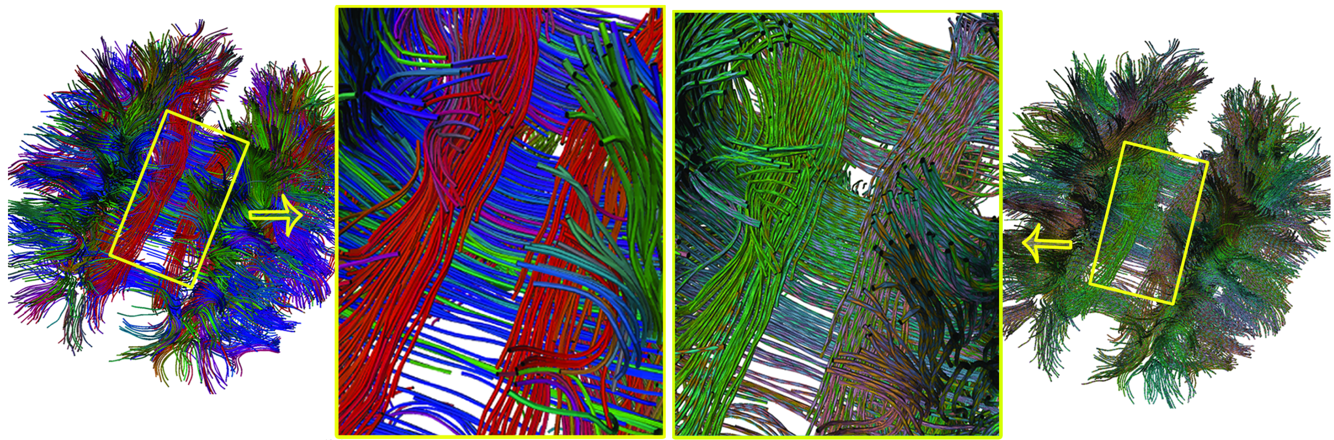

Figure 2: Applying RGB coloring vs. diamond pattern on whole brain model (a) RGB coloring applied. e.g. Notice that the two singular bundle in the middle are colored in red with nearly no noticable subgroup color distinction. (b) Diamond pattern applied. e.g. Notice that smaller subgroups can be visually grouped within the bigger singular bundle

patterns: horizontal, vertical, diagonal and diamond on the integral curves. See Figure. 1. Finally, we apply each of the four texture patterns on the integral curve model obtained from a volunteer's brain DTI dataset.

4 Results and Discussion

We apply our method to visualization of integral curves generated from a normal volunteer's brain DTI dataset. Figure 2 sequentially shows the result of the brain white matter integral curve model by applying horizontal, vertical, diagonal and diamond texture pattern styles. In order to assess the utility of our visualization technique, we conducted a small anecdotal study with two neuropsychologists, who use visualizations of integral curves in their research routinely. For comparison purposes, we also generated a visualization of the same set of the integral using the RGB method. We asked our experts to evaluate both methods according to their help in understanding and exploration of the underlying neural fibers estimated. The experts' comments show that while the RGB method is good at capturing the large structures, our visualization contains more information and has high sensitivity allowing it to capture subtle differences within large structures. Our experts noted that the ability to identify subtle changes within regions of interests is critical in diagnosing neurological abnormalities or disorders affecting the length and shape of neural fibers. Therefore, they pointed out that a useful application of our method would be to identify and compare ROIs across subjects. While one of the experts preferred vertical texture pattern, the other preferred the diamond pattern. Both of the experts, however, gave a similar justification for their preferences, which is the ability to detect sharper boundaries between the curves and find the edges. This is not surprising because the overall perceived orientation of the dark bands in both texture patterns is orthogonal to the principle direction of the streamtubes, which helps to see boundaries of the streamtubes easily. The work presented here is preliminary and focuses on demonstrating the advantages of our method on DTI integral curves.

Figure 3: Textures: (a) Horizontal, (b) Vertical (c) Diagonal, that applied on the tubes, in different positions, give 4 types of patterns(horizontal, vertical, diagonal and diamond).

5 Conclusion

We presented a new method for visualizing DTI integral curves. Our method applies texture patterns on streamtube representations of integral curves, encoding spatial relations between the curves. We demonstrate our method on integral curves obtained from a single person's whole DTI brain data set. Expert feedback shows that our can complement the existing more standard methods by showing subtle differences within large structures of integral curves.

References

[1] A. Brun, H. Park, H. Knutsson, and C. Westin. Coloring of DT-MRI Fiber Traces using Laplacian Eigenmaps. *Computer Aided Systems Theory-EUROCAST 2003*.

[2] A. Civril, M. Magdon-Ismail, and E. Bocek-Rivele. Sde: Graph drawing using spectral distance embedding. In *GD'05*, Limerick, Ireland, 2005.

[3] C. Demiralp, S. Zhang, D. Tate, S. Correia, and D. H. Laidlaw. Connectivity-aware sectional visualization of 3DDTI volumes using perceptual flat-torus coloring and edge rendering. In *Proceedings of Eurographics*, 2006.

[4] S. Pajevic and C. Pierpaoli. Color schemes to represent the orientation of anisotropic tissues from diffusion tensor data: Application to white matter fiber tract mapping in the human brain. *Magnetic Resonance in Medicine*, 42(3):526–540, 1999.

[5] A. Vilanova, S. Zhang, G. Kindlmann, and D. H. Laidlaw. An introduction to visualization of diffusion tensor imaging and its applications. In *Visualization and Image Processing of Tensor Fields*. Springer-Verlag, 2005. In Press.

[6] S. Zhang, C. Demiralp, and D. Laidlaw. Visualizing diffusion tensor MR images using streamtubes and streamsurfaces. *IEEE Transactions on Visualization and Computer Graphics*, 9(4):454–462, 2003.

[7] W. Zhou, P. G. Sibley, S. Zhang, D. F. Tate, and D. H. Laidlaw. Perceptual coloring and 2d sketching for segmentation of neural pathways. In *SIGGRAPH '06: ACM SIGGRAPH 2006 Research posters*, page 172, New York, NY, USA, 2006. ACM Press.