Measuring Seeding Resolution Dependence of Diffusion Tensor Streamtube Visualization

Haipeng Cai*
University of Southern Mississippi
Jian Chen†
University of Southern Mississippi
Alexander P. Auchus ‡
University of Mississippi Medical Center
Juebin Huang §
University of Mississippi Medical Center
David H. Laidlaw ¶
Brown University

ABSTRACT

We present a study to measure the relationship between seeding resolution involved in 3D diffusion tensor magnetic resonance imaging (DTI) tractography and the streamtube visualization of human brain DTI model. We investigate five scales of seeding resolution with the same brain dataset and measure the effect of the resolution difference on user performance on a set of tasks typical of those conducted by neurological experts. The study covers representative fiber bundles in the brain anatomy and the measurement metrics includes users' task performance in terms of correctness, completion time, computer log, and participants' comments collected from post-study interviews. Initial results show that lower resolutions bring about higher task correctness over all tasks consistently, and that the completion time fluctuates with changing resolutions and the pattern of change varies slightly from task to task.

Index Terms: J.3 [LIFE AND MEDICAL SCIENCES]: Medical information system; I.3.8 [COMPUTER GRAPHICS]: Miscellaneous

1 INTRODUCTION

Due to the highly complex structure of the human brain, DTI data processed for visualization of the brain model are usually so dense as to impede effective exploration of the visualization. During the 3D DTI tractography, graphics density is often closely related to the seeding resolution adopted for fiber tracking. While the unit resolution $(1 \times 1 \times 1)$ has been used almost as a default to produce tractography geometries, the effect of various scales of resolution on how the visualization is used in clinical practices is rarely studied. For one thing, higher graphics density has the advantage of conveying complete information of the original MRI data but brings about more visual clutters that can impede effective examination of the visualization in 3D space. Conversely, lower data densities can present the brain clearly and holistically but may risk losing MRI data integrity.

Our study examines the effects of graphics density and visualization of a DTI human brain model by testing a set of tasks close to clinical use against groups of task-oriented data sampled from DTI tractography of the brain at five seeding resolutions. Since graphics density associates with visual complexity in 3D space and our visualization tasks are closely concerned with visual perception, it is reasonable to postulate that a change in seeding resolution that leads directly to variations in the graphics density will give rise to statistic differences in users' performance. Figure 1 shows the difference in graphics density stemming from changing seeding resolution in a tractography of a partial brain around the cingulum (highlighted in yellow) region.

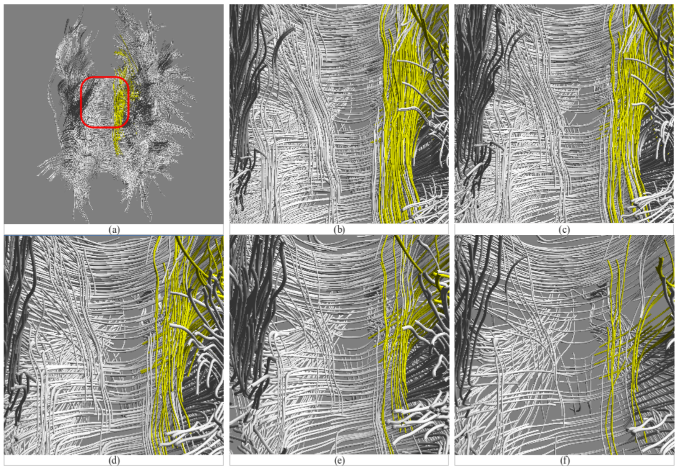

Figure 1: A full brain tractography and 5 closeups into the cingulum region (red boundary) in tractographies produced from 5 seeding resolutions: (a) full brain tractography, (b) $(1 \times 1 \times 1)$, (c) $(2 \times 2 \times 2)$, (d) $(3 \times 3 \times 3)$, (e) $(4 \times 4 \times 4)$, and (f) $(5 \times 5 \times 5)$.

The main contribution of this work is a novel investigation of different seeding resolution in DTI tractography and a preliminary analysis of the difference made by various fiber densities in user task performance. Results from this study can broaden the purview of DTI visualization in the choice of tensor processing parameters during the 3D tractography of DTI dataset.

2 RELATED WORK

Correia et. al. compared consistency of some DTI measurement metrics of three seeding resolutions and found the coefficients of variance of these popluar measures were within 1% range [3]. Kim et. al. studied the effect of spatial resolution of DTI data in terms of voxel size during diffusion weighted imaging (DWI) acquisition on the sensitivity of the fiber tracing, specifically in the occipito-callosal brain region; they analyzed this effect in terms of the number of seed points and fiber tracts together with the variation of fractional anisotropy (FA) and signal-noise ratio (SNR) and concluded that the spatial resolution in DTI data acquisition should be considered in interpreting the fiber tracking data [4]. Alexander et. al. described the interplay between voxel dimension and the partial volume effect and suggested decreasing voxel dimension to minimize adverse effects [1].

Previous work has primarily examined parameters in medical image acquisition or filtering for tractography, thus providing a valuable perspective on the low-level DTI data preprocessing. As a start in investigating tensor processing parameters, examination

---

[*] e-mail: haipeng.cai@eagles.usm.edu
[†] e-mail: jian.chen@usm.edu(corresponding author)
[‡] e-mail: aauchus@umc.edu
[§] e-mail: jhuang@umc.edu
[¶] e-mail: dhl@cs.brown.edu

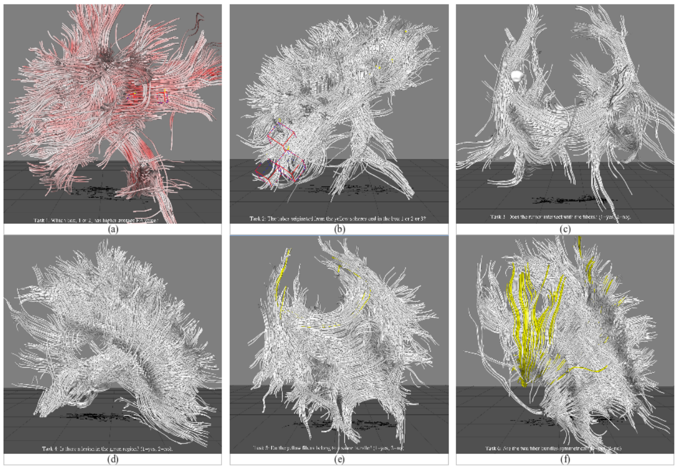

Figure 2: A group of scenes each showing one subtask in every task: (a) task 1 asks for block FA comparison; (b) task 2: fiber tracing (b); (c) task 3: recognition of spatial relationship between tumor and fibers; (d) task 4: lesion detection; (e) task 5: bundle membership identification; (f) task 6: bundle symmetry judgment.

of different seeding resolutions can help give a wider view of the connection of data processing and DTI visualization.

3 EXPERIMENTAL METHODOLOGY

3.1 Dataset

The source MRI images are captured from a normal human brain at a constant resolution of $(0.9375mm \times 0.9375mm \times 4.52mm)$, from which diffusion tensors are calculated with tri-cubic B-spline interpolation [2]. Then fiber tracts are approximated using the 2nd-order Runge-Kutta solver [2]. During the tractography, the full volume seeding algorithm [5] is adopted for seed selection and five seeding resolutions, $(1 \times 1 \times 1)$ to $(5 \times 5 \times 5)$, with step 1 are applied to the tensor field above to produce a tractography sequence. The five major fiber bundles involved in our study tasks were suggested by medical experts and are: corpus callosum (CC), corticospinal tracts (CST), cingulum (CG), inferior longitudinal fasciculus (ILF) and inferior frontal occipital fasciculus (IFO).

3.2 Task Design

Six tasks were designed based on our interviews with hence suggestions from neuroscientists. A question is assigned to each task that is repeated over all subtasks in that task. With five scales of seeding resolution and the five fiber bundles listed above all involved, each task contains at least five subtasks in which a single subtask is concerned with a specific resolution scale and fiber bundle focus. For each participant, all seeding resolutions and fiber bundles are traversed within a task, and the full combinations are performed by all participants. Across different participants, subtasks within a task are ordered by a Latin square. However, due to the study focus as described above, tasks are not shuffled and the natural order is used constantly. Figure 2 shows typical subtask scenes of all these tasks in this study design and the task questions are listed below.

Task 1 Which box, 1 or 2, has higher average FA value?

Task 2 The tubes originated from the yellow spheres end in the box 1 or 2 or 3?

Task 3 Does the tumor intersect with the fibers?

Task 4 Where is the lesion in the bundle?

Task 5 Do the yellow fibers belong to the same bundle?

Task 6 How much does the left bundle differ from the right on in size?

All these tasks correspond to clinical activities in the everyday use of brain DTI (see Fig. 2). Throughout the study, DTI fibers are rendered as streamtubes and monochromatic color is applied (except Task 1). The only interaction enabled is data view rotation by the mouse

3.3 Metrics of Task Performance

Task performance is measured per seeding resolution for each task on two factors: (1) task correctness, which is decided by comparing the user's response to the task question and standard key determined when corresponding task-specific data is sampled and (2) task completion time. For each run of the study by a single participant, the per task log records the resolution used for and answer to each subtask. The final analyses for each task are then conducted based on all these logs combined.

4 RESULTS AND DISCUSSION

In the initial test, we invited five participants (three medical students and two radiology professors) into the study and collected preliminary results. Over the tested tasks, Task 1, 2, 3 and 5, task correctness is generally high (over 90%) and variation in fiber density does not affect this measure from one subtask to another within every task. For the task completion time, however, a difference due to the change in the fiber density can be clearly observed. Moreover, lower resolutions, $(4 \times 4 \times 4)$ and $(5 \times 5 \times 5)$ in particular, bring down the average completion time for subtasks in all four tasks, while the other three scales lead to smaller variations. However, no task shows a monotonic decrease in this measure from one scale of fiber density to another. In addition, the pattern of the change also differs from task to task.

Although comparison between tasks is not a goal of our present study, it is still noteworthy that in Task 2, the most challenging one as participants unanimously reported, the task completion time significantly drops starting from the $(2 \times 2 \times 2)$ resolution, but the difference does not increase afterwards until the $(5 \times 5 \times 5)$ resolution. That this task is the most difficult can be attributed to the inherent difficulty of tracing fiber pathways in a 3D tractography in general, as most participant suggested.

5 CONCLUSION

We present a study measuring the seeding resolution dependence of DTI streamtube visualizations of the human brain. The initial results suggest that lower resolutions tend to enhance the correctness of user tasks consistently and that the change in task completion time is dependent of tasks.

REFERENCES

[1] A. L. Alexander, K. M. Hasan, M. Lazar, J. S. Tsuruda, and D. L. Parker. Analysis of partial volume effects in diffusion-tensor MRI. *Magnetic Resonance in Medicine*, 45(5):770–780, May 2001.

[2] P. J. Basser, S. Pajevic, C. Pierpaoli, J. Duda, and A. Aldroubi. In vivo fiber tractography using DT-MRI data. *Magnetic Resonance in Medicine*, 44:625–632, 2000.

[3] S. Correia, S. Lee, T. Voorn, D. Tate, R. Paul, S. Zhang, S. Salloway, P. Malloy, and D. Laidlaw. Quantitative tractography metrics of white matter integrity in diffusion-tensor mri. *Neuroimage*, 42(2):568–581, 2008.

[4] M. Kim, I. Ronen, K. Ugurbil, and D. S. Kim. Spatial resolution dependence of DTI tractography in human occipito-callosal region. *NeuroImage*, 32:1243–1249, 2006.

[5] A. Vilanova, G. Berenschot, and C. van Pul. DTI visualization with streamsurfaces and evenly-spaced volume seeding. In *Proceedings of VisSym '04 Joint Eurographics - IEEE TCVG Symposium on Visualization*, pages 173–182, 2004.