Enabling Interactive Brain Fiber Tracking with the GPU

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Abstract

Brain fiber tracking allows a neurosurgeon to find fiber bundles in any region of the human brain, rendering it a useful aid to preoperative planning. However, this process requires a significant amount of computation, which limits the interactivity of current applications. We show how executing this process on graphics processing units can significantly improve the user's experience by computing the fiber tracts in real time.

1. Introduction

Brain fiber tracking [2] is a computational procedure which finds the fiber bundles in a patient's brain, thus allowing a neurosurgeon to make a better preoperative planning. Implementations of fiber tracking have to cope with a great amount of mathematical operations, and for that reason they are typically slow at finding the fiber tracts, resulting in a poor interactive experience.

We have previously shown how fiber tracking can be run on the graphics processing units (GPUs) of computers [1] using the Cg language. The speed obtained by executing fiber tracking on GPUs has enabled us to consider an approach to fiber tracking that was not previously possible: find new fiber tracts whenever the volume of interest is dragged by the user or when fiber tracking parameters are changed. While the approach itself does not imply the use of GPUs, they provide the computational power required for a reasonable frames per second rate. This differs from previous work by the way fiber tracking is experienced by the user, who previously had access to a static environment, where the dragging of volumes of interest did not cause the fiber tracts to be updated in real time.

In this paper, we show how this higher level of interactivity can be achieved by executing fiber tracking on GPUs by means of the CUDA (Compute Unified Device Architecture) technology [3]. We compare the interactivity obtained by the execution of fiber tracking on the GPU and on the CPU (central processing unit) by measuring the frames per second (FPS) rate obtained with both implementations.

2. Fiber Tracking with CUDA

CUDA is a set of technologies recently introduced by NVIDIA with the aim of making it easy for developers to write GPU programs. It provides a C compiler with a few extensions and a relatively simple API (application programming interface) for interacting with the GPU. This is a progress over previous models, which had domain-specific languages and typically required the use of complex combination of APIs.

The process of fiber tracking, which in our approach is executed on the GPU, works by looking for fibers at each of a set of seed points, typically a few thousand. Each fiber consists of a set of line segments, and each of these points is calculated by the fourth-order Runge–Kutta method. Despite the great amount of computation involved in finding all points for each fiber, they can be determined independently from each other. Thus, the fact that fiber tracking entails a big amount of complex calculations and high level of data parallelism makes a GPU implementation very attractive.

All fibers are located by the GPU, but they are displayed on the screen by our radiological workstation running on the CPU, that is, the CPU is responsible for the actual visualization of data, whereas the GPU generates raw results. Ultimately, however, the CPU will delegate at least part of the rendering process to the GPU, though in an indirect manner, i.e., with no direct access through CUDA.

The workstation employs a two-phase fiber rendering strategy. While the user is dragging the volume of interest, fibers are shown as simple lines. When the user releases the mouse button, all fibers are immediately rendered as cylinders, which provides for a better visualization of the fibers.

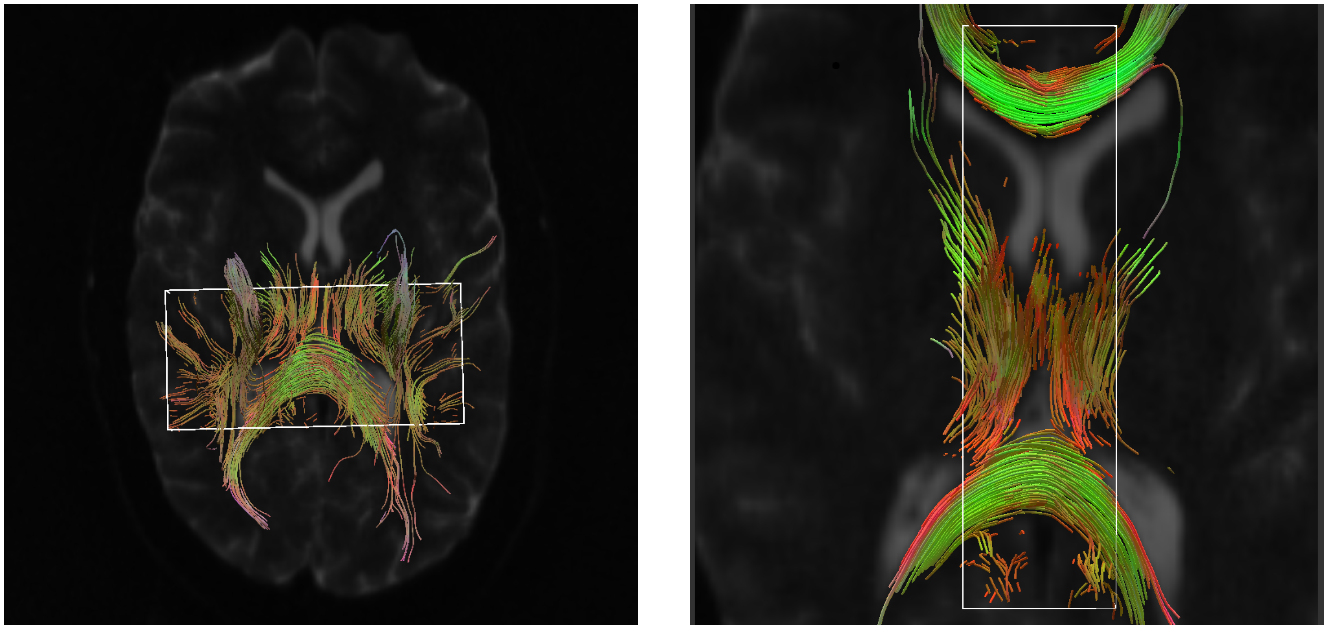

Figure 1. Results of fiber tracking being explored. The white lines define the limits of a volume of interest from which fiber tracts are determined.

3. Results

Although our current CUDA module is not as fast as our previous Cg implementation, it shows promising results. Figure 1 shows two screen shots of a fiber tracking exploration session. To better assess the level of interactivity achieved by our approach, please visit `http://www.lapix.ufsc.br/videos/`, which contains an uncut video showcasing the features of our approach. All experiments were run on a desktop computer, with an Athlon 64 3500+ processor, 2 GB of RAM and a GeForce 8800 GTS video card.

In order to estimate how fast our fiber tracking application is, the following method was used: A cube of dimensions 10 mm × 10 mm × 10 mm is centered at the bottom of the volume and then swept to its top in a total of 100 steps, as though the user were dragging the cube. The number of seeds within the volume is $20 \times 20 \times 5 = 2000$. After each move, fiber tracking takes place and the new trajectories are displayed, thus effectively rendering a new frame on the screen. At the end of the process, the mean and minimum rate of frames per second (FPS) can be found.

Table 1 shows results of this experiment for the GPU and the CPU. The GPU was more than 10 times faster than the CPU on average, and more than 16 times faster on the worst case. Qualitatively, this means the GPU gives the user a better level of interactivity, which we expect to be further improved as GPUs continue to outperform CPUs.

Table 1. Mean and minimum frames per second obtained on both the GPU and the CPU.

	Mean FPS	Minimum FPS
CPU	0.99	0.43
GPU	10.56	7.03

4. Conclusion and Future Work

GPUs enable fiber tracking application to take on a new level of interactivity. The user's experience shifts from a limited and slow process to a real-time, highly interactive exploration of a patient's brain. We expect to further improve the results obtained so far and to find new ways to take advantage of the GPU's processing power.

References

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