Explore the brain white matter networks in real-time: Multi-sticks fiber tracking

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INTRODUCTION: Real-time fiber tractography (RTT) enables the user to interactively tune a series of parameters involved in the tracking process. Most tractography algorithms work with a fixed set of parameters all across the brain. However, we think that those parameters should be accessible and tunable because they vary depending on what region of the brain one is looking at. Neurosurgeons agree on the fact that anisotropy is different across brain regions and that tractography algorithms should not be masked by a single default fractional anisotropy (FA) value. What if the FA threshold stopping criteria forces fibers to terminate at the boundaries of a tumor? This can potentially hide crucial information to the neurosurgeon. In such cases, it is often necessary to allow fibers to infiltrate the tumor region by lowering the threshold value in that region. What if for a certain parameter combination, the resulting fiber tracts are quite different? It appears essential to have the ability to directly see the effect of each tracking parameter on the resulting fiber tracts. Mittman et al [3] proposed a diffusion tensor imaging (DTI) RTT implementation that works on graphic processing units (GPUs). We showed that it could also be achieved on CPU [1], without affecting the fluidity and real-time interactiveness of the procedure. To the best of our knowledge, there is no RTT method for high angular resolution diffusion imaging (HARDI). This work proposes a real-time streamline HARDI fiber tracking method to the FiberNavigator [2] based on the maxima of the fiber ODFs [7, 8].

METHODS: Our new HARDI-RTT module is based on a field of directions. These maxima can come from any HARDI reconstruction technique [5]. Here, we use directions that come from maxima extraction on a field of fiber ODF [7, 8]. We adopted the file format of MRtrix [4] where the peaks are encoded in a [X, Y, Z, 9], 4D nifti file. The maxima can be estimated directly in the FiberNavigator [2] or from MRtrix or any other software. From these maxima, we have implemented the following streamline tracking algorithm. The seeds are initiated by randomly choosing a direction from the maxima located at the current voxel, weighted by its norm. When entering a new voxel, the peak that forms the lowest angle with the incoming direction $\mathbf{V_{n-1}}$ is marked as $\mathbf{V_n}$ and introduced in the following equation, inspired from the tensorline algorithm [6, 1]:

$$\mathbf{V_{n+1}} = (f * \mathbf{V_n}) + (1 - f)((1 - g) * \mathbf{V_{n-1}} + g * \mathbf{V_n}),$$

where f is the FA at the current voxel and g is the puncture parameter between the *in* ($\mathbf{V_{n-1}}$) and *out* ($\mathbf{V_n}$) directions that can be tuned in real-time. As one can see, no maxima interpolation is done between each step. This is what makes the method feasible in real-time. Tournier et al. [4] showed that tracking in an upsampled 1x1x1 mm^3 space (T1 space in our case), as opposed to a 2x2x2 mm^3 diffusion space, accounts for performing interpolation in the native resolution (diffusion space) on the fiber ODF field. By placing a volume of interest (VOI) filled with seeds (also tunable), one can instantaneously generate fiber tracts while dragging the VOI around. The tracking parameters can be tuned at any time by the user while fibers are recalculated and shown automatically. Figure 1 shows the RTT parameters that the user can tune: the minimum FA threshold (which acts as a tracking mask), maximum angle between 2 consecutive steps, the step size, the puncture given by "in and out" directions, as in [6], the minimum and maximum fiber length, and finally, the number of seeds within the VOI. If the user wants to save his RTT fibers for further analysis or filtering, the button "*Convert Fibers*" will convert the current bundle into a scene object, with its own properties.

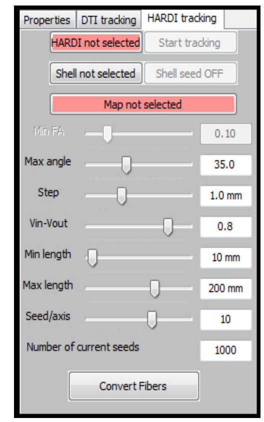

Figure 1. RTT parameters

DATASETS: Datasets were collected on a Siemens 1.5 Tesla (T) imaging system using a single-shot echo-planar (EPI) spin echo sequence (TR/TE = 12500/95 ms), with b-value of 1000 s/mm^2 and 64 uniform directions.

RESULTS: Figure 2 shows the improvement gained from HARDI-RTT (a) over DTI-RTT (b). The goal was to reconstruct the corpus callosum (CC) and the cingulum bundle (Cg), as best as possible, giving free liberty to the parameters used, and the VOI size and position. As expected, the RTT-HARDI clearly overcomes the DTI limitations by finding more fanning and crossings of the CC projections to the lateral cortices. It also recovered the lower part of the Cg, illustrated in blue (a-right). Parameters were chosen as the following :

PARAMETERS	HARDI-RTT		DTI-RTT	
	CC	Cg	CC	Cg
Min FA	0.15	0.10	0.15	0.10
Max Angle	35 deg	35 deg	60 deg	65 deg
Step Size	1 mm	1mm	1.5 mm	1mm
Puncture (*in* / *out*)	0.25	0.80	0.20	0.25
# of Seeds	3375	3375	3375	3375

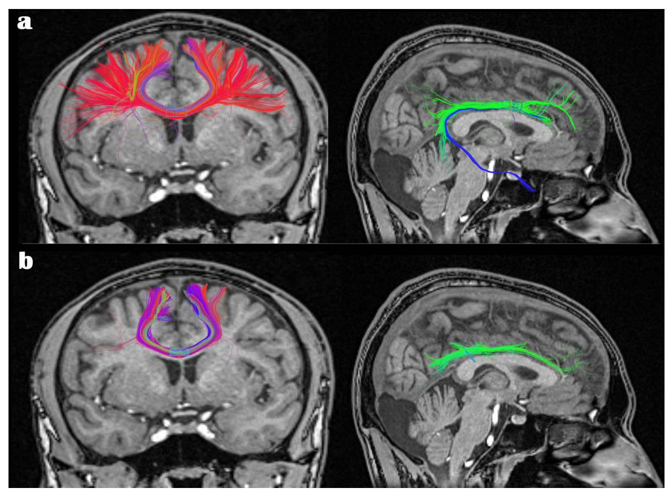

Figure 2. Comparison between HARDI (a) and DTI (b) RTT of the corpus callosum and cingulum bundle.

Another feature is the whole brain tractography option. Instead of launching seeds from a draggable VOI, figure 3-a) shows an isosurface generated to fit the boundaries of gray matter/white matter interface. Seed points are then launched at every vertex of the surface b), generating over 200,000 fibers under the 10 sec mark, running on a single core. Those fibers can then be queried with a selection box for precise exploration of desired areas. Experimentation was done on a laptop with the following specs: System: Ubuntu, Kernel: Linux 2.6.32, Mode: 32-bit, Video card: Geforce GT 435M memory 2048MB 800MHz, NVIDIA Driver: 304.43, CPU: Intel(R)Core(TM) i7 Q840 @ 1,87GHz, 8GB RAM.

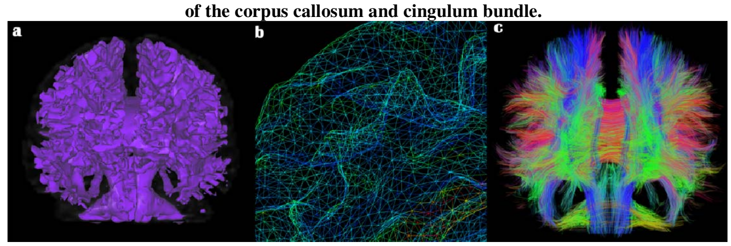

Figure 3. Whole brain fiber tractography obtained via the RTT shell-seeding option.

DISCUSSION & CONCLUSIONS: We presented a new RTT-HARDI feature that takes into account crossing information from HARDI reconstruction techniques. It overcomes the well-known DTI limitations, while remaining interactive in a real-time tunable application due to its implementation on a field of maxima. It remains an open question whether or not tracking on a field maxima leads to better or worst results as opposed to tracking on the field of fiber ODF as such. However, as shown in [4], there are experimental evidences that tracking in an upsampled 1x1x1 space on a field maxima is approximately equivalent, if not better, than tracking on the native 2x2x2 space of fiber ODFs represented in a spherical harmonics basis or as discrete points on the sphere. Further validation must be done in the future. Our RTT has already proven useful for neurosurgical interventions [1]. It gives quick convincing results on the fly and is an important tool to explore specific regions of the brain to find appropriate tractography parameters, given a certain hypothesis, task or application. Our RTT-HARDI technique is aimed at clinical applications and is possible without complex GPU programming. GPU implementation is surely considered for the future but we believe that even a real-time probabilistic tracking could be implemented solely on CPU if seeds are launched from a VOI.

REFERENCES: [1] Chamberland et al, OHBM 2012. [2] Fibernavigator – Online at: http://code.google.com/p/fibernavigator. [3] Mittmann et al, Journal of Digital Imaging 2011, 24(2):339-351. [4] Tournier et al, International Journal of Imaging Systems and Technology, 22(1):53-66. [5] Seunarine et al, book chapter in Diffusion MRI by T.E.B. Behrens and H. Johansen-Berg 2009, p55-72. [6] Lazar et al, HBM 2003, 18(4):306-321. [7] Tournier et al Neuroimage 2007, 35(4):1459-1472. [8] Descoteaux et al, IEEE Transactions on Medical Imaging 2009, 28(2) :269-286.