Choosing Tractography Parameters to Improve Connectivity Mapping

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INTRODUCTION: Diffusion-weighted imaging (DWI) is often used as a starting point for in vivo white matter (WM) connectivity to reconstruct potential WM pathways between brain areas. Tractography algorithms have many parameters which can influence reconstruction and connectivity. Various choices of parameters have been proposed [1, 2, 3]. But how does one choose the best set of parameters? In this study, we varied three critical parameters while monitoring connectivity score using the Tractometer [1] evaluation system on the International Symposium on Biomedical Imaging (ISBI) Challenge [4] synthetic dataset. The three parameters were:

- $\boldsymbol{\theta}$: The maximum deviation angle between two consecutive tractography steps. This addresses the hypothesis of smoothness of the WM pathways.
- $\boldsymbol{\tau}$: The spherical function (SF) threshold. This aims at removing noisy propagation directions during the tractography process.
- $\boldsymbol{\tau_{init}}$: The initial SF threshold. This aims at removing initial noise at the seeds and to start tractography in a good tangent direction to the WM bundle.

METHODS: In this study, deterministic and probabilistic streamline tractography algorithms were used. In our implementation, the spherical harmonics representation of fiber Orientation Distribution Functions (fODFs) are interpolated (tri-linear), projected on a discrete evenly distributed symmetric sphere (724 vertices) and normalized (maximum=1). Propagation directions are always a vector of orientation corresponding to a vertex of the sphere and of length 0.2 mm [2]. The single difference between probabilistic and deterministic algorithms is the way the propagation direction $\mathbf{v_{i+1}}$ is chosen. The discrete set of potential propagation directions can be estimated given a position $\mathbf{p_i}$, a propagation direction $\mathbf{v_i}$, the maximum deviation angle $\boldsymbol{\theta}$ and the SF threshold $\boldsymbol{\tau}$. Given the discrete set of potential propagation directions formed by all vertices on the sphere with an associated SF value greater than τ and within the aperture cone defined by $\boldsymbol{\theta}$ and $\mathbf{v_i}$, $\mathbf{v_{i+1}}$ is:

- Deterministic – The propagation direction with a maximum SF and the closest aligned with $\mathbf{v_i}$ is chosen.
- Probabilistic – A propagation direction drawn from the empirical distribution defined by the SF values of the potential propagation directions is chosen.

If there is no direction with maximal SF in the discrete set of potential propagation directions or if the set is empty, the propagation stops. The tractography stops when $\mathbf{p_i}$ is outside of the tractography mask. In order to compare and evaluate tractography results we computed the following metrics:

- VC - Valid Connections: Streamlines connecting expected regions of interest (ROIs) and not exiting the expected WM mask [1].
- IC - Invalid Connections: Streamlines connecting unexpected ROIs or streamlines connecting expected ROIs but exiting the expected WM mask. These streamlines are spatially coherent, connect ROIs, but do not agree with the ground truth [1].
- NC - No Connections: Streamlines that do not connect two ROIs [1].
- CSR - Connections to Seeds Ratio: If all seeds produces a streamline, CSR = (VC + IC) / (VC + IC + NC).
- VCCR - Valid Connections to Connection Ratio: VCCR = VC / (VC+IC).

Best parameters value maximizes both CSR and VCCR. All metrics are reported in %.

Figure 2: Synthetic dataset. WM (light gray), GM (gray).

DATASET: In this study, we used the ISBI Challenge 2013 dataset [4], which consists of 27 simulated WM bundles mimicking some of the WM structure of the brain in 3D. Given the WM bundles configurations, the DWI signal is simulated in each voxel using the CHARMED model [5], with an approach similar to the Numerical Fiber Generator [6]. The simulated signal is obtained by corrupting the noise-free diffusion weighted signal with Rician noise. We used 64 uniformly distributed gradient directions (b-value = 3000 s/mm^2) at signal to noise ratio (SNR) 10, 20 and 30. The dataset have a spherical shape with the extremities of the simulated WM bundles ending on the surface of the sphere. The simulated Gray Matter (GM) consists of the voxels in the three outer layers of the sphere (see Figure 1). The fODFs [2, 7] were computed using *Mrtrix* [2].

RESULTS AND DISCUSSION: Figure 2 shows results obtained for deterministic and probabilistic tractography varying $\boldsymbol{\theta}$, $\boldsymbol{\tau}$ and $\boldsymbol{\tau_{init}}$, initiating the tractography in all voxel of the tractography mask (8,483 seeds). We first set $\boldsymbol{\tau} = \boldsymbol{\tau_{init}} = 0$ and vary $\boldsymbol{\theta}$. For deterministic tractography, $\boldsymbol{\theta_d}$ in [45°, 90°] provides the best results. We choose $\boldsymbol{\theta_d}$**=45°** since it is smaller and it provides qualitatively good result on real data and it is consistent with the observations of [3] ($\boldsymbol{\theta_d}$ in [45°, 60°] shows similar results on real data). For probabilistic tractography, $\boldsymbol{\theta_p}$ in [15°, 30°] provides the best results. This is higher than what is proposed in [2, 3] (11°) for *Mrtrix* probabilistic tractography. Nevertheless, we choose $\boldsymbol{\theta_p}$**=20°** since it provides quantitatively better results and qualitatively good result have been observed on real data. We then set $\boldsymbol{\theta}$ to the chosen values and vary $\boldsymbol{\tau}$. This shows little influences on deterministic tractography with $\boldsymbol{\tau} < 0.3$. Higher $\boldsymbol{\tau}$ tends to decreases CSR. For probabilistic tractography, VCCR increases with $\boldsymbol{\tau}$ and CSR decreases with $\boldsymbol{\tau}$>0.4. We wanted to keep this parameter value small in order to not remove valid propagation directions from the SF. A value of $\boldsymbol{\tau}$**=0.1** was chosen. It showed qualitatively good results on real data and good result on synthetic data. Finally, we set $\boldsymbol{\tau}$ and $\boldsymbol{\theta}$ to the chosen values and vary $\boldsymbol{\tau_{init}}$. The results show that an initial propagation direction having a higher SF value increases CSR, especially on noisy data. VCCR is stable for all value of $\boldsymbol{\tau_{init}}$. We chose $\boldsymbol{\tau_{init}}$**=0.5**, the smallest value before CSR tends to stabilize. This suggests that the initial propagation direction is more prone to noise than propagation direction along the tractography process. Chosen parameter values show good results on real data.

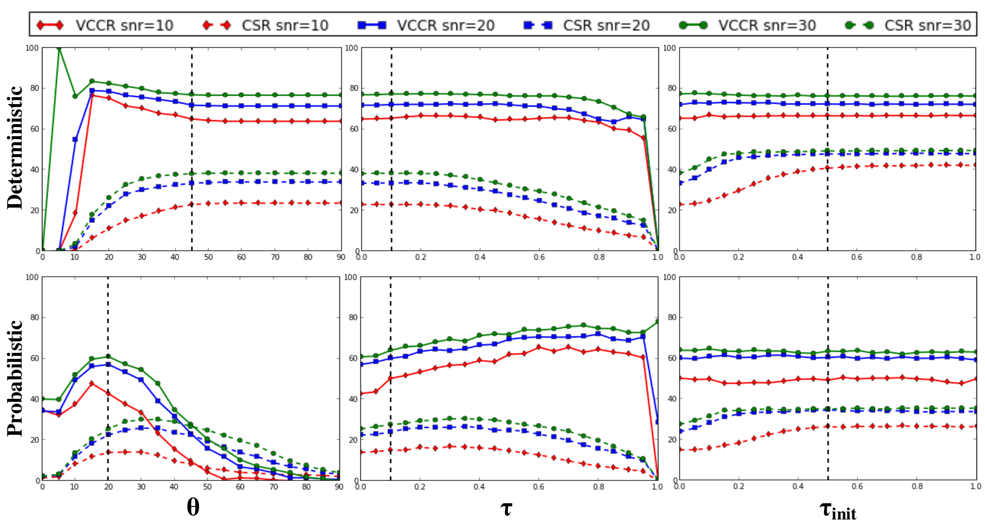

Figure 1: VCCR and CSR (%) obtained on the synthetic dataset. Vertical lines indicate chosen values.

CONCLUSION: We used the Tractometer evaluation strategy [1] to investigate the influence of tractography parameters on synthetic data, and chose the best tractography parameters in terms of CSR and VCCR. We recommend $\boldsymbol{\theta_d}$**=45°**, $\boldsymbol{\theta_p}$**=20°**, $\boldsymbol{\tau}$**=0.1**, $\boldsymbol{\tau_{init}}$**=0.5** for the tractography algorithms used in this study. We believe this provides useful information in accurately selecting between different algorithms and their parameters for studying WM connections in the brain.

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