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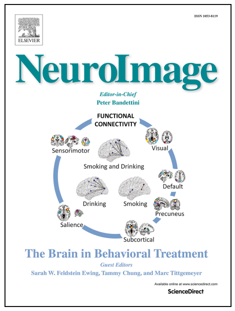

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Tracking and Validation Techniques for Topographically Organized Tractography

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Abstract

Topographic regularity of axonal connections is commonly understood as the preservation of spatial relationships between nearby neurons and is a fundamental structural property of the brain. In particular the retinotopic mapping of the visual pathway can even be quantitatively computed. Inspired from this previously untapped anatomical knowledge, we propose a novel tractography method that preserves both topographic and geometric regularity. We make use of parameterized curves with Frenet-Serret frame and introduce a highly flexible mechanism for controlling geometric regularity. At the same time, we incorporate a novel local data support term in order to account for topographic organization. Unifying geometry with topographic regularity, we develop a Bayesian framework for generating highly organized streamlines that accurately follow neuroanatomy. We additionally propose two novel validation techniques to quantify topographic regularity. In our experiments, we studied the results of our approach with respect to connectivity, reproducibility and topographic regularity aspects. We present both qualitative and quantitative comparisons of our technique against three algorithms from MRtrix3. We show that our method successfully generates highly organized fiber tracks while capturing bundle anatomy that are geometrically challenging for other approaches.

Keywords: connectome, dMRI, retinotopy, corticospinal tract

1. Introduction

Tractography is an exciting technique that enables extraction of the brain connectome, *in-vivo*, using diffusion MRI (dMRI) (Wandell, 2016). However validation of tractograms is challenging due to lack of ground truth (Côté et al., 2013). On the other hand, the regular topographic organization of many fiber systems in human brains provide *a surprisingly untapped anatomical knowledge* for the improvement and validation of tractography techniques. Some of the well-known examples include the retinotopic organization of the visual pathway (Engel et al., 1997), the somatotopic organization of the somatosensory pathway (Ruben et al., 2001), and the tonotopic organization of the auditory pathway (Morosan et al., 2001). In this study, we leverage this anatomical knowledge to develop a novel probabilistic tractography algorithm as well as quantitative techniques to validate tractograms.

There has been a plethora of tractography algorithms proposed in the literature during the last two decades. Initial tractography algorithms were based on the diffusion tensor model and propagation along the direction of the principal eigenvalue (Conturo et al., 1999; Jones et al., 1999; Mori et al., 1999; Basser et al., 2000; Mori and van Zijl, 2002; Lazar et al., 2003). Acknowledging the limitations of the noisy, low resolution dMRI data, there has been a shift towards addressing the uncertainty. This lead to several propagation or *walker* based solutions including techniques based on (i) front evolution and marching methods (Parker et al., 2002; Tournier et al., 2003; Kang et al., 2005; Pichon et al., 2005; Jackowski et al., 2005; Prados et al., 2006; Li et al., 2014), (ii) probabilistic and combinatorial techniques based on random walks and various sampling schemes (Bjrnemo et al., 2002; Behrens et al., 2003; Hagmann et al., 2003; Parker et al., 2003; Lu et al., 2006; Friman et al., 2006; Behrens et al., 2007; Lifshits et al., 2009; Descoteaux et al., 2009; Tournier et al., 2012; Jeurissen et al., 2014), (iii) Kalman filtering (Gössl et al., 2002; Malcolm et al., 2009, 2010), (iv) bootstrap methods (Lazar and Alexander, 2005; Jones, 2008; Jeurissen et al., 2011; Vorburger et al., 2013; Campbell et al., 2014; Jeurissen et al., 2011), (v) graph theoretical techniques (Iturria-Medina et al., 2007; Sotiropoulos et al., 2010) and (vi) particle filtering (Zhang et al., 2009; Savadjiev et al., 2010;