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Towards Quantification of the Brain’s Sheet Structure in Diffusion MRI Data

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Abstract—The recent hypothesis on the occurrence of sheet structure in the brain has posed many questions to the diffusion MRI (dMRI) community as to whether this structure actually exists and can be measured with dMRI. In this work, we exploit the capability of the discrete Lie bracket to infer information on the existence of sheet structure in real dMRI data.

I. INTRODUCTION

The question whether our brain’s structure is best reflected by a three-dimensional manifold or by a set of discrete Lie bracket paths is a fundamental question in the field of diffusion MRI (dMRI). The Lie bracket is a fundamental concept in Lie algebra, and its application to dMRI data has been the subject of much research.

A. Lie bracket theory

The Lie bracket $[V, W]_p$ is a measure of the deviation from $p$ when trying to move around in an infinitesimal loop along the integral curves of the fields $V$ and $W$ (Fig. 1). If and only if $[V, W]_p$ lies in the plane spanned by $V_p$ and $W_p$, i.e., when the normal component of the Lie bracket [3] $[V, W]_p = [V, W]_p |_{h_1} = V_p \times W_p$, the vector fields form a sheet at $p$ [6]. The Lie bracket can be approximated by various difference vectors $r_{h_1, h_2}$ according to

$$r_{h_1, h_2} = h_1 h_2 [V, W]_p + \Delta(h_1, h_2),$$

where $h_1$ and $h_2$ are walking distances and $\Delta(h_1, h_2)$ is an error term that scales with $h_1$ and $h_2$. See references [5,7] for details.

B. Implementation and experiments

Starting from point $p$ in the data, we assign two fiber orientation distribution function (fODF) peaks [4] as representative members of vector fields $V$ and $W$. We use nearest neighbor streamline tractography using steps of size $\Delta h$ to find the difference vectors. Each difference vector is based on $4$ consecutive tractography paths $2$ (Fig. 1) of up to $h_{max} = \Delta h$ streamline steps. At each streamline step the local vectors are assigned to one of the fields based on their cosine similarity with the vectors at the previous point. Tracts passing through voxels with only one peak are ignored. Subsequently, $[V, W]_p$ is calculated as an indicator of sheet structure in a simulated dMRI dataset that was known to represent a sheet [5,8] and in high resolution mouse brain data.

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Fig. 3 Mouse brain dMRI data with $b = 4000 s/mm^2$, measured with 120 different directions and 11 b-values, 0 images, voxel size 0.043 mm isotropic. (a) Direction encoded fractional anisotropy map. (b) $[V, W]_p$ between two largest fODF peaks, with $\Delta h = 0.043 mm$ and $h_{max} = 5$. The blue location shows a region with low $[V, W]_p$, the yellow location one with noisy $[V, W]_p$. (c) The corresponding DTI geometry map.

1These authors contributed equally to this work.

2In this work we consider the difference vector $(\Phi^n \ast \Phi^n \ast \Phi^n \ast \Phi^n) (p) = p - (\Phi^n \ast \Phi^n \ast \Phi^n \ast \Phi^n) (p)$, and $(\Phi^n \ast \Phi^n) (p) = (\Phi^n \ast \Phi^n) (p)$, where the flow operator $\Phi^n (p)$ denotes moving a distance $x$ along the integral curve of vector field $X$ starting from point $p$.

REFERENCES