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

Chantal M.W. Tax*,1, Tom C.J. Dela Jorritsma†,1, Andrea Fuster*, Remco Duits*, Max A. Viergever*, Evan Calabrese1, G. Allan Johnson†, Luc M.J. Florack1, and Alexander Leemans‡

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 3-dimensional Manhattan street grid or by the intricate streets of Victorian London added three Science publications to the dMRI literature [1-3]. Wedeen et al. [1,3] analyzed adjacency and crossings between cerebral fiber pathways of the brain using diffusion spectrum imaging (DSI) and tractography, and proposed [5] the end point. Difference vector $\mathbf{r}_p$ approximates $[\mathbf{V}, \mathbf{W}]_p$ [5].

We believe that in order to accept or reject the sheet structure conjecture, more extensive quantitative analyses are needed. Previous work [5] focused on evaluating the discrete Lie bracket as a tool to quantitatively assess the presence of sheet structure in simulated vector fields. In this work, we extend this approach to real dMRI data.

II. THEORY AND METHODS

A. Lie bracket theory

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

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

(1)

where $h_1$ and $h_2$ are walking distances and $\Delta (h_1, h_2)$ 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 $\mathbf{V}$ and $\mathbf{W}$.

III. RESULTS AND DISCUSSION

Complementing previous results on the method’s dependence on resolution [5], Fig. 2 shows the influence of the curvature on the present sheet structure on the ability to detect it. Fig. 3 shows the presence of sheets formed by the two largest fODF peaks. Within the blue demarcation there is clear evidence for the presence of sheet structure, while in the yellow area other combinations of fODF peaks need to be taken into account before we can conclude anything.

IV. CONCLUSION

In this work we extend the analysis of the Lie bracket normal component as a tool for the detection of sheet structure in artificial vector fields, to vector fields derived from diffusion MRI data. We have shown that spatial resolution and the curvature influence the ability to detect sheet structures. We present preliminary but promising results of a high resolution mouse brain, which shows the presence of a sheet formed by two main fODF peaks in correlation with a diffusion tensor imaging (DTI) geometry map.

REFERENCES