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Evaluation of neuronal fiber tractography

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This chapter summarizes the contributions of this thesis. The first contribution is a comprehensive survey of the current state of the art in the evaluation of DW-MRI-based neuronal fiber tractography, presenting the phantom, ex vivo and in vivo evaluation strategies and studies developed over the past years (cf. chapter 3).

Section 4.1 describes a framework for the interactive creation of realistic diffusion-weighted software phantoms that is superior to the state of the art in terms of usability of its user interface, its flexibility in generating a large diversity of fiber configurations, and the realism of the simulated datasets. The framework was used to create a close replication of the well-known FiberCup hardware phantom dataset as well as several variations of this dataset. The simulated datasets were employed to analyze the effects of multiple realistic magnetic resonance imaging (MRI) artifacts on the outcome of a series of fiber tractography experiments.

Section 4.2 presents a novel metric for assessing the local plausibility of tractograms. This metric is the first method to quantitatively evaluate the local progression of fibers in vivo in a reference-based and automated way. As proof of concept, the metric was employed to analyze the tractograms obtained with several tractography methods on ten in vivo datasets.

In section 4.3 the integration of the methods and datasets introduced in the previous two sections in the online fiber tractography evaluation framework Tractometer is described. Furthermore, this section describes the setup of an extensive tractography evaluation study involving a total of 25196 tractograms. The analysis was performed including a comprehensive set of evaluation metrics, tractography algorithms and diffusion modeling methods as well as multiple types of datasets. Additionally, the effects of several important tractography parameters on the tractography results were analyzed.

Chapters 5 and 6 provide a detailed analysis of the capabilities and limitations of a representative set of fiber tractography algorithms obtained in the experiments described in chapter 4. The experiments conducted in this work represent the first comprehensive analysis of fiber tractography fulfilling all the criteria described in chapter 3.

- The findings that resulted from this work are summarized as follows:

- Clear recommendations for the choice of certain tractography parameters could be given.
- The conducted studies confirmed that the diffusion tensor (DT) model is not a suitable model for fiber tractography. Recommendations for models that describe the actual fiber configuration more accurately and can yield more valid tractography results were given.
- The first study that assesses the impact of individual MRI artifacts and image settings on the outcome of fiber tractography has been performed and the effects that showed the strongest influence on the results have been identified successfully.
- The necessity of additional information incorporated in the tractography process became apparent, be it in the form of constraints on the tracked fibers or additional information obtained prior to the tractography process.
- The capabilities and limitations of the major algorithm classes deterministic, probabilistic and global in conjunction with the chosen local modeling technique and their implications for tasks such as connectomics, surgery planning and tissue quantification have been elaborated.
- The findings of this work were able to successfully confirm and complement the results of earlier studies.

The final contribution of this thesis is its dedication to the idea of open-source, open-data and open-applications, which is of central interest in this work and the importance of which for the future development of this whole field of research must not be underestimated. The source code developed during this thesis is included in the open-source Medical Imaging Interaction Toolkit (MITK), a binary application including the methods developed is available at www.mitk.org/DiffusionImaging and the simulated phantom datasets are available for download at http://www.nitrc.org/projects/diffusion-data/. The developed local metric, the simulated dataset A10, and the global Gibbs tractography have furthermore been integrated into the online tractography evaluation system Tractometer. All of these measures ensure persistent availability, comparability and usability of the developed methods and datasets.