Orientation Distribution Analysis of nerve fibers with SLI and PLI Imaging

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MOTIVATION

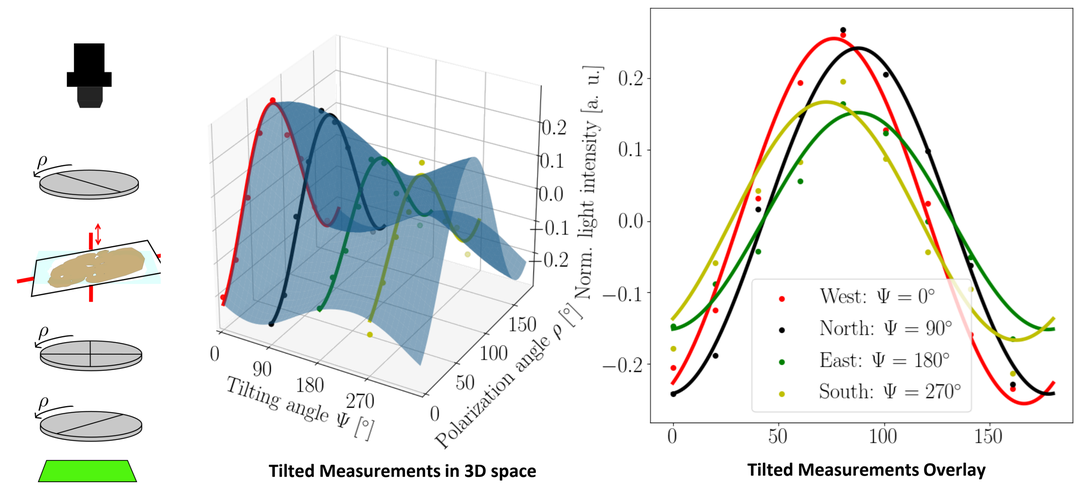
Established methods for the analysis of **Polarized Light Imaging (3D-PLI) [1]** and **Scattered Light Imaging (SLI) [2]** reveal only the most prominent orientation of the nerve fibers, but not the orientation distribution (fODF).

Given the complexity of the data no manual annotations by neuroscientist for the ground truth fiber orientations is available.

Therefore, the estimation of the orientation distribution relies on **leveraging the physical knowledge** of the SLI and 3D-PLI signals. Nevertheless, closing the gap existing between the physics simulations and the analysis models remains as the cornerstone for improving the estimation of the fiber architecture distribution.

Here, we present a both **physics-based and data-driven** approach to reconstruct the fODF in SLI and PLI images.

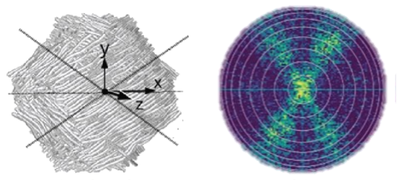
OBLIQUE 3D-PLI AT GLANCE [3]

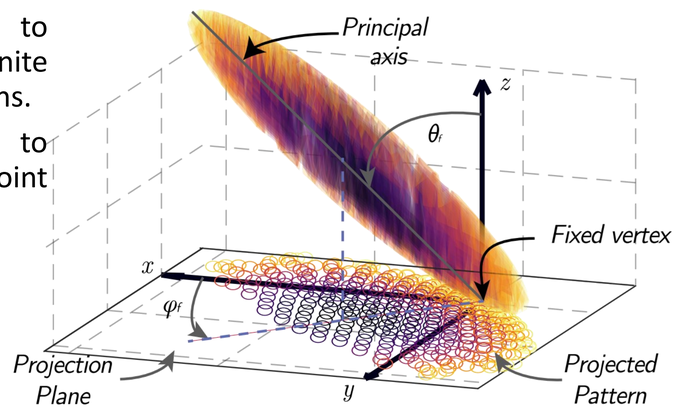


$$I_\rho(I_0, \varphi, \alpha, t_{rel}) = I_0 + I_0 \cdot \sin\left(\tfrac{\pi}{2} t_{rel} \cos(\alpha)^2\right) \cdot \sin(2\varphi - 2\rho)$$

PHYSICAL INSPIRED SIGNAL RECONSTRUCTION FOR SLI

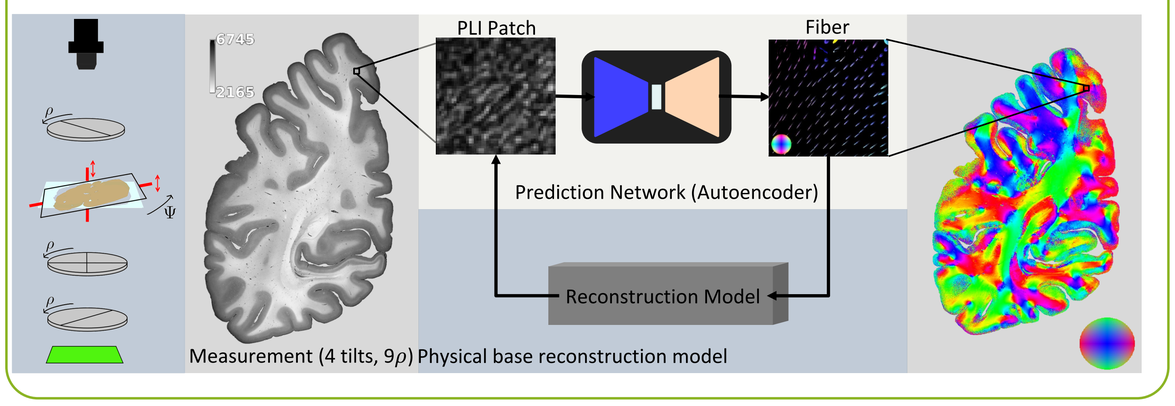
- Signal reconstructed thanks to algebraic model derived from Finite Difference Time Domain Simulations.
- Pattern mixture model is used to combine the response at each point of HEALPix spherical response





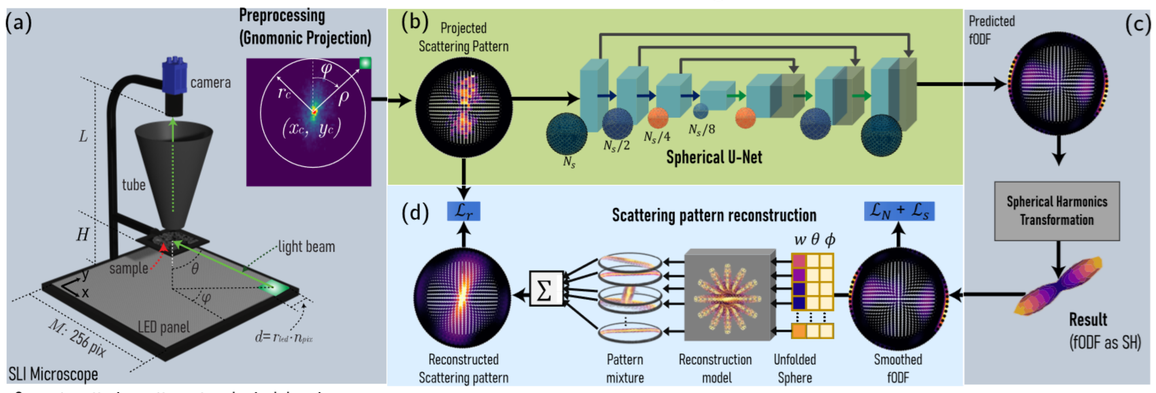
METHOD II: CNN based orientation estimation in PLI [4]

- Improve the reconstruction of the fiber orientation considering **contextual information from adjacent pixels.**
- Reconstruct the input signals by **physically inspired optic models without ground truth**.



METHOD I: GRAPH BASED SLI RECONSTRUCTION [4]

- Convolutions respect signal domain (Sphere), and topology allows multiresolution.
- DEEPSphere: Graph-based Convolutions (Robustness)Fast convergence and equivariance
- Reconstruction based on simulation models of the SLI signals



OBJECTIVES

- Reconstruction loss:

$$\mathcal{L}_r = \|S - S_r\|^2 + \lambda_r(1 - PCC(S, S_r))$$

- Sparsity loss (Cauchy distribution) :

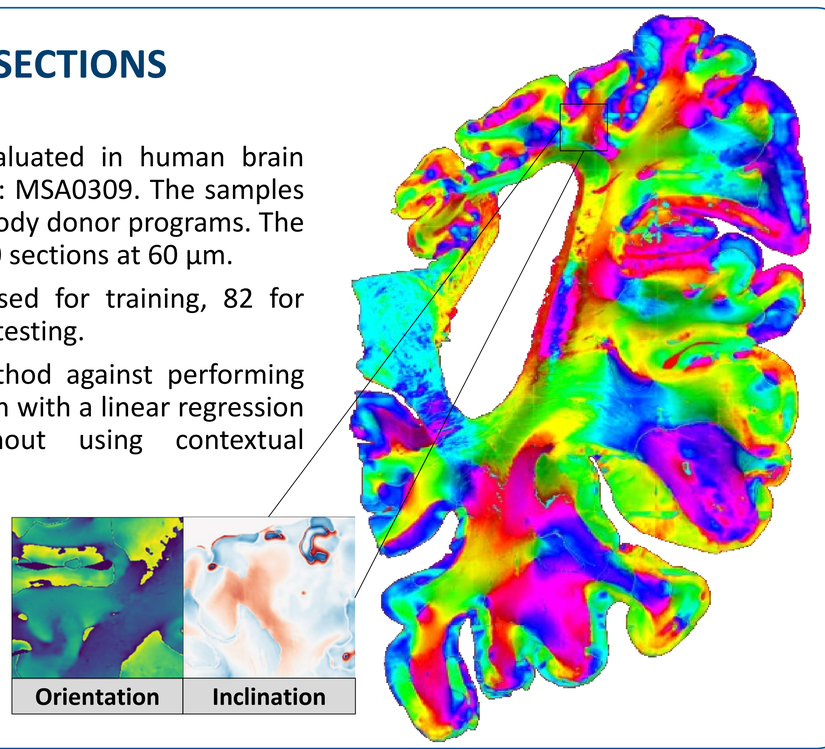
$$\mathcal{L}_s = \lambda_s \sum_{i=1}^{N} \log\left(1 + \frac{\text{fODF}_i^2}{2\sigma_s^2}\right)$$

- Non-negativity loss:

$$\mathcal{L}_N = \left\| \text{fODF}_{\text{fODF}_i<0} \right\|^2$$

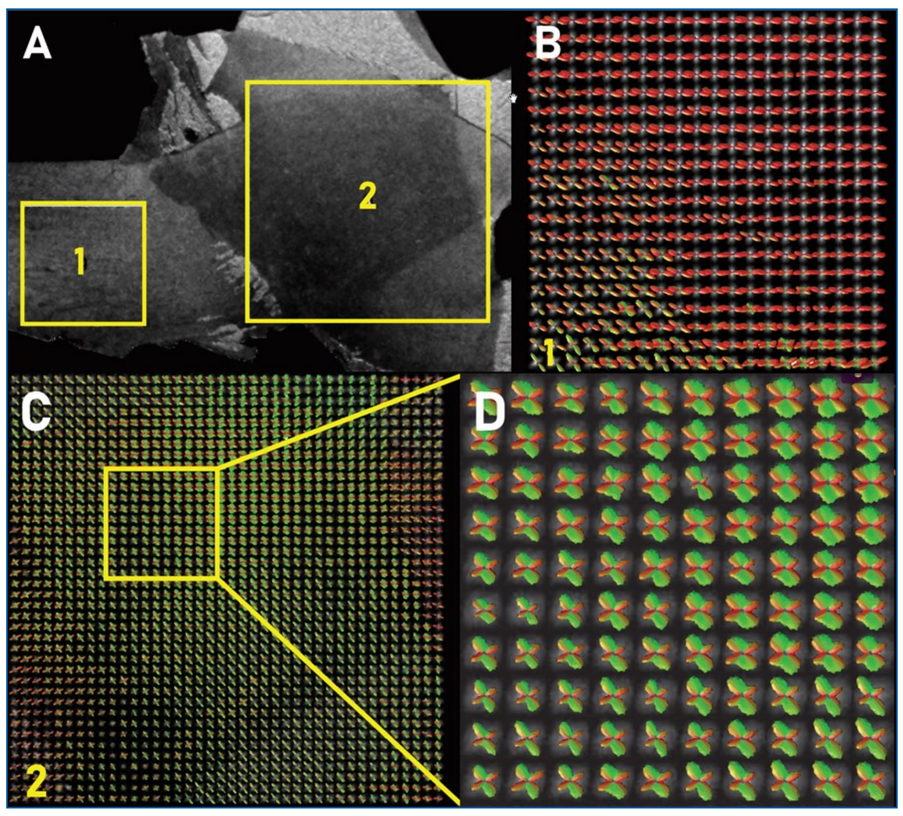
RESULTS IN PLI SECTIONS

- Our method was evaluated in human brain sections with brain ID: MSA0309. The samples were obtained from body donor programs. The dataset comprises 840 sections at 60 µm.
- 676 sections were used for training, 82 for validation, and 82 for testing.
- We evaluate our method against performing pixel-wise optimization with a linear regression model (ROFL) without using contextual information.



RESULTS OF GORDA IN SLI SAMPLES (crossing vs parallel fibers)

Optic Tracks Section Performance



CONCLUSIONS

- Here, we presented two strategies to improve the reconstruction of the fODF in 3D-PLI and SLI images, the introduction of deep learning in the analysis shows a great potential to improve the prediction and use neighboring information in the analysis.
- This works shows that the use of simulations and DL is a possible way to reveal the fiber architecture of the brain in SLI and PLI images, allowing to disentangle the fiber crossings and out-of-plane fibers
- Results obtained with the DL method show a significant correlation with the analytical (pixels based) methodologies.

References

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[4] Vaca, Esteban, et al. "GORDA: Graph-Based Orientation Distribution Analysis of SLI Scatterometry Patterns of Nerve Fibres." 2022 IEEE 19th International Symposium on Biomedical Imaging (ISBI). IEEE, 2022.

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