White Matter Multi-Resolution Segmentation Using Fuzzy Set Theory

*Alessandro Delmonte[1,2], *Corentin Mercier[1,3], Johan Pallud[4], Isabelle Bloch[1,2], Pietro Gori[1]

[1]LTCI, Télécom ParisTech, Université Paris-Saclay, Paris, France
[2]IMAG2 Laboratory, Imagine Institute, Paris, France
[3]LIX, Ecole Polytechnique, Palaiseau, France
[4]Neurosurgery Department, Sainte-Anne Hospital, Paris, France

* equally contributed to this work

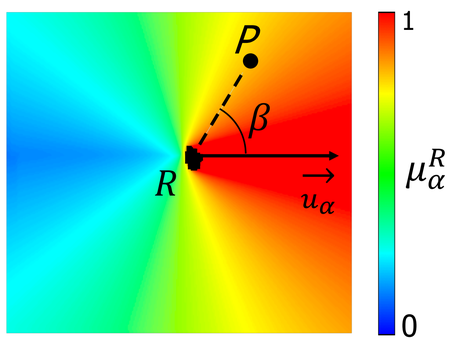
INTRODUCTION / OBJECTIVE

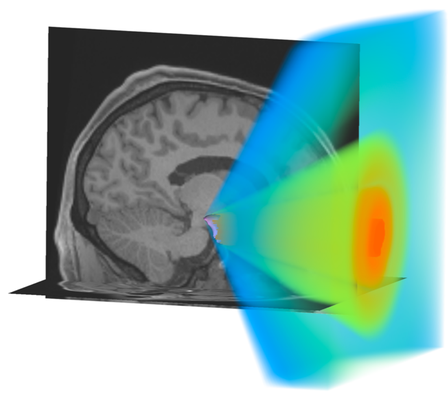
White matter fiber bundles are often described using qualitative spatial relationships (e.g. anterior of Amygdala) [1]. We propose to model their inherent vagueness using the theory of fuzzy sets [2]. Furthermore, to cope with the high redundancy of tractograms and ease interpretation, we introduce an interactive navigation and exploration technique based on a multi-resolution representation.

SPATIAL RELATIONS MODELING

Bundles are defined as a logic combination of spatial (*anterior of*, …), connectivity (*endpoint in*, …) and trajectory (*crossing,* …) relations.

Every voxel *P* in the space is assigned a membership value μ describing the degree of satisfaction of the combined relations. A FS score is computed for each fiber (with endpoints *f)* as the weighted average of μ values of the voxels the fiber passes through.





Directional: $\mu_\alpha^R(P) = max\ (0, g(\beta_{min}))$, $g(\beta_{min}) = \frac{1-2\beta_{min}}{\pi}$

Connectivity: $EP = min_{r \in R}(e^{\frac{\|f-r\|_2^2}{\lambda^2}})$

An anatomical coherence score (ACS) [3] is obtained for each fiber/cylinder in a conjunctive way.

$$ACS = FS * EP$$

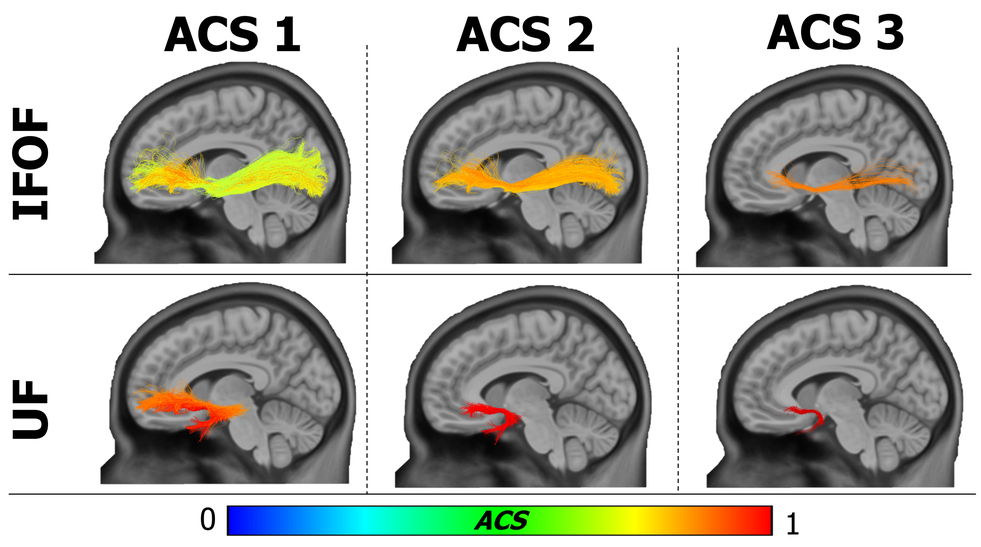


Fig. 1: Fibers of interest can be selected via an ACS based thresholding operation.

MULTI-RESOLUTION REPRESENTATION

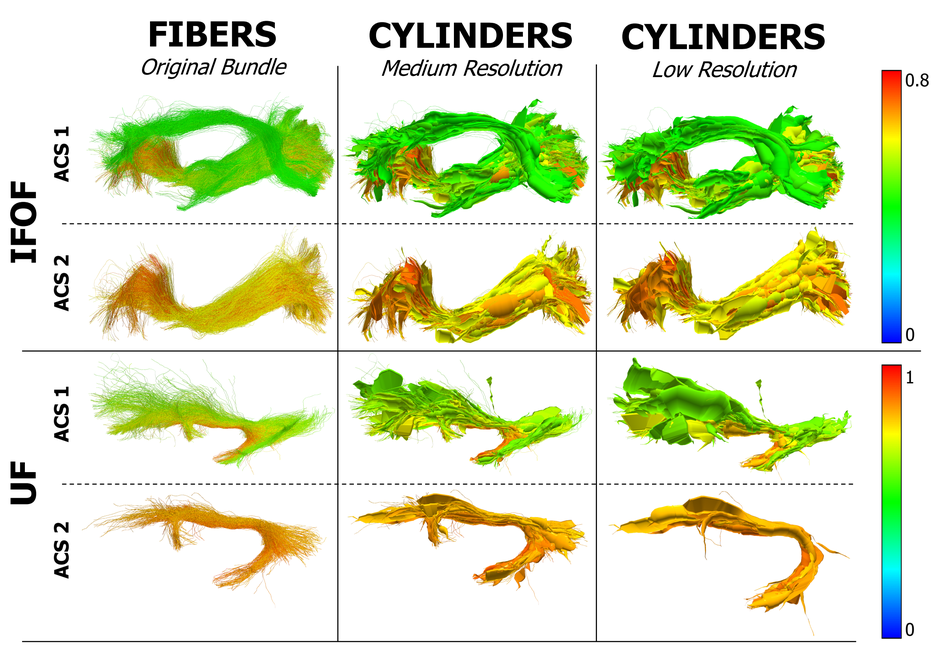


Fig. 2: Multi-resolution fiber bundles visualization

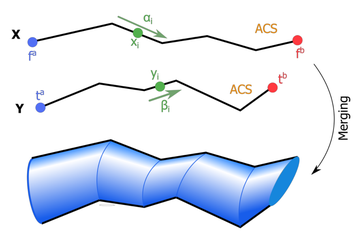
White matter multi-resolution [4] technique progressively merges fibers together in generalized cylinders.

- Real-time multi-resolution navigation
- Interactive ACS thresholding for segmentation

Fibers are selected using an extension of the Weighted Currents [5] similarity, containing an ACS term.

$$WC_{ext} = K_c(|ACS_X - ACS_Y|) K_a(\|f_a - t_a\|_2)\ K_b(\|f_b - t_b\|_2) \left| \sum_{i=1}^{N-1} \sum_{j=1}^{M-1} \alpha_i^T\ K_g(\|x_i - y_i\|_2) \beta_j \right|$$

with $K_c(|A-B|) = 1 - |A-B|$, and $K_a\ K_b\ K_g$ being Gaussian kernels.



RESULTS

- We validated our results on 5 unrelated healthy adults subjects from the *HCP* dataset.
- The interactive analysis helped neurosurgeons to better understand the structure of the bundles and find an optimal ACS threshold for the segmentation of IFOF and UF.
- A smaller fiber dispersion, compared to state-of-the-art methods, can be observed.
- ACS thresholds were reproducible among different subjects.

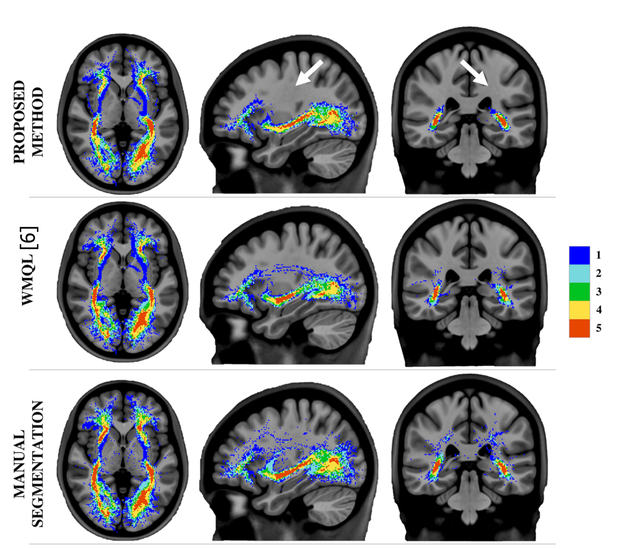


Fig. 3: Tracts dispersion map

FUTURE WORKS

We plan to extend the proposed technique to more tract bundles, implementing more fuzzy relations, and perform statistical analyses.

References

[1] S. Wakana *et al.*, "Reproducibility of quantitative tractography methods applied to cerebral white matter", *NeuroImage*, vol. 36, no. 3, pp. 630–644, 2007.
[2] I. Bloch, "Fuzzy spatial relationships for image processing and interpretation: a review", Image and Vision Computing, vol. 23, no. 2, pp. 89–110, 2005.
[3] A. Delmonte *et al.,* "Segmentation of White Matter Tractograms Using Fuzzy Spatial Relations", in Organization for Human Brain Mapping (OHBM), Singapore, 2018.
[4] C. Mercier *et al.,* "Progressive and Efficient Multi-Resolution Representations for Brain Tractograms", in EG VCBM, 2018.
[5] P. Gori *et al.*, "Parsimonious Approximation of Streamline Trajectories in White Matter Fiber Bundles," IEEE TMI, vol. 35, no. 12, pp. 2609–2619, 2016.
[6] D. Wassermann *et al.,* "The white matter query language: a novel approach for describing human white matter anatomy," Brain Structure and Function, vol. 221, no. 9, pp. 4705–4721, 2016.

Poster n°**582**

https://github.com/CorentinMercier/FBTS

Contacts: alessandro.delmonte@institutimagine.org
corentin.mercier@telecom-paristech.fr

IEEE International Symposium on Biomedical Imaging – 2019 – April 8-11, 2019 Venice (IT)