White Matter Multi-Resolution Segmentation Using Fuzzy Set Theory

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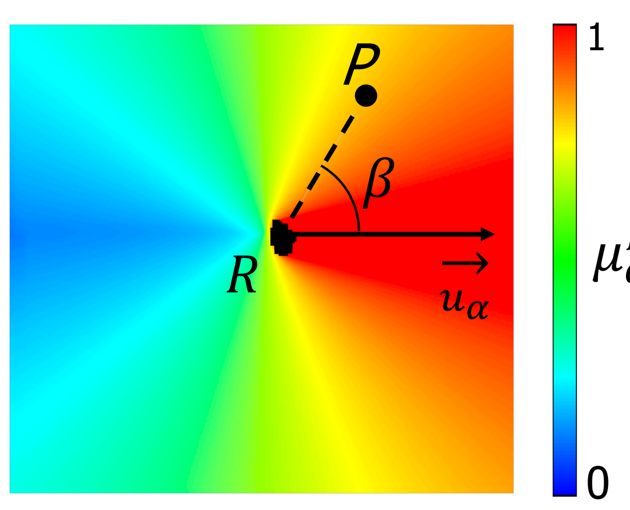
INTRODUCTION / OBJECTIVE

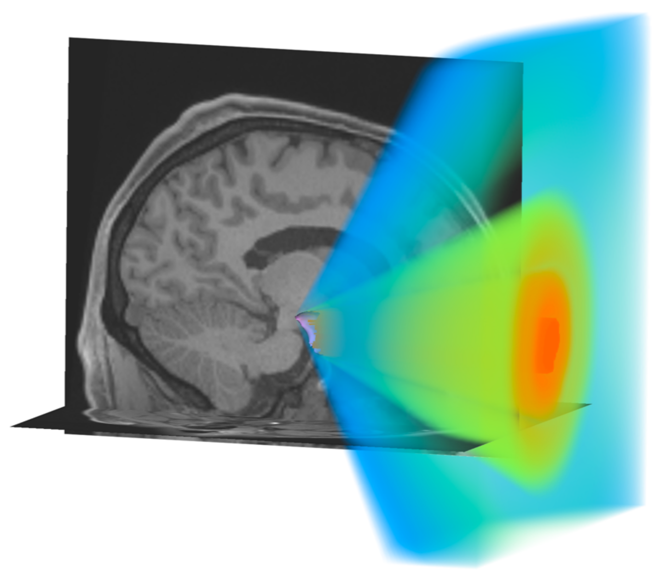
White matter fiber bundles are often described using qualitative spatial relationships (e.g. anterior of Amygdala) [1]. We propose to model their inherent vagueness using the theory of fuzzy sets [2]. Furthermore, to cope with the high redundancy of tractograms and ease interpretation, we introduce an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

$$ACS = FS * EP$$

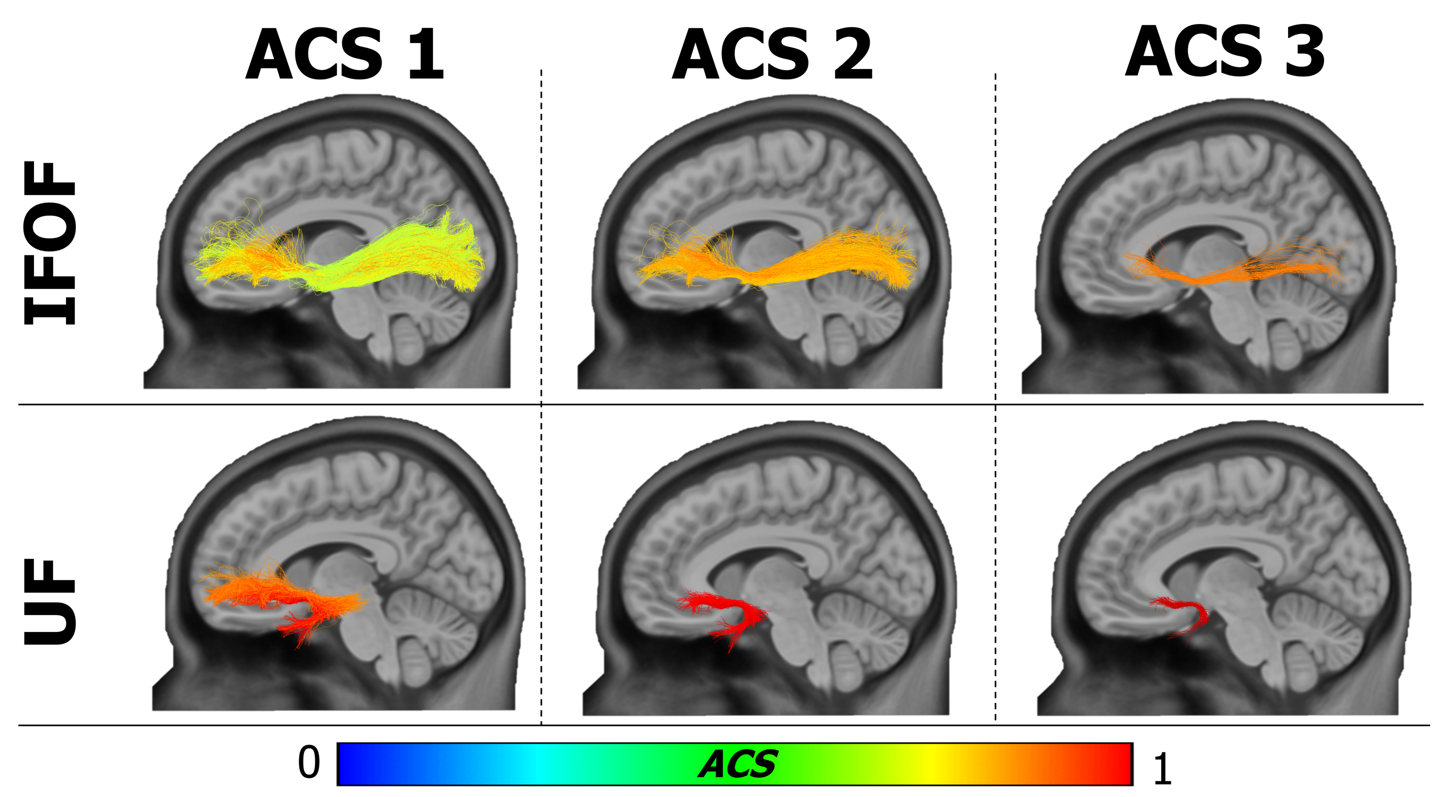


Fig. 1: Fibers of interest can be selected via an ACS based thresholding operation.

MULTI-RESOLUTION REPRESENTATION

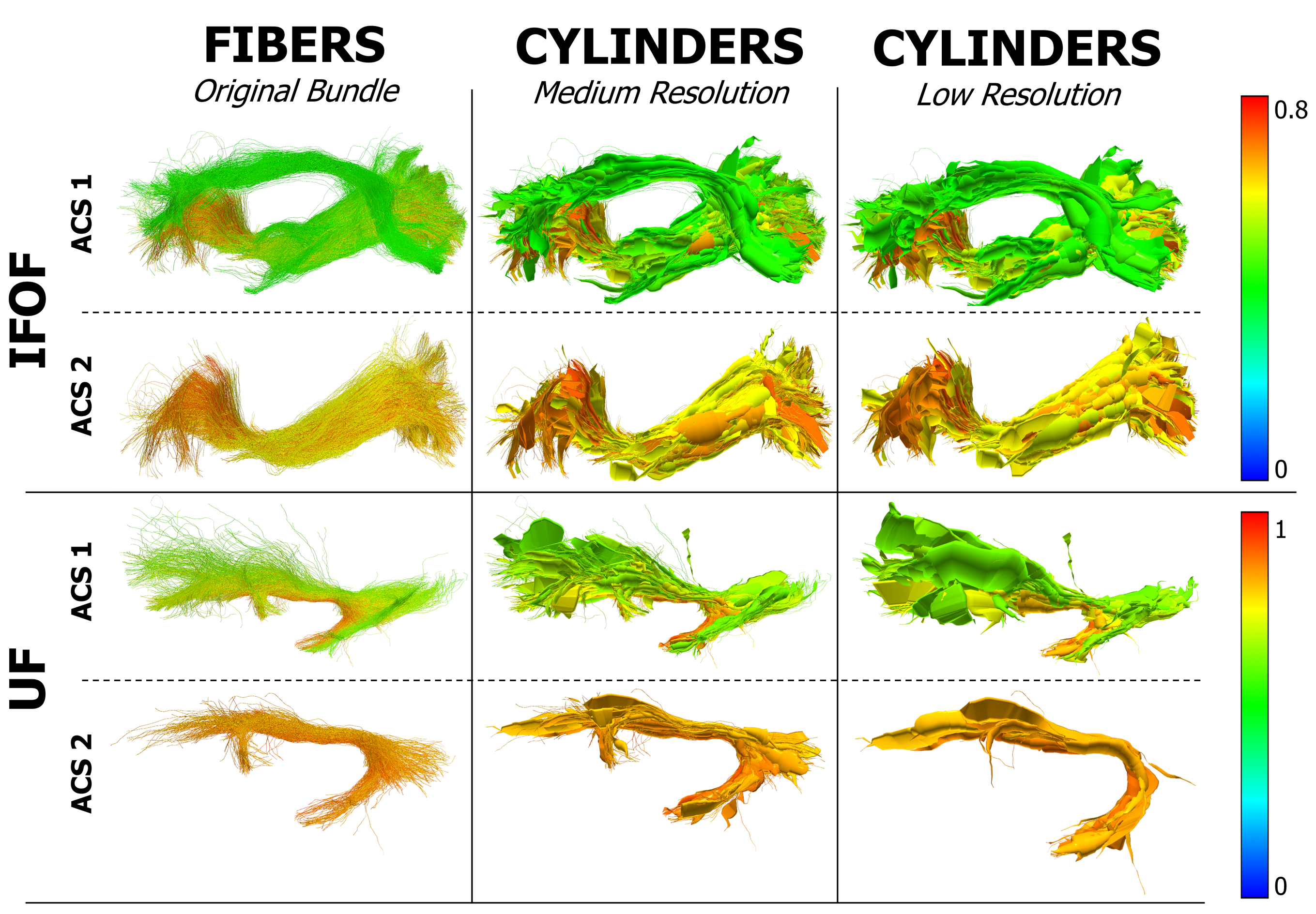


Fig. 2: Multi-resolution fiber bundles visualization

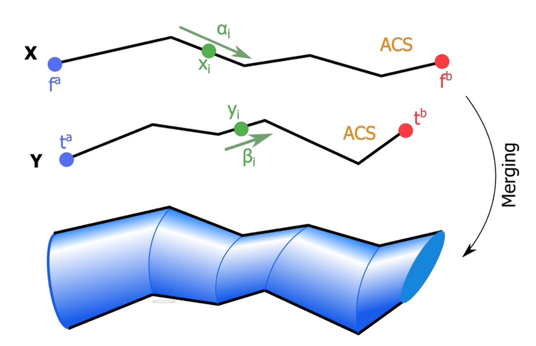
White matter multi-resolution [4] technique progressively merges fibers together in generalized cylinders.

- 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.

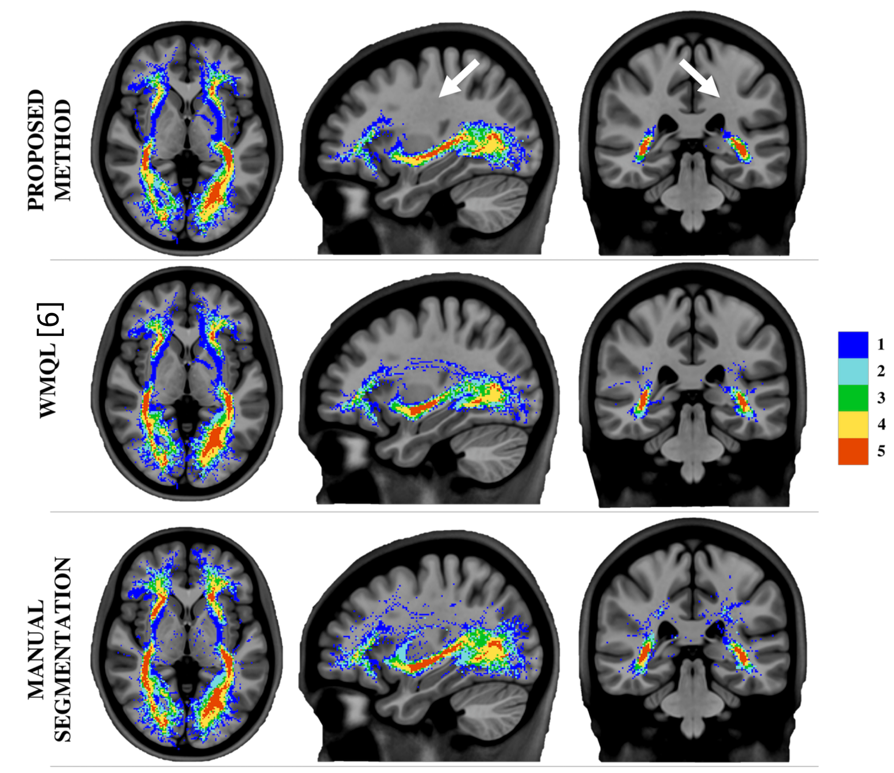


Fig. 3: Tracts dispersion map

FUTURE WORKS

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

References
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https://github.com/CorentinMercier/FBTS

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