White Matter Multi-Resolution Segmentation Using Fuzzy Set Theory

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INTRODUCTION / OBJECTIVE

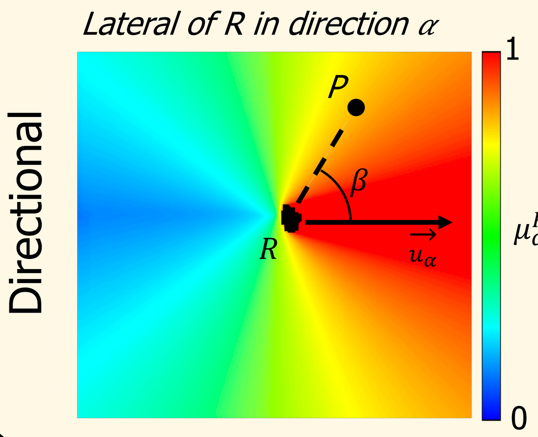
White matter fiber bundles are often described using qualitative spatial relationships (e.g. anterior of Amygdala) [1]. We propose to model their inherent vagueness using the theory of fuzzy sets [2]. Furthermore, to cope with the high redundancy of tractograms and ease interpretation, we introduce an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

SPATIAL RELATIONS MODELING

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

Membership functions μ, describing the satisfaction degree to the relations, are evaluated for every point P in the image space. Spatial (*FS*) and connectivity (*EP*) fuzzy scores are computed for each fiber F (composed by N points and with endpoints f_a *and* f_b).

Directional



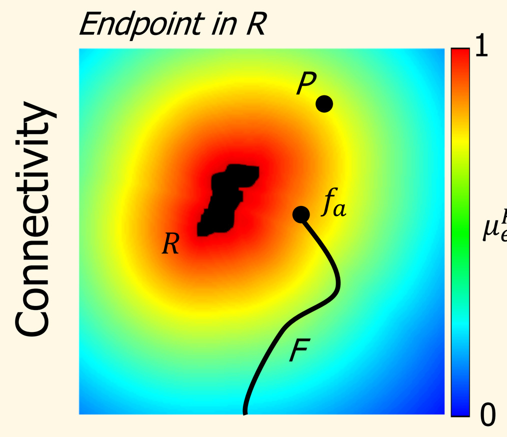
$$FS(F) = \frac{1}{N}\sum_{i=1}^{N} \mu_\alpha^R(F(i))$$

$$\mu_\alpha^R(P) = max(0, g(\beta_{min}))$$

$$g(\beta_{min}) = 1 - \frac{k\beta_{min}}{\pi}$$

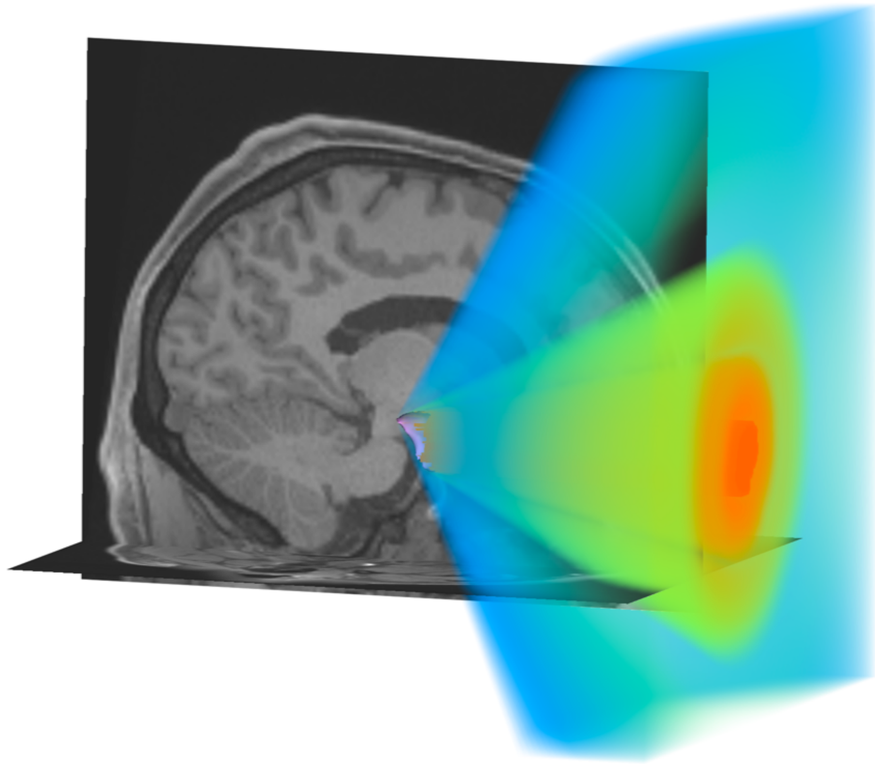
$$\beta_{min} = min_{r\in R}\, \beta(\vec{u_\alpha}, \vec{rP})$$

Connectivity



$$EP(F) = max(\mu_e^R(f_a), \mu_e^R(f_b))$$

$$\mu_e^R(P) = max_{r\in R}\, e^{-\frac{\|P-r\|_2^2}{\lambda^2}}$$



In case of multiple relations, membership functions are combined in a conjunctive way. Finally, a single anatomical coherence score (*ACS*) [3] is assigned to each fiber.

$$ACS(F) = FS(F) \cdot EP(F)$$

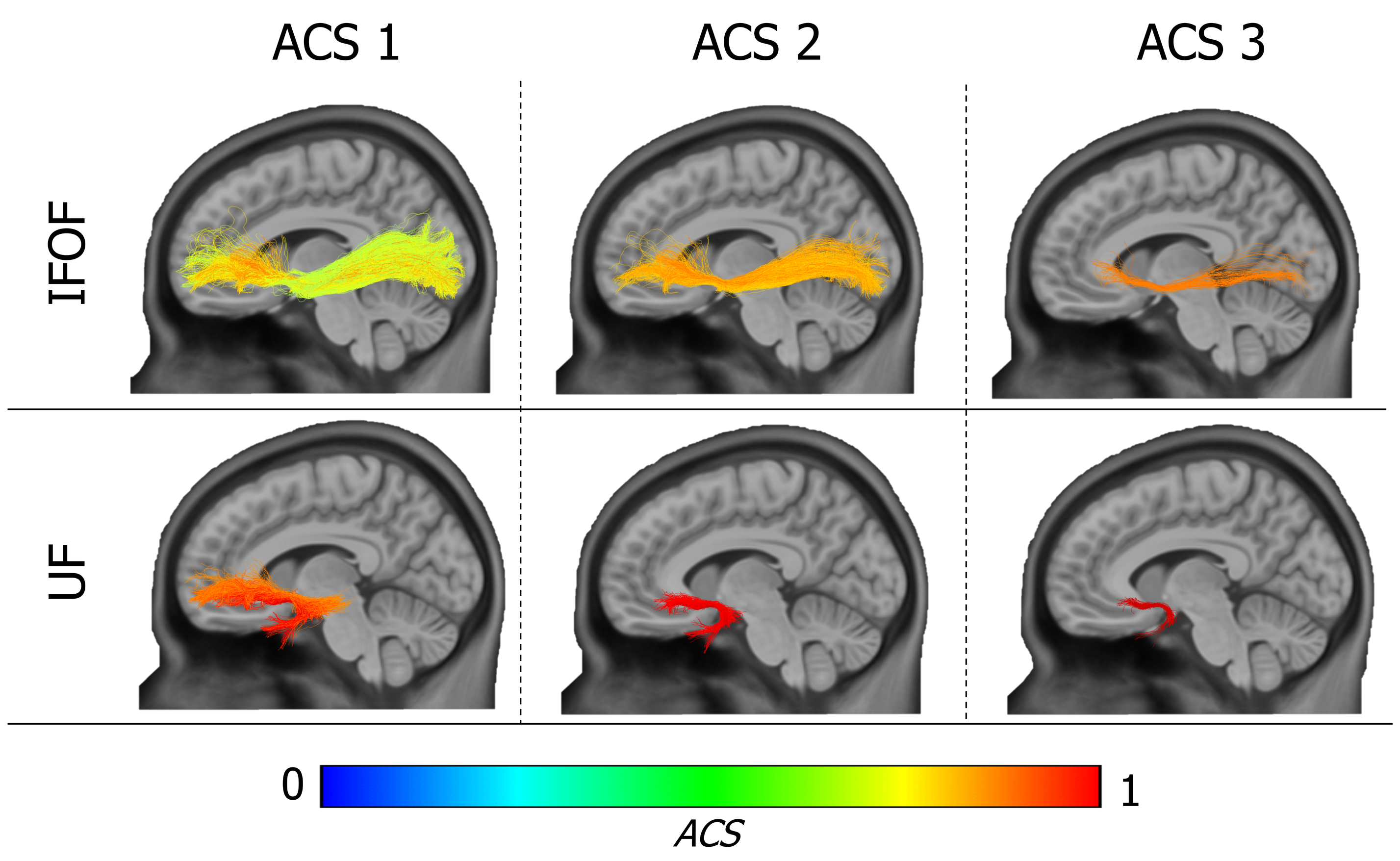


Fig. 1: Fibers of interest can be selected via an ACS based thresholding operation.

MULTI-RESOLUTION REPRESENTATION

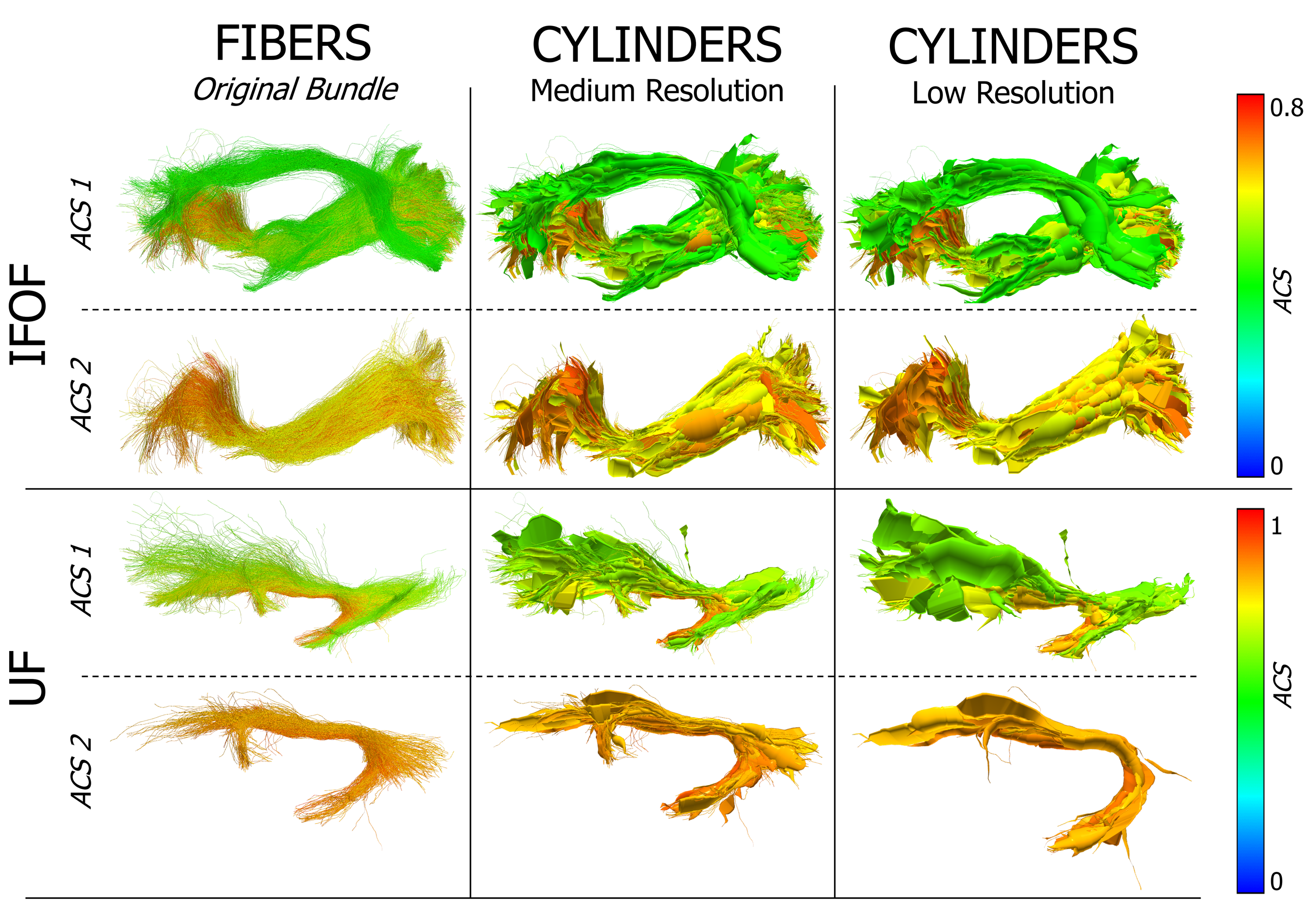
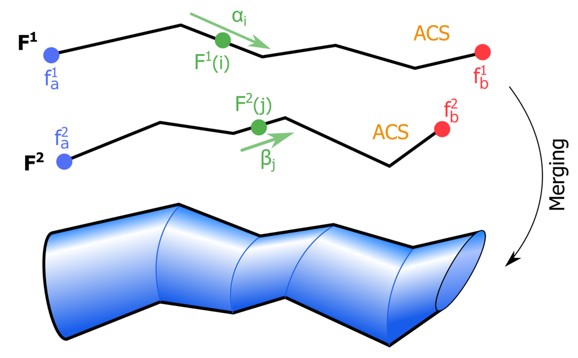


Fig. 2: Multi-resolution fiber bundles visualization

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.

$$WC_{ext} = K_c(|ACS_{F^1} - ACS_{F^2}|)K_a(\|f_a^1 - f_a^2\|_2)K_b(\|f_b^1 - f_b^2\|_2)\left|\sum_{i=1}^{N-1}\sum_{j=1}^{M-1} \alpha_i^T K_g(\|F^1(i) - F^2(j)\|_2)\beta_j\right|$$

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

In order to reduce complexity, a Delaunay tetrahedralization is used to build an adjacency relationship among fibers extremities.

RESULTS

- Results were validated on 5 unrelated healthy adults subjects from the *HCP* dataset.
- The interactive analysis helped neurosurgeons to better understand the bundles properties and to find the optimal ACS thresholds for IFOF and UF segmentation.
- Compared to state-of-the-art methods, a smaller fibers dispersion can be observed.
- ACS thresholds were reproducible among different subjects.

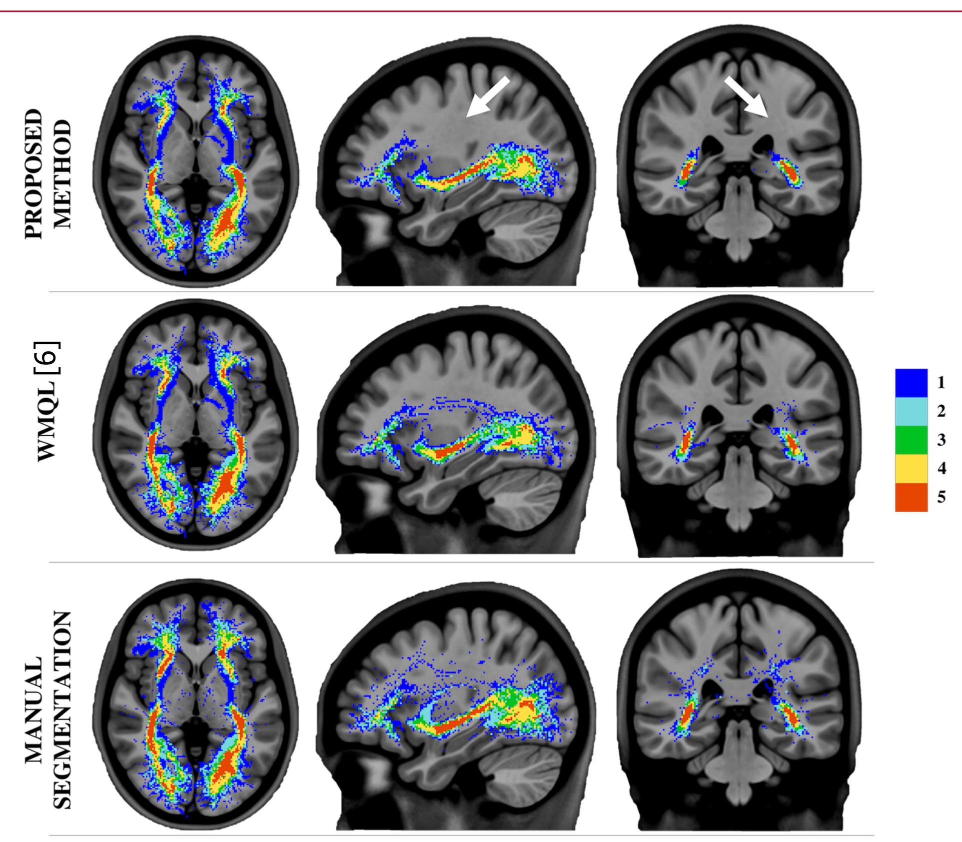


Fig. 3: Tracts dispersion map

FUTURE WORKS

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

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

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