A robust Reeb graph model of white matter fibers

A Reeb graph-based approach discovers the branch and merge structure of the streamlines that unravels a topological understanding of white matter fibers.

S. Shailja [1], Scott T. Grafton [2], B. S. Manjunath [1]

[1] Department of Electrical and Computer Engineering

[2] Psychological and Brain Sciences Department

UC **SANTA BARBARA**

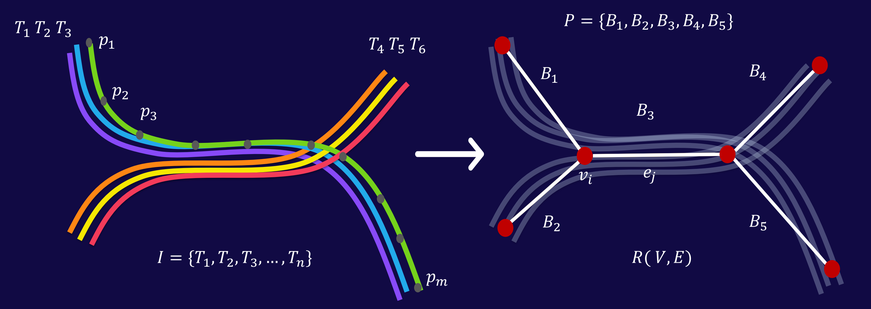
Introduction

- Tractography generates billions of complex curvilinear fibers (streamlines).
- Streamlines are usually noisy, and in turn affect structural brain connectivity analysis.

Objective

Problem: To model the bundling structures of streamlines.

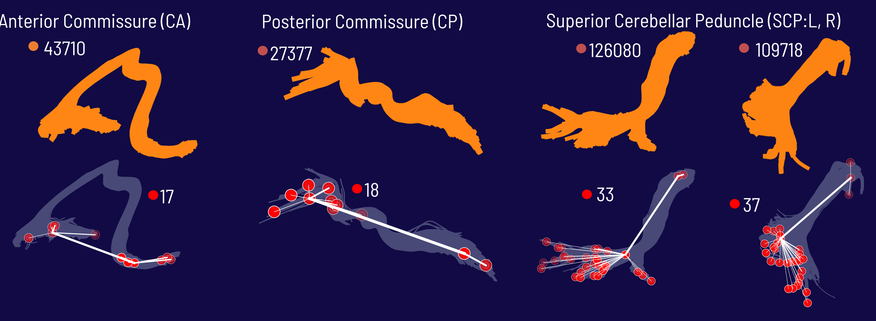
Solution: We propose a computational geometry approach using Reeb graphs.



An example showing the branching structure of the streamlines and the Reeb graph where nodes encode the merge, split, and termination characteristics.

Results

Reeb graph representation of major tracts from International Society for Magnetic Resonance in Medicine (ISMRM) dataset [4].



Runtime: CA (4s), CP(5s), SCP_L(21s), SCP_R(34s)
Complexity: *O(NlogN)*

References

[1] Shailja, S., Scott T. Grafton, and B. S. Manjunath. "A robust Reeb graph model of white matter fibers with application to Alzheimer's disease progression." bioRxiv (2022).

[2] Shailja, S., Angela Zhang, and B. S. Manjunath. "A computational geometry approach for modeling neuronal fiber pathways." International Conference on Medical Image Computing and Computer-Assisted Intervention. Springer, Cham, 2021.

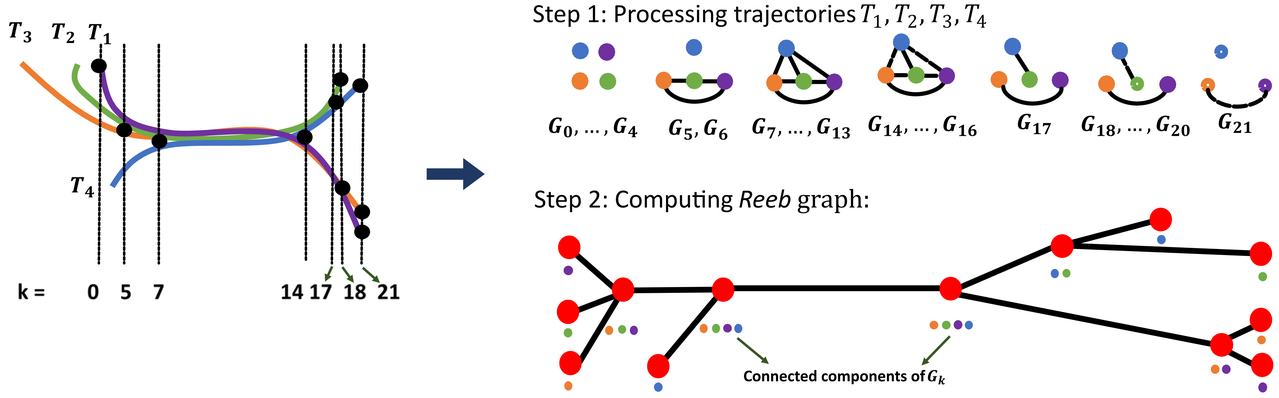
[3] Buchin, Kevin, et al. "Trajectory grouping structure." Workshop on Algorithms and Data Structures. Springer, Berlin, Heidelberg, 2013.

[4] Maier-Hein, Klaus H., et al. "The challenge of mapping the human connectome based on diffusion tractography." Nature Communications , 2017.

shailja@ucsb.edu

github.com/UCSB-VRL/ReebGraph

Algorithm



We solve a subtrajectory clustering problem by maintaining a spatially dynamic graph G representing the ε-connected relation.

Steps:

1. Construct dynamic graph G.
2. Find connected components in G.
3. Compute *R*.

Key idea: If a continuous portion of a set of fibers are "close", they share a common anatomical behavior.

Robustness

ε – distance between a pair of streamlines in a bundle that defines its sparsity

α – spatial length of the bundle that introduces persistence

δ – the bundle thickness

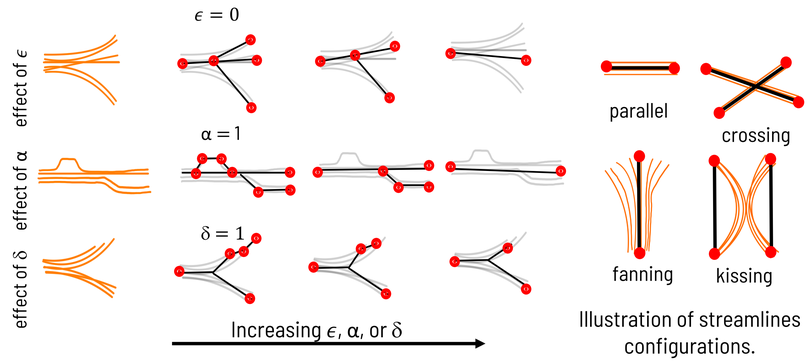
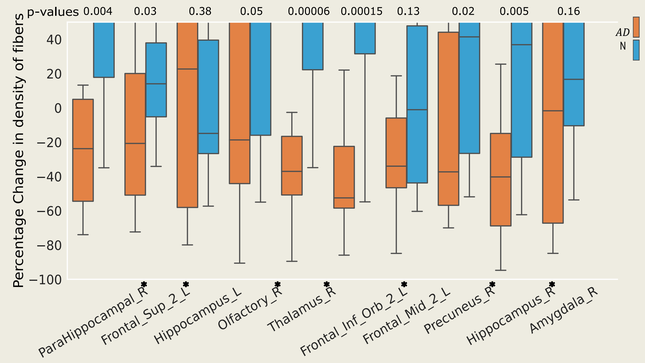


Illustration of streamlines configurations.

Applications

- Ranking, quantification, and comparing disease-relevant region of interests.
- Reeb graph skeletons for active diagnosis with increasing age and physiological changes in the brain.



Relevant brain regions for Alzheimer's Disease show severe decrements in the fiber density (ROIs marked with *).

Conclusion

- We present a computational model of spatial evolution of neuronal trajectories to encode the critical points of the pathways.
- Point correspondence of the critical coordinates in the 3D brain is an essential requirement of the tract-orientated quantitative analysis.

We would like to thank Vikram Bhagavatula and Angela Zhang for their insightful discussion on the research project. This research was supported by NSF award: SSI # 1664172.