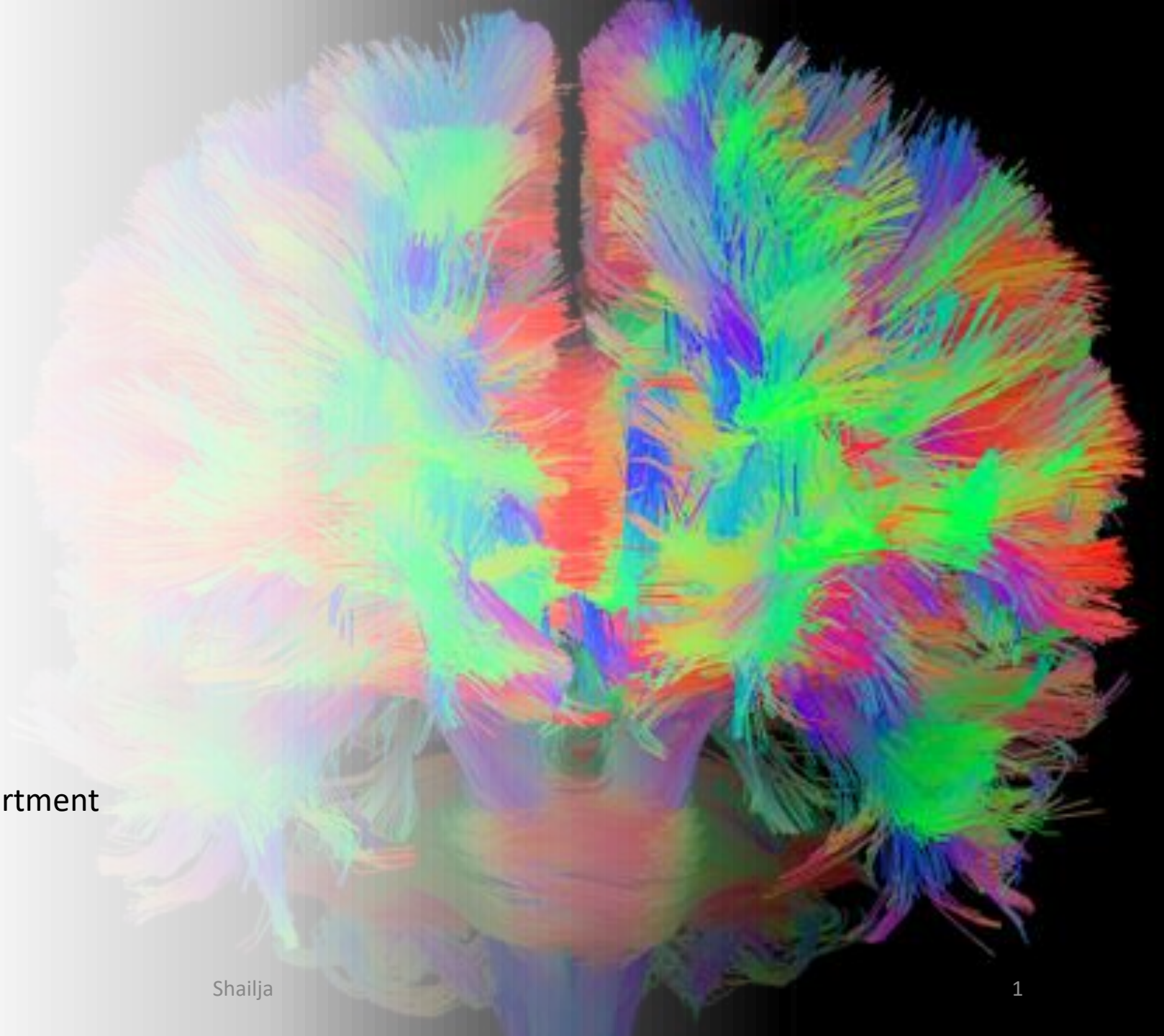
UC SANTA BARBARA

MICCAI 2023 Vancouver CANADA

ReTrace

Topological evaluation of white matter tractography algorithms using Reeb graphs



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Tractography

- Reconstruct white matter fiber pathways from diffusion magnetic resonance images (dMRIs).
- They play a crucial role in understanding neuroanatomy and studying various brain disorders.
- To ensure accurate interpretation of the obtained tractography,
  - evaluate the performance of tractography methods on neuroanatomical bundles.
  - select appropriate metrics for assessment.

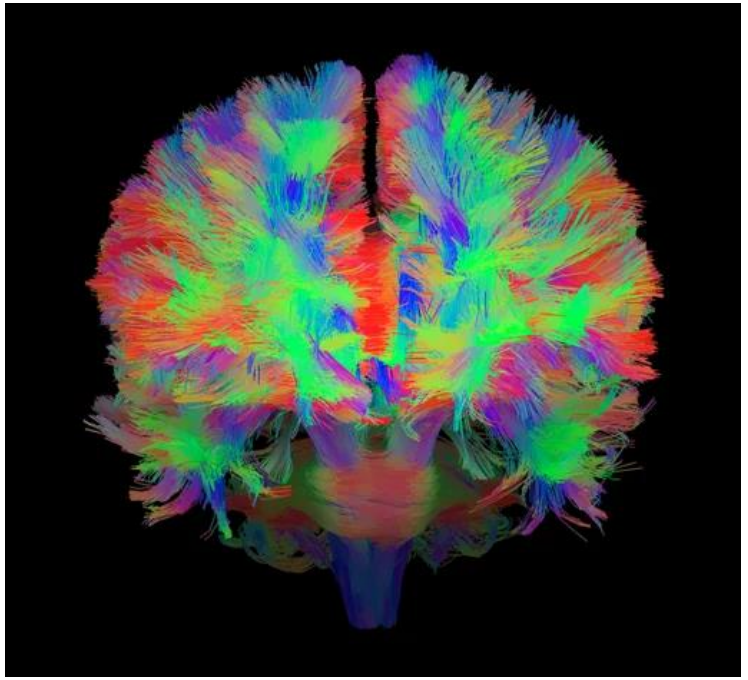


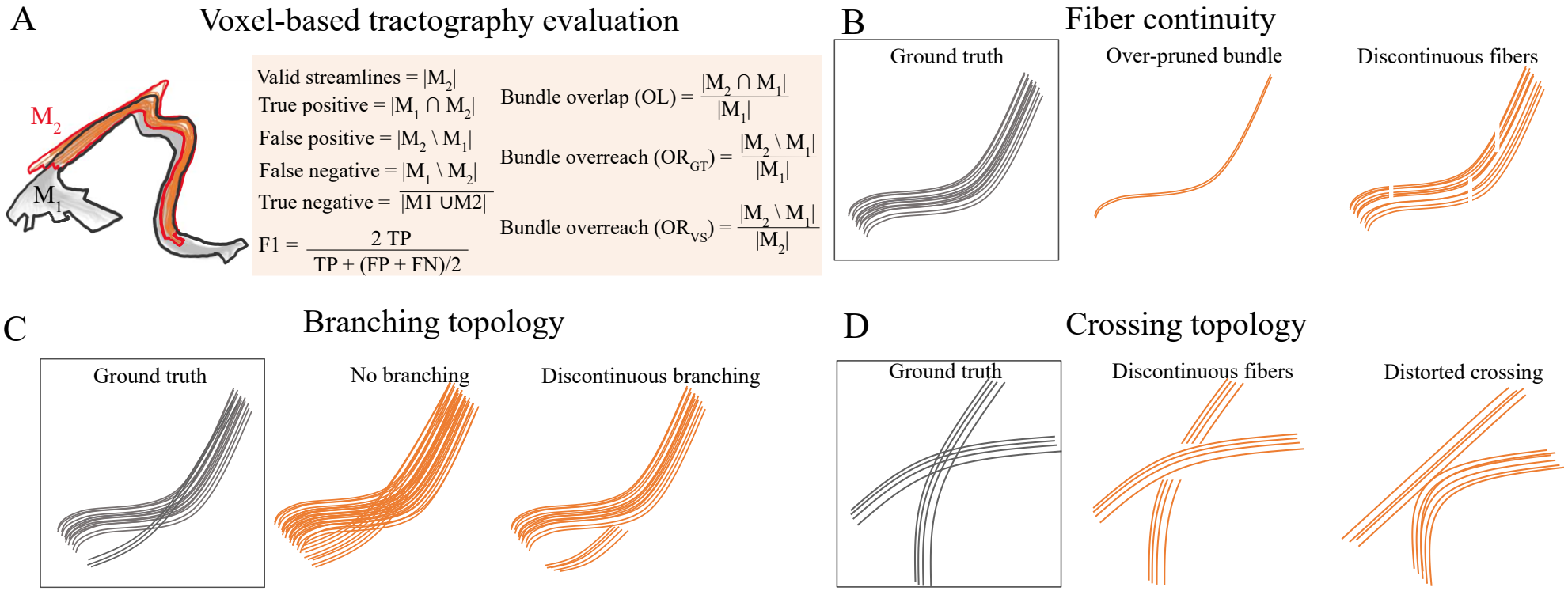
Image source: https://support.qmenta.com/knowledge/dmri-tractography

Is your tractography algorithm effectively capturing the intricate white matter pathways and their neuroanatomical topology?

Limitations of traditional metrics

- Voxel-wise agreement is the main emphasis.

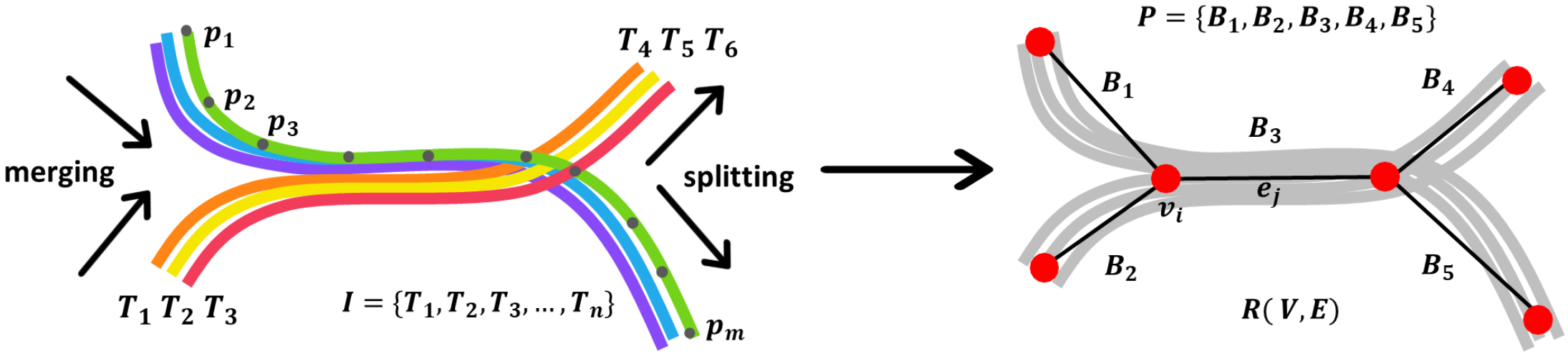
- Spatial localization, branching, and complex fiber orientations are not considered.



Maier-Hein, Klaus H., et al. "The challenge of mapping the human connectome based on diffusion tractography." *Nature communications* 8.1 (2017): 1349.

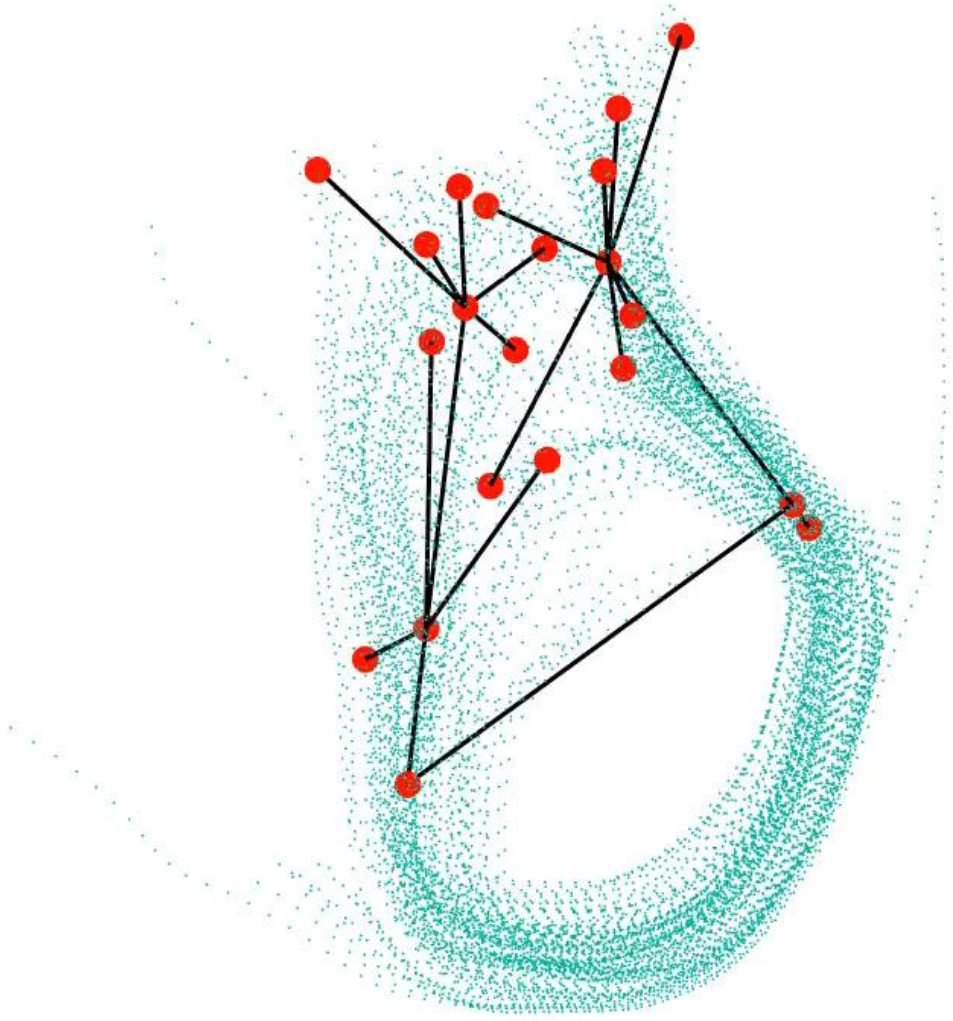
Bundling structure of streamlines as Reeb Graphs

- Nodes encode the merge, split, and termination characteristics and edges represent the bundles.



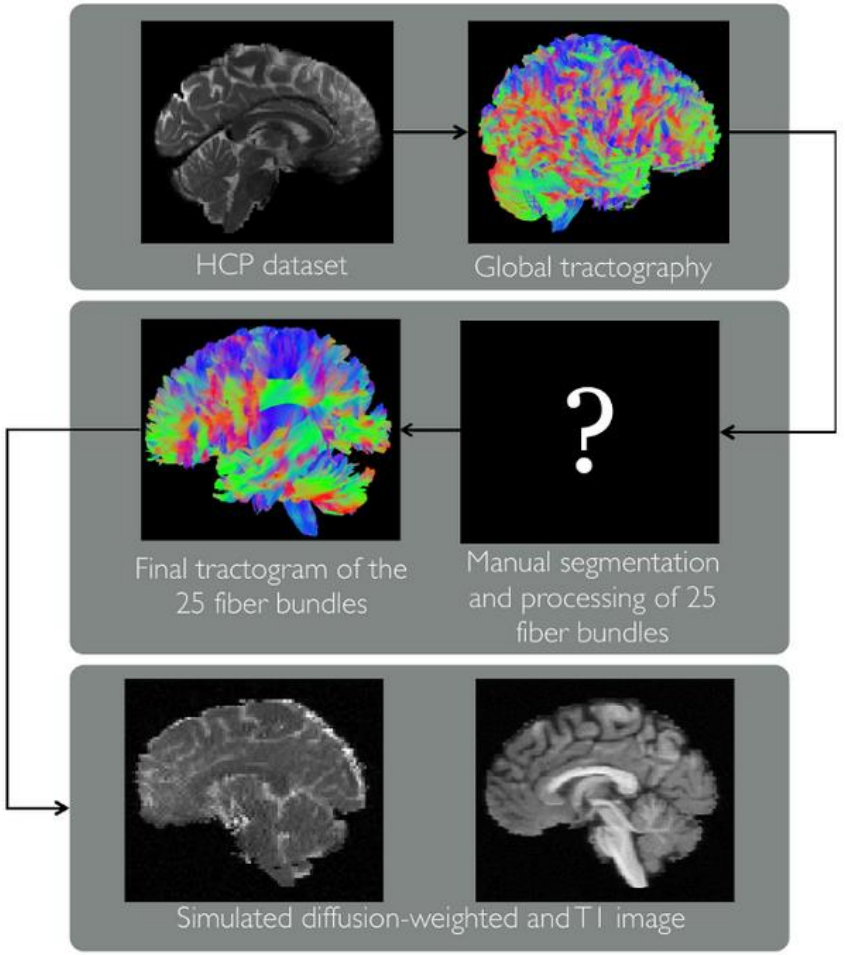
Shailja S, Bhagavatula V, Cieslak M, Vettel JM, Grafton ST, Manjunath BS. ReeBundle: a method for topological modeling of white matter pathways using diffusion MRI. IEEE Transactions on Medical Imaging. 2023 Aug 17.

Visualization of Reeb Graphs in 3D

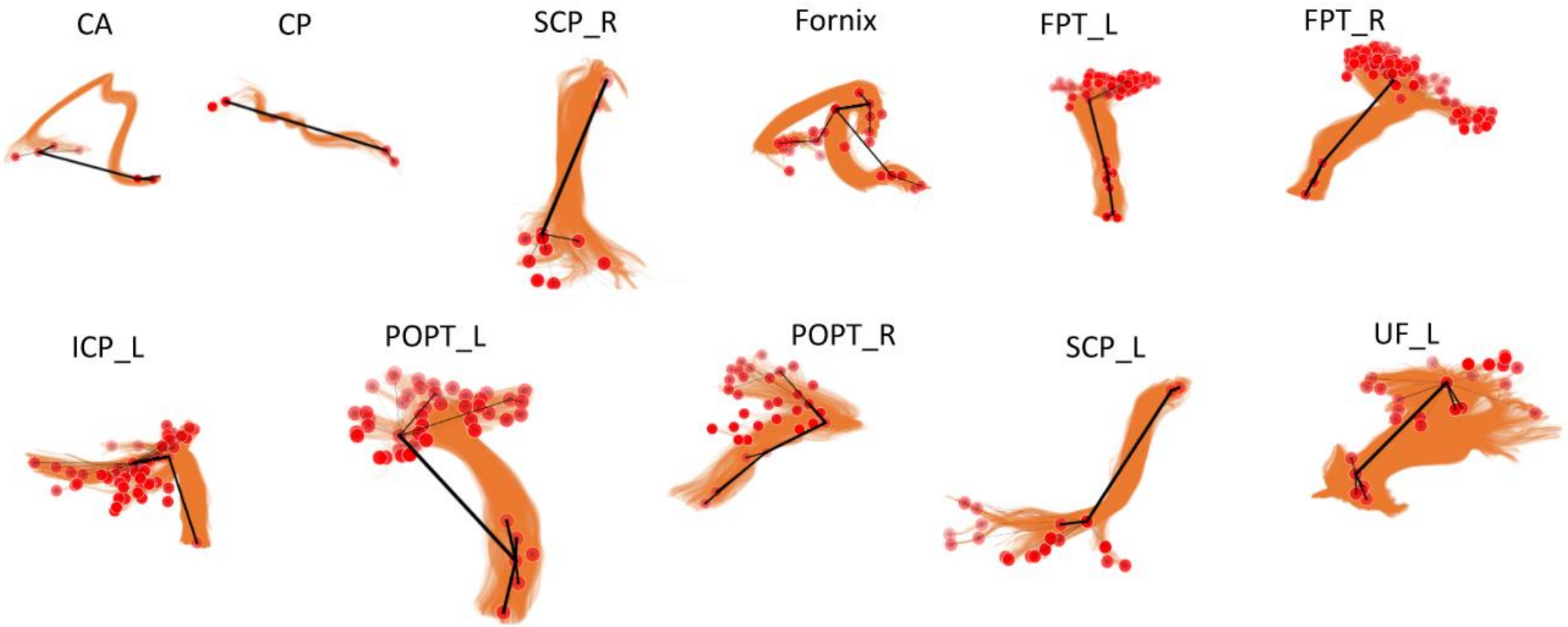


ISMRM Tractography Challenge

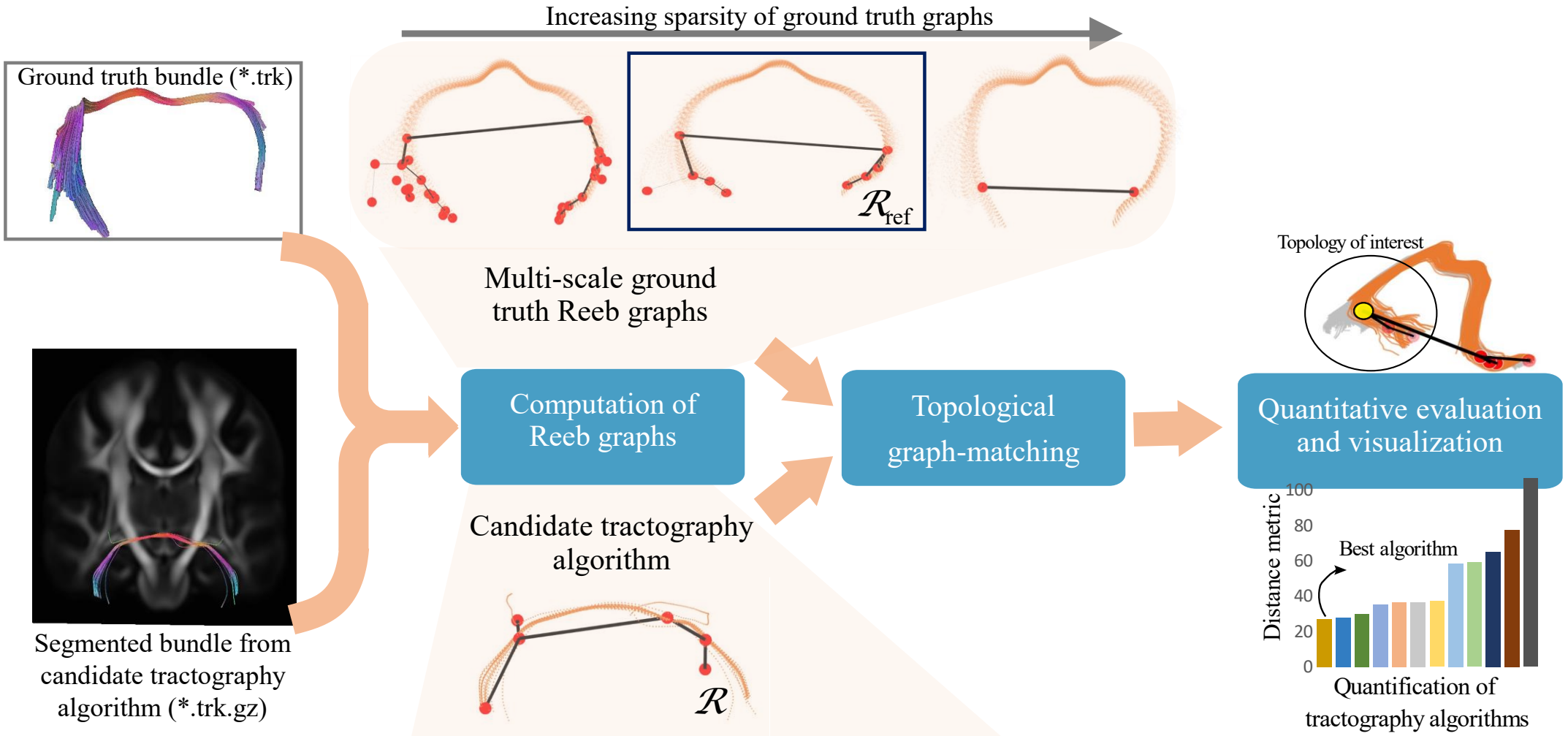
- International Society for Magnetic Resonance in Medicine (ISMRM) FiberCup dataset establish a ground truth.
- Tractograms were divided into 25 major bundles in the ISMRM dataset.
- The final tractogram was then used in Fiberfox to simulate the fitting DWI.
- 96 tractogram submissions, available publicly for download: https://zenodo.org/record/840086
- Varied pre-processing, tractography, and post-processing algorithms.



Reeb Graphs for ISMRM Dataset

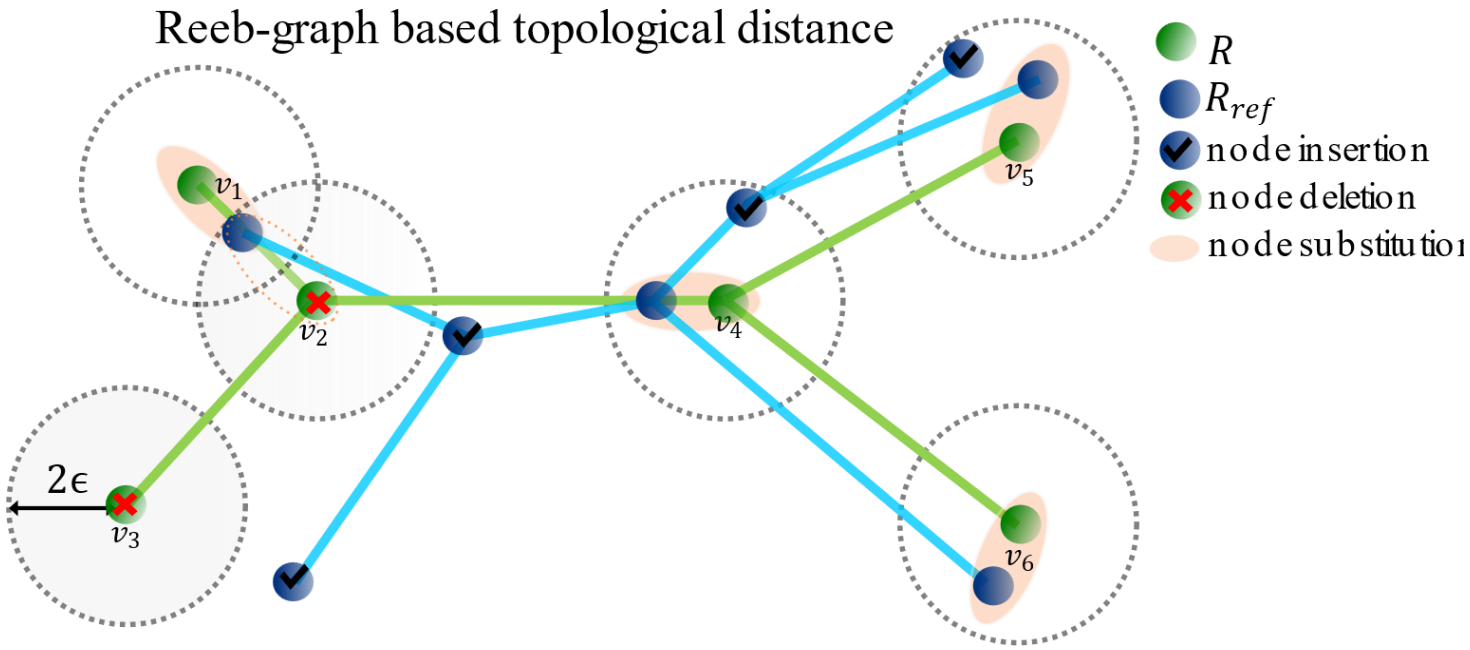


Overall Pipeline of ReTrace



Reeb Graph Matching

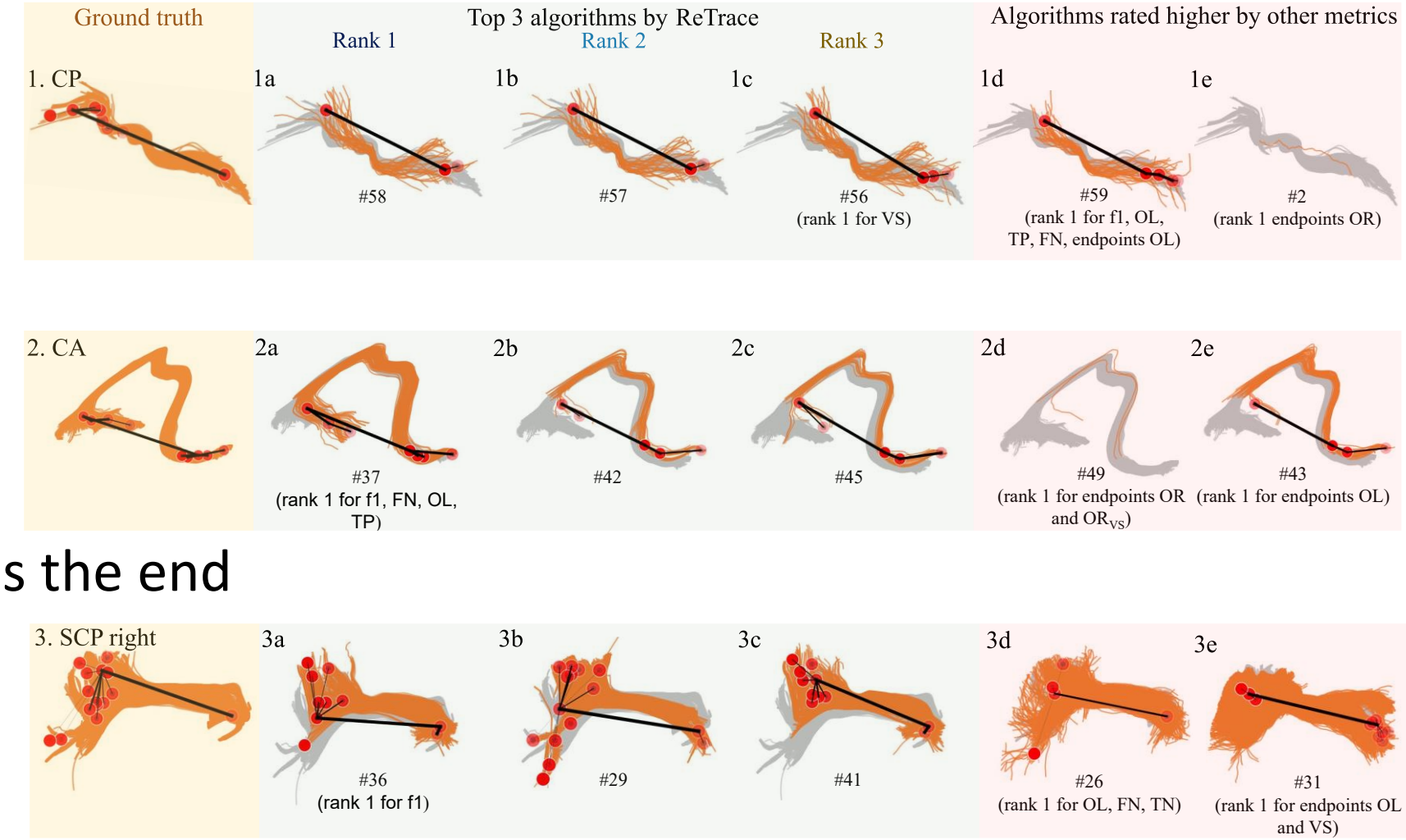
- Spatial position-based features: 3D location in the brain
- Local network-level features: : degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality



Mheich A, Hassan M, Khalil M, Gripon V, Dufor O, Wendling F. SimiNet: a novel method for quantifying brain network similarity. IEEE transactions on pattern analysis and machine intelligence. 2017 Sep 8;40(9):2238-49.

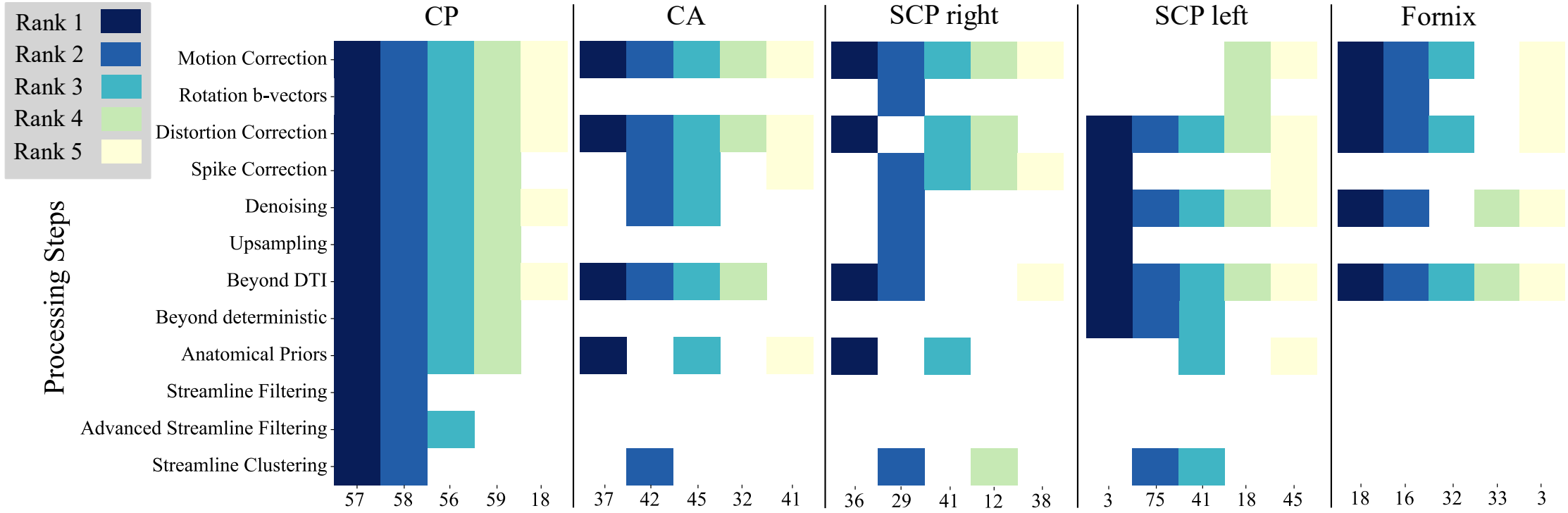
Results

- Fiber continuity
- Fiber distortion
- Branching towards the end



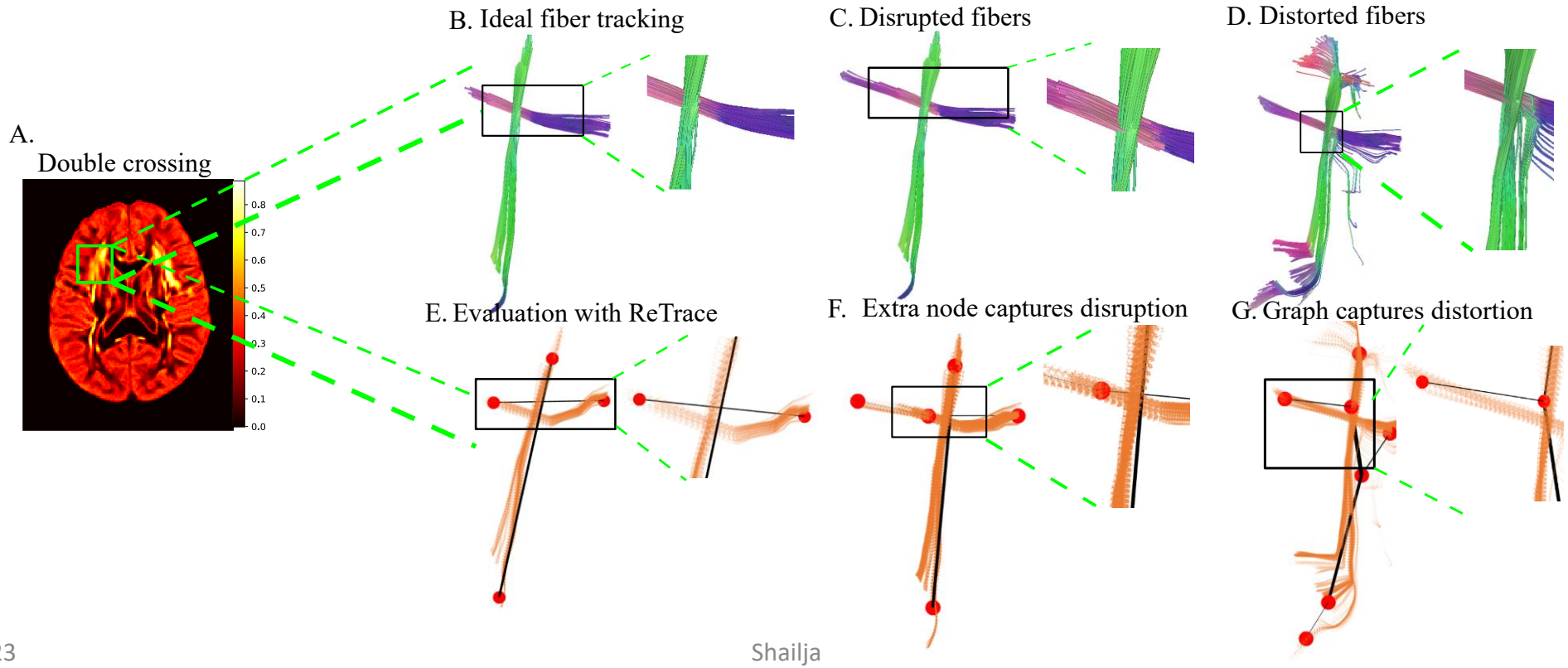
ReTrace provides insights on algorithm design from a topological point of view

- Preprocessing (from motion correction to upsampling)
- Tractography (deterministic to probabilistic)
- Postprocessing (incorporation of anatomical priors to streamline clustering).



ReTrace evaluates algorithms in the presence of fiber crossing

- An additional node in the Reeb graph captures the fiber crossing or bending.
- A thicker edge indicates bending of the fibers, whereas ideally, the fiber should only cross without bending.



Limitations

- The metric is not normalized
  - To account for relative variations
- May take more time to compute the Reeb graphs with very noisy data
  - Such bundles can be eliminated in initial pass.
- Manual selection of parameters is required depending on resolution
  - Initial set of parameters are good enough
  - Provides tunability

Conclusions

- An innovative evaluation method for tractography algorithms.
- Focuses on the topological accuracy of reconstructed pathways.
- Applicable to both synthetic and real-world datasets to demonstrate the branching fidelity
- The rankings proposed by our method are in contrast with the rankings using the conventional voxel-based tractography metrics.
- Highlight the topological features: branching, fiber continuity, localization, and crossing.
- Deterministic tractography algorithms perform better in tracking the fundamental properties of fiber bundles compared to probabilistic tractography.

Thank you!

Dr. B.S. Manjunath

Dr. Scott Grafton

Dr. Jeff Chen

NSF award: SSI # 1664172

References:

1. Shailja S, Chen JW, Grafton ST, Manjunath BS. ReTrace: Topological evaluation of white matter tractography algorithms using Reeb graphs. bioRxiv. 2023:2023-07.
2. Shailja S, Bhagavatula V, Cieslak M, Vettel JM, Grafton ST, Manjunath BS. ReeBundle: a method for topological modeling of white matter pathways using diffusion MRI. IEEE Transactions on Medical Imaging. 2023 Aug 17.
3. Shailja S, Zhang A, Manjunath BS. A computational geometry approach for modeling neuronal fiber pathways. In International Conference on Medical Image Computing and Computer-Assisted Intervention 2021 Sep 21 (pp. 175-185). Cham: Springer International Publishing.

Questions?