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Learning Macroscopic Brain Connectomes via Group-Sparse Factorization

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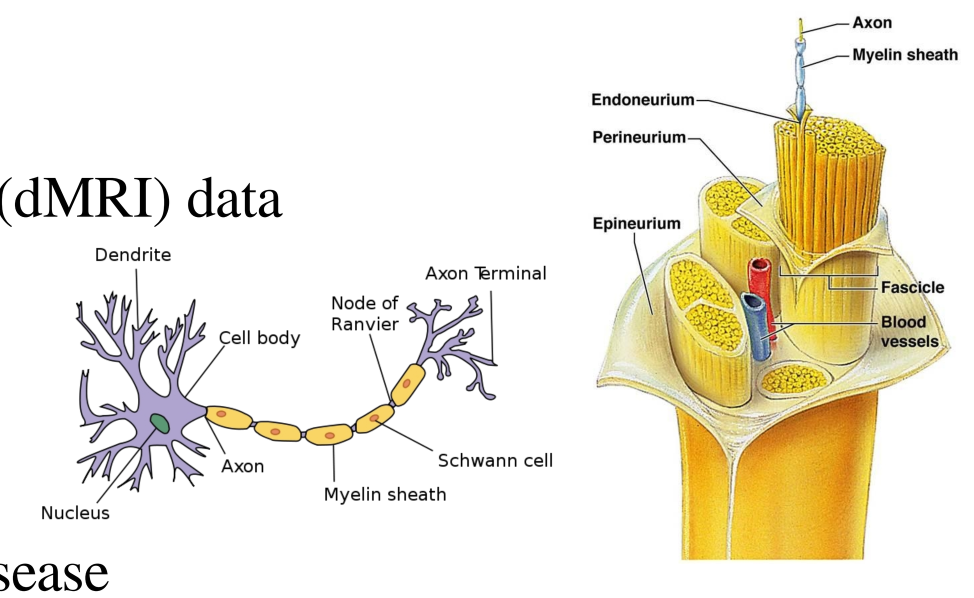
BACKGROUND & SETTING

1. Motivations

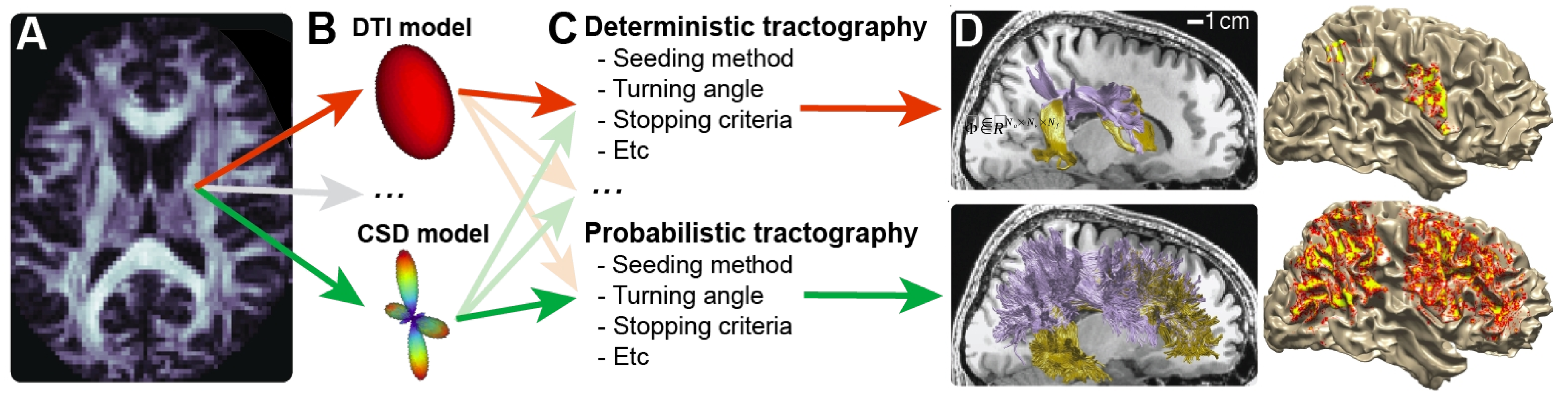
Goal:

- Given:
  - Diffusion magnetic resonance imaging (dMRI) data
- We want to:
  - Map structural brain connectome



Applications:

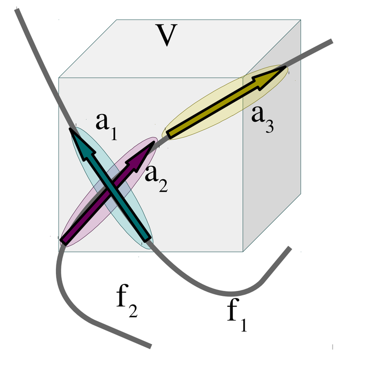
- Investigating white matter health and disease



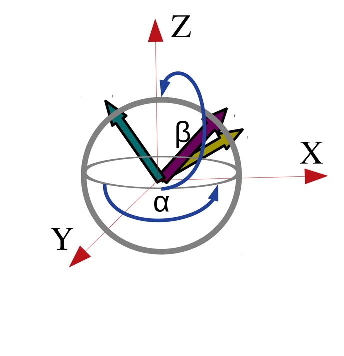
2. Encoding Brain Connectomes as Tensors

ENCODE:

- Represents brain structure by a 3D sparse tensor
  - $\Phi \in R^{N_a \times N_v \times N_f}$
    - N_a: #orientations, fascicles orientation at each position
    - N_v: #voxels, fascicles spatial position
    - N_f: #fascicles, indices of each fascicle

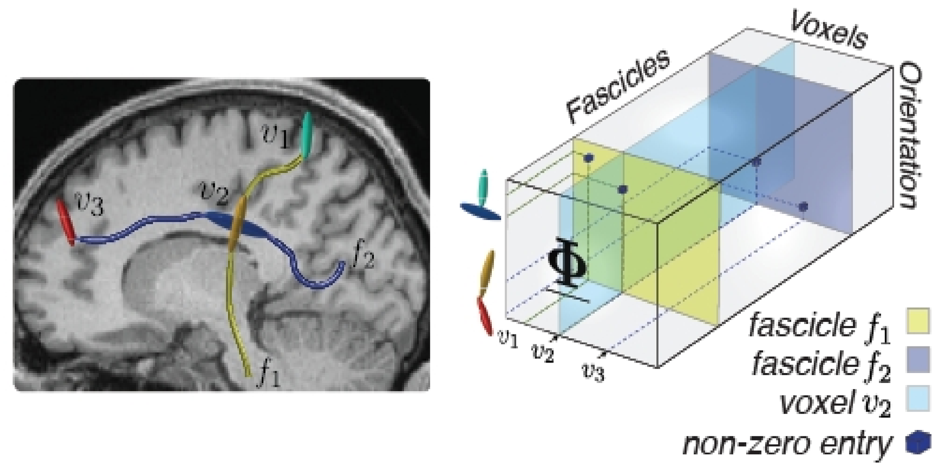


A. Encoding one voxel



B. Discretizing space

- Unifies dMRI signal with connectome structure
  - Matrix of dMRI signal $Y \in R^{N_\theta \times N_v}$
    - θ is gradient direction
  - Factorizing **Y** into **Φ** and dictinary **D**
    - $D \in R^{N_\theta \times N_a}$
    - $Y \approx \mathbf{\Phi} \times_1 D \times_3 W$, where $W \in R^{N_f}$



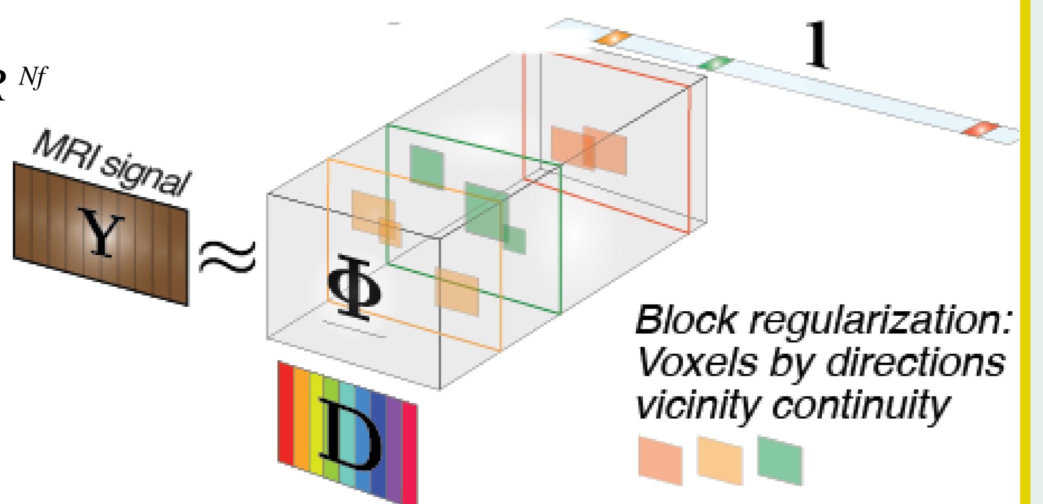
C. Natural brain space and tensor encoding

THEORY & ALGORITHMS

3. A Tractography Objective for Extracting Brain Connectomes

- Unconstrained objective to extract **Φ**
  - $\mathbf{\Phi} = \text{argmin}_{\mathbf{\Phi}} \|Y - \mathbf{\Phi} \times_1 D \times_3 1\|^2$, where $1 \in R^{Nf}$
- Regularizer – smooth, continuous, sparse
- Constrained objective to learn **Φ**
  - $\min_{\mathbf{\Phi}} \|Y - \mathbf{\Phi} \times_1 D \times_3 1\|^2 + \lambda R(\mathbf{\Phi})$,

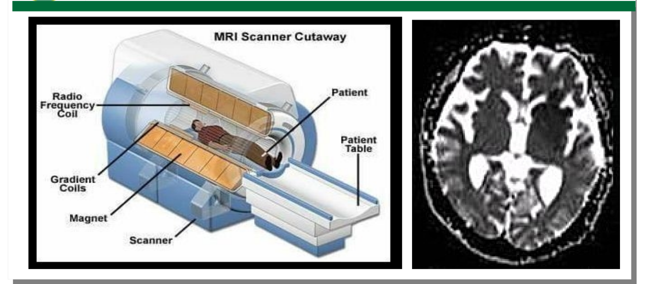
$$R(\Phi) = \sum_{f \in F} \sum_{\mathcal{G}_{\mathbf{V}} \in \mathbf{V}} \sum_{\mathcal{G}_{\mathcal{A}} \in \mathcal{A}} \sqrt{\sum_{v \in \mathcal{G}_{\mathbf{V}}} \left(\sum_{a \in \mathcal{G}\mathcal{A}} |\Phi_{a,v,f}| \right)^2}$$



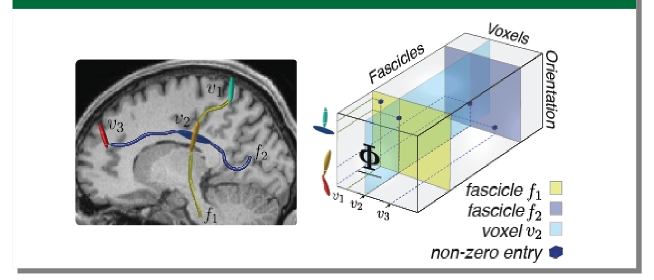
Model formulation and block regularizer

4. A Pipeline for Extracting Brain Connectomes

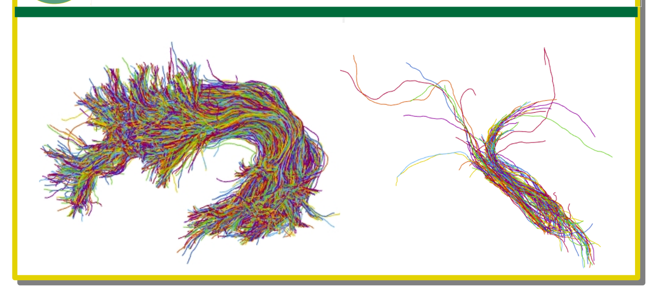
1 dMRI



2 LiFE & ENCODE



3 Brain Structure



4 Greedy Screening

Greedy $\bar{g}(S) \overset{def}{=} g(S) + \sum_{s \in S} g(s)$

OR

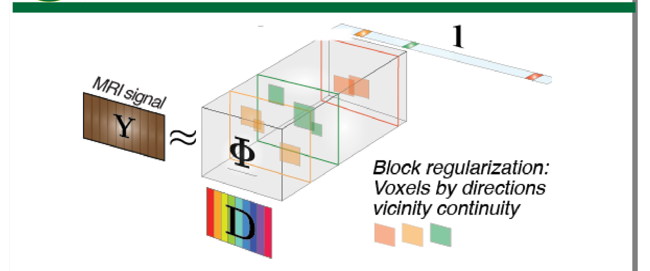
OMP $\bar{g}(S) \overset{def}{=} g(S)$

5 Global Optimization

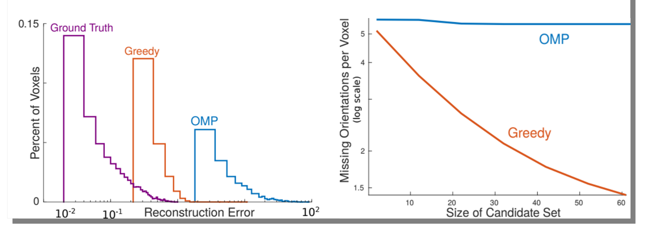
I. Tensor factorization

II. Regularized objective

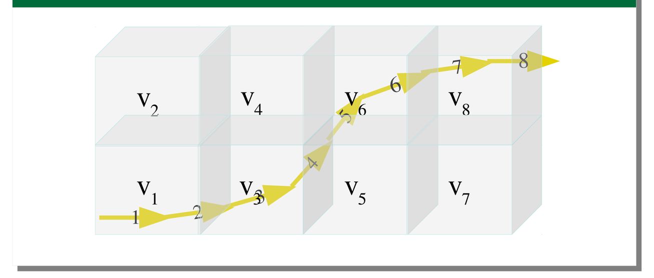
6 Extracted Φ



7 Evaluation



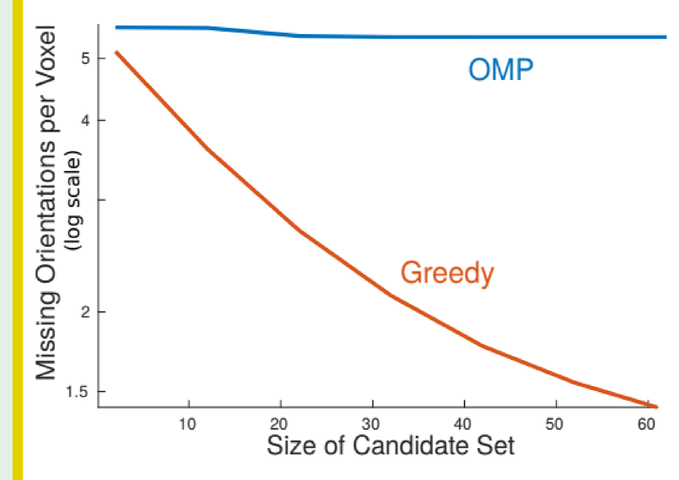
8 Visualization



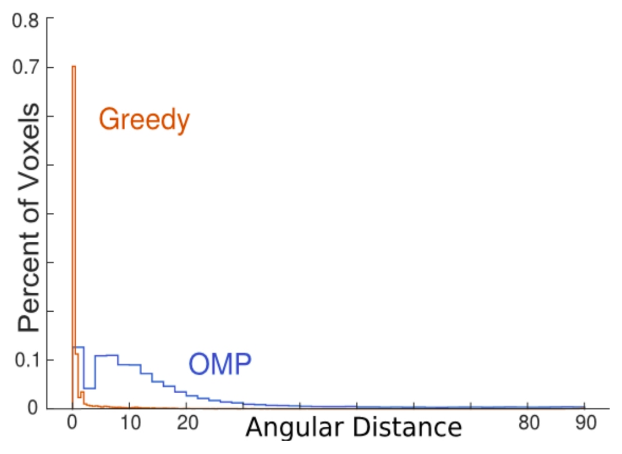
9 Brain Structure

EMPIRICAL RESULTS

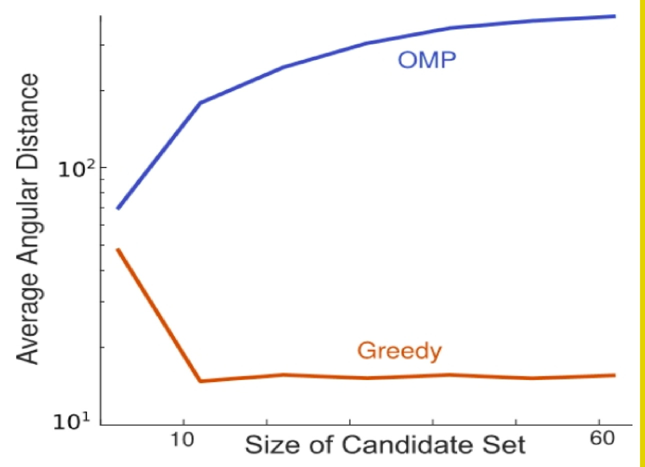
5. Reconstructing the Anatomical Structure of Tracts



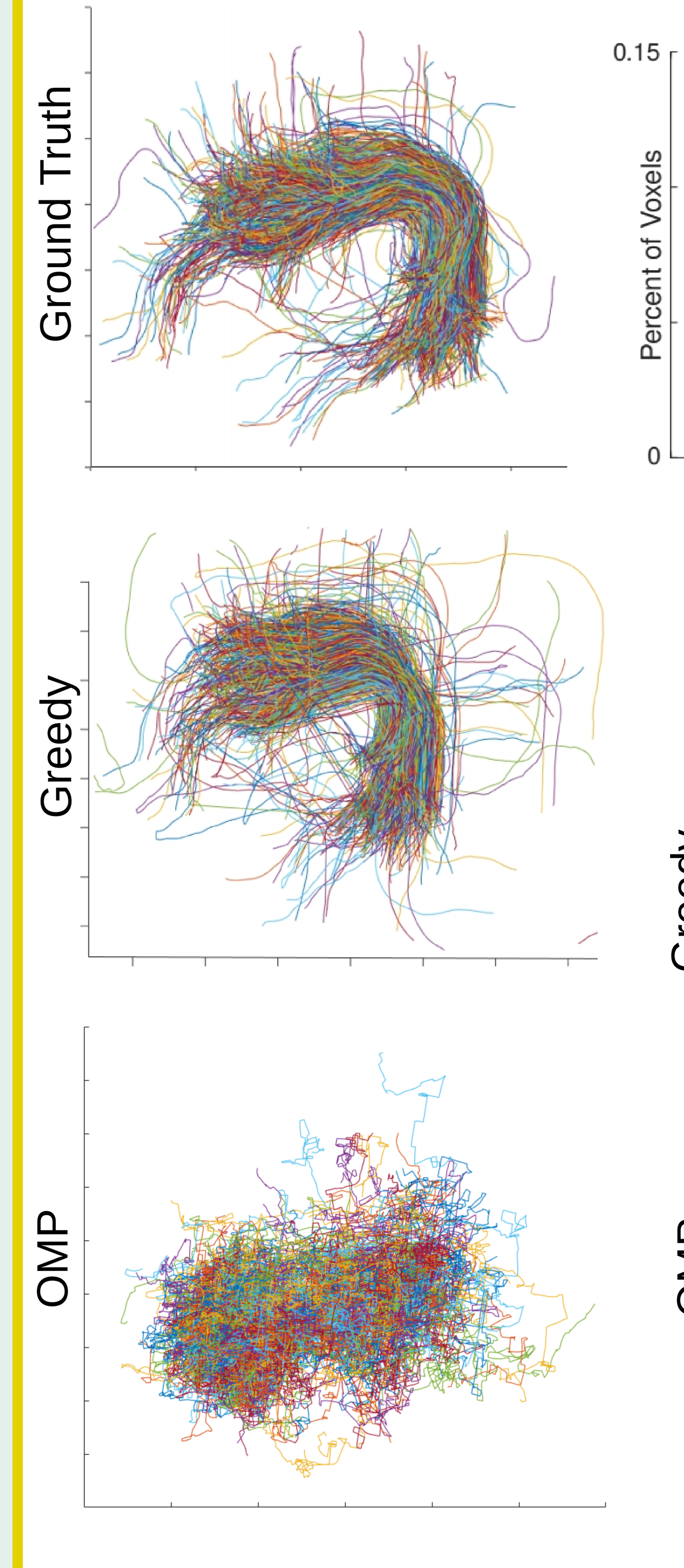
A. Screening: missing orientations vs. k



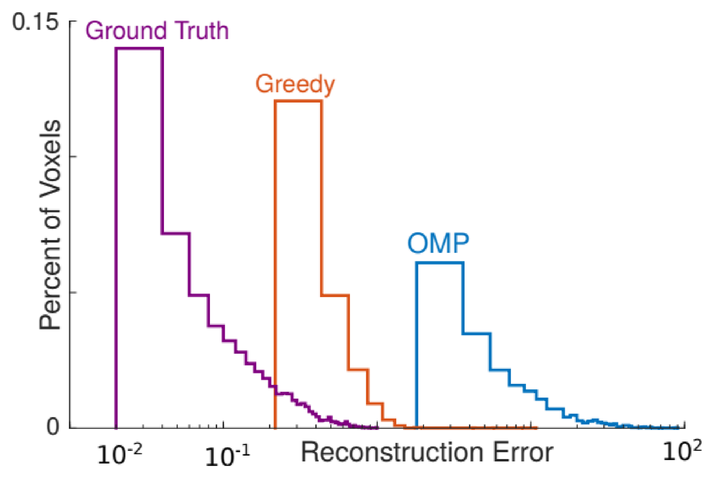
B. Screening: pdf of voxels' angular distance



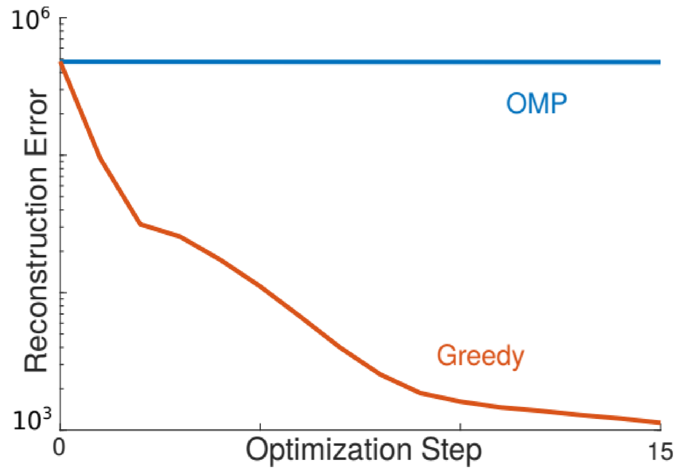
C. Screening: avg. angular distance by k



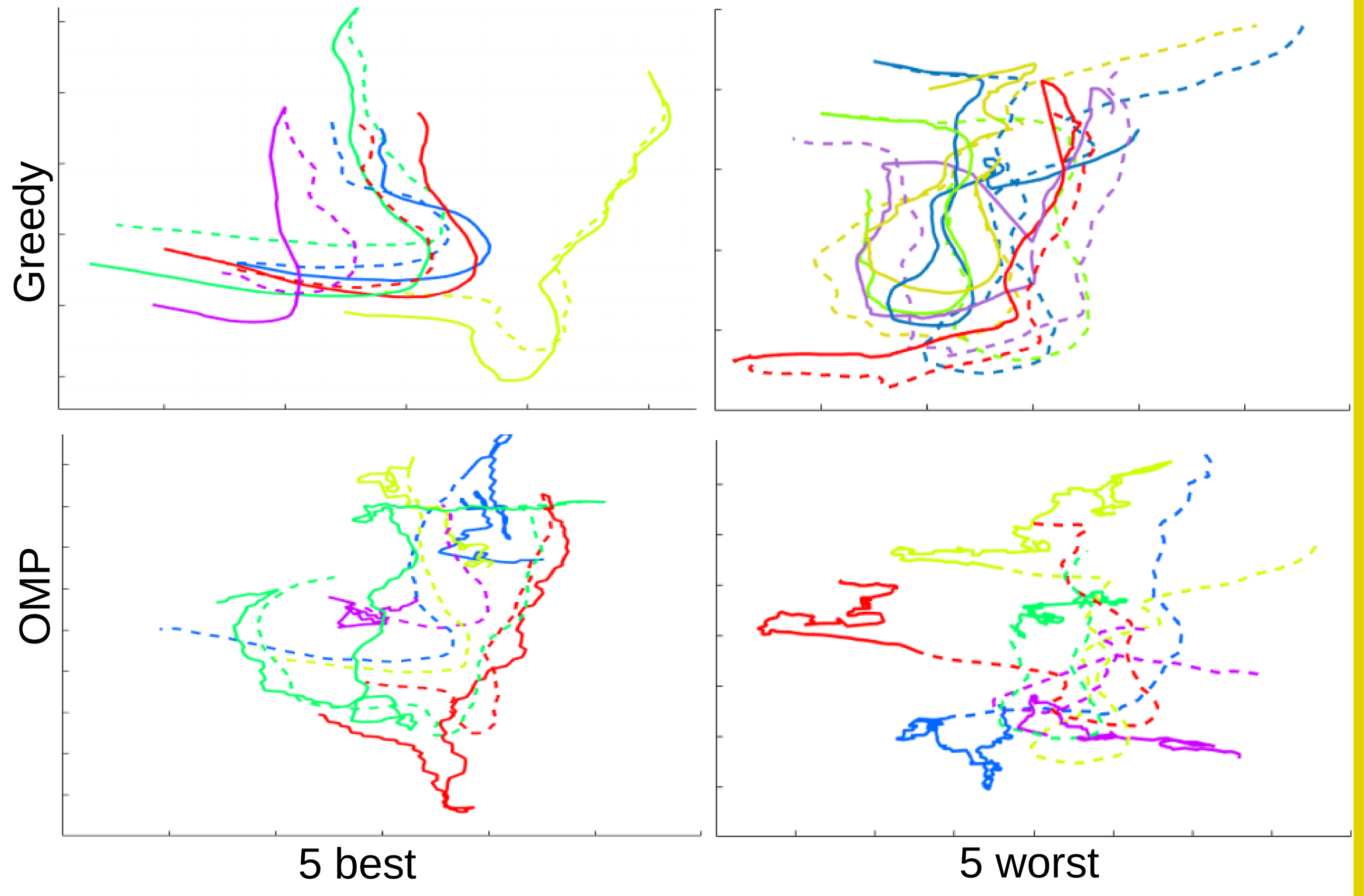
F. Optimization: visualization of Φ



D. Screening: pdf of reconstruction error



E. Screening: reconstruction error improvement



G. Optimization