Segmentation of Nerve Bundles and Ganglia in Spine MRI using Particle Filters

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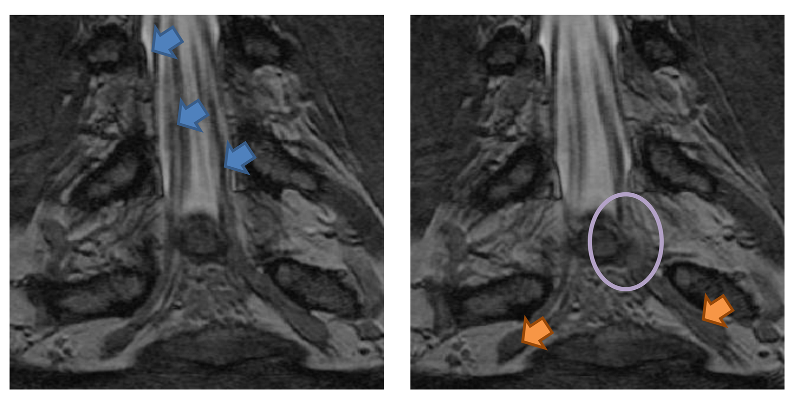
Background

Motivation

- New high-res MRI - visualization of **nerve bundles** from inside to outside of vertebral canal
- Segmentation of bundles useful for spinal pathologies - **diagnosis**, **treatment planning** and **image-guided interventions**
- Manual segmentation is **time-consuming & challenging** - impractical to construct nerve maps

GOAL: Provide an automatic segmentation method for nerve bundles and ganglia in spinal MRI.



MRI slices showing nerve bundle, pathology and ganglia

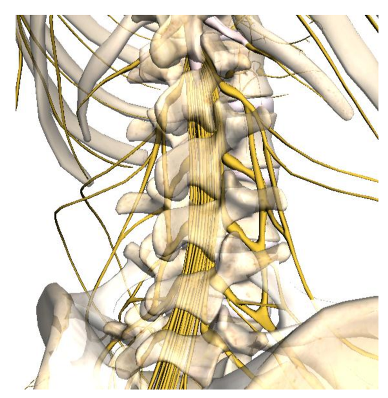


Illustration of nerve bundles (Google Body)

Related Work

Most relevant work is vessel segmentation. Assumptions and requirements differ from nerve data

- Region-growing approaches (problems: leakage, sensitive to contrast)
- Active contour methods (problems: good initialization, sensitive to leakage)
- Centerline extraction (problems: interactive re-seed, endpoints, sensitive to tissues)

Our Approach

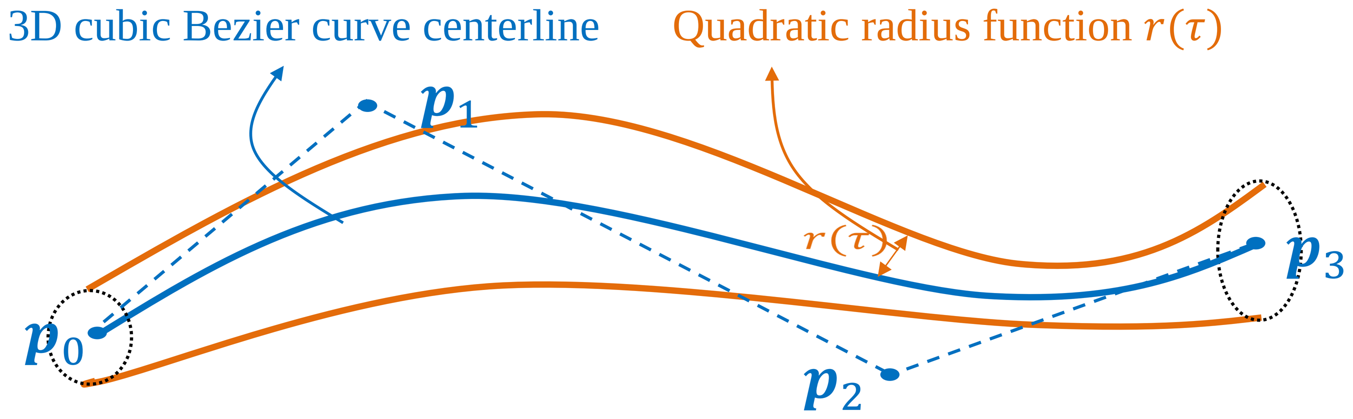
- Tracking approach based on **particle filters** with minimal input requirement

Representations

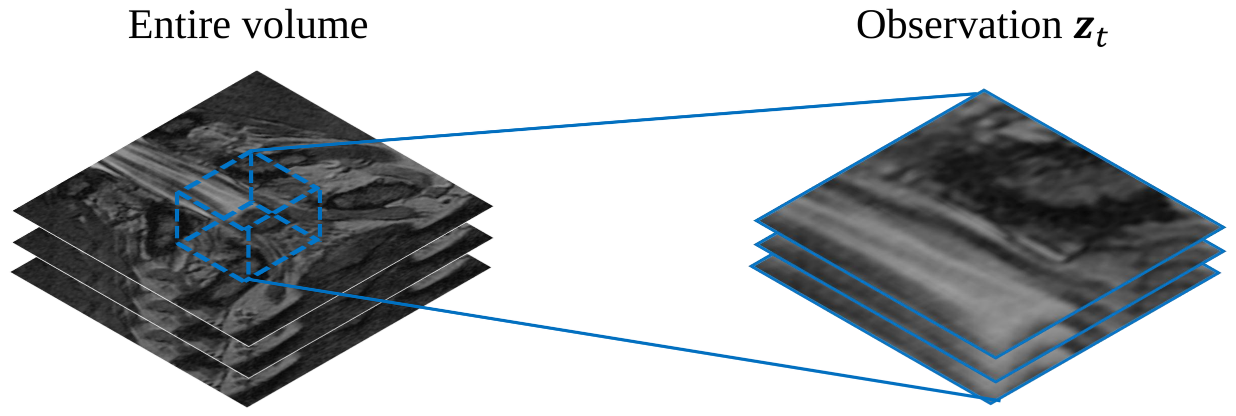
Nerve Segments - Particles

$$\boldsymbol{h} = (\underbrace{\boldsymbol{p}_0, \boldsymbol{p}_1, \boldsymbol{p}_2, \boldsymbol{p}_3}_{\text{3D cubic Bezier curve centerline}}, \underbrace{r_0, r_1, r_2}_{\text{Quadratic radius function } r(\tau)}, \mu)$$

intensity



Observation $\boldsymbol{z}_t$ at step t (in 3D)



Volume: 512x512x100 voxels
Voxel: 0.5x0.5x1.0mm

Particle: 15-30 voxels long x 2-15 voxels wide
Observation: particle length, 2x particle width

Algorithm

Initialization

Two manual clicks – generate a set of weighed particles approximating $p(\boldsymbol{h}_1|\boldsymbol{z}_1)$

For each successive step t:

Goal: obtain a particle set given observations $\boldsymbol{z}_{1:t}$ -- approximating posterior $p(\boldsymbol{h}_t|\boldsymbol{z}_{1:t})$

1. Sample particles from $p(\boldsymbol{h}_{t-1}|\boldsymbol{z}_{t-1})$

2. Propagate particles via **dynamics model** $p(\boldsymbol{h}_t|\boldsymbol{h}_{t-1})$
   - Require **continuity** and **smoothness** of centerline and radius
   - Encourage consistent nerve direction, thickness and intensity

3. Weigh particles based on observation via $p(\boldsymbol{z}_t|\boldsymbol{h}_t)$
   - $weight = p(\boldsymbol{z}_t|\boldsymbol{h}_t) \propto \exp\{-(d_\nabla^2 + \lambda d_\mu^2)\}$. (scale to sum to 1)

$$d_\mu^2 = \left[\mu_t - \frac{1}{|V|}\sum_{v\in V} I\right]^2$$ **intensity** distance over volume of particle V

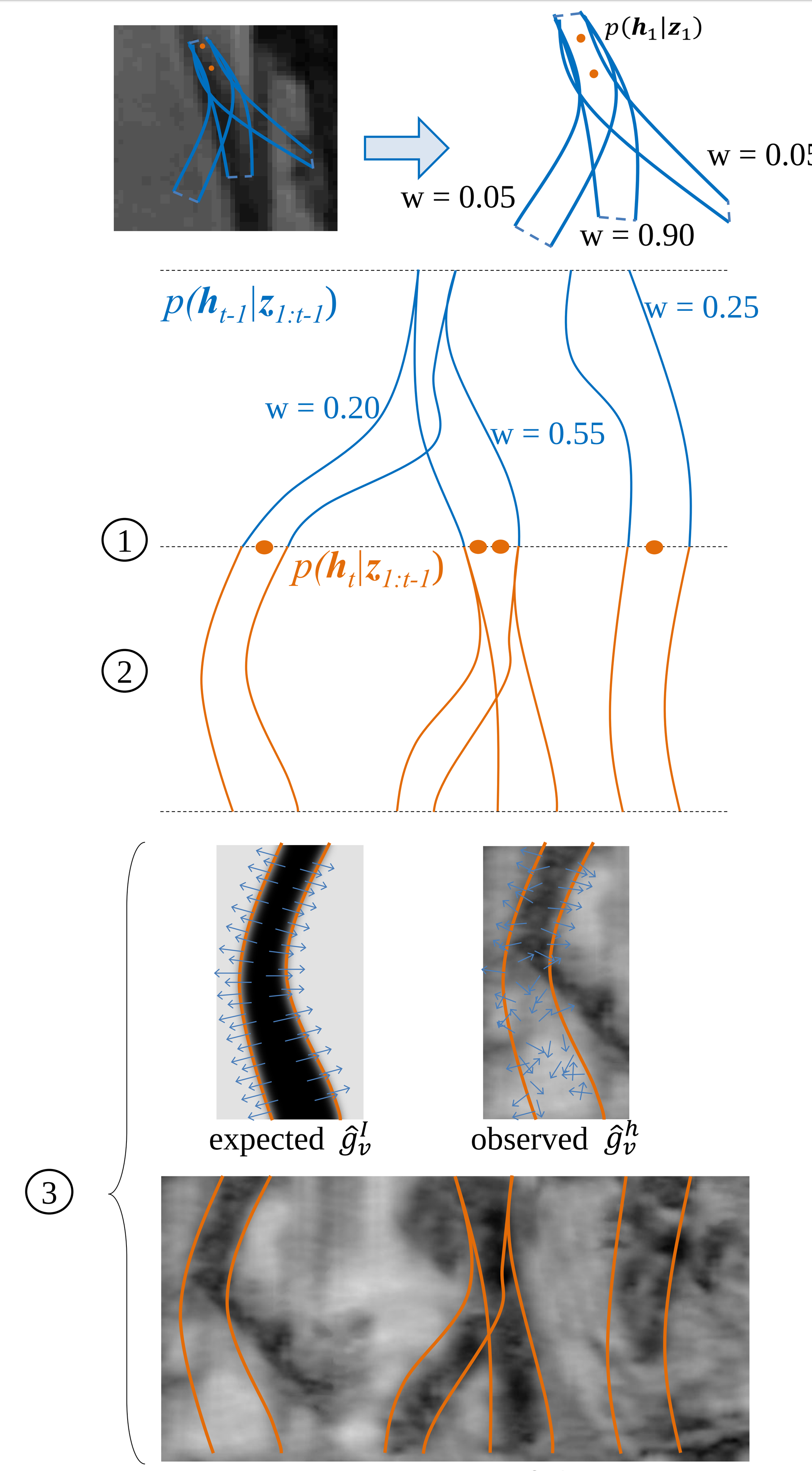
$$d_\nabla^2 = \frac{1}{|V|}\sum_{v\in V} ||\hat{g}_v^h \times \hat{g}_v^I||^2$$ **gradient** distance over volume of particle V

These steps form samples from the desired distribution:

$$\boldsymbol{h}_t \sim p(\boldsymbol{h}_t|\boldsymbol{z}_{1:t}) \propto \underbrace{p(\boldsymbol{z}_t|\boldsymbol{h}_t)}_{3} \sum_{\boldsymbol{h}_{t-1}} \underbrace{p(\boldsymbol{h}_t|\boldsymbol{h}_{t-1})}_{2} \underbrace{p(\boldsymbol{h}_{t-1}|\boldsymbol{z}_{1:t-1})}_{1}$$

Post-Processing clean-up

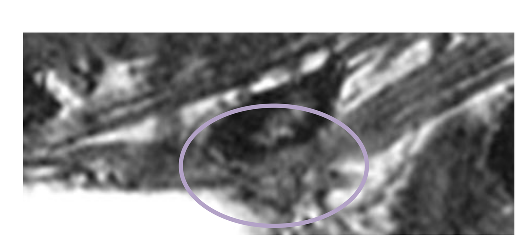
- Tracks that were not re-sampled until the end are eliminated
- Entire tracks are **re-weighed** with the scoring function (3)
- **Top tracks** are selected as final output

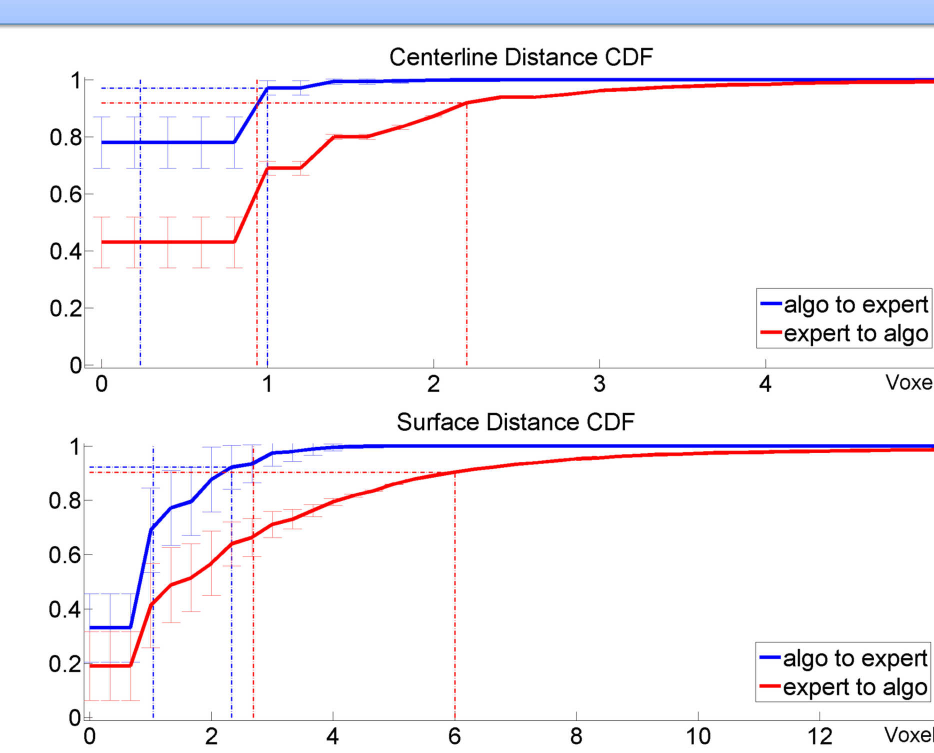


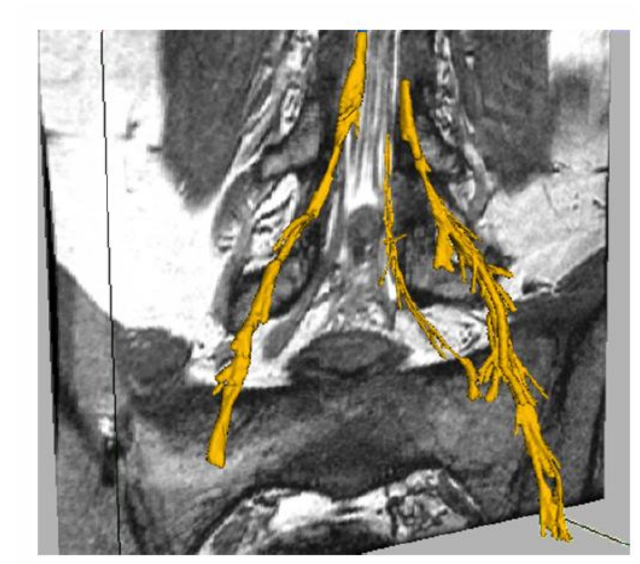
Results

CDFs of distances (voxels) between **automatic** and **manual** segmentations for centerlines & surfaces

- Ten nerve bundles from five subjects
- **Strong core and path estimation**
- Under-segmentation in thick ganglia. Expert segmentation surfaces have irregularities and pinching in thick areas







Conclusions

- Introduced **particle filter based tracking method** for nerve bundles in high-resolution spine MRI; minimal user input
  - Defined a **particle representation** for nerve segments & appropriate dynamics model
  - Described a **likelihood measure** based on gradient fields and nerve intensities
- Demonstrated **successful tracking** on spinal MRI dataset
- Further work: precise estimation of thickness and segmentation of peripheral nerves

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