Globally-Optimal Anatomical Tree Extraction from 3D Medical Images using Pictorial Structures and Minimal Paths

Zahra Mirikharaji, Mengliu Zhao, Ghassan Hamarneh

SFU SIMON FRASER UNIVERSITY ENGAGING THE WORLD

MIAL Medical Image Analysis Lab

Problem

- Extracting centerline of anatomical trees in 3D medical images

Goal

- Encode the geometrical and topological priors of trees
- Ensure a globally optimal tree extraction solution

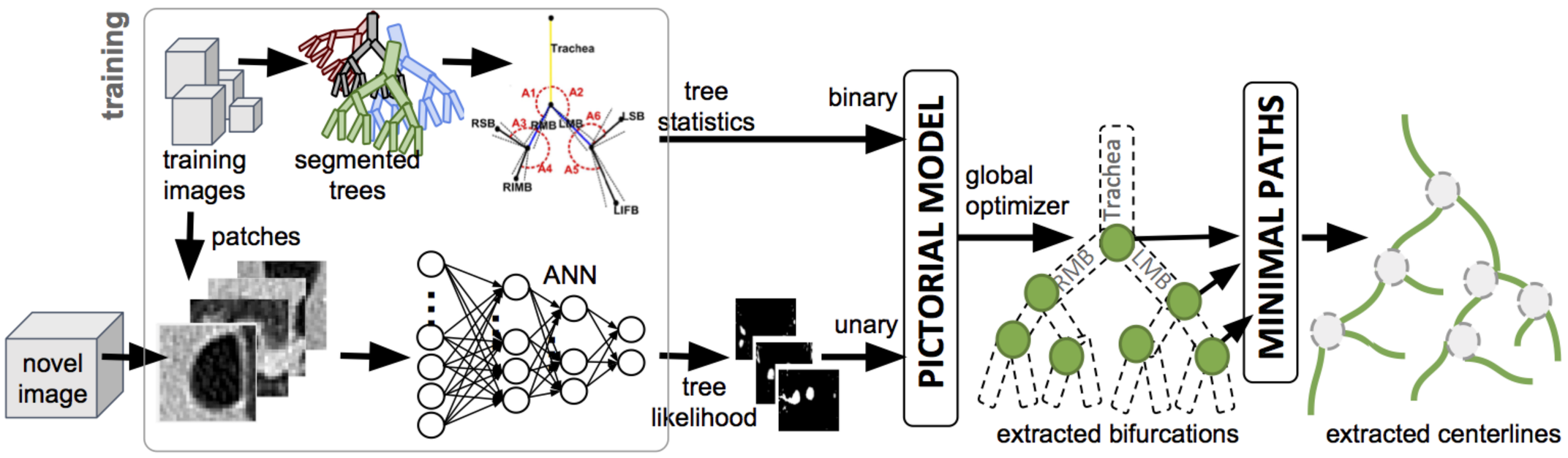
Pictorial Structure

$$\mathcal{L}^* = \underset{\mathcal{L}=\{\mathcal{L}_1,\ldots,\mathcal{L}_n\}}{\arg\min} \left(\sum_{i=1}^{n} \mathcal{U}(\mathcal{L}_i|\mathcal{I}) + \sum_{e_{ij}\in E} \mathcal{B}(\mathcal{L}_i,\mathcal{L}_j)\right)$$

$U(L_i|I)$: degree of mismatch for part V_i

$B(L_i, L_j)$:degree of deformation of the model when part V_i is at L_i and part V_j is at L_j

Methodology



- Pictorial node: 3D anatomical tree bifurcations
- Deformation cost: branch directions and lengths statistics

μ_{ij}: mean of displacement vectors
$\boldsymbol{\Sigma_{ij}}$: covariance matrix of displacement vectors

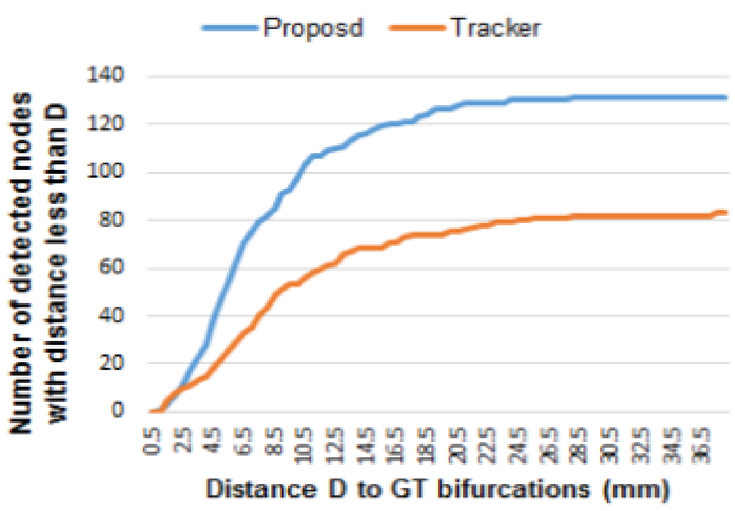
$$\mathcal{L}^* = \underset{\mathcal{L}=\{\mathcal{L}_1,\ldots,\mathcal{L}_n\}}{\arg\min} \underbrace{\left(\sum_{i=1}^{n} \mathcal{U}(\mathcal{L}_i|\mathcal{I})\right)}_{\text{Unary Term via an ANN}} + \underbrace{\sum_{e_{ij}\in E} \mathcal{B}(\mathcal{L}_i,\mathcal{L}_j)}_{\text{Binary Term from Geometrical Statistical Priors}}$$

$$\Sigma_{ij} = U'_{ij} M_{ij}^{-1} U_{ij} \qquad \mathcal{B}(\mathcal{L}_i,\mathcal{L}_j) = [T_{ij}(\mathcal{L}_i) - T_{ji}(\mathcal{L}_j)]' M_{ij}^{-1} [T_{ij}(\mathcal{L}_i) - T_{ji}(\mathcal{L}_j)]$$

$$T_{ij} = U'_{ij}(\mathcal{L}_i - \mu_{ij}) \qquad T_{ji} = U'_{ij}(\mathcal{L}_j)$$

Experimental Validation

Validation measures:
$\boldsymbol{N_D}$: number of detected bifurcations with distance less than D from the ground truth locations.
M: mean distance between the ground truth bifurcations and the corresponding closest detected bifurcations.
$\mu_{\boldsymbol{D}}$: the average distance between centerlines



Variation of N_D on real data for proposed method and Tracker

	Method	M (mm)	μ_D (mm)	bifurcation det./ path init.
A	Tracker [1]	9.41 ± 6.84	9.21 ± 9	manual for root seed only
B	OOF [2]	NR†	3.24 ± 1.68	manual bif. det.
C	Minimal path + ANN + DT	NR†	3.09 ± 1.5	manual bif. det.
D	Proposed (pict w/o stats + mininal path)	14.54 ± 16.54	4.87 ± 4.84	automatic
E	Proposed (pict with stats + minimal path)	8.39 ± 7.41	3.51 ± 2.4	automatic

†NR: Not reported since bifurcations are manually selected.

Performance of different methods on clinical data with measure M and μ_D. Distance unit in mm and values shown in format mean ± std.

SNR	∞ (noise-free)	10	5	3.3
M (voxel)	5.19 ± 3.30	5.29 ± 3.23	6.69 ± 11.29	7.83 ± 9.3

Effect of SNR on measure M for synthetic data (mean ± std)

References
[1] Macedo, et al.: A centerline-based estimator of vessel bifurcations in angiography images, SPIE Medical Imaging. (2013)
[2] Law, et al.: Three dimensional curvilinear structure detection using optimally oriented flux, ECCV (2008)

MICCAI Quebec City CONFERENCE 10.-14. SEPTEMBER 2017