Structure-Aware Image Segmentation with Homotopy Warping
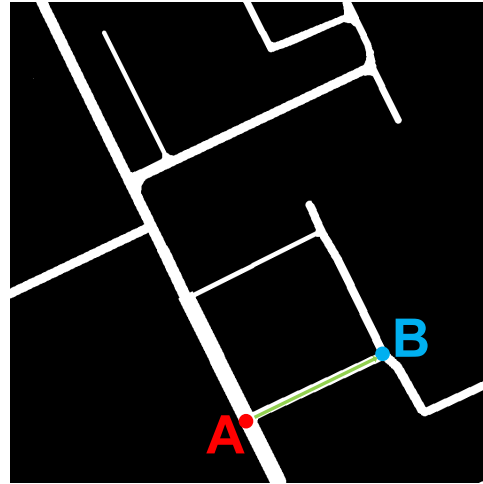
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Why topology-aware segmentation?
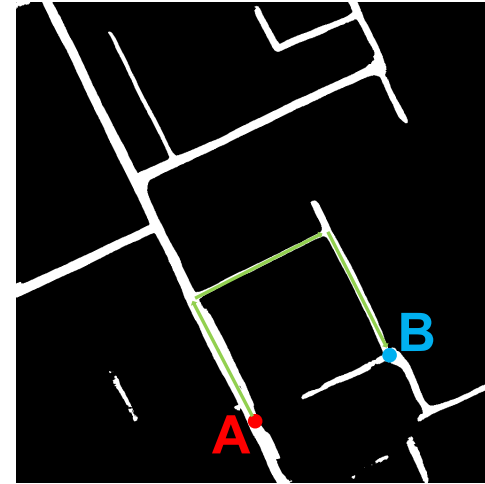
- Small pixel errors leads to topological errors
  - Road reconstruction -> incorrect navigation route

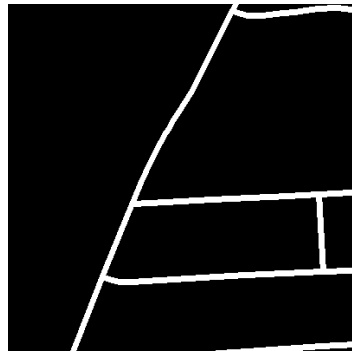**Input**

GT mask

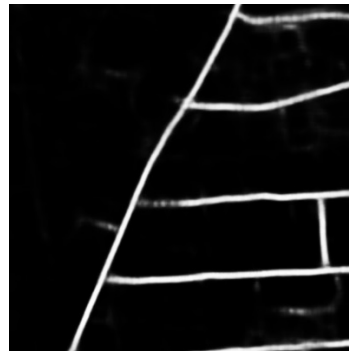**Unet prediction**

Why homotopy warping?

- Fix topological errors with persistent homology
    - [Hu et al. NeurIPS'19] – Topological loss by matching persistence diagram
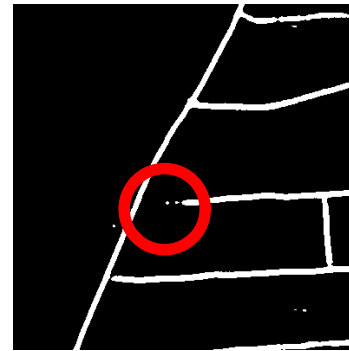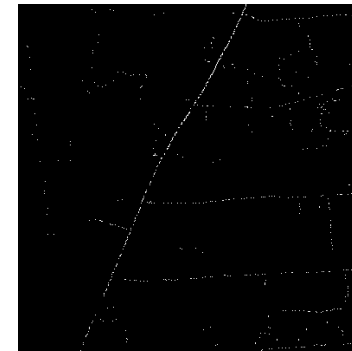   - Noisy and often not related topology

Input   **GT mask**   **Likelihood**   **Pred. mask**   **TopoNet**   **Warping**
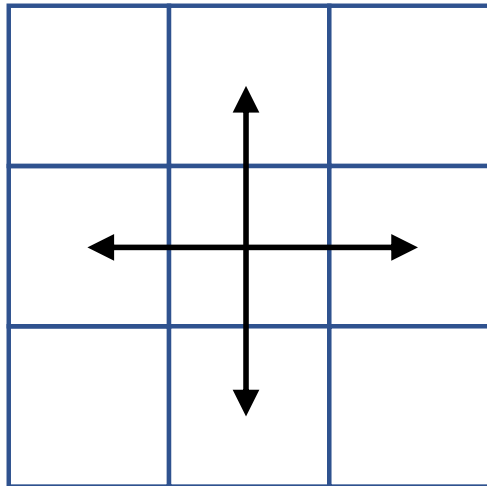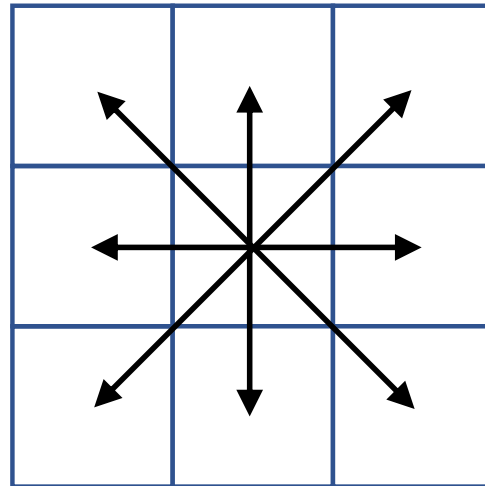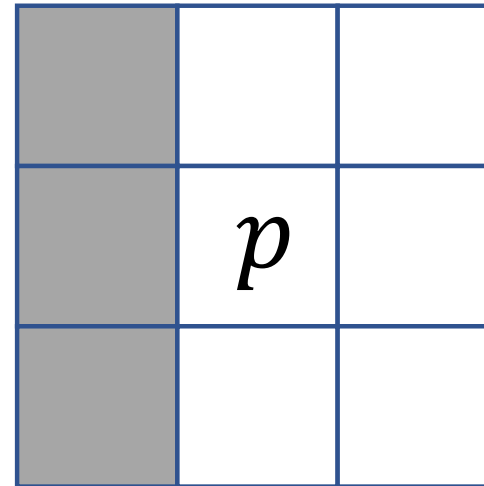
Simple points

- Flipping the label of p will not change the topology

4-adjacent   **8-adjacent**   **Simple Point**   **Non-simple Point**
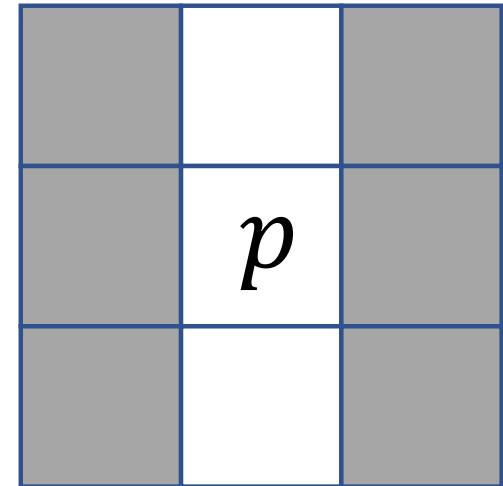
Homotopy warping: flip simple points

- Warping red mask towards the white
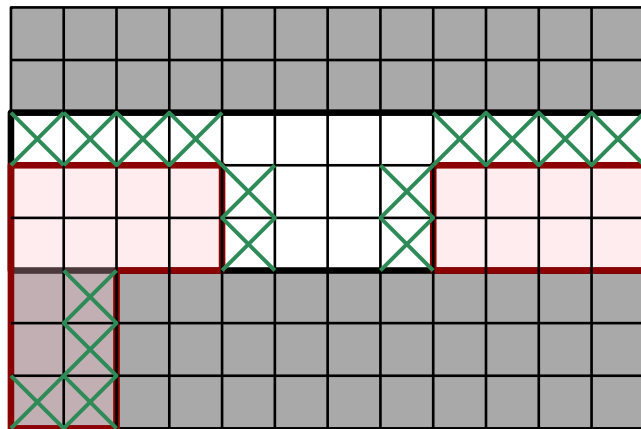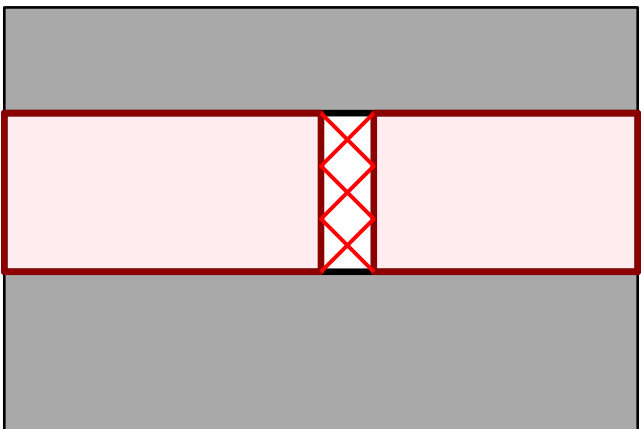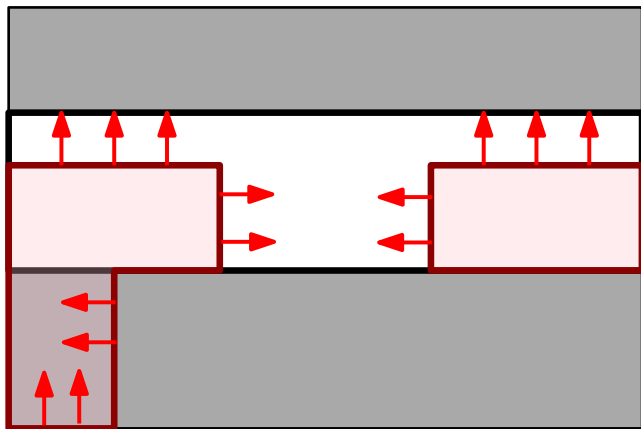
- Warping white mask towards the red
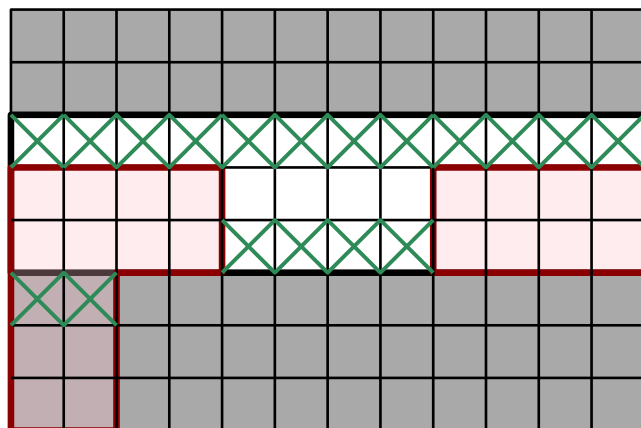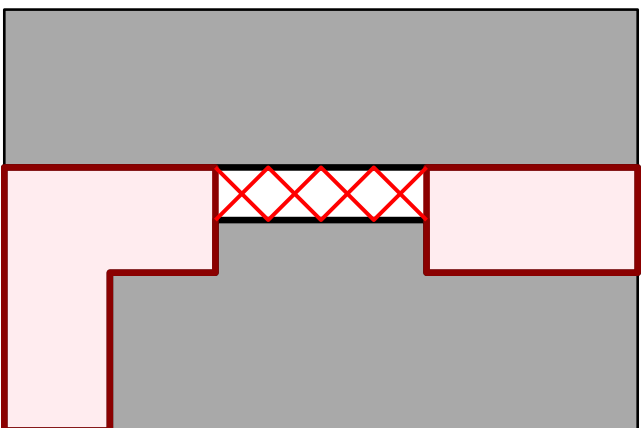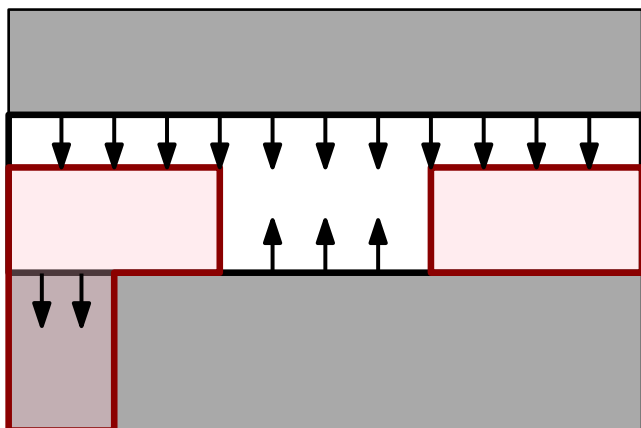
Warping example
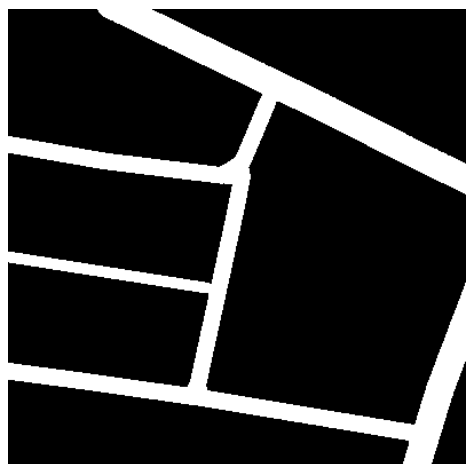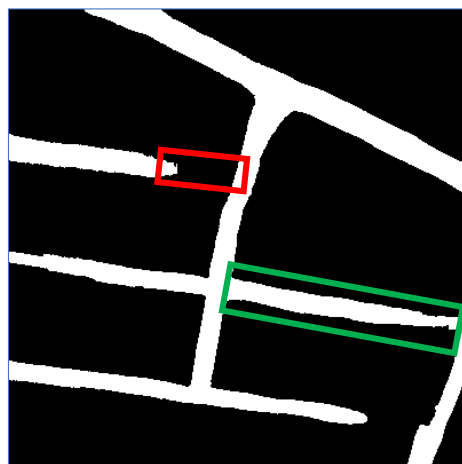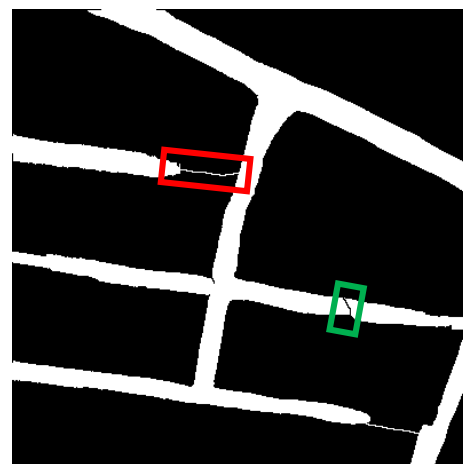
GT Prediction Warp GT Zoom-in Zoom-in

Homotopy warping loss

- Loss function – train the model to be topology-aware
  - Identity the critical points more efficiently

$$L_{warp} = L_{pixel}(f, g) \odot M$$

Input Image

U-Net

Predicted Mask

GT Mask

Homotopy Warping

Topological Critical Mask M

Qualitative results

(a) Original   (b) GT   (c) UNet   (d) Ours

Quantitative results

- DICE score, Betti number error, Adjusted Rand Index and Warping error

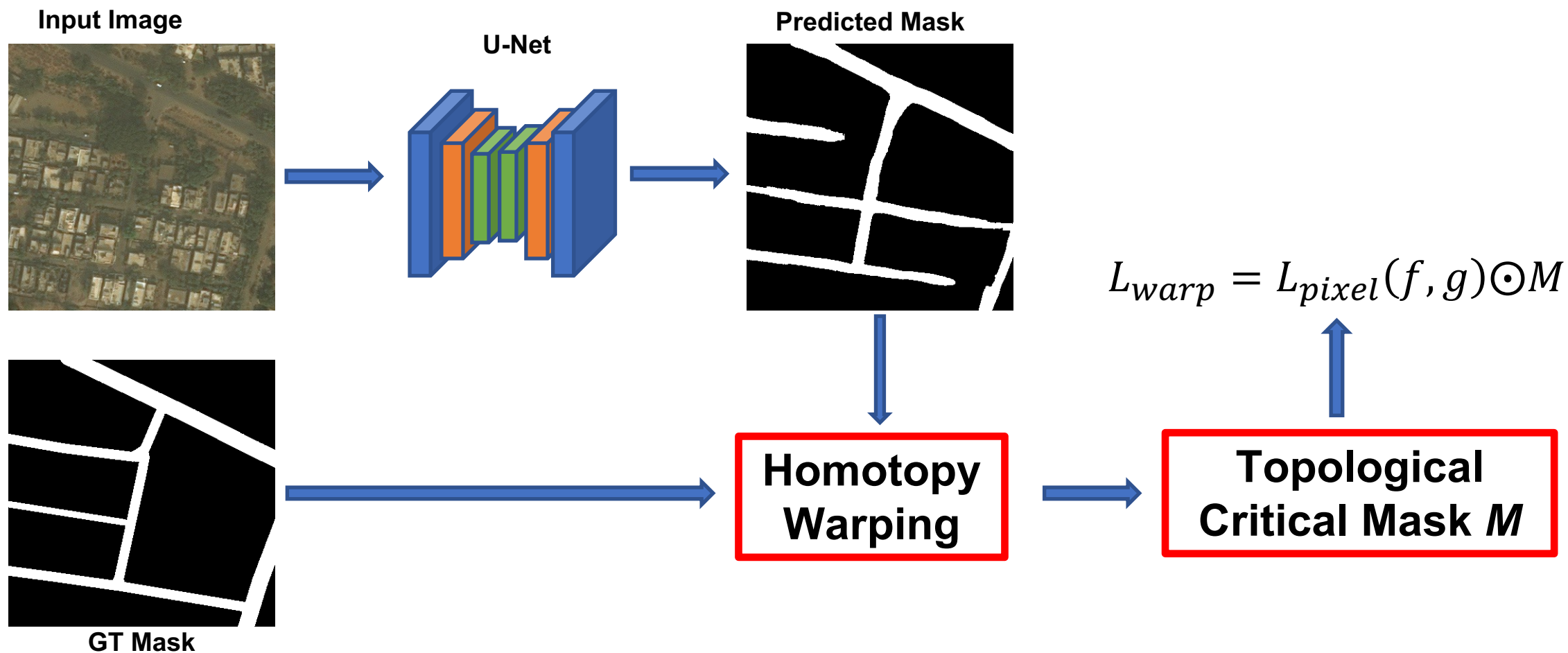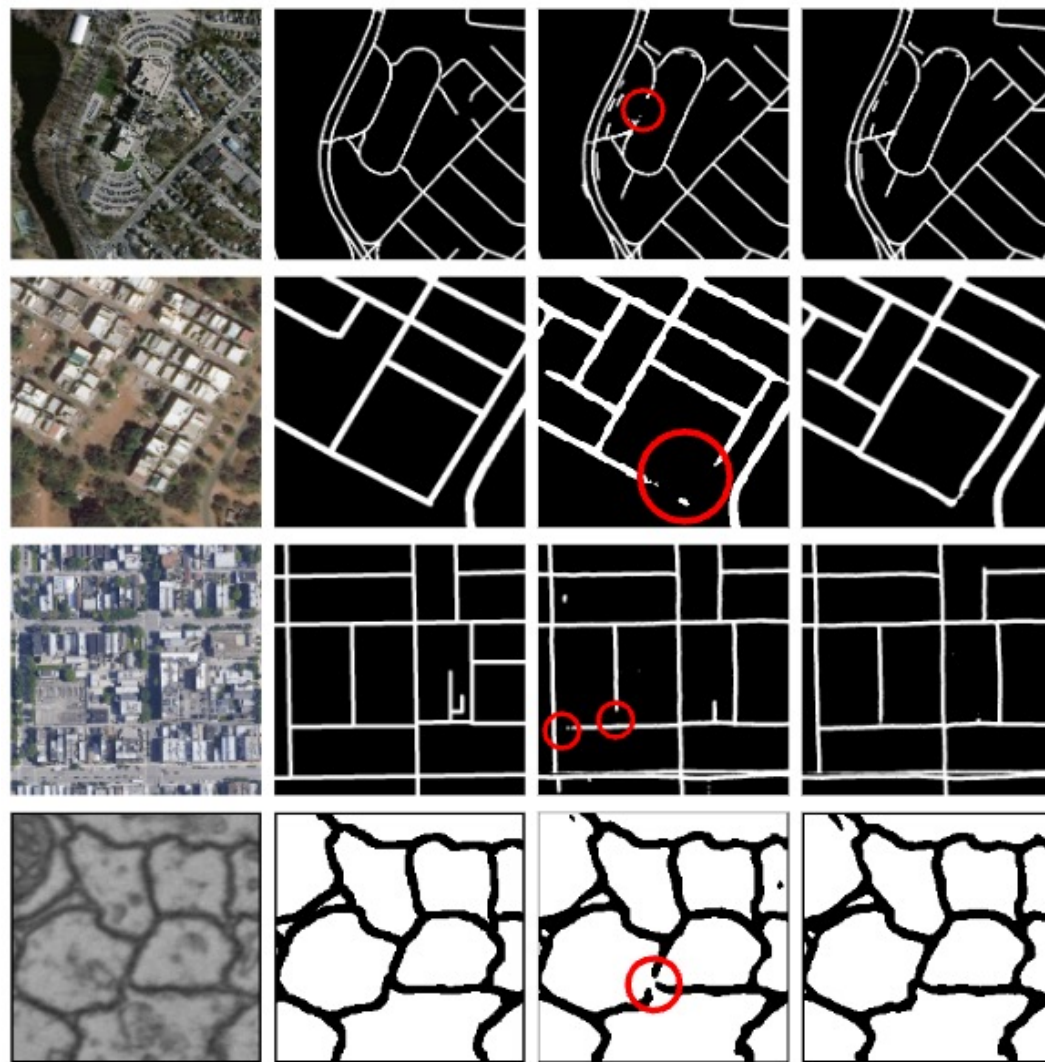| Method	DICE↑	ARI↑	Warping↓	Betti↓
RoadTracer				
UNet [41]	0.587	0.544	10.412×10^{-3}	1.591
RoadTracer [4]	0.547	0.521	13.224×10^{-3}	2.218
VecRoad [50]	0.552	0.533	12.819×10^{-3}	2.095
iCurb [54]	0.571	0.535	11.683×10^{-3}	1.873
VGG-UNet [36]	0.576	0.536	11.231×10^{-3}	1.607
TopoNet [25]	0.584	0.556	10.008×10^{-3}	1.378
clDice [44]	0.591	0.550	9.192×10^{-3}	1.309
DMT [26]	0.593	0.561	9.452×10^{-3}	1.419
Warping	**0.603**	**0.572**	$\mathbf{8.853} \times 10^{-3}$	**1.251**
DeepGlobe				
UNet [41]	0.764	0.758	3.212×10^{-3}	0.827
VGG-UNet [36]	0.742	0.748	3.371×10^{-3}	0.867
TopoNet [25]	0.765	0.763	2.908×10^{-3}	0.695
clDice [44]	0.771	0.767	2.874×10^{-3}	0.711
DMT [26]	0.769	0.772	2.751×10^{-3}	0.609
Warping	**0.780**	**0.784**	$\mathbf{2.683} \times 10^{-3}$	**0.569**

Conclusions

- Homotopy warping loss identifies critical points that are relevant to image topology

- Propose Distance-Ordered Homotopy Warping strategy

- Works for both 2D and 3D images with rich structures

Thank you for your attention!

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