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FÉDÉRALE DE LAUSANNE

From Neurons to Roads: Detection of Curvilinear Structures in Images

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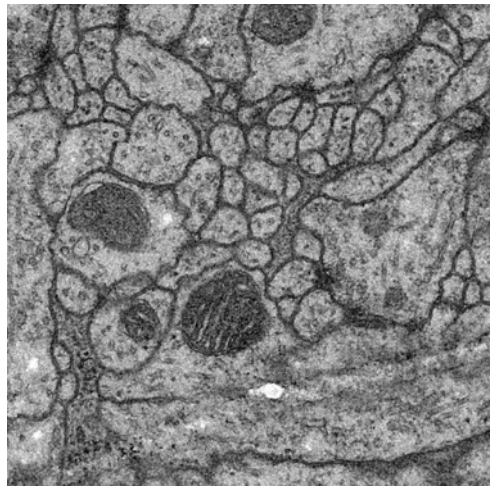
Linear Structures

~1nm

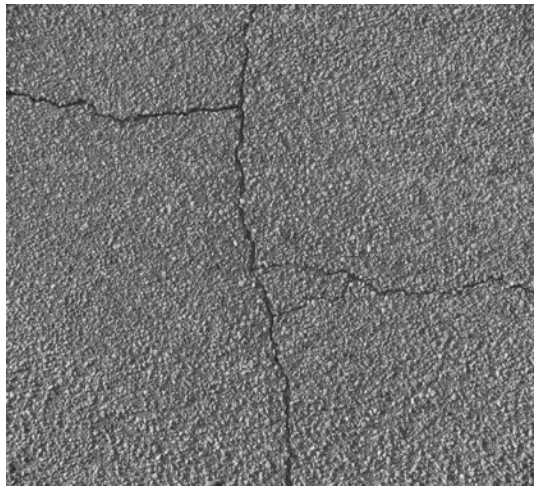


Neuronal membranes

~1mm

Blood vessels

~10cm



Cracks

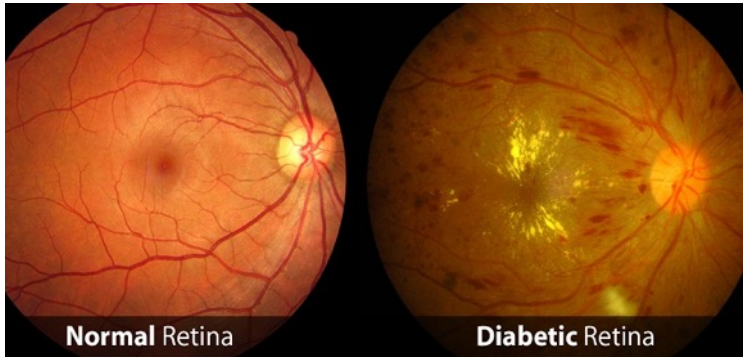
~10km

Roads

Motivation

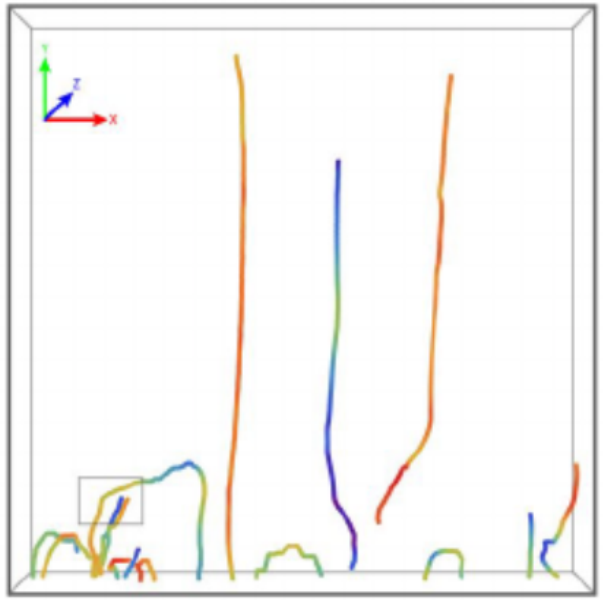
Brain connectivity

Diagnostics



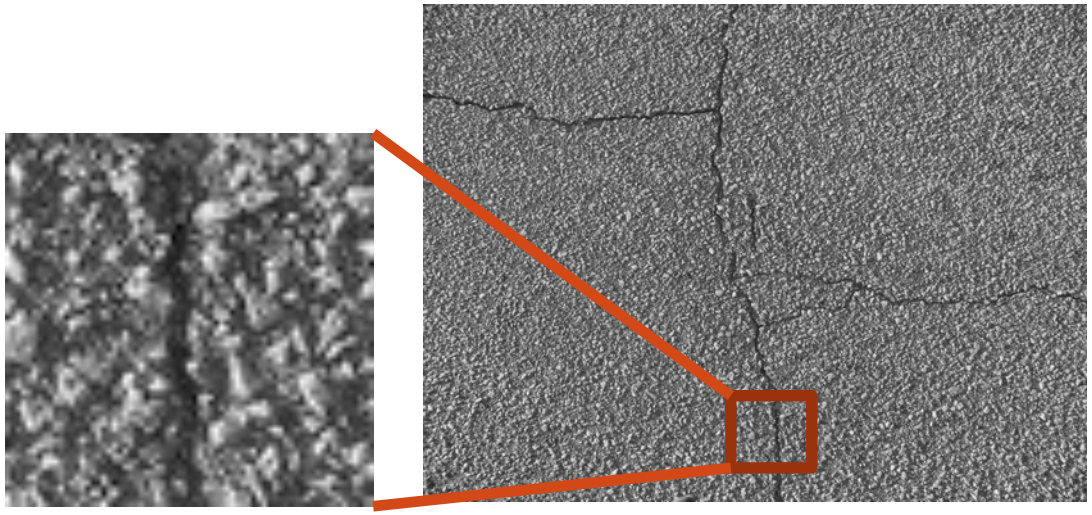
Autonomous driving

Material properties



Challenges

Requires large context



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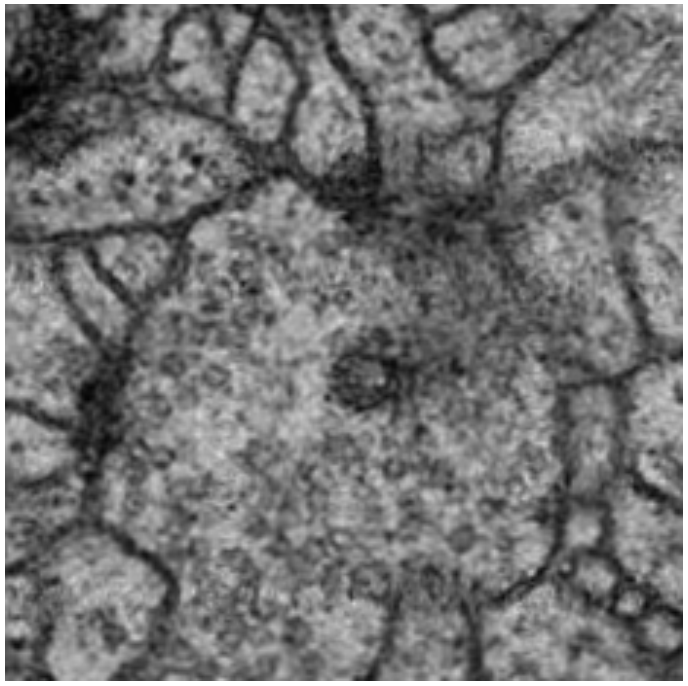
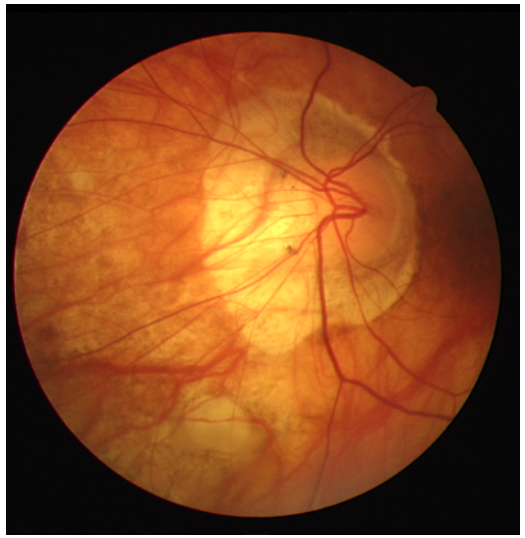
Challenges

Occlusions and noise

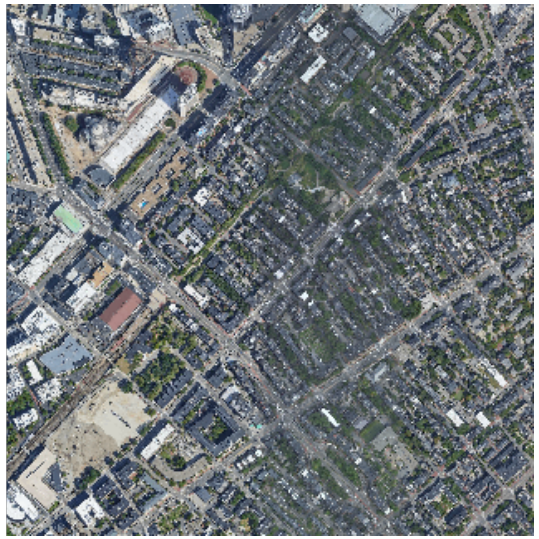


Challenges

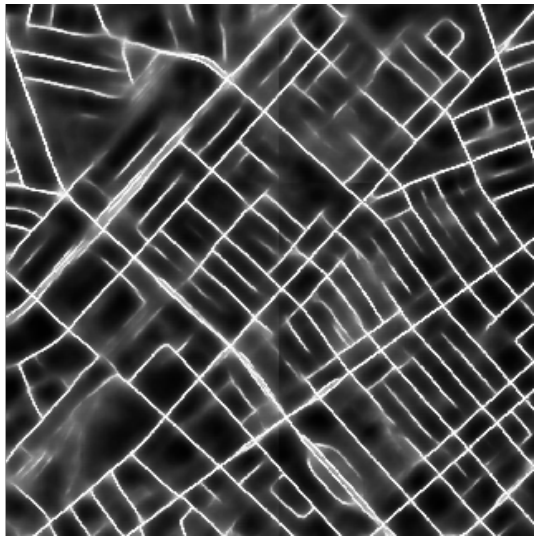
Variability of appearances, presence of other linear structures



Detection Pipeline



Image

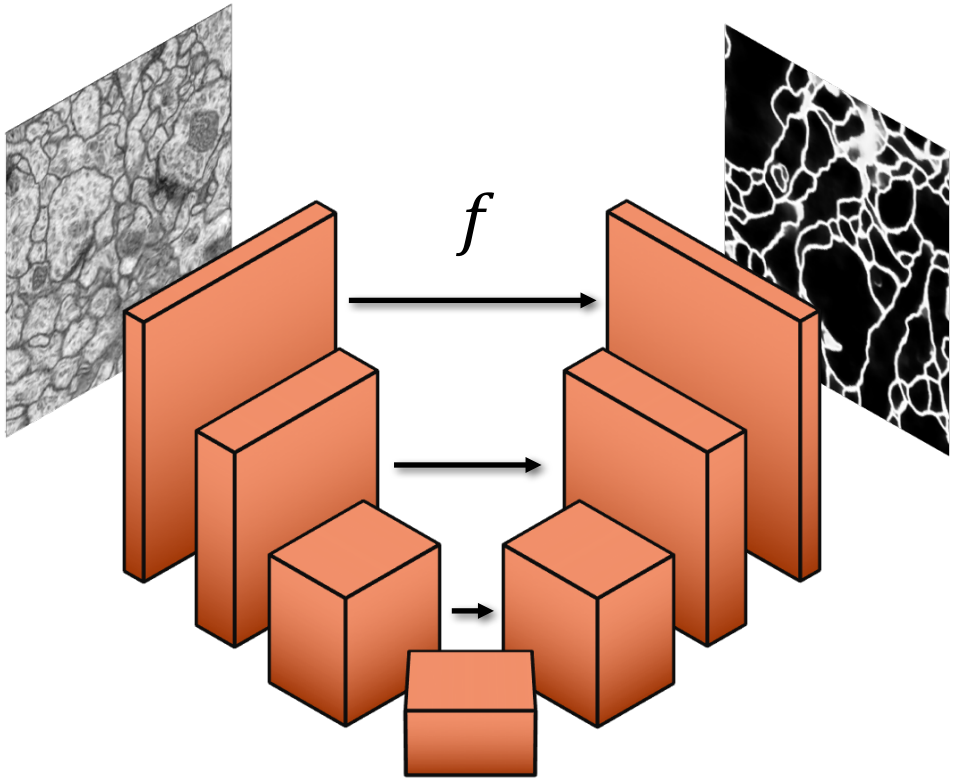


Segmentation

Final Graph

Current Approach – Pixelwise Loss

Encoder-decoder architecture trained using binary cross-entropy

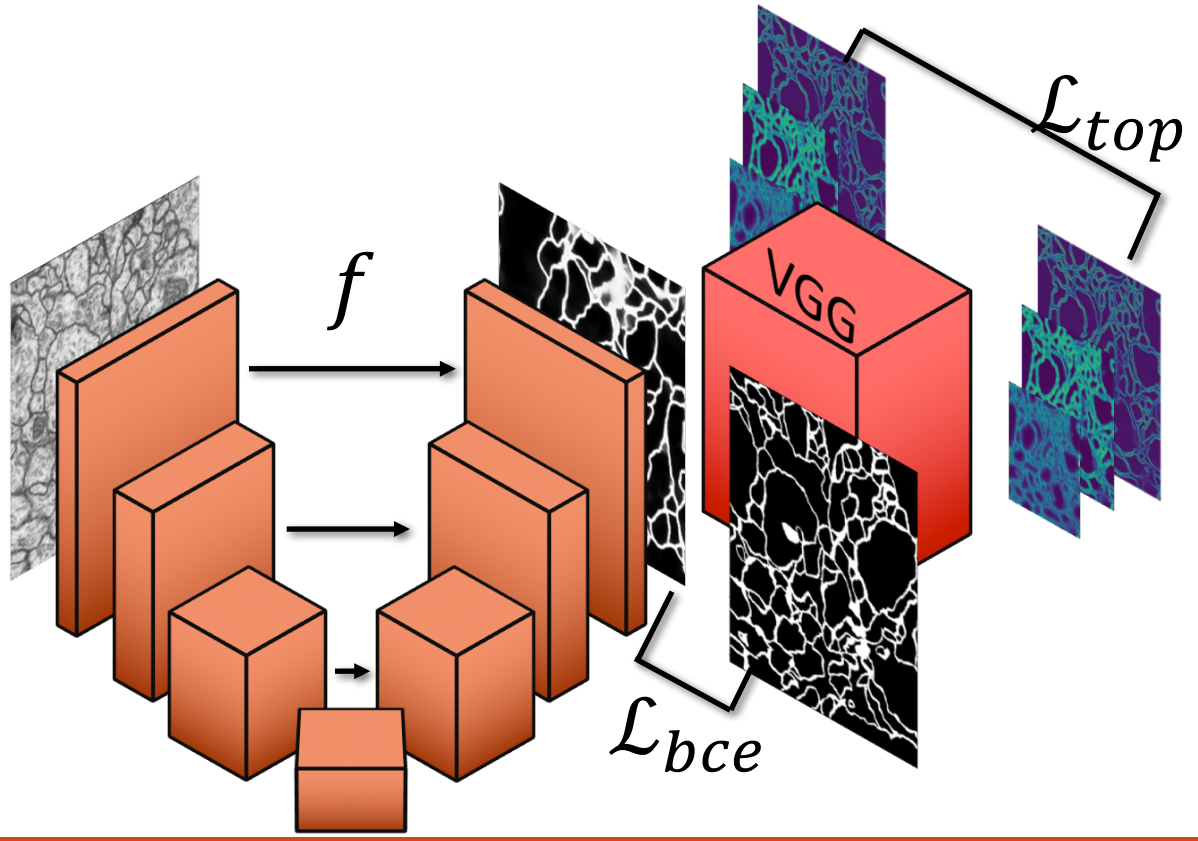


$$\mathcal{L}_{bce}(\mathbf{x}, \mathbf{y}, \mathbf{w}) = -\sum_i [(1 - \mathbf{y}_i) \cdot \log(1 - f_i(\mathbf{x}, \mathbf{w})) + \mathbf{y}_i \cdot \log f_i(\mathbf{x}, \mathbf{w})] .$$

$\mathbf{x}$ – input patch
$\mathbf{y}$ – ground truth
f – function parametrized by $\mathbf{w}$

Topology Loss

Train using direct pixel-wise loss and topology loss that captures higher-level features



$$\mathcal{L}_{top} = \sum_{n=1}^{N} \frac{1}{M_n W_n H_n} \sum_{m=1}^{M} \left(l_n^m(\boldsymbol{y}) - l_n^m\left(f(\boldsymbol{x}, \boldsymbol{w})\right)\right)^2$$

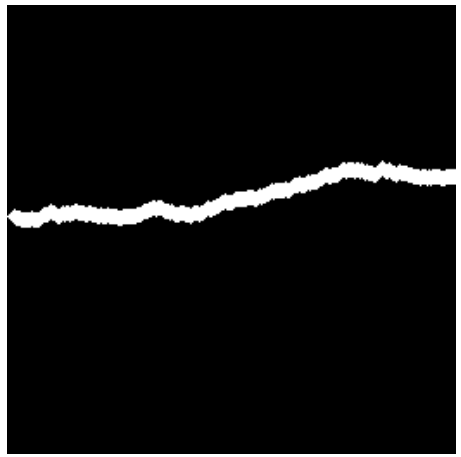
l_n^m – nth channel of mth layer of a pretrained VGG

$$\mathcal{L} = \mathcal{L}_{bce} + \mu \mathcal{L}_{top}$$

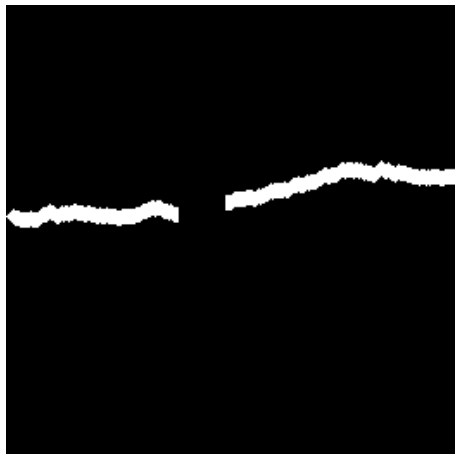
Mosinska et al., CVPR 2018

Pixelwise vs. Topology Loss

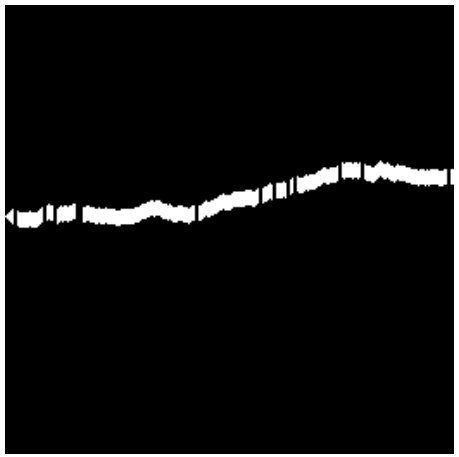
Binary cross entropy is the same in every case, but topology loss differentiates between mistakes depending on how much they alter the geometry.



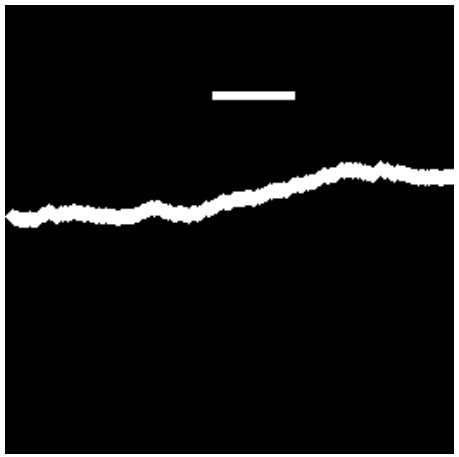
Ground truth



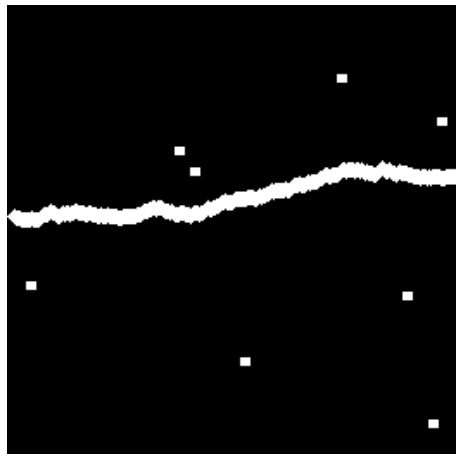
$\mathcal{L}_{top} = 0.2858$



$\mathcal{L}_{top} = 0.9979$



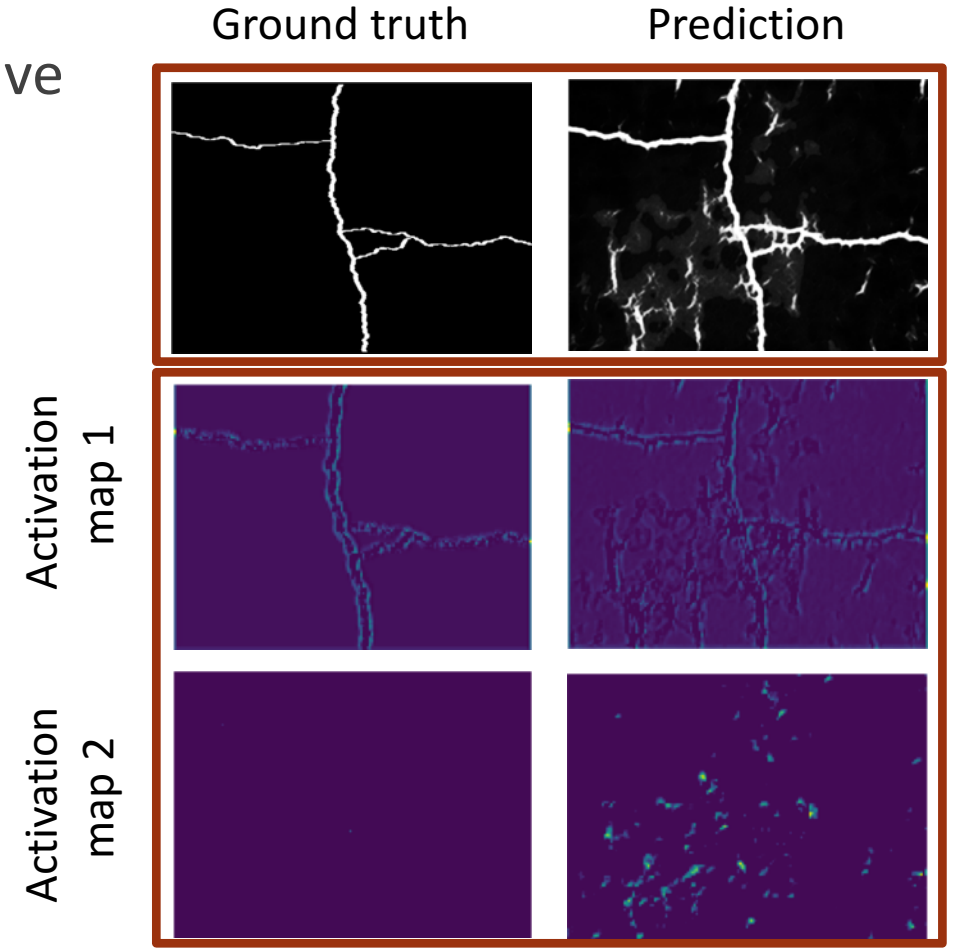
$\mathcal{L}_{top} = 0.2279$



$\mathcal{L}_{top} = 0.7795$

Activations

- Different filters are scale- and orientation-selective
- Some respond to long, smooth lines, while the others are activated by small background noise



Relation to Perceptual Loss

- Perceptual loss measures perceptual similarity between the original and generated images
- Unlike in our application there is no defined ground truth for style transfer
- Pre-trained VGG is applied here to natural images rather than binary masks

Content

Style

Style-transferred image

Results

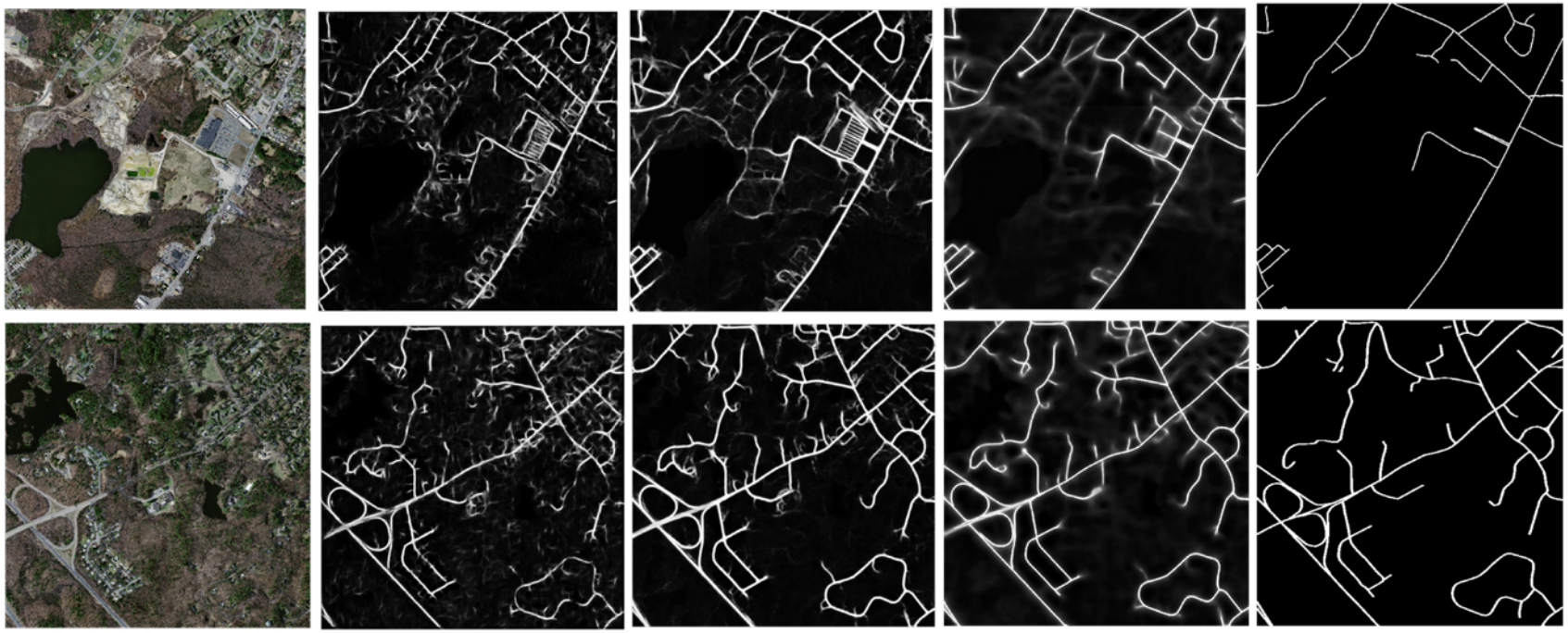


Image | Mnih | BCE Loss | BCE and Topo Loss | Ground truth

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Results

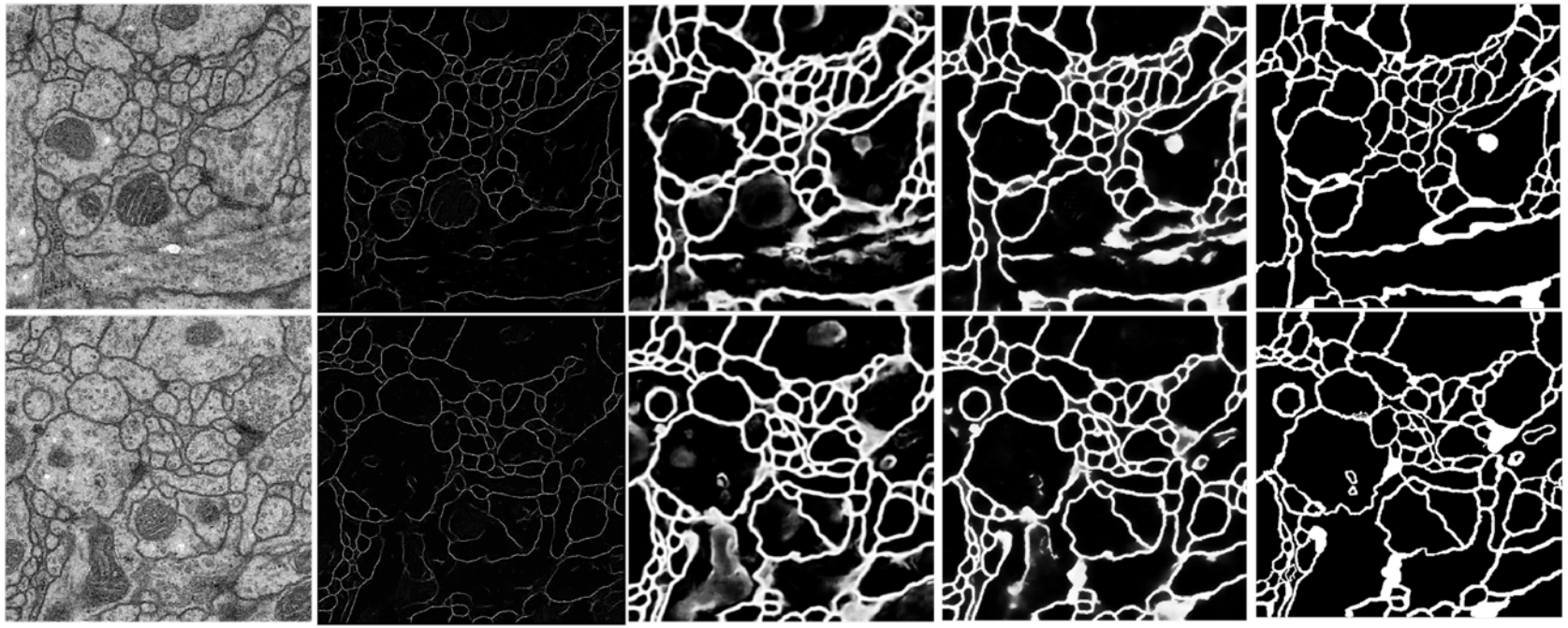
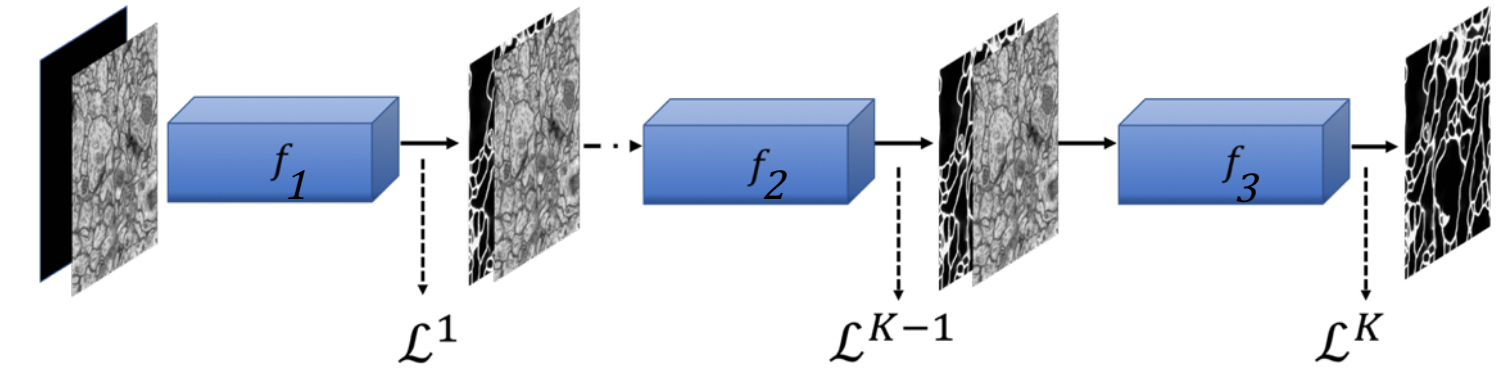


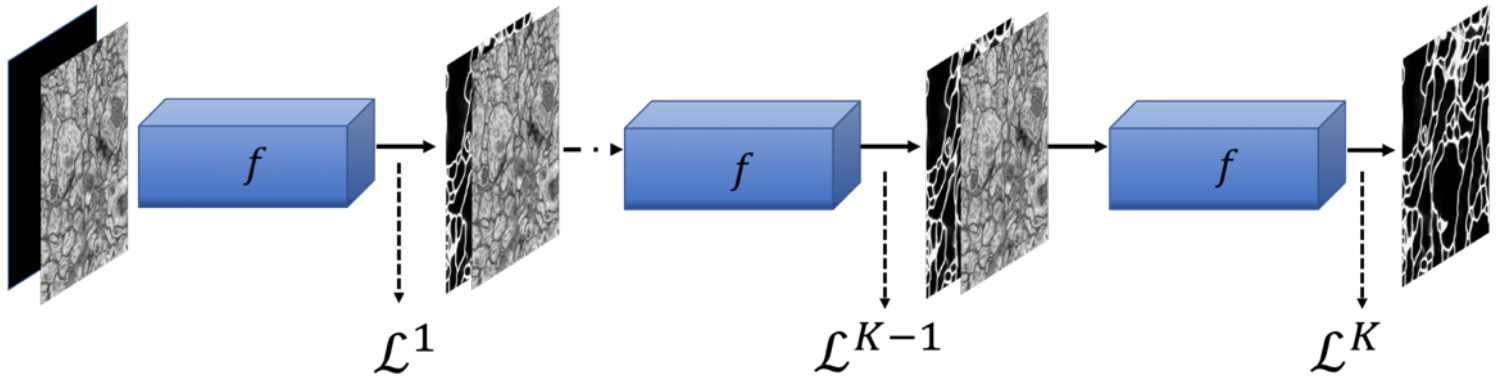
Image | RegAC | BCE Loss | BCE and Topo Loss | Ground truth

Recursive Refinement

- Use the same network to progressively refine the results keeping the number of parameters constant



VS.



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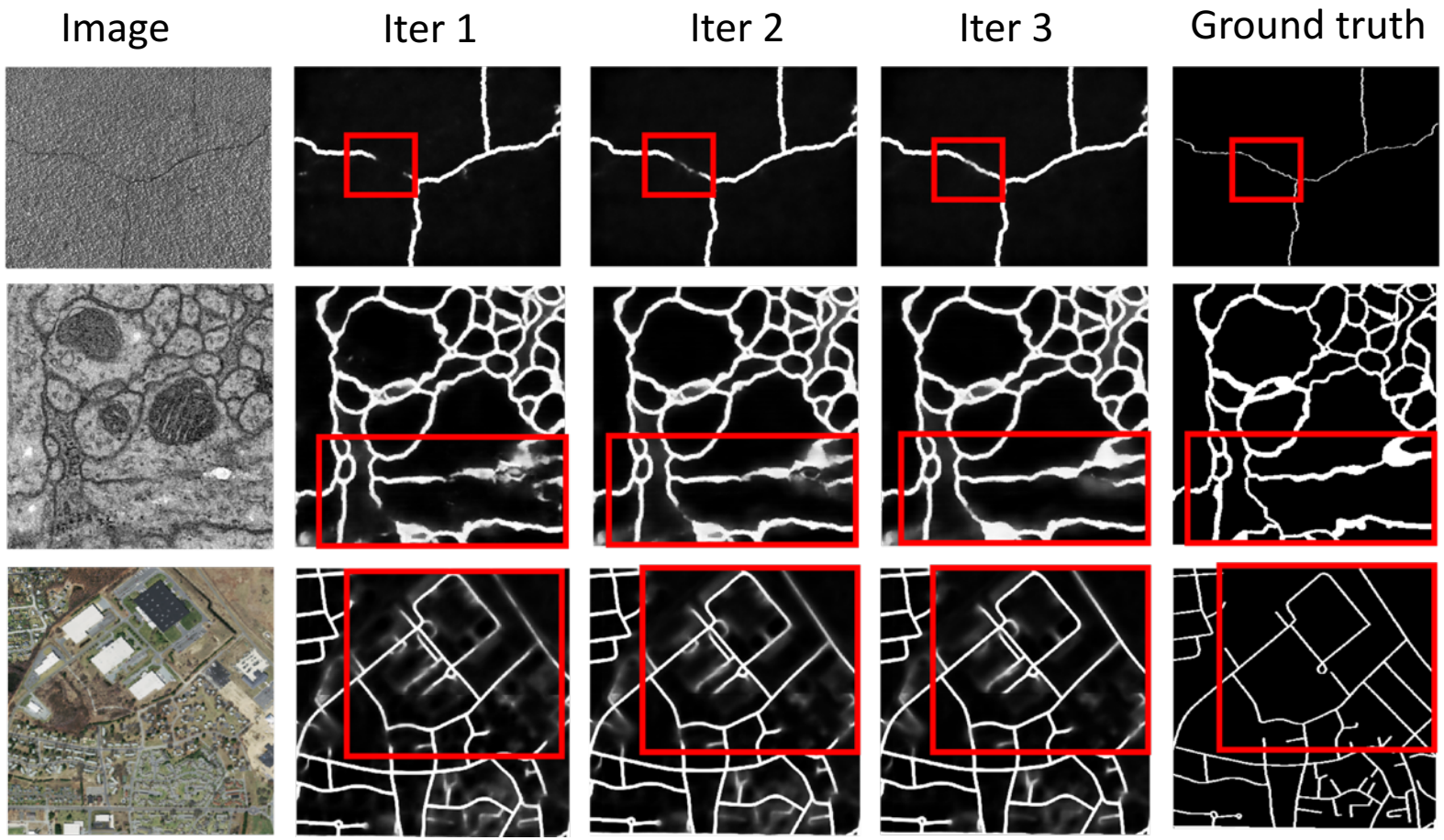
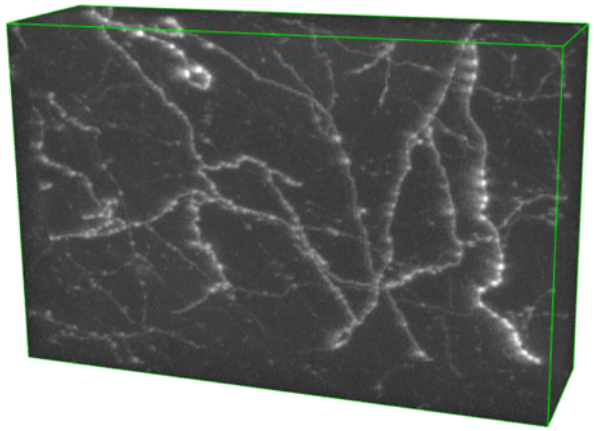
Results

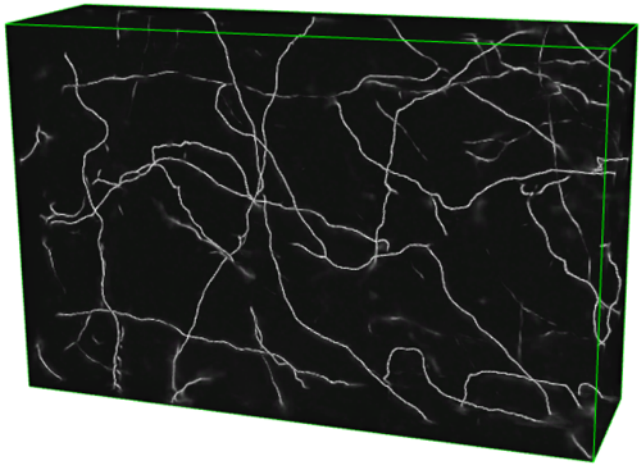


Inferring Connectivity

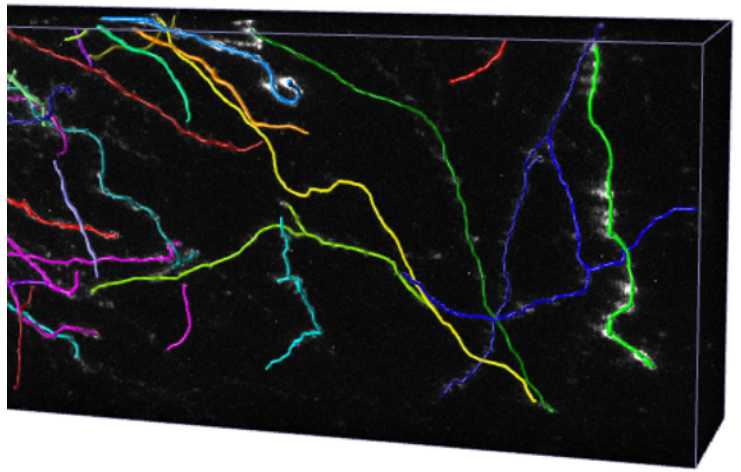
Image



Segmentation



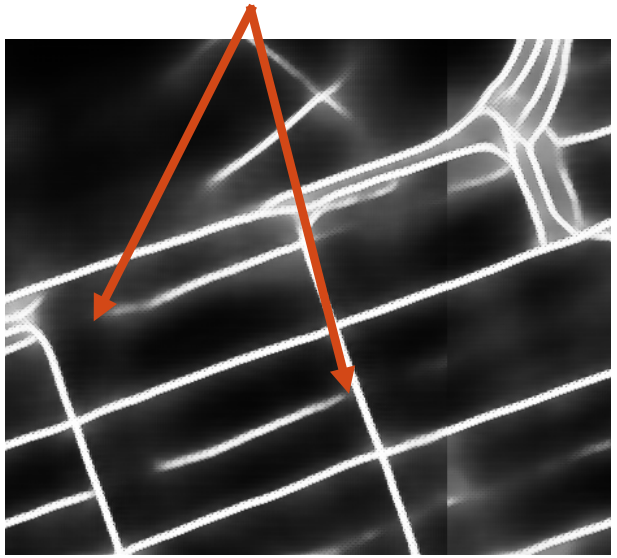
Graph



Inferring Connectivity

- Segmentation may still contain some mistakes – gaps or redundant predictions.
- It is not enough just to threshold it.

Should those road segments be connected?



How are those neurons connected?

- We need to infer long-range relationships between the detected segments to recover the connectivity.

Path Classification

- Sample possible paths from the segmentation.
- For every candidate path extract HOG-like features that describe its curvature and neighbourhood.
- Train a classifier to assign probability to every path.
- The result is a weighted graph where weight is the cost of keeping path in the final solution

Negative paths

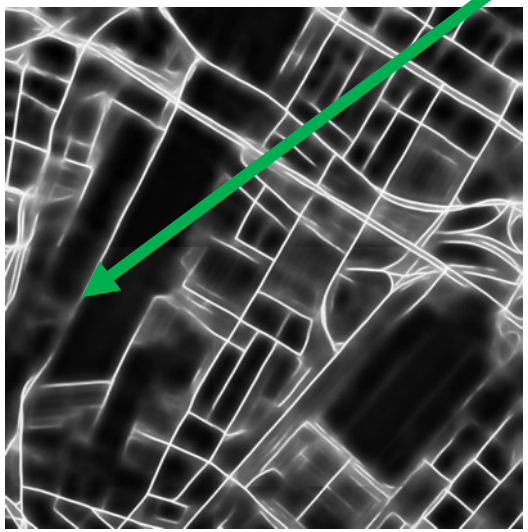
Positive paths

Turetken et al., PAMI 2014

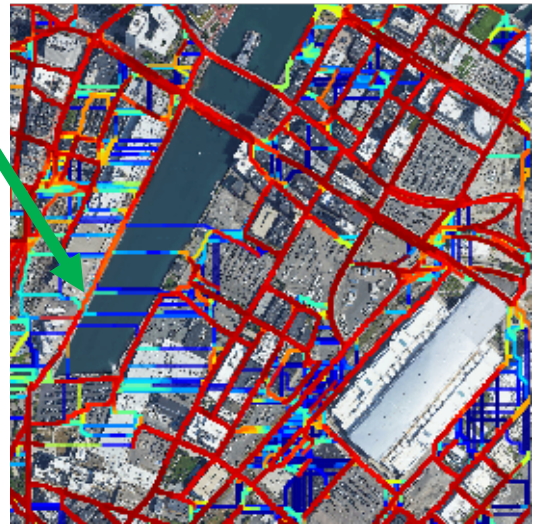
Path Classification

Corrected road fragment

Image



Segmentation



Sampled paths with overlaid probabilities

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Mixed Integer Program

In order to ensure connectivity and other constraints:

- Every path treated as a binary variable:
  - ”1” – leave in the solution
  - “0” – discard it

- Find minimum cost subgraph subject to constraints:
  - Allow/disallow loops
  - Conservation of flow
  - Connection to the root

Turetken et al., PAMI 2014

From Segmentation to Large-scale Reconstruction

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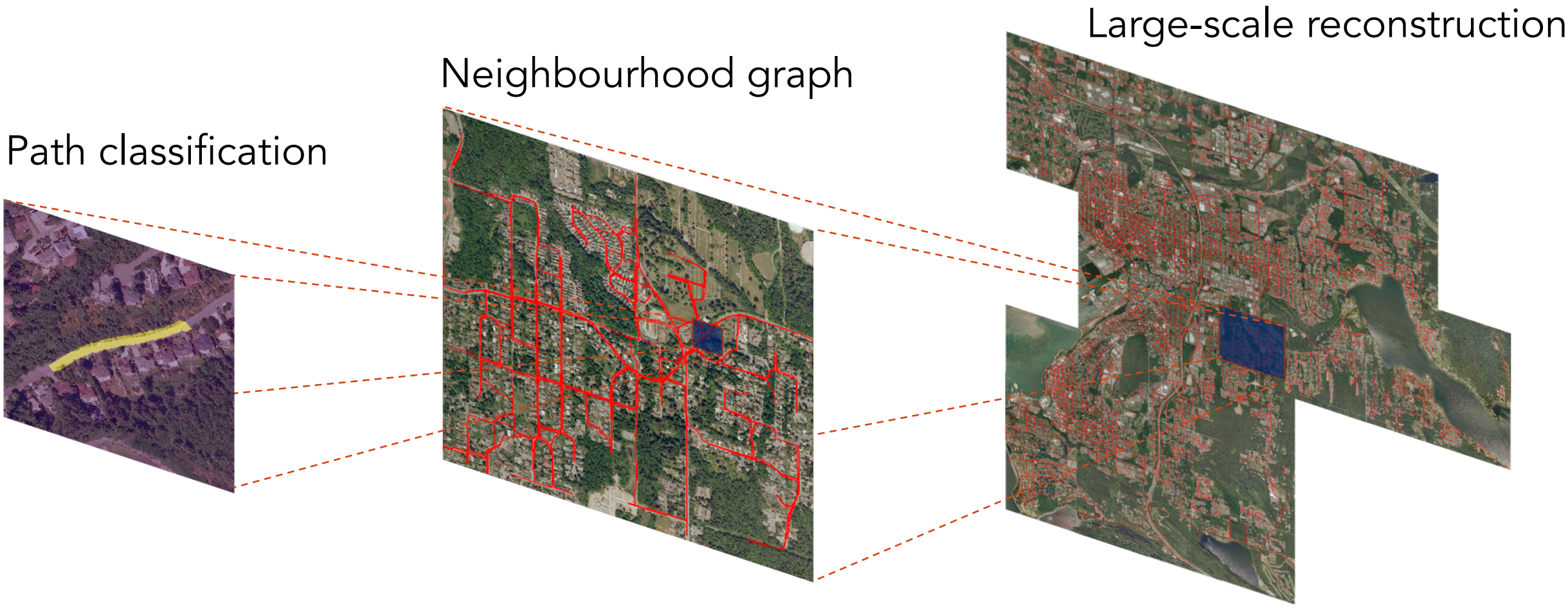

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Conclusion

- Investigating larger context and higher-level features of linear structures is essential for effective delineation
- Topology quality can be approximated by the features extracted using a pre-trained VGG.
- By reasoning about the long-range interactions between linear segments we can recover full connectivity of curvilinear structures.

Thank you for attention

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