

SYMPOSIUM ON GEOMETRY PROCESSING 2021



TORONTO ONTARIO



Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

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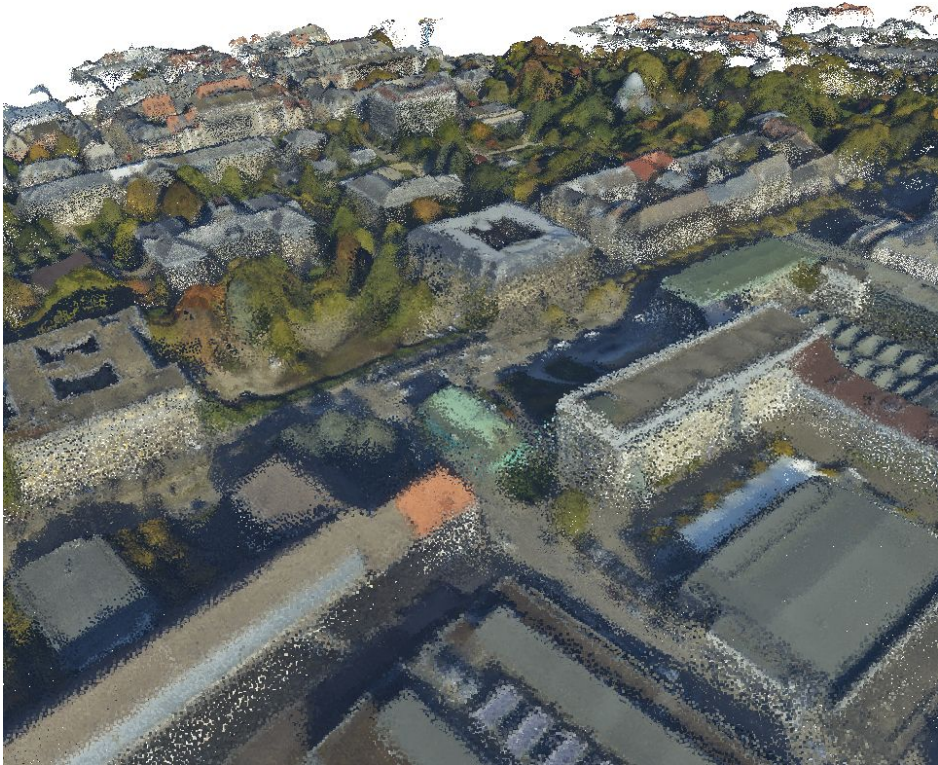
² LIGM, Ecole des Ponts, Univ Gustave Eiffel, CNRS, Marne-la-Vallée, France

³ valeo.ai, Paris, France

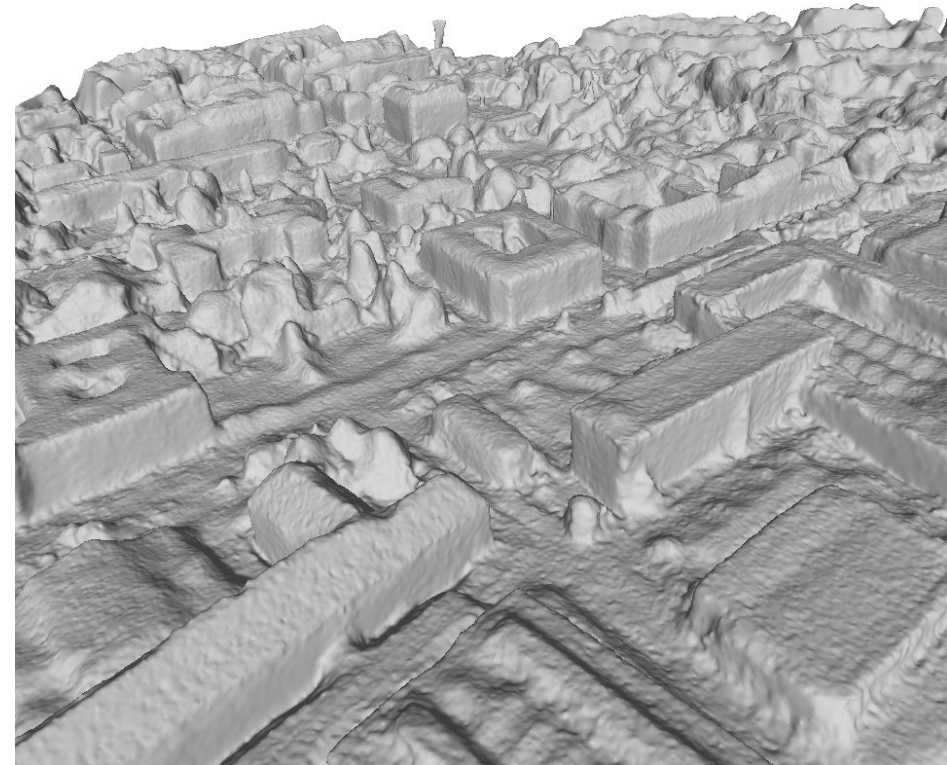


Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

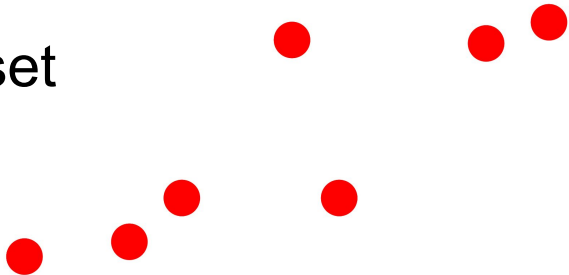
What is surface reconstruction?



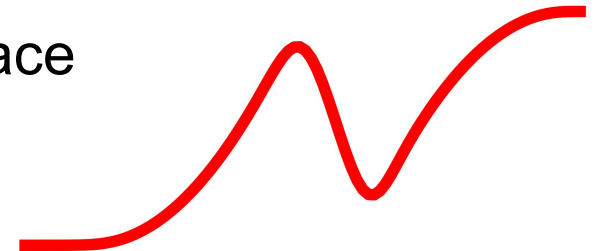
Surface reconstruction



Point set

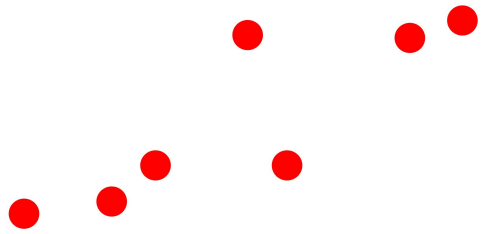


Surface

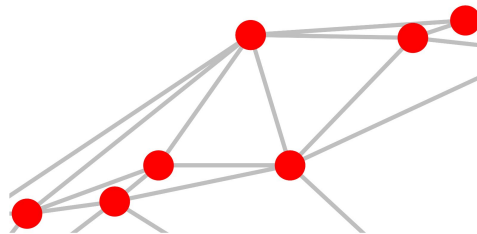


Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

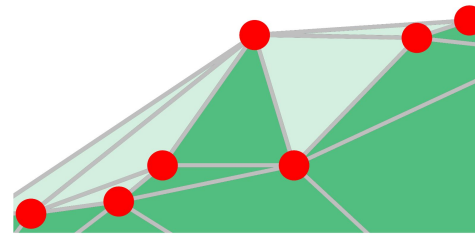
Delaunay based **Surface Reconstruction** using interior / exterior classification and explicit visibility modeling



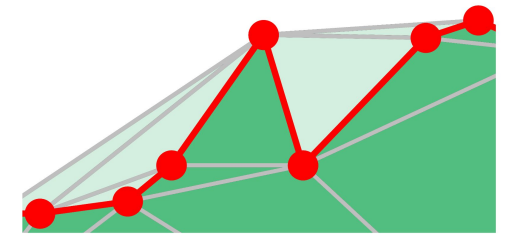
1. Input point set



2. Delaunay triangulation



3. Empty / full classification



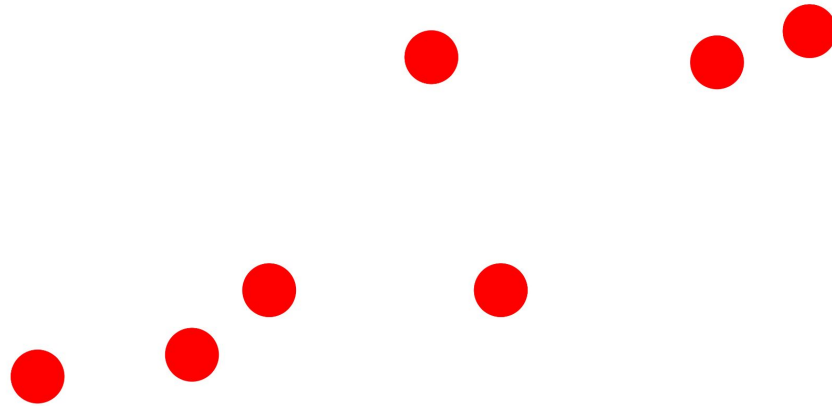
4. Surface as interface

- Labatut, P., Pons, J. P., & Keriven, R. (2009). Robust and efficient surface reconstruction from range data. In *Computer graphics forum* (Vol. 28, No. 8).
- Vu, H. H., Labatut, P., Pons, J. P., & Keriven, R. (2011). High accuracy and visibility-consistent dense multiview stereo. *IEEE transactions on pattern analysis and machine intelligence*.
- Jancosek, M., & Pajdla, T. (2014). Exploiting visibility information in surface reconstruction to preserve weakly supported surfaces. *International scholarly research notices*.

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Input

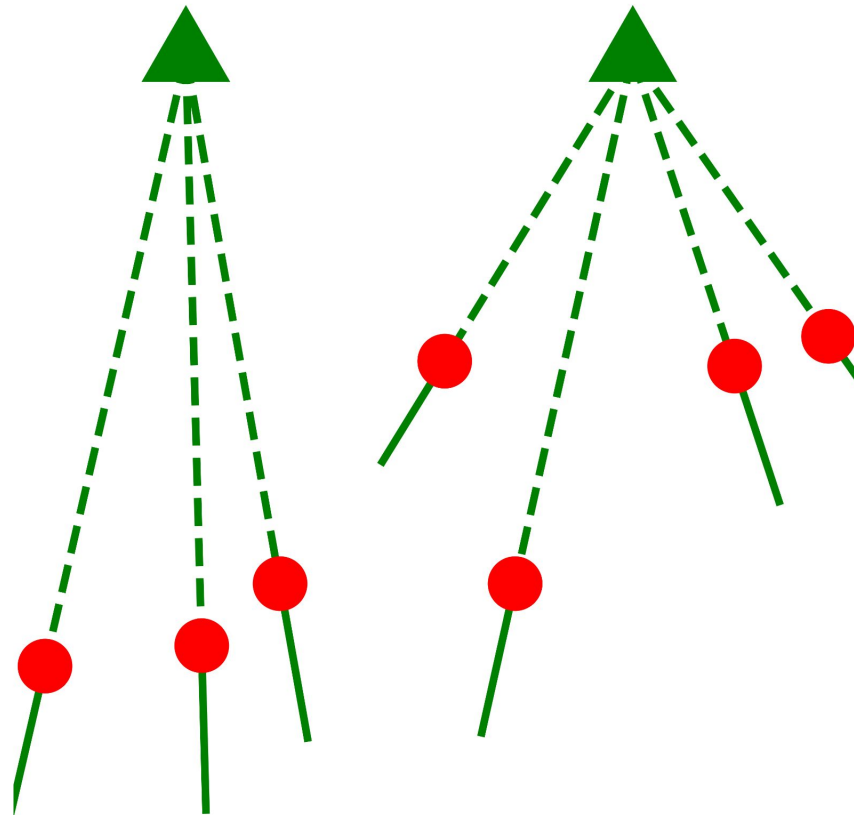
Input Point Cloud



Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Input

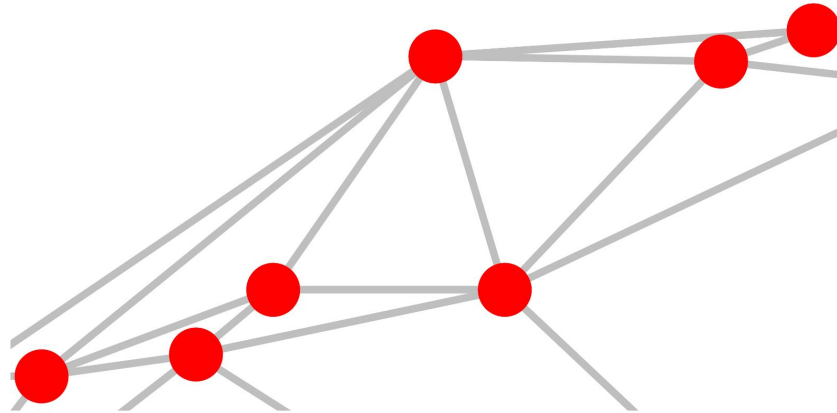
Input **Point Cloud** with **Visibility Information**



Scalable **Surface Reconstruction** with Delaunay-Graph Neural Networks

Input

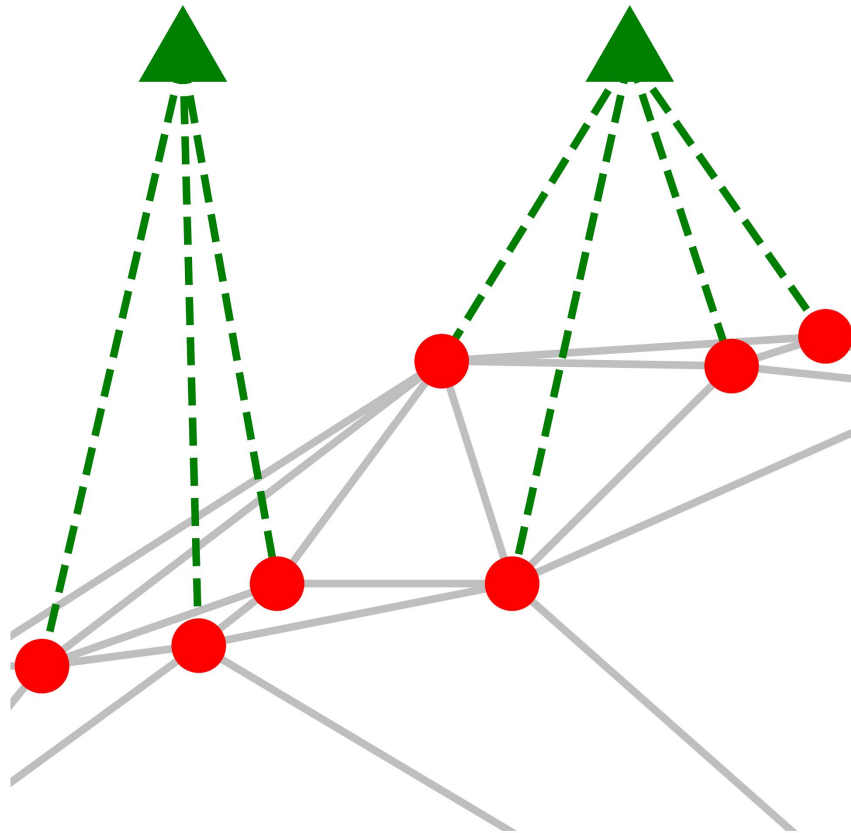
3D Delaunay triangulation



Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

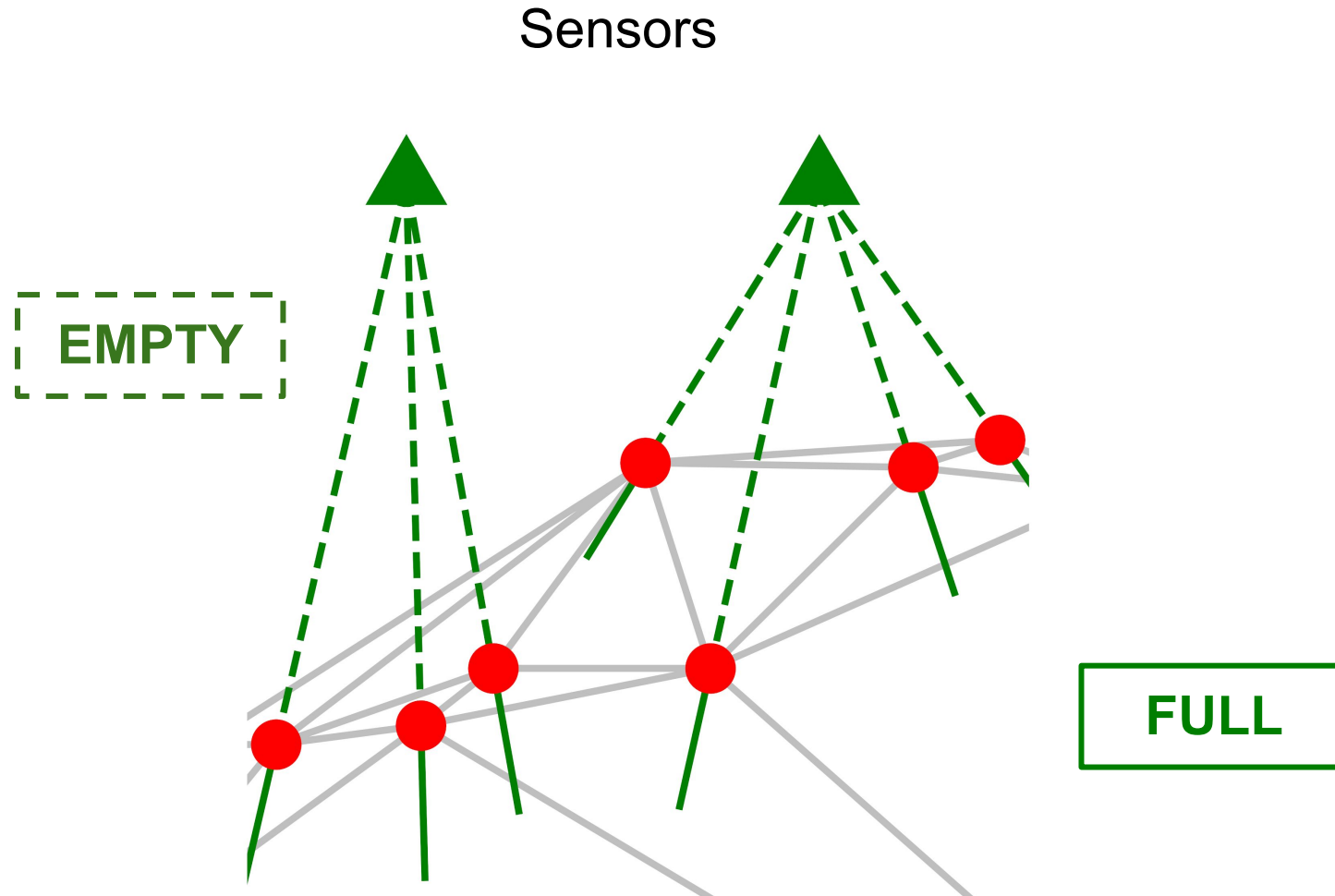
Tessellated point set with visibility information

Sensors



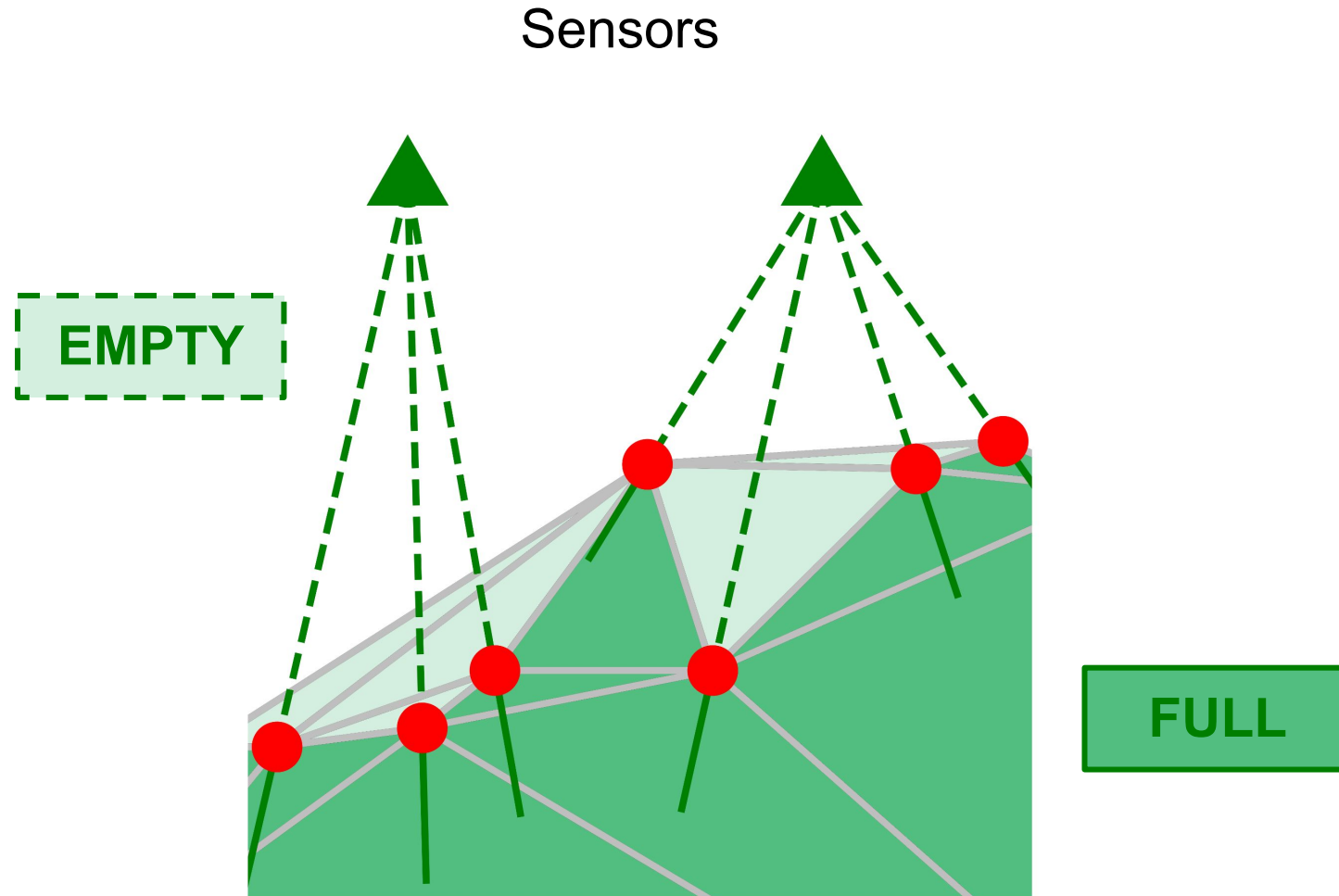
Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Tessellated point set with visibility information



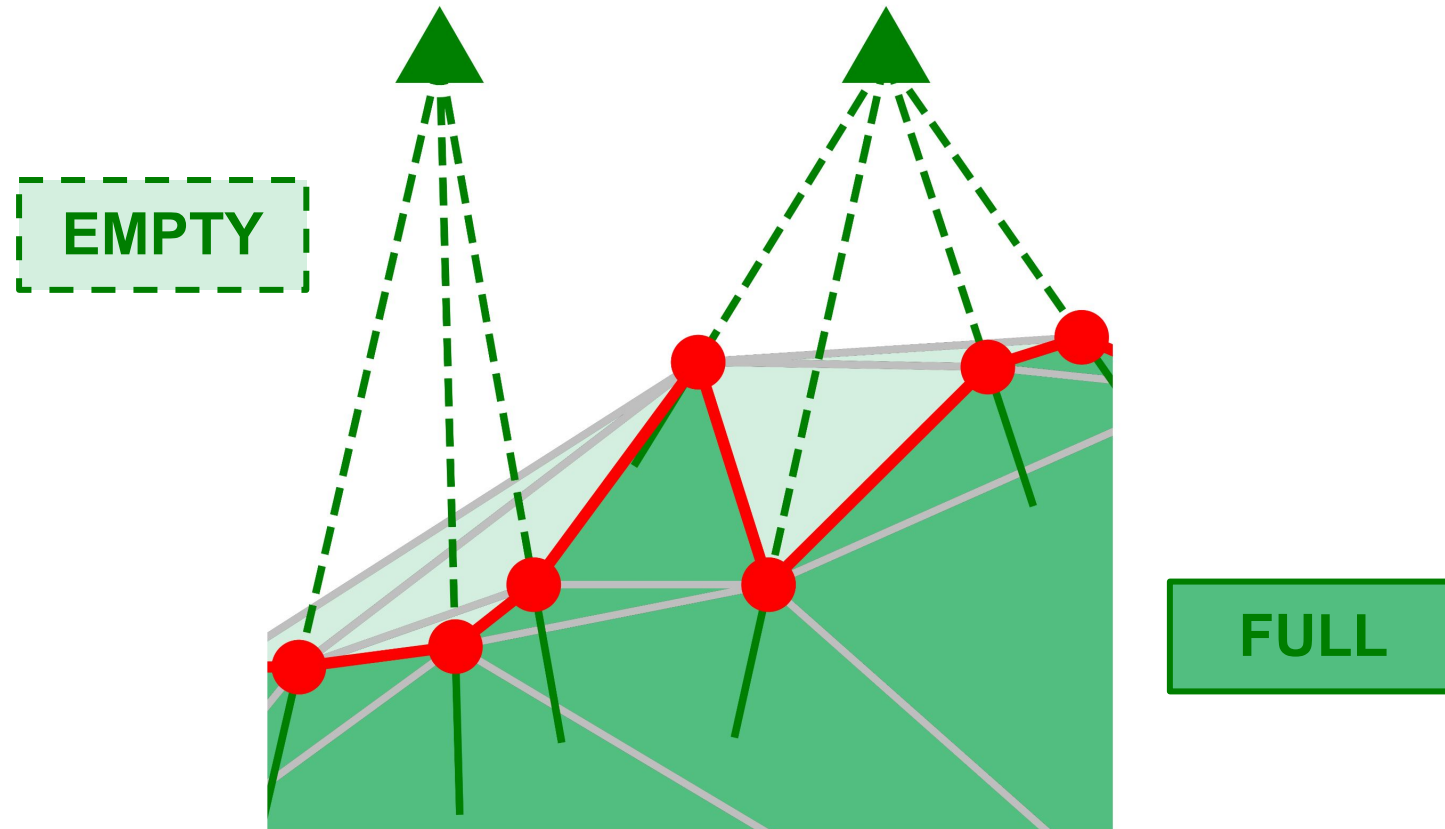
Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Empty / full classification of Delaunay tetrahedra



Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Extracted surface



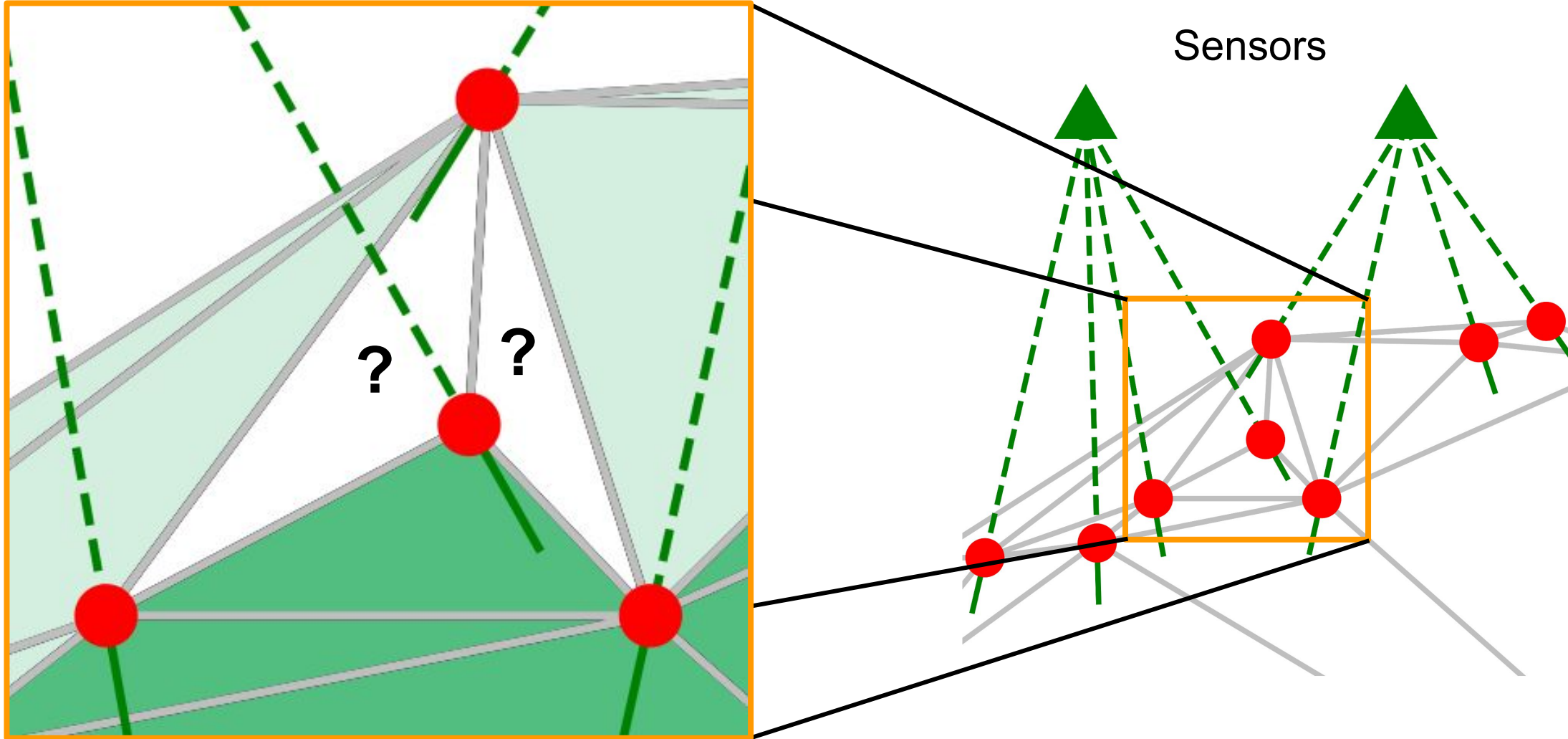
Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Point cloud acquisition with noise



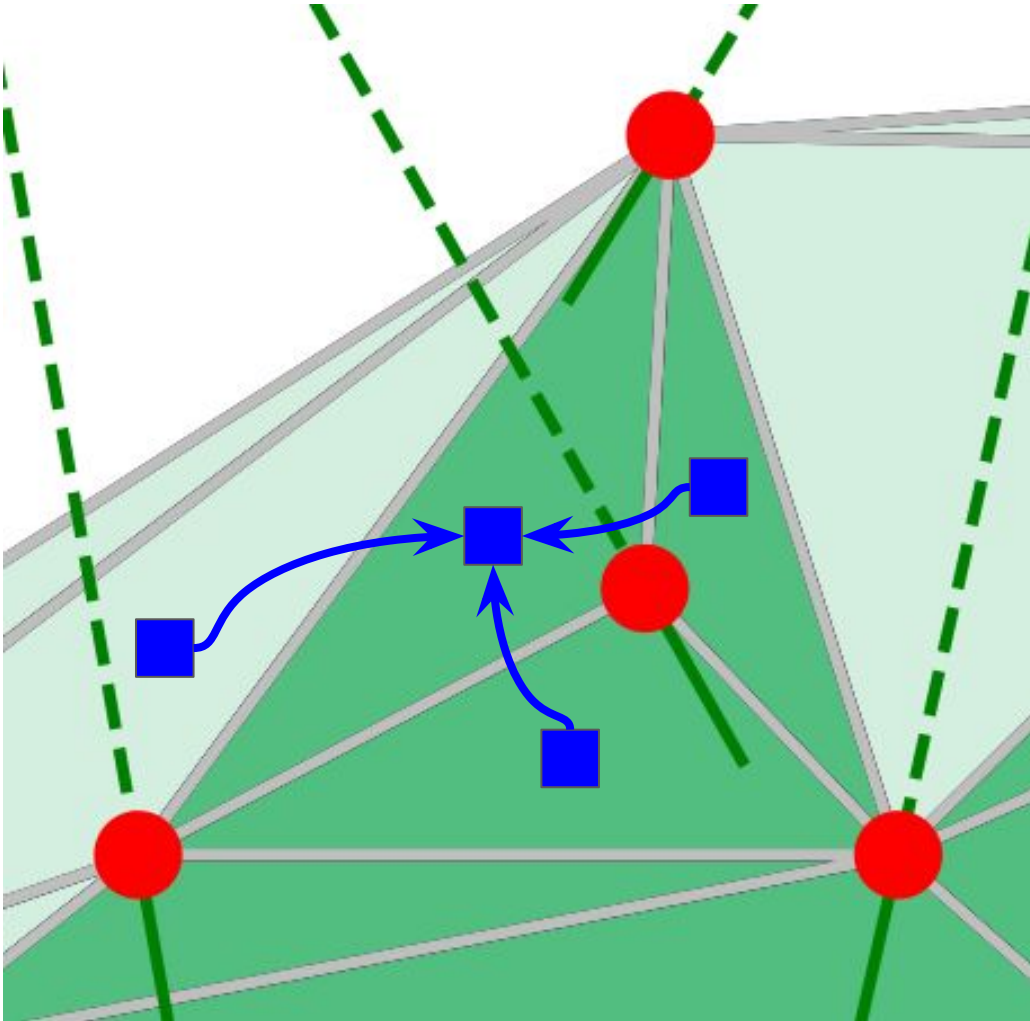
Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Point cloud acquisition with noise



Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Energy formulation for globally optimal tetrahedron labelling with learned likelihood



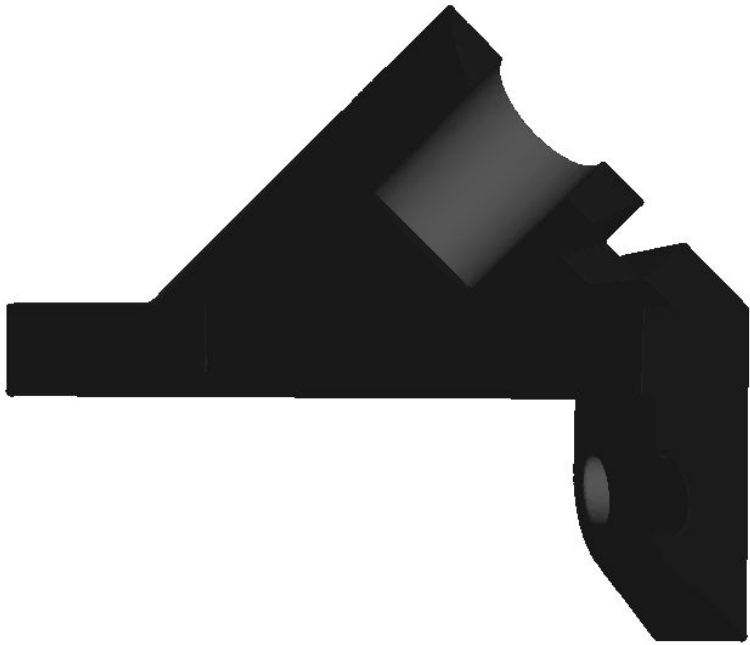
Labatut *et al* 2009

$$E(S) = \underbrace{E_{\text{vis}}(S, \mathbf{P}, \mathbf{v})}_{\text{learned likelihood}} + \lambda E_{\text{smooth}}(S)$$

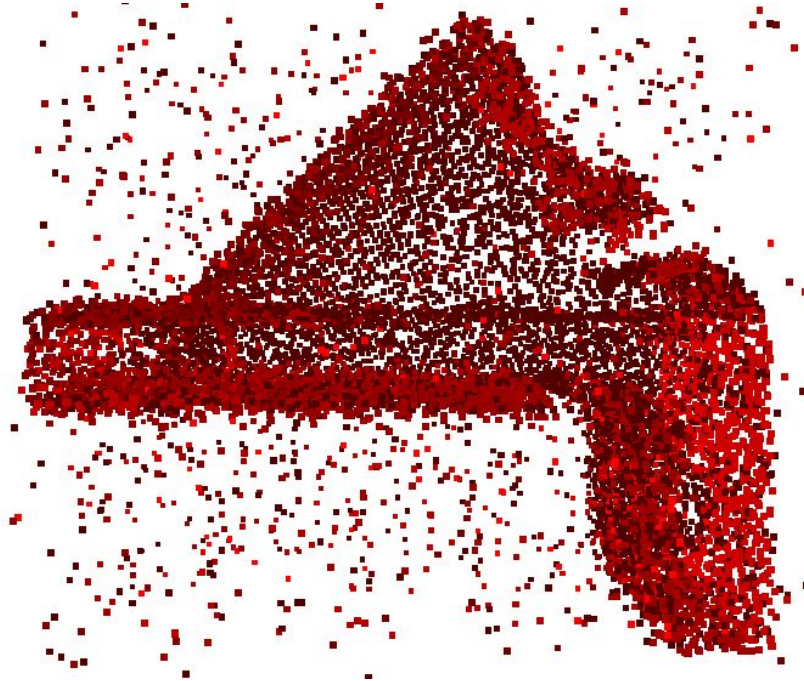
- Apply **graph convolutions** on dual graph of Delaunay triangulation
 - Aggregate **geometric** and **visibility information** from local neighborhood
 - Independently infer **empty** / **full** likelihood

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

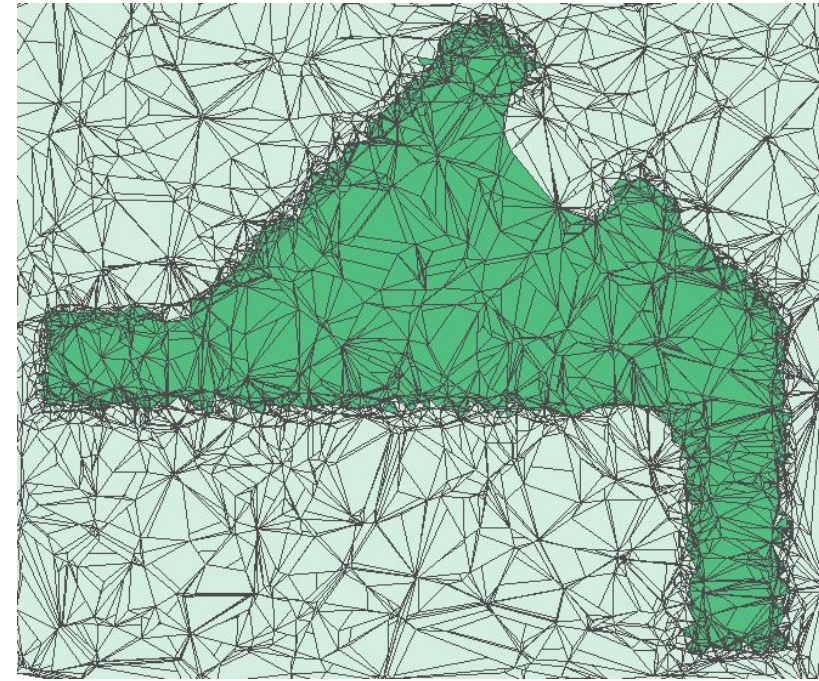
Training on Delaunay triangulation from defect-laden point sets



Ground truth surface



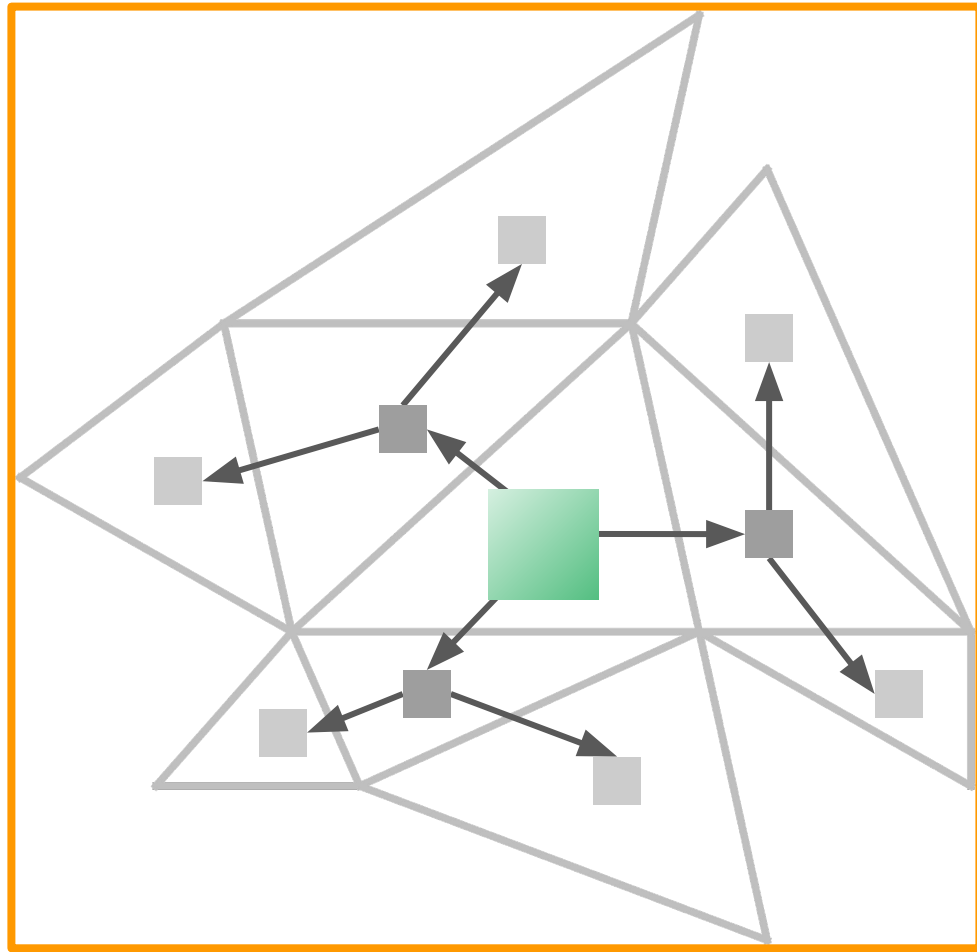
Defect-laden scan



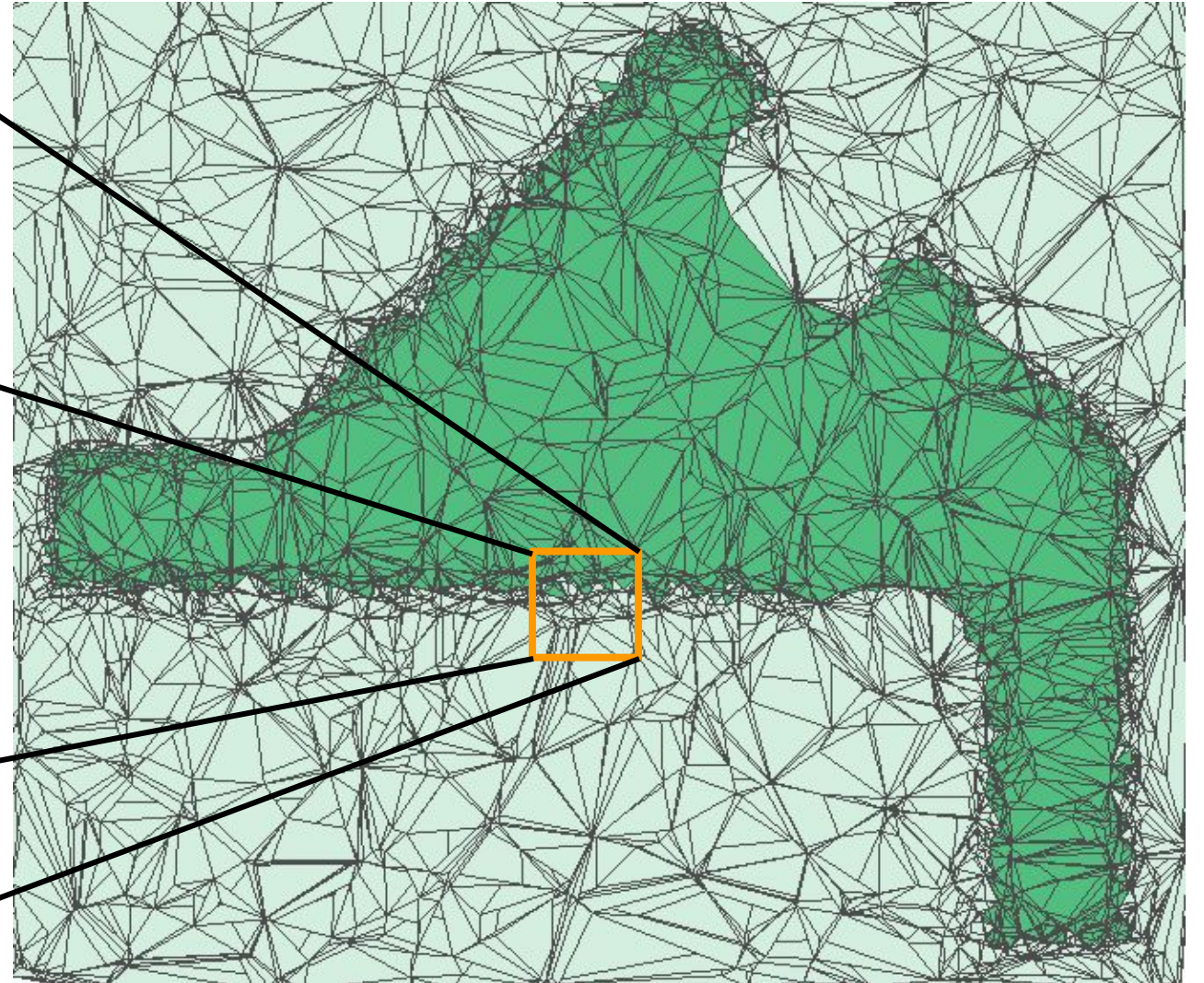
Empty / **full** ground truth

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Subgraph extraction

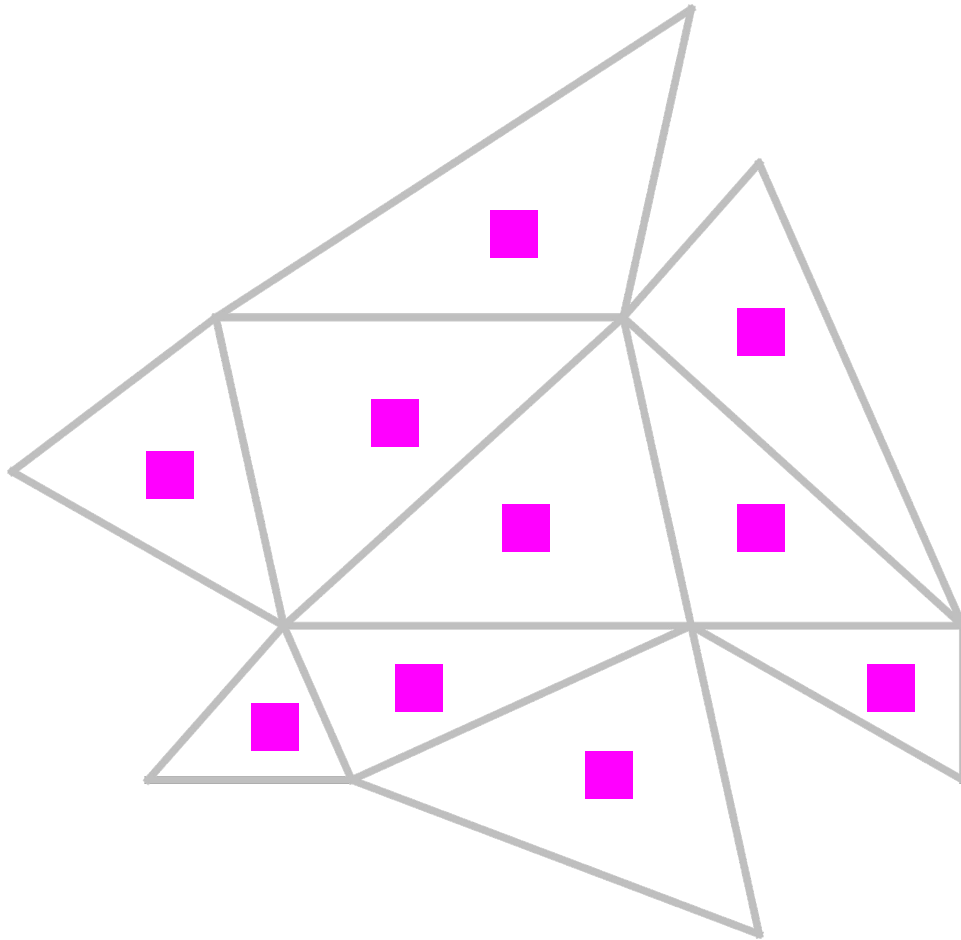


Target → 1-hop → 2-hop



Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Graph Neural Network operating on dual graph of Delaunay triangulation

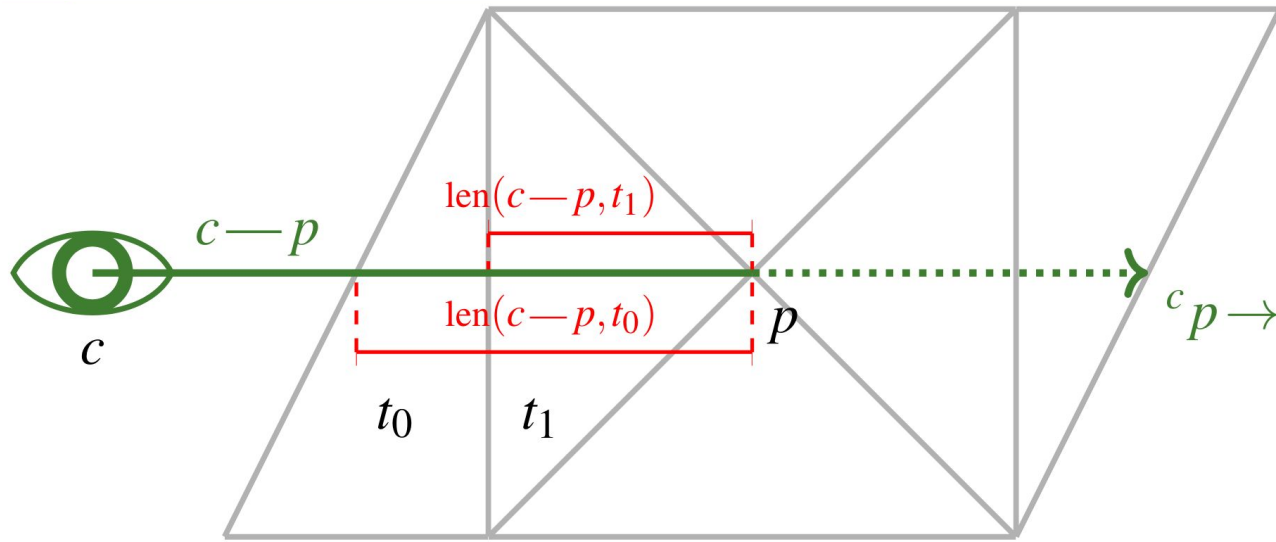


Start with **feature information** for each tetrahedron in local neighborhood



Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

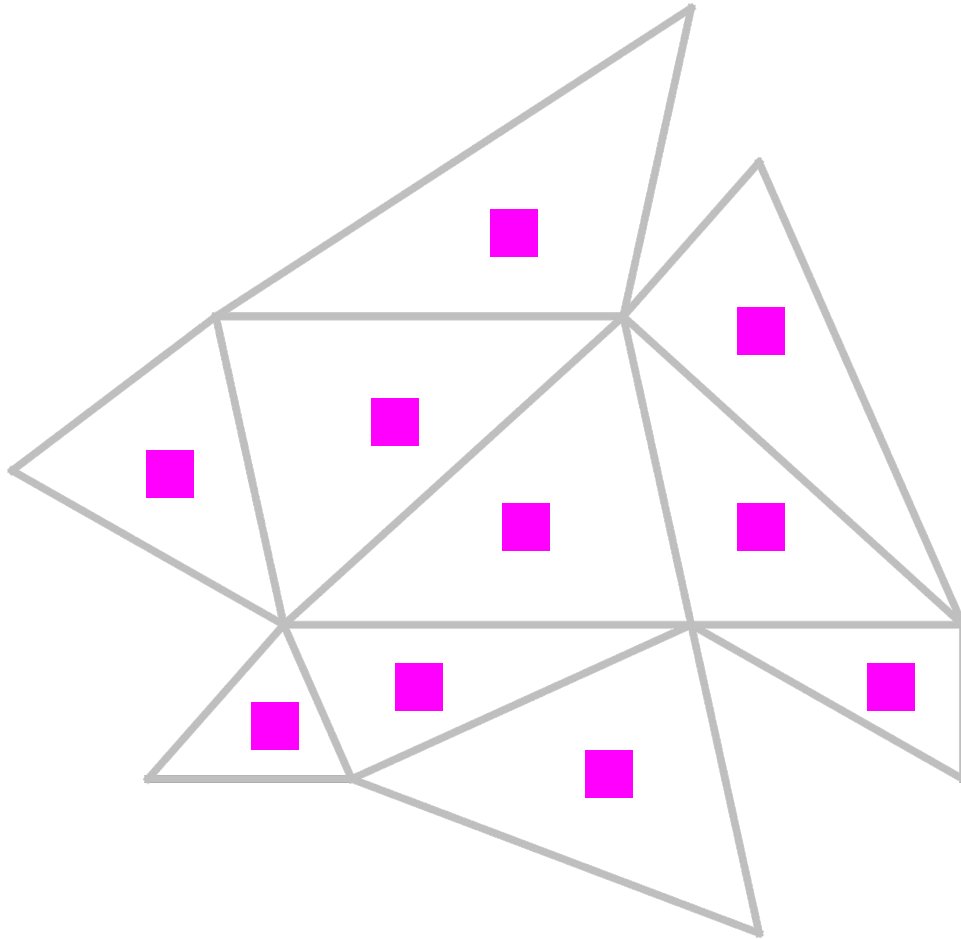
Feature extraction



- **8 visibility features**
 - Count and min intersection length of all **(extended) lines-of-sight** ending at a point of the tetrahedron
 - Count and min intersection length of all **(extended) lines-of-sight** *not* ending at a point of the tetrahedron
- **4 morphological features**
 - Min and max edge length
 - Volume
 - Radius of circumsphere

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Graph Neural Network operating on dual graph of Delaunay triangulation



Start with **feature information** for each tetrahedron in local neighborhood



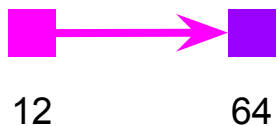
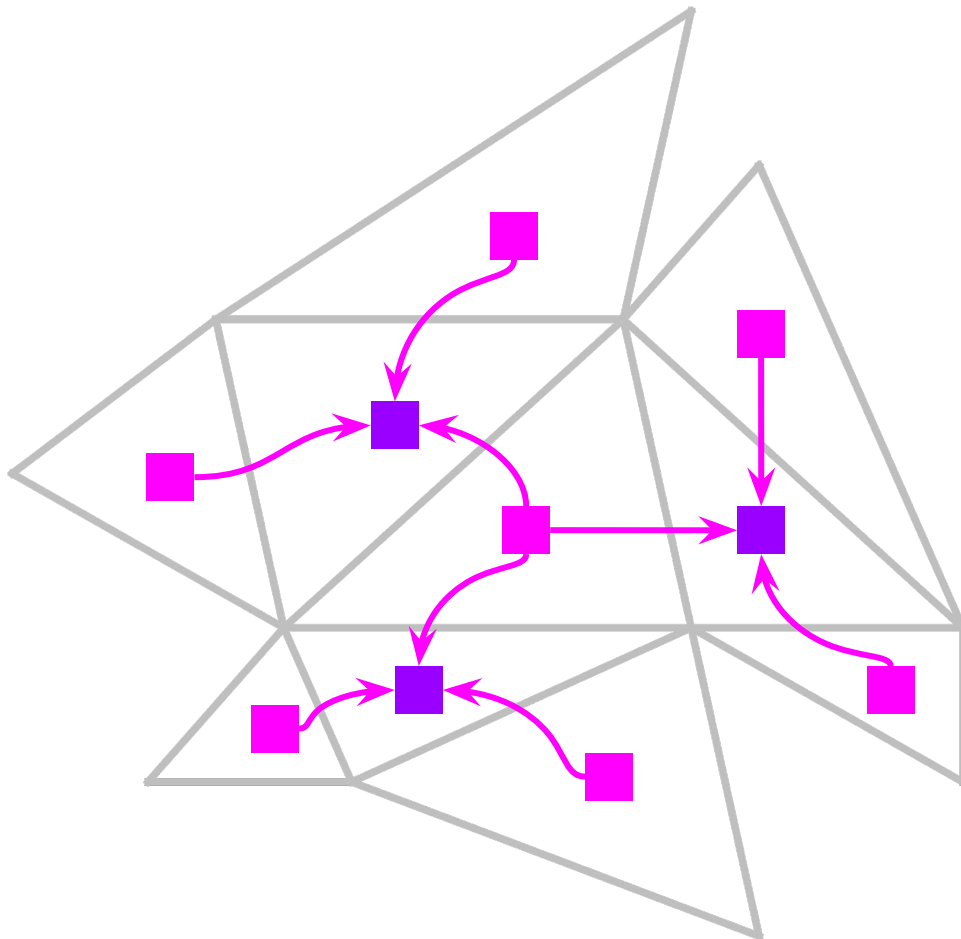
Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Graph Neural Network operating on dual graph of Delaunay triangulation

Hamilton *et al* 2017¹

Apply Graph Convolution Scheme

- $x_v = \sigma \left(W^{(k)} \left[x_v \parallel \text{mean}_{u \in N_v^t} (x_u) \right] \right)$
- $\mathcal{X}$: k -hop cell embedding
- $W^{(k)}$: learned weight matrix at k -hop
- σ : activation + normalization



[1] Hamilton, W. L., Ying, R., & Leskovec, J. (2017). Inductive representation learning on large graphs. In *NeurIPS*.

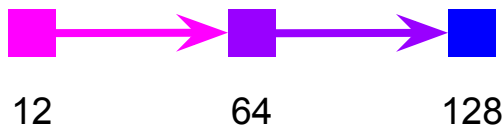
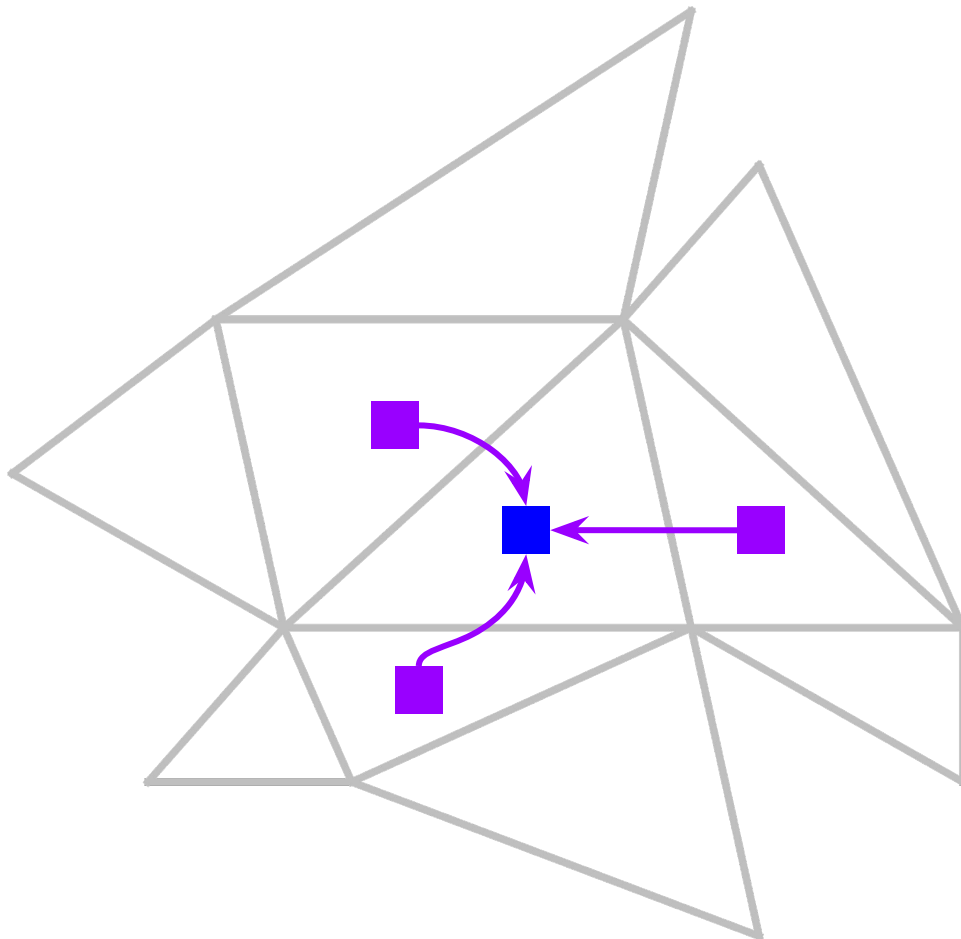
Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Graph Neural Network operating on dual graph of Delaunay triangulation

Hamilton *et al* 2017¹

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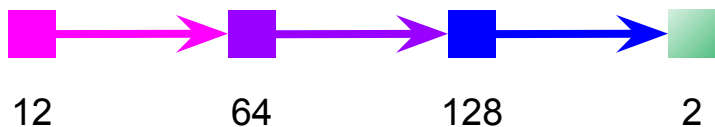
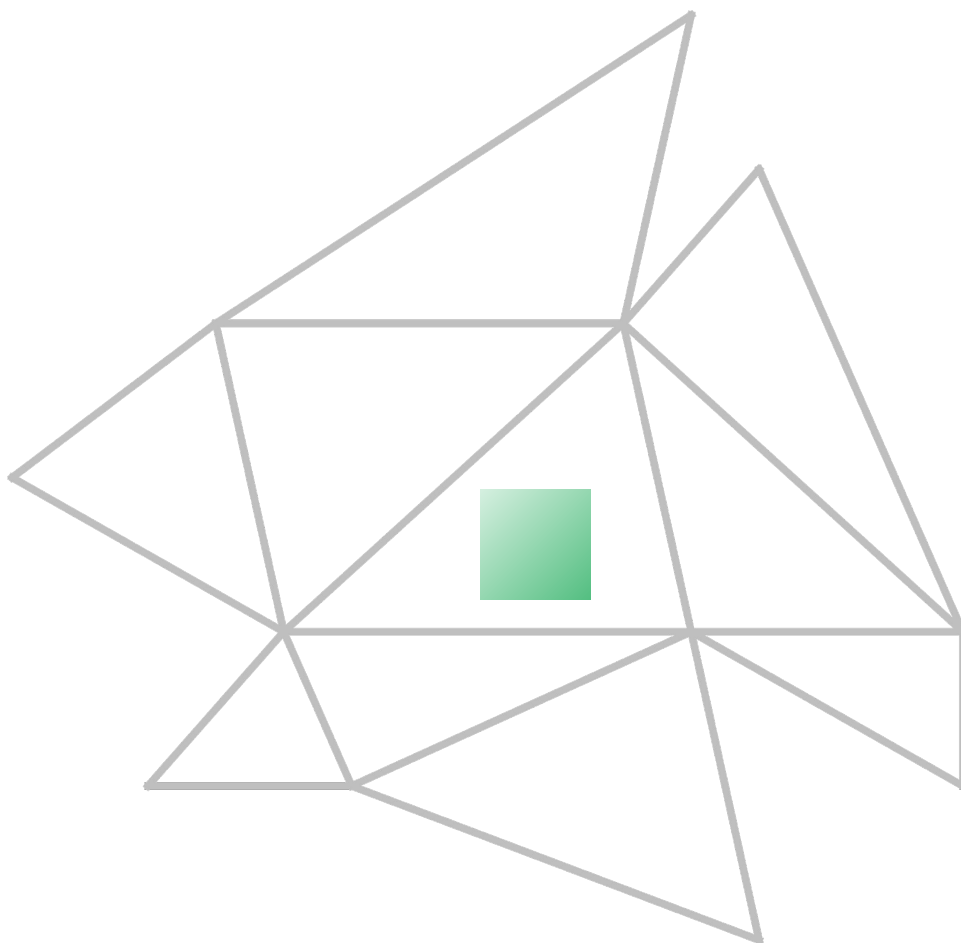
Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Graph Neural Network operating on dual graph of Delaunay triangulation

Hamilton *et al* 2017¹

Predict empty / full likelihood

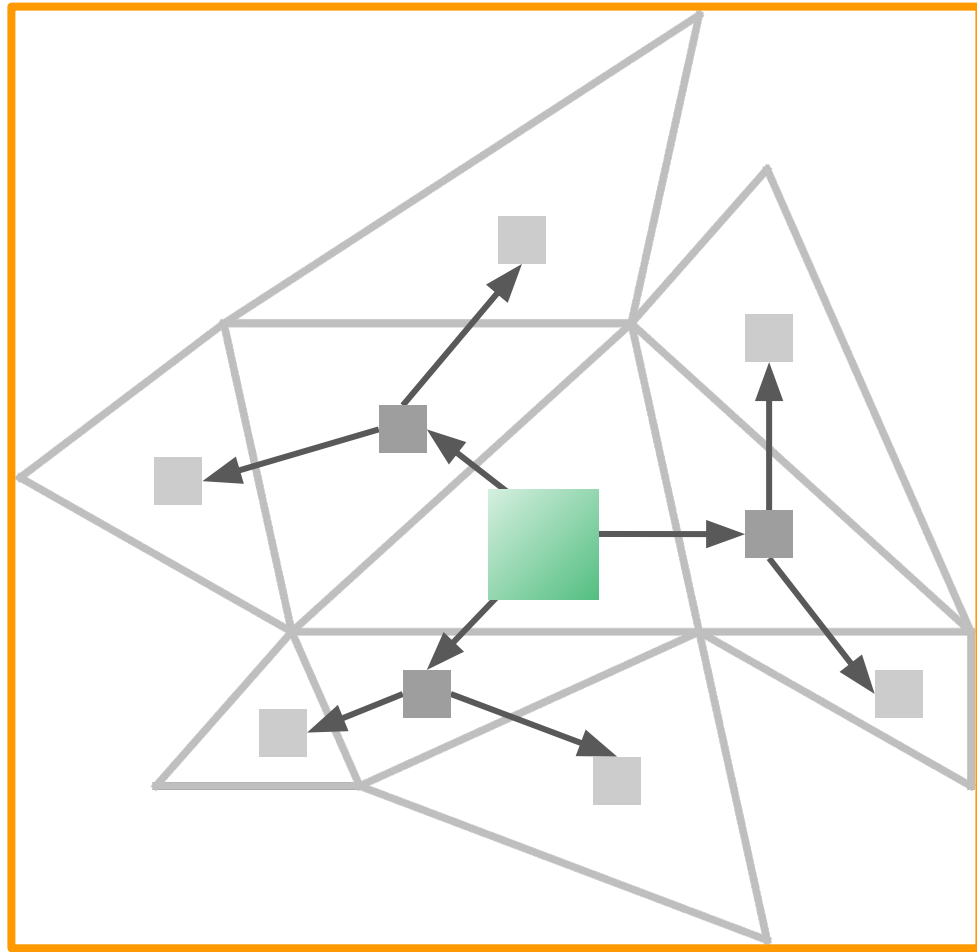
- $\left(e_v, f_v \right) = MLP \left(x_v \right)$
- x : k-hop cell embedding
- MLP : multi-layer perceptron



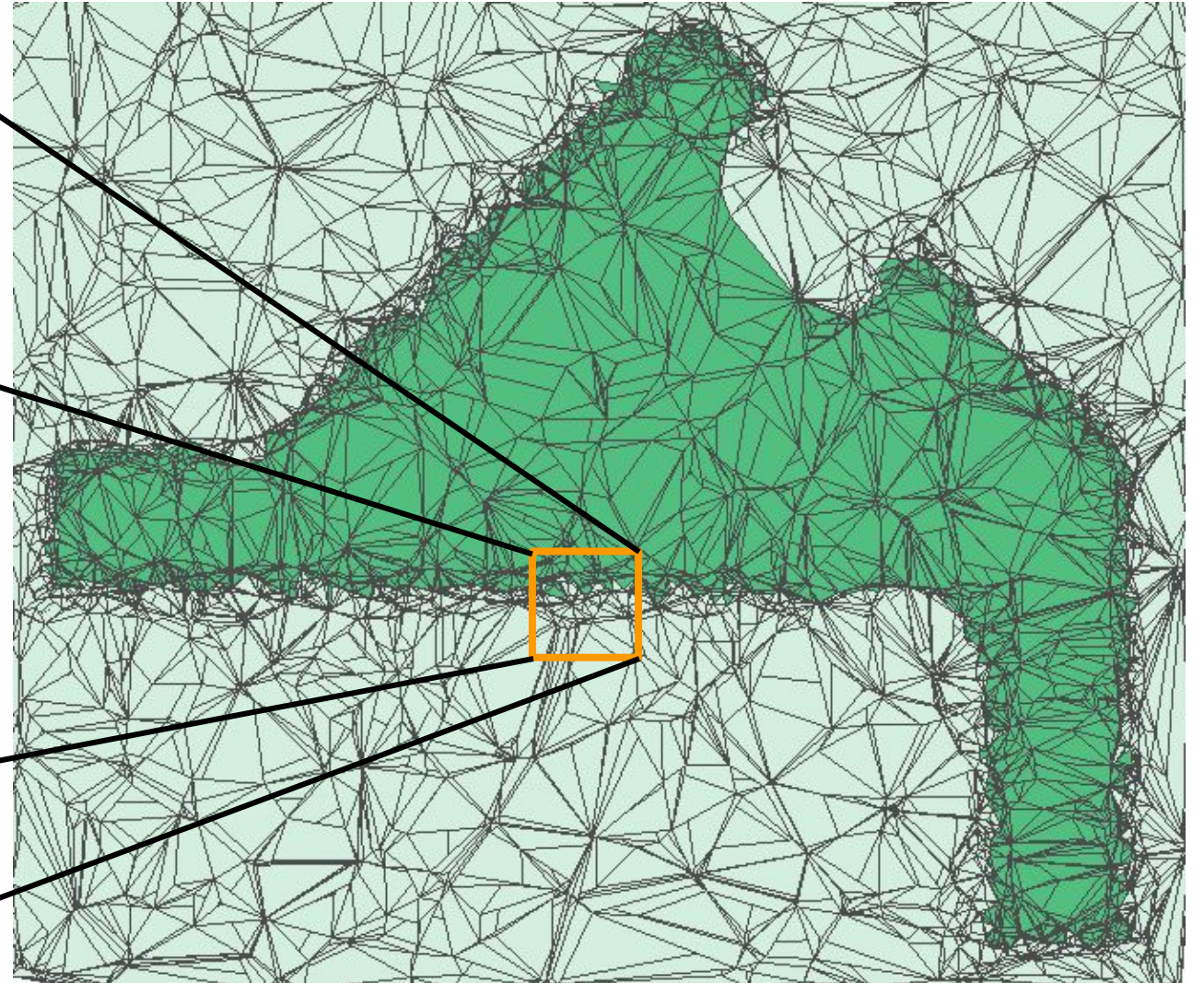
[1] Hamilton, W. L., Ying, R., & Leskovec, J. (2017). Inductive representation learning on large graphs. In *NeurIPS*.

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Subgraph extraction



Target → 1-hop → 2-hop

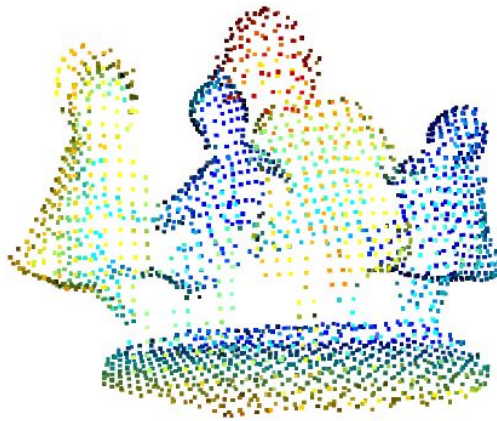


Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

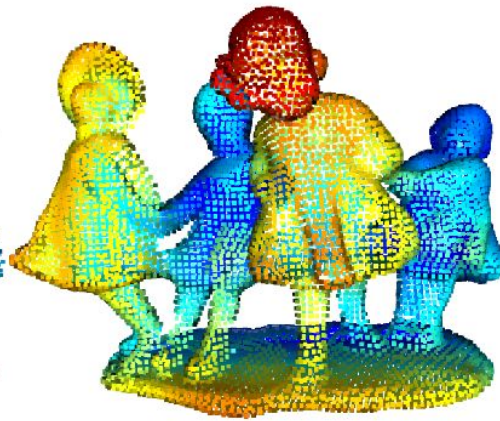
Objects of Berger et al. benchmark²



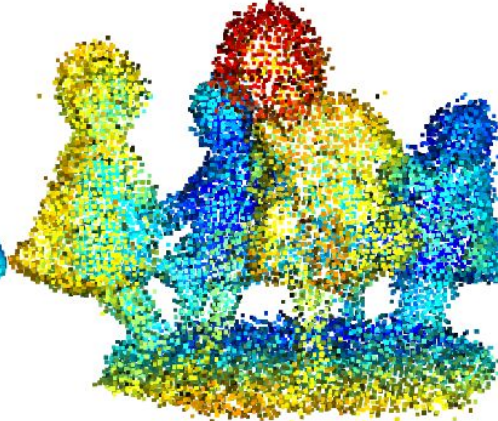
Ground truth



Low resolution (LR)



High resolution (HR)



HR + noise (HRN)



HR + outliers (HRO)



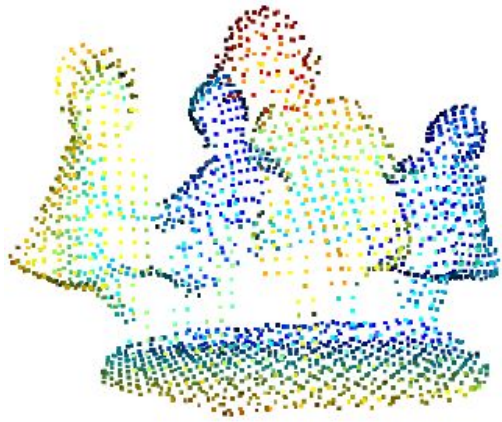
HR + noise + outliers

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

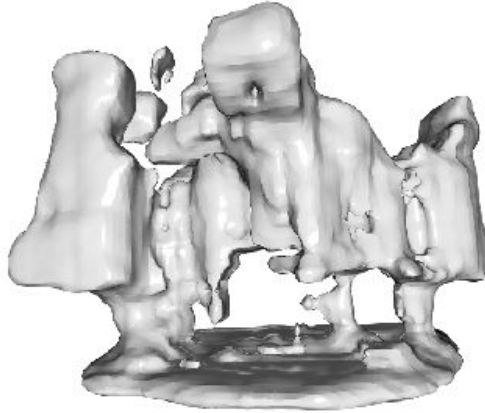
Objects of Berger et al. benchmark²



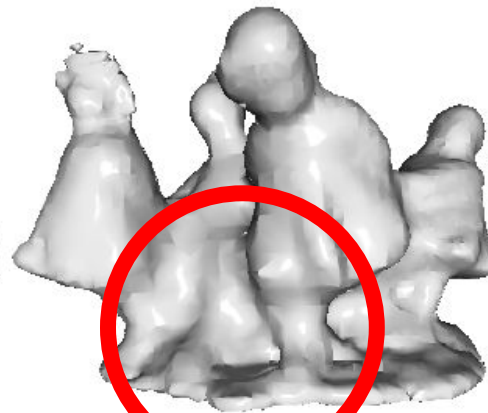
Ground truth



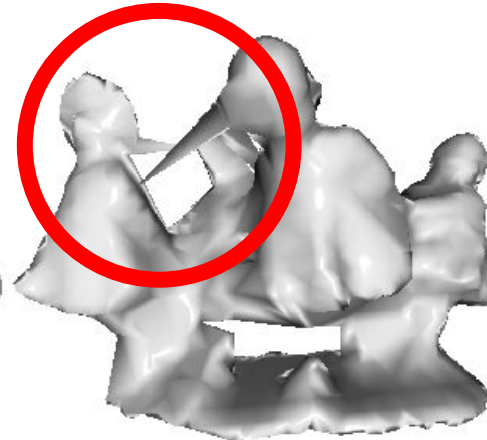
Low resolution (LR)



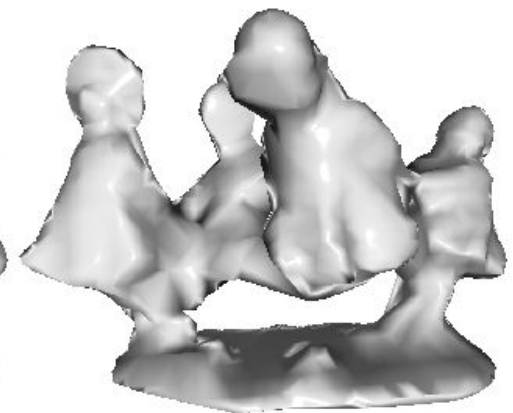
ConvONet



Screened Poisson



Labatut *et al.*



Ours

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

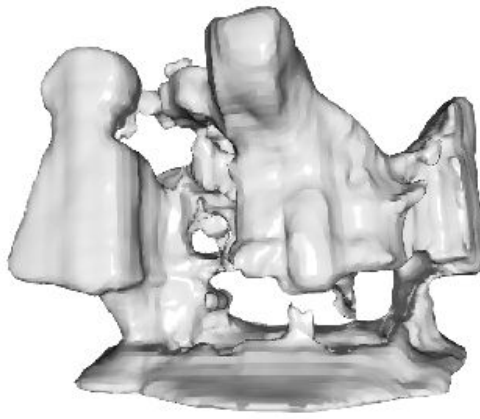
Objects of Berger et al. benchmark²



Ground truth



High resolution (LR)



ConvONet



Screened Poisson



Labatut *et al.*



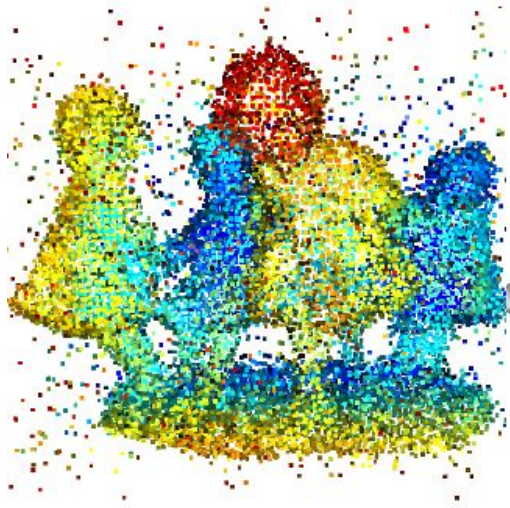
Ours

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

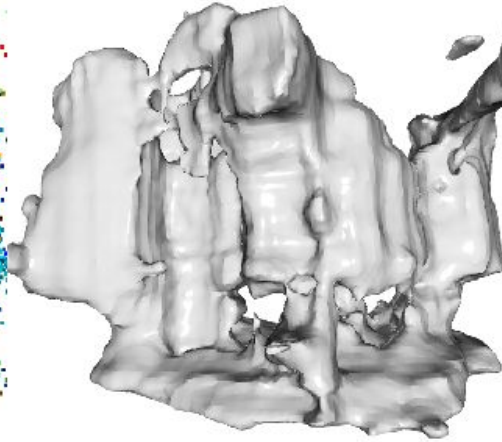
Objects of Berger et al. benchmark²



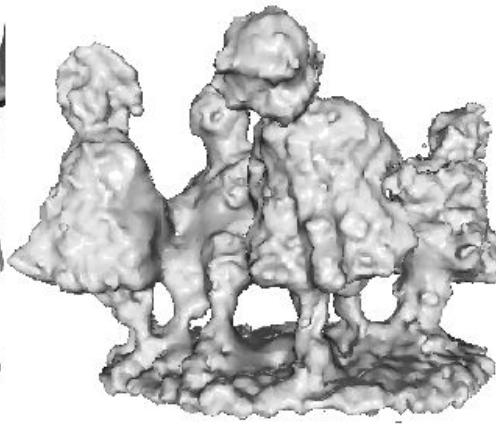
Ground truth



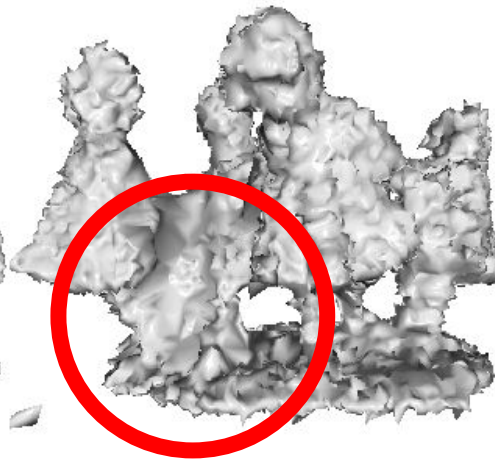
HR + noise + outliers



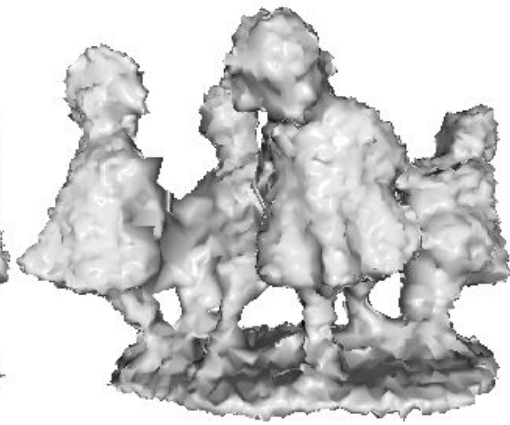
ConvONet



Screened Poisson



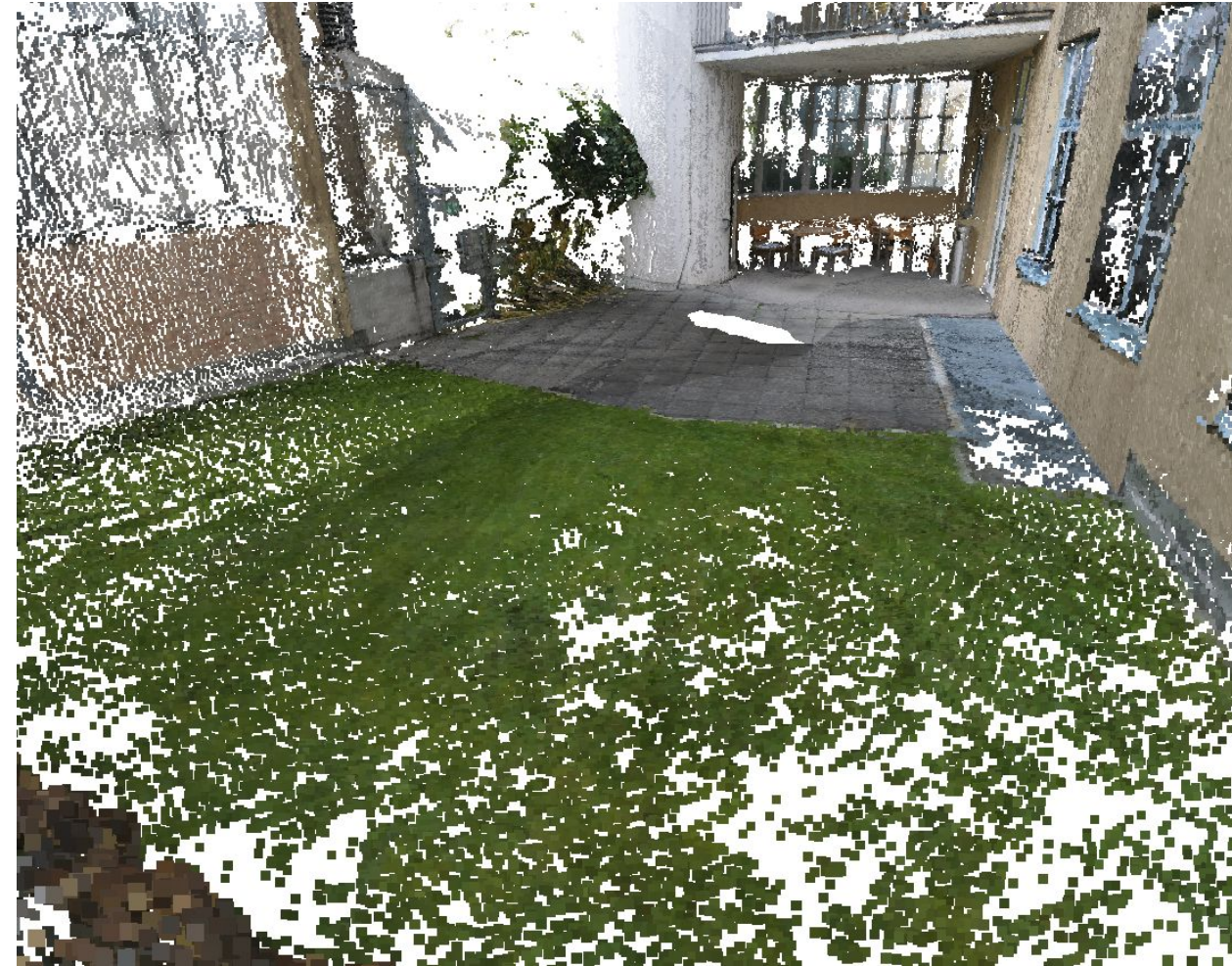
Labatut *et al.*



Ours

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Results on ETH3D dataset with 1.1 M points



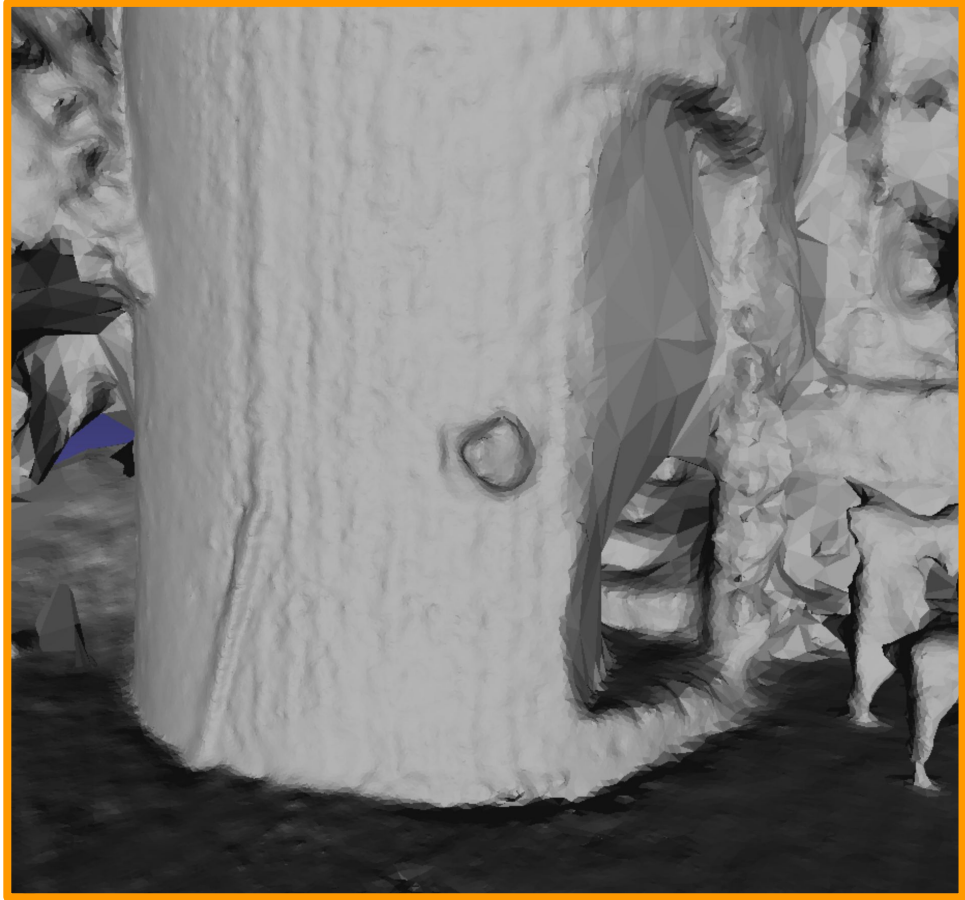
Point cloud



Surface Mesh

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Results on ETH3D dataset with 1.1 M points



Surface Mesh



Surface Mesh

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

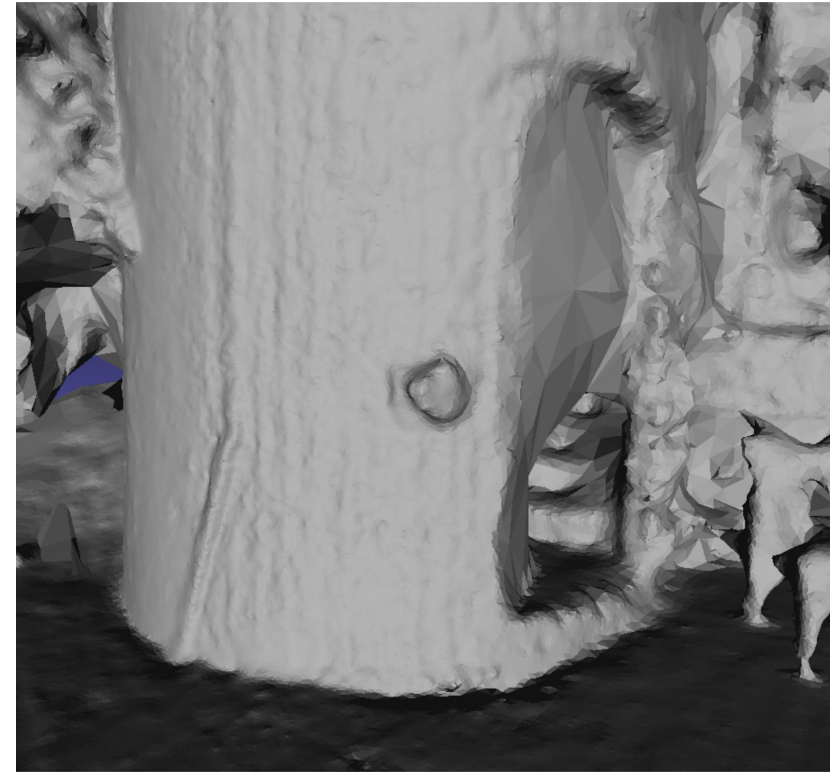
Results on ETH3D dataset with 1.1 M points



Image



Jancosek *et al* 2014



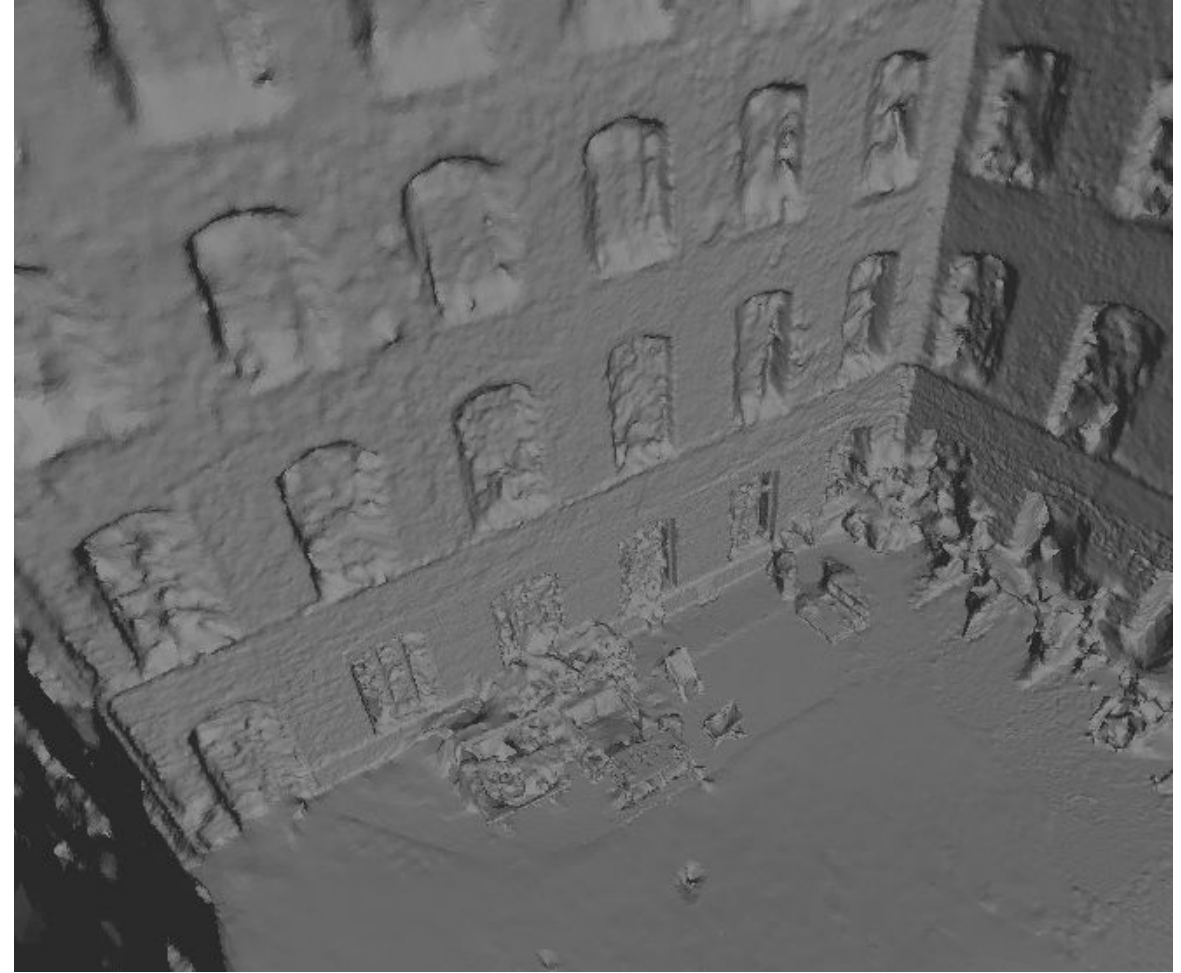
Our reconstruction

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Results on ETH3D dataset with 2.5 M points



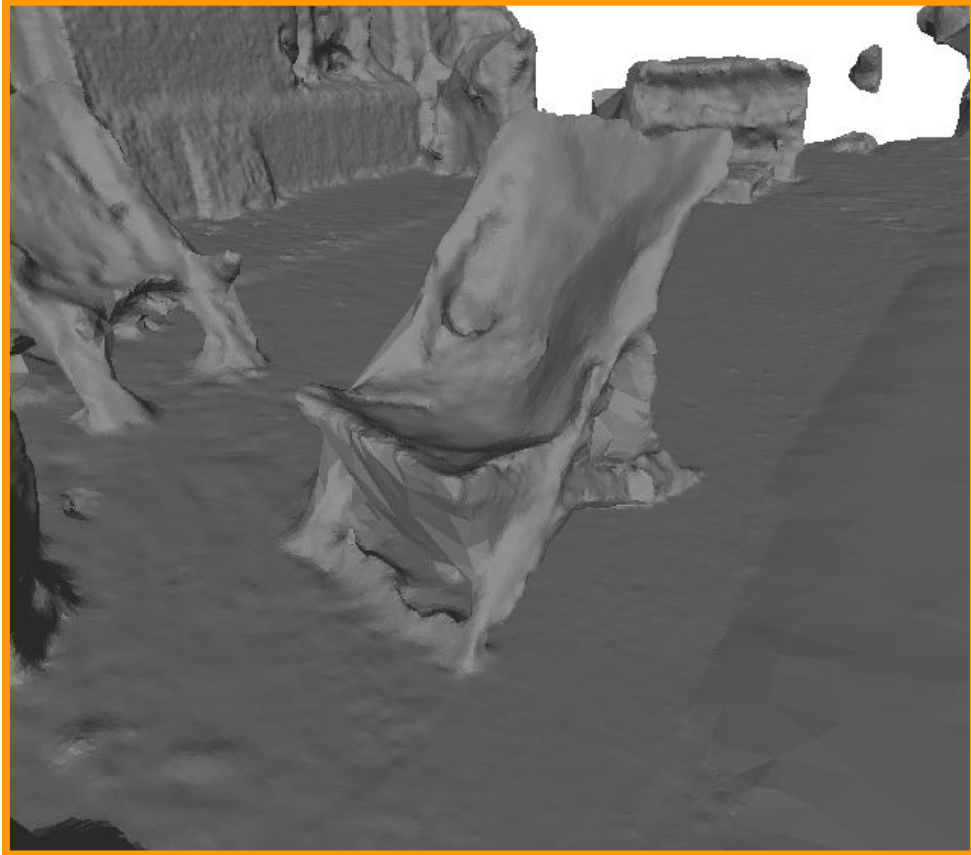
Point cloud



Surface Mesh

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Results on ETH3D dataset with 2.5 M points



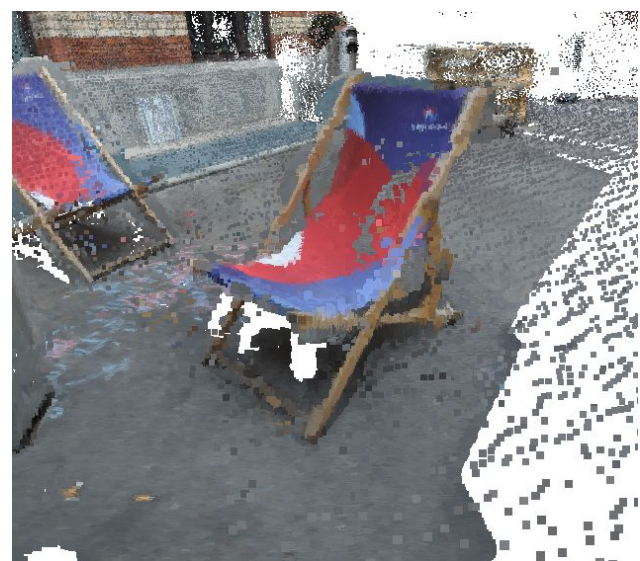
Surface Mesh



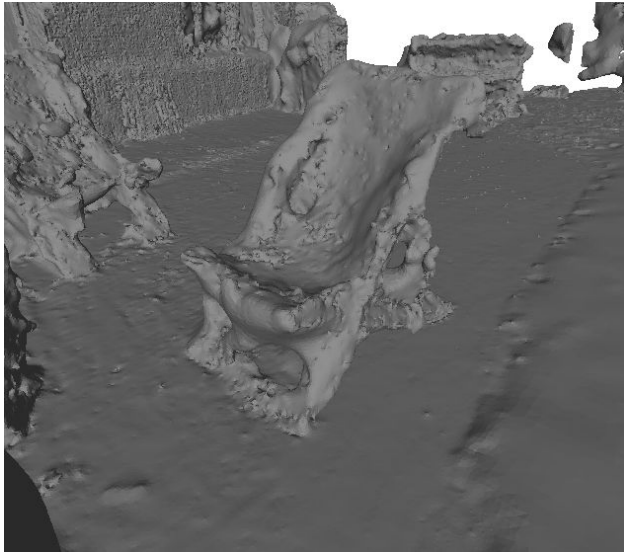
Surface Mesh

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

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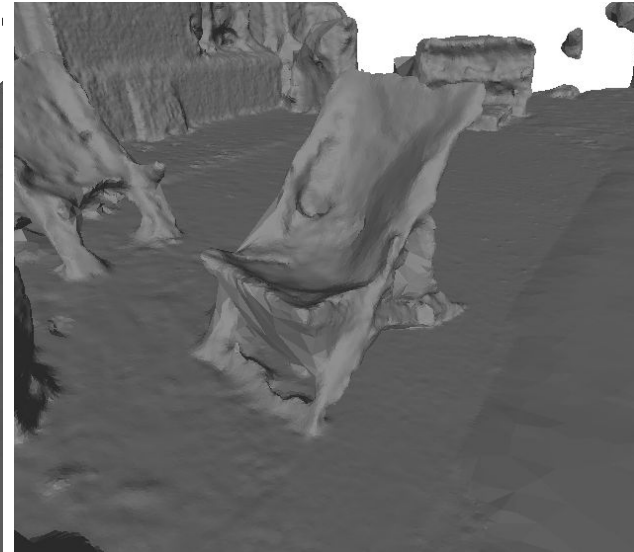
Point cloud



Screened Poisson



Vu *et al* 2011



Ours

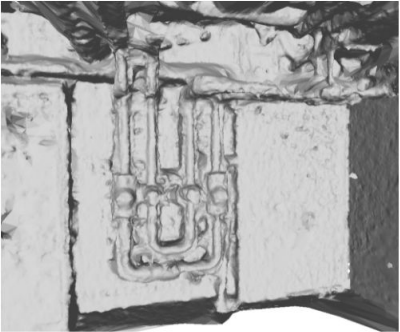
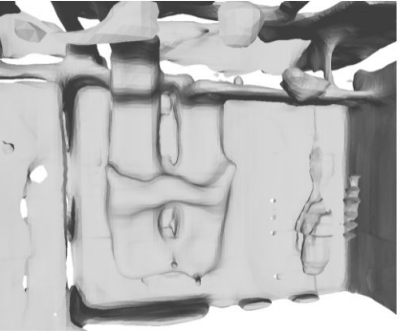
Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Code and data available online:

<https://github.com/raphaelsulzer/dgnn>

 README.md 

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks [SGP 2021]

		
MVS point cloud	Ours	ConvONet [1]

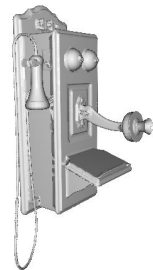
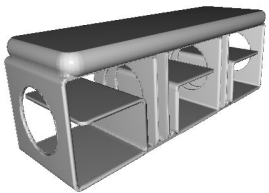
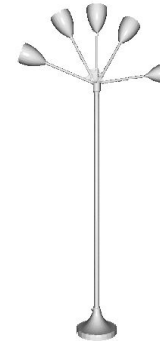
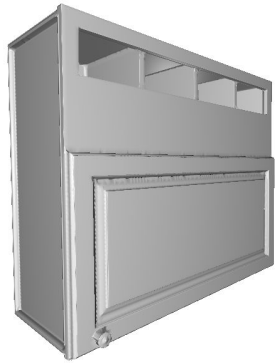
[Paper](#) | [Video](#)

This repository contains the implementation of the paper:

Scalable Surface Reconstruction with Delaunay-Graph Neural Networks
Raphael Sulzer, Loic Landrieu, Renaud Marlet, Bruno Vallet
[SGP 2021](#)

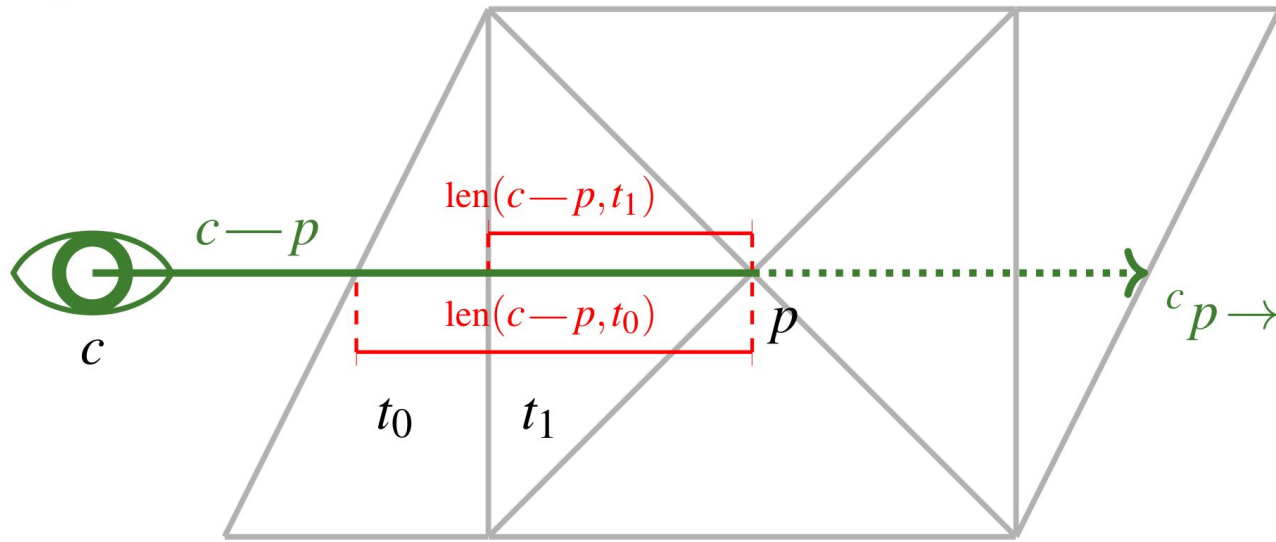
Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Training data - Objects from ShapeNet



Scalable Surface Reconstruction with Delaunay-Graph Neural Networks

Feature extraction



- **8 visibility features**
 - Count and min intersection length of all **(extended) lines-of-sight** ending at a point of the tetrahedron
 - Count and min intersection length of all **(extended) lines-of-sight** not ending at a point of the tetrahedron
- **4 morphological features**
 - Min and max edge length
 - Volume
 - Radius of circumsphere