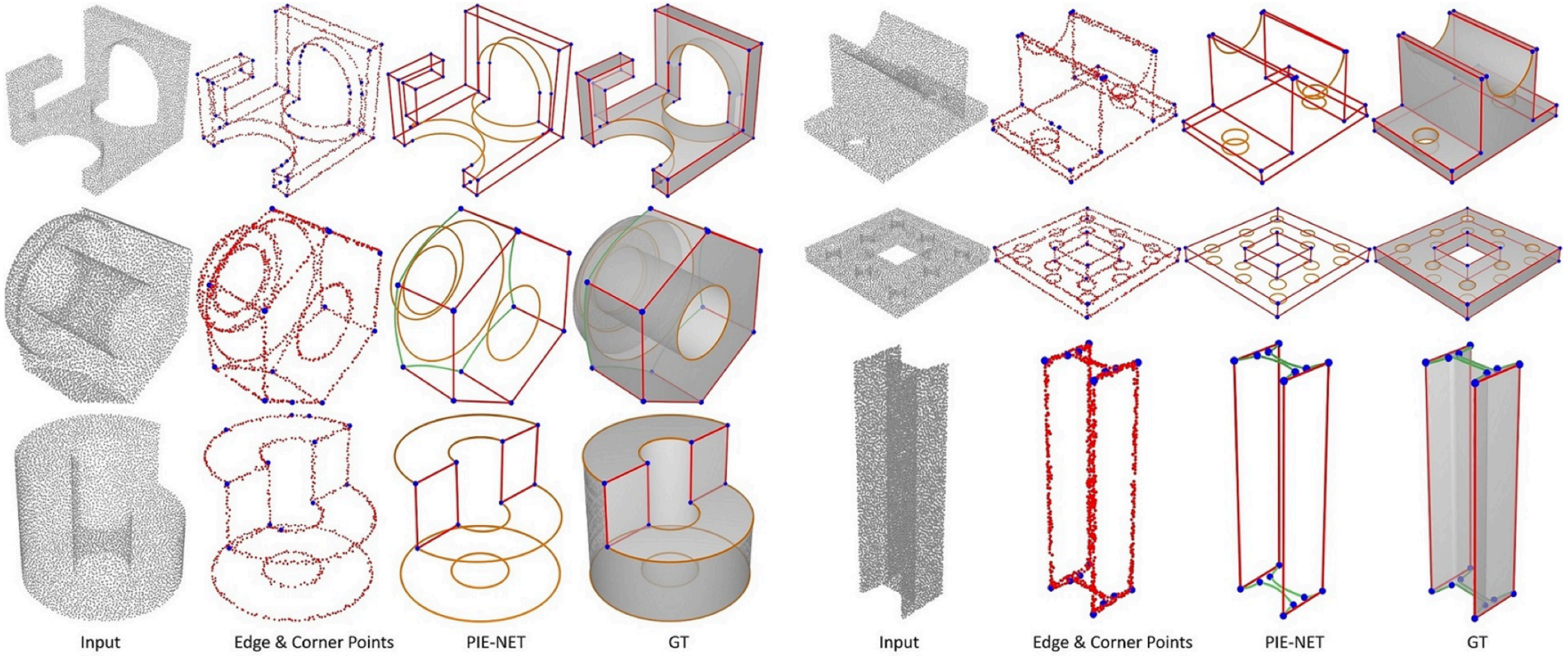
PIE-NET: Parametric Inference of Point Cloud Edges



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PIE-NET: Parametric Inference of Point Cloud Edges

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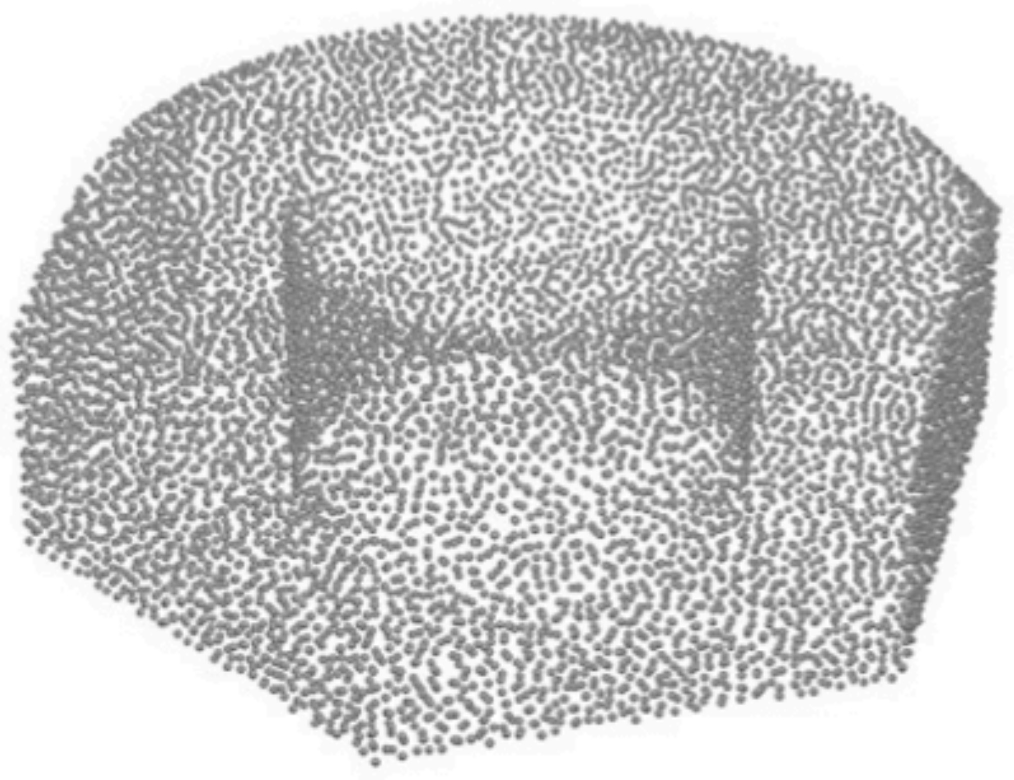
Edge Detection for 2D Images

- Well-studied problem, existing tools and methods produce reasonable results

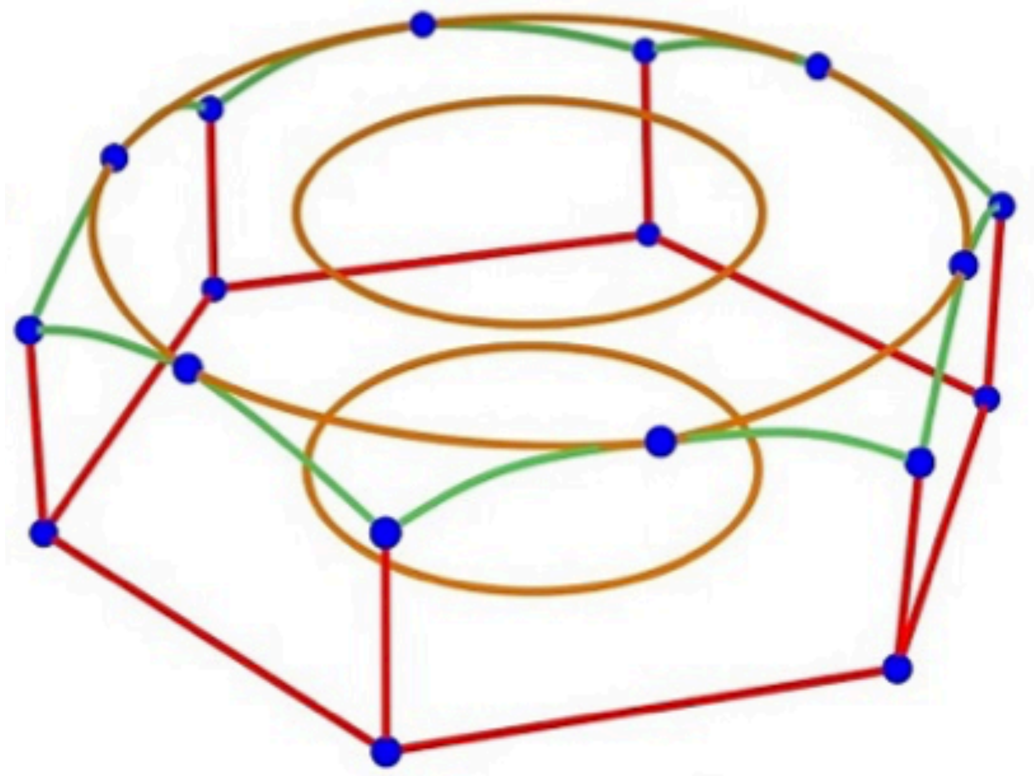
- But what about edge detection for 3D data?

Edge Detection for 3D Point Clouds

- **Input**
  - 3D Point Cloud - collection of xyz points $\{(x_i, y_i, z_i)\}$
- **Output**
  - Edges, represented as parametric curves (lines, circles, B-splines)



Input point cloud



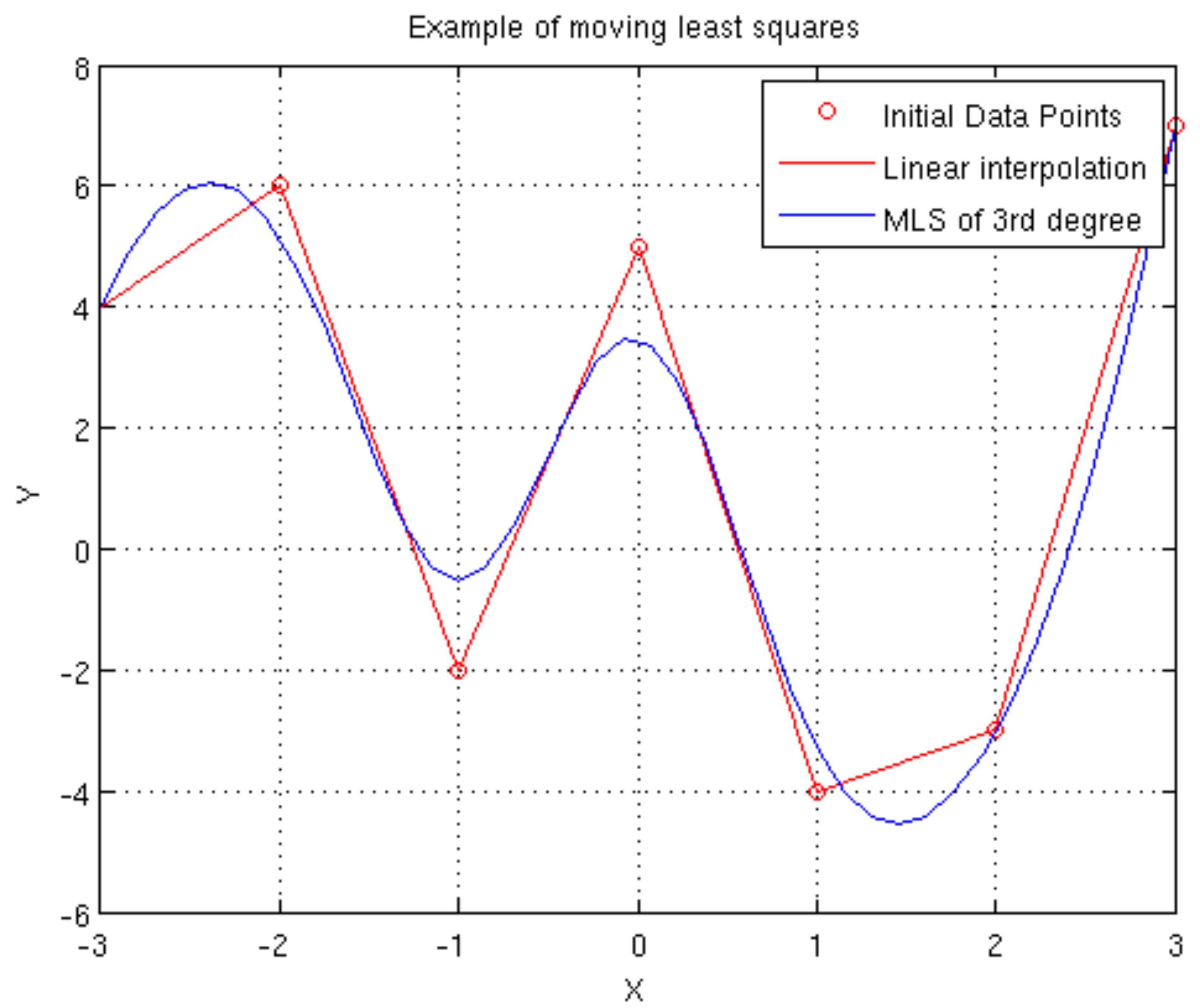
Curve Result

Related Work

- **Edge Feature Detection**
  - Analyze local geometric properties (e.g. normals, curvatures)
  - Reconstruct Moving Least Squares (MLS) surface from point cloud

$$S = \{(x_i, f_i) | f(x_i) = f_i\}$$

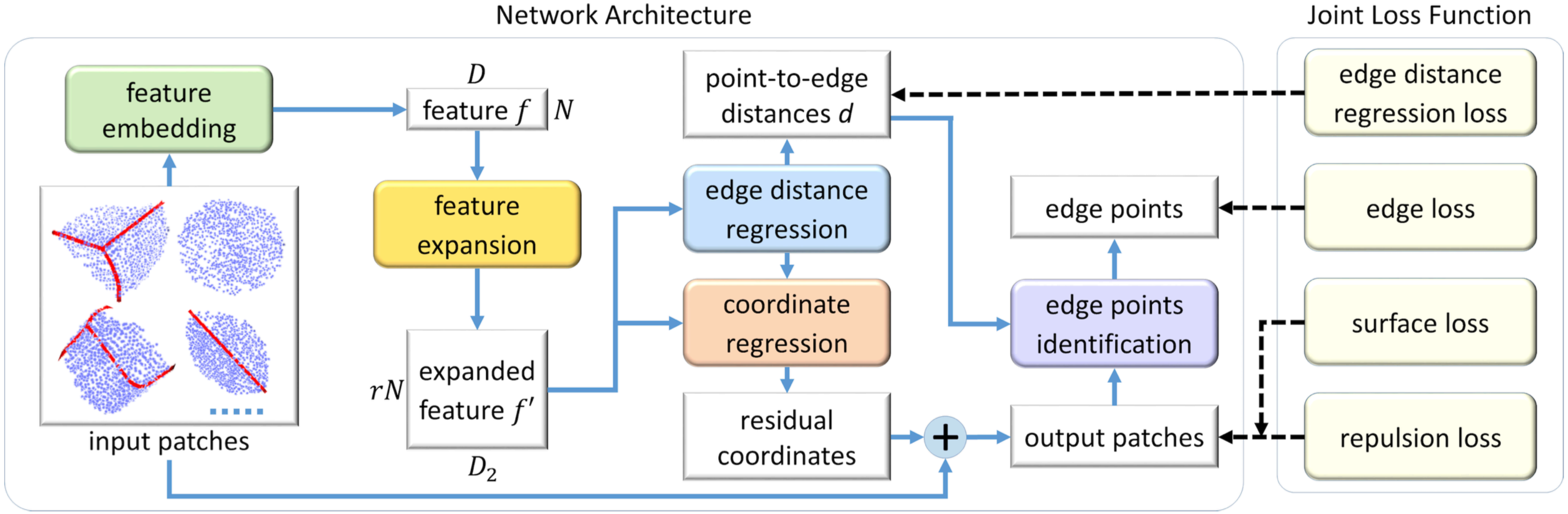
$$\sum_{i \in I} (p(x_i) - f_i)^2 \theta(\|x - x_i\|)$$



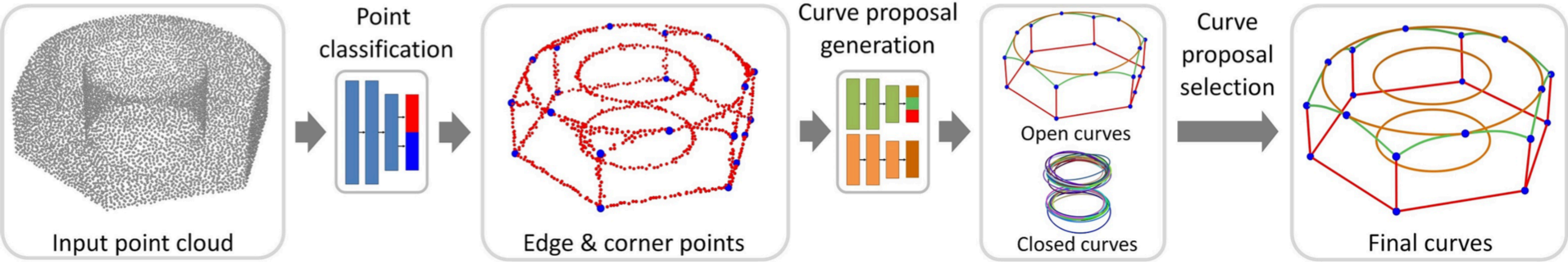
  - Extract feature curves from reconstructed MLS

Related Work

- **Edge Feature Detection**
  - Point cloud segmentation network on local geometric features
  - EC-Net [Yu et al. 2018]
    - Point classification + predict per-point distance to edge
    - Edge points = points with zero distance to edge



Overall Approach

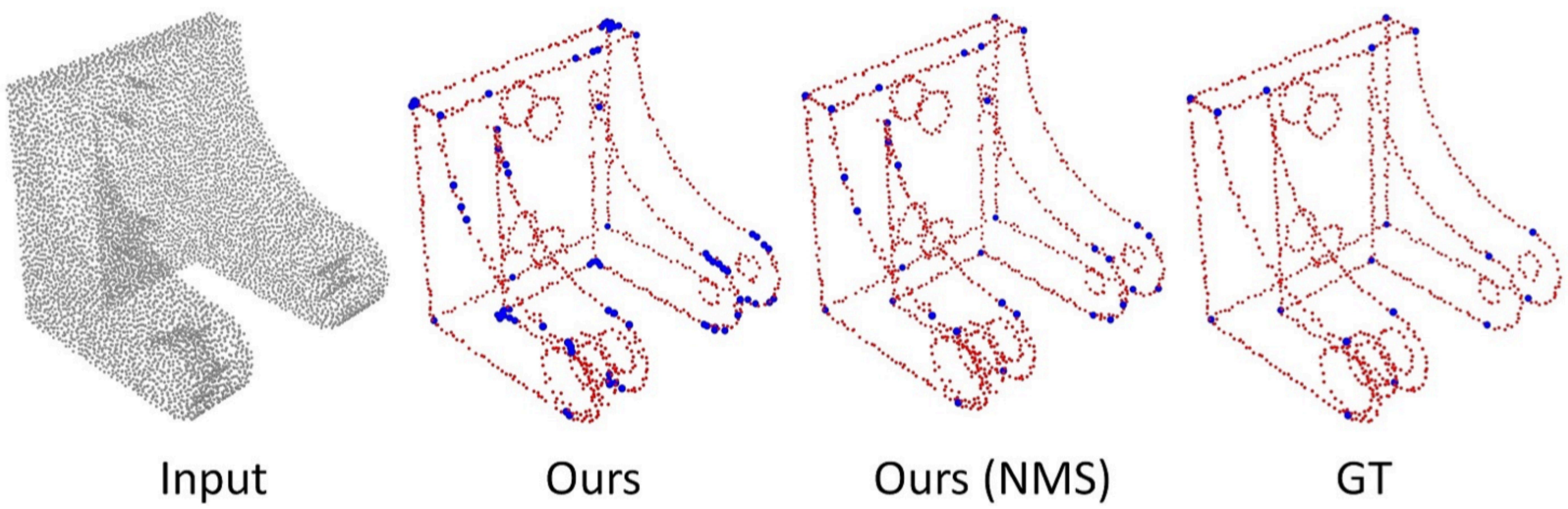


Point Classification

- PointNet++ Classification Networks
  - Predict probability of corner and probability of edge
  - Predict offset vector to corner or edge

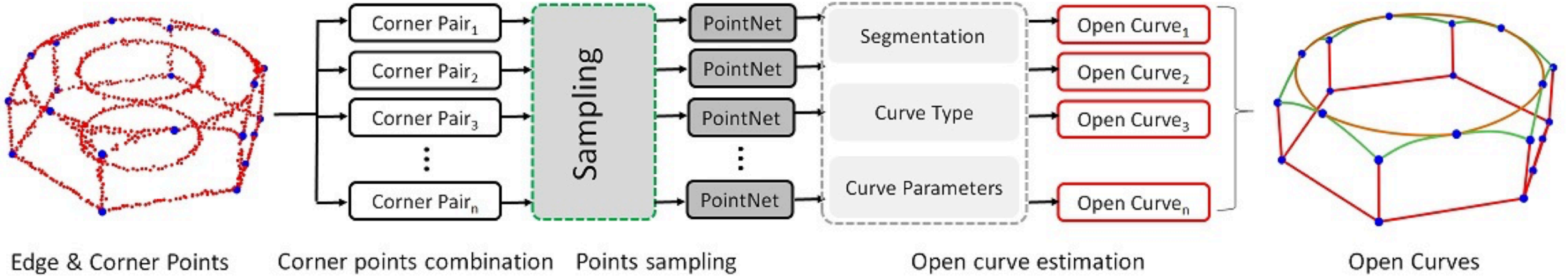
$$\mathcal{L}_{\text{edge}} = \mathcal{L}_{\text{cls}}(T_e, \hat{T}_e) + \hat{T}_e \cdot \lambda_e \mathcal{L}_{\text{reg}}(D_e, \hat{D}_e),$$
$$\mathcal{L}_{\text{corner}} = \mathcal{L}_{\text{cls}}(T_c, \hat{T}_c) + \hat{T}_c \cdot \lambda_c \mathcal{L}_{\text{reg}}(D_c, \hat{D}_c),$$

  - Perform post-processing clustering to clean up predictions



Curve Proposal

- Generate all pairs of corner points
- Sample edge points in between each pair of corner points
- For each corner pair, predict:
  - Segmentation — whether each point belongs to the curve or not
  - Curve Type — line, circle, or B-spline
  - Curve Parameters — parameterization for the curve type

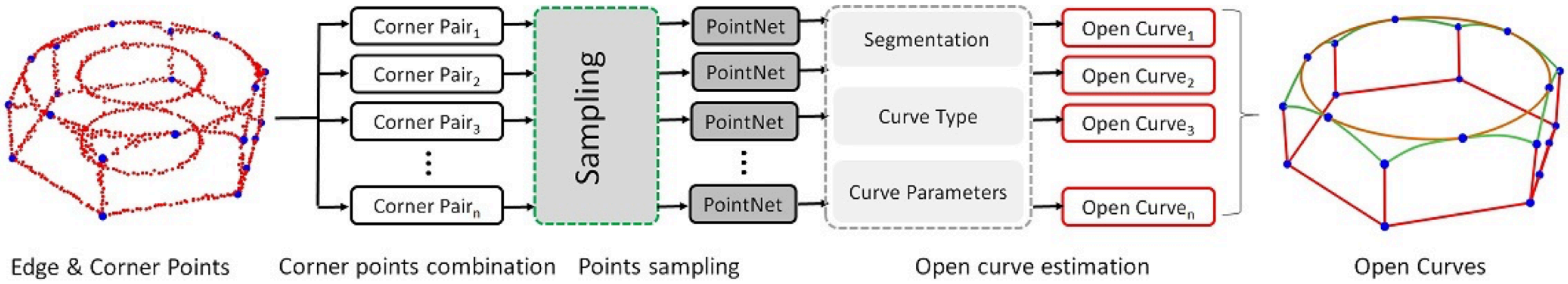


Curve Proposal

- Training Losses

$$\mathcal{L}_{\text{proposal}} = w_{\text{m}}\mathcal{L}_{\text{mask}}(M_p, \hat{M}_p) + w_{\text{c}}\mathcal{L}_{\text{cls}}(T_p, \hat{T}_p) + w_{\text{p}}\mathcal{L}_{\text{para}}(\beta),$$

$$\mathcal{L}_{\text{para}} = \hat{T}_{\text{circle}} \cdot \mathcal{L}_{\text{circle}}(\beta) + \hat{T}_{\text{line}} \cdot \mathcal{L}_{\text{line}}(\beta) + \hat{T}_{\text{spline}} \cdot \mathcal{L}_{\text{spline}}(\beta),$$



Dataset and Metrics

- ABC Dataset — large collection of 3D CAD models

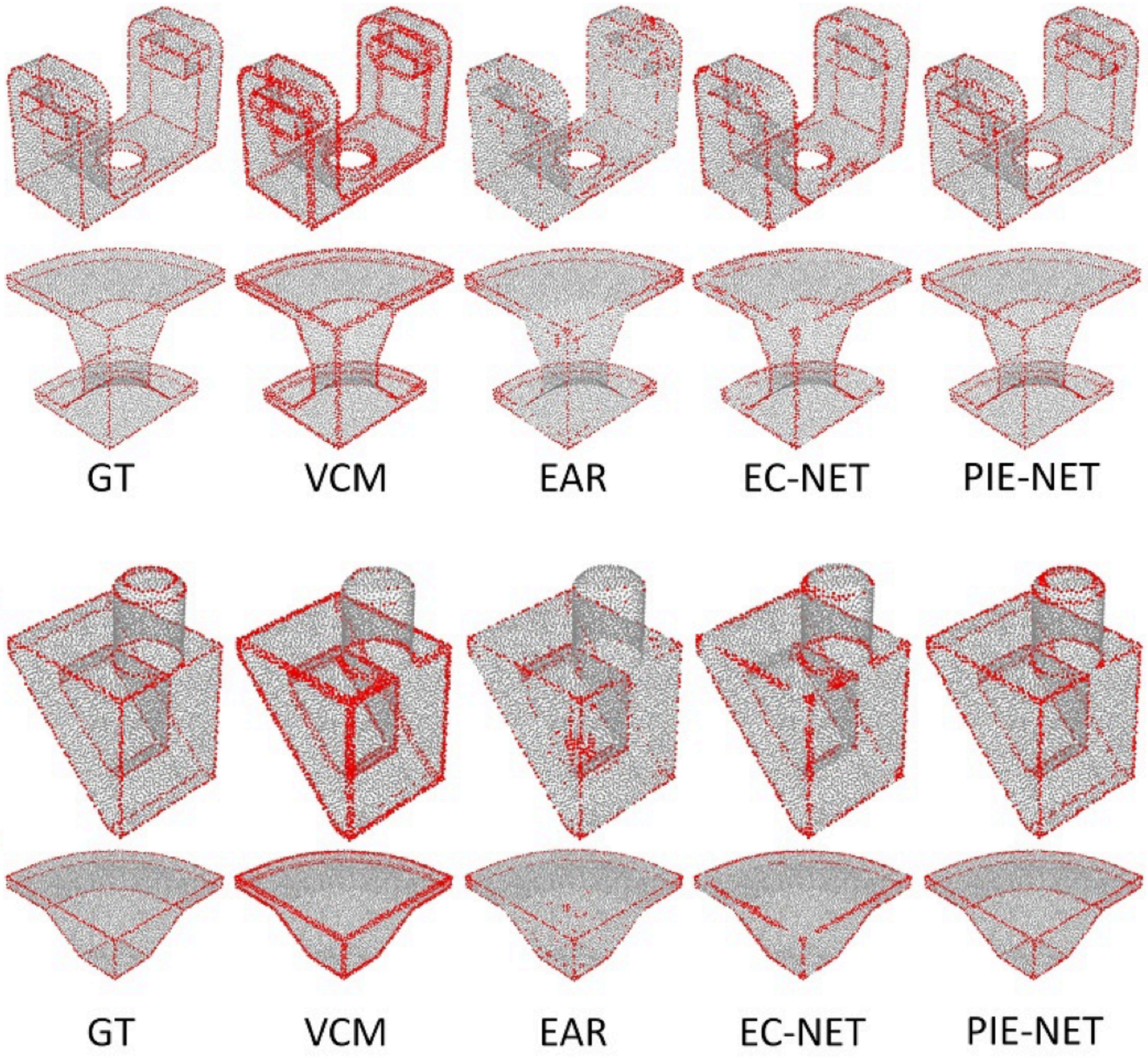
- Edge Classification
  - Precision & Recall — measure of true positives
  - IoU — intersection / union of two sets
- Geometric Accuracy of Edges
  - Edge Chamfer Distance

Quantitative Results

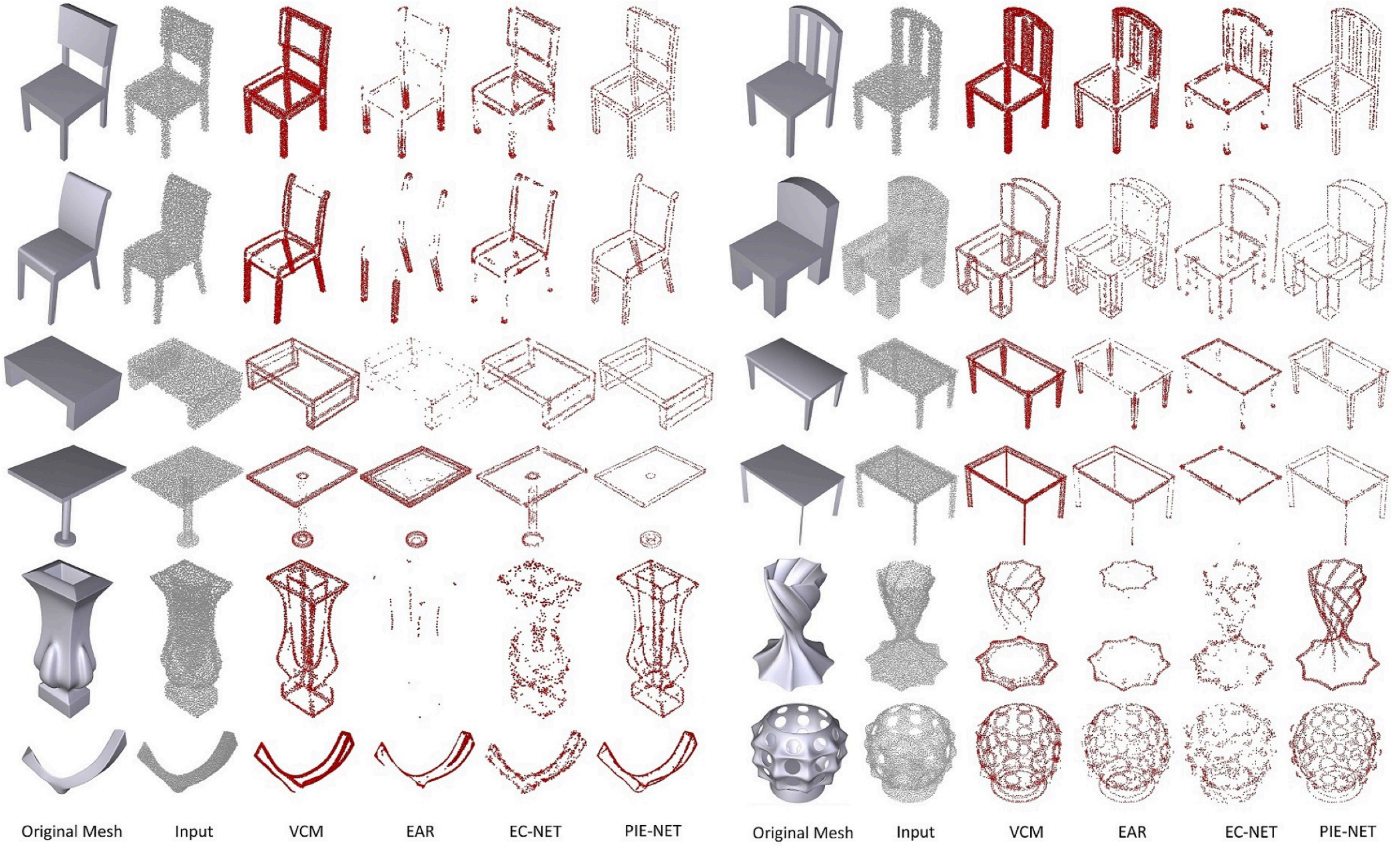
	VCM			EAR			EC-Net	PIE-NET
	τ=0.12	τ=0.17	τ=0.22	τ=0.03	τ=0.035	τ=0.04		
ECD ↓	0.0321	0.0430	0.0569	0.0679	0.0696	0.0864	0.0360	**0.0088**
IOU ↑	0.2841	0.2854	0.2855	0.3404	0.3250	0.2844	0.3561	**0.6223**
Precision ↑	0.3063	0.3244	0.3456	0.5560	0.4149	0.6523	0.4872	**0.6918**
Recall ↑	0.8385	0.7644	0.6937	0.4820	0.5910	0.3578	0.5736	**0.8584**

- Voronoi Covariance Measure (VCM) and Edge Aware Resampling (EAR)
    - Classical non-learning methods
- EC-Net [Yu et al. 2018]
    - Neural network approach

Qualitative Results



Qualitative Results (unseen shapes)



Takeaways

- Edge detection on 2D images is a well studied problem, but the 3D point cloud setting is still relatively new
- Proposes a new learning-based method that outperforms previous works
  - Requires less domain-specific knowledge to analyze geometric features
- Future work — consider other approaches of identifying salient edge features, such as using attention and transformers