ETH zürich

NEURAL INFORMATION PROCESSING SYSTEMS

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Shape As Points

A Differentiable Poisson Solver

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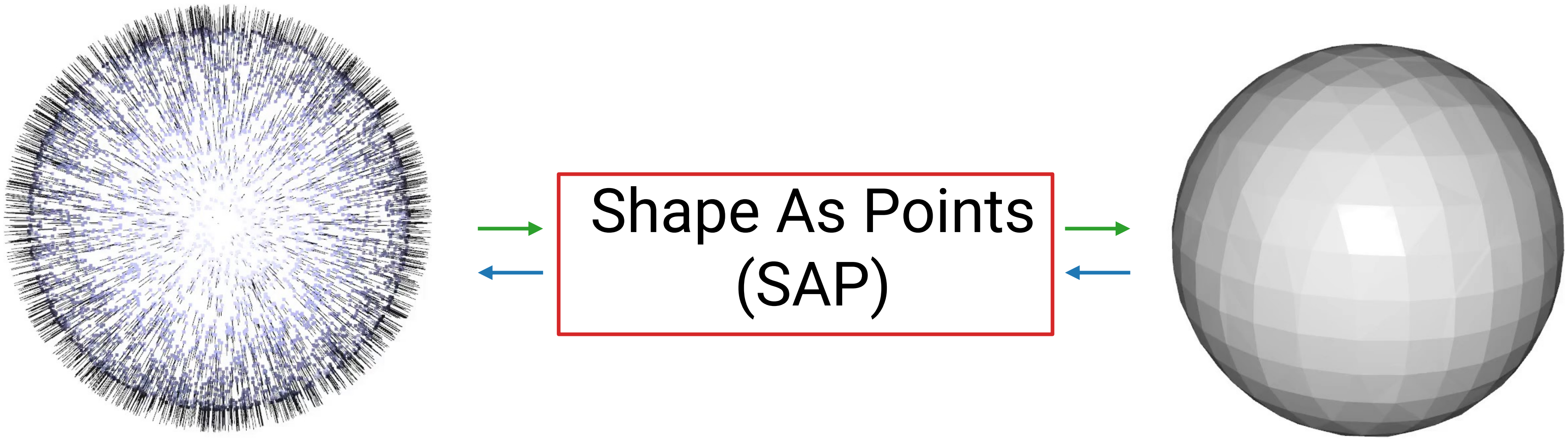
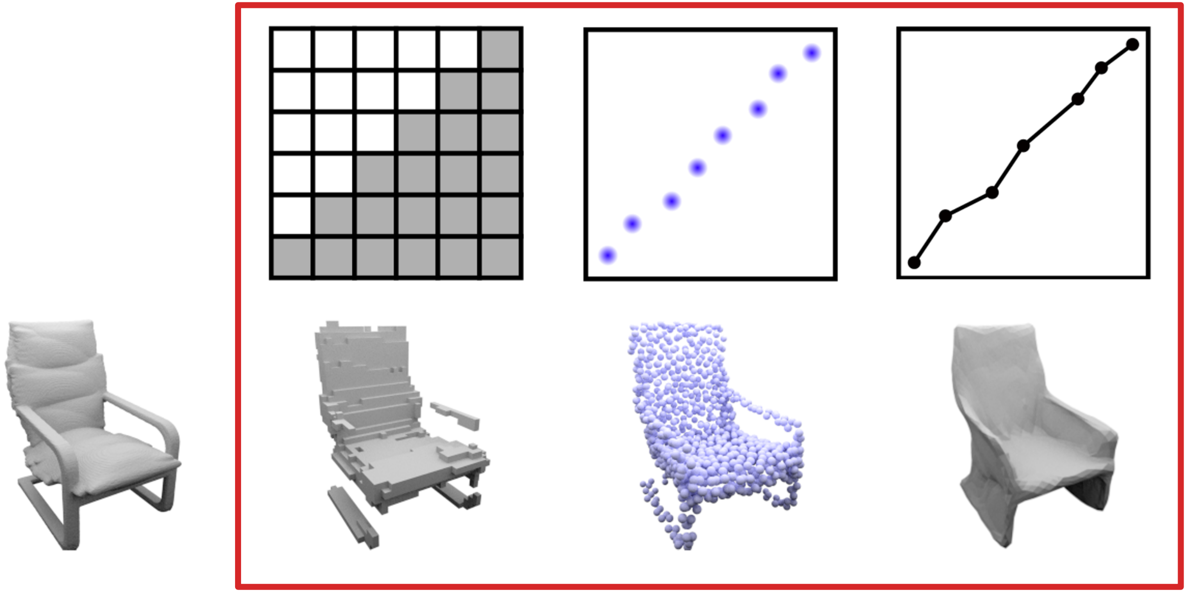
GAMES Seminar



Duality between **oriented point clouds** and **3D dense geometry**

What is a good **3D shape representation**?

3D Shape Representations

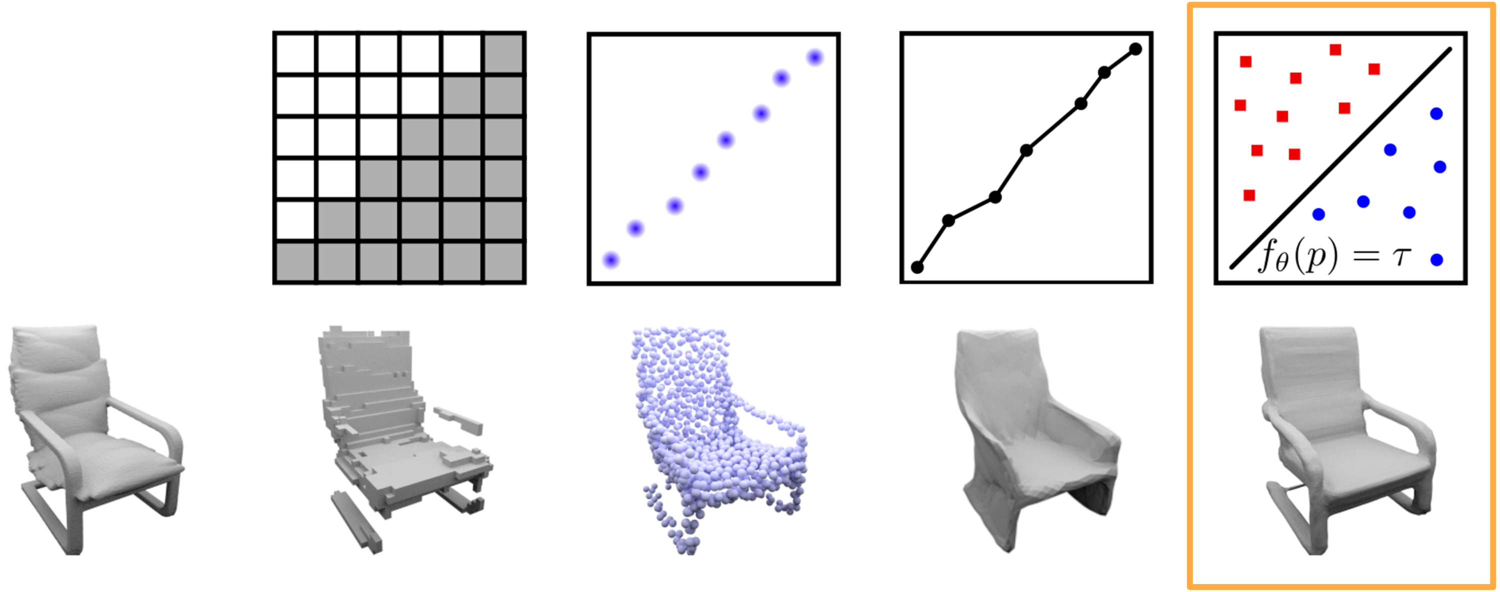


Traditional Explicit Representations

- ✚ Fast inference
- ▬ Discrete

Mescheder, Oechsle, Niemeyer, Nowozin and Geiger: Occupancy Networks: Learning 3D Reconstruction in Function Space. CVPR, 2019

3D Shape Representations

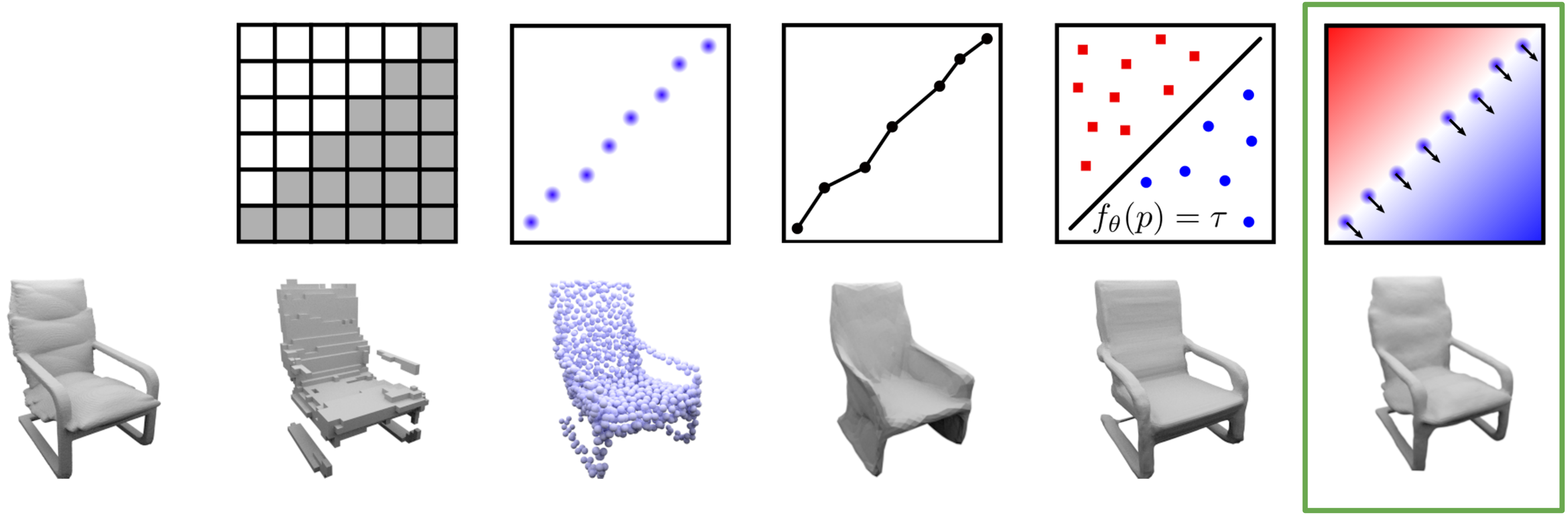


Neural Implicit Representations

- ➕ Continuous, watertight
- ➖ Slow inference
- ➖ Difficult to initialize

Mescheder, Oechsle, Niemeyer, Nowozin and Geiger: Occupancy Networks: Learning 3D Reconstruction in Function Space. CVPR, 2019

3D Shape Representations



Shape As Points (SAP) - Hybrid Representation

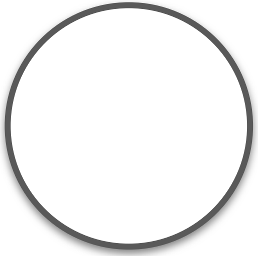
- ✚ Discrete ⇒ Continuous
- ✚ Fast inference
- ✚ Easy initialization, topology-agnostic

Method

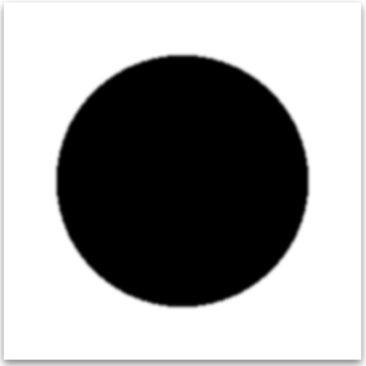
Differentiable Poisson Solver

Intuition of Poisson Equation

$$\nabla^2 \chi := \nabla \cdot \nabla \chi = \nabla \cdot \mathbf{v}$$



Shape



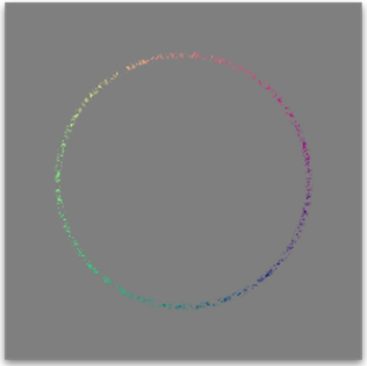
χ

Indicator Function

$\nabla \chi$

Gradient

$\approx$



$\mathbf{v}$

Point Normals

Our Poisson Solver

$$\nabla^2 \chi := \nabla \cdot \nabla \chi = \nabla \cdot \mathbf{v}$$

- **Discretization** allows to invert the divergence operator

$$\chi = (\nabla^2)^{-1} \nabla \cdot \mathbf{v}$$

- **Spectral methods** to solve the Poisson equation
  - Derivatives of signals in spectral domain are computed analytically
  - Fast Fourier Transform (FFT) are **highly optimized on GPUs/TPUs**
  - Only **25-line code**

$$\tilde{\mathbf{v}} = \mathrm{FFT}(\mathbf{v}) \longrightarrow \tilde{\chi} = \tilde{g}_{\sigma,r}(\mathbf{u}) \odot \frac{i\mathbf{u} \cdot \tilde{\mathbf{v}}}{-2\pi \|\mathbf{u}\|^2} \longrightarrow \chi' = \mathrm{IFFT}(\tilde{\chi})$$

Surface Reconstruction from Unoriented Point Clouds

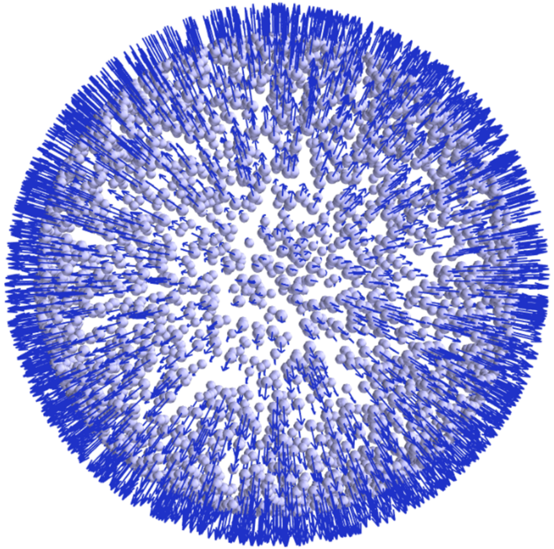
1. SAP for **Optimization-based** 3D Reconstruction
2. SAP for **Learning-based** 3D Reconstruction

SAP for Optimization-based 3D Reconstruction

Pipeline - Forward Pass

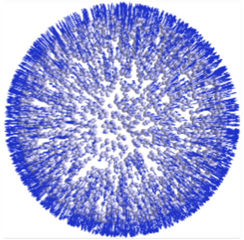
Input an initial oriented point cloud

(noisy / incomplete observations)

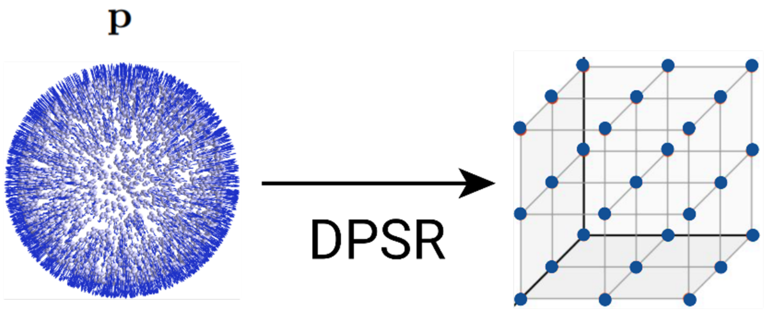


Pipeline - Forward Pass

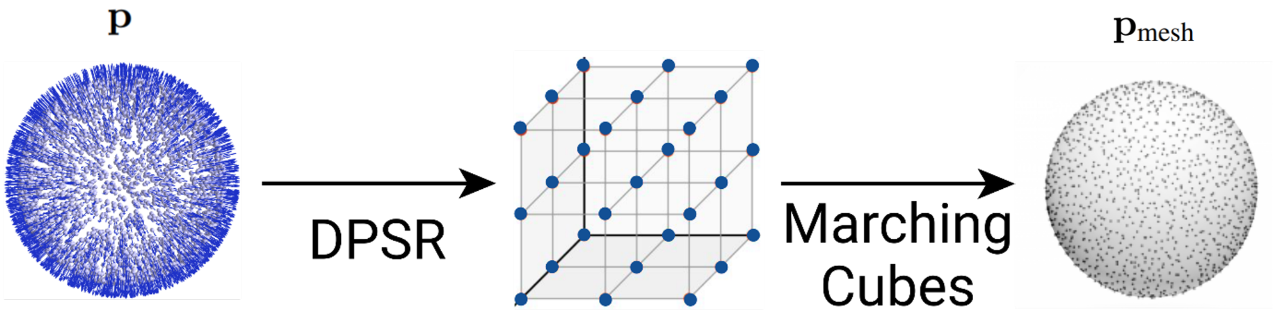
$\mathbf{p}$



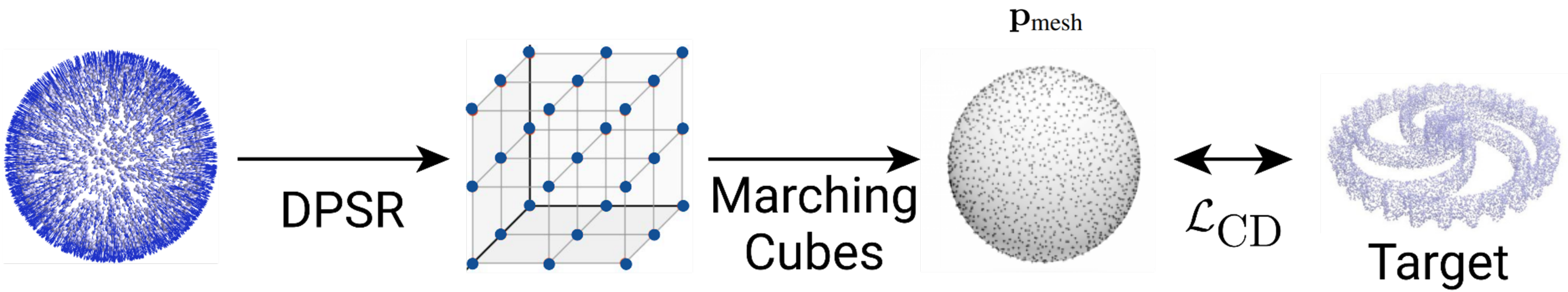
Pipeline - Forward Pass



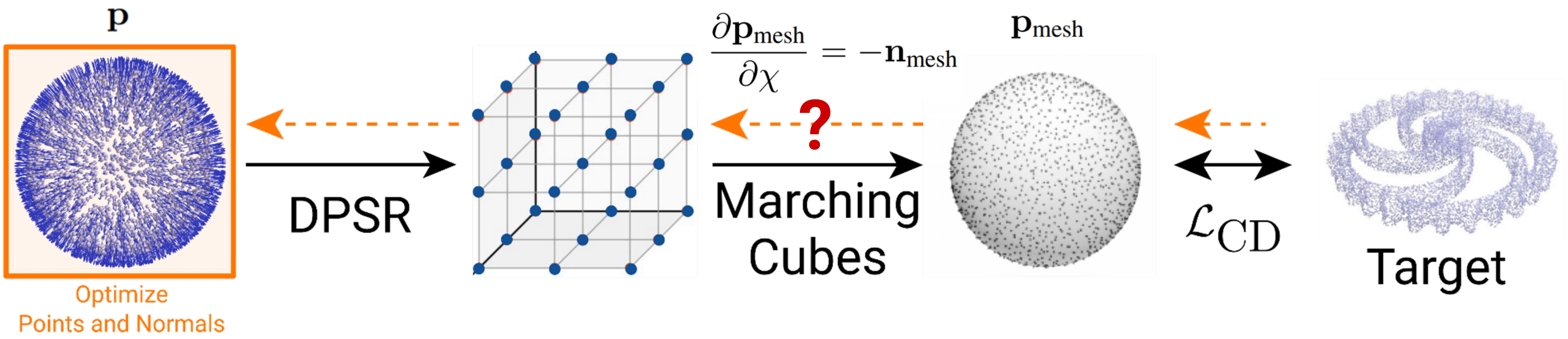
Pipeline - Forward Pass



Pipeline - Forward Pass



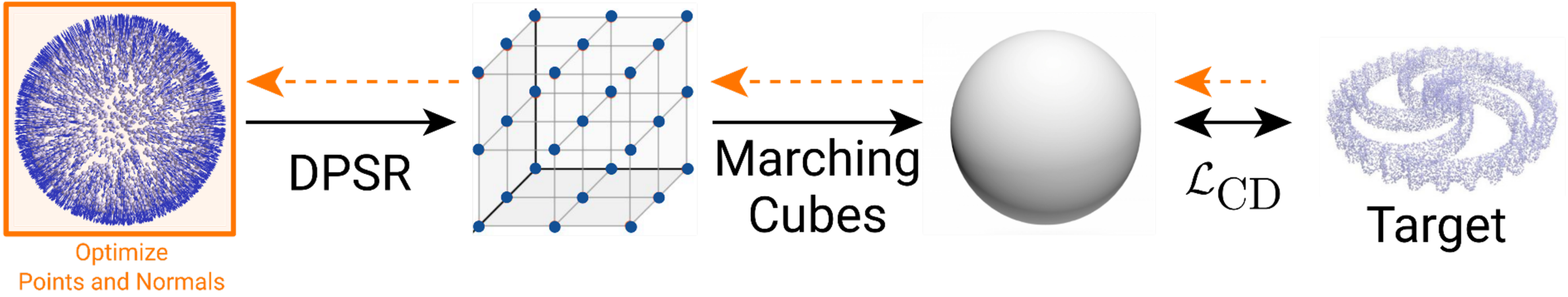
Pipeline - Backward Pass



$$\frac{\partial \mathcal{L}_{\text{CD}}}{\partial \mathbf{p}} = \frac{\partial \mathcal{L}_{\text{CD}}}{\partial \mathbf{p}_{\text{mesh}}} \frac{\partial \mathbf{p}_{\text{mesh}}}{\partial \chi} \frac{\partial \chi}{\partial \mathbf{p}}$$

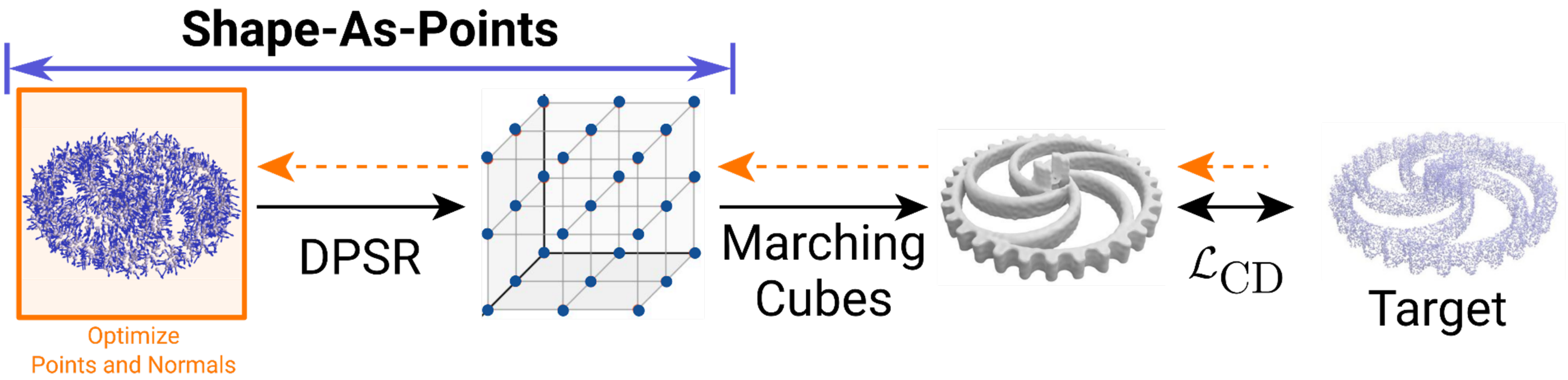
?

Pipeline

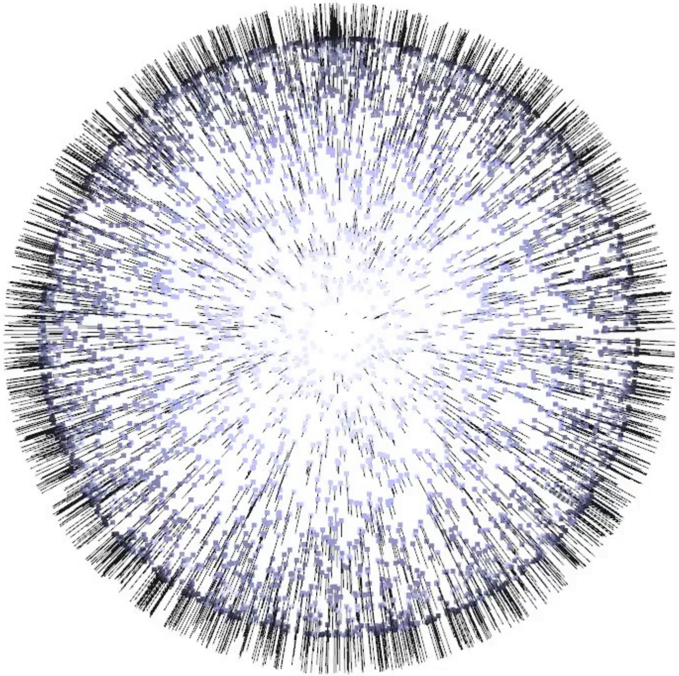


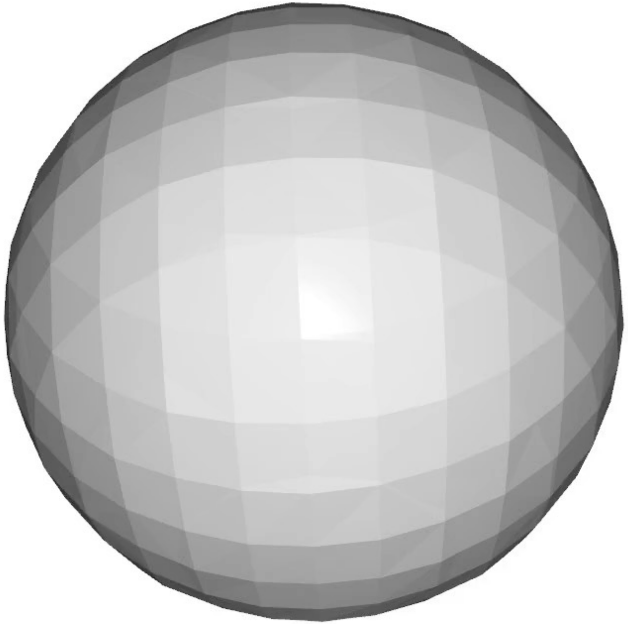
DPSR
Marching
Cubes
$\mathcal{L}_{\text{CD}}$
Target
Optimize
Points and Normals

Pipeline

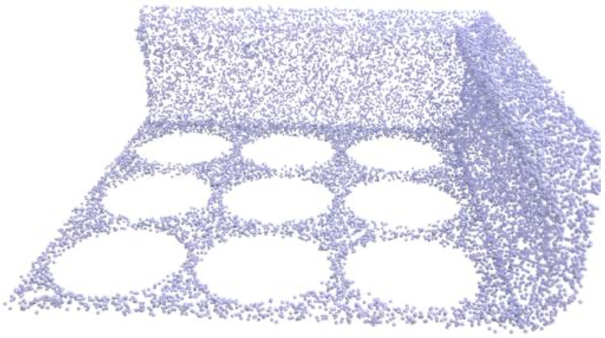


Shape-As-Points
DPSR
Marching Cubes
$\mathcal{L}_{\mathrm{CD}}$
Target
Optimize
Points and Normals





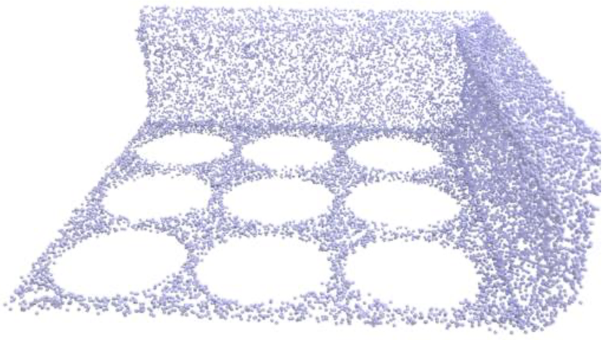
Comparison



Unoriented Point Clouds

GT Mesh

Comparison



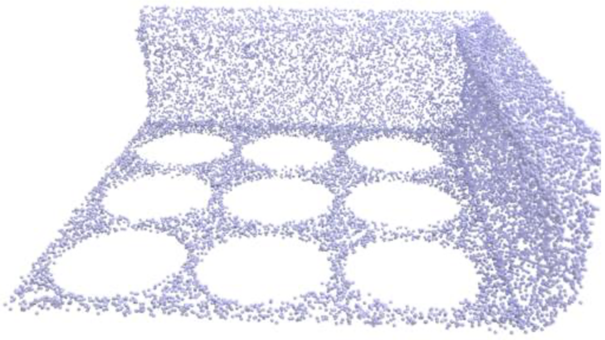
Unoriented Point Clouds

Point2Mesh

Runtime: 62 mins

Hanocka, Metzer, Giryes, Cohen-Or: Point2Mesh: A Self-Prior for Deformable Meshes. SIGGRAPH, 2020

Comparison



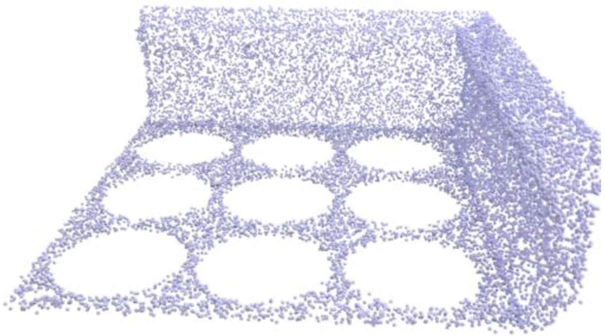
Unoriented Point Clouds

IGR

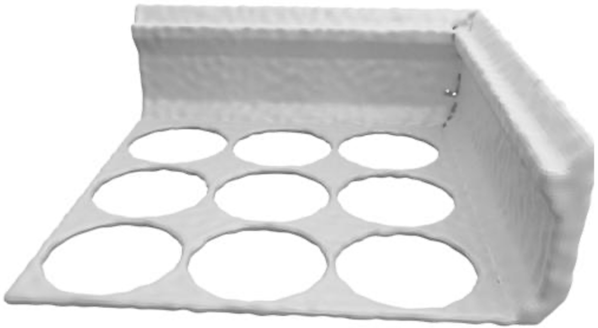
Runtime: 30 mins

Gropp, Yariv, Haim, Atzmon and Lipman: Implicit Geometric Regularization for Learning Shapes. ICML, 2020

Comparison



Unoriented Point Clouds



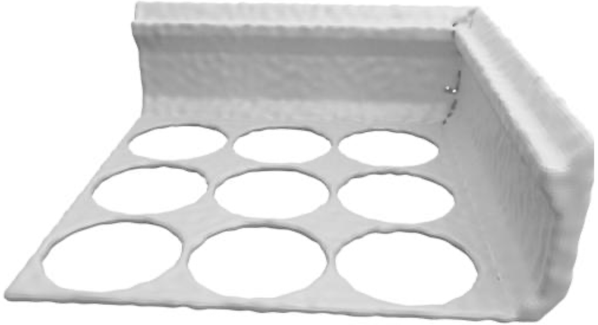
SAP

Runtime: ~6 mins

Comparison

SPSR

Runtime: ~9 sec



SAP

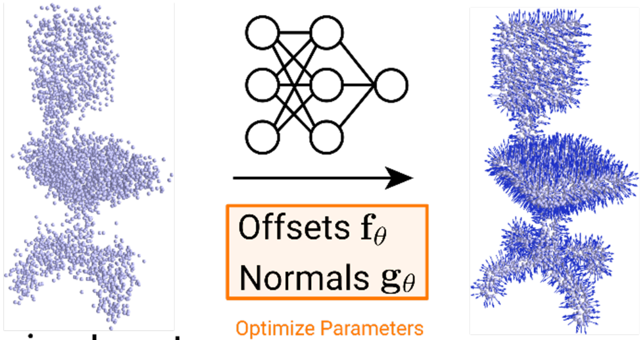
Runtime: ~6 mins

Kazhdan and Hoppe: Screened Poisson Surface Reconstruction. SIGGRAPH, 2013

Can we further leverage the **differentiability** of the Poisson solver for **deep neural networks**?

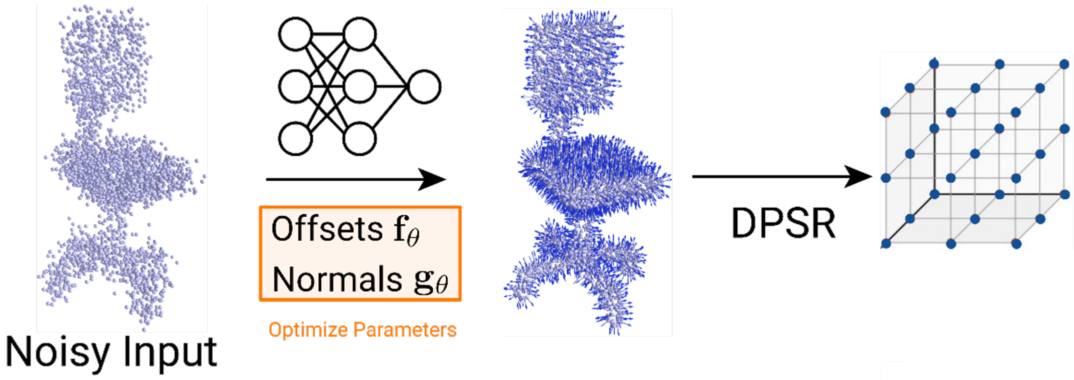
SAP for Learning-based 3D Reconstruction

Learning-based Pipeline

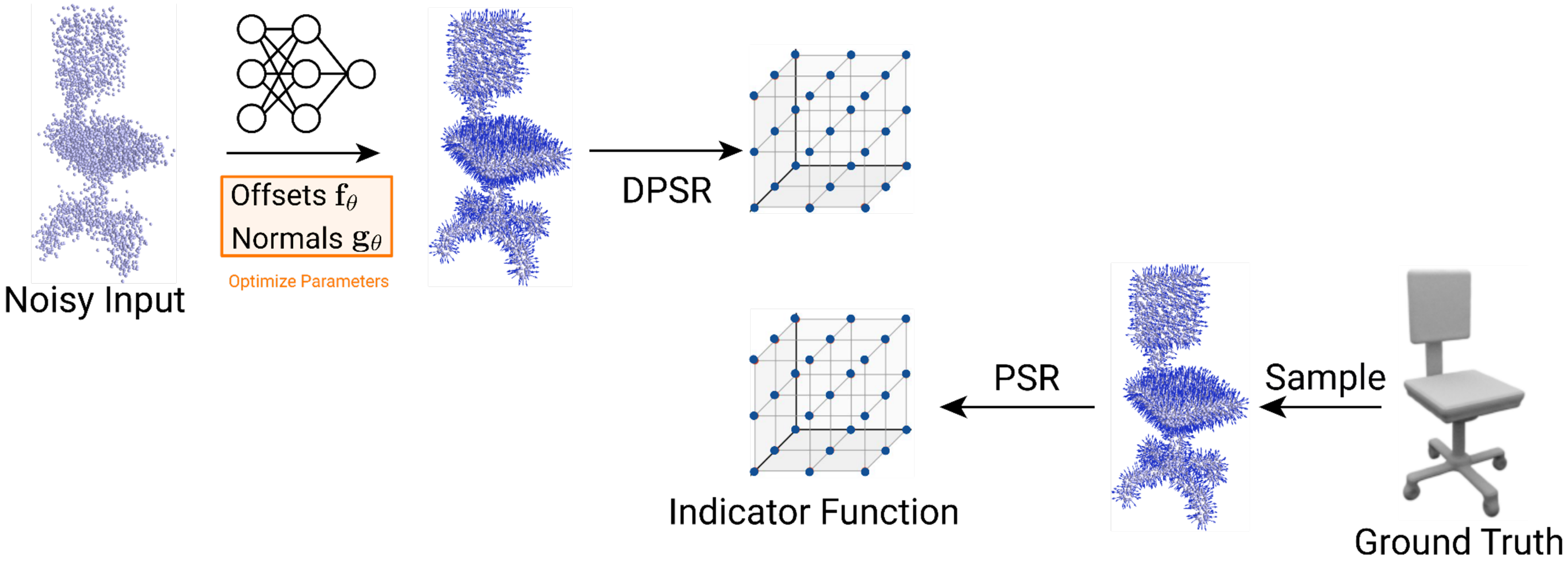


Noisy Input

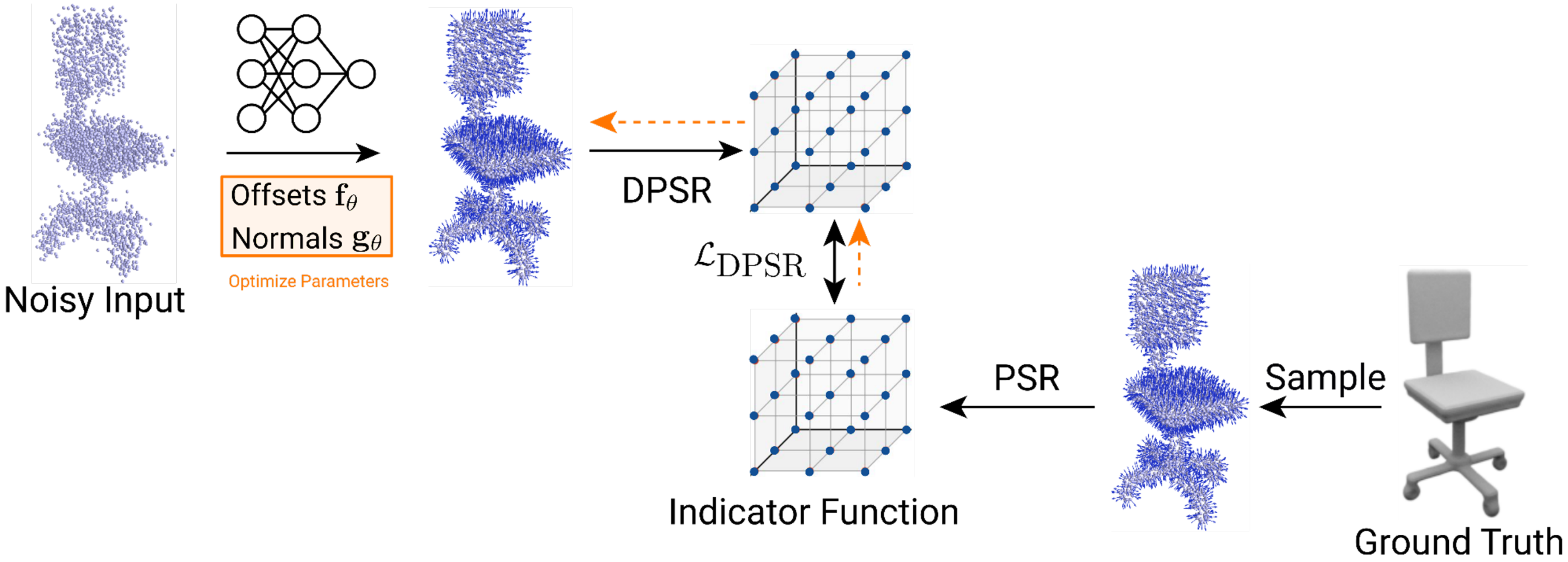
Learning-based Pipeline



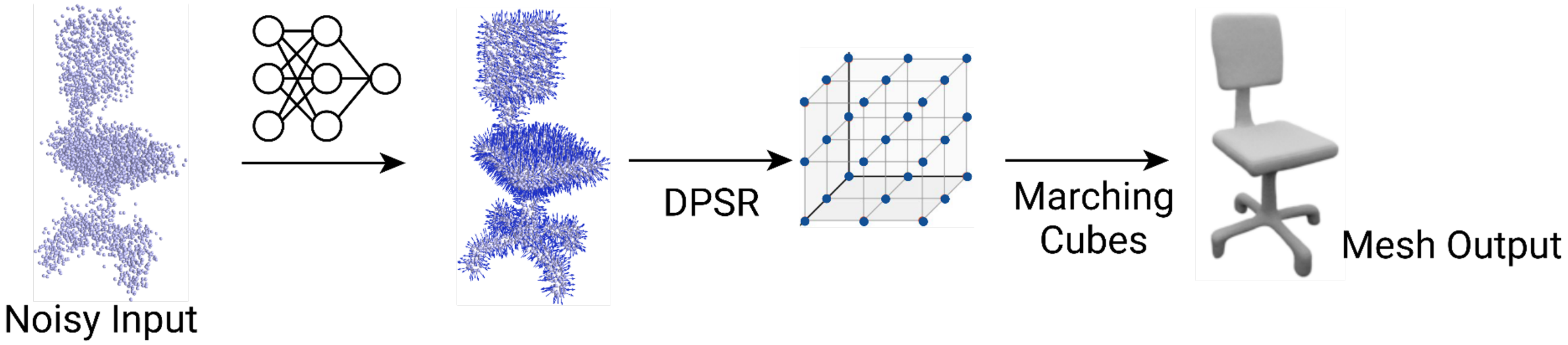
Learning-based Pipeline



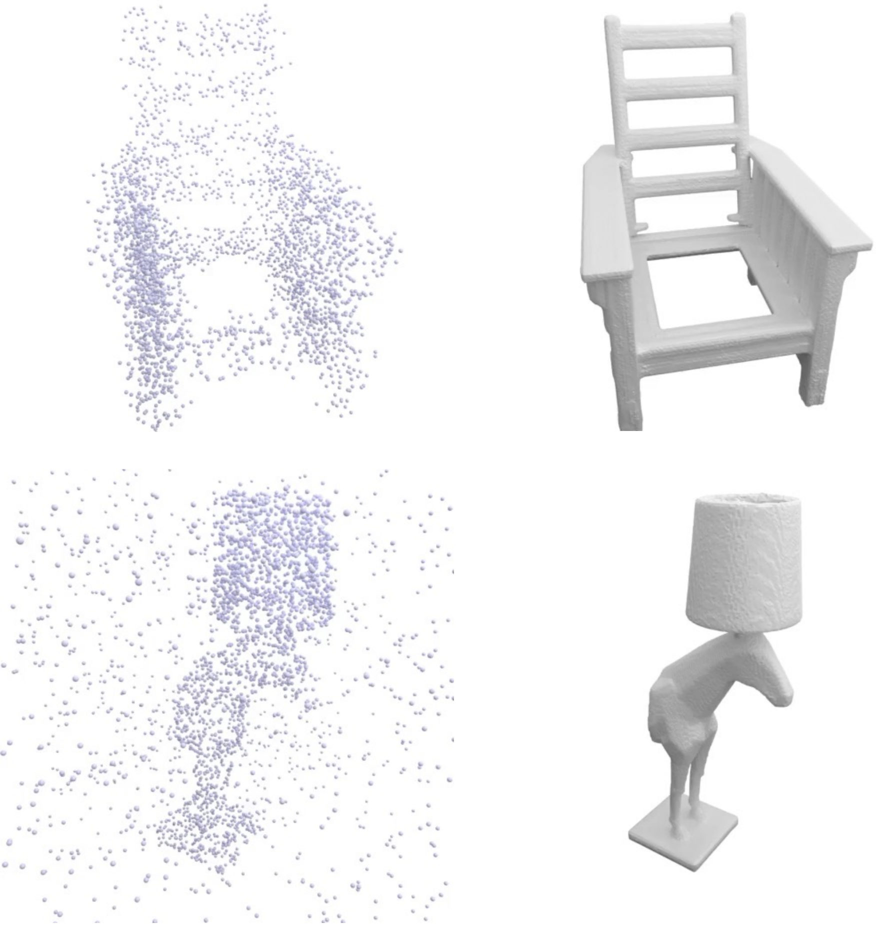
Learning-based Pipeline



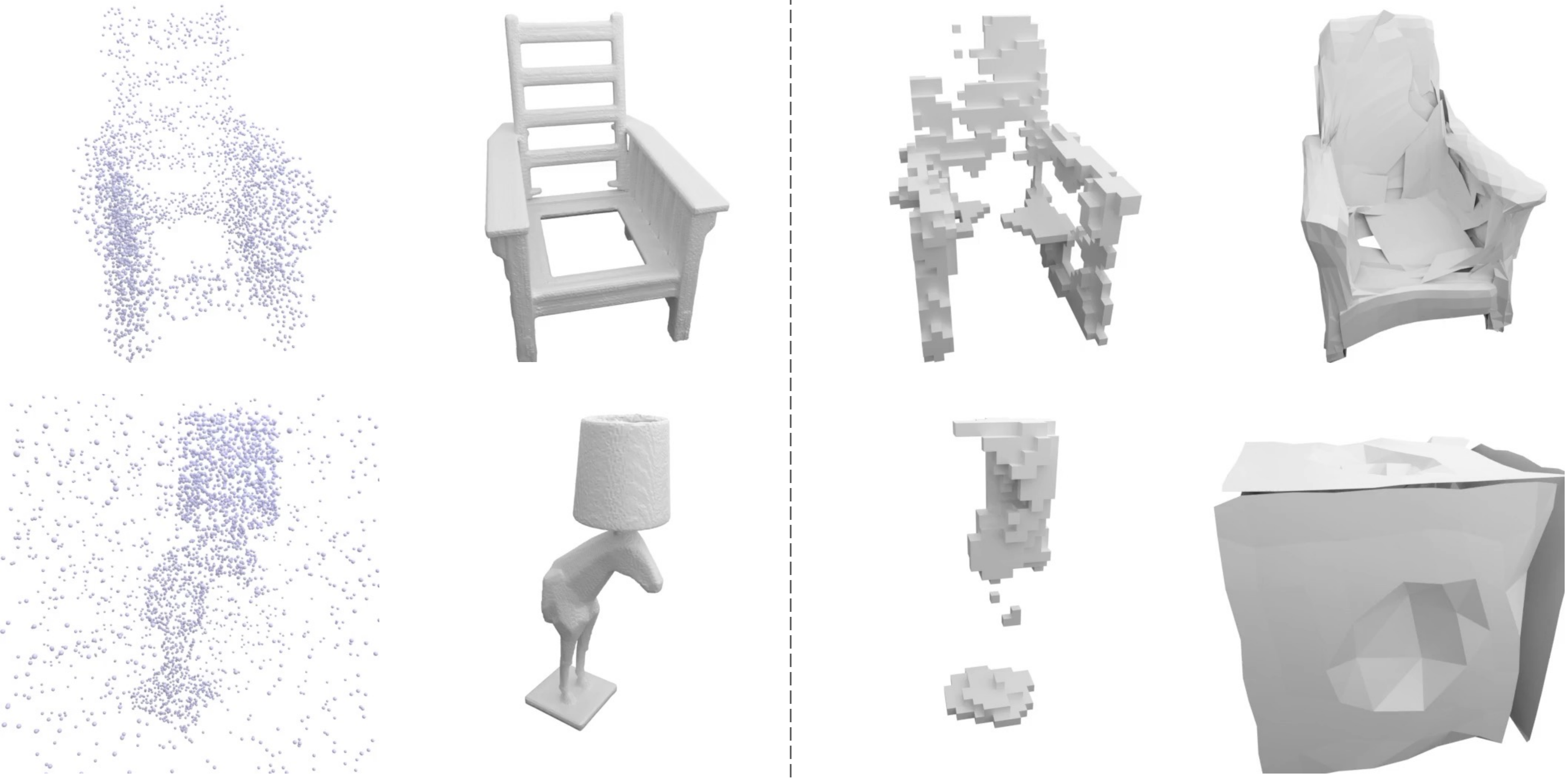
Learning-based Pipeline



Results



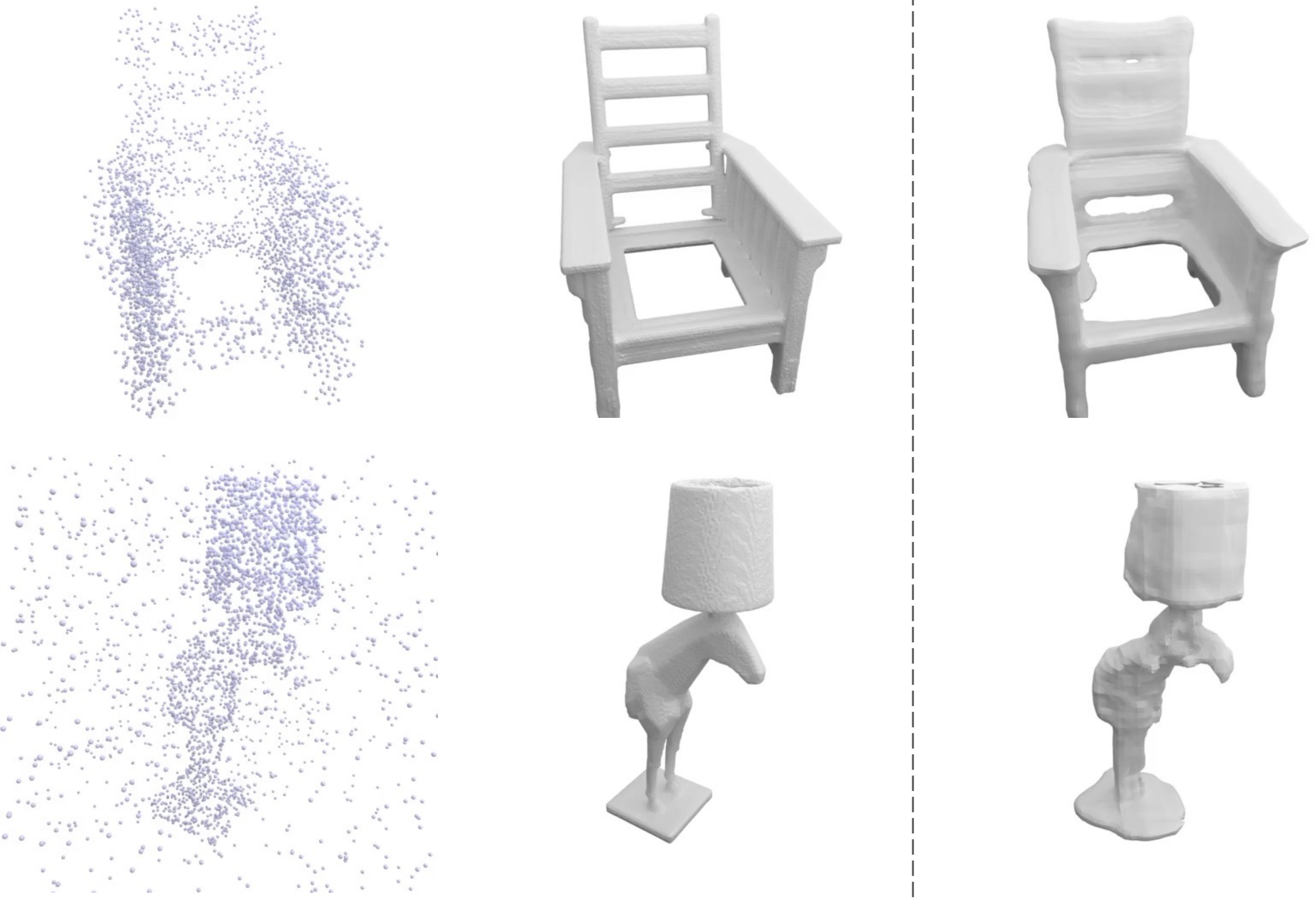
Inputs GT Mesh



Inputs | GT Mesh | R2N2 | AtlasNet

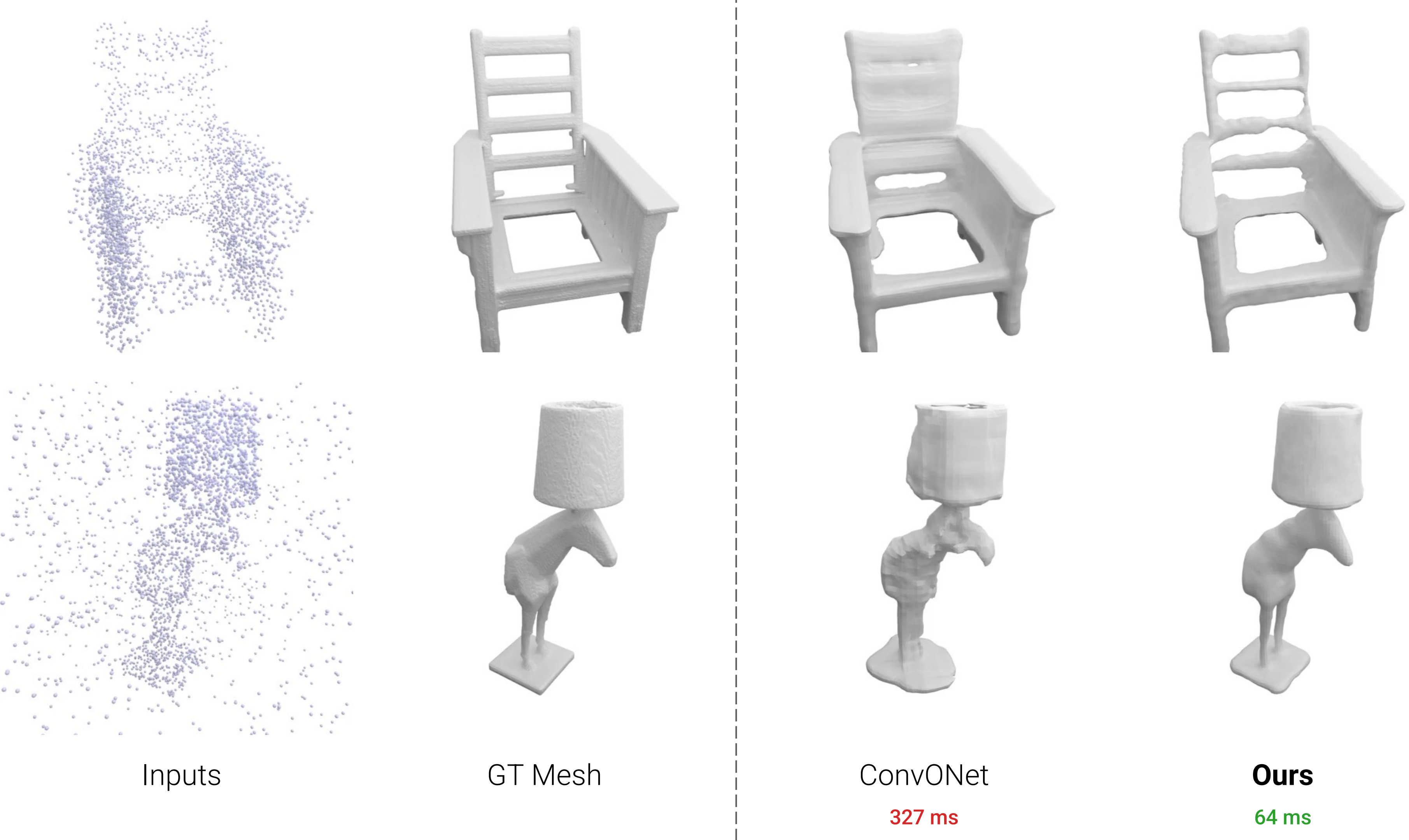
R2N2: **15 ms**

AtlasNet: **25 ms**

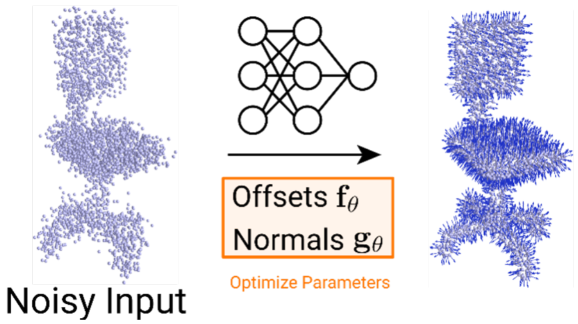


Inputs GT Mesh ConvONet

327 ms


Inputs
GT Mesh
ConvONet
327 ms
Ours
64 ms

Benefit of Geometric Initialization



Chamfer distance over the training process

Iterations	10K	50K	100K	200K	Best
ConvONet	0.082	0.058	0.055	0.050	0.044
Ours	**0.041**	**0.036**	**0.035**	**0.034**	**0.034**

SAP converges much faster!

Conclusions

- SAP is **interpretable**, **lightweight** and guarantees **HQ watertight meshes**
- SAP is also **topology agnostic**, enables **fast inference**
- Our Poisson solver is **differentiable** and **GPU-accelerated**

Limitation: Cubic memory requirements limits SAP for small scenes

Thank You!

https://pengsongyou.github.io/sap