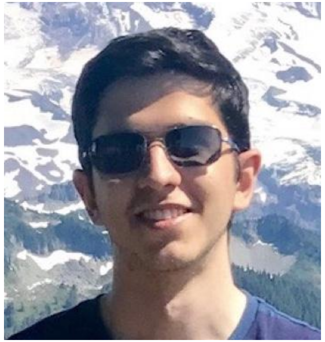
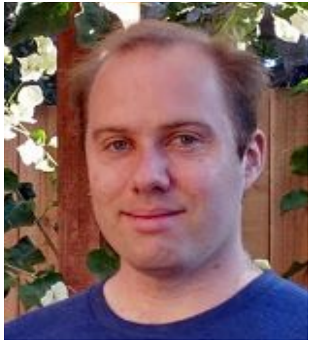
Coupling Explicit and Implicit Surface Representations for Generative 3D Modeling

Omid Poursaeed Matthew Fisher Noam Aigerman Vladimir G. Kim

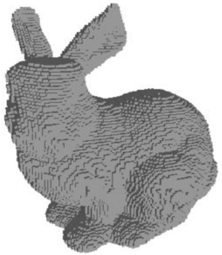



Representing 3D Shapes

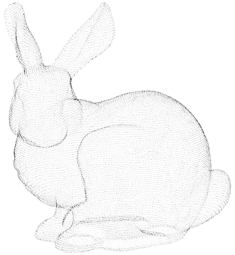
Discretized representations

- ❏ Fixed sampling density

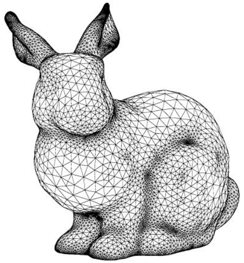
Voxel grid



Point Cloud



Mesh

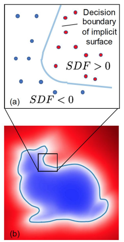


Continuous representations

- ❏ Arbitrary resolution

Surface Atlas

Implicit Function



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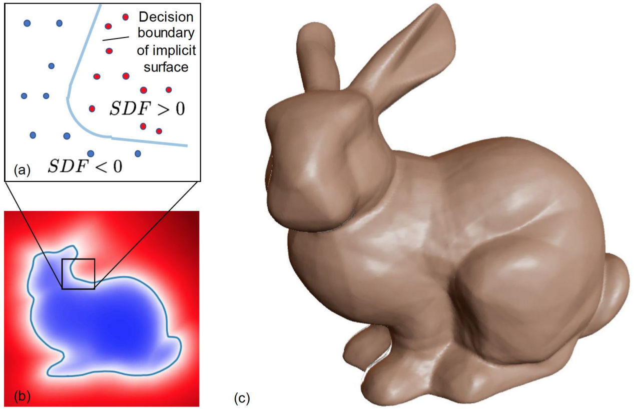
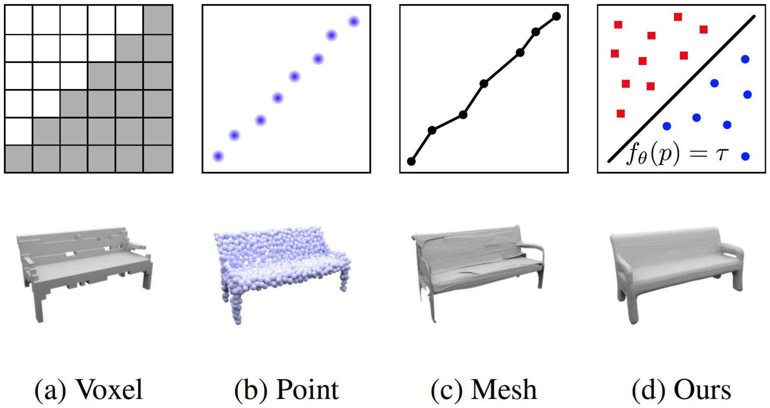
Implicit Functions

Map each 3D point to inside/outside the shape





DeepSDF: Learning Continuous Signed Distance Functions for Shape Representation, Park et al., CVPR 2019

Occupancy Networks: Learning 3D Reconstruction in Function Space, Mescheder et al., CVPR 2019

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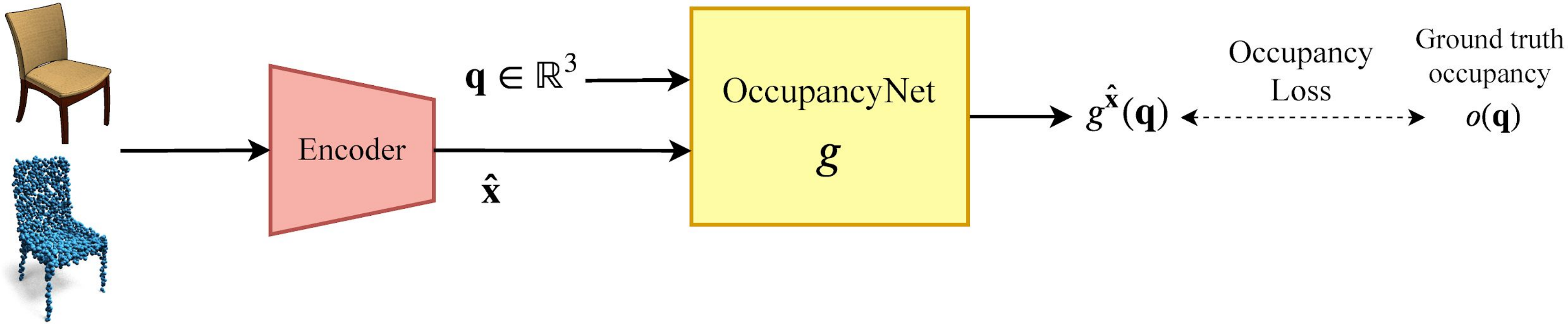
Implicit Functions

OccupancyNet: $g^{\hat{\mathbf{x}}} : \mathbb{R}^3 \rightarrow [0, 1]$ (Occupancy Probability)



τ : Surface threshold

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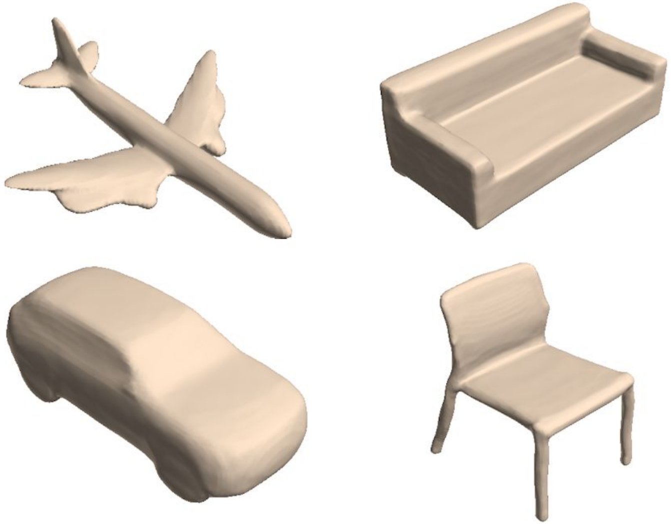
Implicit Functions

OccupancyNet results

+ Smooth
- Fail to capture details
- Slow rendering (Marching Cubes)



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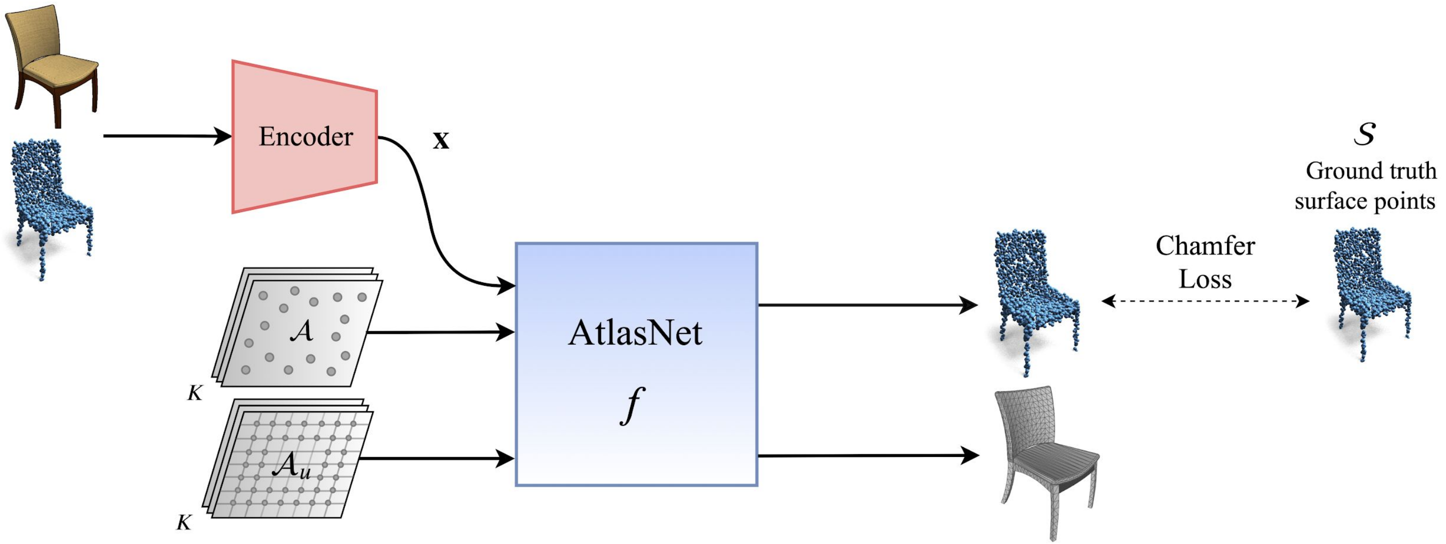
Surface Atlas

AtlasNet: maps points on 2D patches to the surface $f_i^{\mathbf{x}} : [0, 1]^2 \to \mathbb{R}^3$



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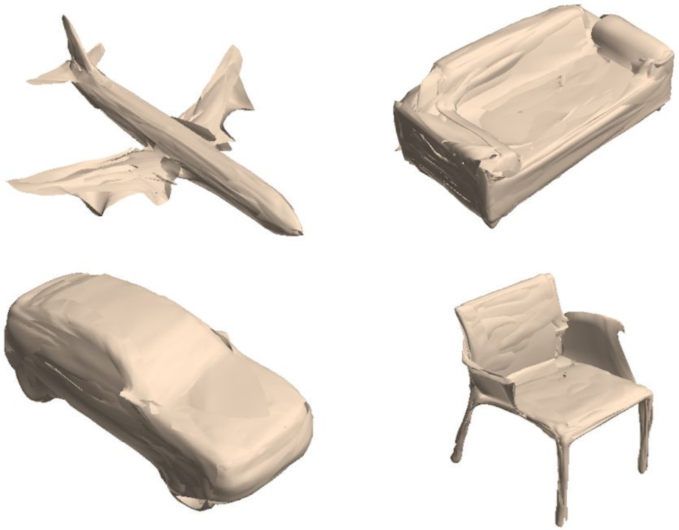
Surface Atlas

AtlasNet results

- \+ Fast rendering
- \+ Easy to store textures
- \- Non-smooth
- \- Artifacts at boundaries of patches



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Hybrid Explicit / Implicit Model

Hybrid Approach:

- Aligning the **surface** generated by AtlasNet to the level-set of the implicit function

$$g^{\hat{\mathbf{x}}}\left(f_i^{\mathbf{x}}(\mathbf{p})\right) = \tau$$

- Aligning AtlasNet and OccupancyNet **normals**

$$\mathcal{N}_{\text{occ}} = \mathcal{N}_{\text{atlas}}$$

$$\mathcal{N}_{\text{atlas}} = \frac{\partial f_i^{\mathbf{x}}}{\partial u} \times \frac{\partial f_i^{\mathbf{x}}}{\partial v}\bigg|_{\mathbf{p}}$$

$$\mathcal{N}_{\text{occ}} = \nabla_{\mathbf{q}} g^{\hat{\mathbf{x}}}(\mathbf{q})$$

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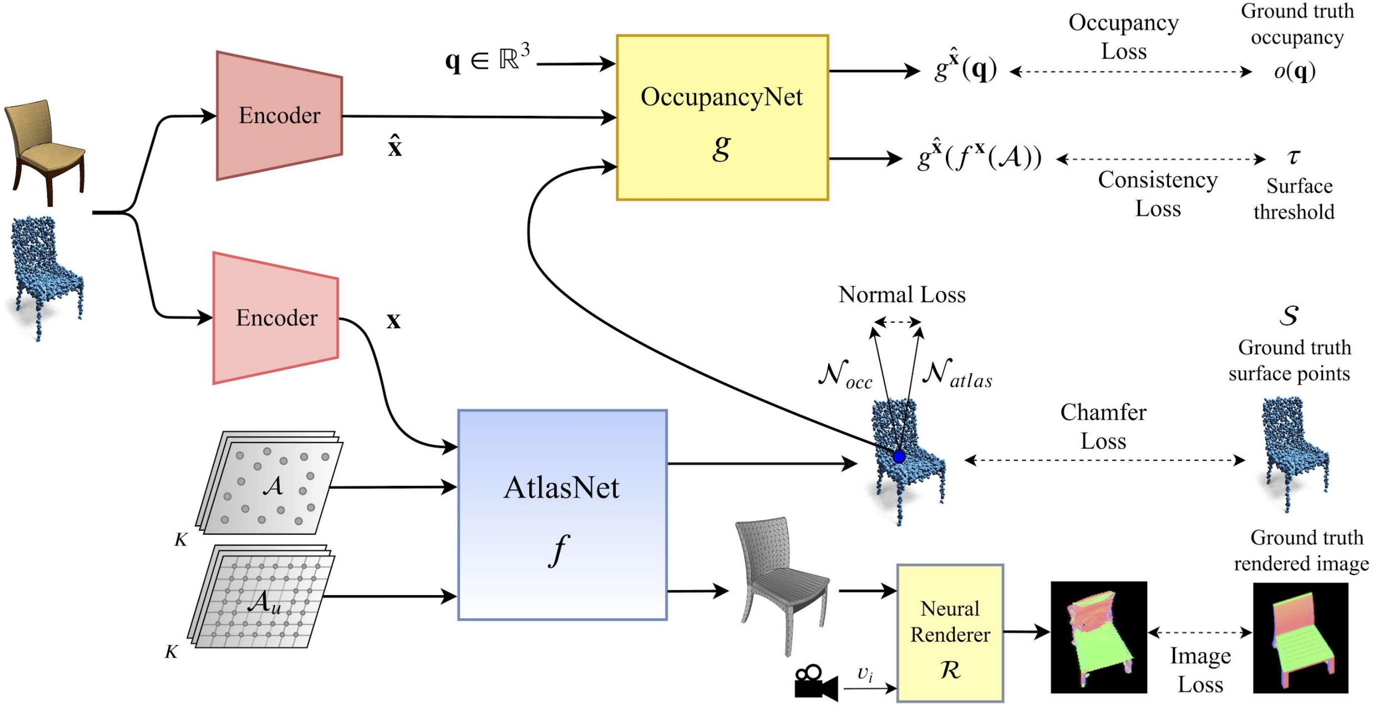
Hybrid Explicit / Implicit Model

Architecture:



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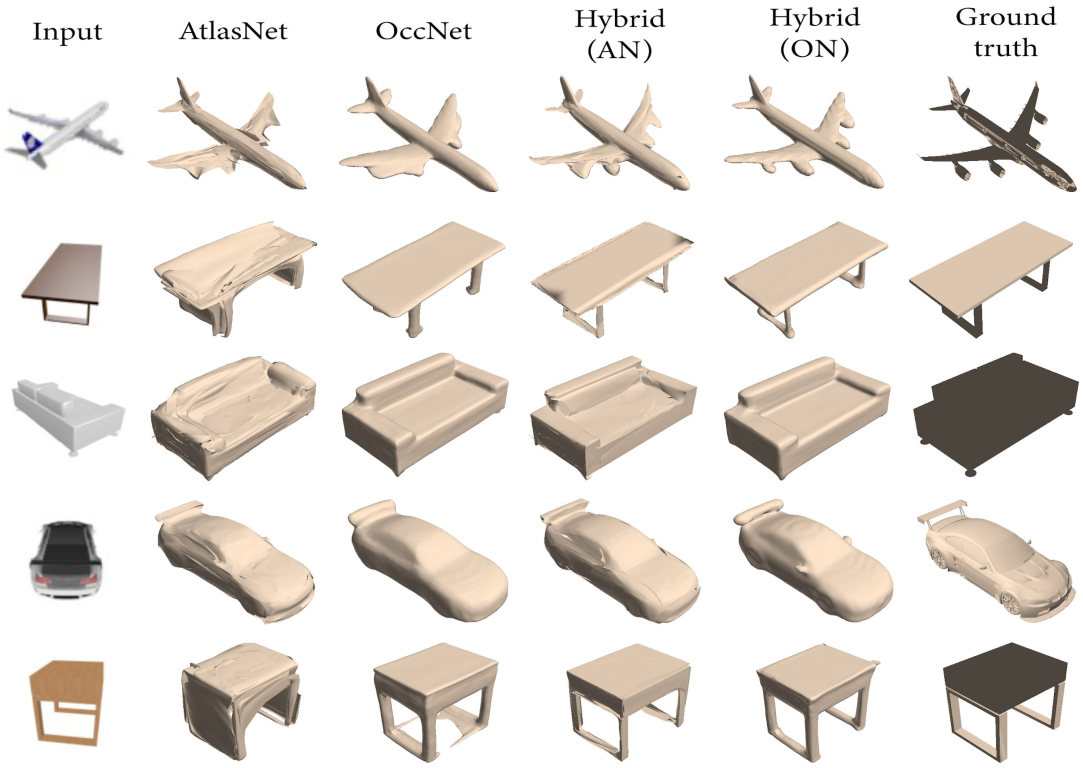
Results

Single-view reconstruction



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Results

Single-view reconstruction

Metric	Chamfer-L_1 ($\times 10^{-1}$)									
Model	AN	ON	Hybrid		No $\mathcal{L}_{img}$		No $\mathcal{L}_{norm}$		No $\mathcal{L}_{img}, \mathcal{L}_{norm}$	
Branch			AN	ON	AN	ON	AN	ON	AN	ON
airplane	1.05	1.34	**0.91**	1.03	0.96	1.10	0.95	1.08	1.01	1.17
bench	1.38	1.50	**1.23**	1.26	1.27	1.31	1.26	1.29	1.32	1.38
cabinet	1.75	1.53	1.53	**1.47**	1.57	1.49	1.55	1.49	1.61	1.50
car	1.41	1.49	**1.28**	1.31	1.33	1.37	1.33	1.36	1.37	1.42
chair	2.09	2.06	1.96	**1.95**	2.02	2.01	1.99	1.99	2.04	2.03
display	1.98	2.58	**1.89**	2.14	1.92	2.24	1.90	2.19	1.94	2.29
lamp	3.05	3.68	**2.91**	3.02	2.93	3.09	2.91	3.06	2.99	3.21
sofa	1.77	1.81	**1.56**	1.58	1.61	1.63	1.59	1.61	1.68	1.71
table	1.90	1.82	1.73	**1.72**	1.80	1.78	1.78	1.76	1.83	1.79
telephone	1.28	1.27	**1.17**	1.18	1.22	1.21	1.19	1.19	1.24	1.24
vessel	1.51	2.01	**1.42**	1.53	1.46	1.60	1.46	1.58	1.48	1.69
mean	1.74	1.92	**1.60**	1.65	1.64	1.71	1.63	1.69	1.68	1.77

Results

Single-view reconstruction

Metric	Normal Consistency ($\times 10^{-2}$)									
Model	AN	ON	Hybrid		No $\mathcal{L}_{img}$		No $\mathcal{L}_{norm}$		No $\mathcal{L}_{img}, \mathcal{L}_{norm}$	
Branch			AN	ON	AN	ON	AN	ON	AN	ON
airplane	83.6	84.5	85.5	**85.7**	85.3	85.6	84.8	85.3	84.3	85.0
bench	77.9	81.4	81.4	**82.5**	80.9	82.2	80.4	81.9	79.9	81.7
cabinet	85.0	88.4	88.3	**89.1**	88.1	89.0	87.2	88.7	86.8	88.6
car	83.6	85.2	86.2	**86.8**	85.8	86.5	85.3	86.0	84.9	85.8
chair	79.1	82.9	83.5	**84.0**	83.1	83.7	82.4	83.4	82.0	83.2
display	85.8	85.7	**87.0**	86.9	86.7	86.6	86.3	86.1	86.0	85.9
lamp	69.4	75.1	74.9	**76.0**	74.7	75.9	73.3	75.6	72.8	75.4
sofa	84.0	86.7	87.2	**87.5**	86.9	87.4	86.4	87.1	85.9	86.9
table	83.2	85.8	86.3	**87.4**	86.0	87.1	85.3	86.4	84.9	86.1
telephone	92.3	93.9	94.0	**94.5**	93.8	94.4	93.6	94.2	93.3	94.1
vessel	75.6	79.7	79.2	**80.6**	78.9	80.4	77.7	80.0	77.4	79.9
mean	81.8	84.5	84.9	**85.5**	84.6	85.4	83.9	85.0	83.5	84.8

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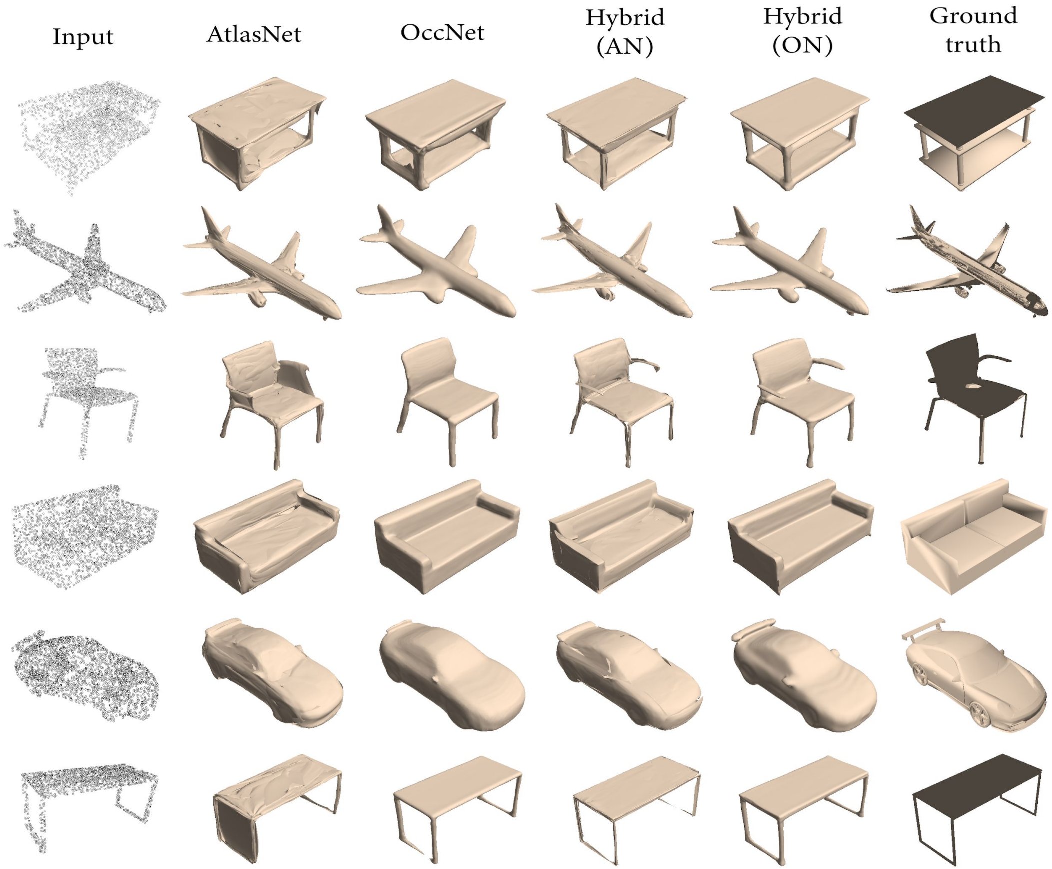
Results

Auto-encoding point clouds



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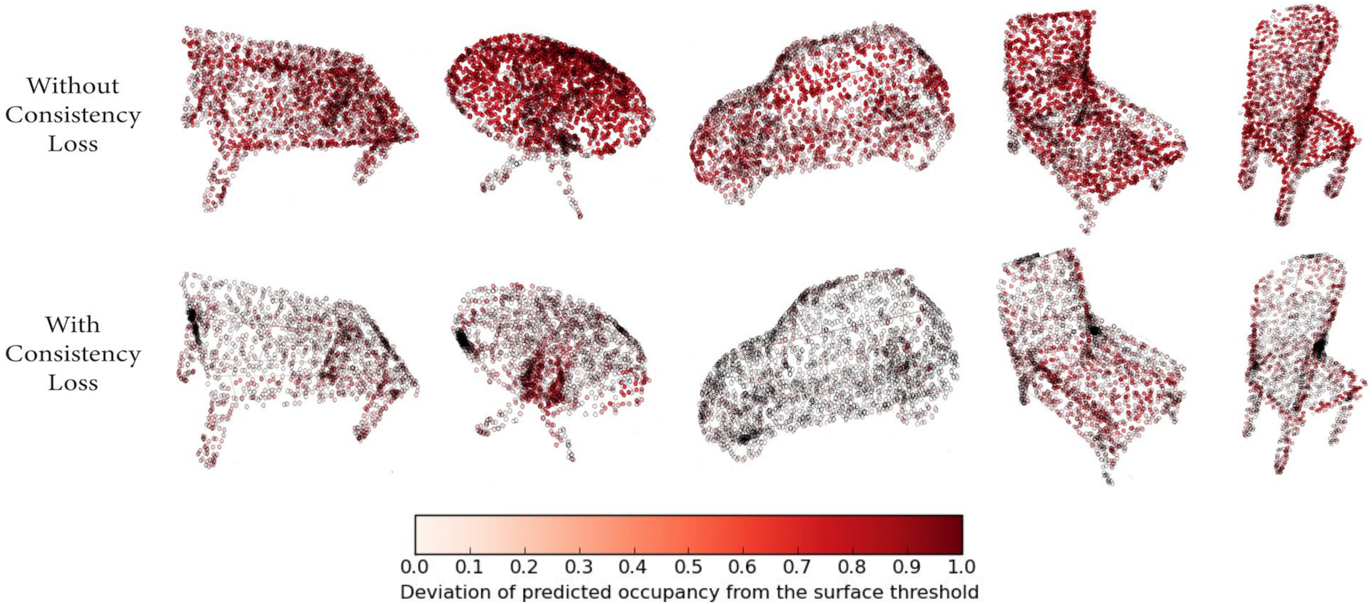
Impact of Loss Components

Consistency Loss



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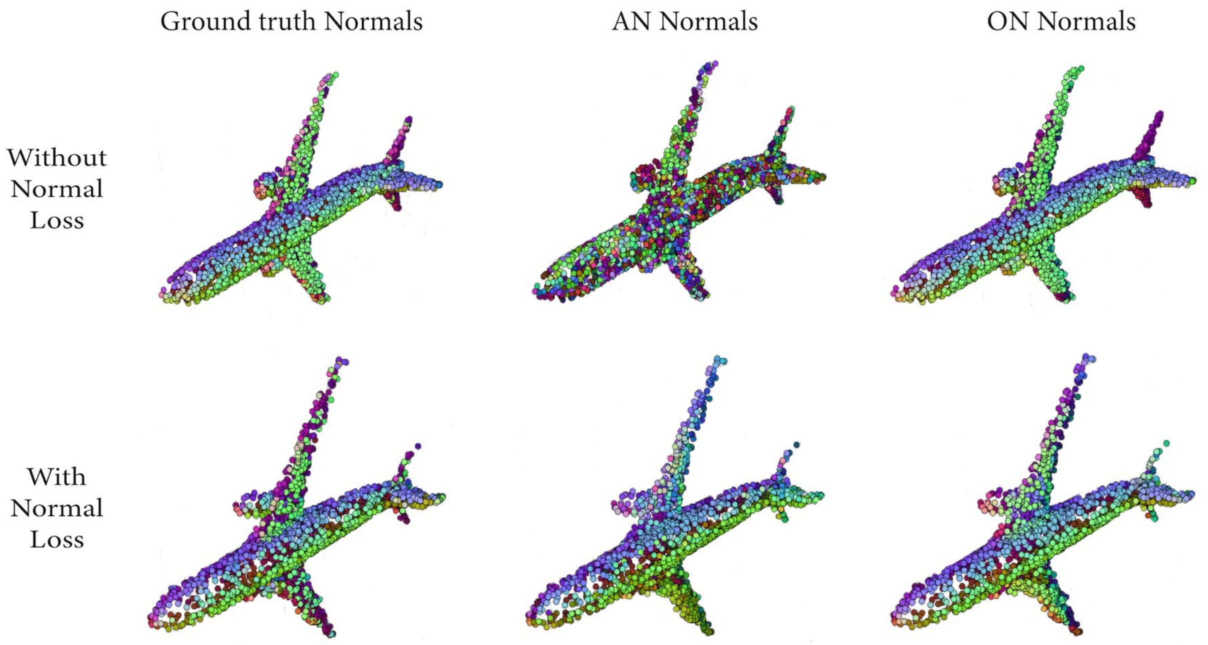
Impact of Loss Components

Normal Loss



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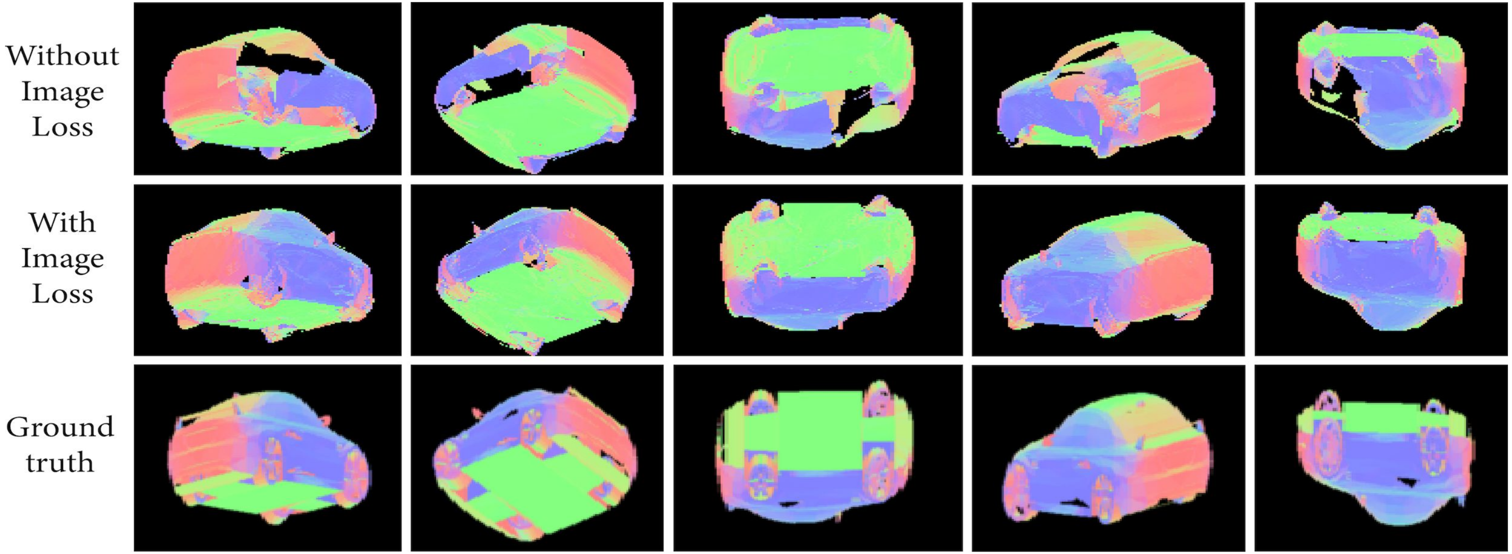
Impact of Loss Components

Image loss



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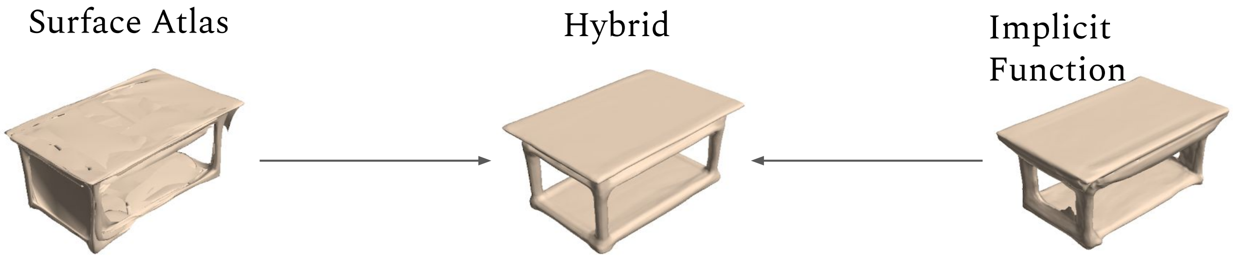
Summary: Hybrid Approach

Advantages:

- Learning smoother surface
- Accurate normals
- Accurate surface: small chamfer distance to ground truth
- Faster inference



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