CoRL 2022

CADSim: Robust and Scalable in-the-wild 3D Reconstruction for Controllable Sensor Simulation

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1 Waabi

2 University of Toronto

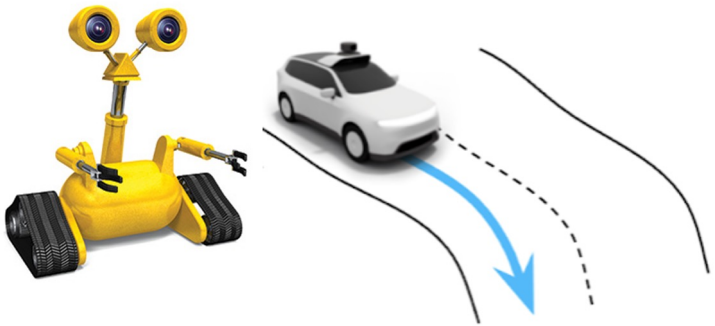
3 MIT

Outline

- Motivation
- Methodology
- Additional Experiment Results
- Applications – Mixed Reality Simulation, Texture Transfer

Simulation for Robot Learning and Testing

- Long-tail scenarios are critical for robot learning and evaluation
- We need scalable and affordable way to generate experiences - Simulation!
- Realistic sensor simulation is key for running the full autonomy system



Autonomy testing with sensor simulation

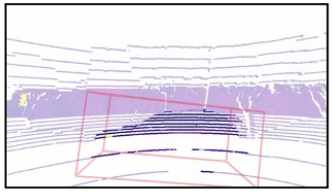
Existing Simulators Lack Scale and Diversity

- Standard game engines for simulation - (a) not scalable: artists create assets manually + simple automation; (b) lacking diversity; (c) not realistic
- We need to cover the full space in the real world for small domain gap

[1] CARLA: An open urban driving simulator. [Dosovitskiy, et al. CoRL 2017]

Building Assets from In-the-Wild Data for Diversity

LiDAR Points



Camera Images

CADSim

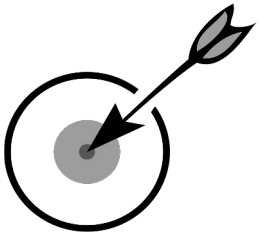
Fast Recon.

360° Textured
Vehicle Assets

Real-time rendering

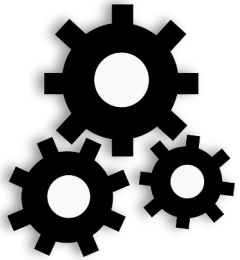
Realistic and Controllable Simulation

Assets for Self-driving



Accurate shape and appearance

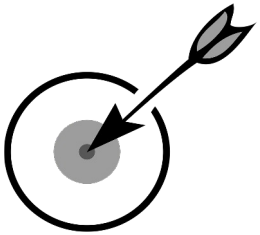
Editable



Controllable

Real-time rendering

Assets for Self-driving



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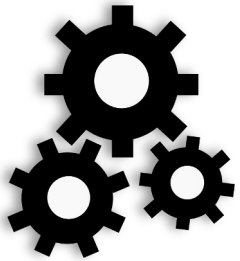
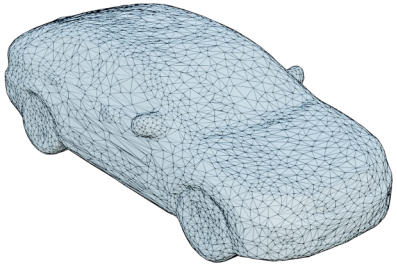


Controllable

Real-time rendering



Mesh Representation

Current Mesh Approaches do not work in the Wild

- Underlying geometry is poor

Recon.

NeuS [1]

NeRS [2]

NVDiffRec [3]

Sphere Deform [4]

Ellipsoid Deform [5]

SAMP [6]

[1] Wang et al. NeuS: Learning Neural Implicit Surfaces by Volume Rendering for Multi-view Reconstruction. NeurIPS 2021
[2] Zhang et al. NeRS: Neural Reflectance Surfaces for Sparse-view 3D Reconstruction in the Wild. NeurIPS 2022
[3] Munkberg et al. Extracting Triangular 3D Models, Materials, and Lighting From Images. CVPR 2022.
[4] Kanazawa et. al. Learning Category-Specific Mesh Reconstruction from Image Collections. ECCV 2018.
[5] Wang et. al. Pixel2mesh: Generating 3d mesh models from single rgb images. ECCV 2018.
[6] Engelmann et al. SAMP: Shape and Motion Priors for 4D Vehicle Reconstruction. WACV 2017.

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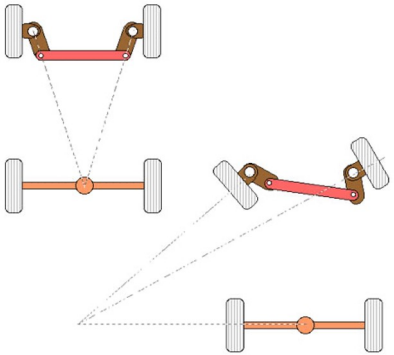
SAMP [6]

- Generates rigid mesh that cannot be articulated

Needs to be articulated



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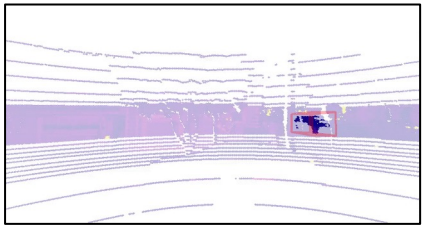
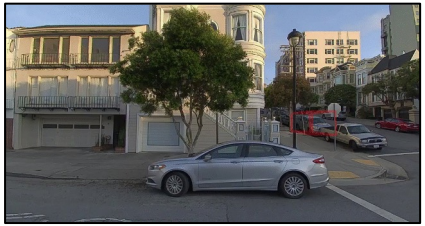
CADSim

LiDAR Points



Camera Images

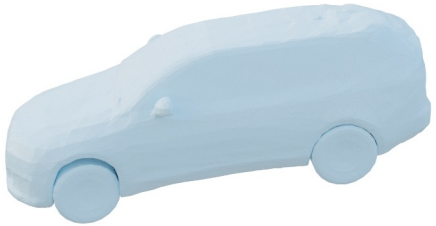


Generic CAD Models

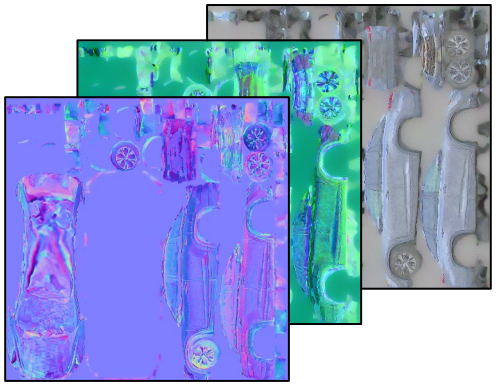
CADSim

Fast Recon.

Geometry



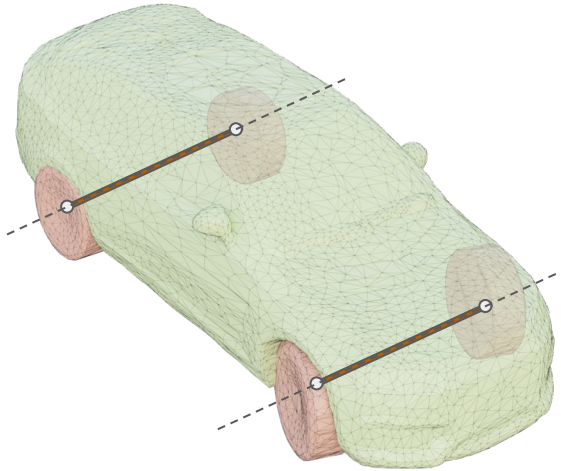
Material



Appearance

Lighting

CADSim - Vehicle Parameterization



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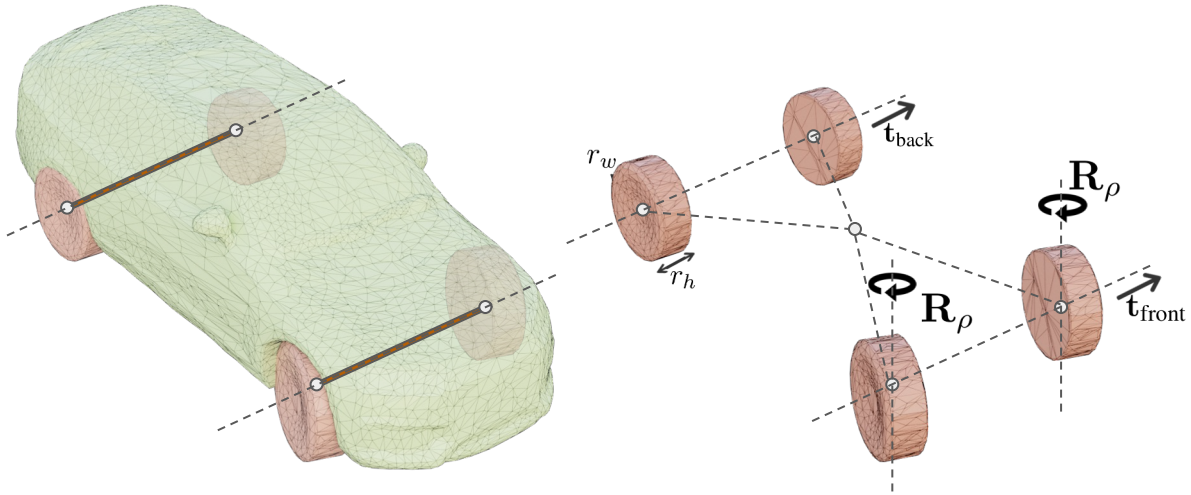

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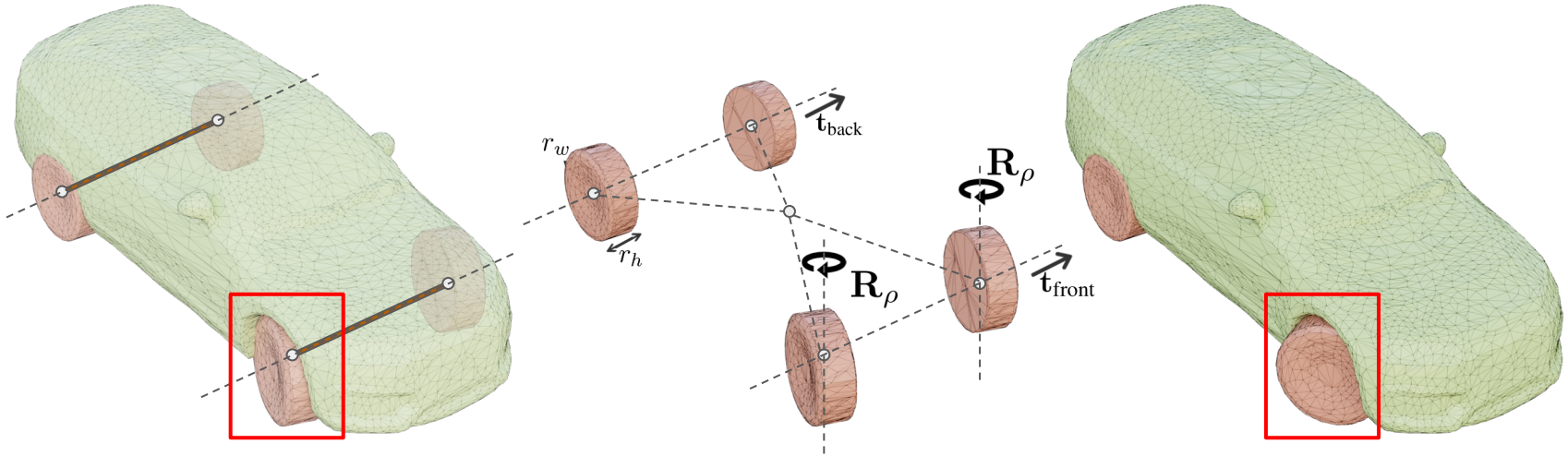
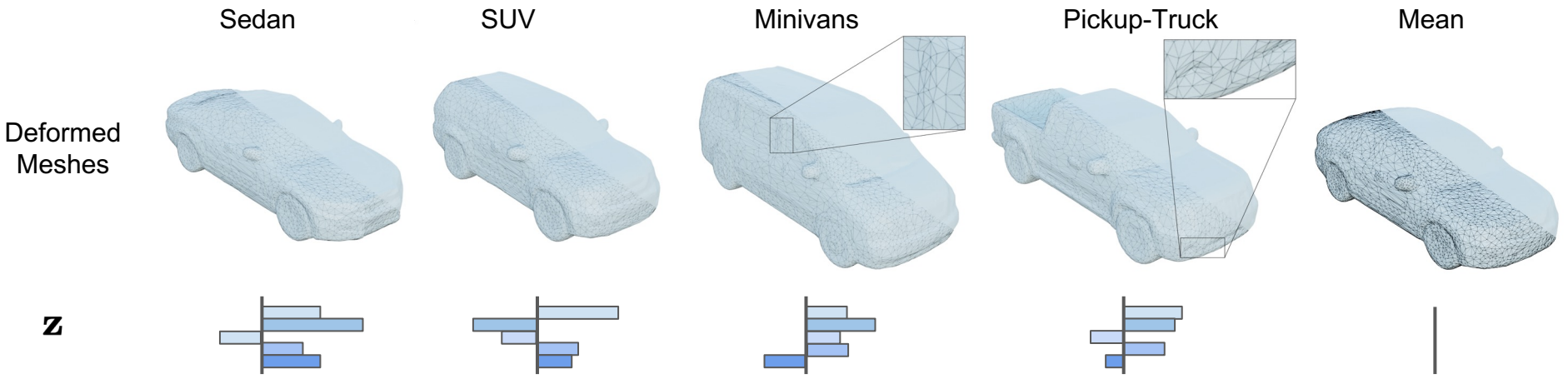
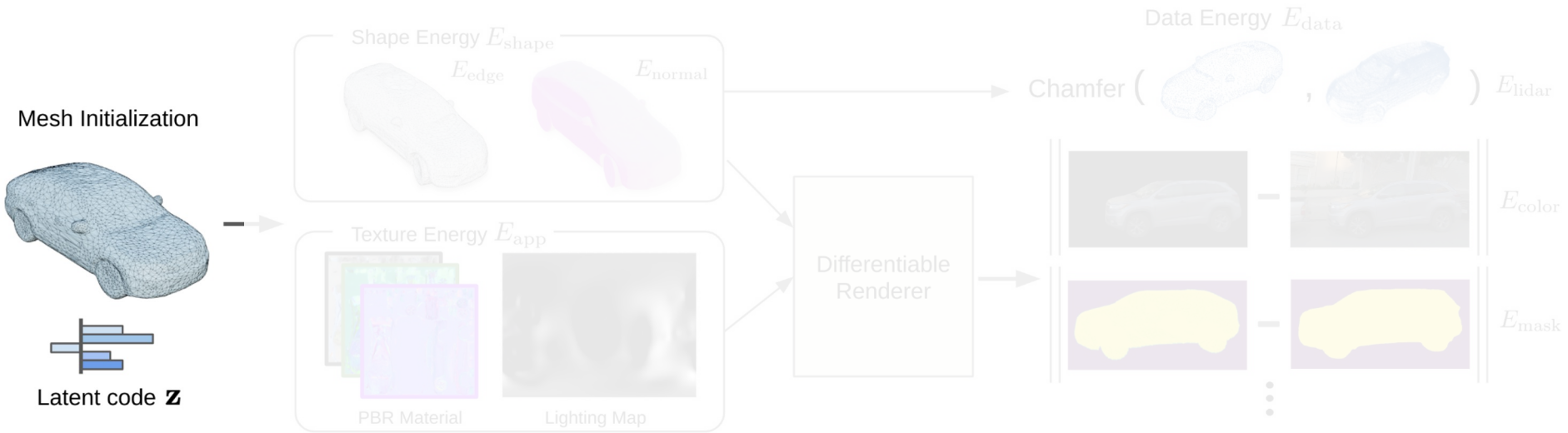


Learning a Shape Prior over a CAD Library



CADSim - Differentiable Rendering



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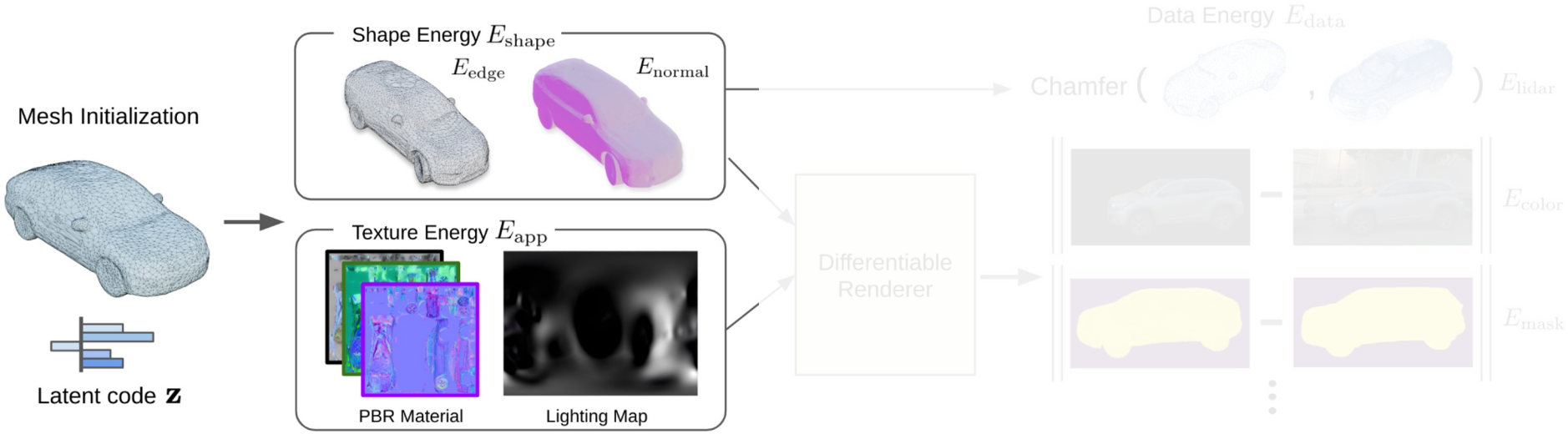

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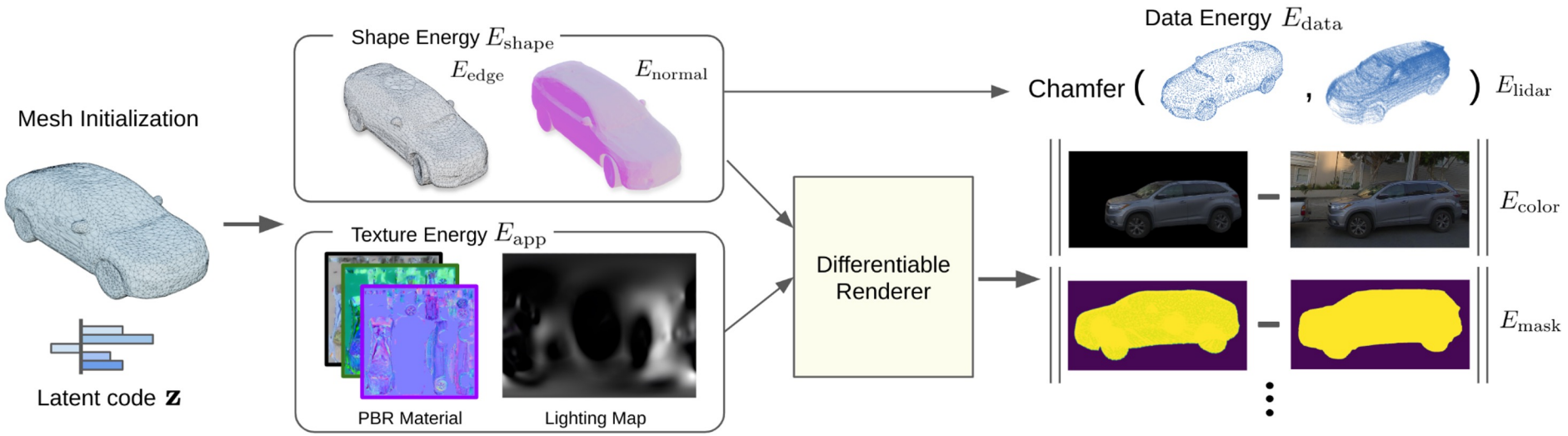
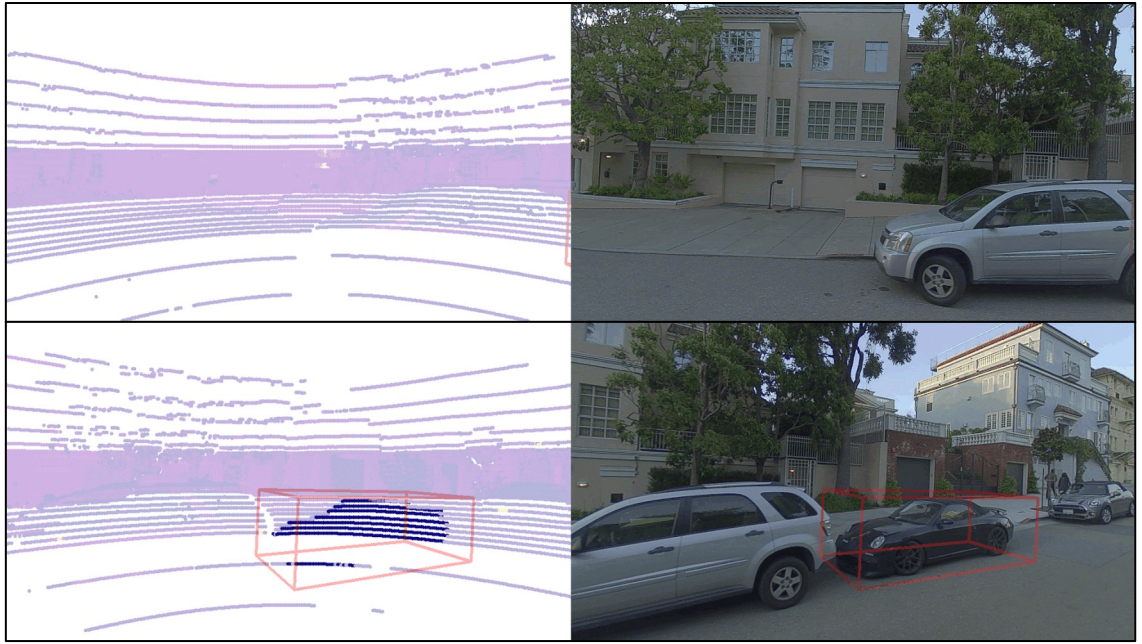


PandaVehicle Dataset

Training frames (left camera)

Testing frames (front-left camera)



LiDAR sensor

Camera sensor

Novel View Synthesis SOTA Comparison

Ground-Truth

Instant-NGP [1]

NeuS [2]

SAMP [3]

CADSim (Ours)

[1] Müller et al. Instant Neural Graphics Primitives with a Multiresolution Hash Encoding SIGGRAPH 2022

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Quantitative Comparison

- CADSim produces the best performance on all metrics

Method	SSIM ↑	LPIPS ↓	T (hour)	FPS
NeRF++ [Zhang et al., 2020]	0.611	0.300	4.70	0.05
Instant-NGP [Müller et al., 2022]	0.641	0.319	0.05	1.14
NeRS [Zhang et al., 2021]	0.562	0.265	1.37	3.23
NVDiffRec [Munkberg et al., 2021]	0.593	0.396	1.07	51.2
NeuS [Wang et al., 2021]	0.640	0.247	6.25	0.02
SI-ViewWarp [Tulsiani et al., 2018]	0.514	0.371	–	1.67
SAMP [Engelmann et al., 2017]	0.628	0.283	0.09	71.4
CADSim (ours)	**0.674**	**0.220**	0.13	49.6

Quantitative Comparison

- CADSim produces the best performance on all metrics
- CADSim results in fast reconstruction and real-time rendering

Method	SSIM ↑	LPIPS ↓	T (hour)	FPS
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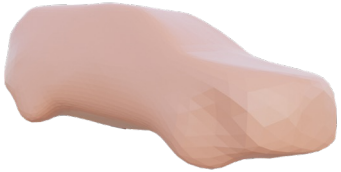
Leveraging CAD Improves Reconstruction

Unit Sphere

Ellipsoid

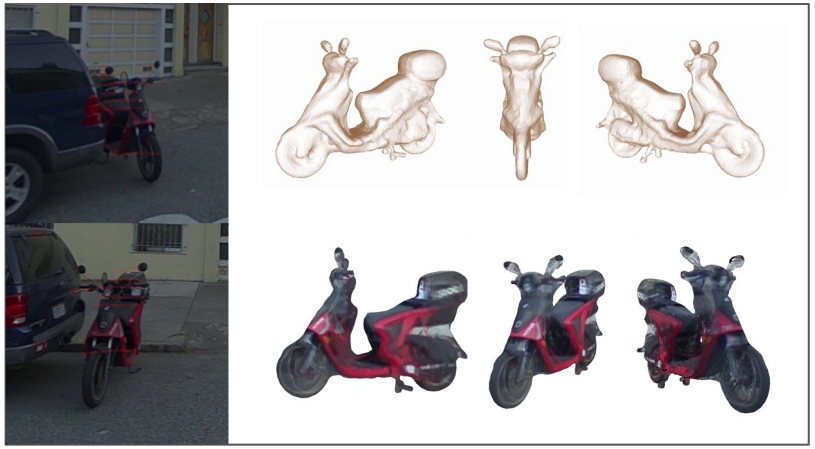


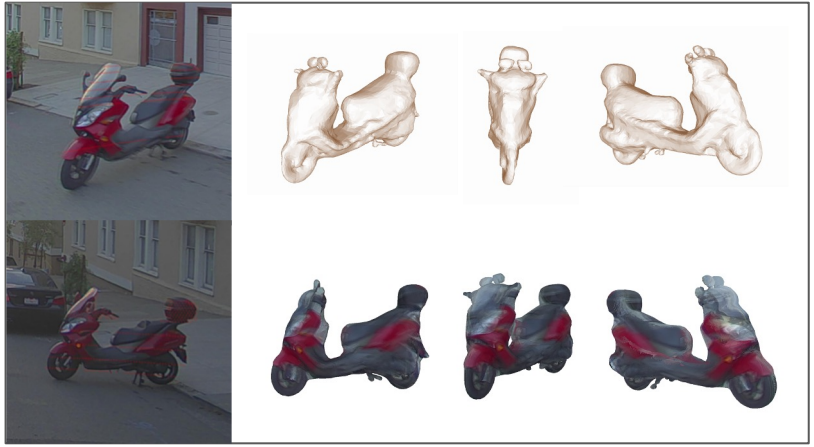
NeRS

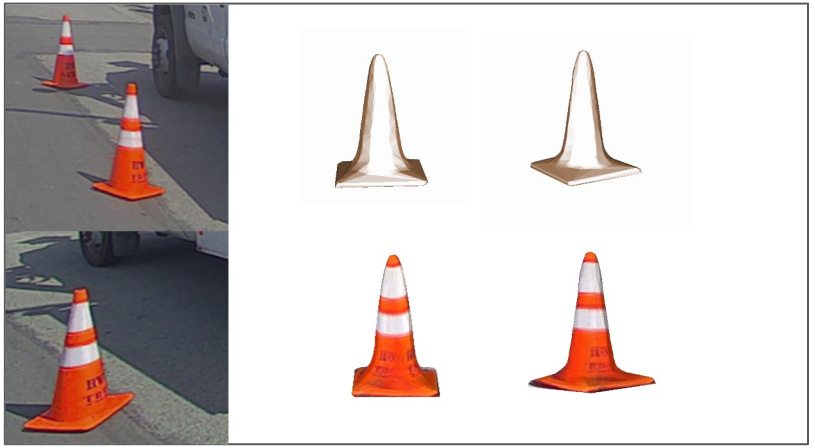
SAMP

Ours

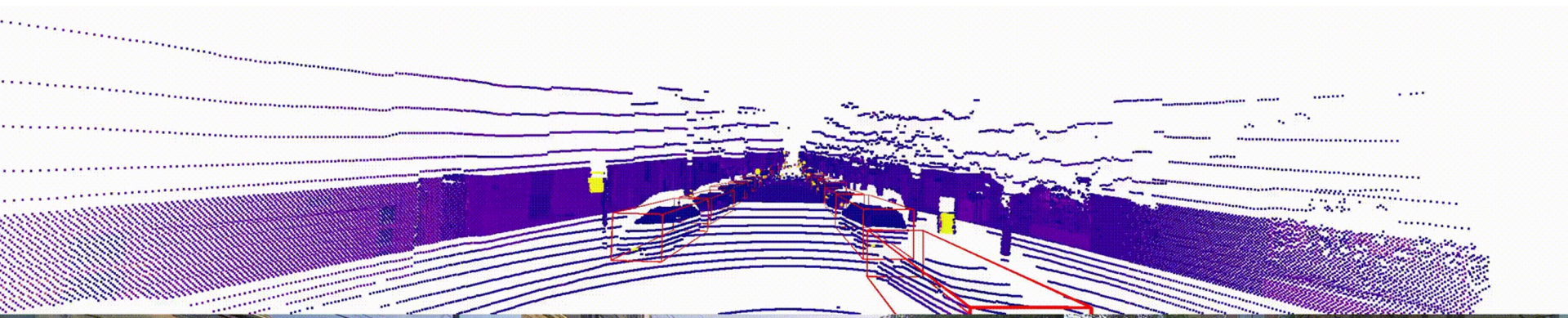
Results on Non-vehicle Objects





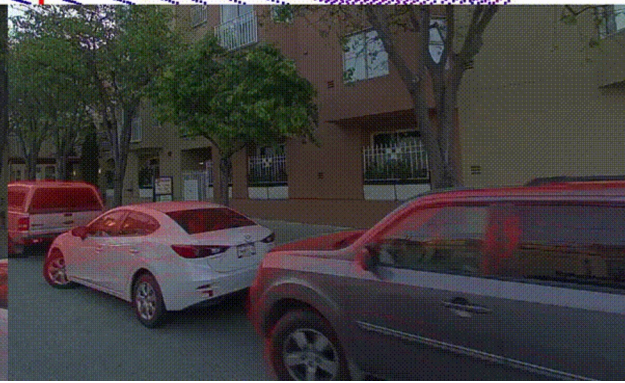


Sensor Observations (Log 028)



Left Camera

Front Camera

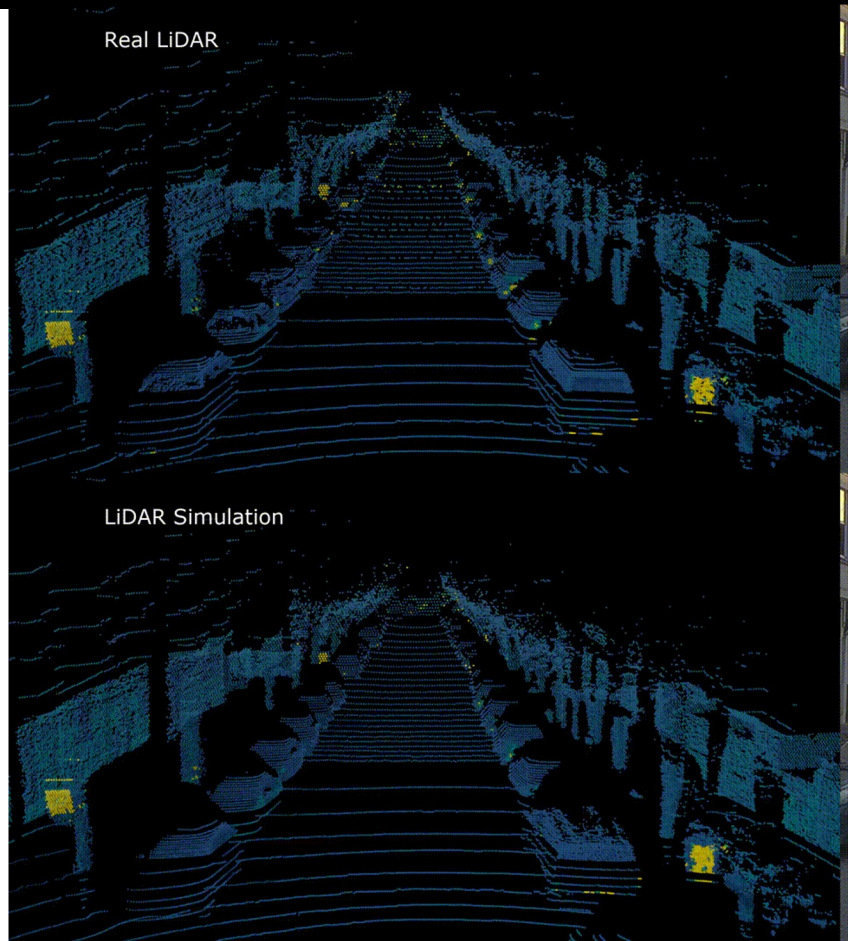


Right Camera

Reconstructing Nearby Vehicles (Log 028)

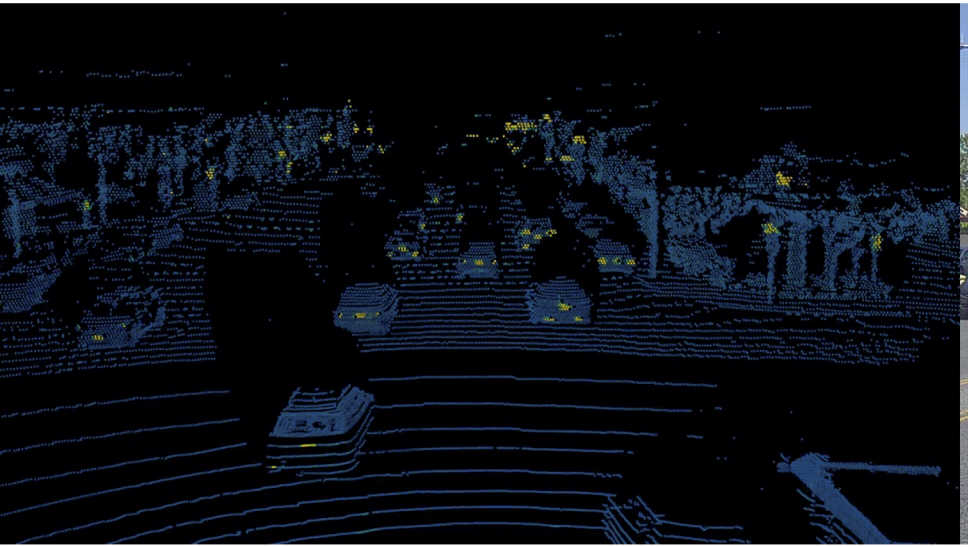
Reconstructing Nearby Vehicles (Log 028)

Log-Replay Simulation (Log 028)



Log-Replay Simulation (Log 028) - Side Camera

Mixed Reality: Actor Manipulation



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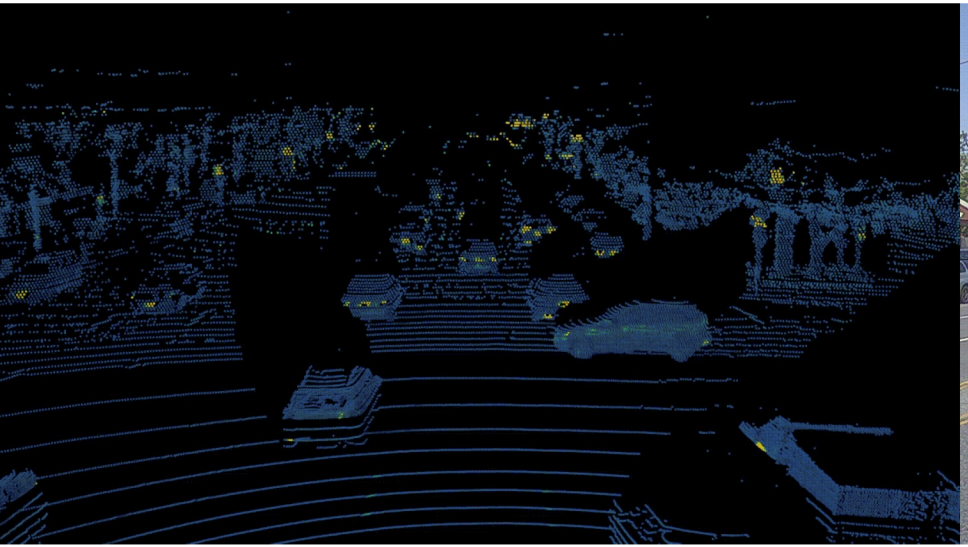
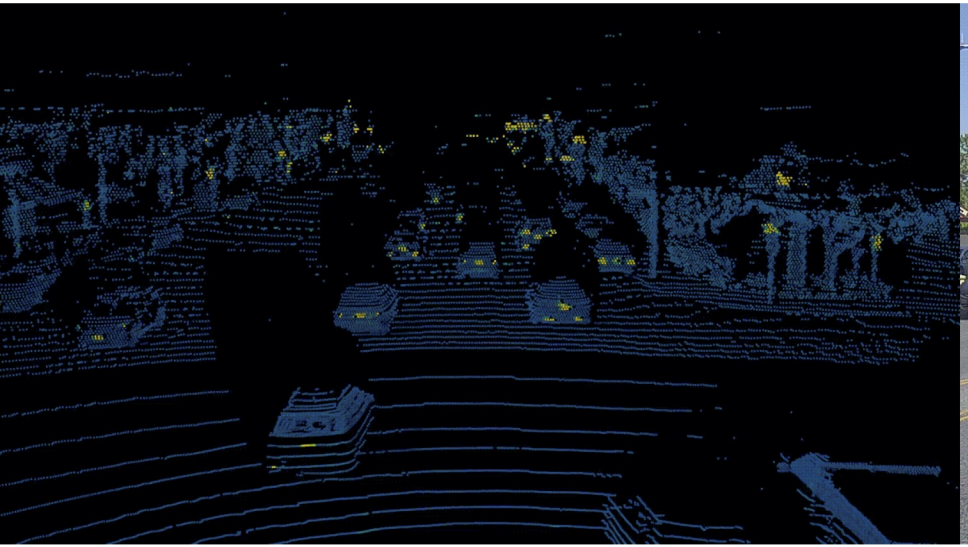


Mixed Reality: Safety-Critical Scenario



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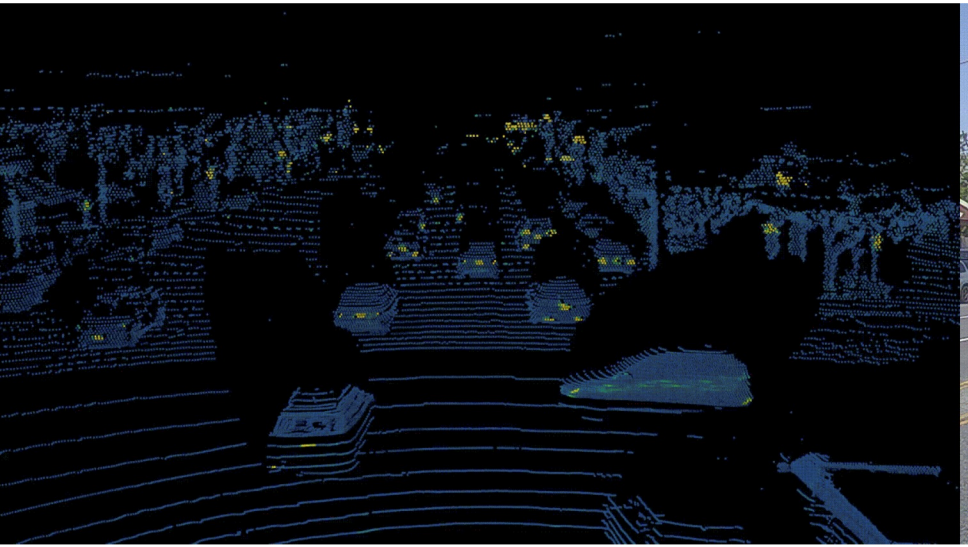

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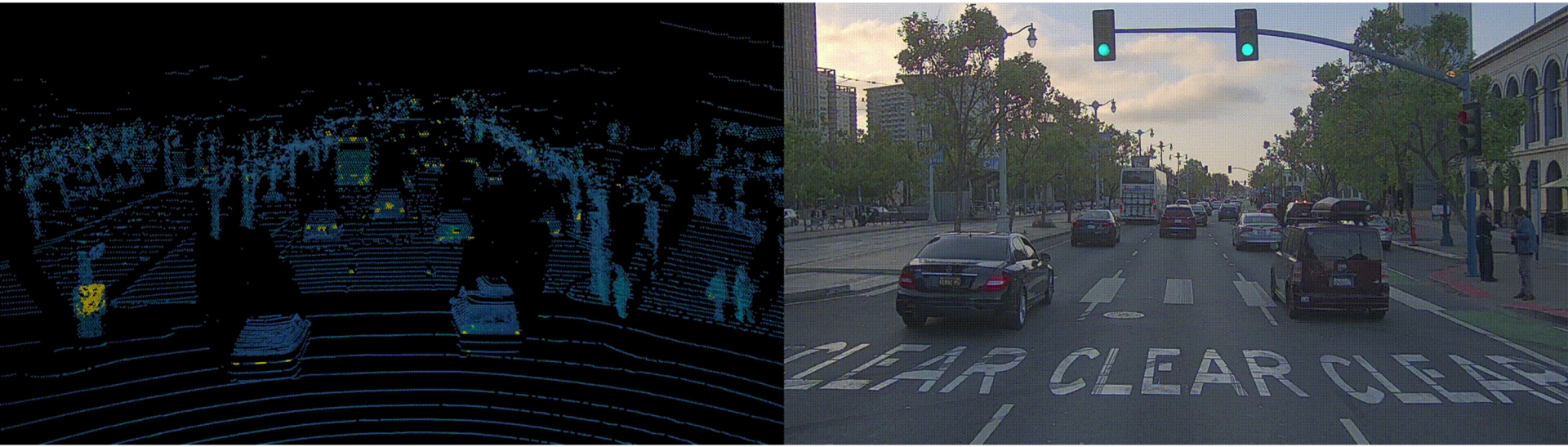

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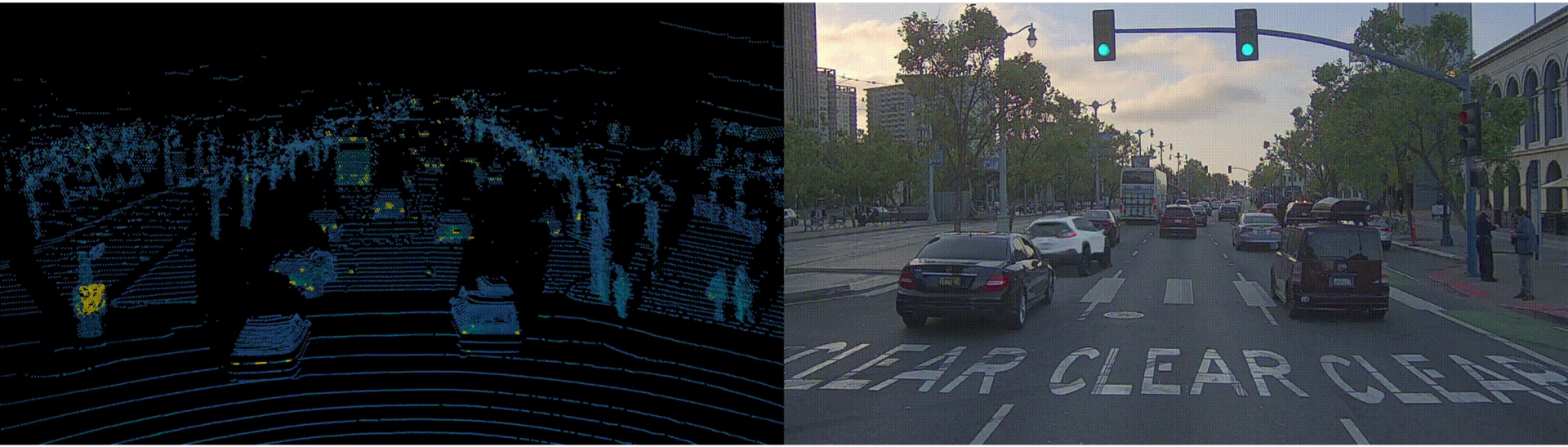

Swapping Texture in the Real World

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Thank you!

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Supplementary Video

This video contains audio.