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UniSim: A Neural Closed-Loop Sensor Simulator

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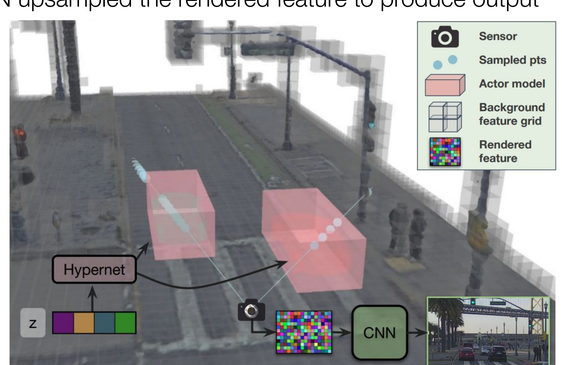
Motivation: Closed-Loop Sensor Simulation

- **Long-tail scenarios** are critical for robot evaluation
- **Closed-loop simulation** allows the autonomy system to reactively interact with the environment, enabling testing self-driving at large-scale with low-cost and low-risk.
- **Existing methods** are not scalable due to manual creation of assets, lack diversity due to the limited number of scenes and assets available, and lack realism due to domain gap.
- **UniSim:** build digital twin from real world data and test autonomy in closed-loop for insight and development

Method: Building Digital Twin

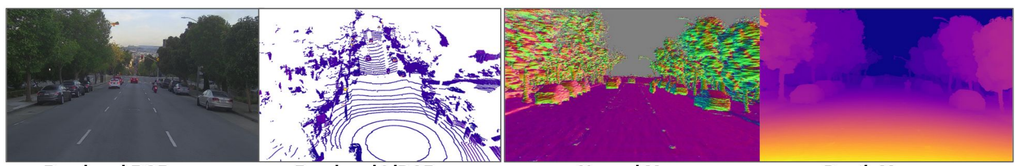
Scene is decomposed into **static background** and **dynamic actors**

1. Static background is modelled with sparse hash grid
2. Dynamic actors' representation are generated by a hyperNet
3. Volume render feature map for each ray
4. A CNN upsampled the rendered feature to produce output



Capabilities

Reconstruction: manipulable digital twin is reconstructed from collected data



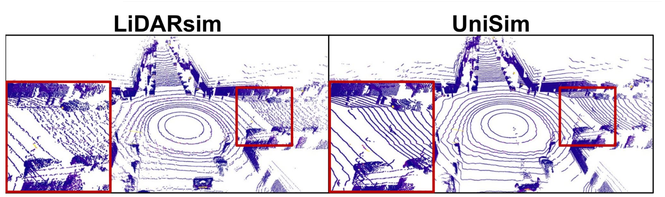
Scene manipulation: manipulate actors behavior to create new scenarios

SDV control: control SDV reaction or sensor placement

Closed-loop simulation: create counterfactual scenarios and let the autonomy system reactively interact with the environment

Results

Visual Realism



Ablation

Autonomy Testing: UniSim is more "realistic" from autonomy perspective

Log Replay		
Method	Real2Sim	Sim2Real
FVS	36.9	38.7
Instant-NGP	22.6	34.0
Ours	**40.2**	**39.9**

Lane Shift		
Method	Real2Sim	Sim2Real
FVS	30.3	32.2
Instant-NGP	18.1	26.5
Ours	**37.0**	**37.1**

Detection domain gap, mAP.

	Instant-NGP	FVS	Ours
Sim	32.4	39.2	**41.4**
Real + Sim	40.1	41.1	**42.9**

Augmenting with simulation, mAP.

	Det. Agg. ↑	Pred. ADE ↓	Plan Cons. ↓
FVS	0.80	2.35	6.15
Instant-NGP	0.42	3.24	13.44
Ours	**0.82**	**1.68**	**6.09**

Open-Loop Real2Sim Autonomy Evaluation

Highway Simulation

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