



6.1820/MAS.453: Mobile and Sensor Computing aka IoT Systems

<https://6mobile.github.io/>

Lecture 8: mmWave Sensing and Self-Driving Cars

Some slides adapted from Haitham Hassanieh (EPFL)

Course Staff	Announcements
<p><u>Lecturers:</u> Fadel Adib (fadel@mit.edu)</p>	<p>1- PSet 1 due today</p> <p>2- Lab 2 due March 10</p>
<p><u>TAs:</u> Maisy Lam (mllam@mit.edu) Laura Dodds (ldodds@mit.edu)</p>	<p>3- If you do not have Lab2 Equipment, please partner with someone who does</p>

This Week in IoT

mmWave Pedestrian Detection

21 AUGUST 2025

Pedestrian Detection Millimeter-Wave Sensor Successfully Deployed in the U.S. to Be Showcased for the First Time at ITS World Congress 2025

[PRESS RELEASES](#)

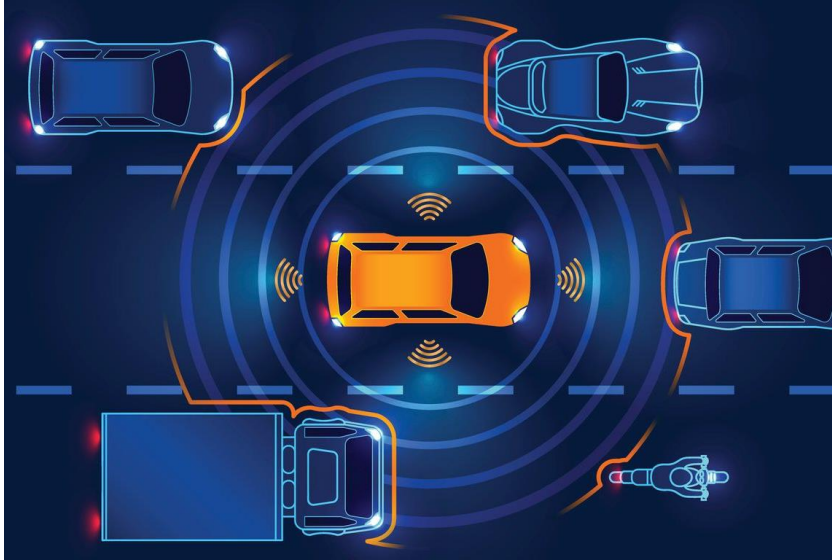
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What else are mmWave Radars used for today?

Advanced Driver Assistance Systems



Smart Homes



Industrial Automation



Airport Security



What are we learning today?

Learn the fundamentals, applications, and implications of
mmWave Sensing

- 1- What are the pros and cons of mmWave vs Vision?
- 2- What is an mmWave radar? How does it work?
- 3- How does specularities impact mmWave imaging?
- 4- Can Generative AI help us with mmWave shortcomings?

How does mmWave compare to vision?

Millimeter-Wave

Low Resolution

No Color Information

High Noise

Typically 3D

Operates through occlusions and
in poor visibility

Vision

High Resolution

Color Information

Low Noise

Typically 2D

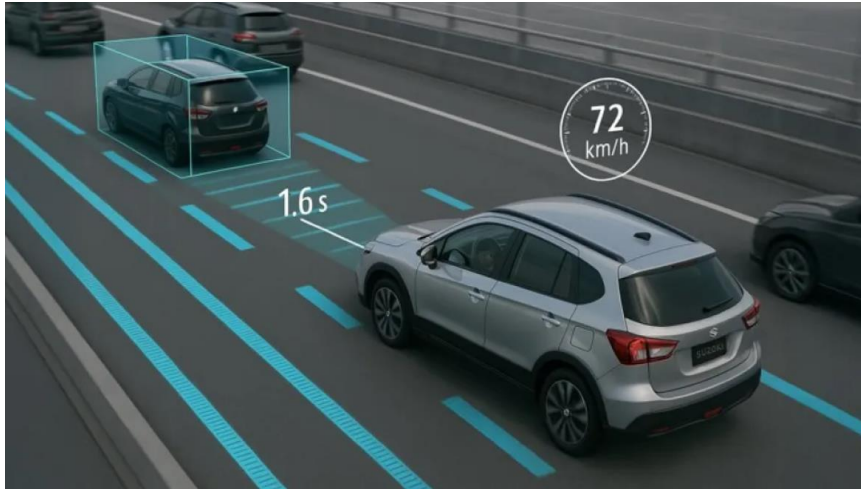
Cannot operate through occlusions or
in poor visibility

Tesla in Fog



How are mmWave Radars Used Today in Self-Driving Cars?

Adaptive Cruise Control



Blind Spot Monitoring



Collision Avoidance & Emergency Breaking

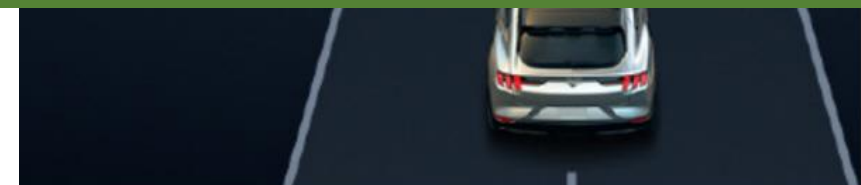


Lane Change Assistance



What two main features do mmWave radars sense to enable these?

Range and Angle



How do mmWave Radars Measure Range?

How do mmWave Radars Measure Angle?

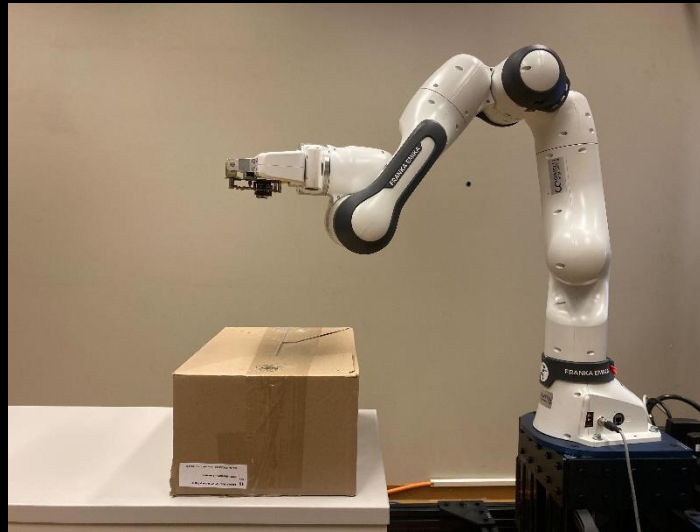
Moving from Coarse Sensing to Non-Line-of-Sight Imaging with mmWave Radars

Non-Line of Sight Imaging with Millimeter Wave Radars

Operate in Bad Weather



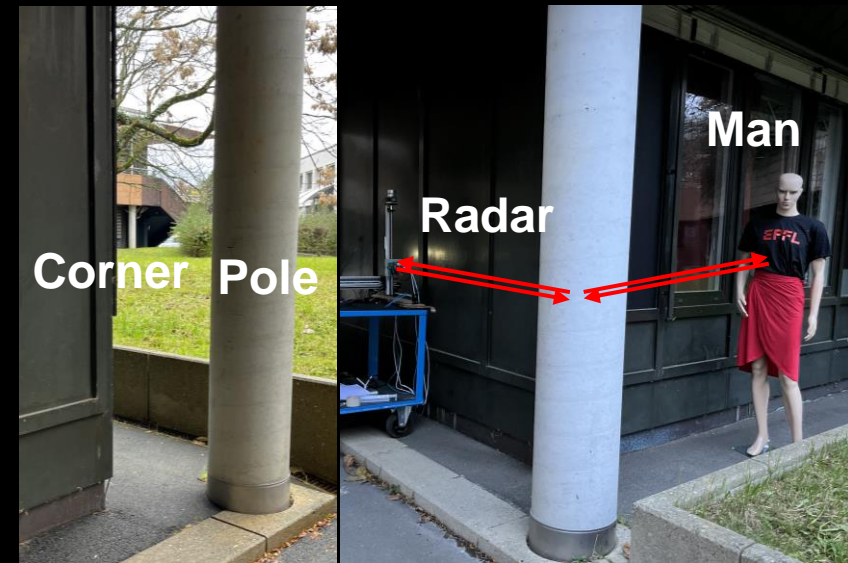
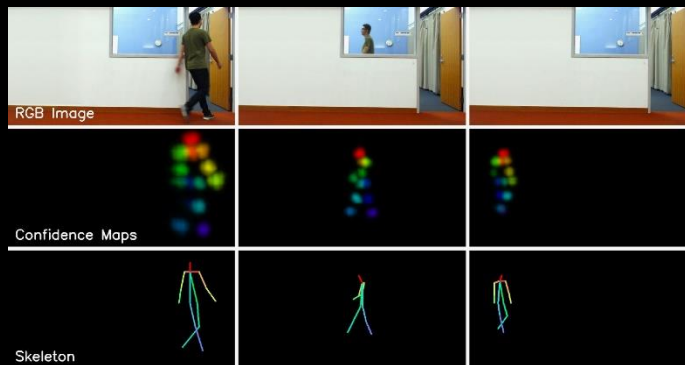
Through Occlusions



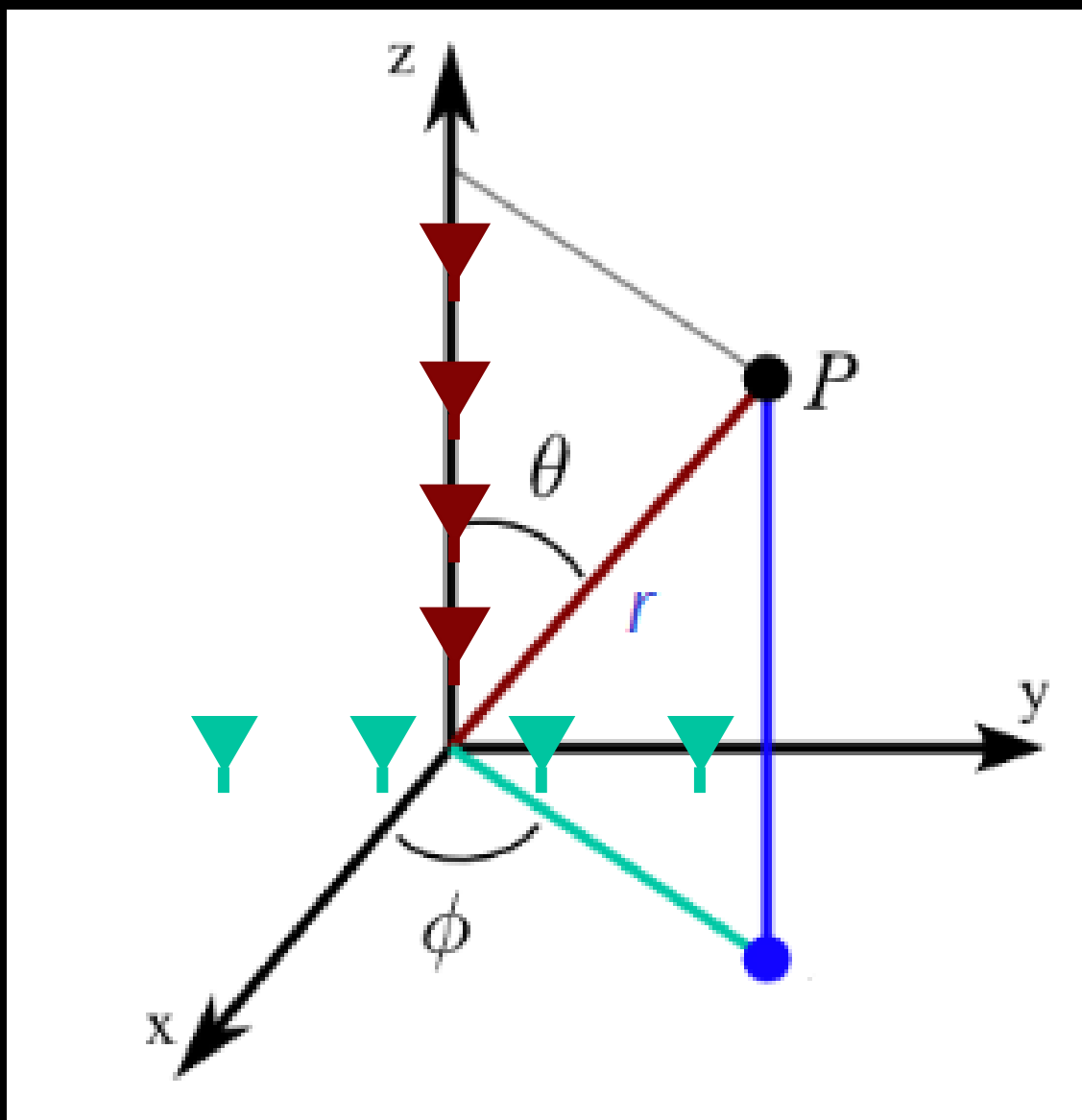
Around Corners



Search & Rescue Robots



How to go from 2D to 3D?



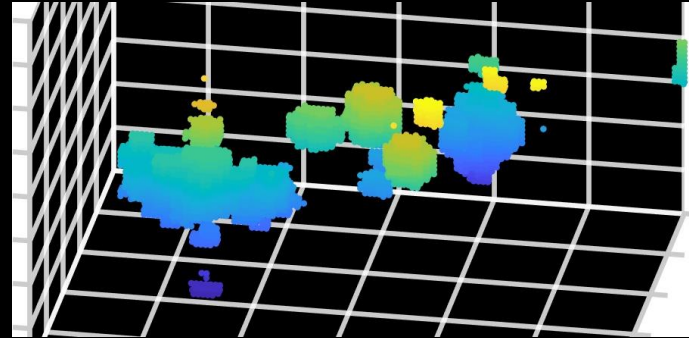
How to go from Range & AoA to a 3D Image?

Example mmWave Image

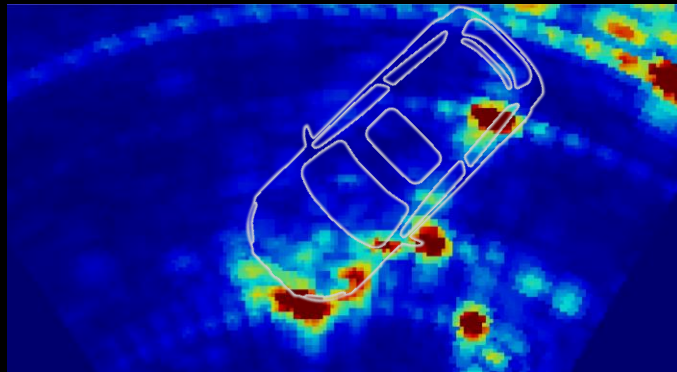
Camera Image



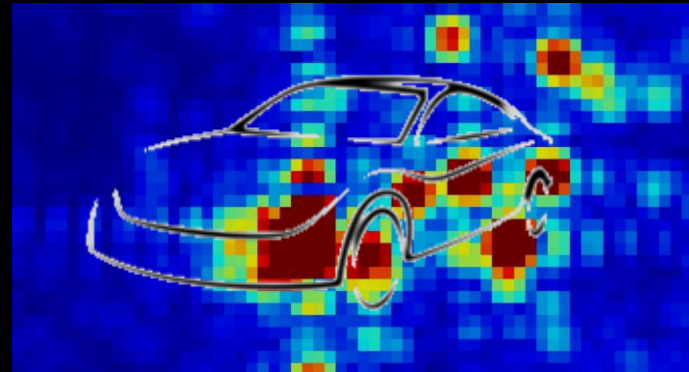
Point Cloud



Top-View



Front-View



Huge Performance Gap Between Radar and Vision!

Challenges in Radar Perception

1. Low Angular Resolution

- Blobs of reflected power
- No sharp boundaries/shapes

2. Specularity

- Missing major parts of cars

3. Multipath

- Spurious Reflections

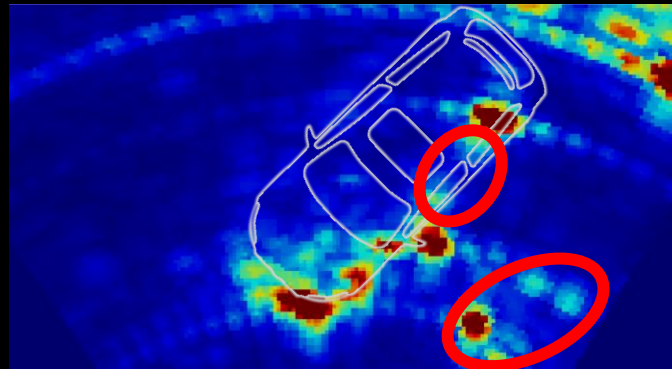
Camera Image



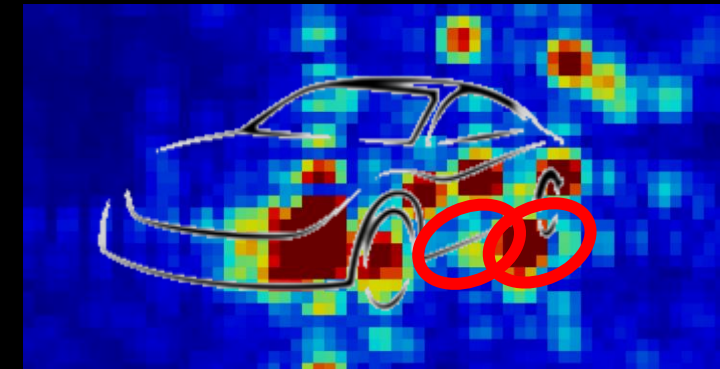
Point Cloud



Top-View



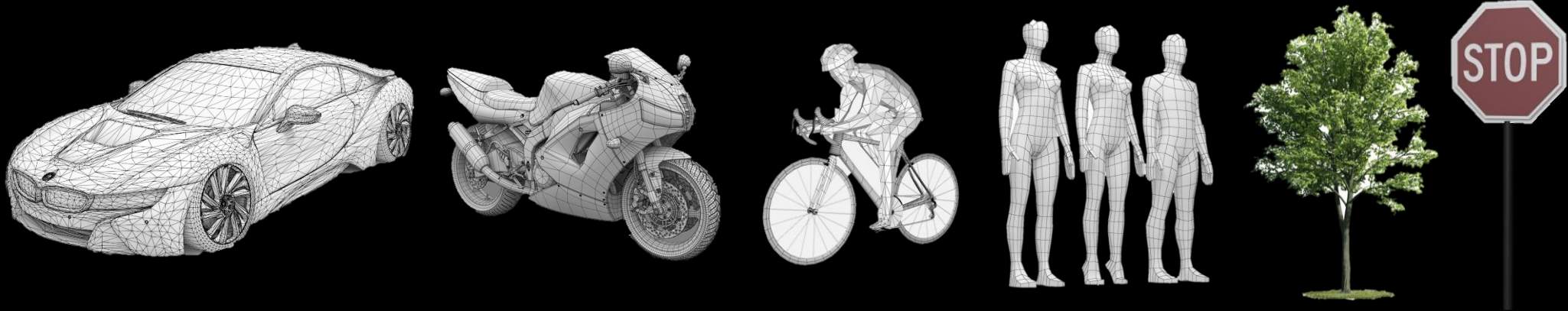
Front-View



Cast mmWave Radar Perception as a Learning Problem

Hawkeye Solution

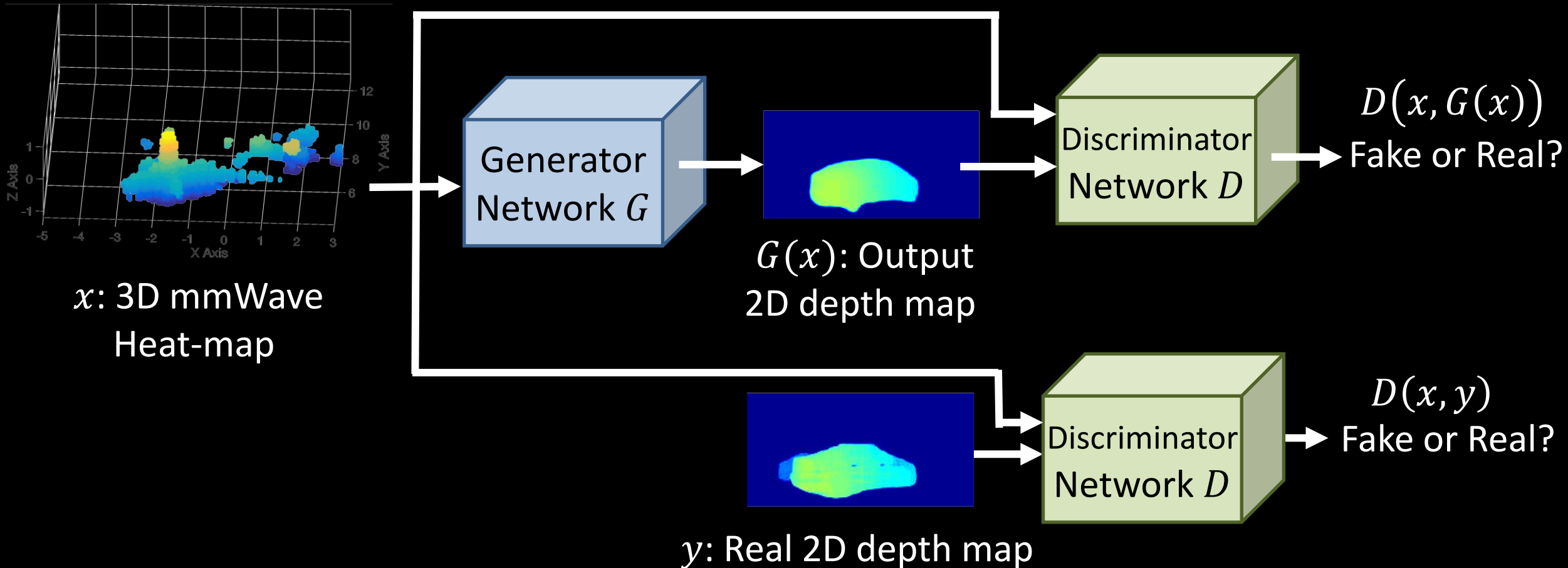
Learning *geometric priors* on structures of commonly found streetside objects.



Generative Adversarial Network (GAN) is effective for various computer vision tasks: super-resolution, learning image prior, image style transformation, etc.

Conditional Generative Adversarial Network (cGAN)

- Generator takes 3D radar heatmap as input and outputs high resolution depth map.
- Discriminator tries to guess if the high resolution depth map is real or fake.
- Generator's goal is to fool the discriminator into thinking this is real

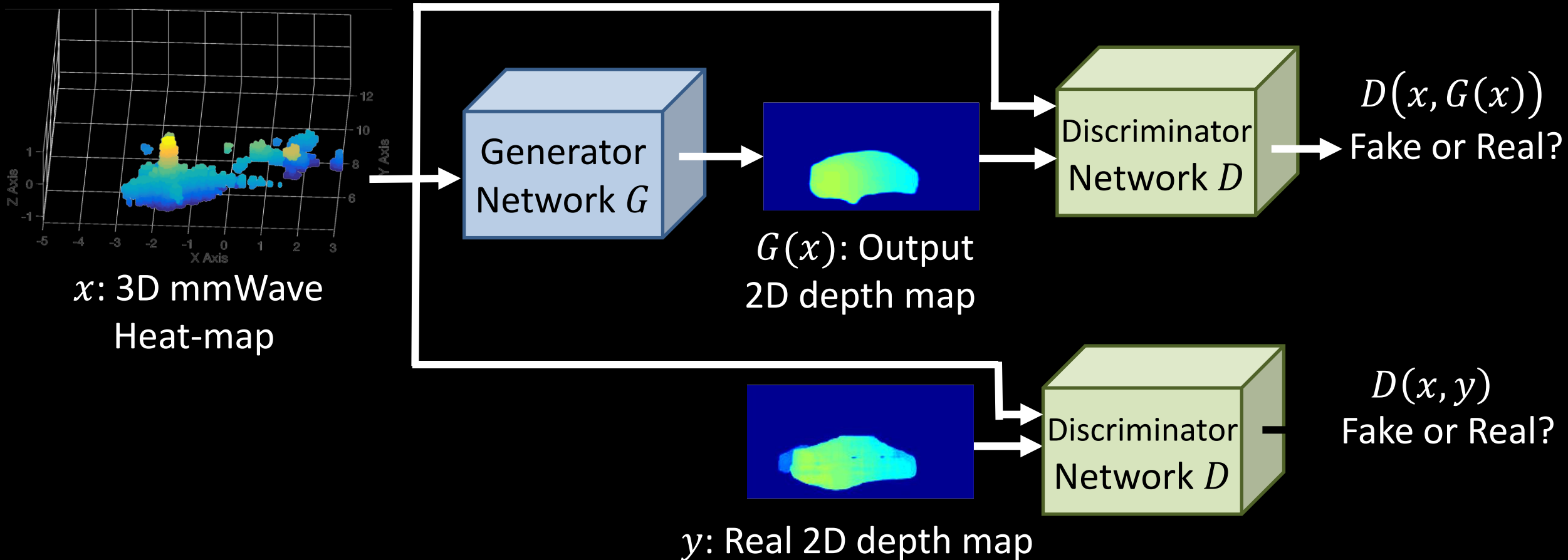


Conditional Generative Adversarial Network (cGAN)

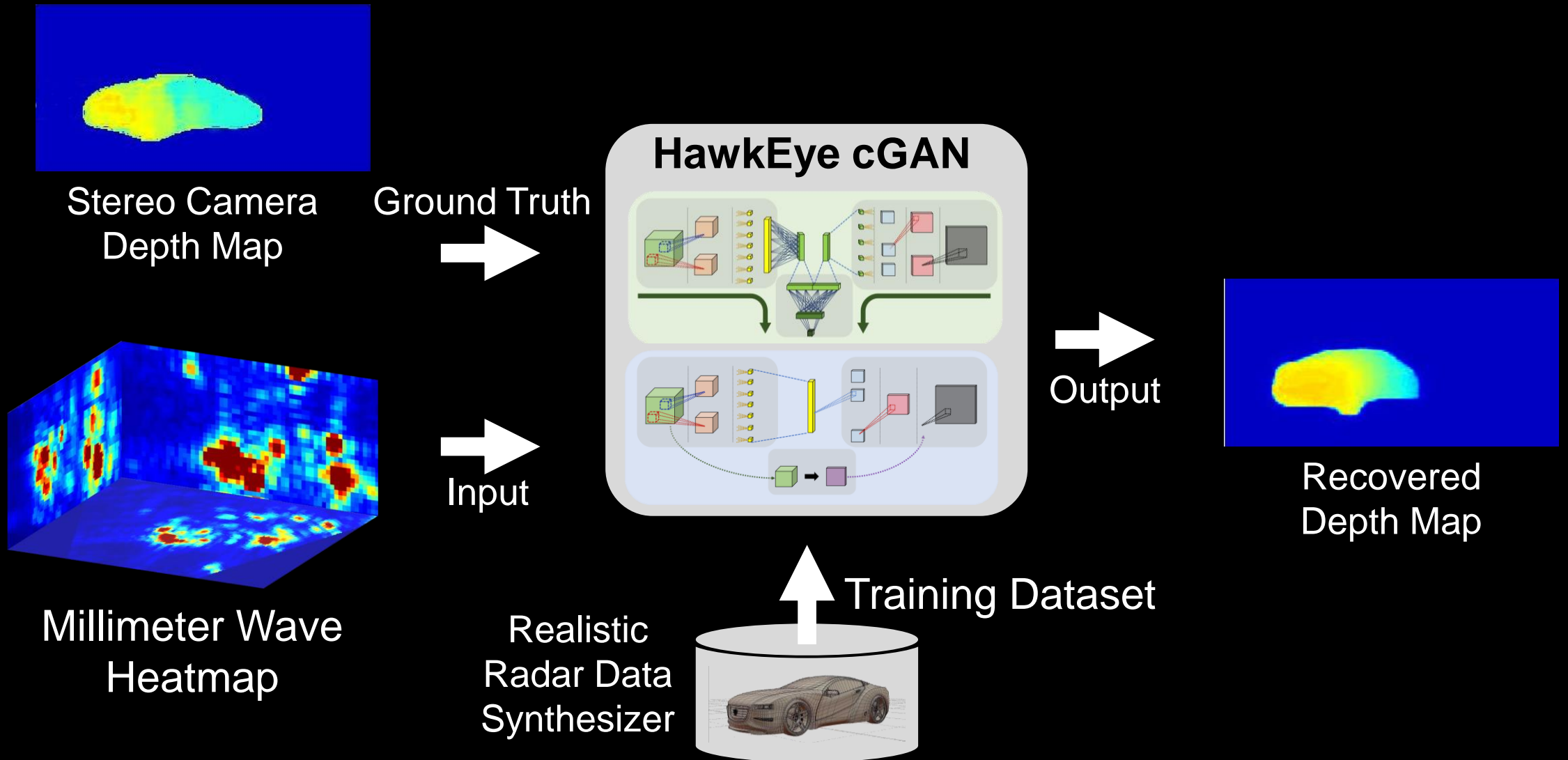
$$\mathcal{L}_1(G) = \mathbf{E}\|y - G(x)\|_1$$

$$\mathcal{L}_p(G) = \mathbf{E}\|VGG(y) - VGG(G(x))\|_1$$

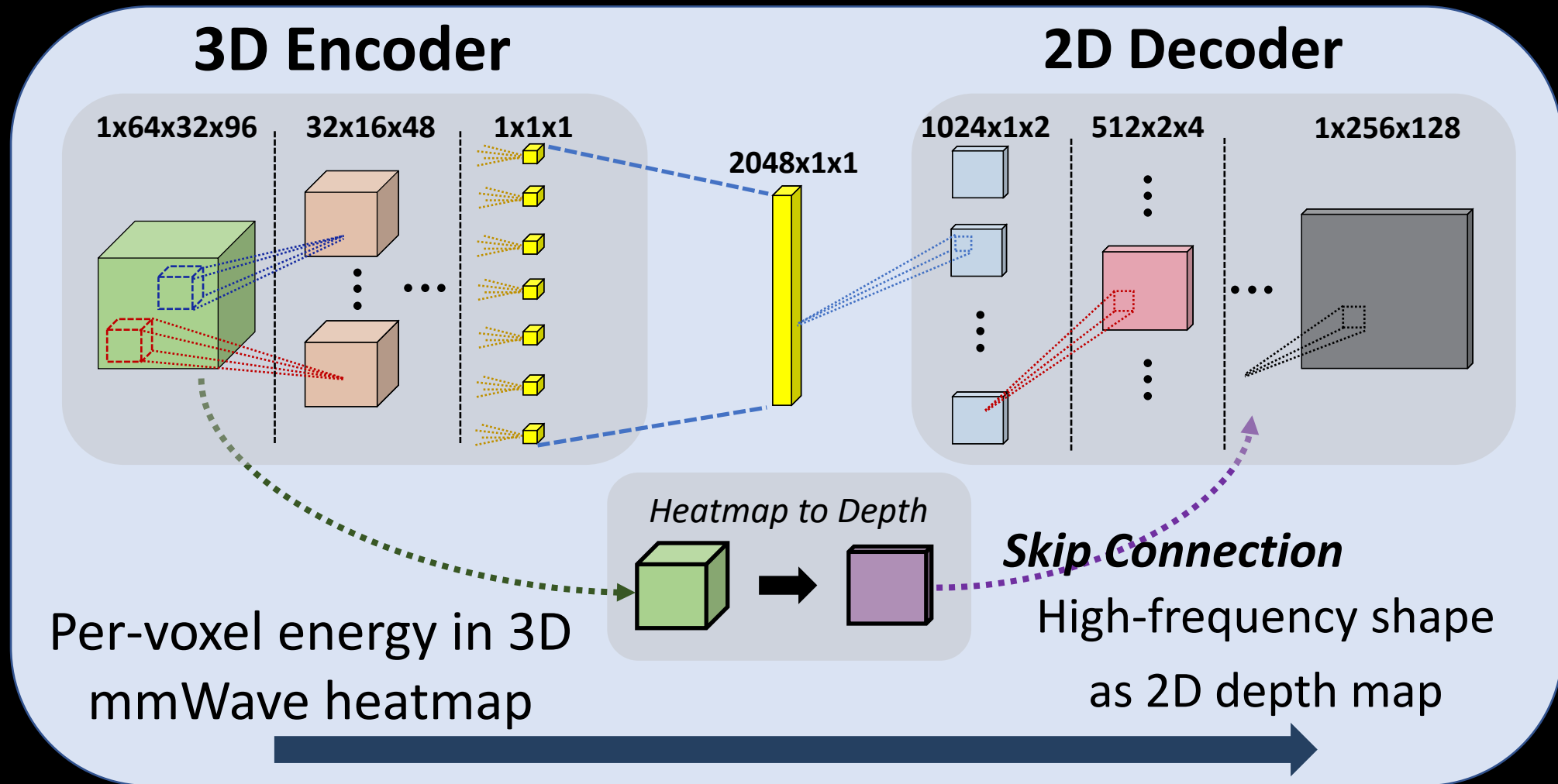
$$\mathcal{L}_H(G) = \mathcal{L}(G) + \lambda_1 \mathcal{L}_1 + \lambda_p \mathcal{L}_p$$



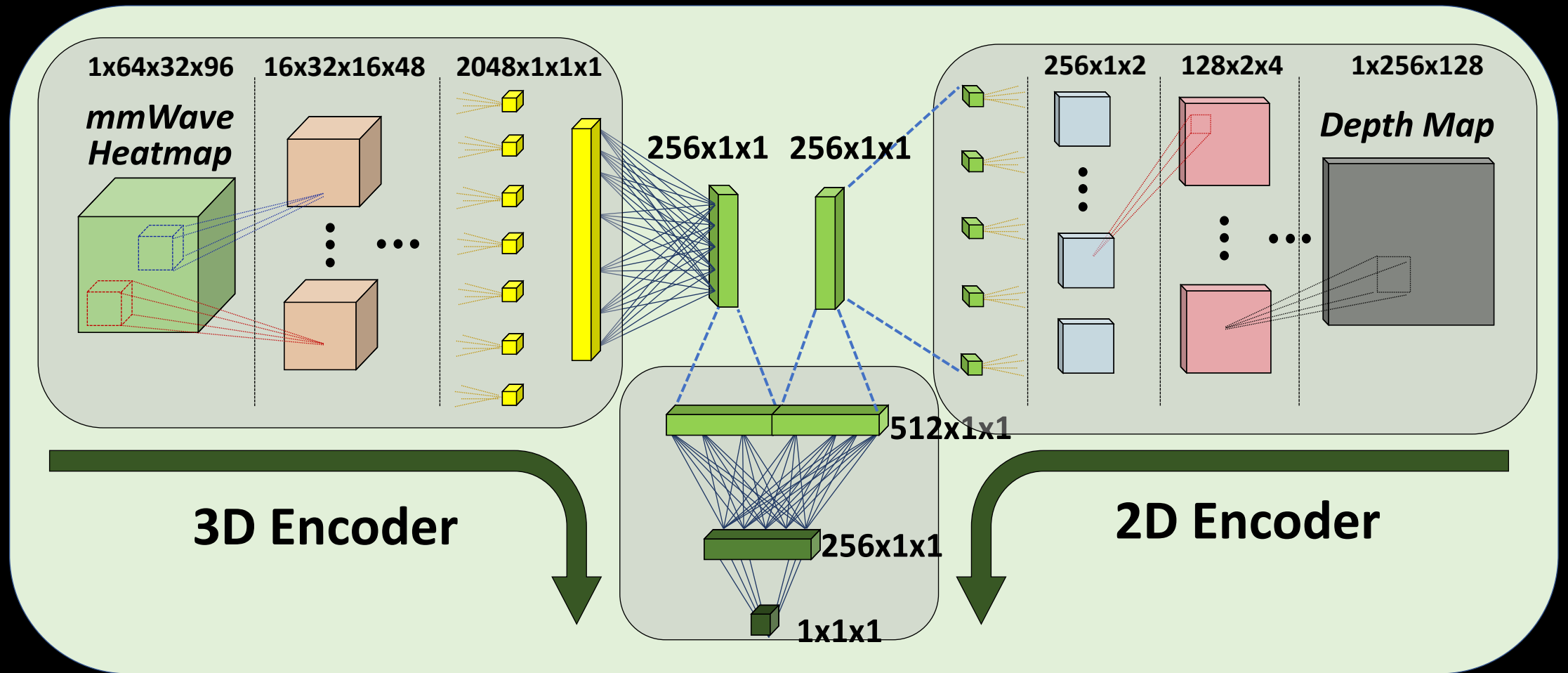
Hawkeye Overview



Generator Architecture



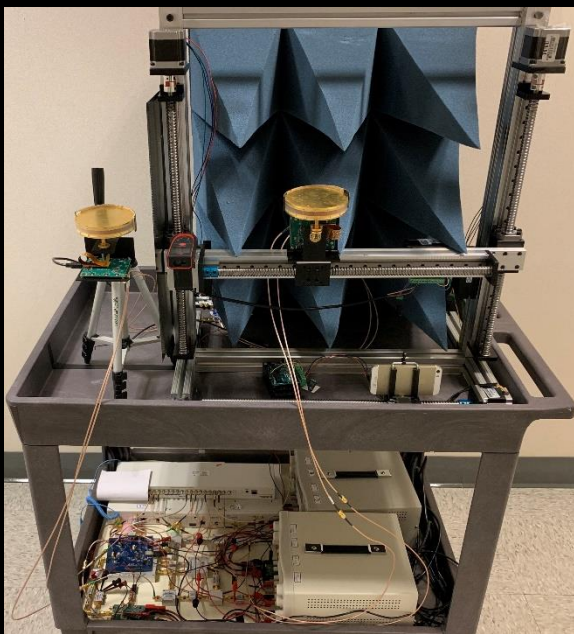
Discriminator Architecture



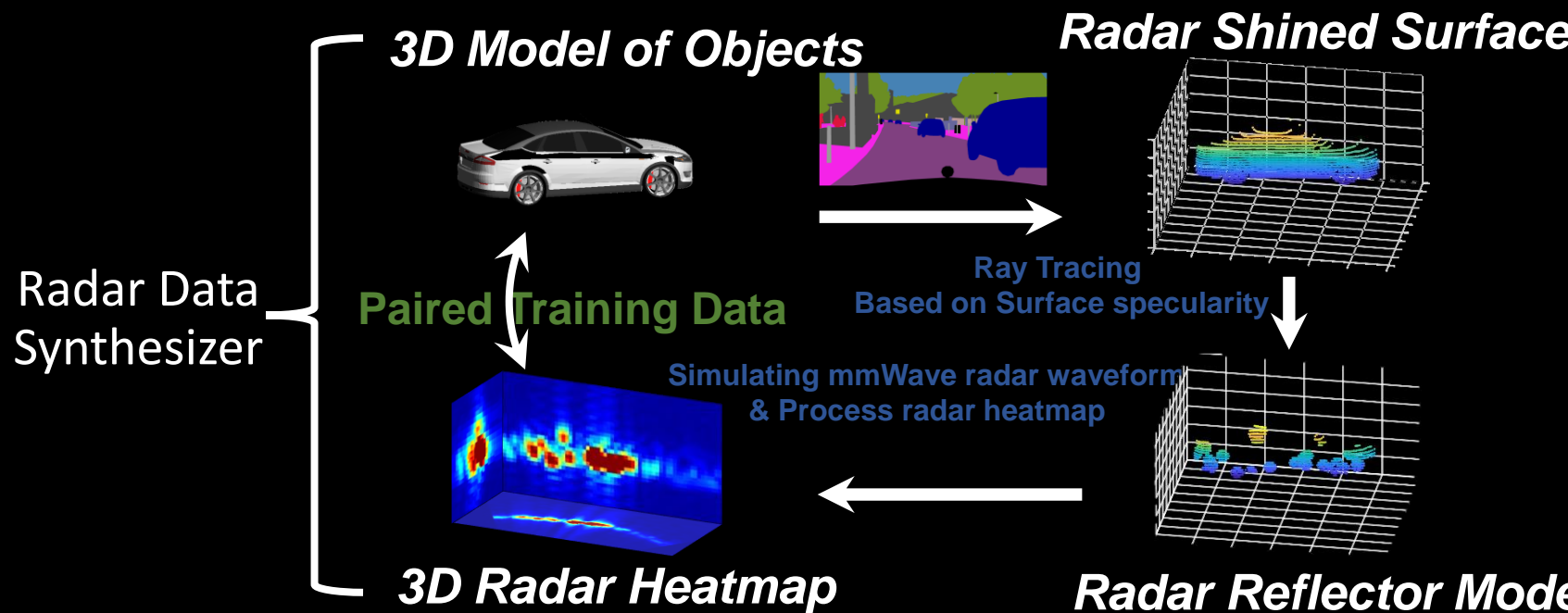
HawkEye[CVPR 2020]

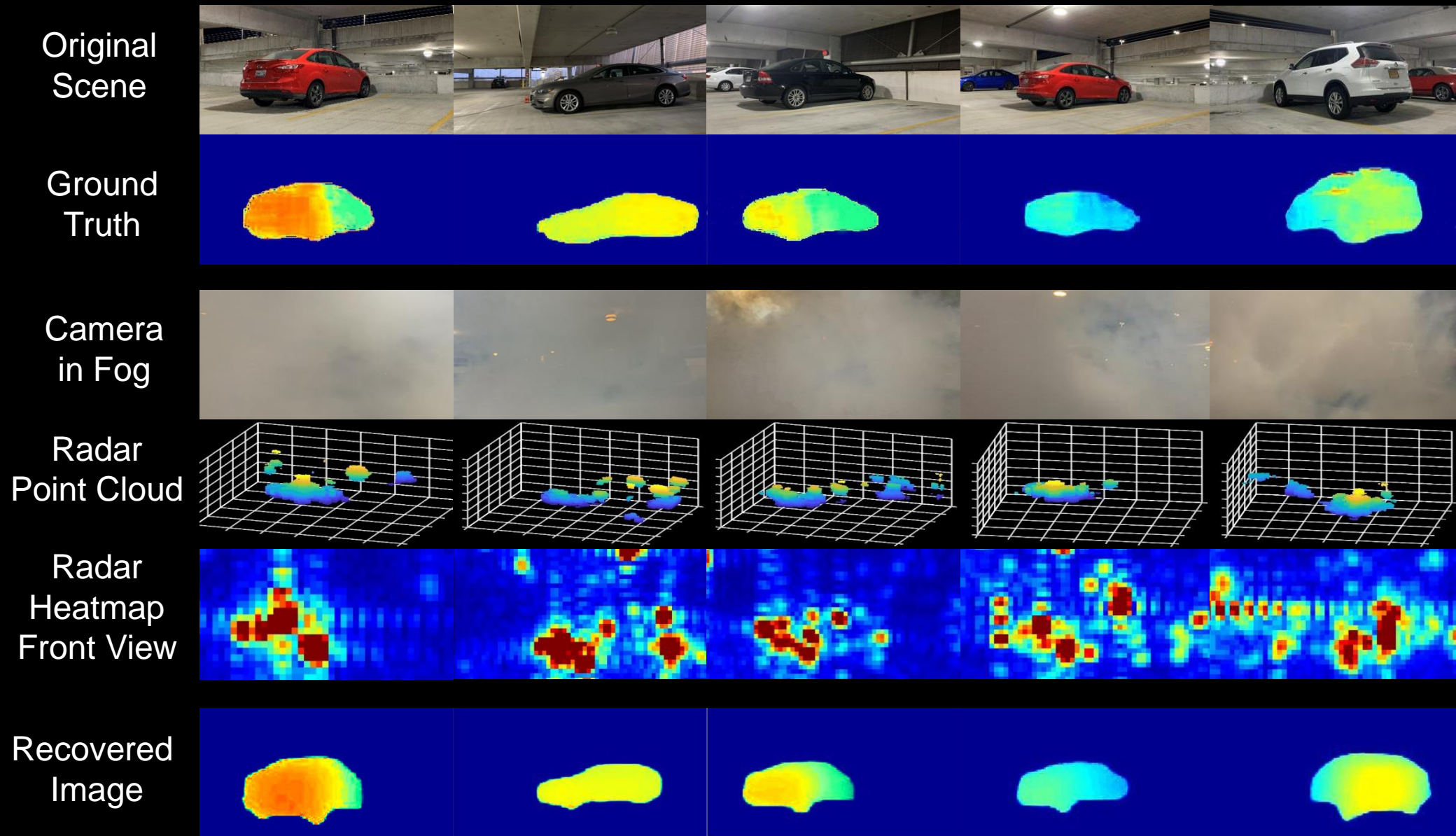
High Resolution Through Fog 3D Millimeter Wave Imaging Using cGANs

Training done using simulated data and tested using real data



mmWave FMCW
Imaging Platform



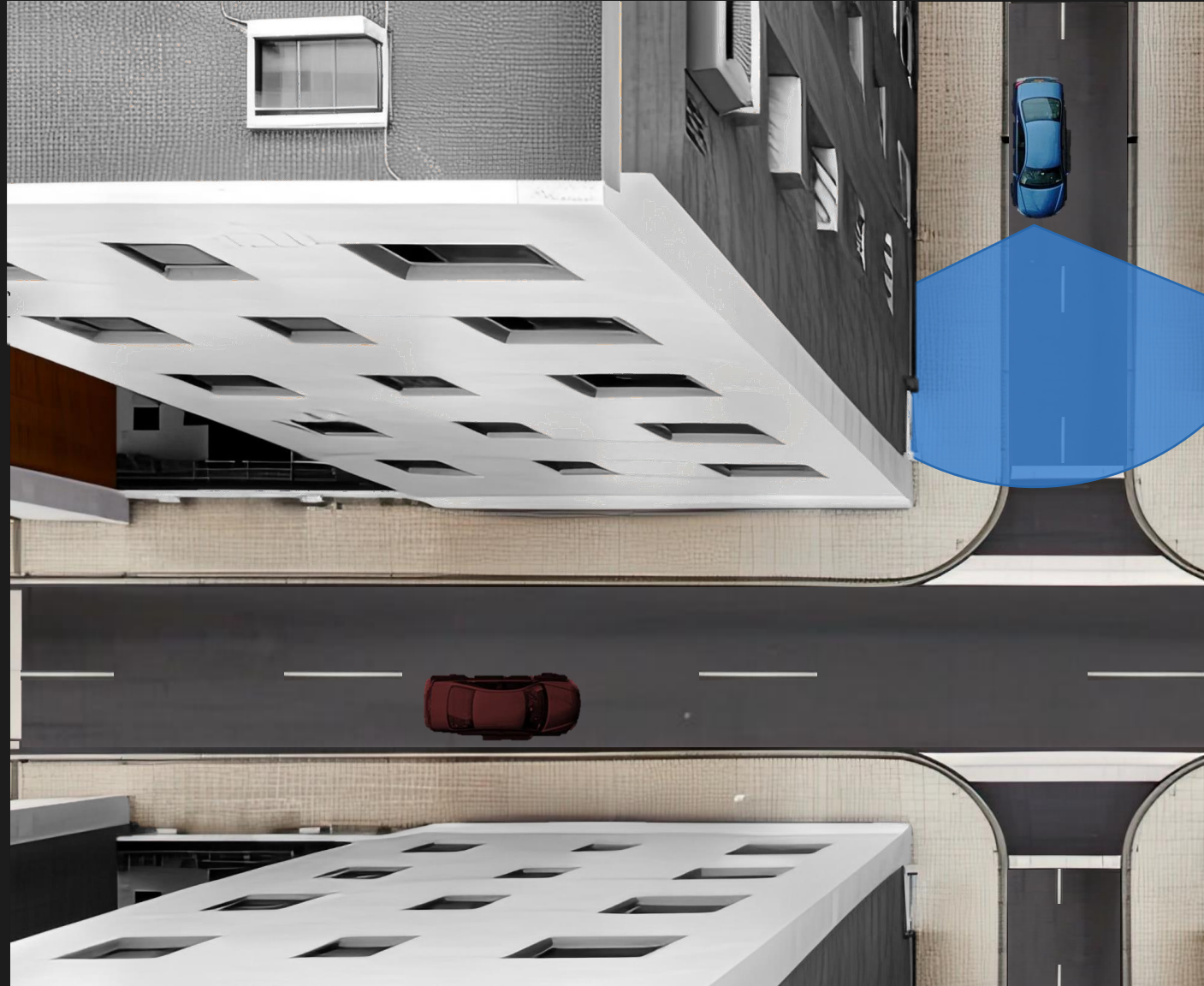


Trained using simulated data and tested using real data.

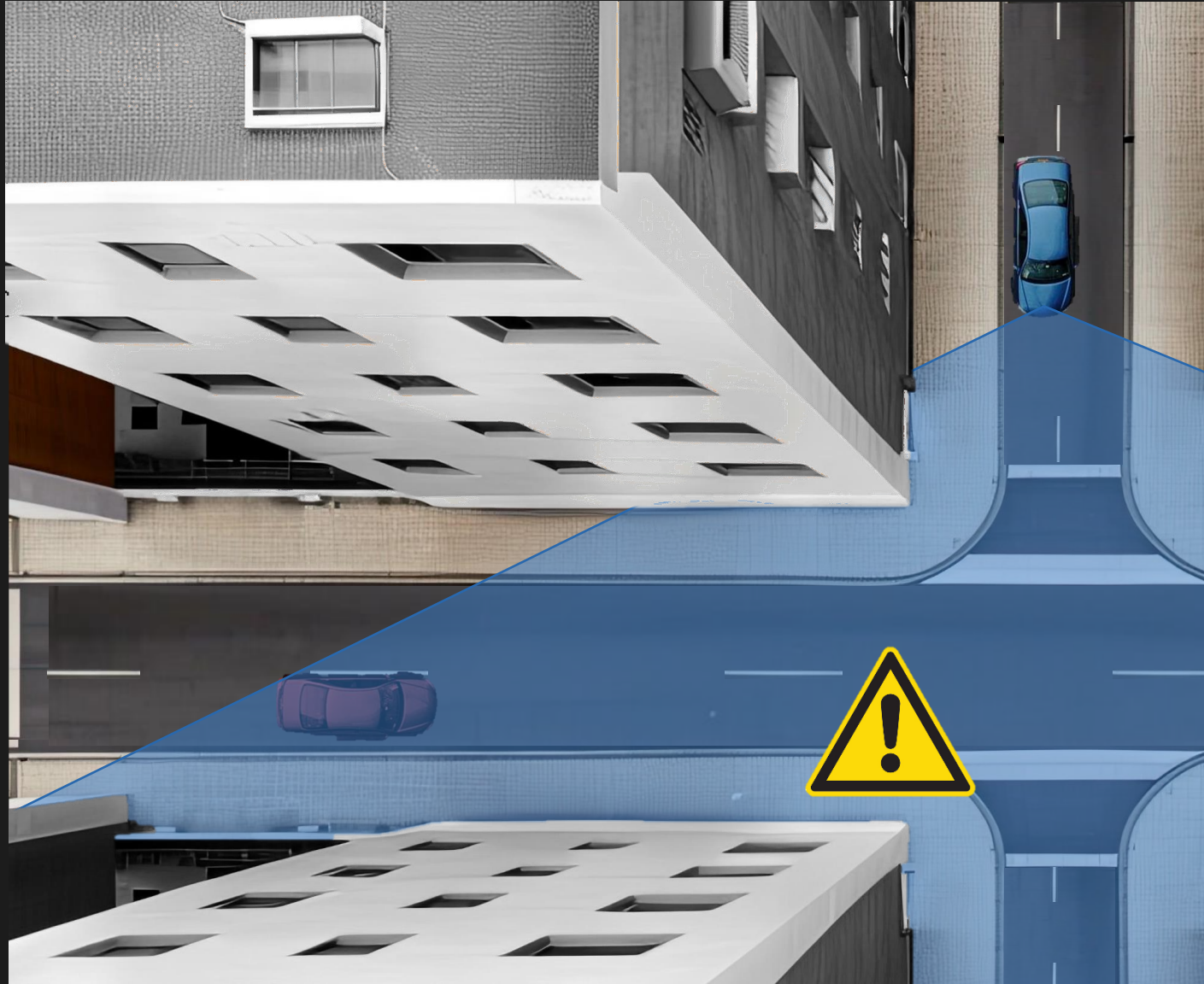
Bonus:

Around-the-Corner mmWave Imaging

Classic Sensing Modalities are Limited to Line-of-Sight



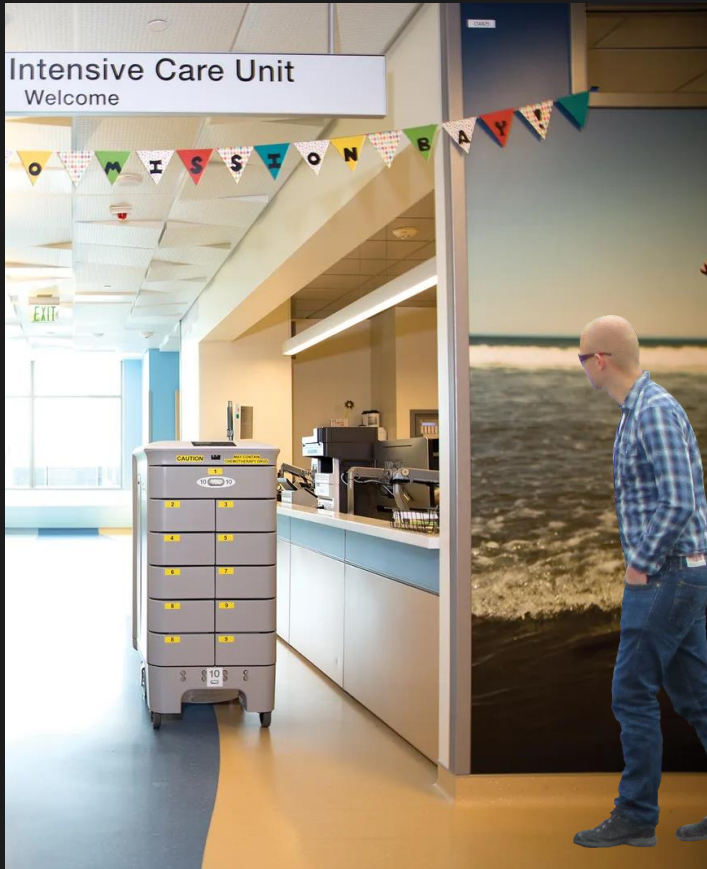
Can We Produce RF Images of Objects Around-the-Corner?



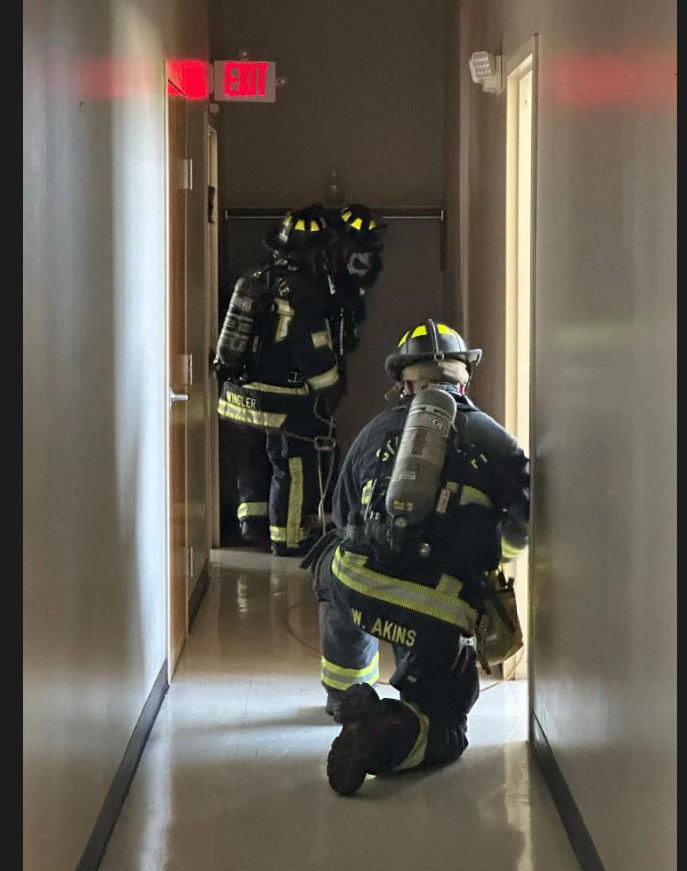
The Ability to Image Around-the-Corner has Many Applications



Autonomous Driving

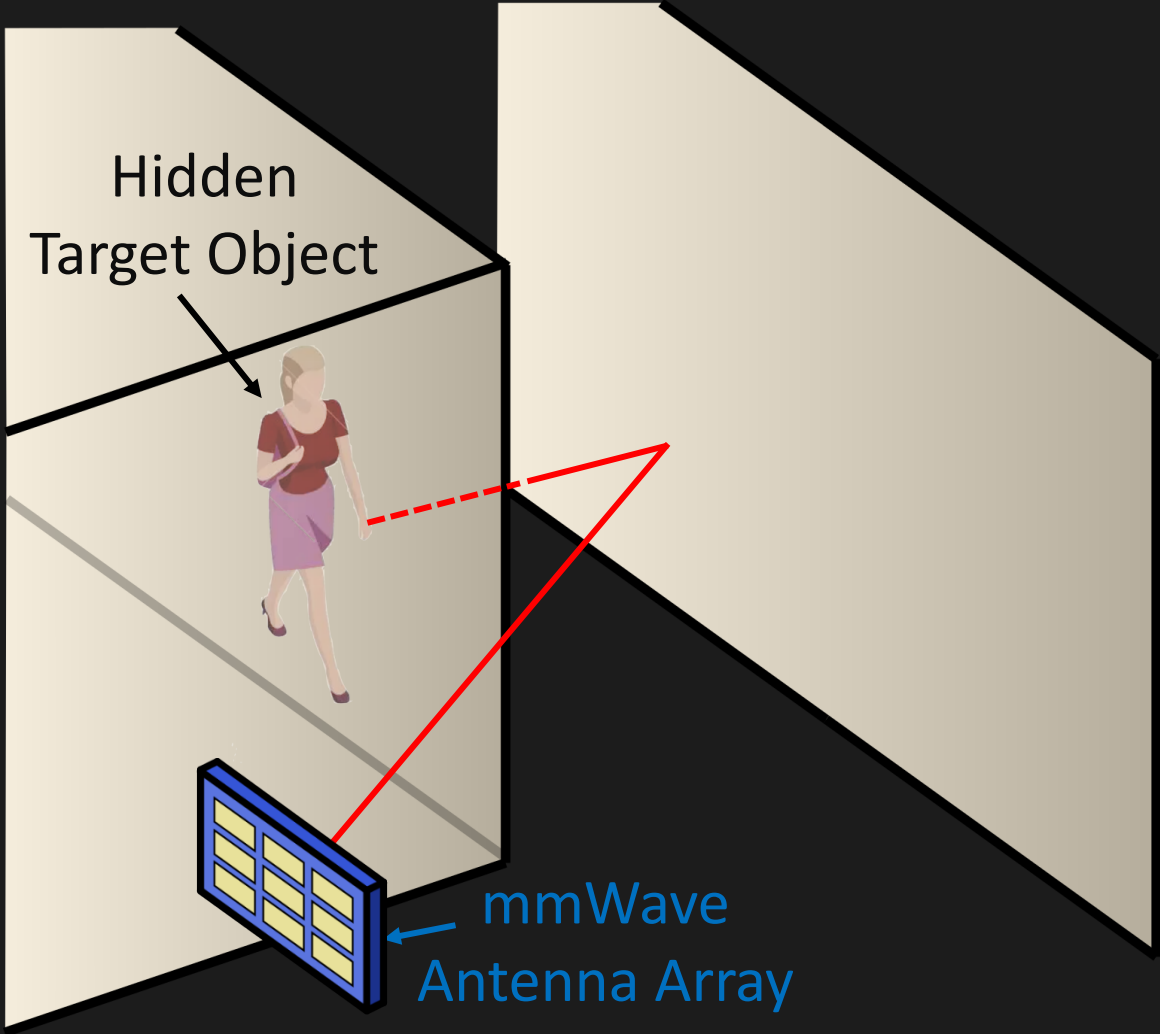


Robotic Navigation



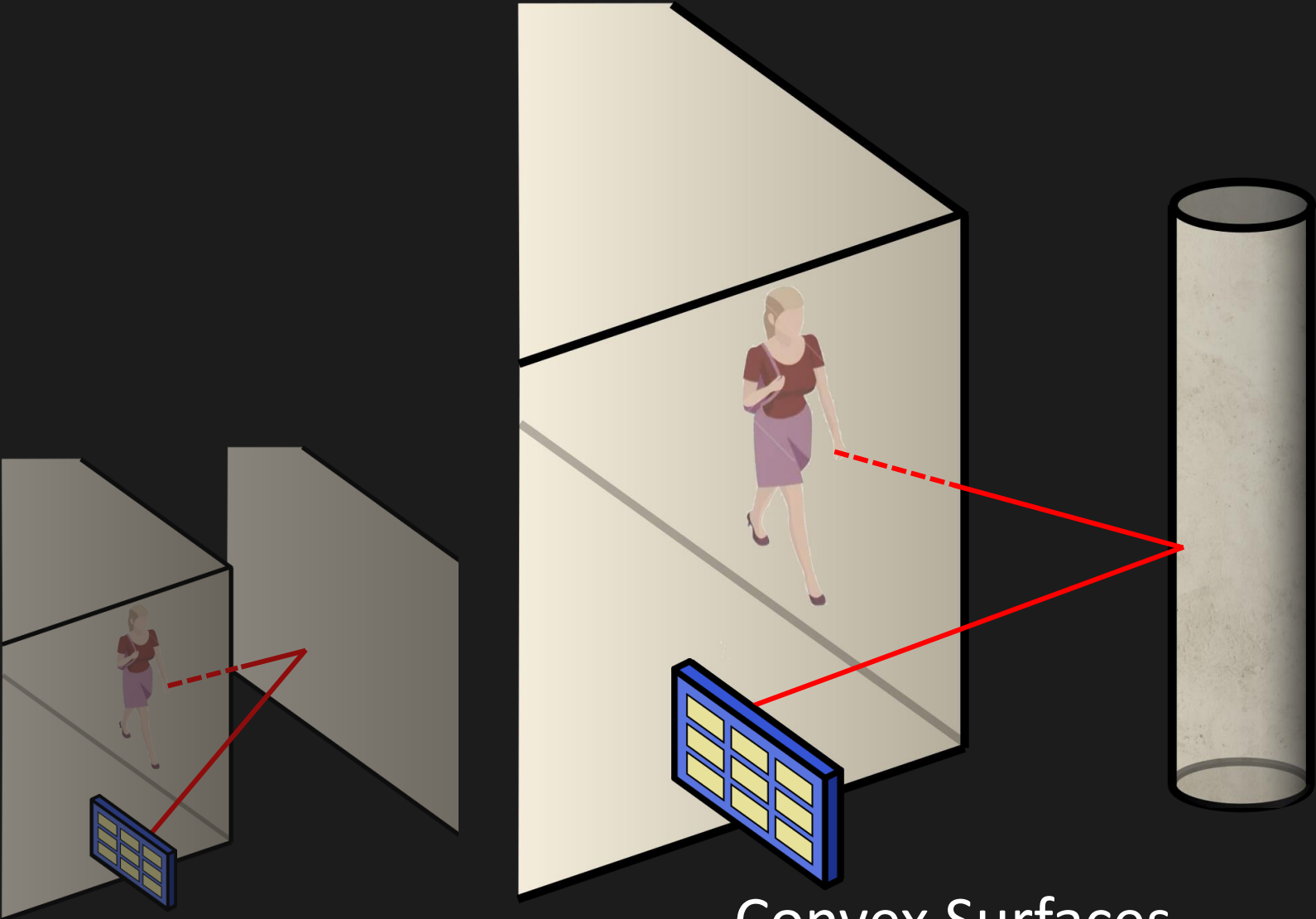
Search and Rescue

Practical Environments Contain a Variety of Reflecting Surfaces



Planar Surfaces

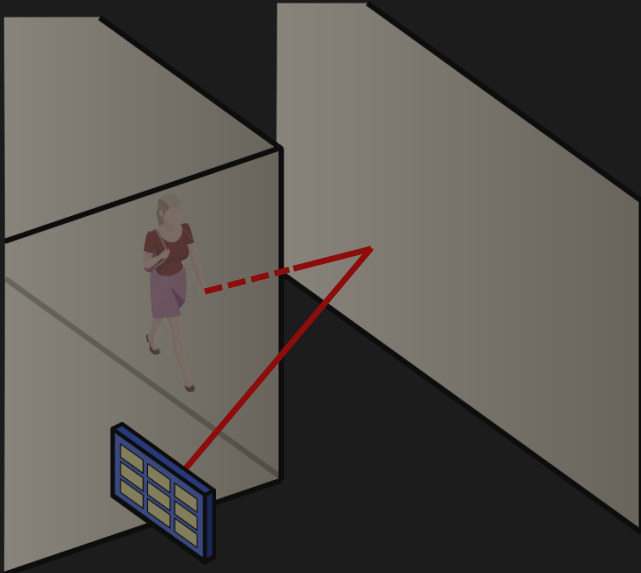
Practical Environments Contain a Variety of Reflecting Surfaces



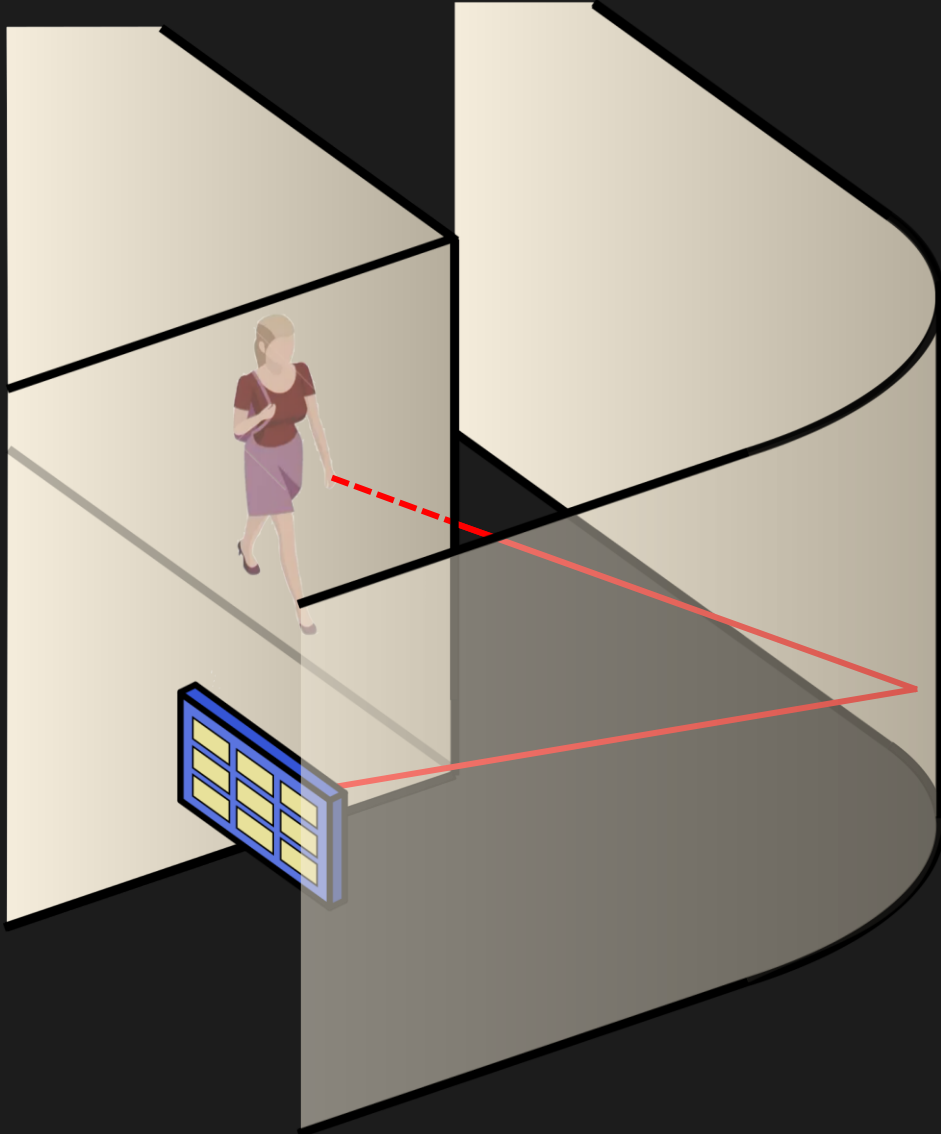
Planar Surfaces

Convex Surfaces

Practical Environments Contain a Variety of Reflecting Surfaces

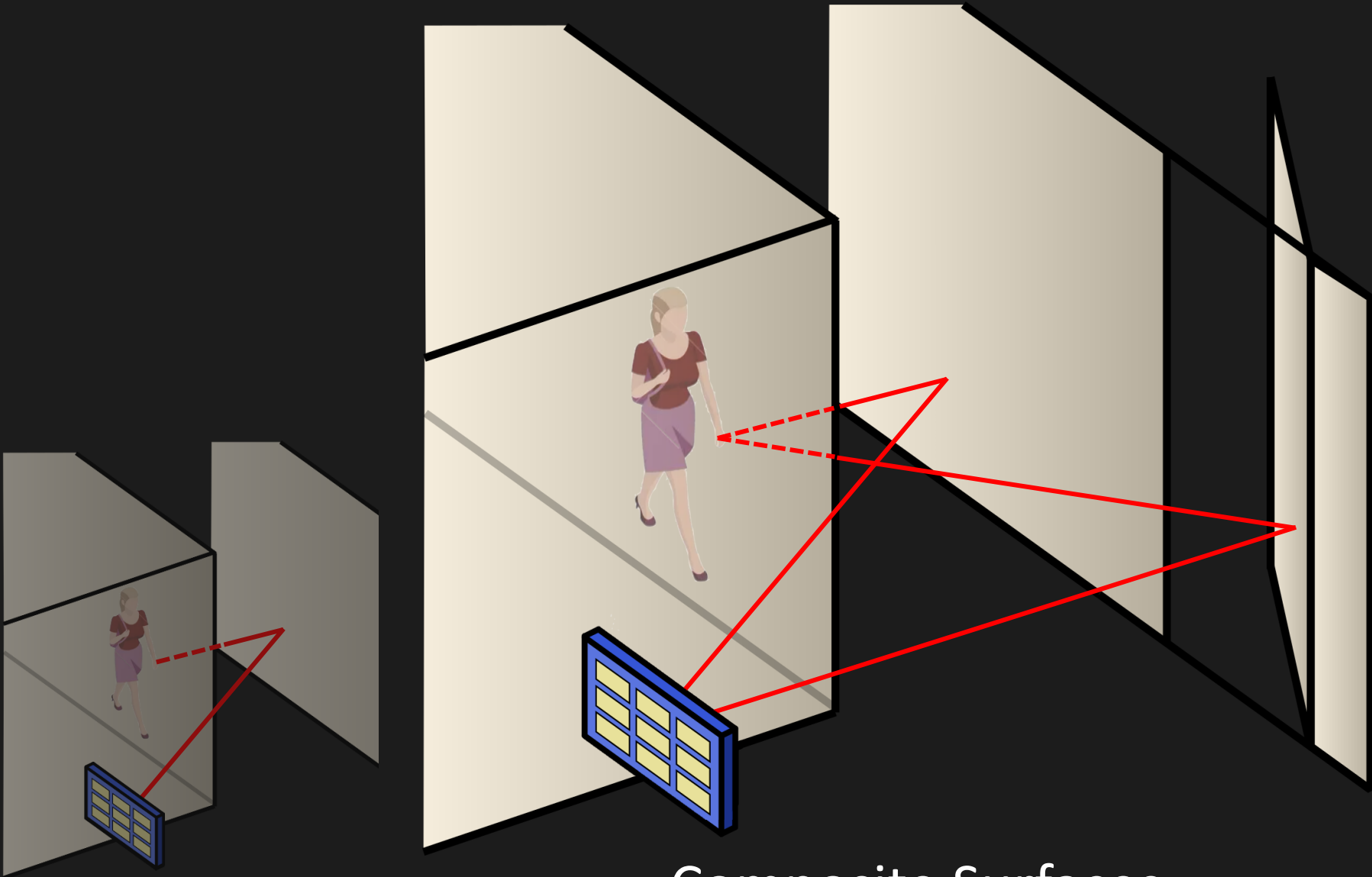


Planar Surfaces



Concave Surfaces

Practical Environments Contain a Variety of Reflecting Surfaces



Planar Surfaces

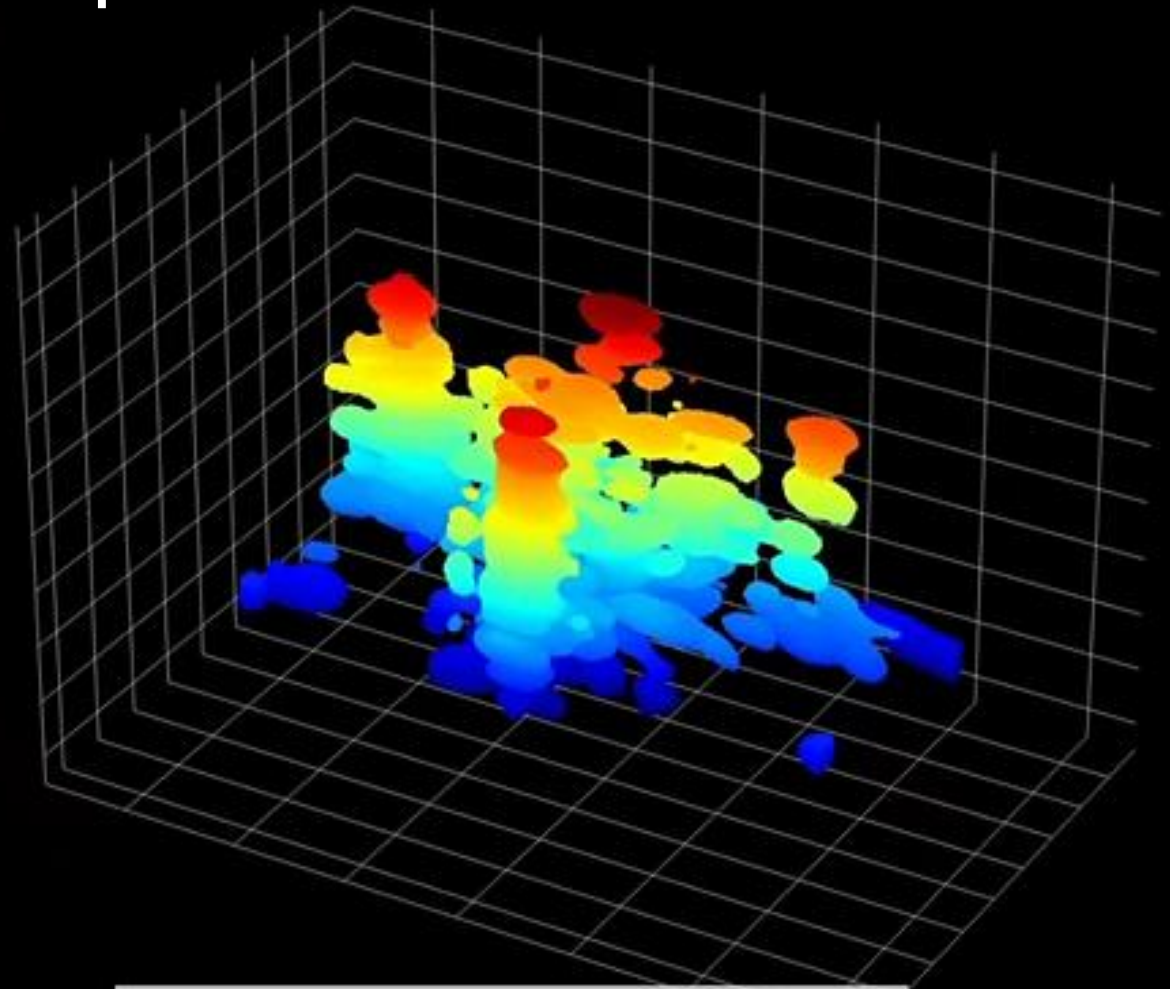
Composite Surfaces

CONCAVE SURFACES

Qualitative Results: Concave Reflectors Curved Computer Monitor



TAJ MAHAL

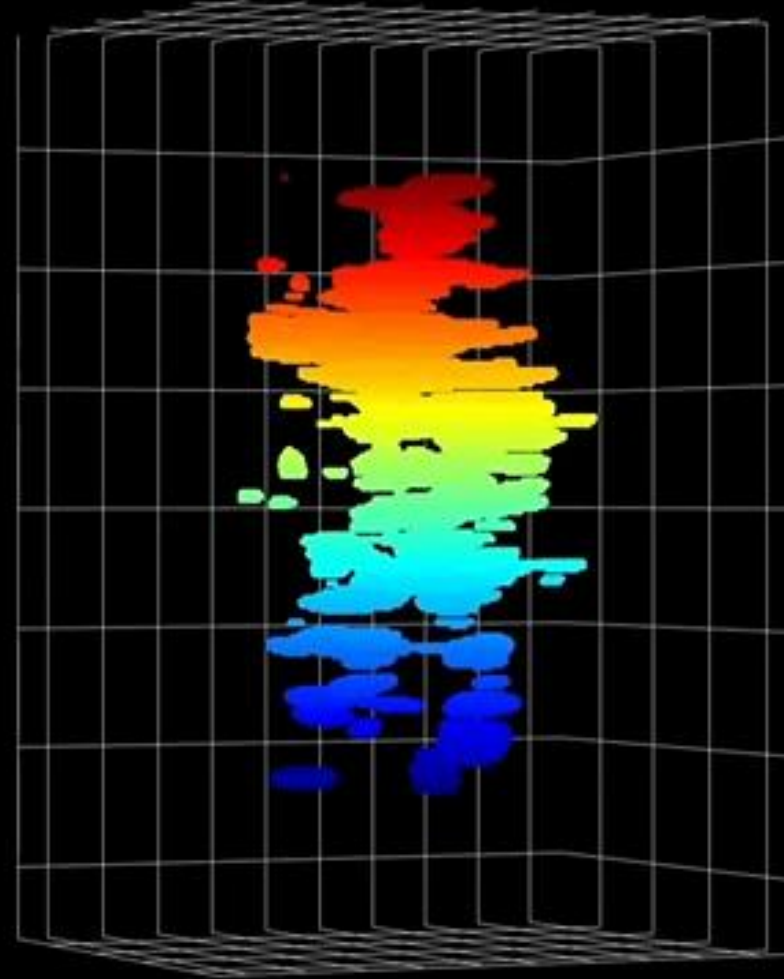


NLOS 3D Reconstruction
Concave Reflection

Qualitative Results: Convex Reflectors Building Column



MANNEQUIN



NLOS 3D Reconstruction
Convex Reflection

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