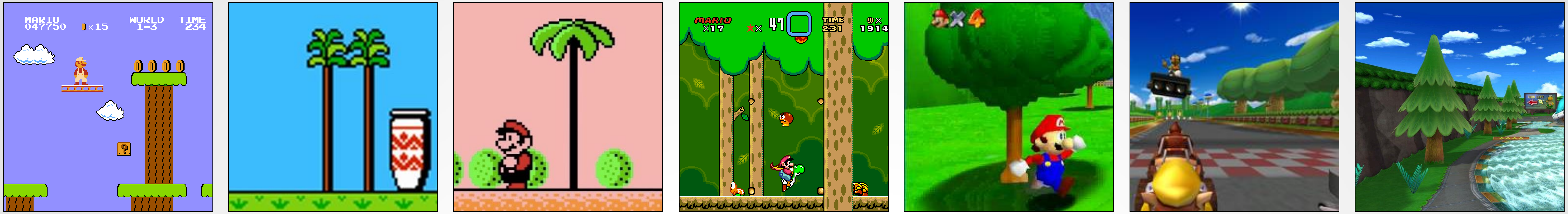
Fidelity Requirements for Digital Scenes in Off-Road AGV Simulation

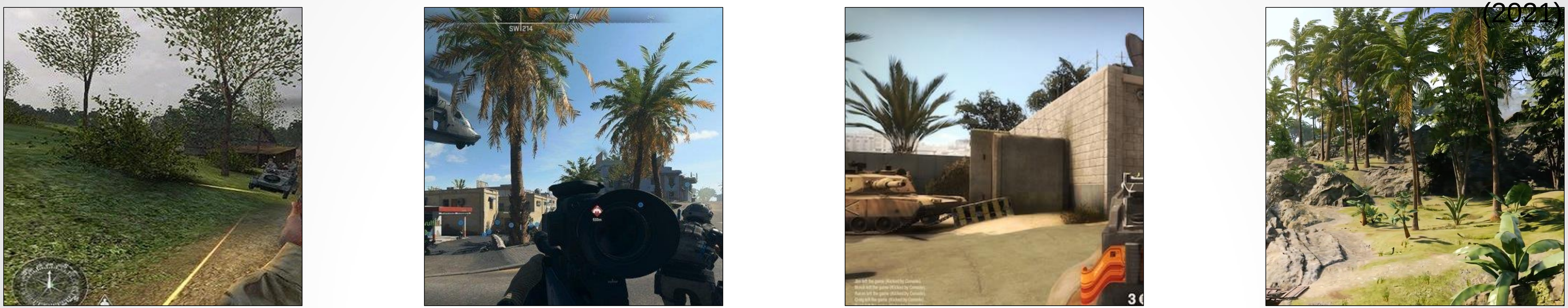
Christopher Goodin, Daniel W. Carruth, Lalitha Dabbiru, Michael Hedrick, Brandon Black
Mississippi State University
Zachary Aspin, Justin T. Carrillo
US Army Engineer Research and Development Center
John Kaniarz
U.S. Army DEVCOM Ground Vehicle Systems Center

Simulation Scene Fidelity

Super Mario Bros (1986) → Mario Kart, (2021)



Call of Duty (2003) → Call of Duty Vanguard (2021)



How Good is Good Enough?

Research Goal: Give the project sponsor an objective relationship between fidelity and quality that they can use to make resource allocation decisions.

Research Challenge:
- Quality Metric
- Fidelity Metric
- Experiments

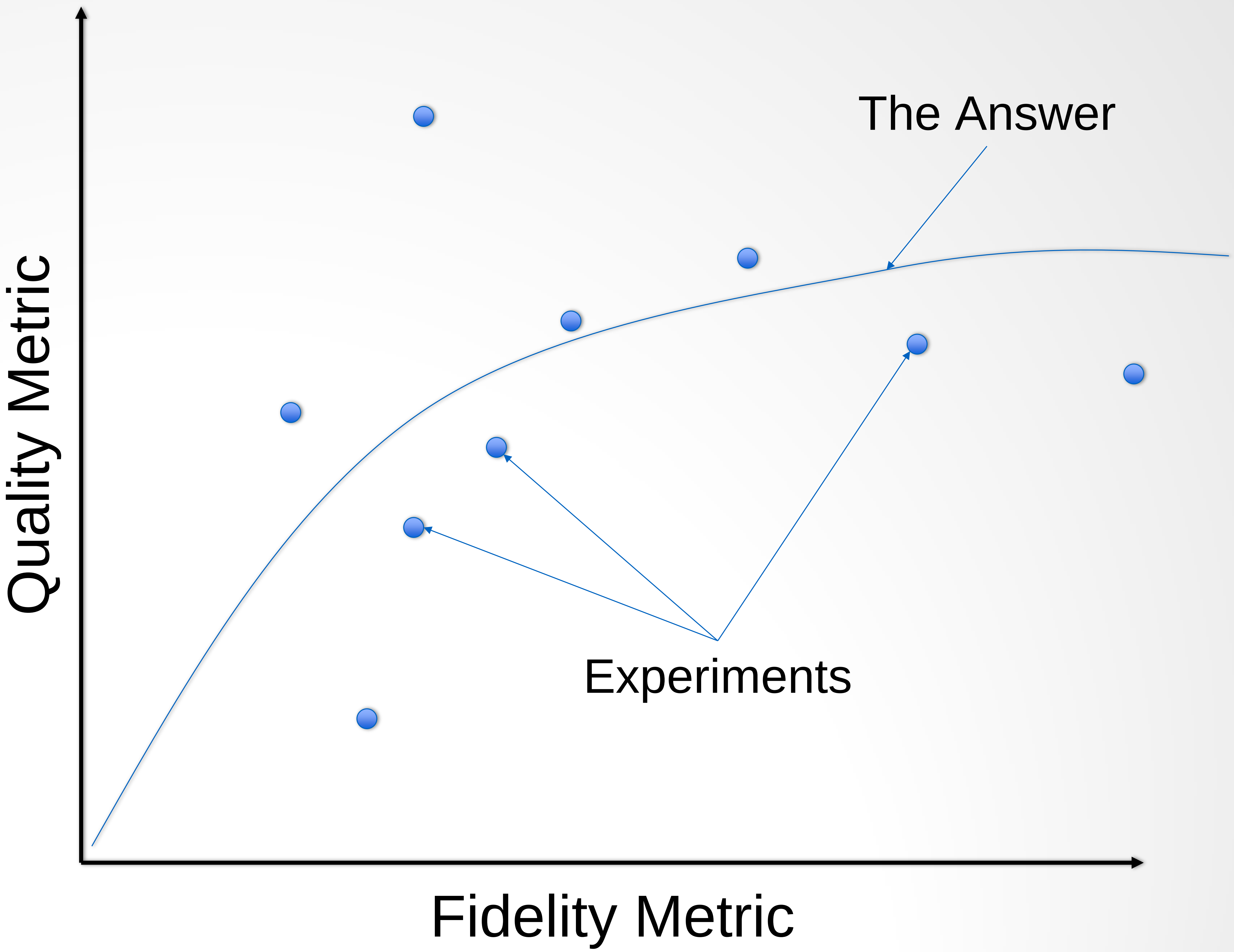
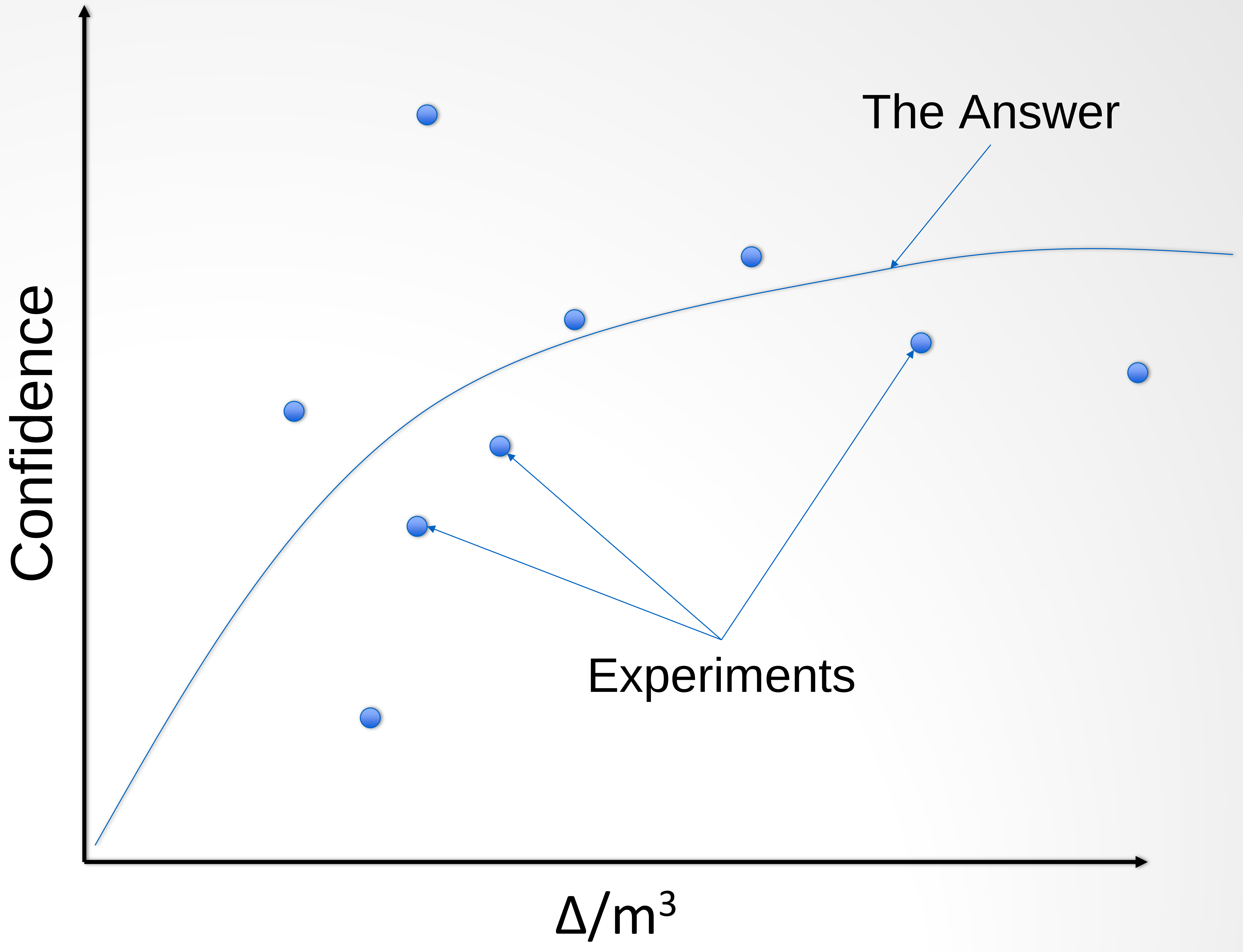


Image Experiments

1. Train and test an image classifier (Googlenet) on real-world data
2. Generate images from scenes with varying levels of geometric fidelity
3. Run classifier on synthetic images
4. Compare to real world



Retraining Googlenet

- Googlenet retrained on 5 classes using MATLAB
- 70% train, 30% test
- 10 epochs, 15 iterations / epoch
- Classification confidence near 100%

- Construction Barrel: 35 images
- Jersey Barrier: 30 images
- Tree: 68 images
- HMMWV: 41 images
- MRZR: 42 images

Synthetic Data: The MSU Autonomous Vehicle Simulator

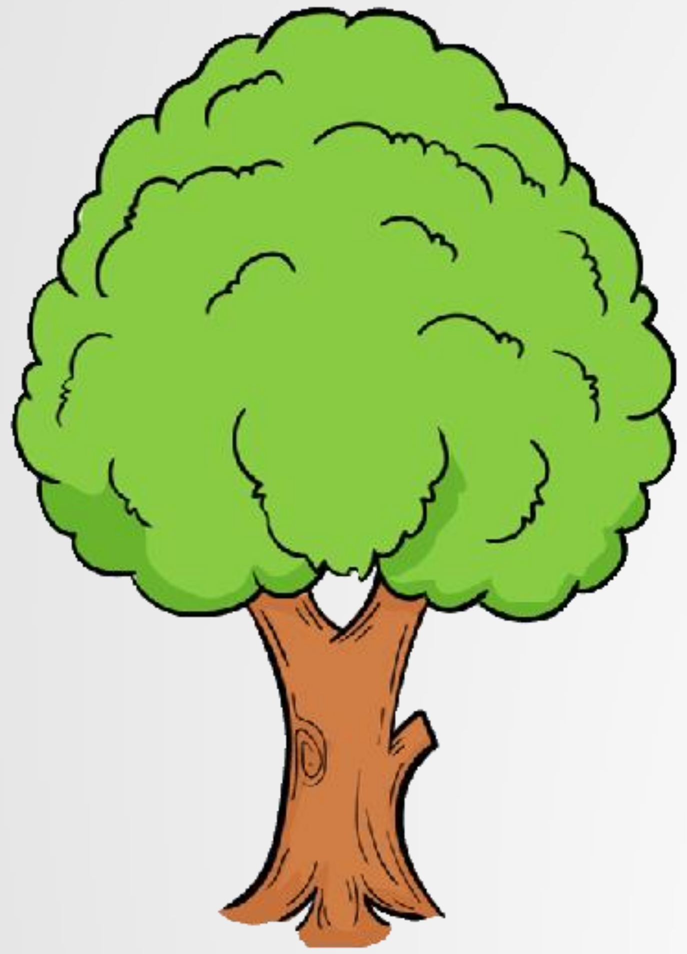
MAVS is:

- A C++ software library for simulating autonomous vehicles in realistic digital terrain.
- A real-time simulator for evaluating the performance of autonomous perception and navigation software.
- A user-friendly Python API for composing custom simulations.
- A physics-based sensor simulator for LIDAR, GPS, cameras, and other sensors.
- A lumped-parameter vehicle-dynamics simulator.
- ROS compatible

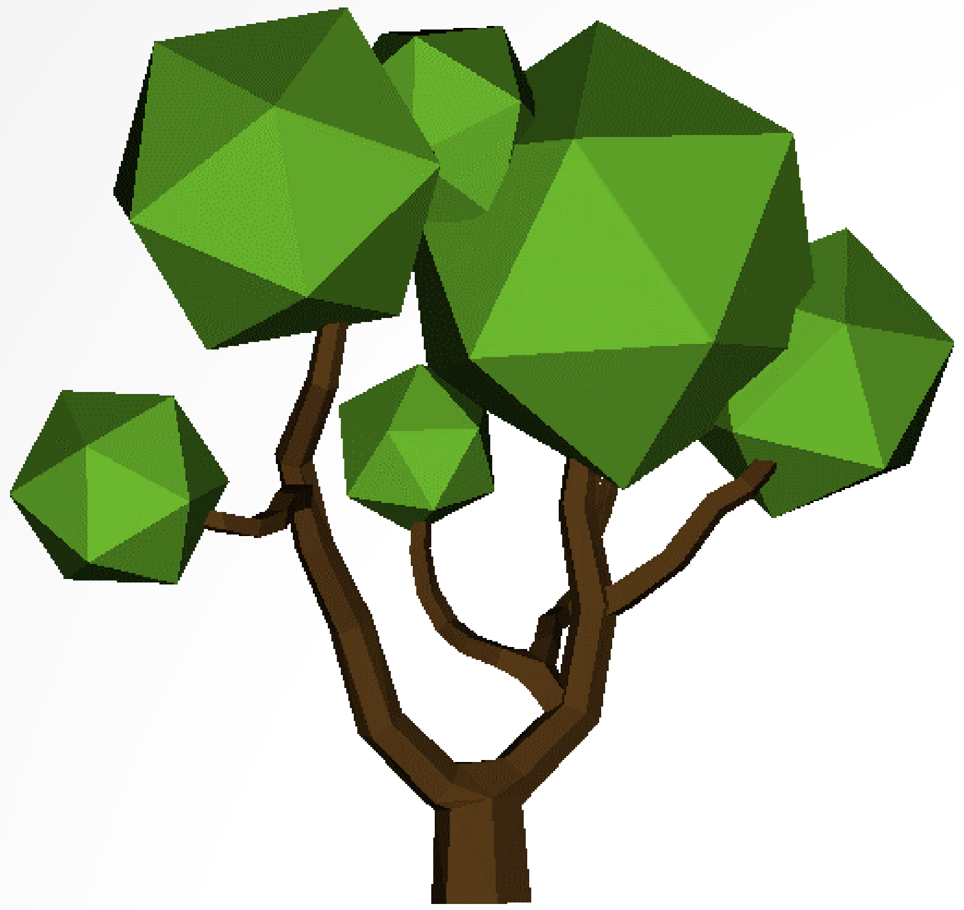
Varying Scene Fidelity

Δ/m^3

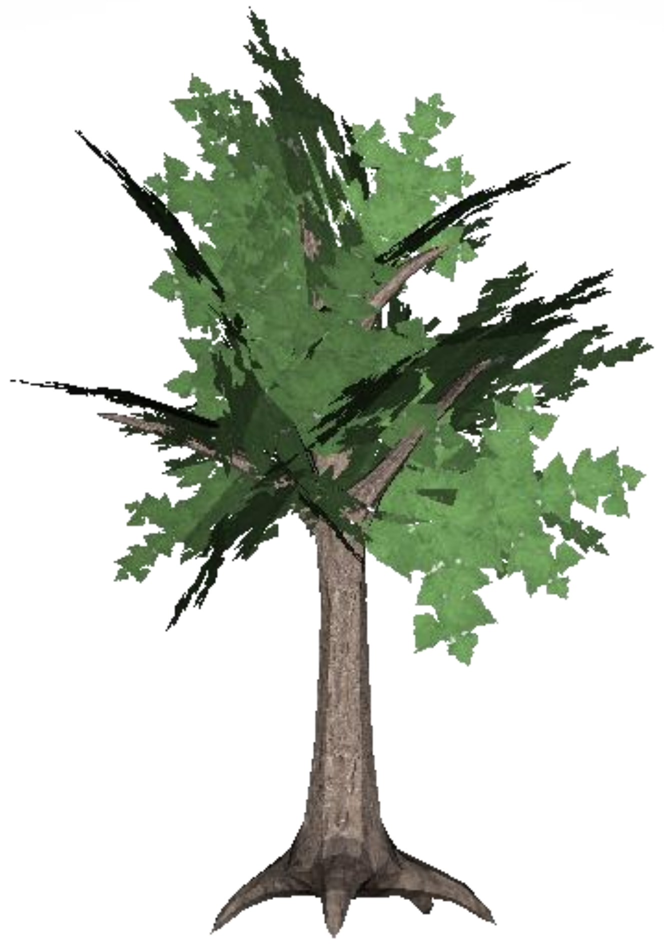
$<1/m^3$



$4/m^3$



$7.5/m^3$



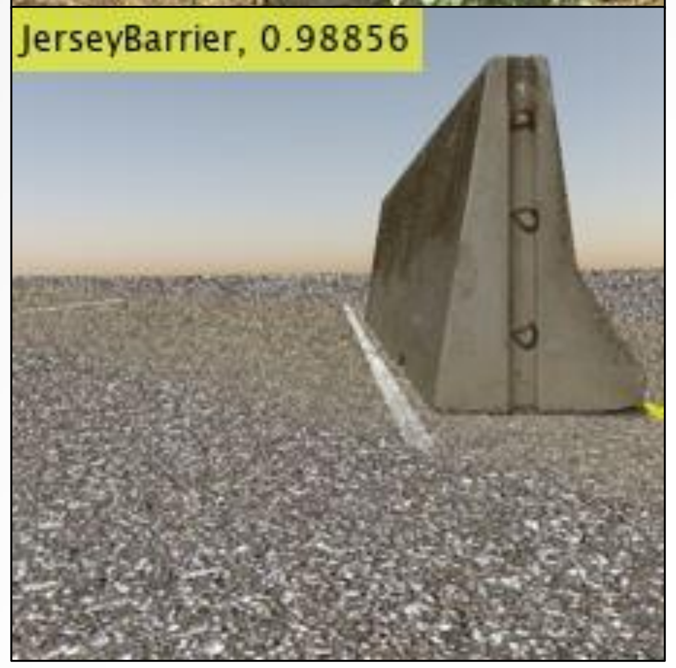
$890/m^3$

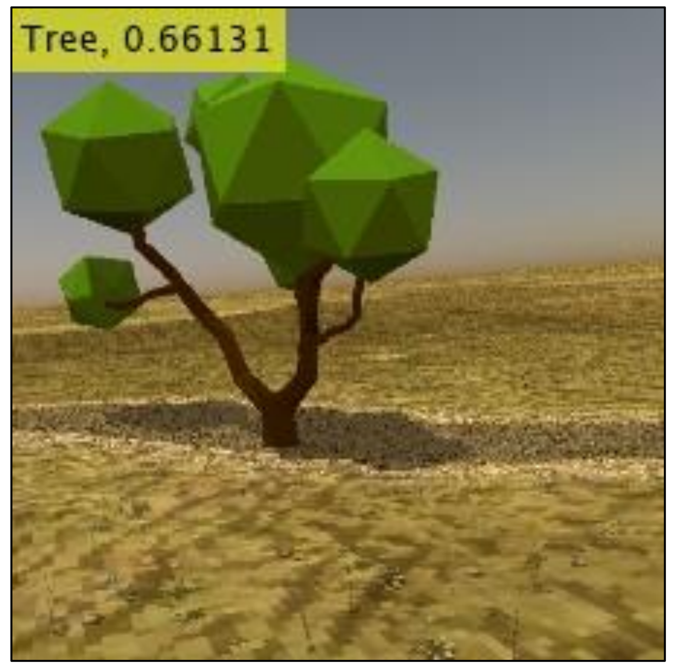
$54k/m^3$

Simulation Results

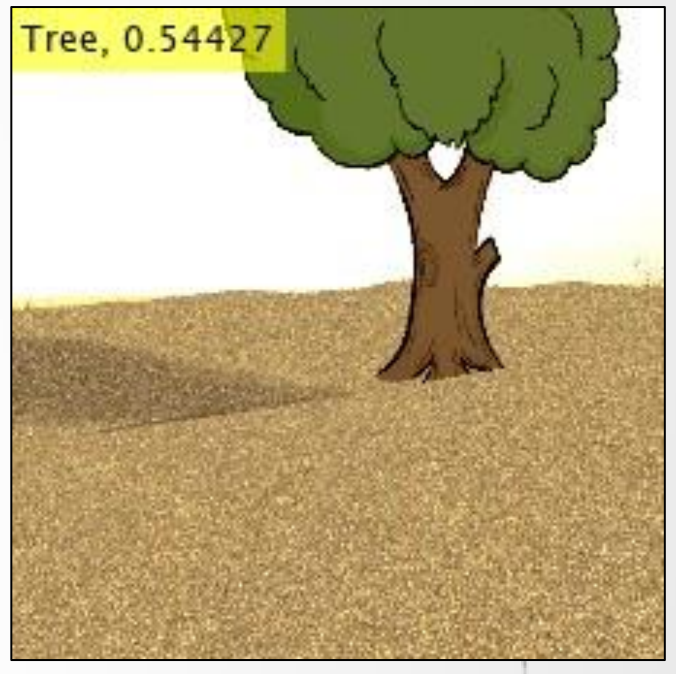
UE4, Med-fid

MAVS lo-fid



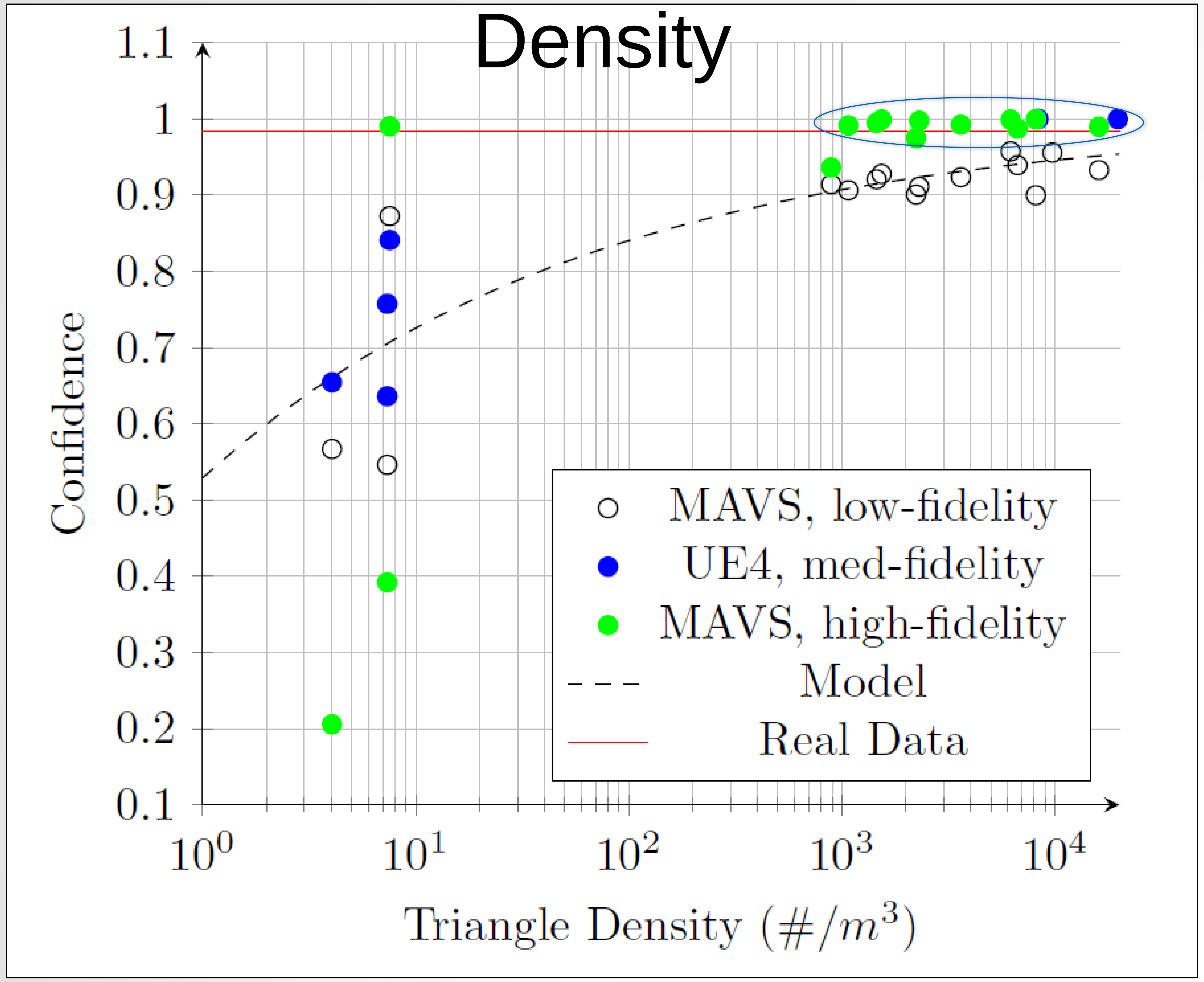


MAVS Hi-fid



Fidelity Requirements

Versus Triangle Density



Versus Rendering Fidelity

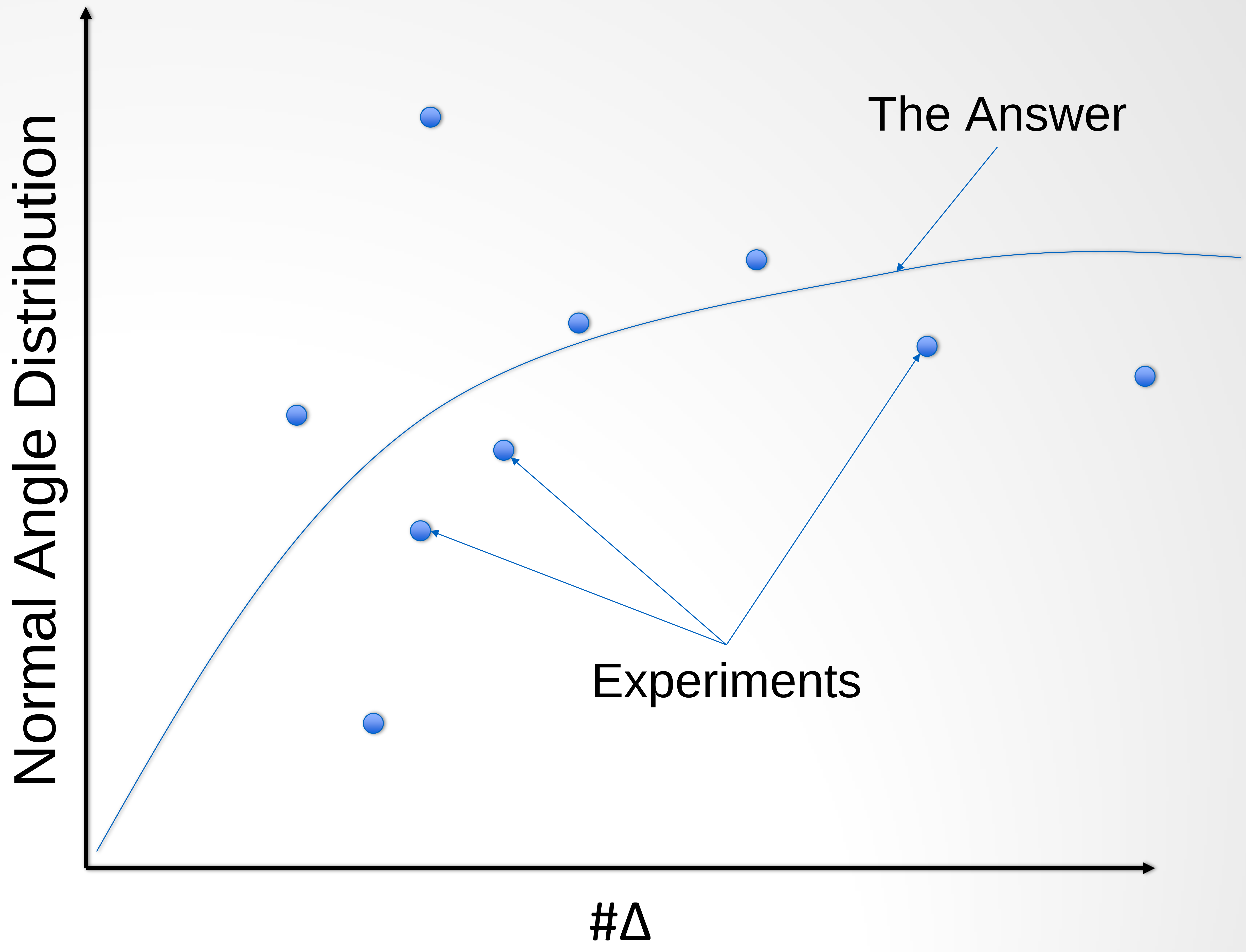
Class	Low	Med	High	Real
Construction Barrel	0.948	0.998		0.998
HMMWV	0.796	0.999		0.999
Jersey Barrier	0.846	0.998		0.997
MRZR	0.870	0.993		0.997
Tree	0.930	0.999	0.992	0.985

κ = Confidence
ρ = Triangle Density
α = Fit Coeff = 0.471
β = Fit Exp = 0.235
R^2 = 0.856

$$\kappa = 1 - \alpha\rho^{-\beta}$$

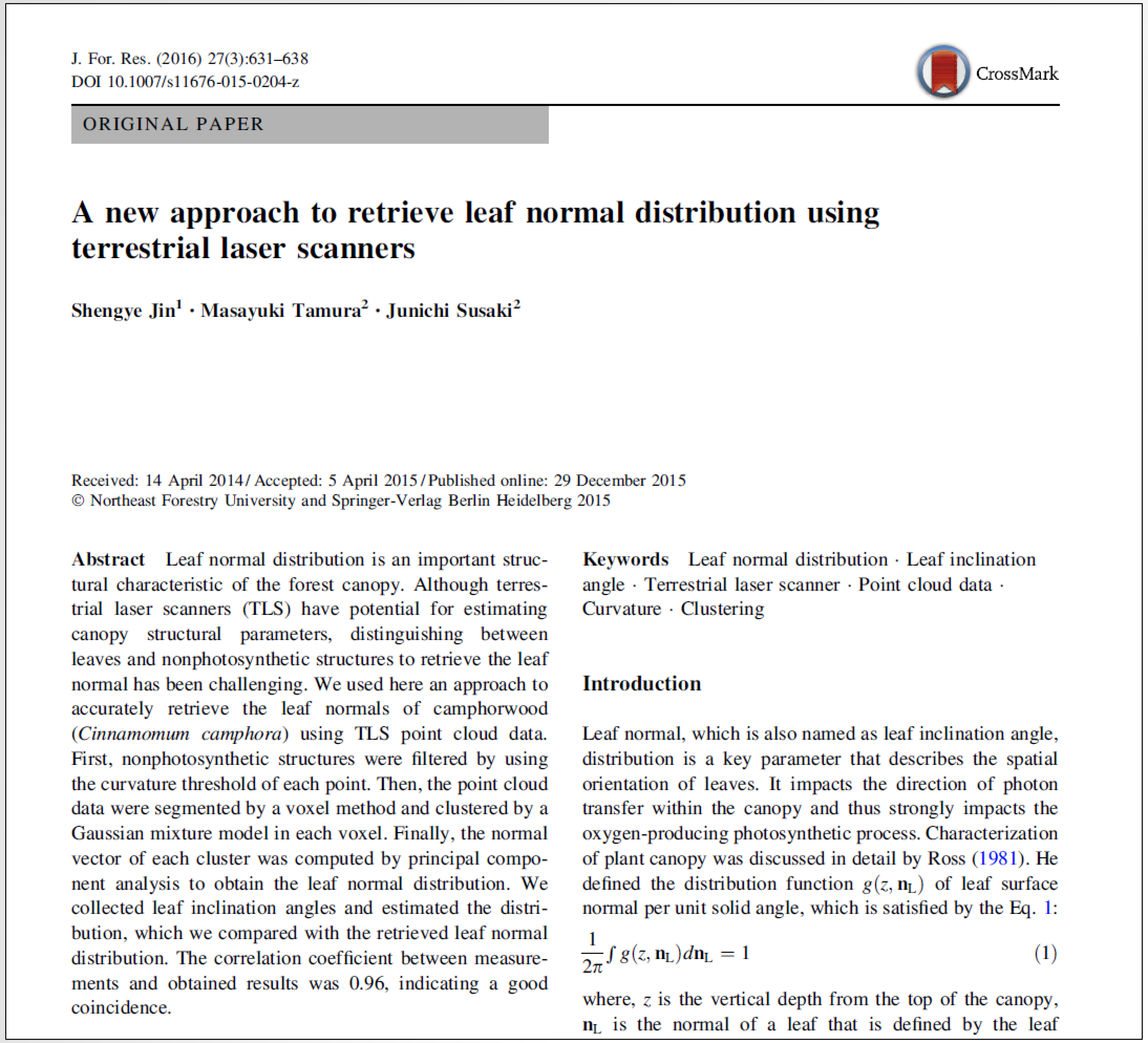
Lidar Experiments

- Recent research shows leaf normal angles follow predictable distribution*
- Compare leaf angle distributions between real and simulated datasets
- Calculate “realism metric”
- Define triangle number cutoff



*Jin, Shengye, Masayuki Tamura, and Junichi Susaki. "A new approach to retrieve leaf normal distribution using terrestrial laser scanners." *Journal of forestry research* 27 (2016): 631-638.

Leaf Normal Angle: Real



J. For. Res. (2016) 27(3):631–638
DOI 10.1007/s11676-015-0204-z

CrossMark

ORIGINAL PAPER

A new approach to retrieve leaf normal distribution using terrestrial laser scanners

Shengye Jin[1] · Masayuki Tamura[2] · Junichi Susaki[2]

Received: 14 April 2014 / Accepted: 5 April 2015 / Published online: 29 December 2015

Abstract Leaf normal distribution is an important structural characteristic of the forest canopy. Although terrestrial laser scanners (TLS) have potential for estimating canopy structural parameters, distinguishing between leaves and nonphotosynthetic structures to retrieve the leaf normal has been challenging. We used here an approach to accurately retrieve the leaf normals of camphorwood (*Cinnamomum camphora*) using TLS point cloud data. First, nonphotosynthetic structures were filtered by using the curvature threshold of each point. Then, the point cloud data were segmented by a voxel method and clustered by a Gaussian mixture model in each voxel. Finally, the normal vector of each cluster was computed by principal component analysis to obtain the leaf normal distribution. We collected leaf inclination angles and estimated the distribution, which we compared with the retrieved leaf normal distribution. The correlation coefficient between measurements and obtained results was 0.96, indicating a good coincidence.

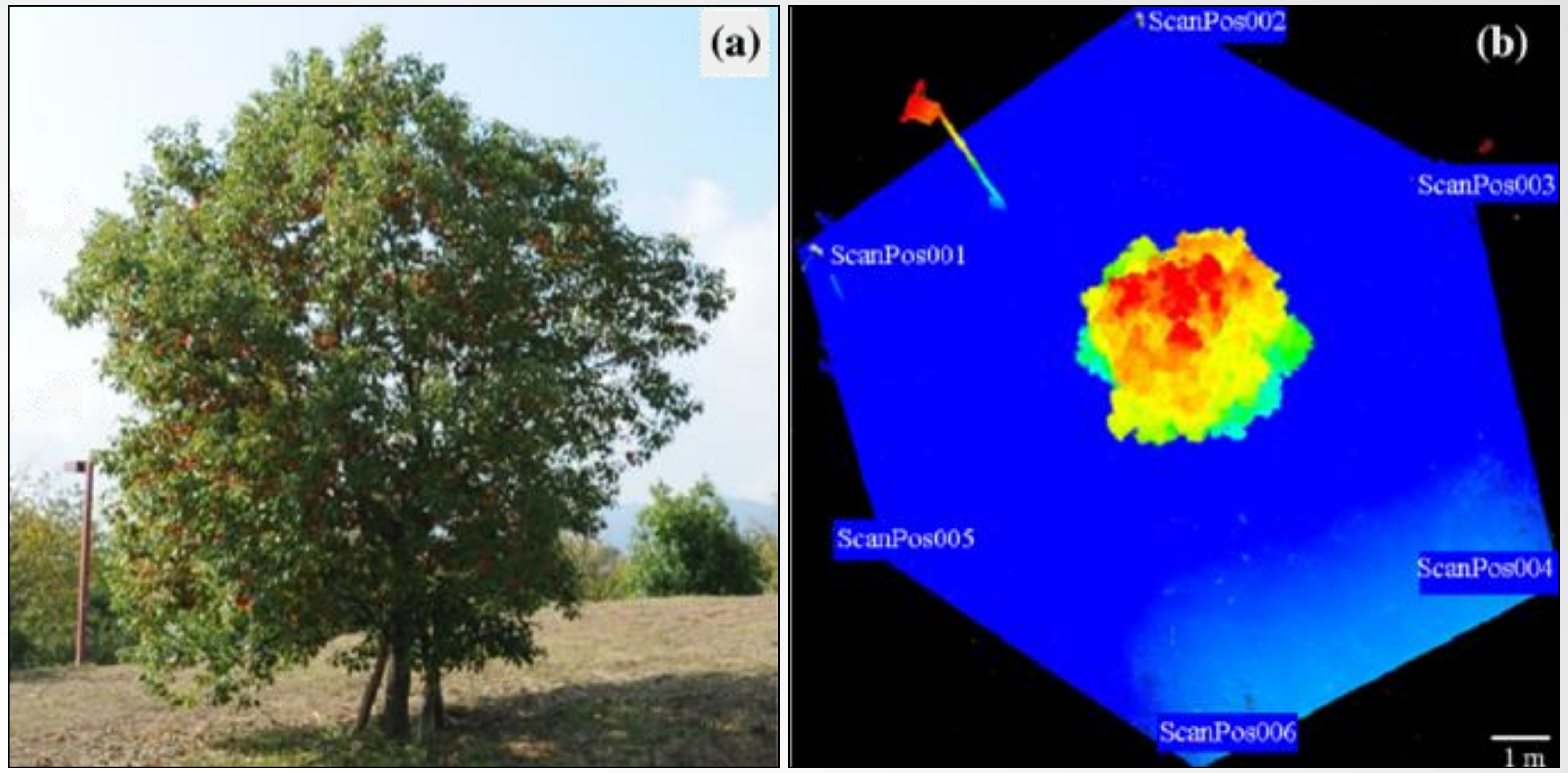
Keywords Leaf normal distribution · Leaf inclination angle · Terrestrial laser scanner · Point cloud data · Curvature · Clustering

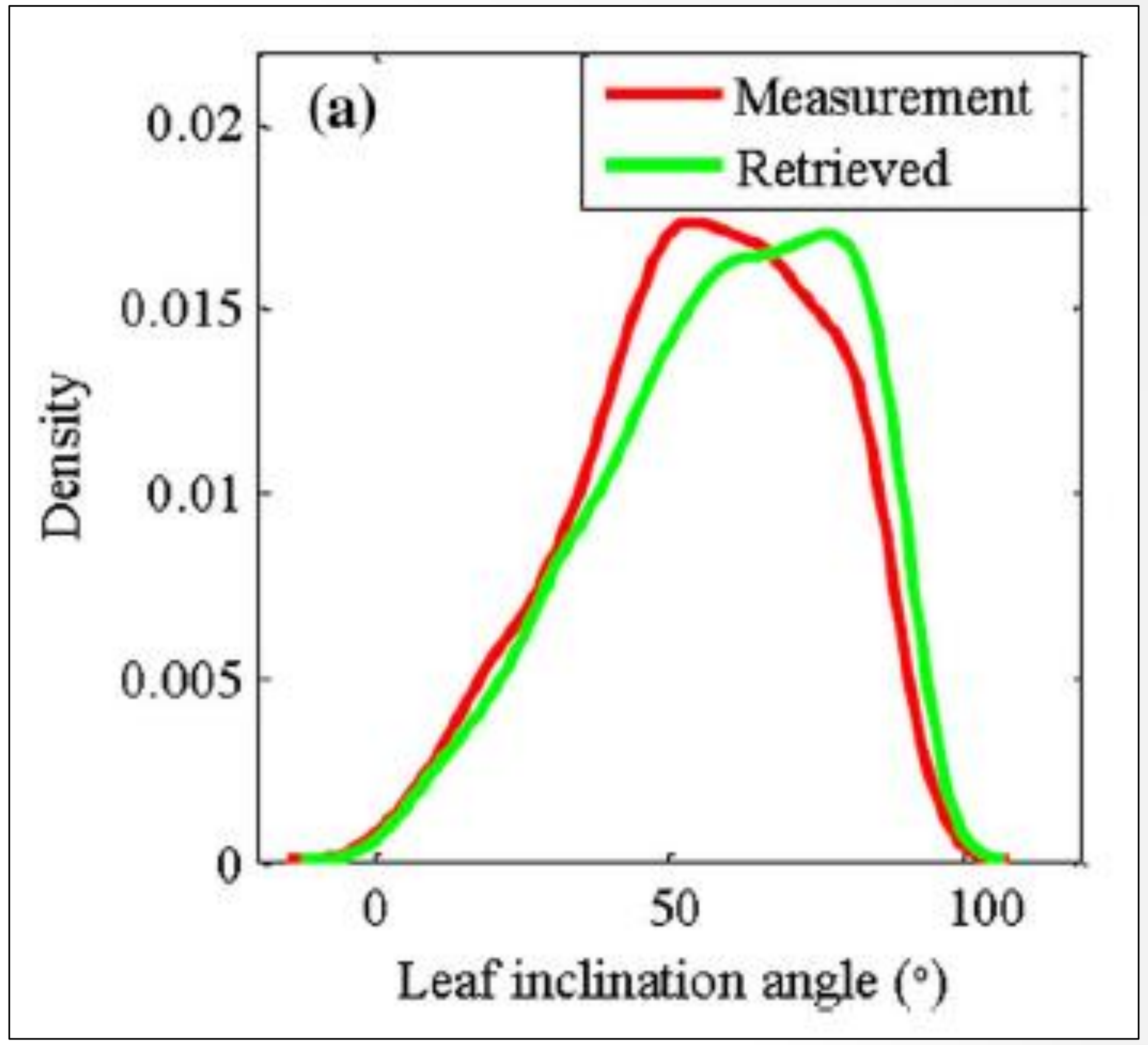
Introduction

Leaf normal, which is also named as leaf inclination angle, distribution is a key parameter that describes the spatial orientation of leaves. It impacts the direction of photon transfer within the canopy and thus strongly impacts the oxygen-producing photosynthetic process. Characterization of plant canopy was discussed in detail by Ross (1981). He defined the distribution function $g(z, \mathbf{n}_L)$ of leaf surface normal per unit solid angle, which is satisfied by the Eq. 1:

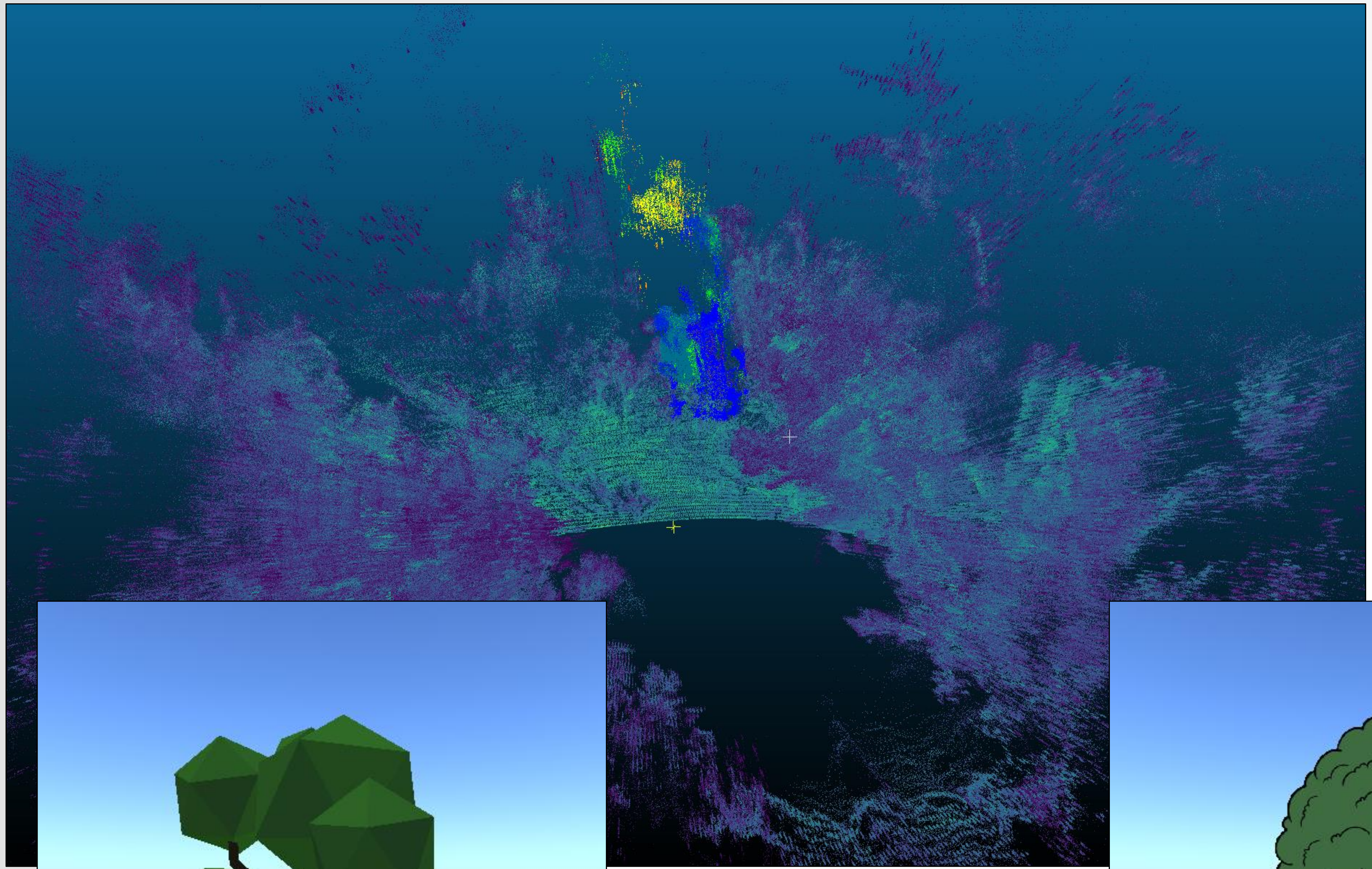
$$\frac{1}{2\pi}\int g(z, \mathbf{n}_L)\,d\mathbf{n}_L = 1 \qquad (1)$$

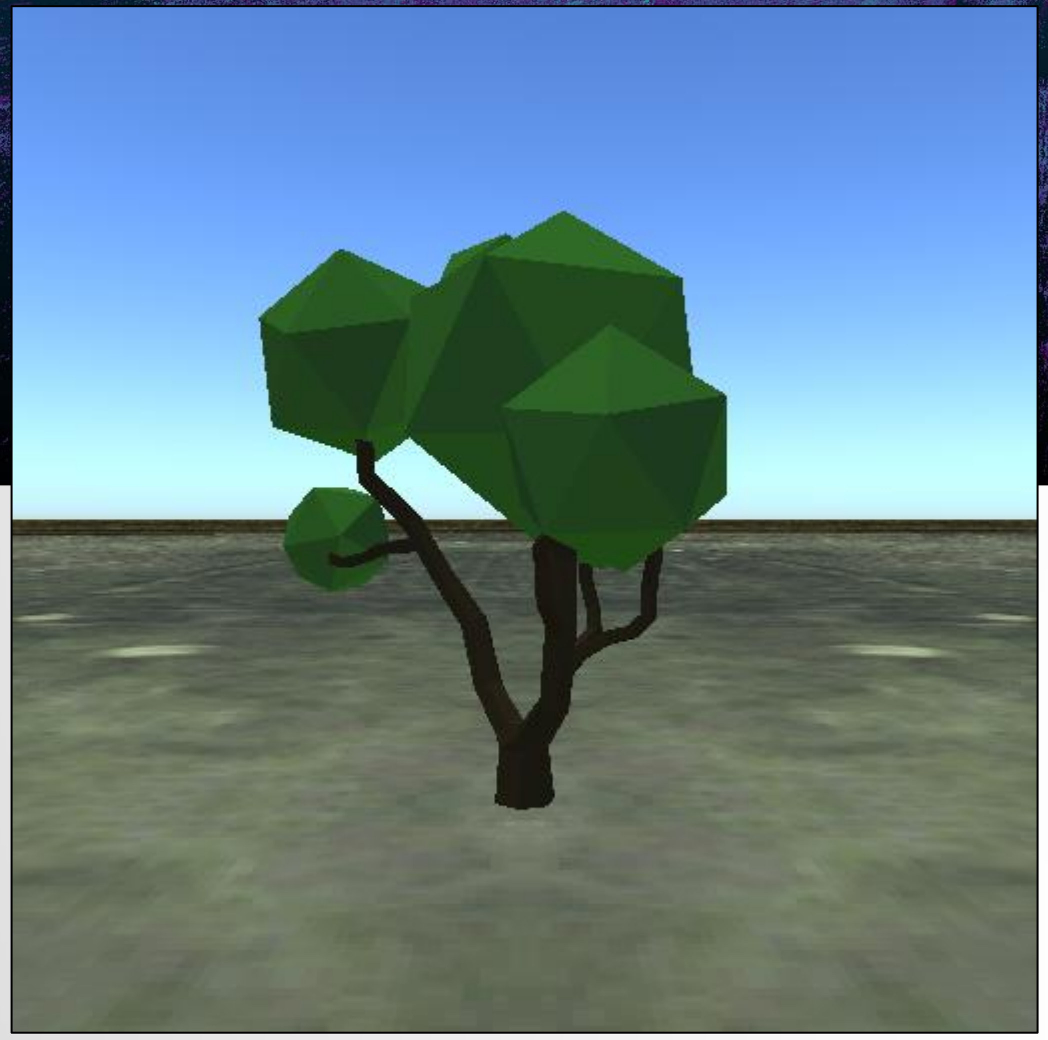
where, z is the vertical depth from the top of the canopy, $\mathbf{n}_L$ is the normal of a leaf that is defined by the leaf

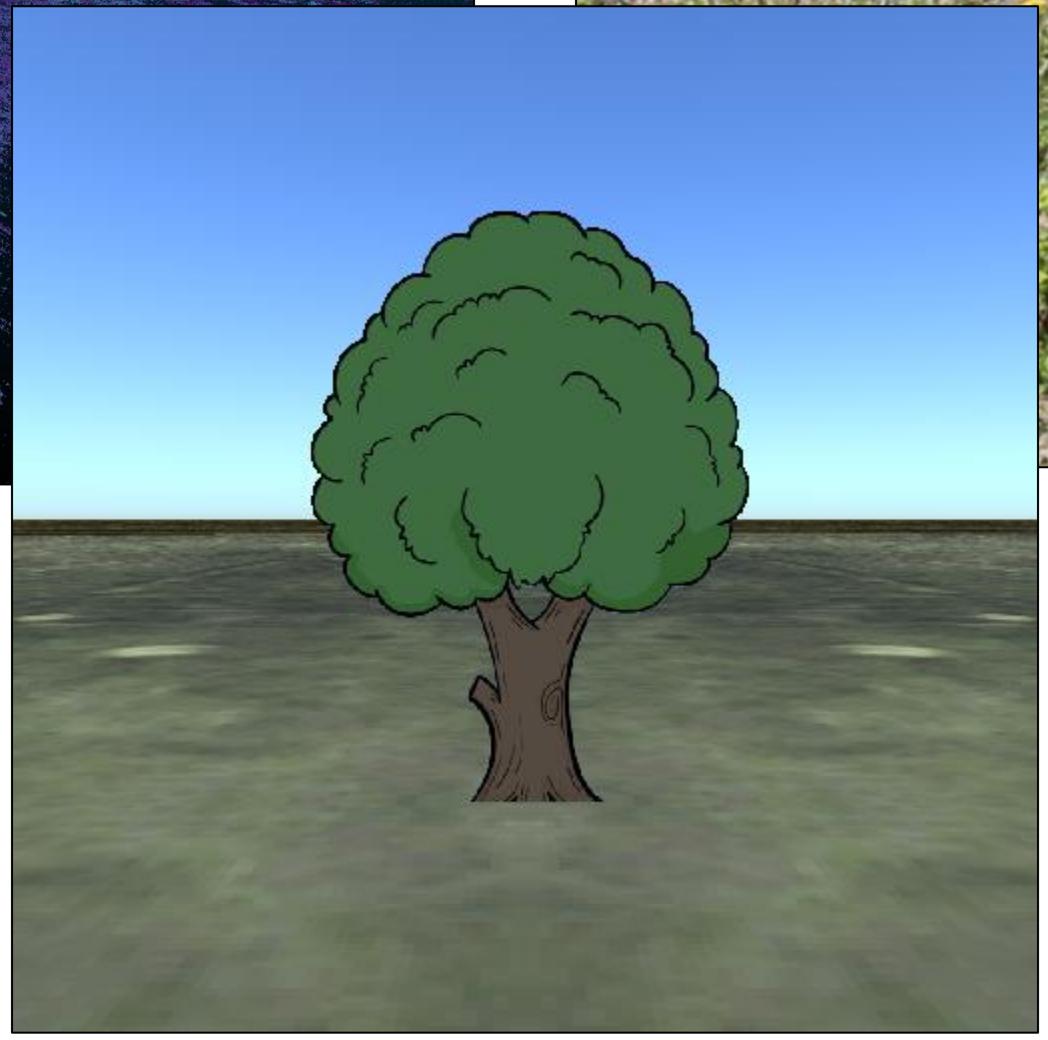


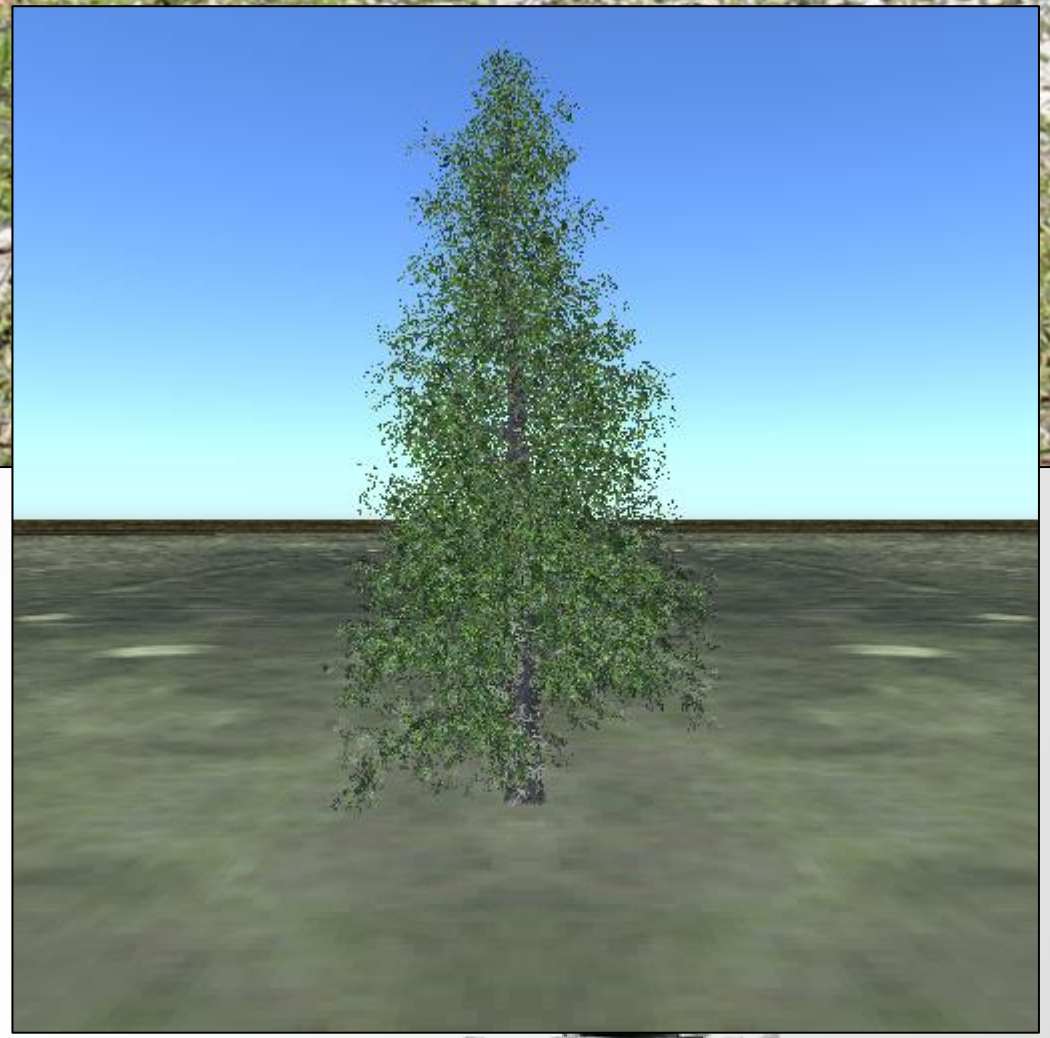


Real and Sim Data Collection



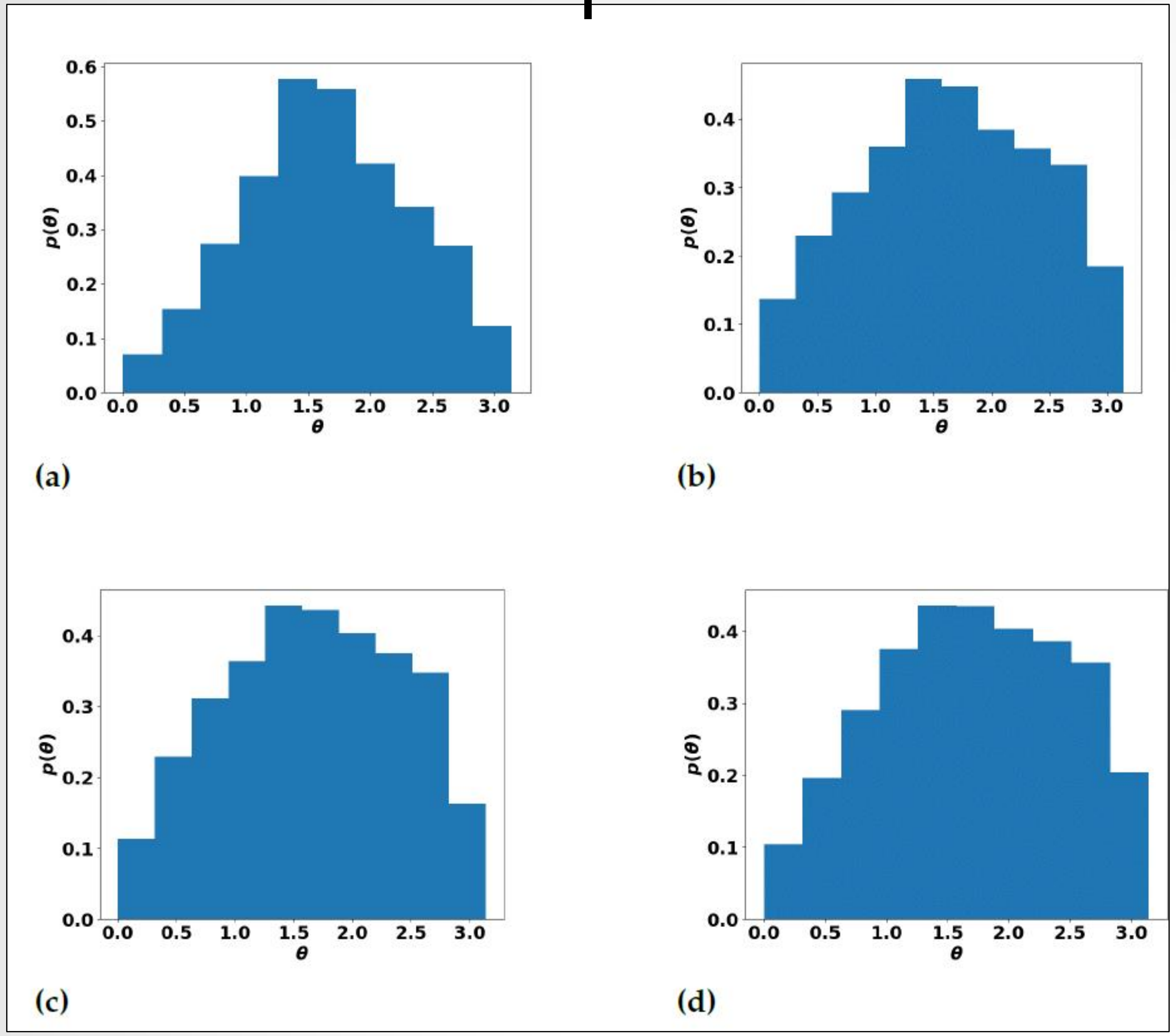




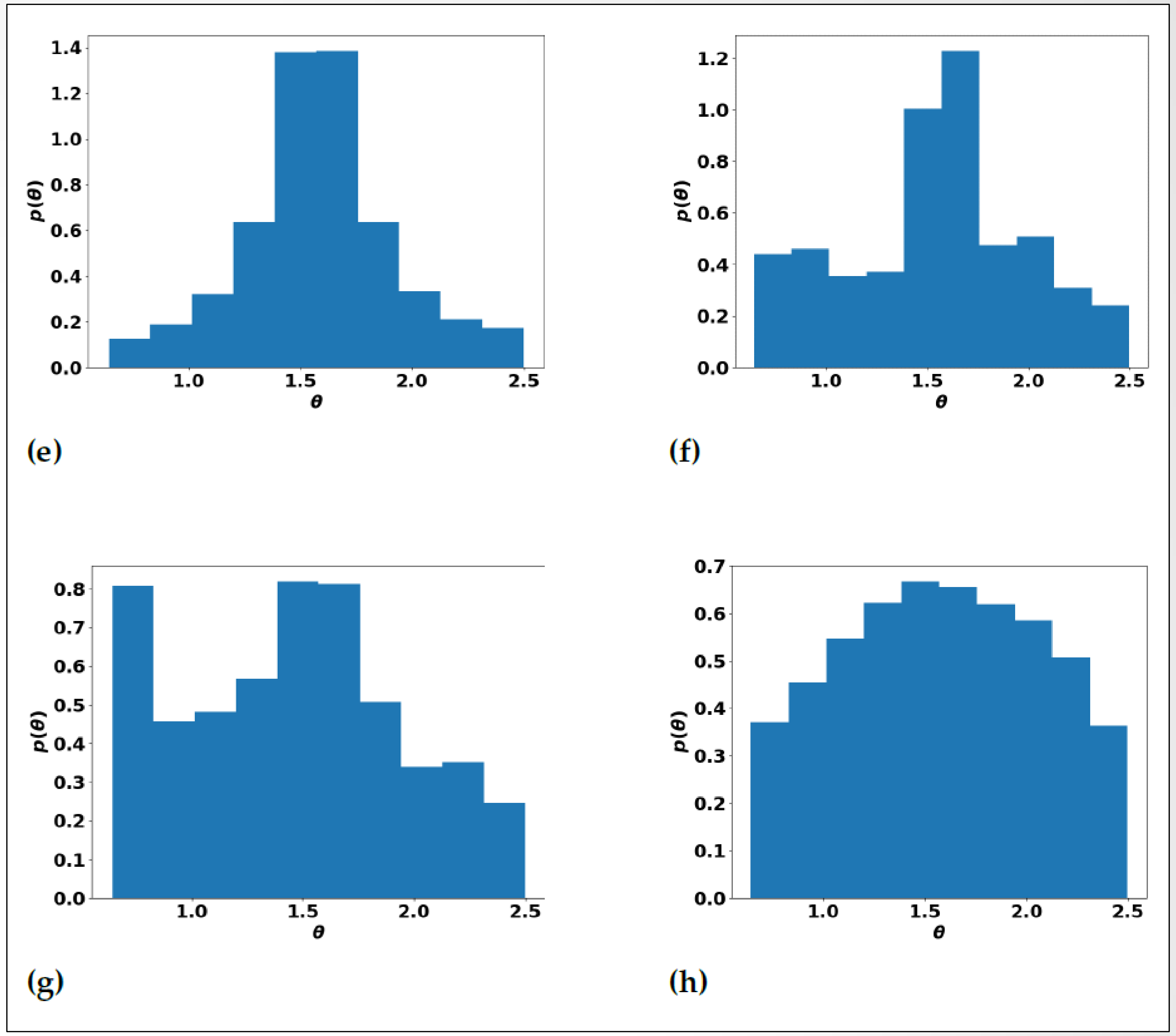


Real vs Sim Leaf Normals

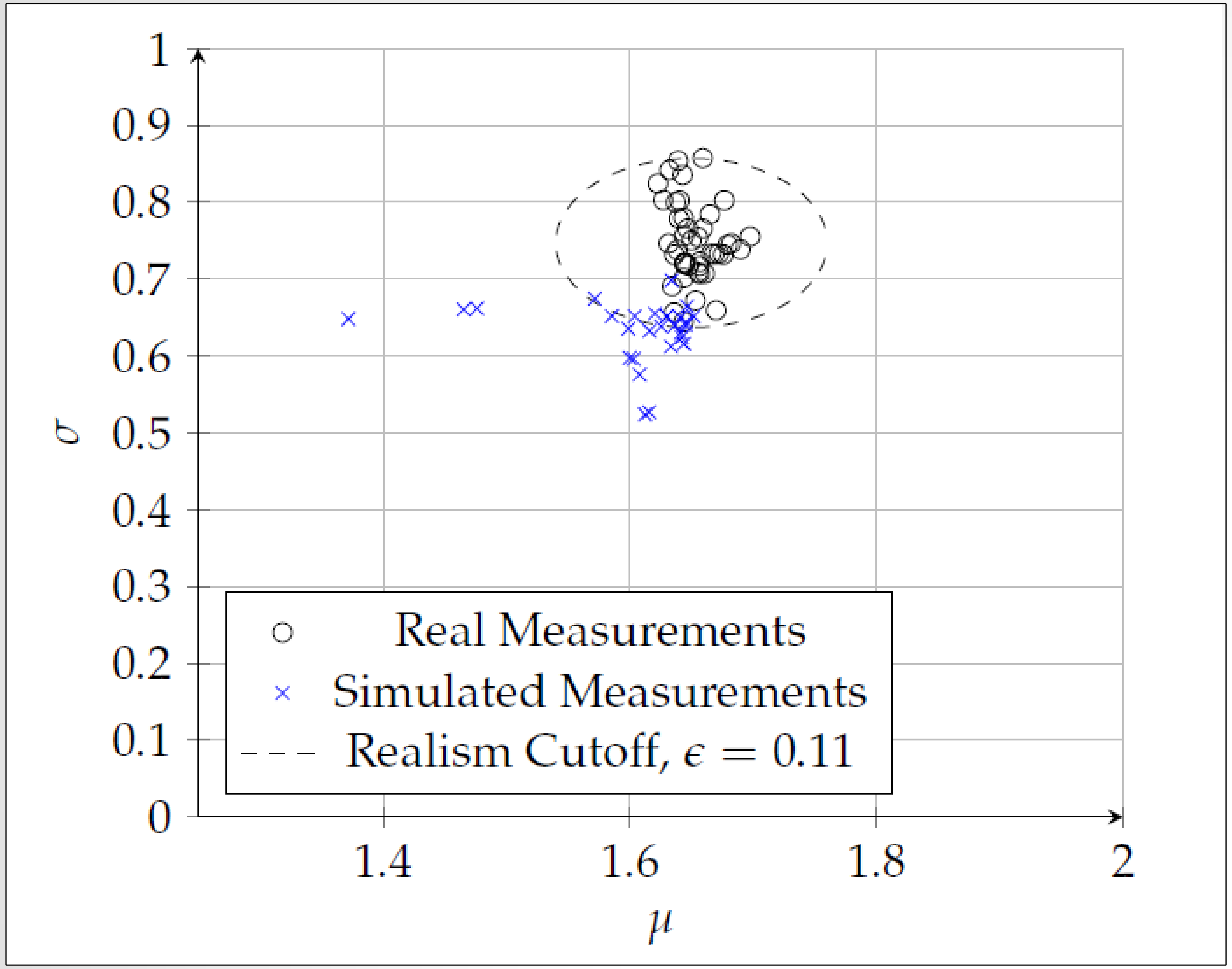
Rea
l

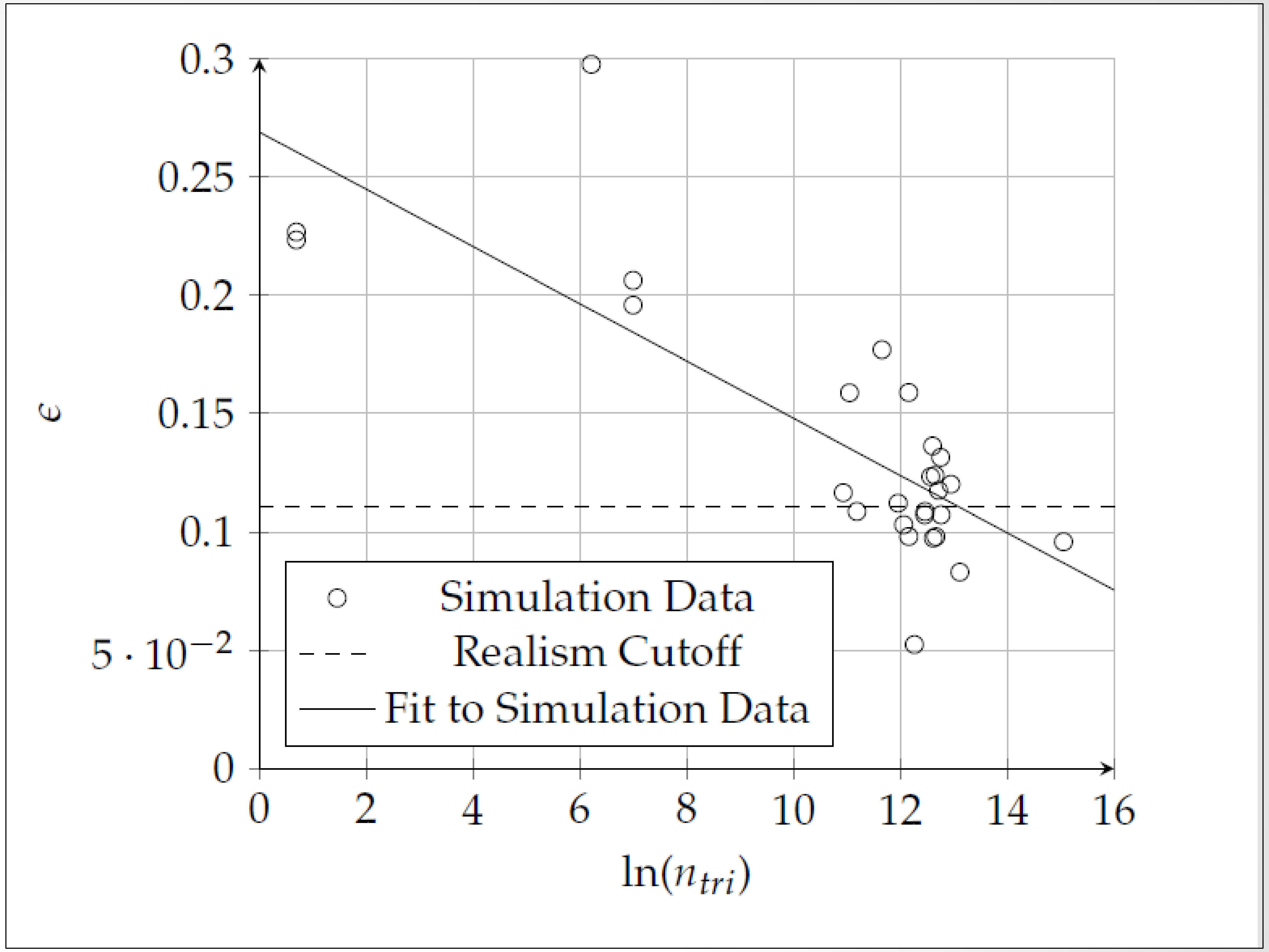


Sim



Lidar Fidelity Analysis





Summary

Challenges

- Finding the right metrics
- Depends on the use-case / AI model

Experiments

- Geometric fidelity requirements for vegetation meshes in imagery
  - Classification accuracy vs triangle density
- Geometric fidelity requirements for vegetation meshes in lidar
  - Normal angle distribution vs number of triangles

Results

- Images: >1K/ m^3 triangles, global illumination must be solved
- Lidar: 11K triangles recommended, 1,600 required