Observing the Peaks and Troughs of Inverse Rendering

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Motivation

Emerging fields like Virtual Reality depend on 3D meshes to represent objects and scenes, making it increasingly important to **accurately** represent 3D objects. Creating 3D objects from 2D images was previously done with Multi-View Stereo, which generated **point clouds** – a set of points in 3D space. However, point clouds are generally grainy.

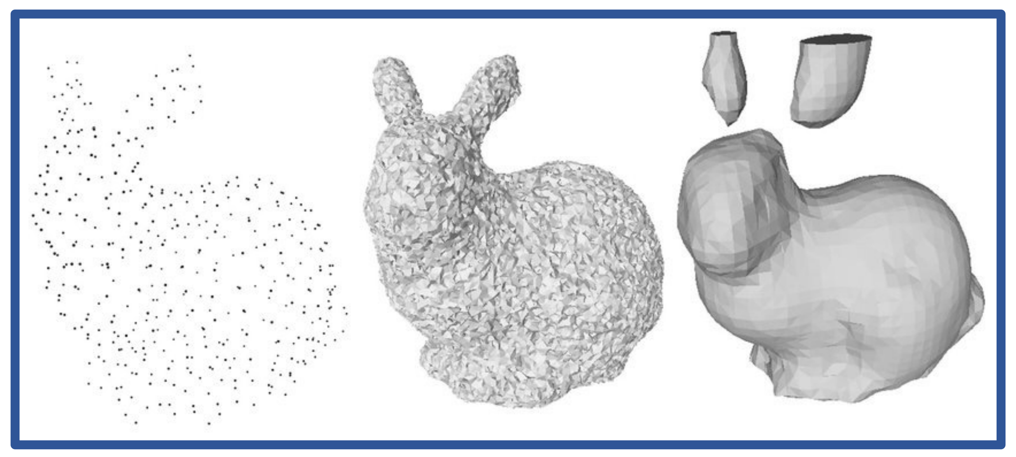


Figure 1: Sparse Point Cloud, Dense Point Cloud, and Mesh Representations of Stanford Bunny. [1]

Recent efforts use more detailed **triangular meshes**, which are generated using Inverse Rendering algorithms. With optimization, these reconstructions can become more accurate.

Background

Inverse Rendering begins with an initial guess and a set of 2D images. The initial mesh is changed using differentiable rendering to the match the target images.

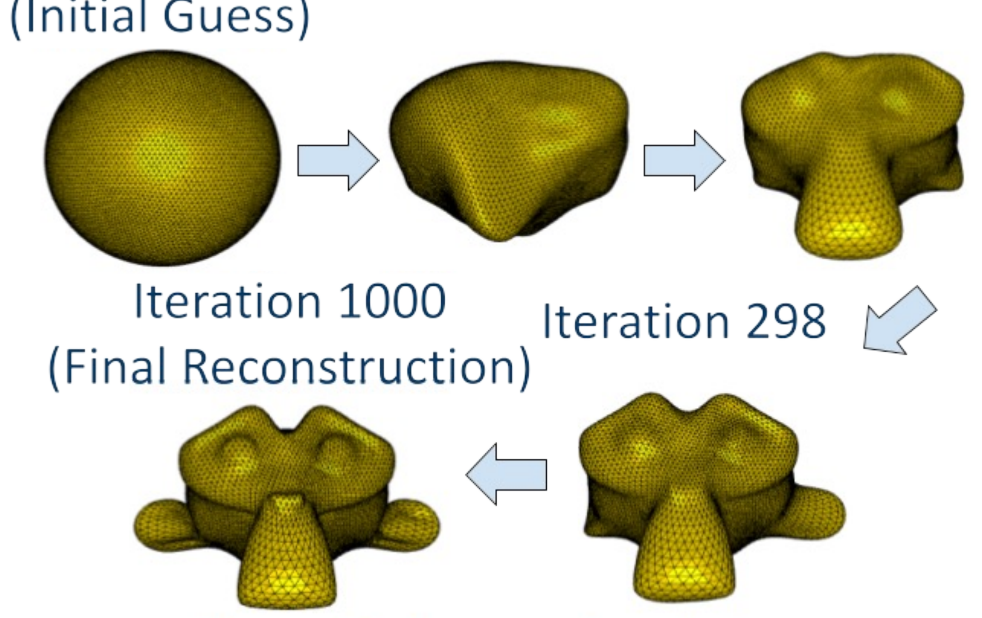


Figure 2: Inverse Rendering from Sphere to Suzanne

Many factors play a role in scene reconstruction, such as hyperparameters, regularization, and properties of the initial guess.

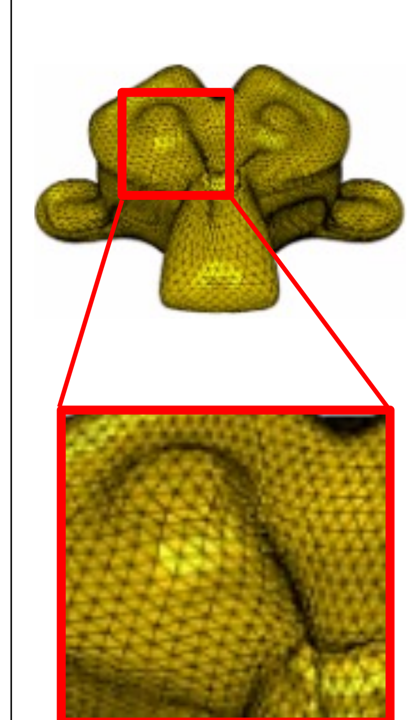
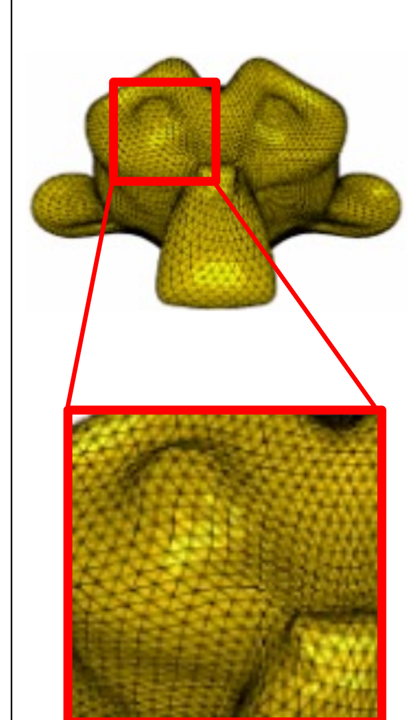
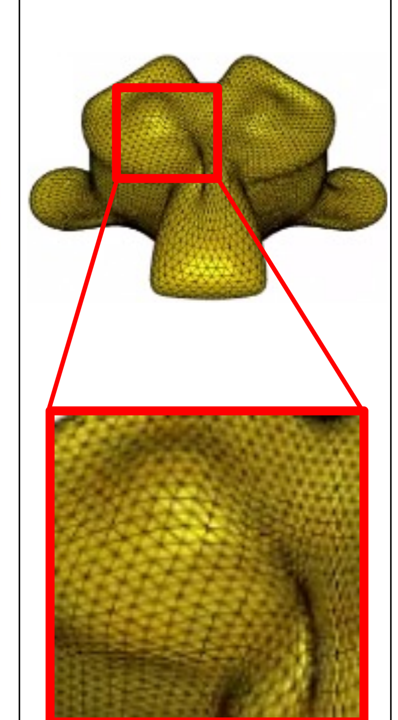
Problem Statement

Our goal is to **observe** different initial guesses, hyperparameters and regularization techniques to better understand what **variables** have the most **influence** on the **quality** of 3D reconstructions.

Tests and Results

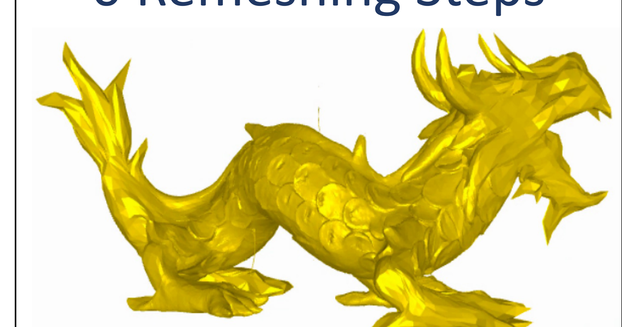
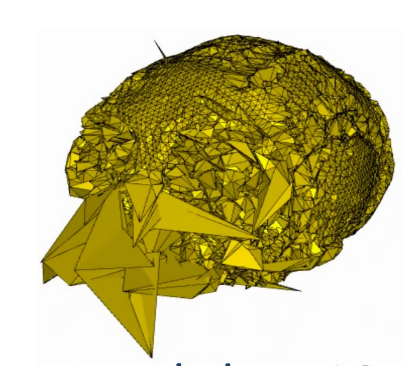
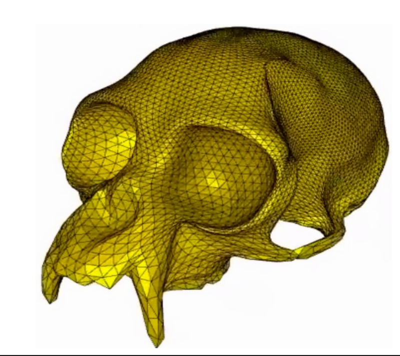
Using a renderer from a previous work, "Large Steps in Inverse Rendering of Geometry" [2], we run controlled experiments to independently study factors such as different loss functions, coarse to fine optimizations, Laplacian smoothing, and shape and size of initial meshes.

Exploring Different Hyperparameters

Training Loss with		
L1 Loss	L2 Loss	L3 Loss
		

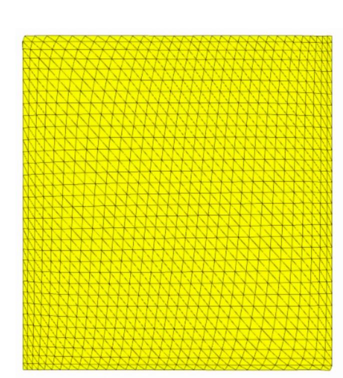
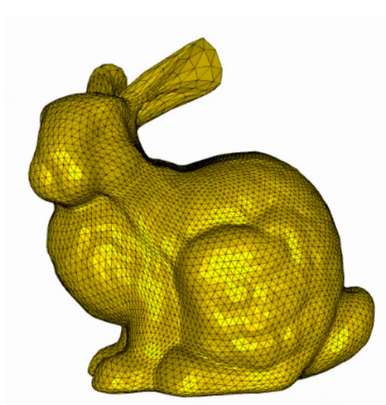
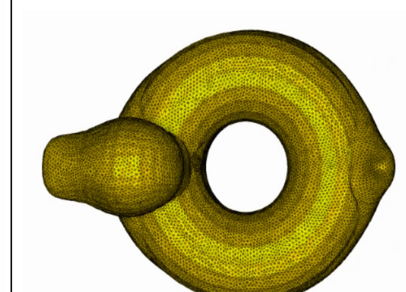
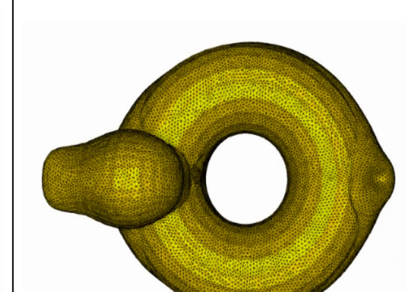
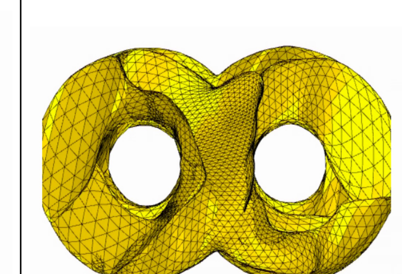
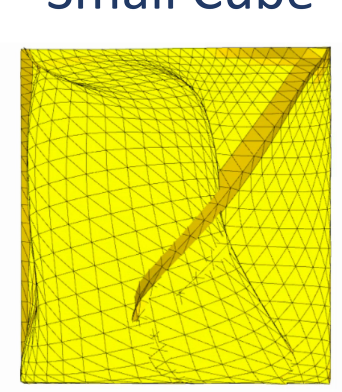
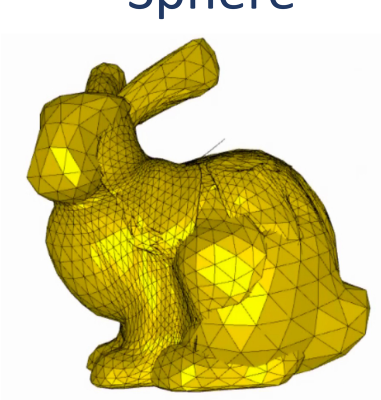
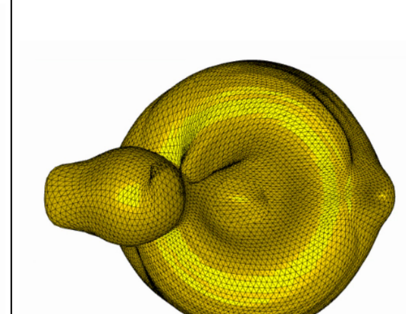
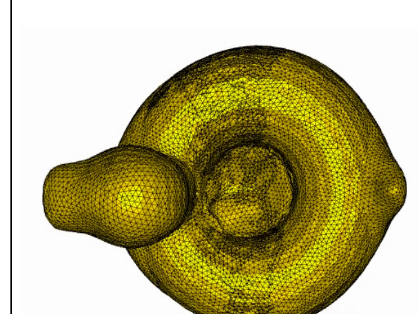
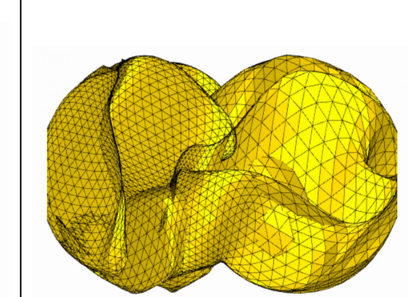
L2 loss is accurate, others may result in artifacts.

Exploring Different Regularization Techniques

Coarse To Fine	Lambda
Target: Dragon	Target: Cranium
0 Remeshing Steps 	Lambda = 0 
8 Remeshing Steps 	Lambda = 10 

Coarse to fine and large lambda captures detail.

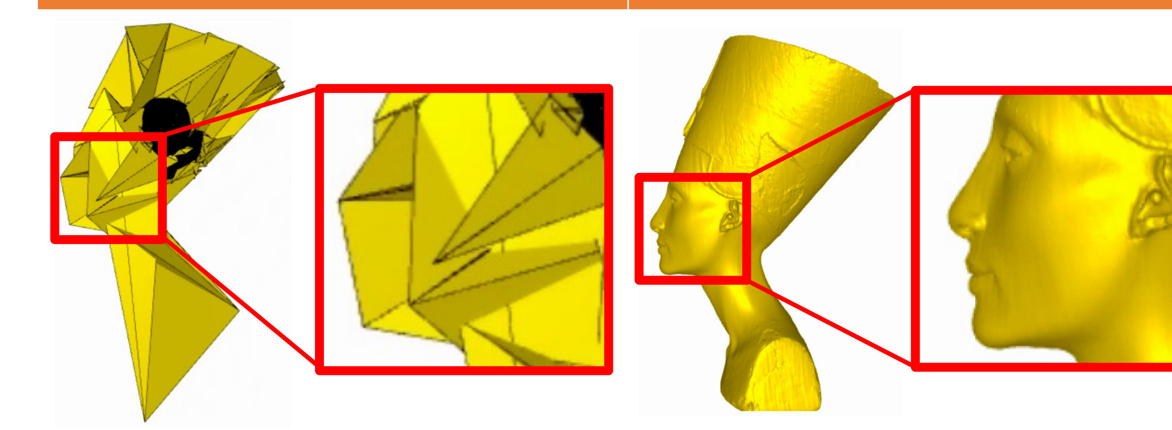
Observing Different Properties of Initial Guesses

Property:	Size	Smoothness	Same Genus	Rotation	Position
Target:	Medium Cube	Bunny	Duck Floatie	Duck Floatie	2 Hole Torus
Reconstruction of First Initial Guess:					
Initial Guess 1:	Small Cube	Sphere	Torus	Torus	Sphere (x=0)
Reconstruction of Second Initial Guess:					
Initial Guess 2:	Large Cube	Spiky Sphere	Sphere	Rotated Torus	Sphere (x=-1)

Using different initial guesses with the same target results in reconstructions of varying quality.

Conclusion

Before Optimization	After Optimization



Based on our results, we found the following factors result in higher quality reconstructions.

Initial Guess Properties	Hyper-parameters	Regularization
Smaller Size	L3 Loss Best for Smooth Targets	Coarse-to-Fine Optimization for High-Poly Meshes
Smooth	L2 Loss Best in General	No Difference for Bilaplacian and Laplacian
Same Genus as Target	More Images of Final Target	
Proper Positioning		

Future Works

Future works can use our conclusions to improve reconstructions in **Robotics** and **Autonomous Driving**.

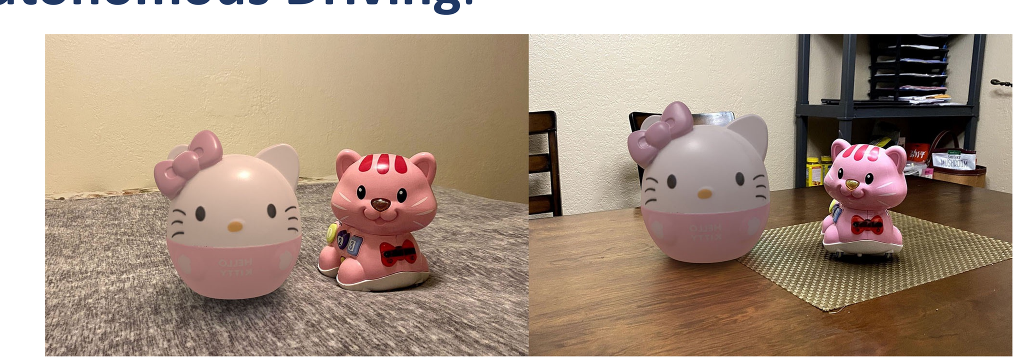


Figure 3: Children's Toys Represented with Texture and Geometry. [3]

Furthermore, optimizations in **texture** can be found to accurately represent the surface, color, and light reflection of objects.

Acknowledgements

Special thanks to Vaidehi Gupta, Tzu-Mao Li, Ravi Ramamoorthi, Christine Alvarado, and Mai ElSherief for their support in this undergraduate research opportunity.

[1] Brüel-Gabrielsson, Rickard, et al. "Topology-Aware Surface Reconstruction for Point Clouds." *Computer Graphics Forum*. Vol. 39. No. 5. 2020.
[2] Nicolet, Baptiste, Alec Jacobson, and Wenzel Jakob. "Large steps in inverse rendering of geometry." *ACM Transactions on Graphics (TOG)* 40.6 (2021): 1-13.
[3] Luan, Fujun, et al. "Unified shape and svbrdf recovery using differentiable monte carlo rendering." *Computer Graphics Forum*. Vol. 40. No. 4. 2021.