Reparameterizing Discontinuous Integrands for Differentiable Rendering,

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Agenda

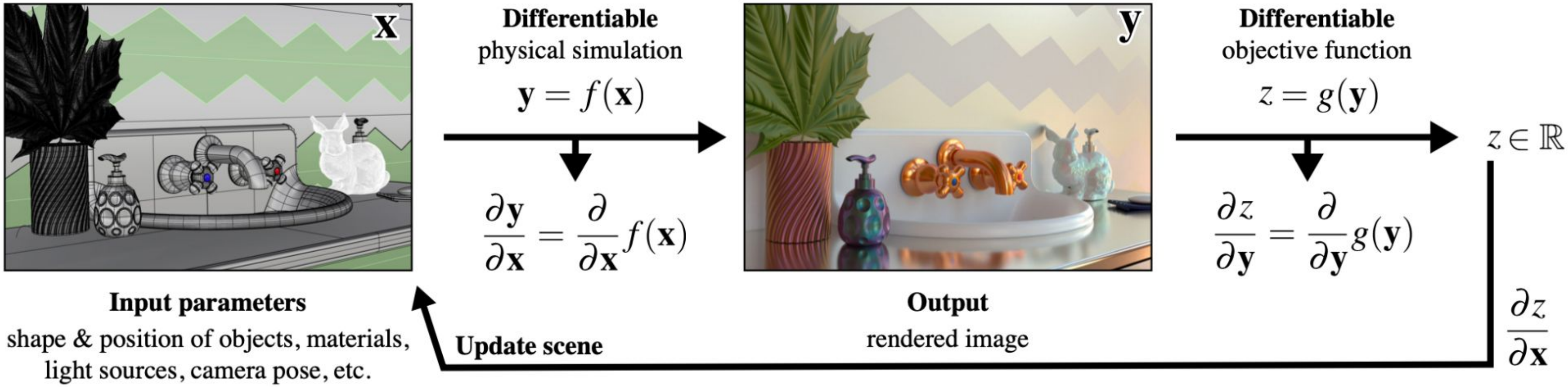
1. Differentiable Rendering
2. Review of Edge Sampling
3. Reparametrizing Integrals
4. Results

Differentiable Rendering

- Allows the gradients of 3D objects to be calculated and propagated through images
- Crucial to optimization, inverse problem, and deep learning
- Gradient w.r.t camera parameters, light sources, scene geometry, material appearance

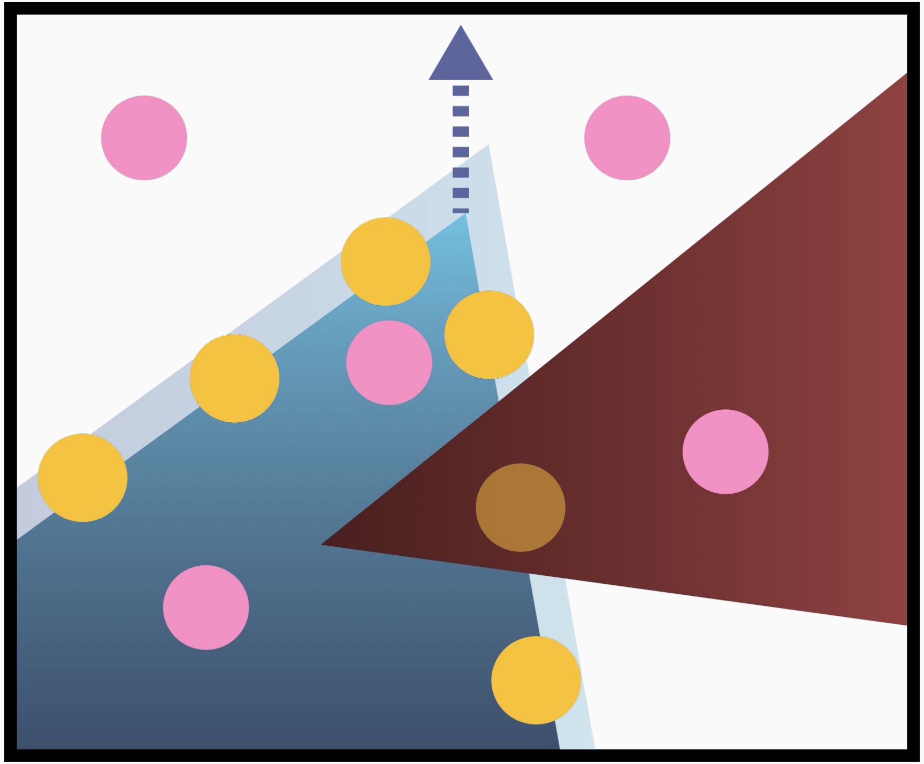
Kato, Hiroharu, et al. "Differentiable rendering: A survey." arXiv preprint arXiv:2006.12057 (2020).

Differentiable Rendering



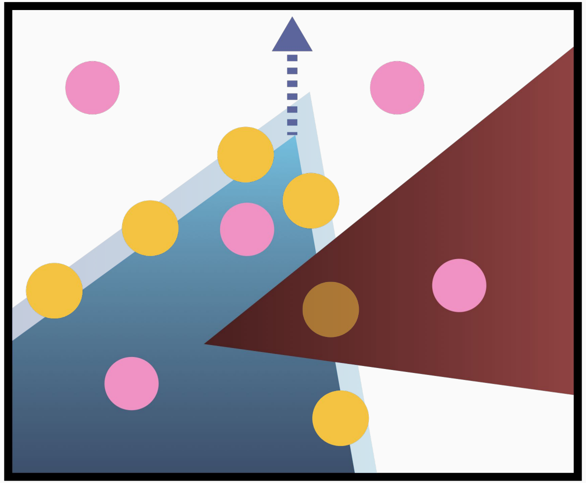
Zhao, Shuang, Wenzel Jakob, and Tzu-Mao Li. "Physics-based differentiable rendering: from theory to implementation." ACM SIGGRAPH 2020 Courses. 2020. 1-30.

Review of Edge Sampling



From Tzu-Mao Li's slides

Review of Edge Sampling



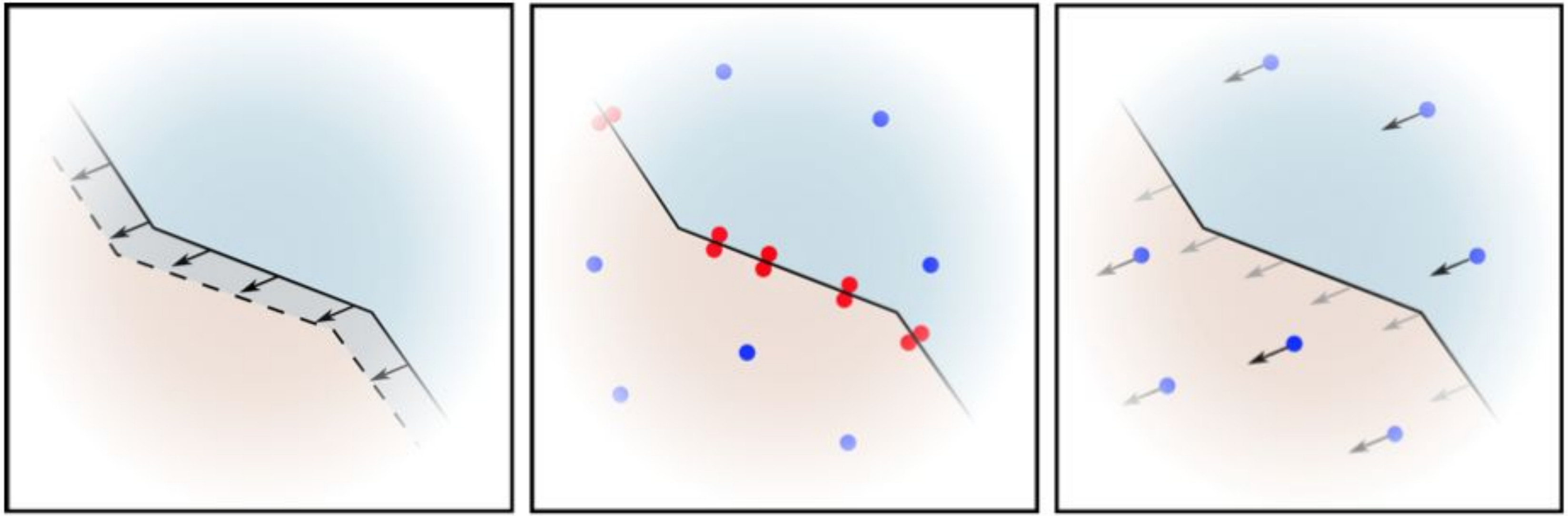
- Model edge using step function
- Differentiation
- Monte Carlo Sampling
- Edge sampling → bottleneck

$$\begin{aligned}
&\nabla \int\int \theta(\alpha_i(x,y)) f_i(x,y)\,dx\,dy \\
&= \int\int \delta(\alpha_i(x,y))\nabla\alpha_i(x,y) f_i(x,y)\,dx\,dy \\
&\quad + \int\int \theta(\alpha_i(x,y))\nabla f_i(x,y)\,dx\,dy
\end{aligned}$$

From Tzu-Mao Li's slides

Goal:
Compute gradient
without edge sampling

Reparametrizing Integrals - Example



(a) Integrand with discontinuity

(b) Edge sampling [Li et al. 2018]

(c) Using changes of variables (ours)

Approach: Reparametrizing Integrals

- Parameter that affects the positions of discontinuities
- Move sample points along the discontinuity
- → Discontinuity becomes static w.r.t the parameter

Reparametrizing Integrals

d : Location of discontinuity

θ : Step function

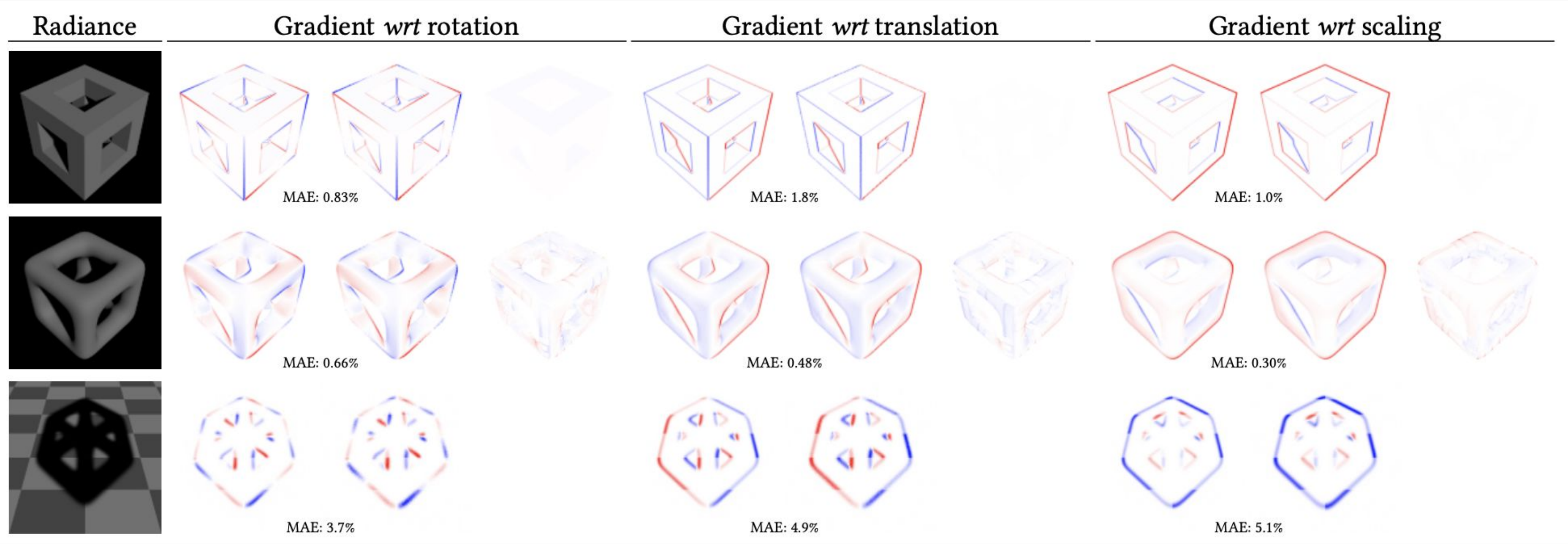
$$\begin{aligned} I &= \int_X \theta(x-d)k(x)dx \\ &= \int_Y \theta(y)k(y+d)dy \end{aligned} \qquad y = x - d$$

→ No delta function in the derivative w.r.t d

Details

- Assumes only one discontinuity in a pixel
    - Apply convolution to the smooth the integrand
- Change of variables using rotation to eliminate discontinuity
- Variance reduction
    - Control variates using pairs of correlated paths
    - Reuse random numbers to sample correlated paths

Results - vs Reference Gradient



Radiance

With changes of variables

Reference

Without changes of variables

With changes of variables

Reference

Without changes of variables

With changes of variables

Reference

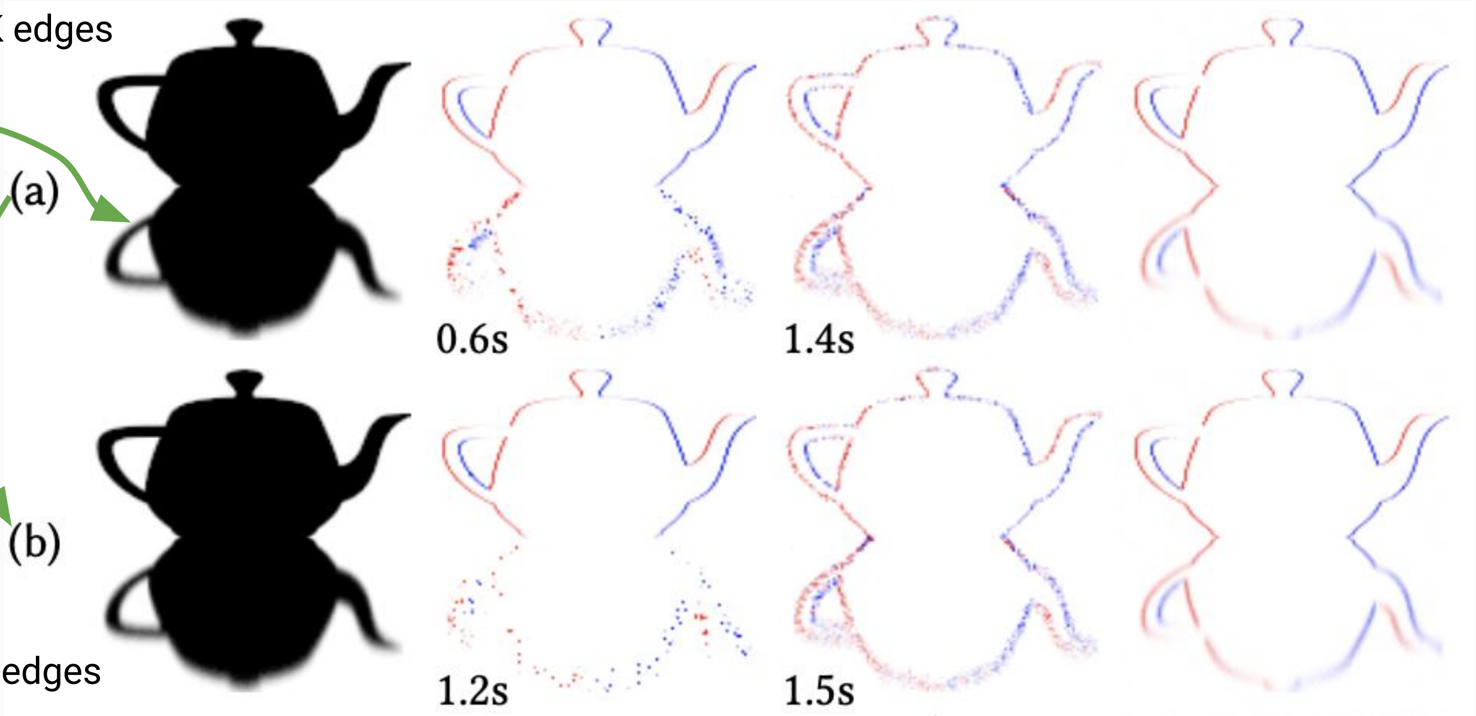
Without changes of variables

Results - vs Edge Sampling

16K edges

Glossy reflection

Mesh subdivision



1M edges

Radiance

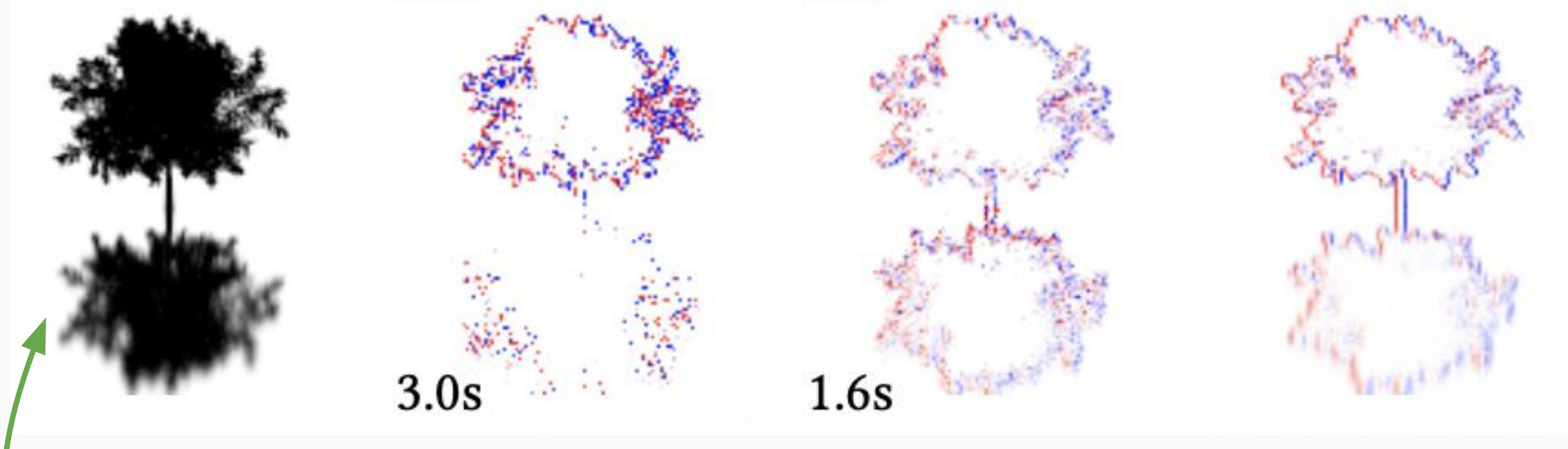
Edge sampling

Reparametrization

Reference

Results - vs Edge Sampling

5M edges



Radiance

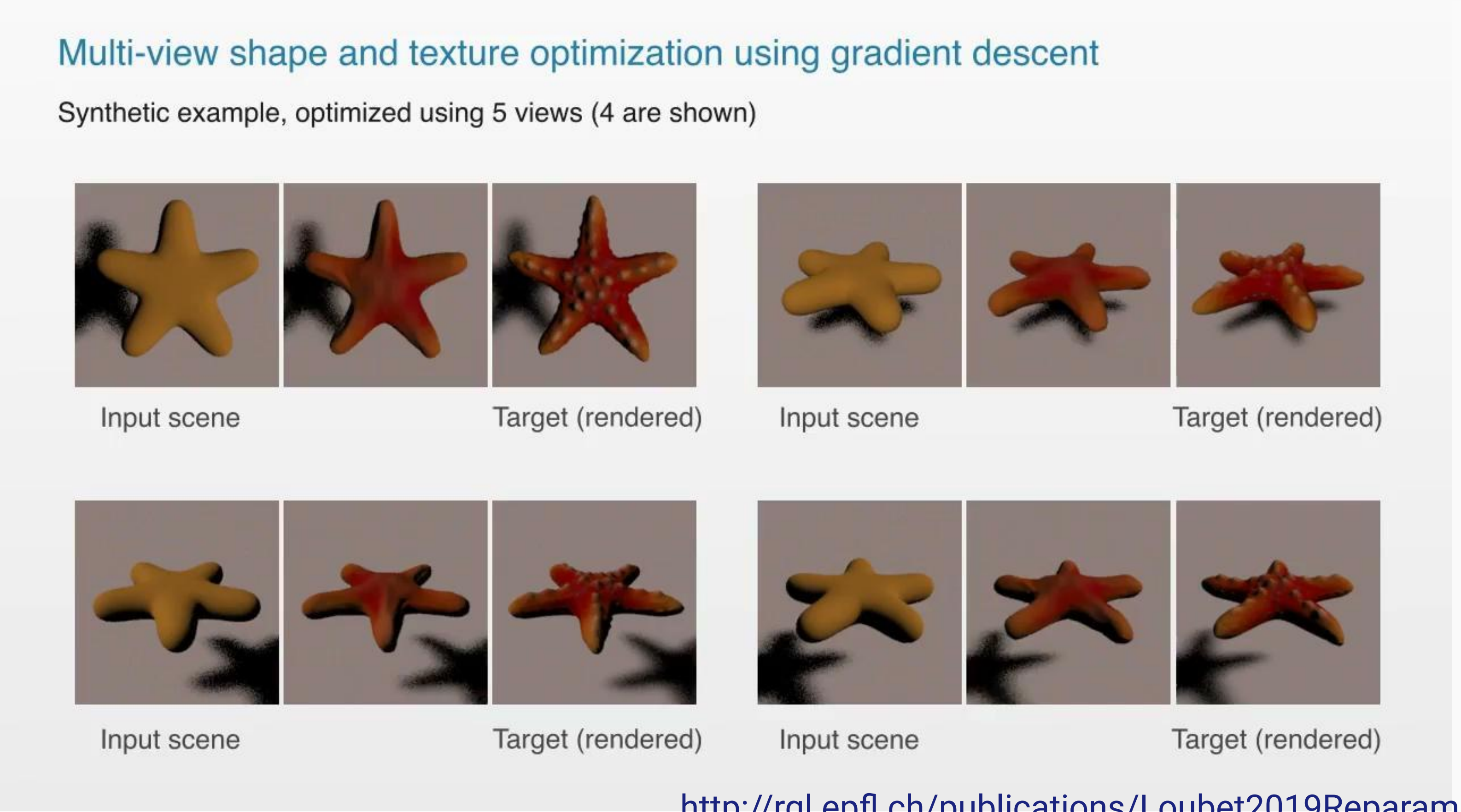
Edge sampling

Reparametrization

Reference

Glossy
reflection

Application - Reconstruction from Rendered Image



Multi-view shape and texture optimization using gradient descent

Synthetic example, optimized using 5 views (4 are shown)

Input scene

Target (rendered)

Input scene

Target (rendered)

Input scene

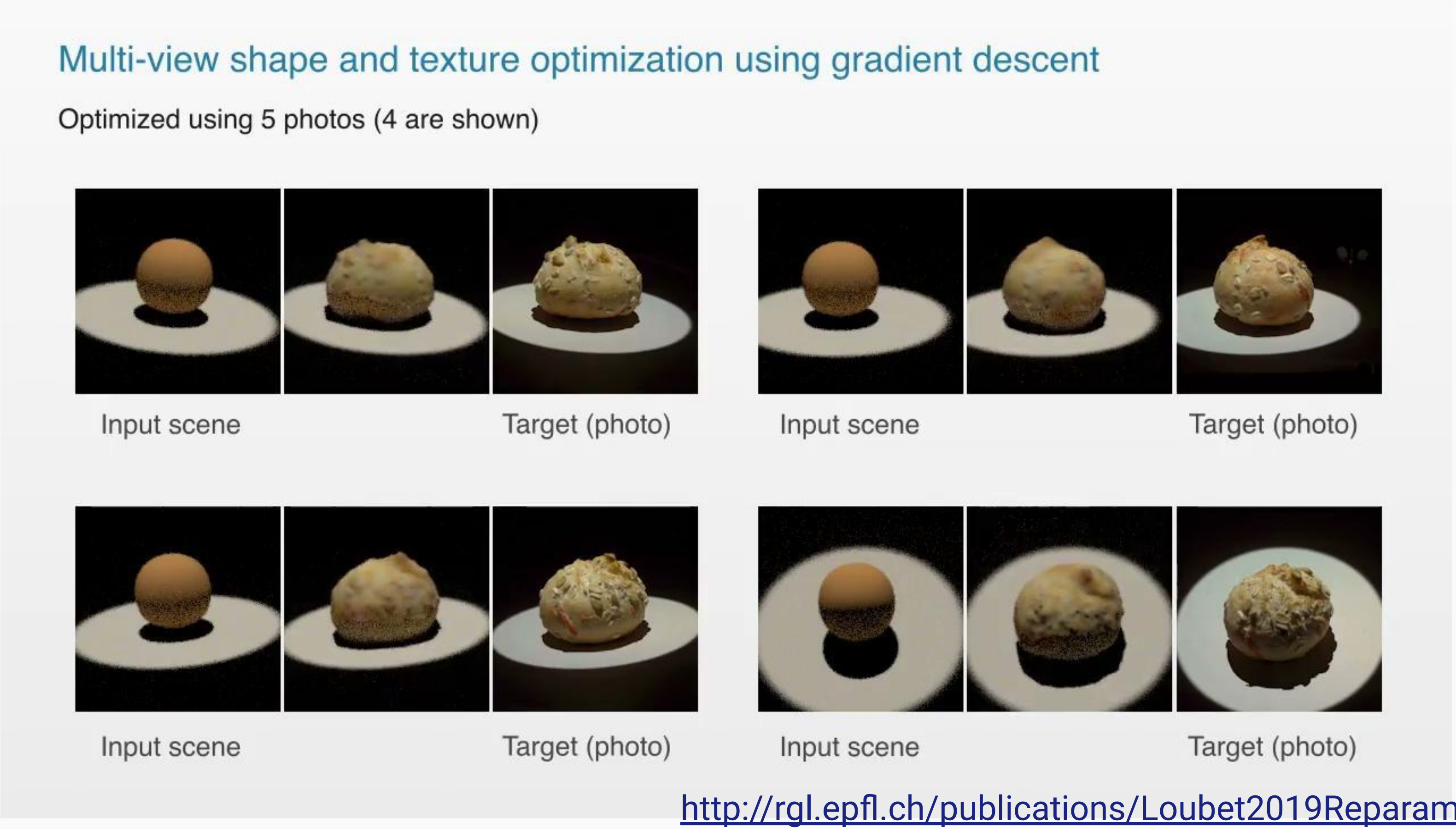
Target (rendered)

Input scene

Target (rendered)

http://rgl.epfl.ch/publications/Loubet2019Reparameterizing

Application - Reconstruction from Photo



Multi-view shape and texture optimization using gradient descent

Optimized using 5 photos (4 are shown)

Input scene Target (photo)

Input scene Target (photo)

Input scene Target (photo)

Input scene Target (photo)

http://rgl.epfl.ch/publications/Loubet2019Reparameterizing

Summary

- Edge sampling → bottleneck
- Differentiable path tracer without edge sampling
- Reparametrization → Monte Carlo estimators become differentiable
- Scales to scenes with high geometric and depth complexity
- More robust to complex geometry, shadows, and glossy reflections
    - For primary visibility, edge sampling is more robust

Limitations

- Significant variance in cases including high-order diffuse interreflection
    - Variance reduction is less effective for higher number of bounces
- Assumption of single discontinuity in a pixel
    - Two discontinuities in a pixel - explicit edge sampling
    - Did not manifest in optimization problems conducted in this work

Thank you! :)