Realistic Image Synthesis

Introduction

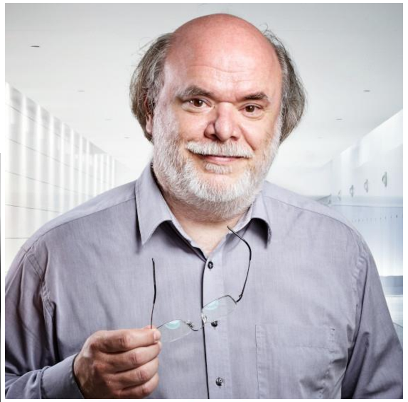
Which One is Real?
A
B
© 3DAS

What?

- Goal: Create photorealistic images
- Applications
  - Movies and games
  - Design and architecture
  - Visualization and simulation
  - Optimization, inverse rendering
  - AI and machine learning

Who?

- Instructors
  - Philipp Slusallek
    - http://graphics.cg.uni-saarland.de/slusallek/
  - Karol Myszkowski
    - http://www.mpi-inf.mpg.de/~karol/
  - Pascal Grittmann
    - https://graphics.cg.uni-saarland.de/people/grittmann.htm
  - Corentin Salaun
    - http://people.mpi-inf.mpg.de/~csalaun/
- Tutors
  - Ben Samuel Dierks
  - Filippo Garosi

Administrative information

- Type
  - Advanced lecture
  - 9 credit points
- Prerequisites
  - Interest in math, physics
  - Basic programming experience in C++
  - Core lecture “Computer Graphics” recommended but not required
- Web-page: https://graphics.cg.uni-saarland.de/courses/ris-2025/
- CMS: https://cms.sic.saarland/ris_25/

Grading

- Exam admission requires
  - 50% of the total points across all assignments
  - 30% of the maximum points in **every** assignment
- Final grade
  - Assignments: 50%
  - Final exam: 50%

Assignments

- Irregular rhythm
  - Sometimes 1 week, sometimes 2
- Type
  - A few theoretical assignments
  - Mostly practical ones
- Teamwork
  - Can be done in groups of two
  - Make sure you understand everything your partner worked on!
- Published, handed-in, and graded via CMS

Reading materials

- Pharr, Jakob, and Humphreys. *Physically based rendering: From theory to implementation*. Morgan Kaufmann, 2016.
  - Free e-book: http://www.pbr-book.org/
- More listed on the website

- Shirley et al., Realistic Ray Tracing, 2. Ed., AK. Peters, 2003
- Jensen, Realistic Image Synthesis Using Photon Mapping, AK. Peters, 2001
- Dutre, at al., Advanced Global Illumition, AK. Peters, 2003
- Glassner, Principles of Digital Image Synthesis, 2 volumes, Morgan Kaufman, 1995
- Cohen, Wallace, Radiosity and Realistic Image Synthesis, Academic Press, 1993
- Apodaca, Gritz, Advanced Renderman: Creating CGI for the Motion Pictures, Morgan Kaufmann, 1999
- Ebert, Musgrave, et al., Texturing and Modeling, 3. Ed., Morgan Kaufmann, 2003
- Reinhard, Ward, Pattanaik, Debevec, Heidrich, Myszkowski, High Dynamic Range Imaging, Morgan Kaufmann Publishers, 2nd edition, 2010.
- Myszkowski, Mantiuk, Krawczyk. High Dynamic Range Video. Synthesis Digital Library of Engineering and Computer Science. Morgan & Claypool Publishers, San Rafael, USA, 2008.

Applications

Where are the things you will learn here used?

Movies: Visual Effects (VFX)

Game of Thrones

Avatar: The Way of Water

Movies: Animated Films

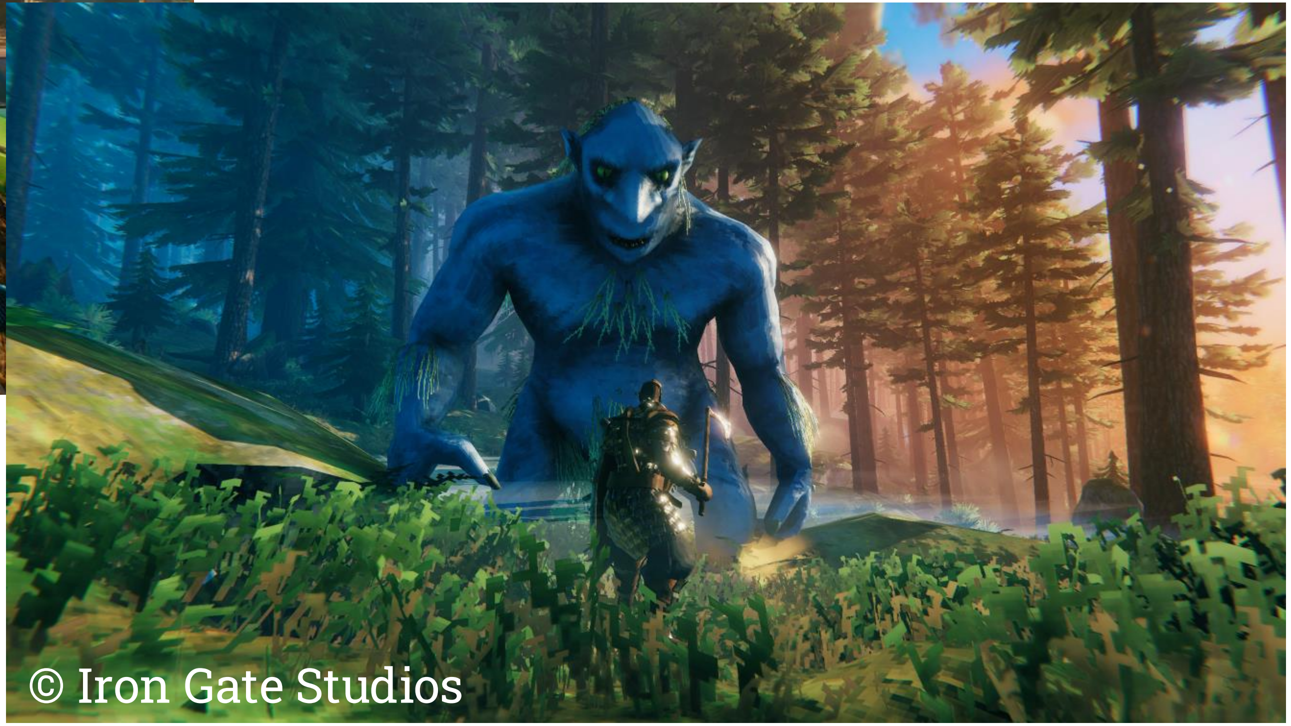
The Lion King (2019)

The Sea Beast

Video Games

Cyberpunk 2077

Valheim



Simulation

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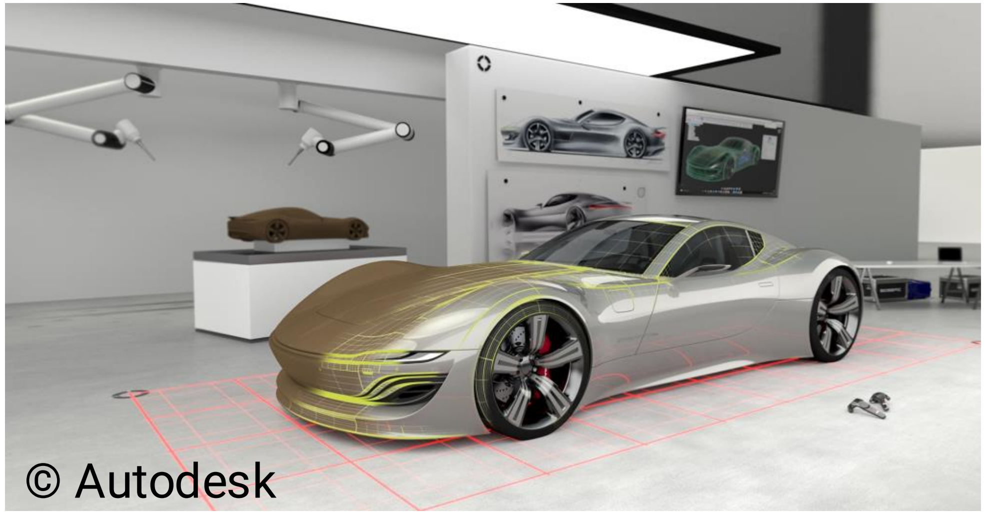
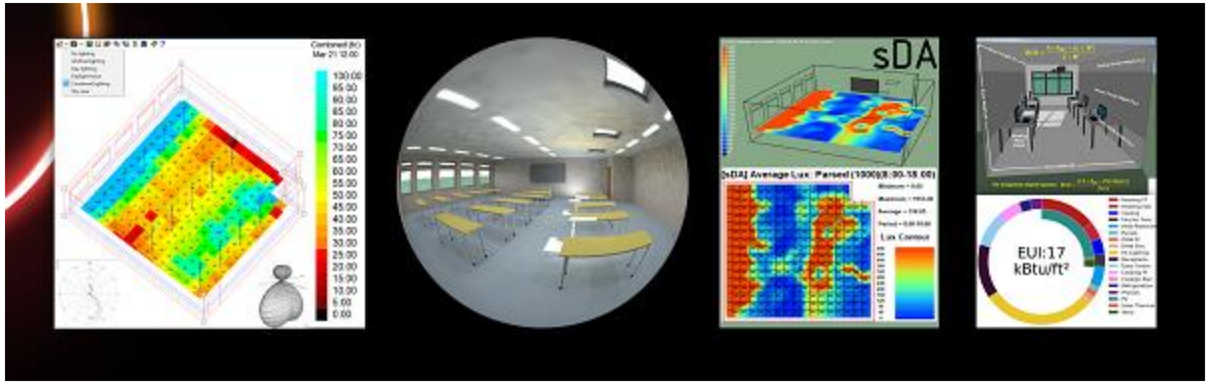
Design and Engineering





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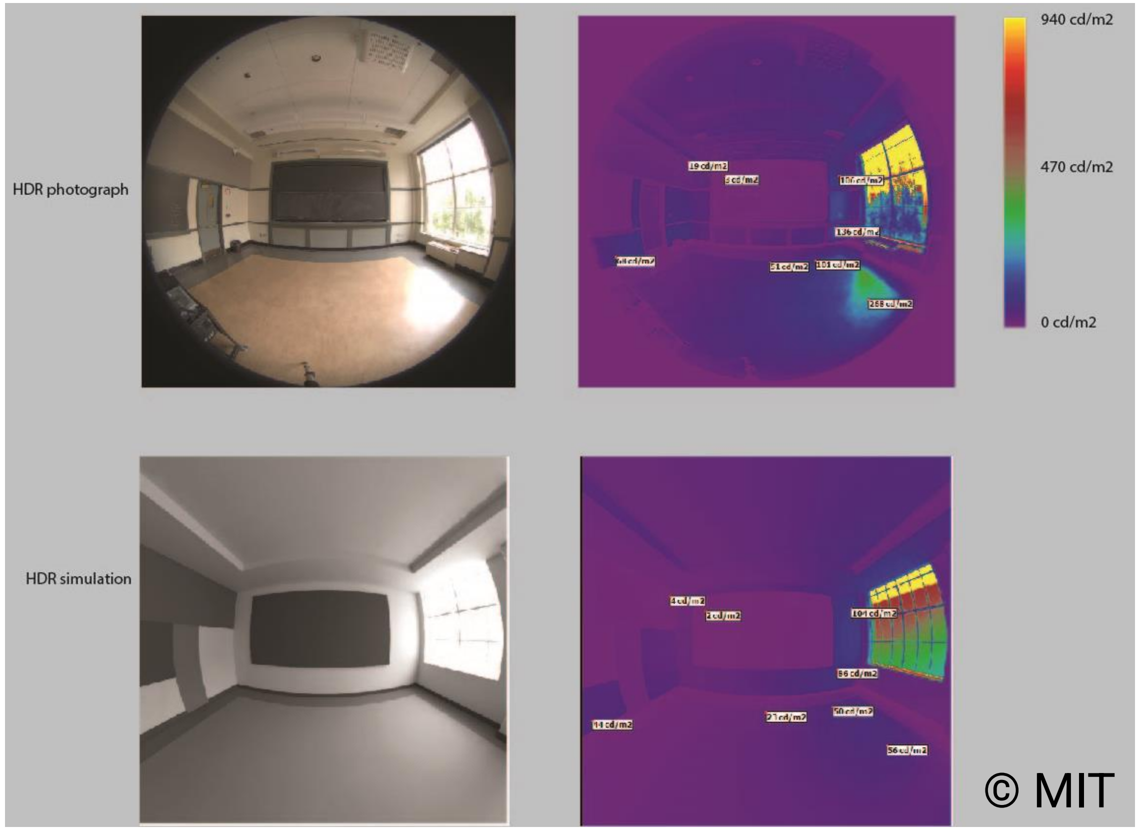


Product Visualization and Advertisement

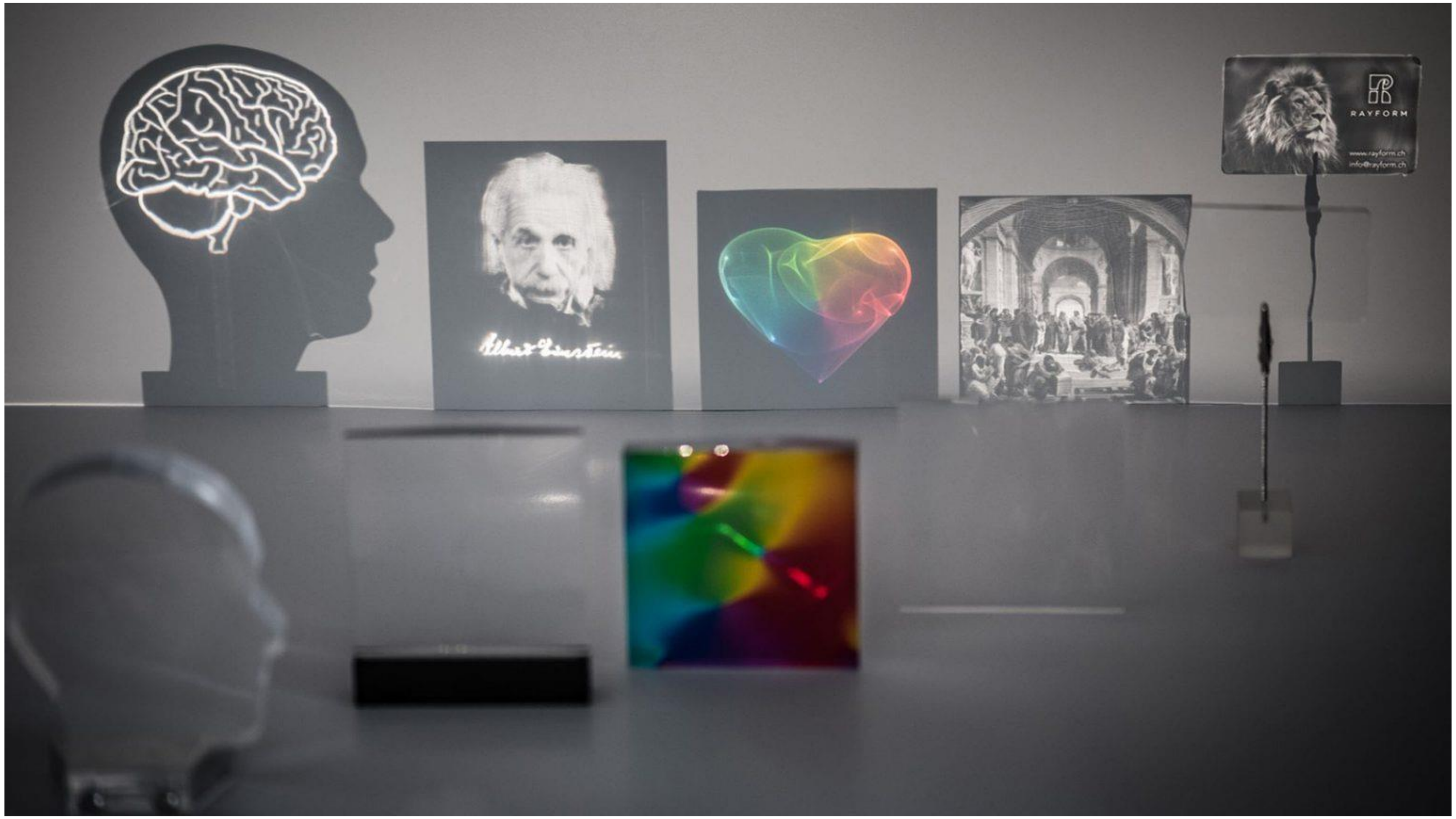
© IKEA

© Nissan

Architecture

© Pixelcraft Work

Optimization and Inverse Rendering



© Schwartzburg et al. 2014

Artificial Intelligence

Course overview

What will you learn?

Course Overview

- Core concepts
  - Rendering equation
  - Probability theory and Monte Carlo integration
  - BRDFs and path tracing
  - Advanced sampling
  - Spatio-temporal sampling
- Bidirectional and adaptive algorithms
  - Bidirectional methods
  - Photon mapping/density estimation
  - Markov chain Monte Carlo
  - Path guiding
- Advanced effects
  - Volume rendering
  - Spectral rendering
- Perception and imaging
  - HDR and tone mapping
  - Perception and modern display technology
- Machine learning
  - Denoising and Supersampling
  - Differentiable rendering

Rendering Equation

Outgoing light

Emitted light

Incident light
(recursively given by the same equation)

Projection

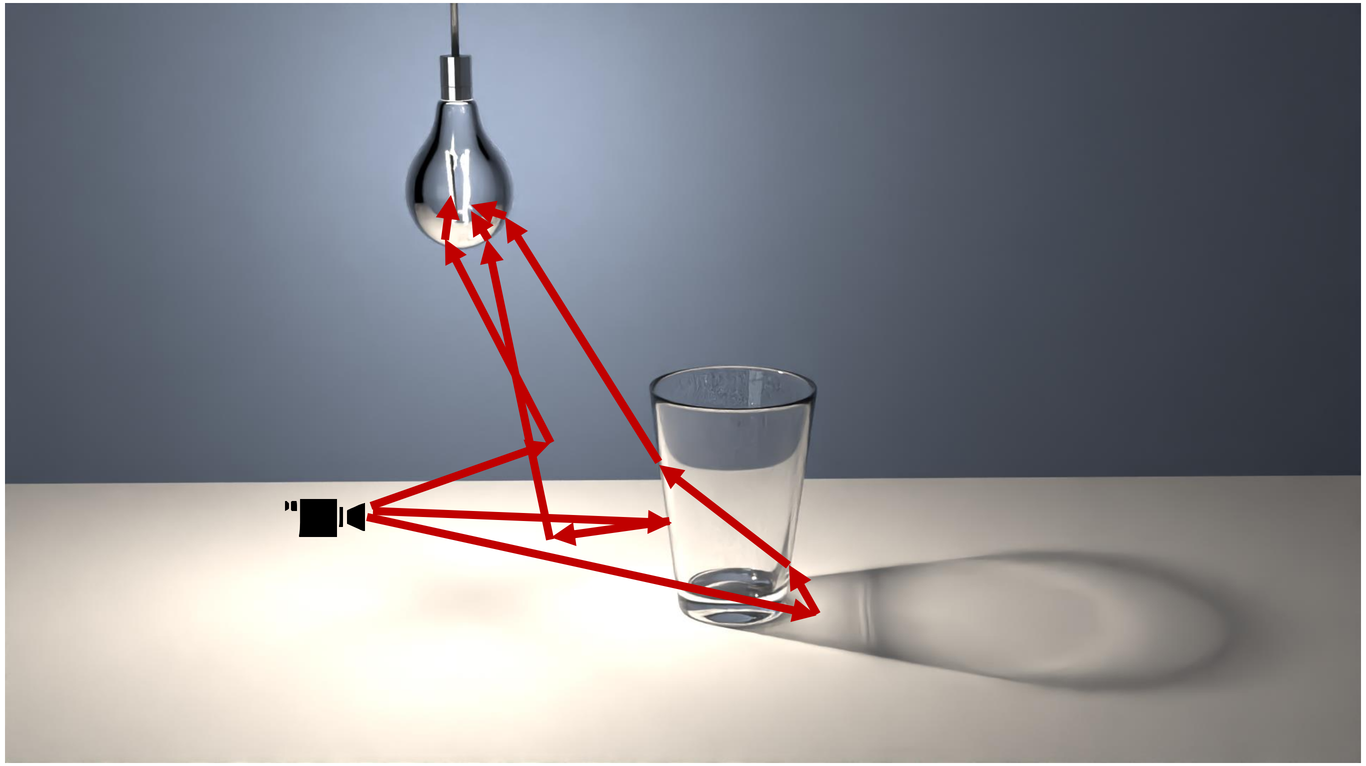
$$L_o(x, \omega_o) = L_e(x, \omega_o) + \int_\Omega L_i(x, \omega_i) f_r(\omega_o, x, \omega_i) \cos\theta_i \, d\omega_i$$

Integral over all directions
(computes reflected light)

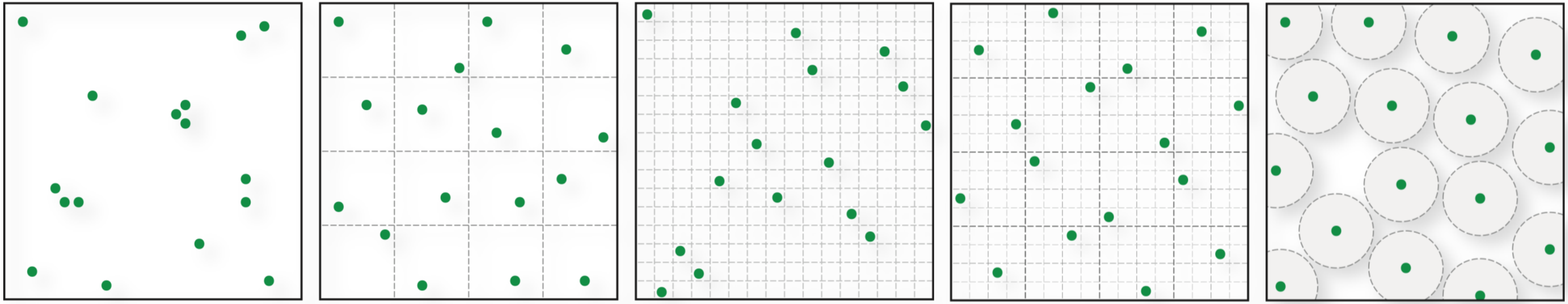
BSDF: Material properties

Monte Carlo Integration and Path Tracing

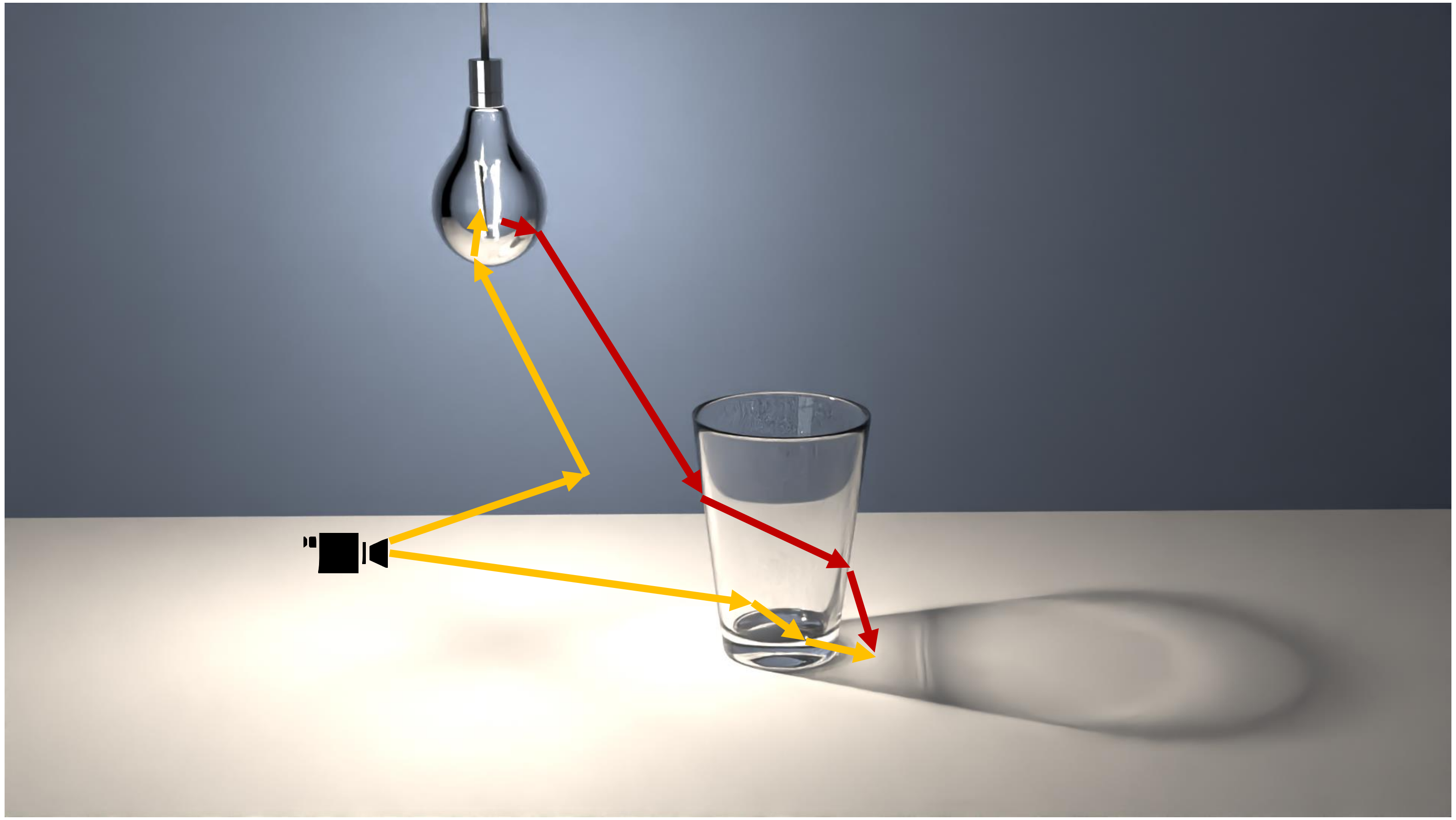
$$\int_X f(x)\, dx \approx \frac{1}{n} \sum_{i=1}^{n} \frac{f(x_i)}{p(x_i)}$$



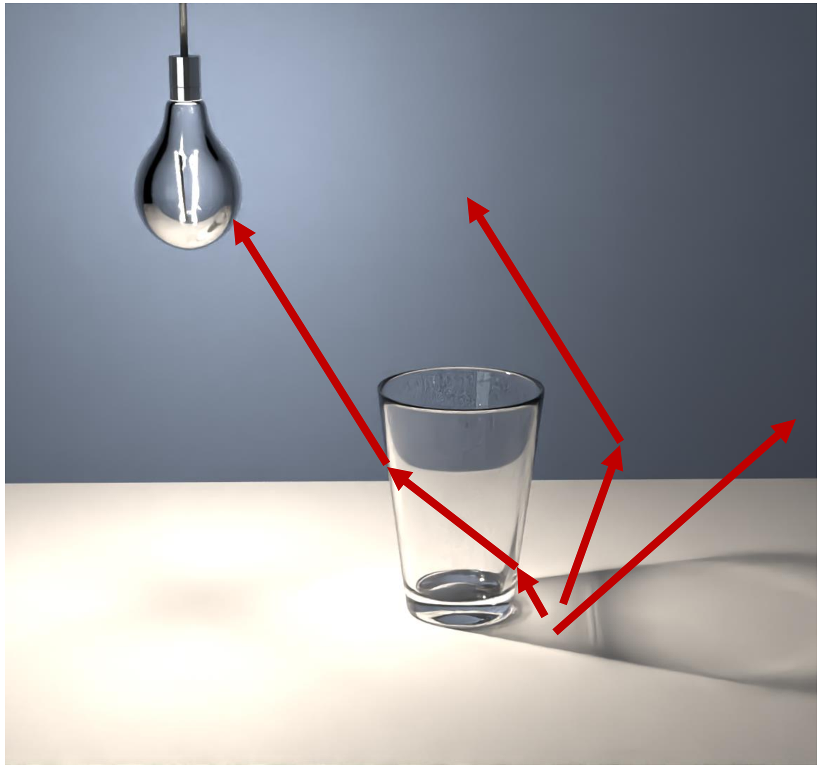
Advanced Sampling



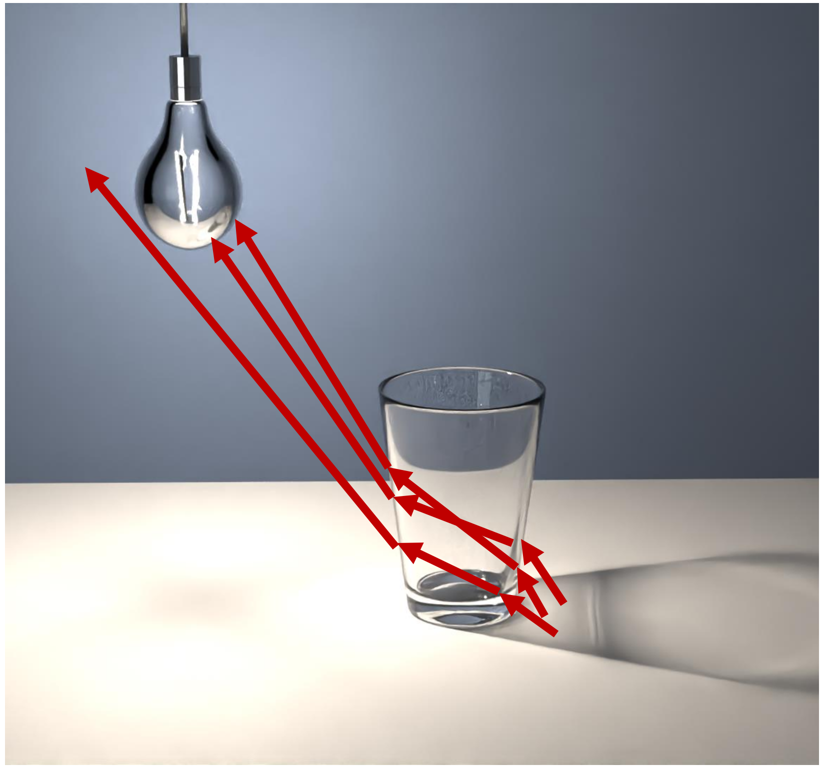
Bidirectional Methods



Adaptive / Learned Sampling

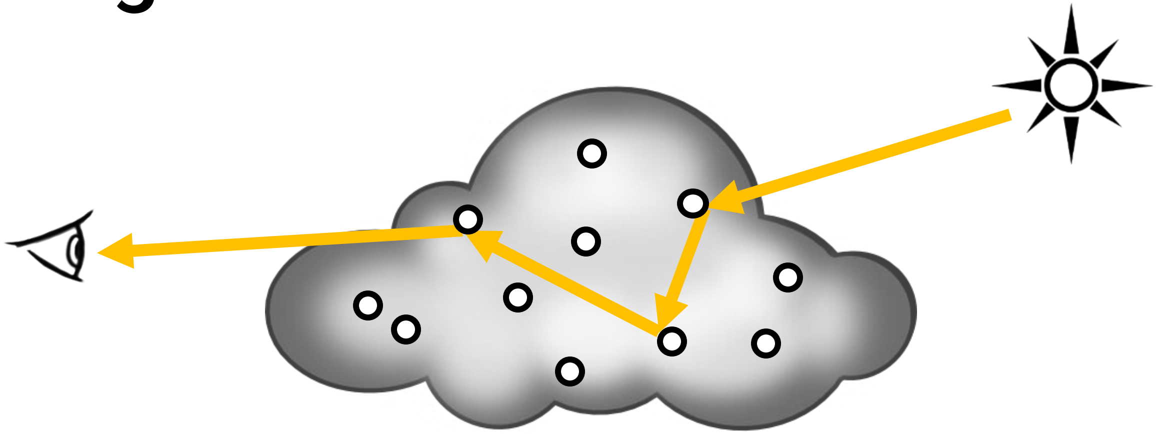


Initial training samples



Guided samples

Volume Rendering

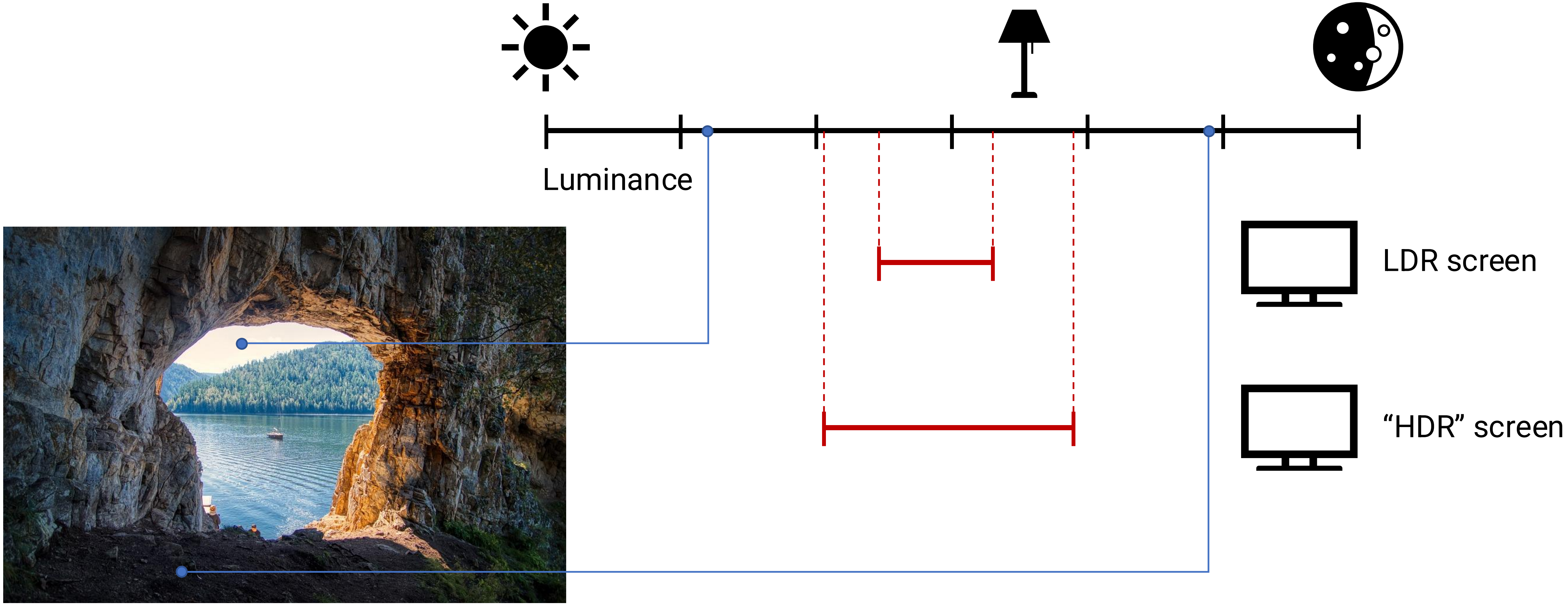


http://coclouds.com

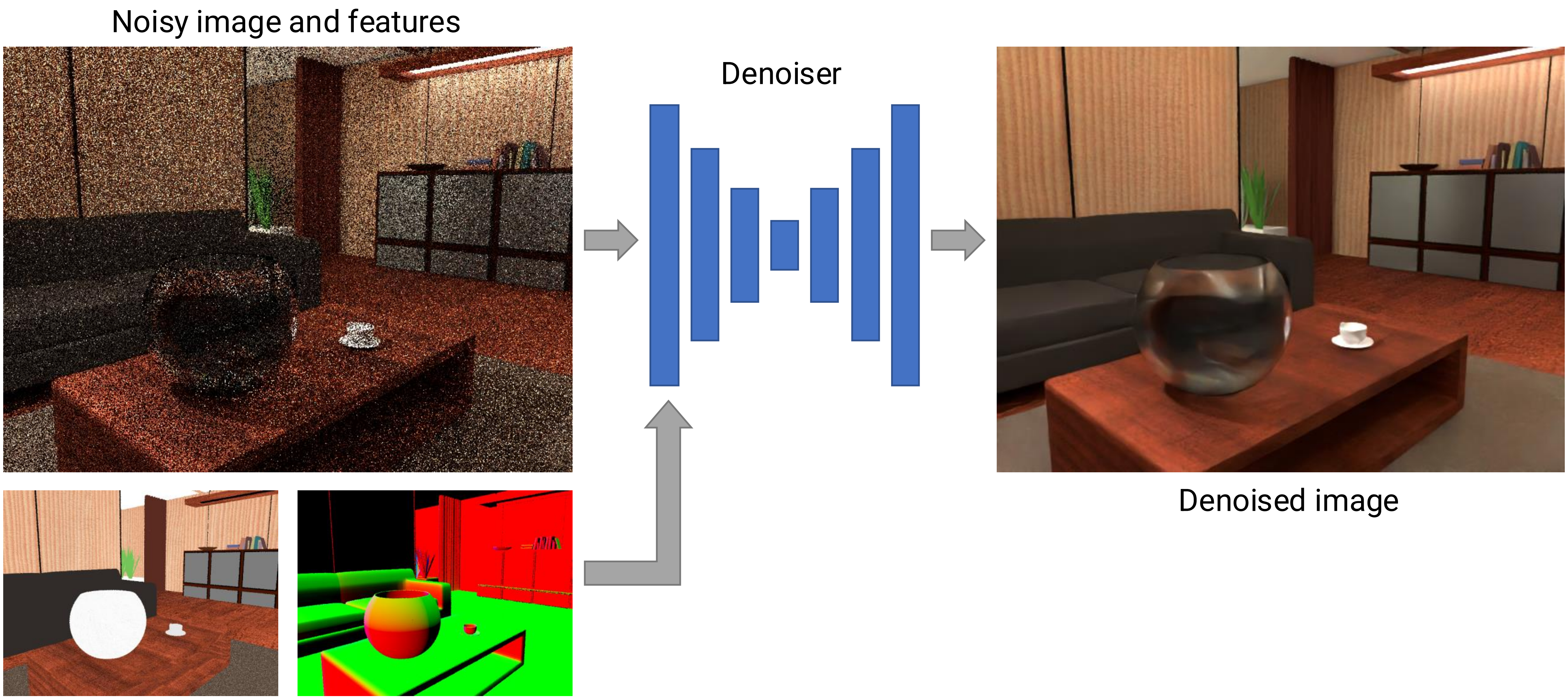
http://wikipedia.org

http://commons.wikimedia.org

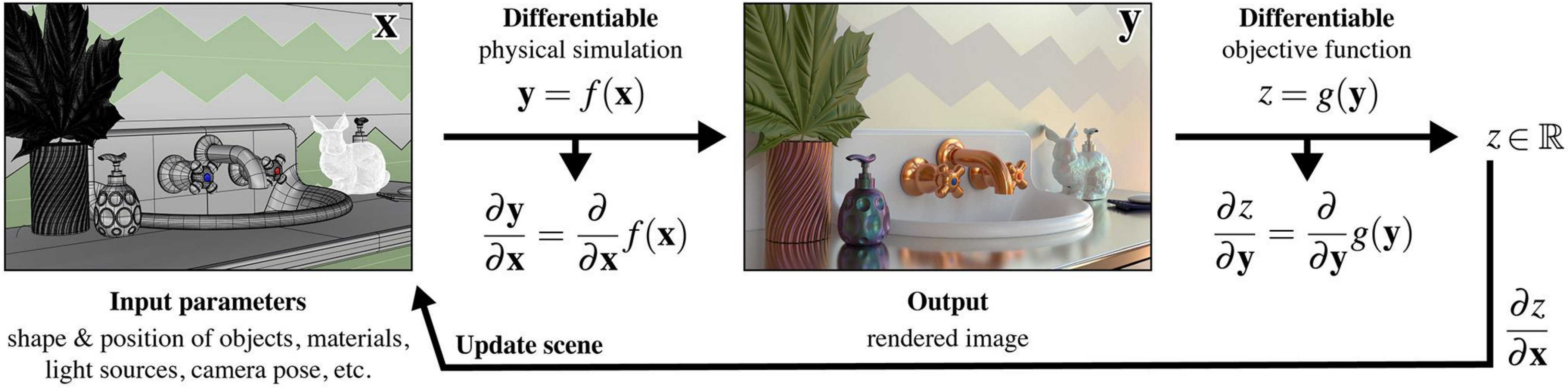
HDR and Tone Mapping



Denoising



Differentiable Rendering



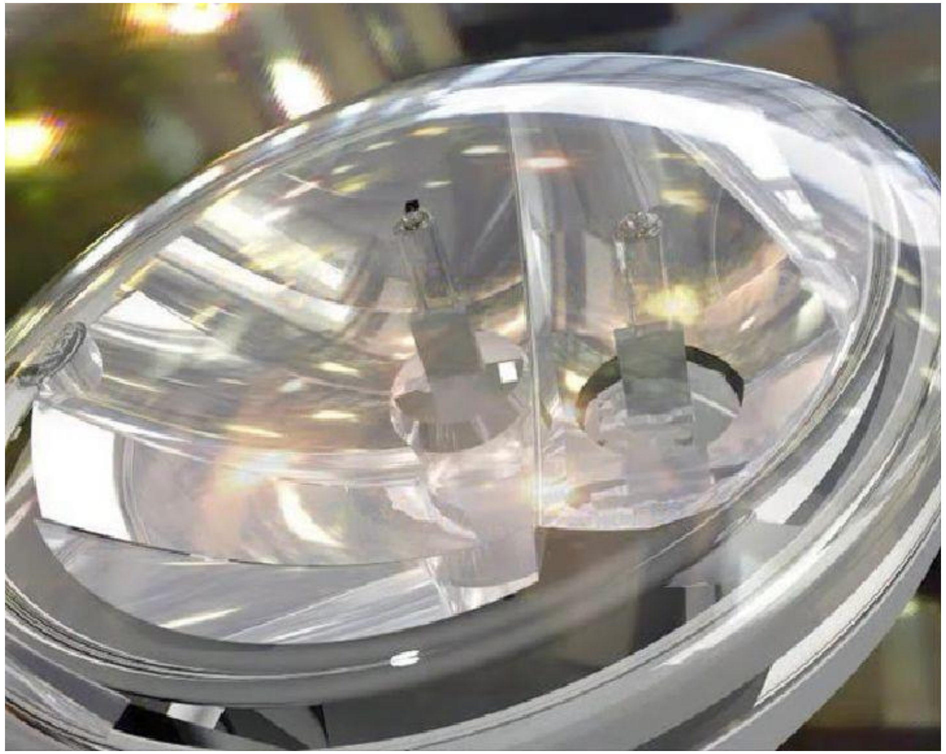
© Jakob et al. (https://mitsuba.readthedocs.io/)

Beyond this course

How and where can you apply what you will learn?

Reflection & Refraction

- Visualization of a car headlight
  - It reflects and refracts light almost entirely from the environment. Up to 50 rays per path are needed to render this image faithfully (800k triangles).

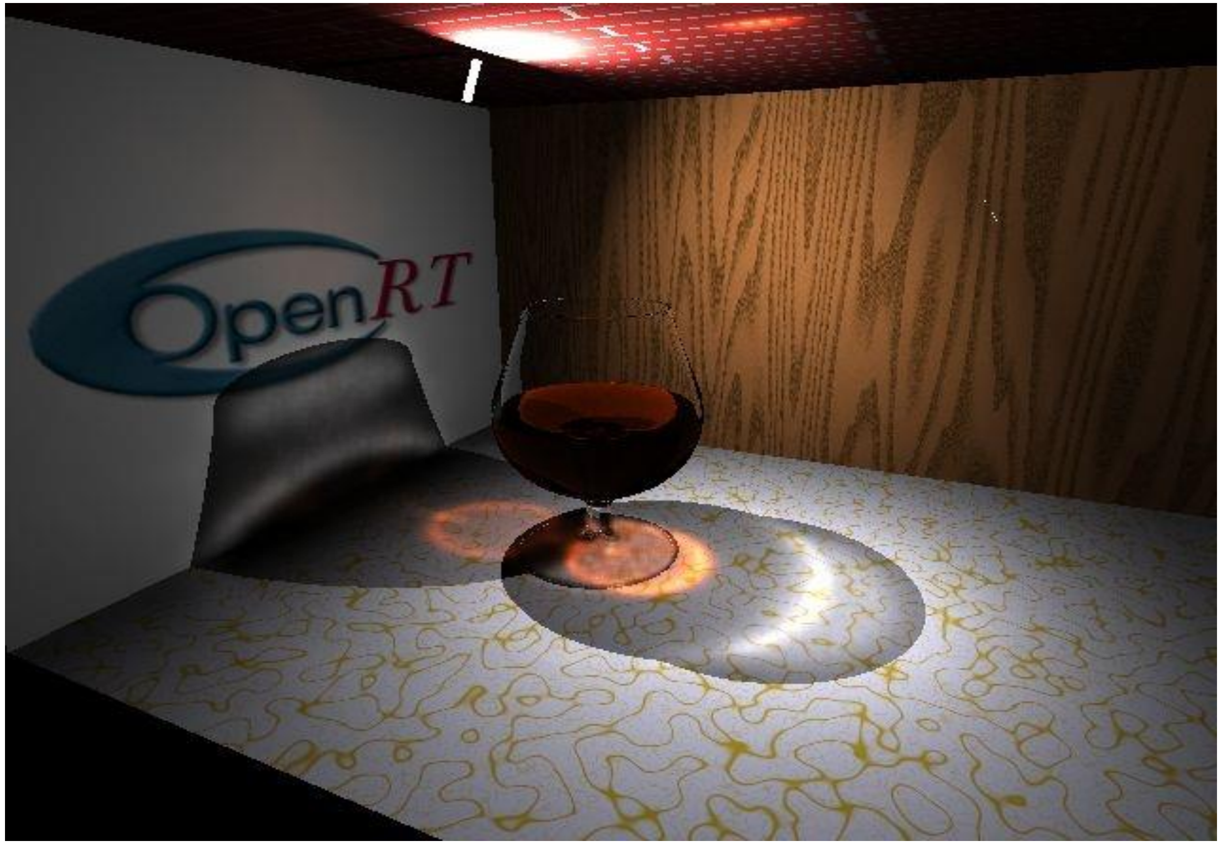


Instant Global Illumination

- Real-time simulation of indirect lighting ("many-light method")

Real-Time Photon Mapping

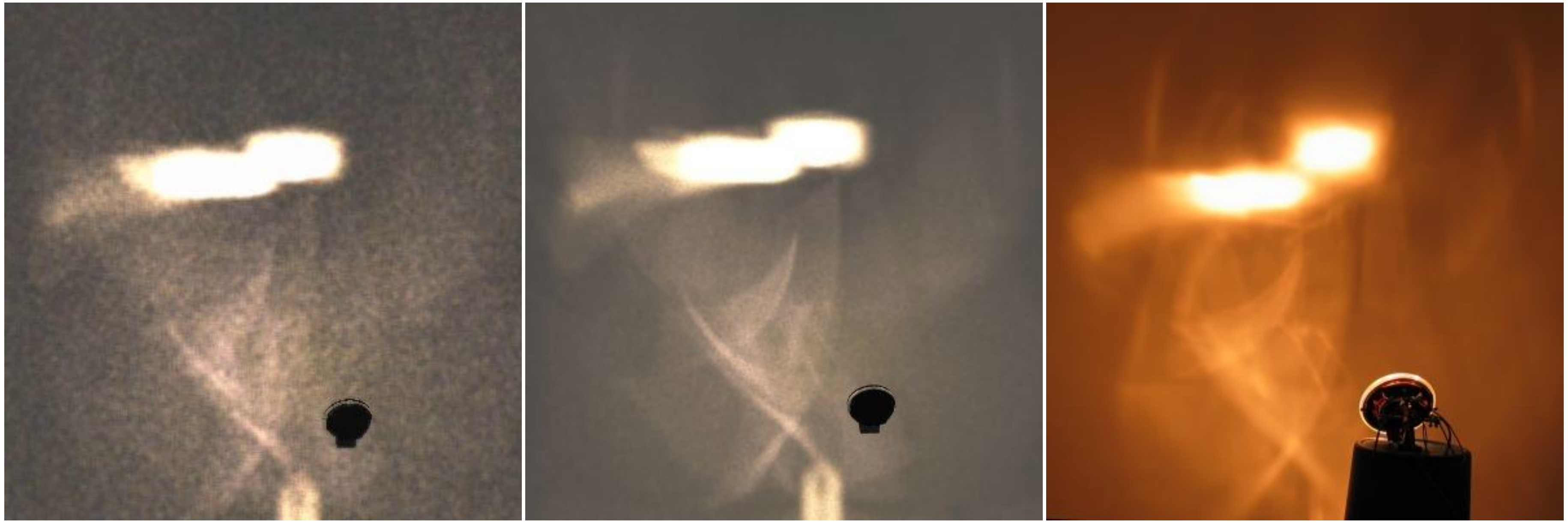
- Real-time performance with procedural textures and density estimation. Interleaved sampling allows to reduce computation by a factor of 10.



Photon Mapping

- Car headlight used as a light source

Photons are emitted and traced until they hit a wall. Density estimation is used to reconstruct the illumination. The results run at 3 FPS with 250k photons on a cluster of 25 cores (in 2004). Visualization without running the simulation achieves even 11 FPS (lower center) and compare well to a real photograph (lower right).

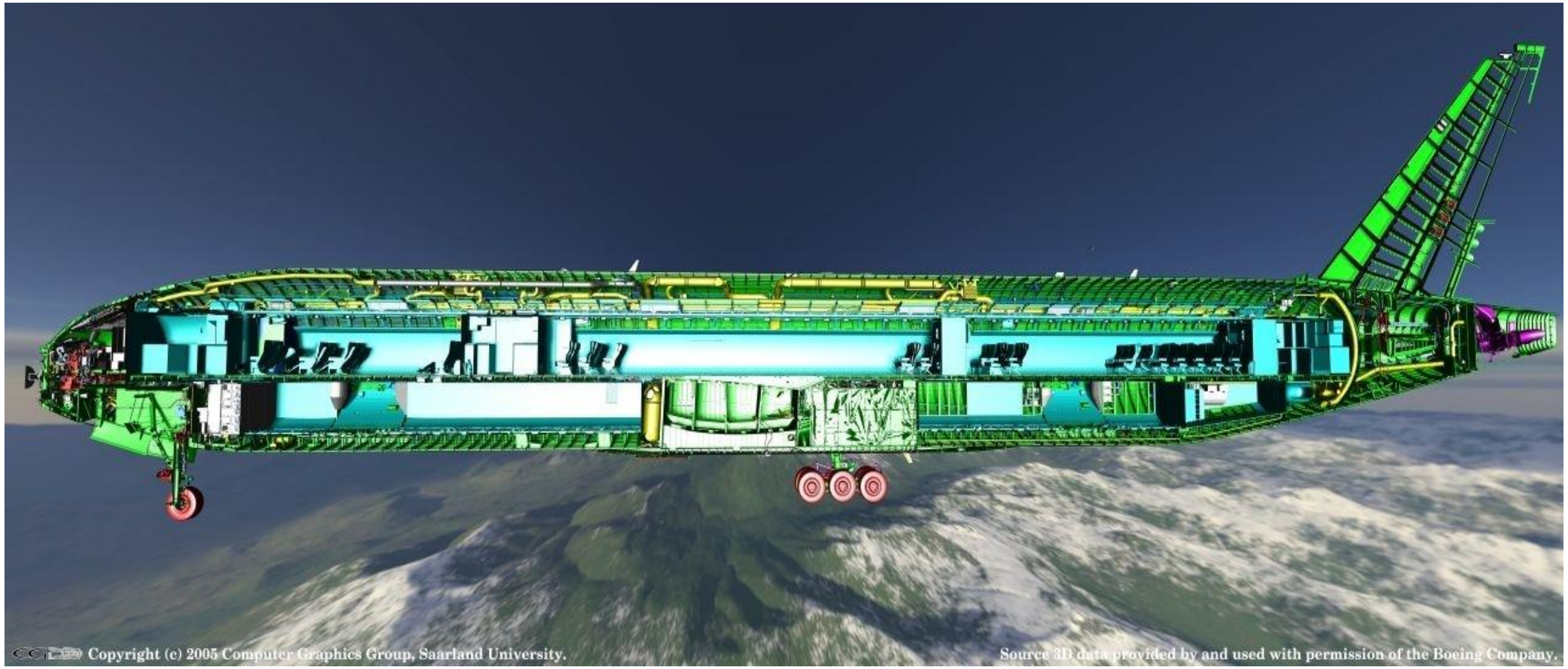


Light Transport Simulation

- Volkswagen’s large Corporate Visualization Center in Wolfsburg using using ray tracing technology developed in Saarbrücken (Spin-off “inTrace”).

Massive Models

- The original CAD model of a Boeing 777 consisting of 365 million polygons (30 GB). Ray tracing was the first method to allow real-time visualization of such models.



Massive Models

- Visualization of large outdoor scenes (300x300m2) with 365k plants and several billion triangles.

Massive Models

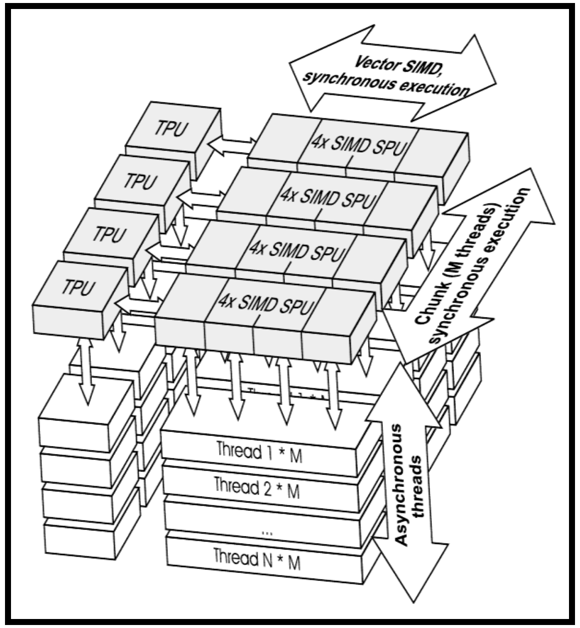
- Much larger outdoor scene (80x80 km²) with realistic lighting and full vegetation ($90*10^{12}$ triangles)

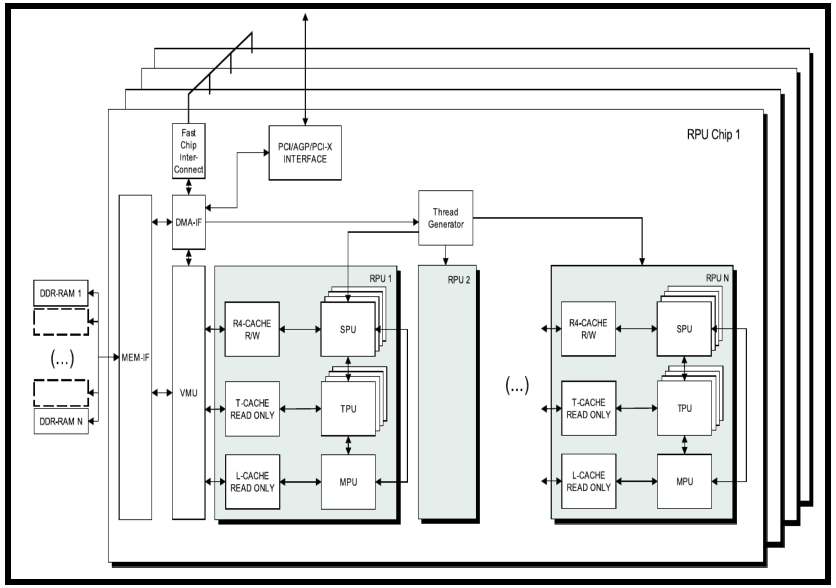
High-Performance Simulation

- Advanced rendering techniques in games

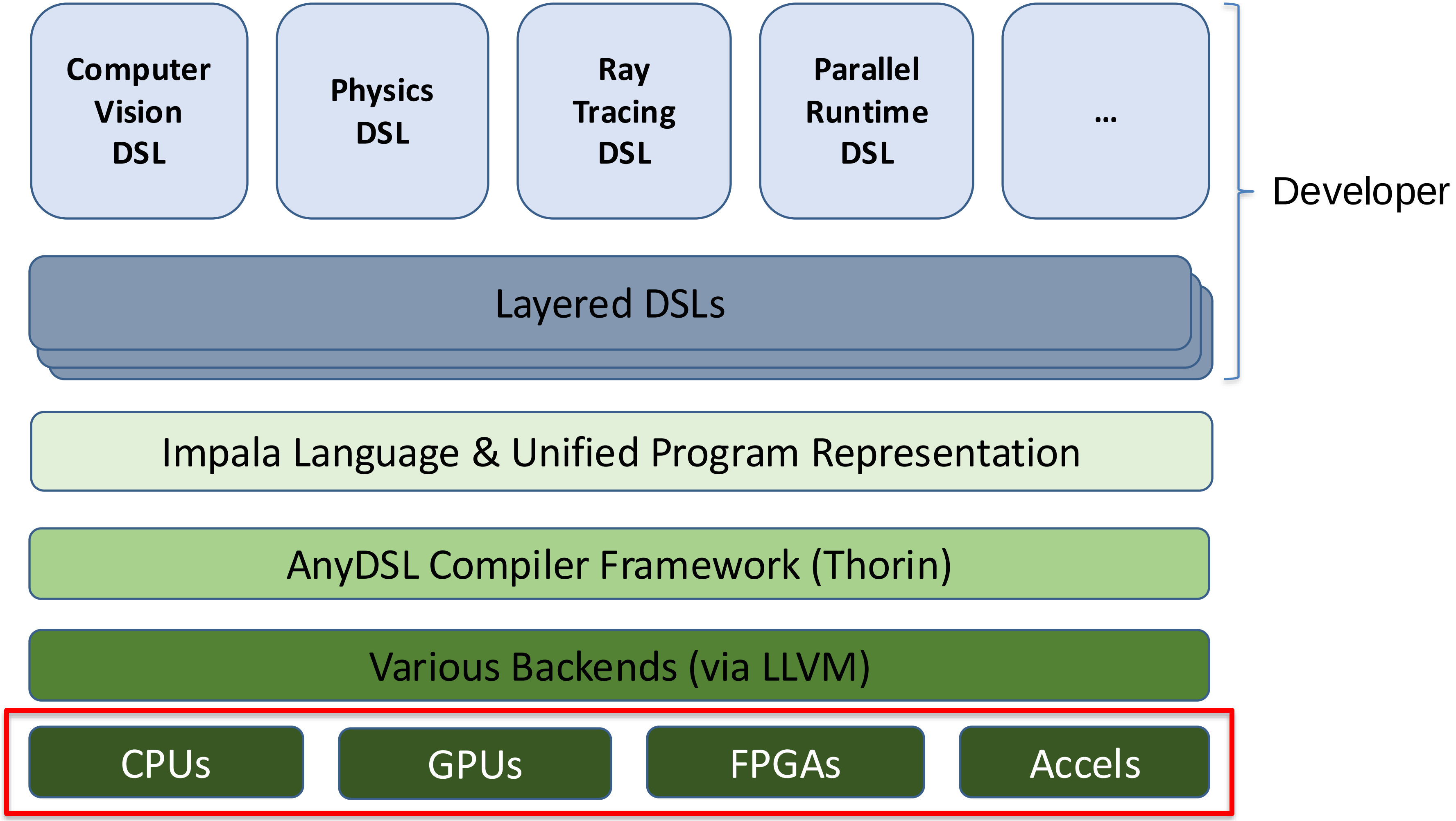
Physically-Based Image Synthesis with Real-Time Ray Tracing

Custom Ray Tracing Processor [Siggraph'05]



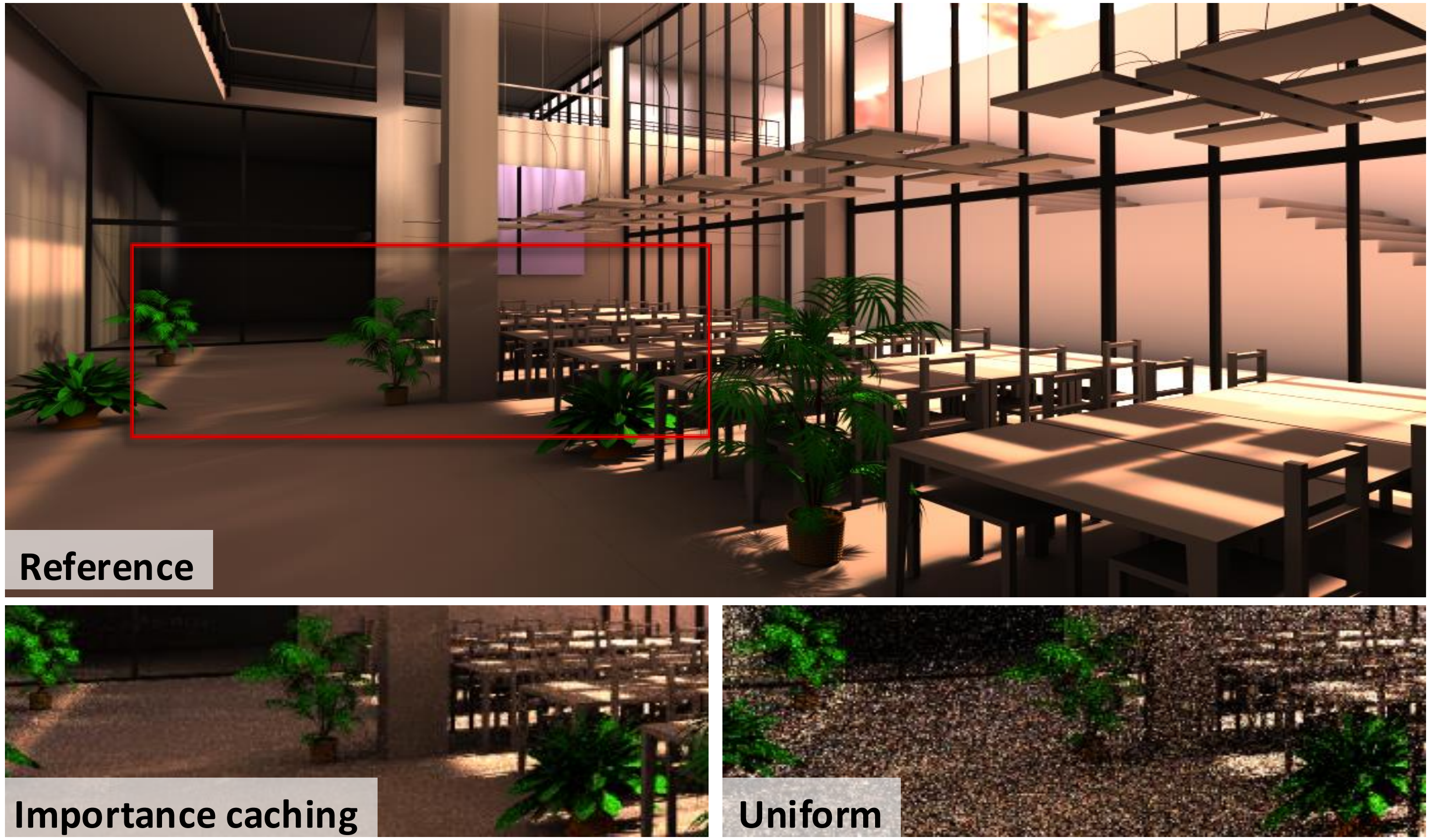


AnyDSL Compiler Framework



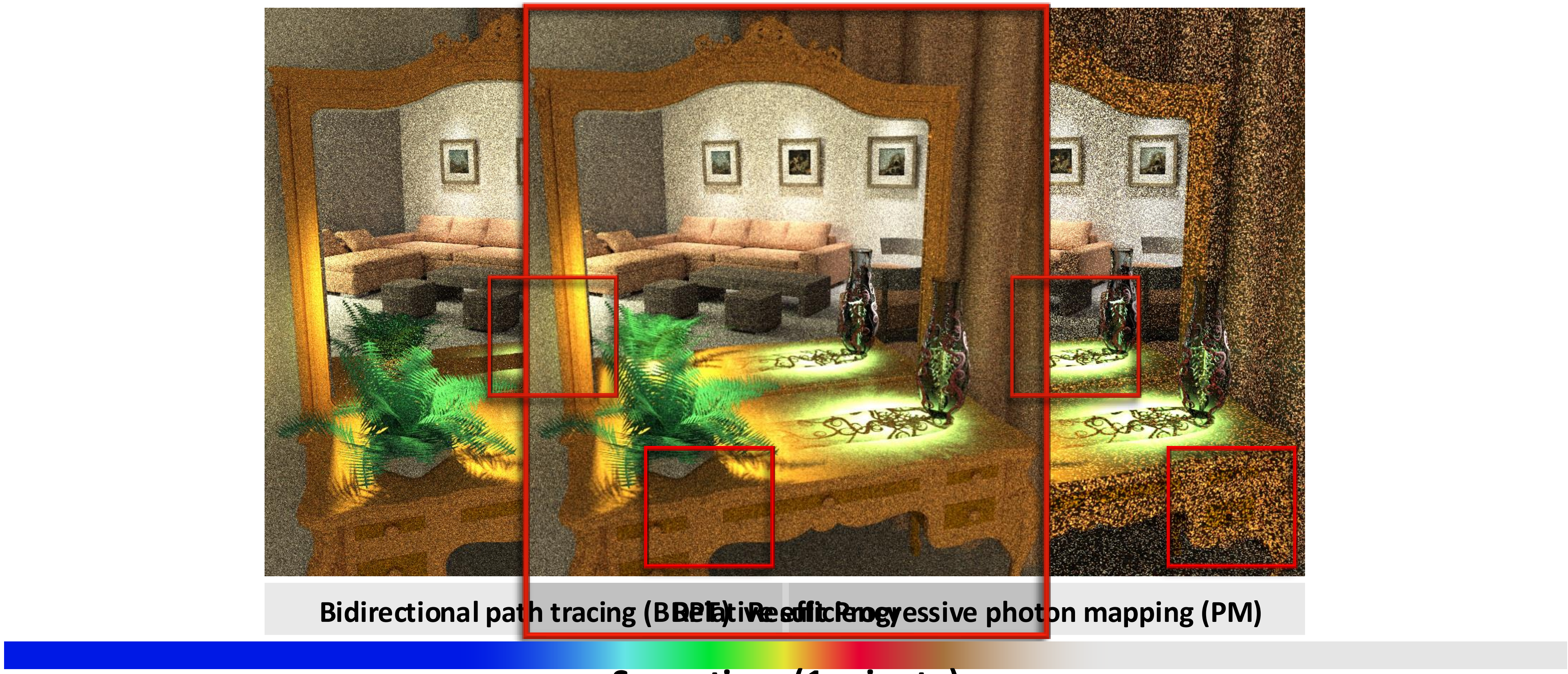
Importance Caching

- Iliyan Georgiev, et al. [Eurographics 2012]



Monte-Carlo vs Density Estimation

- Vertex Connection & Merging, Ilijan Georgiev [SiggraphAsia´12]
    - Formulating Density Estimation algorithms as a Monte-Carlo (MC) techniques



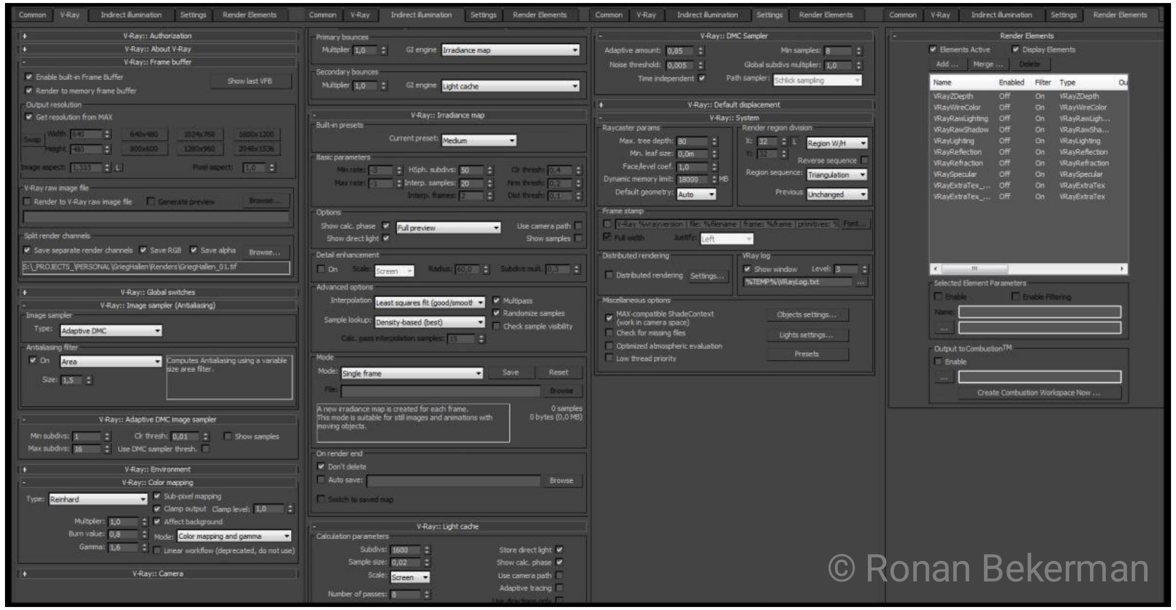
Same time (1 minute)

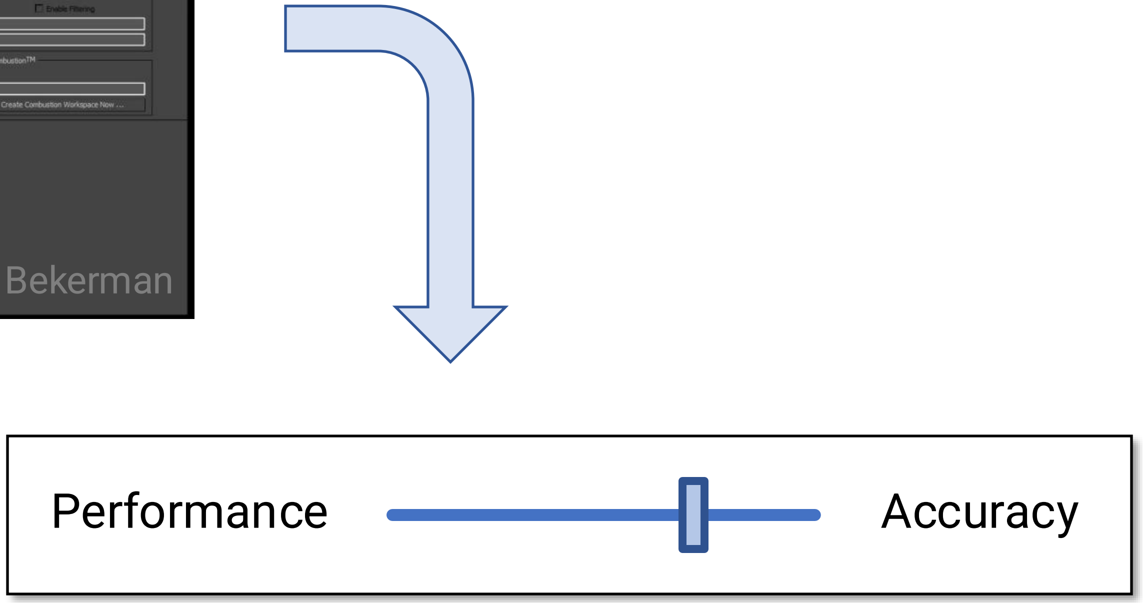
A Quick Glance at (Some of) Our Current Research

- Goal: General, robust, and efficient rendering algorithms
- “One algorithm to render them all”

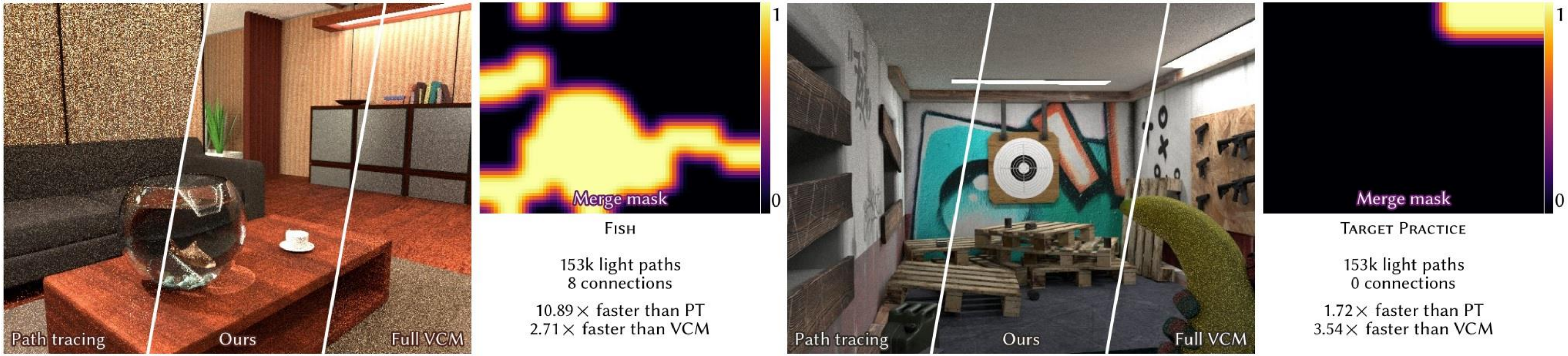
- Methodology: Adapt the algorithm to the scene based on statistics from initial samples
  - Learn better sample distributions
  - Optimize parameter values and sample counts
  - Adapt weighting functions and combinations

Motivation



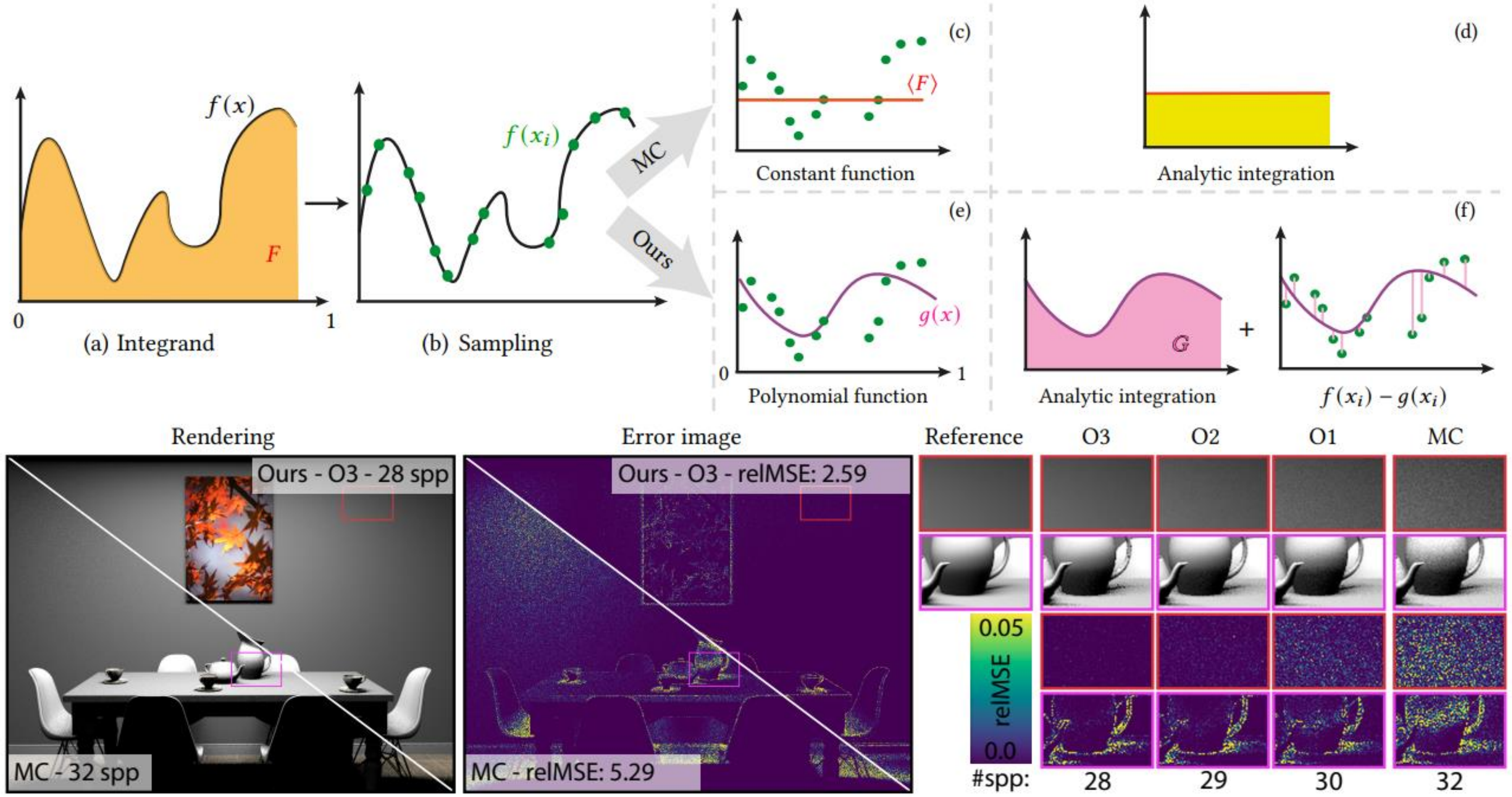


Adapting Parameters and Sample Counts



Grittmann et al. – Efficiency-aware multiple importance sampling
SIGGRAPH 2022

Adaptive Monte Carlo Variance Reduction

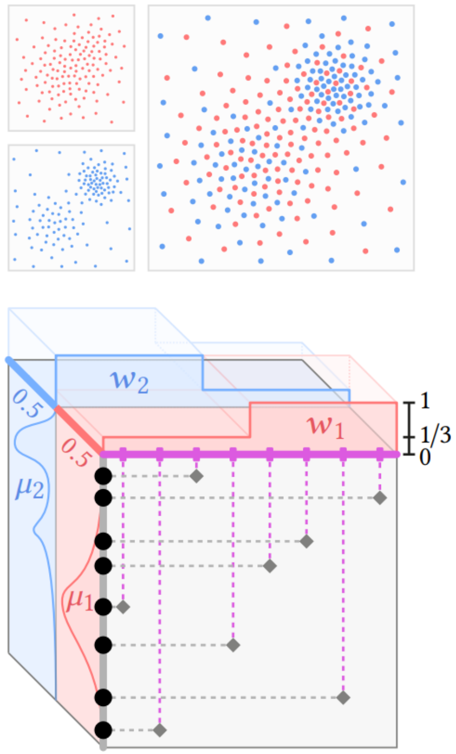


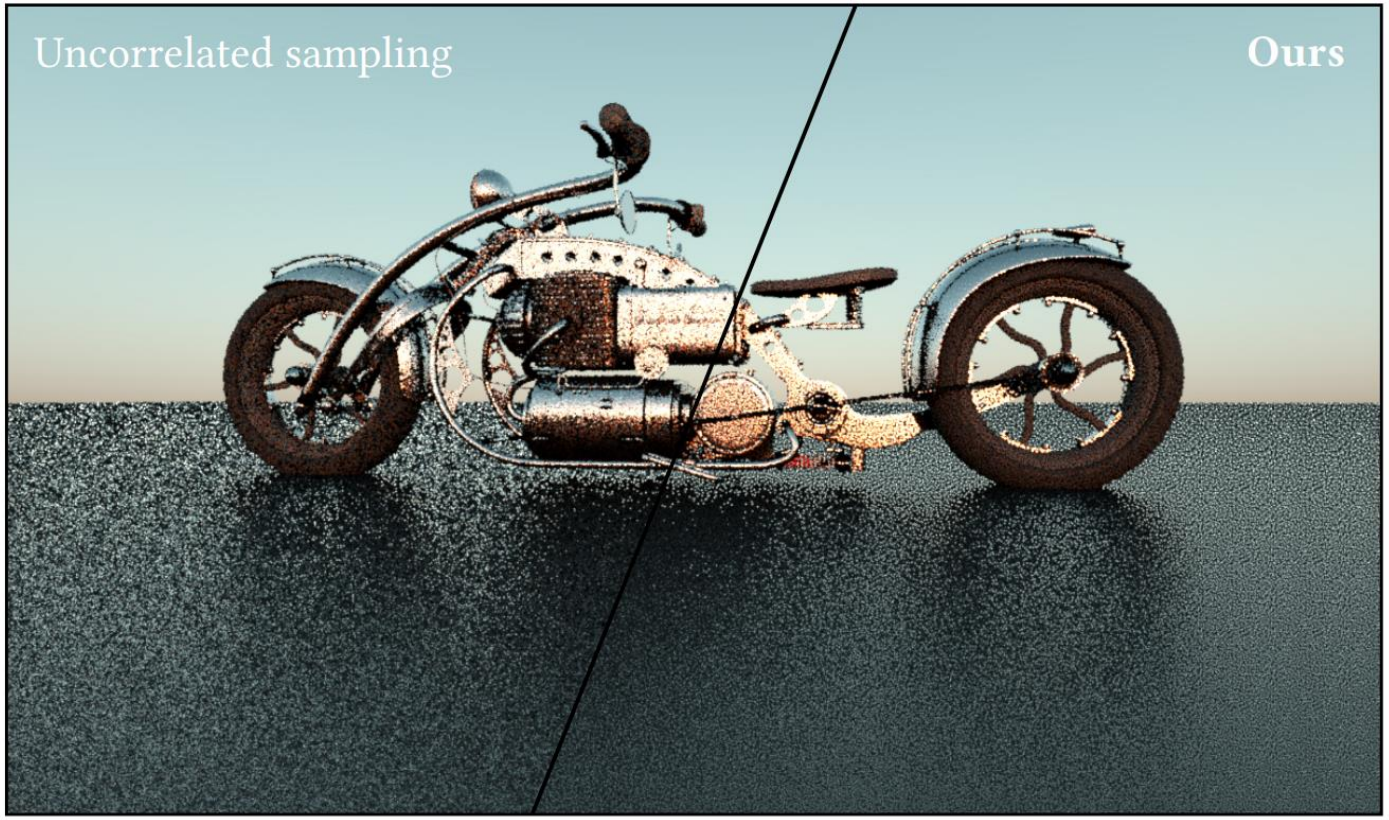
Salaun et al. – Regression-based Monte Carlo Integration.
SIGGRAPH 2022

Sample Optimization for Error Distribution

Chizhov et al. – Perceptual error optimization for Monte Carlo rendering.
TOG 2022

Sample Optimization for Error Distribution

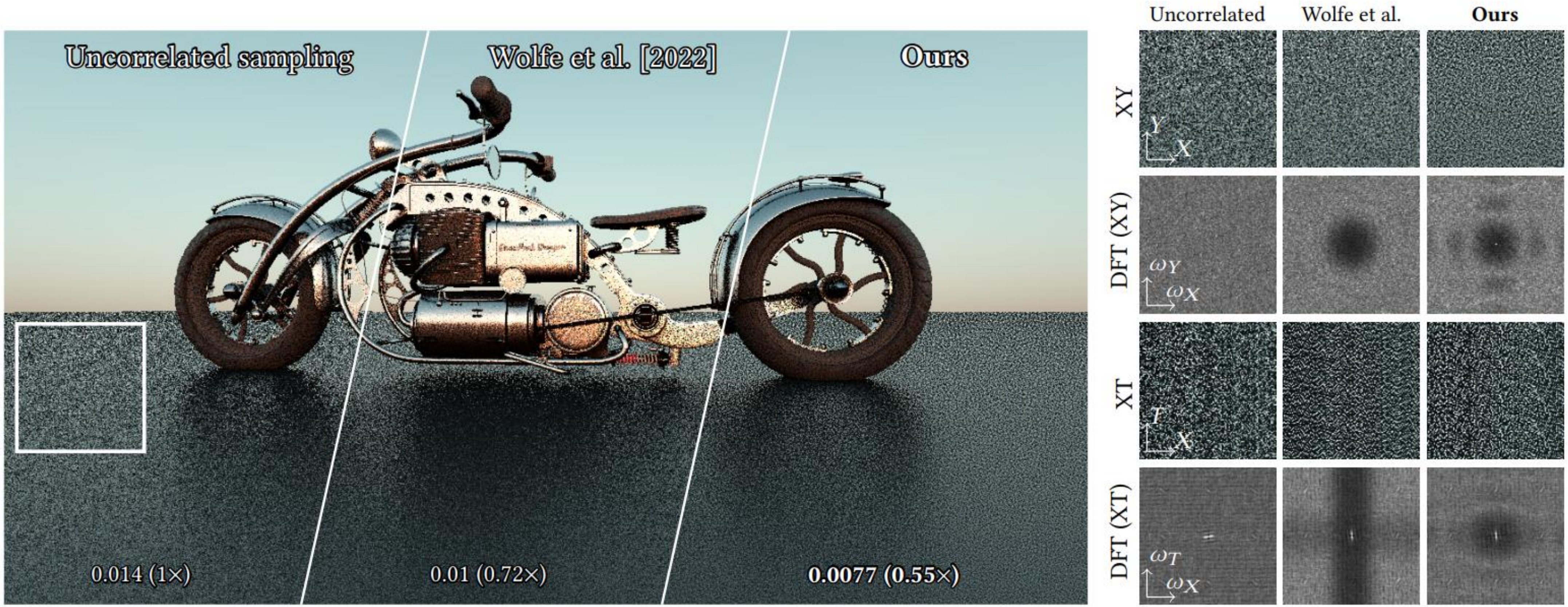




Perceptual error optimization

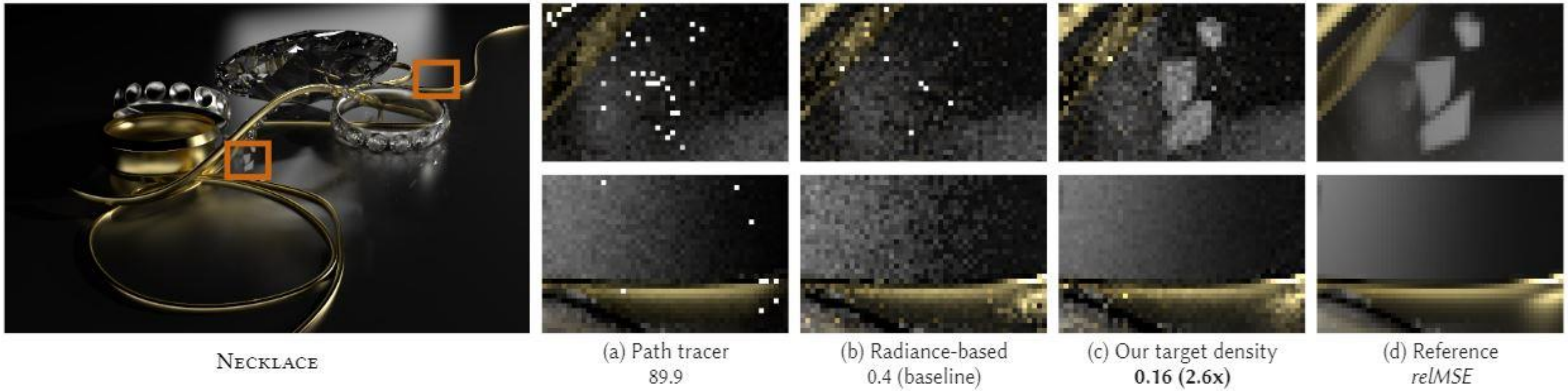
Salaun et al. – Scalable multi-class sampling via filtered sliced optimal transport. SIGGRAPH Asia 2022

Sample Optimization for Error Distribution



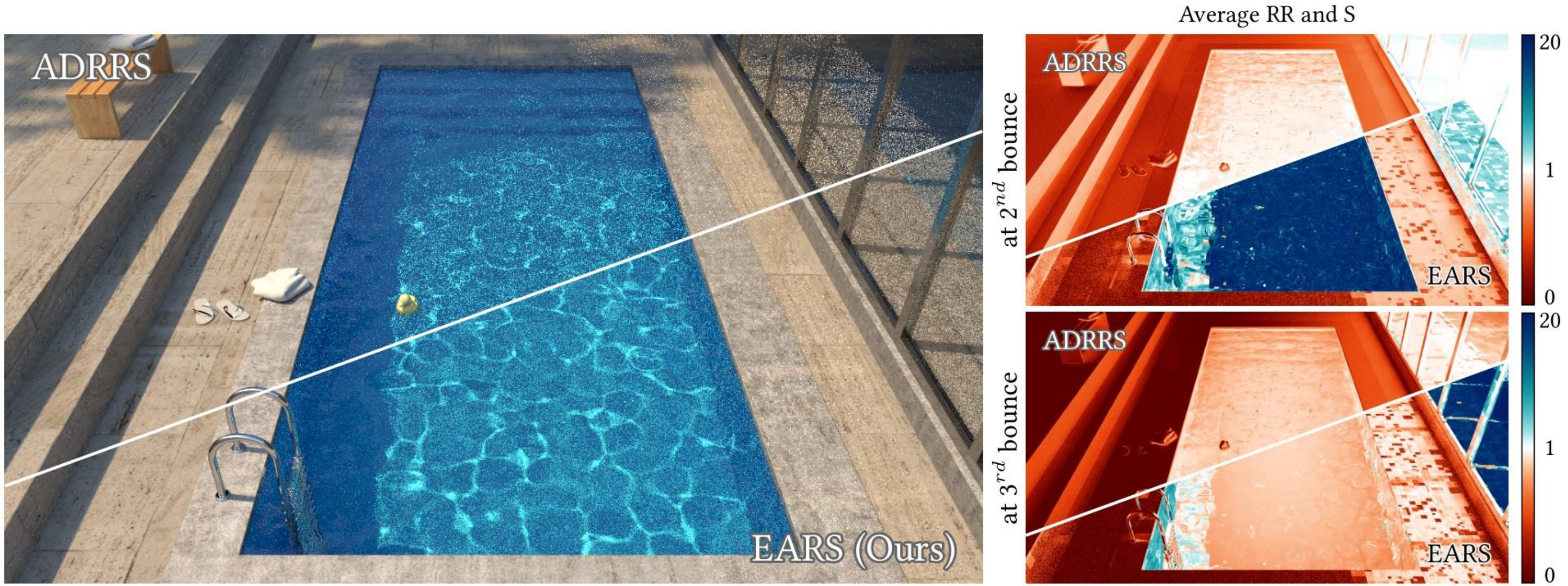
Korać et al. – Perceptual error optimization for Monte Carlo animation rendering. SIGGRAPH Asia 2023

What Should Path Guiding Learn?



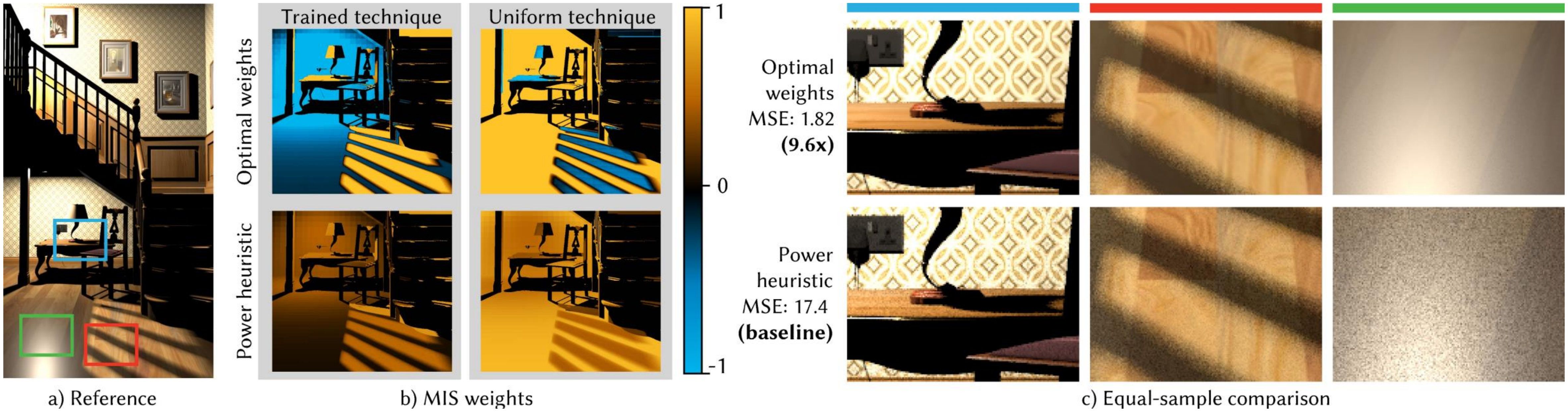
Rath et al. – Variance-aware path guiding. SIGGRAPH 2020

Path Termination and Splitting



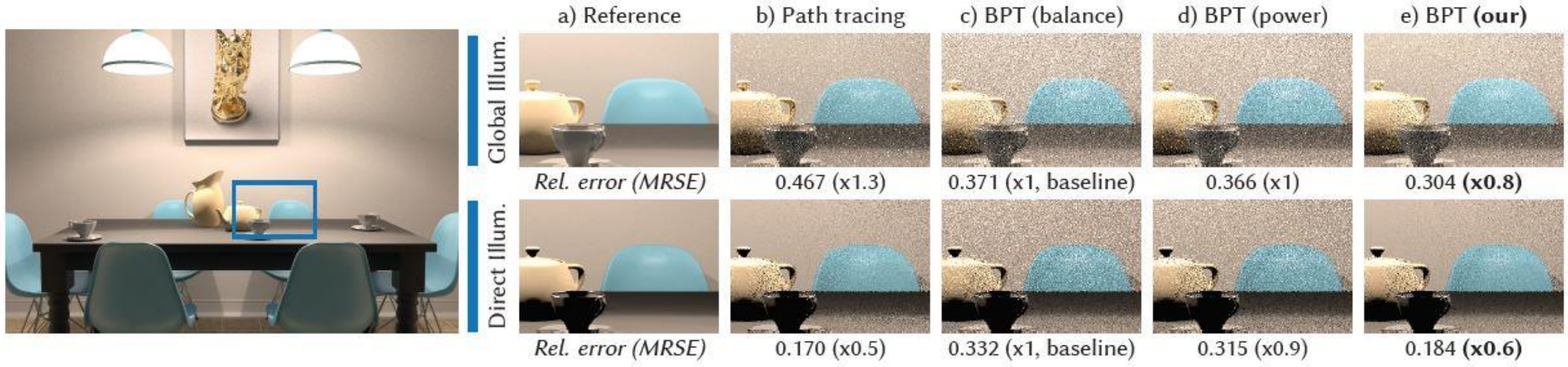
Rath et al. – EARS: Efficiency-aware Russian roulette and splitting
SIGGRAPH 2022

Optimal MIS



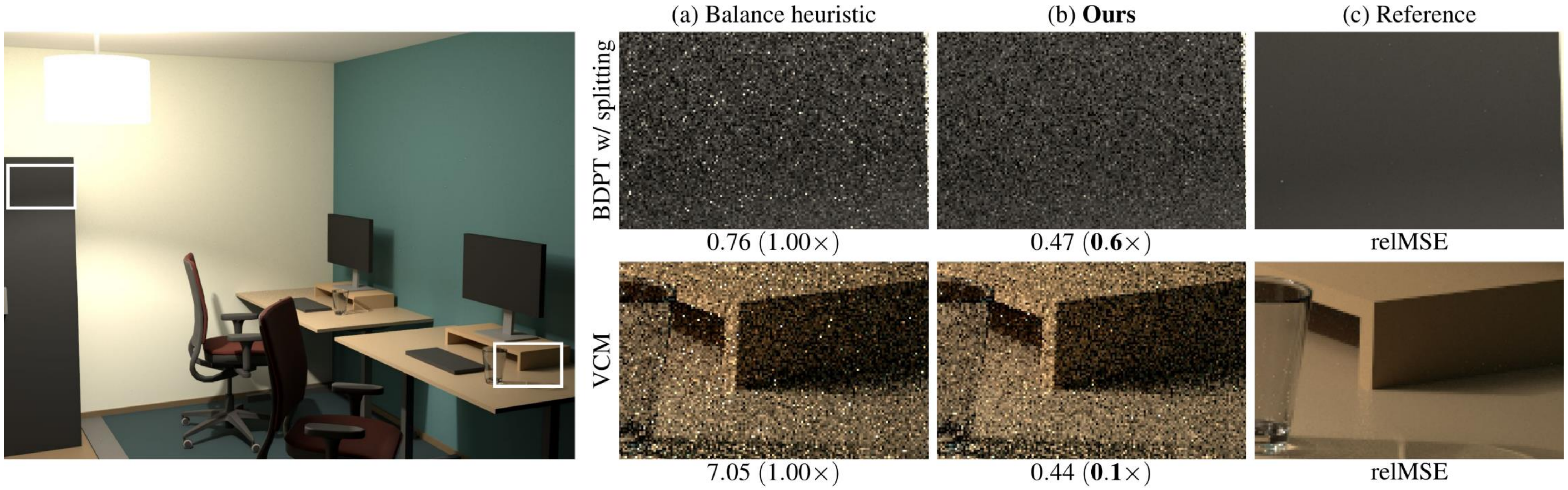
Kondapaneni et al. – Optimal multiple importance sampling
SIGGRAPH 2019

Fixing MIS for Bidirectional Methods



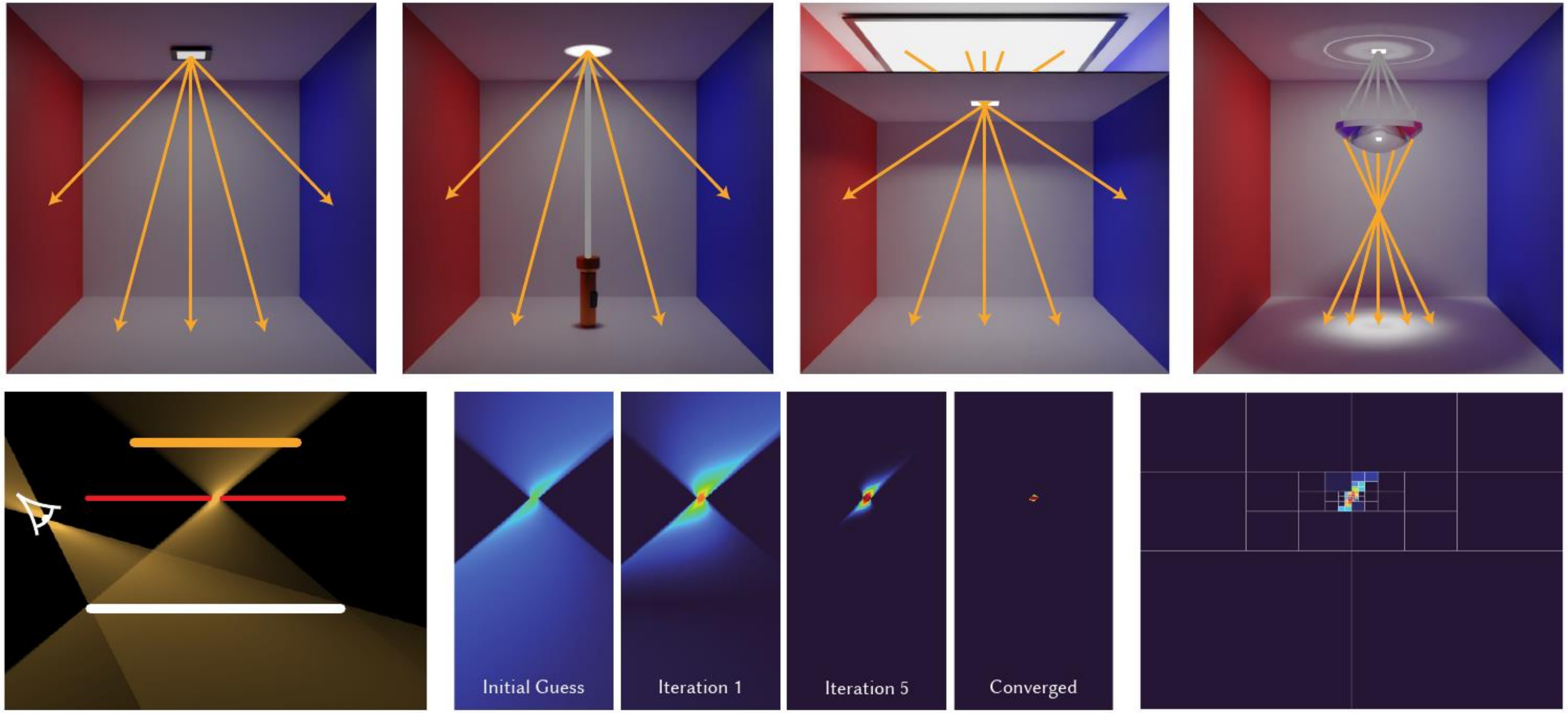
Grittmann et al. – Variance-aware multiple importance sampling
SIGGRAPH Asia 2019

Fixing MIS for Bidirectional Methods – Part II



Grittmann et al. – Correlation-aware multiple importance sampling
Eurographics 2021

Identifying Guiding Targets not on Surfaces

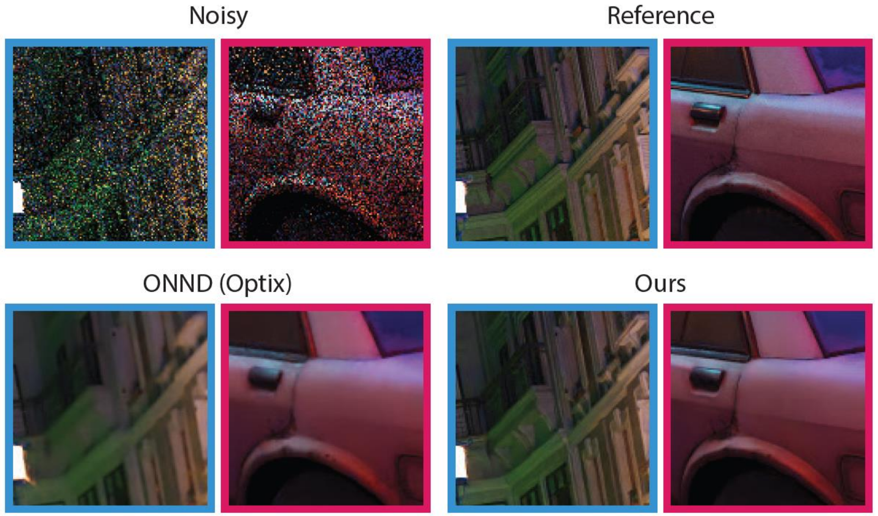


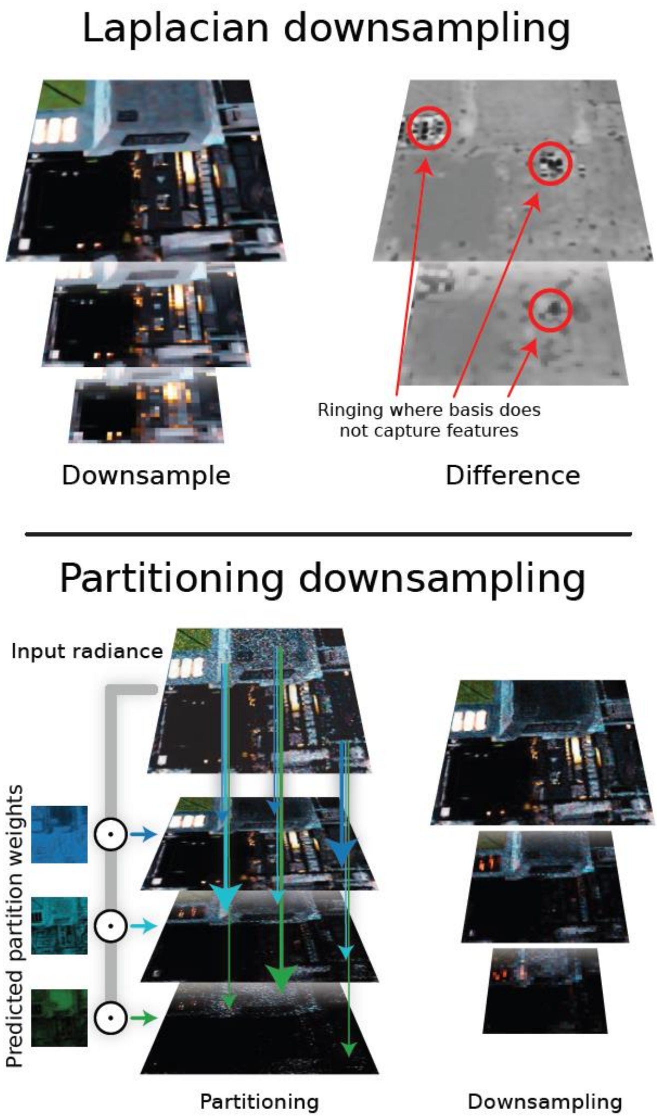
Rath et al. – Focal Path Guiding
Siggraph 2023

Learning Compact Scene Representations

Weier, et al. – Rendering with mixed geometric and neural representations.
Siggraph 2023 + 2024

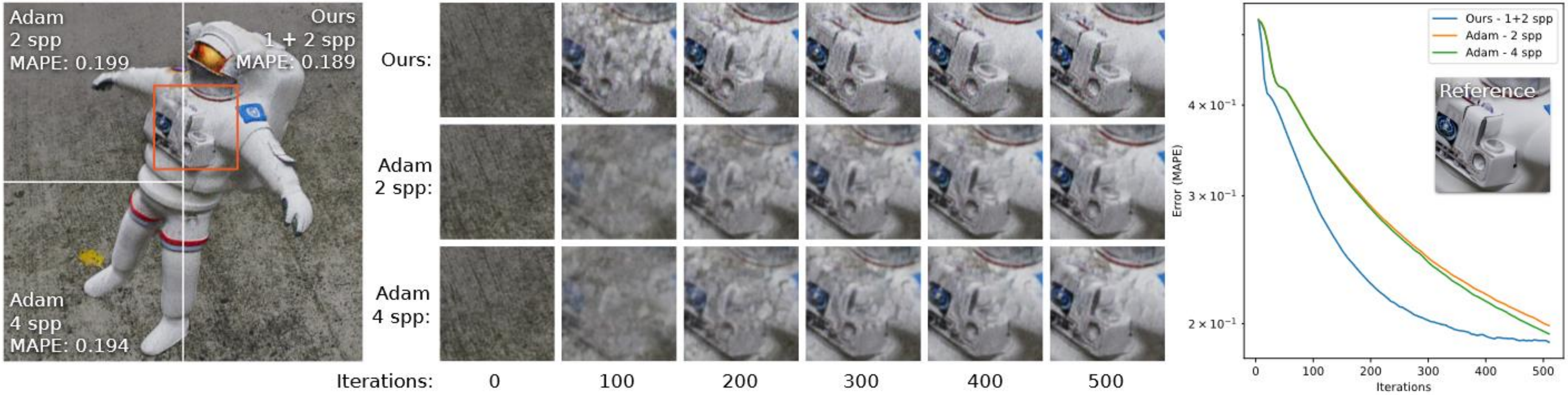
Learning to denoise from few samples





Balint et al. – Neural Partitioning Pyramids for Denoising Monte Carlo Renderings
Siggraph 2023

Faster optimization with inverse path tracing



Balint et al. – Joint sampling and optimisation for inverse rendering
Siggraph Asia 2023