Realistic Image Synthesis

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Personnel

- Instructors:
  - Philipp Slusallek
    - http://graphics.cg.uni-saarland.de/slusallek/
  - Karol Myszkowski
    - http://www.mpi-inf.mpg.de/~karol/
  - Gurprit Singh
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- Teaching Assistant:
  - Pascal Grittmann
- Secretary:
  - Hanna Loger

Administrative Information

- Type
  - Special topic lecture
  - Applied computer science (Praktische Informatik)
- ECTS
  - 9 credit points
- Prerequisites
  - Interest in mathematics, physics, programming
- Language
  - All lectures will be given in English
- Time and Location
  - Monday 10-12 & Thursday, 10-12h, HS 01, E1.3
- Web-Page
  - http://graphics.cg.uni-saarland.de/courses/
  - Schedule, slides as PDF
  - Literature, assignments, other information
- Mailing list
  - Up-to-date information, exercise updates, etc…
  - Please also do not forget to sign up on LSF for the course

Grading

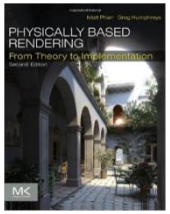
- Weekly assignments
  - Average of at least 50% of all assignments in the semester
  - Required for admission to final exam
  - Demonstrate your solution in exercise groups
- Practical assignments
  - Longer-term projects
  - Build your own physically-based renderer
- Final grade
  - Assignments: 50%
  - Final oral exam: 50%

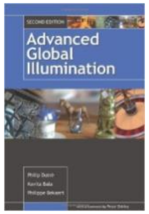
Textbooks

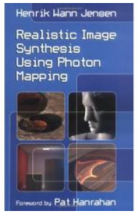
- Pharr & Humphreys, **Physically-Based Rendering: From Theory to Implementation**, Morgan Kaufmann, 3rd Edition (Dec 2016)
- Dutre, Bekaert, Bala, **Advanced Global Illumination**, A.K. Peters, 2006, 2nd Edition.
- Jensen, **Realistic Image Synthesis Using Photon Mapping**, A.K. Peters, 2005, 2nd Edition.
- Shirley & Morley, **Realistic Ray Tracing**, A.K. Peters, 2003, 2nd Ed.
- Reinhard, Ward, Pattanaik, Debevec, Heidrich, Myszkowski**, High Dynamic Range Imaging**, Morgan Kaufmann Publish.,2010,2nd Ed.

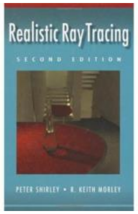
- Cohen & Wallace, **Radiosity and Realistic Image Synthesis**, Academic Press, 1993.
- Apodaca & Gritz, **Advanced Renderman: Creating CGI for the Motion Pictures**, Morgan Kaufmann, 1999.
- Glassner, **Principles of Digital Image Synthesis**, 2 volumes, Morgan Kaufman, 1995.

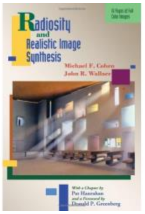
- Iliyan Georgiev, **Path Sampling Techniques for Efficient Light Transport Simulation**, PhD Thesis, Saarland University, 2015











Ingredients for Realistic Images

- *Shape* (Geometry)
  - Objects in our scene: surfaces, volumes, points, ...
- *Material* of surfaces & volumes
  - Places of interaction of light with matter
    - Reflection, refraction, scattering, absorption, ...
  - Applied to shapes (“shaders”)
- *Light sources*
  - Sources of light
    - Position, color, directional characteristics, …
  - Applied to shapes or independent (“light shaders”)
- *Camera*
  - Sensor that captures the light from the scene
    - Lenses, shutter & film; also surfaces can be sensors: e.g. light maps
- **Simulation of Light Propagation**
  - Computing the distribution of light at the sensor (and thus in scene)

Motivation

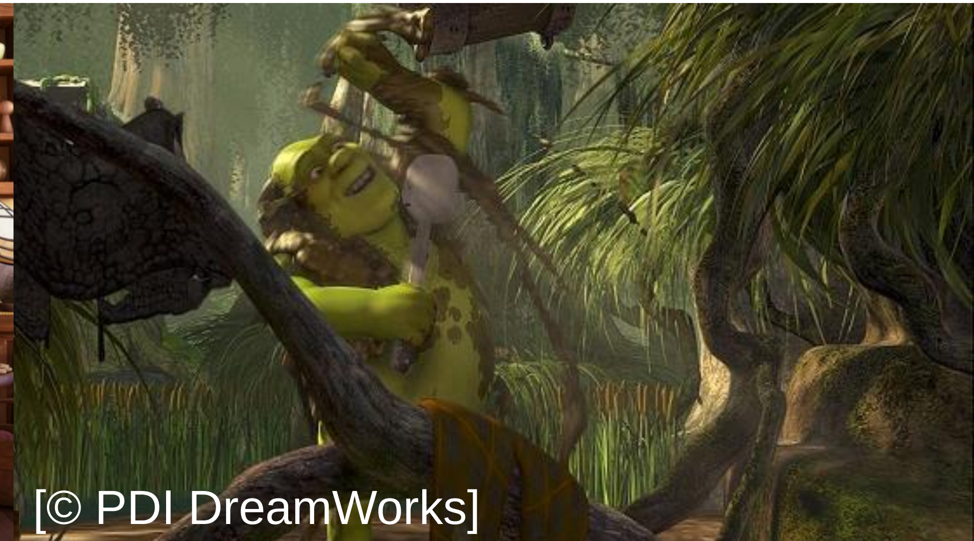
- Goal: Create images on the computer that are
  - Indistinguishable from reality
    - “(Photo-)Realistic rendering” or “Predictive rendering”
    - Must understand human perception
  - That convey specific information
    - “Visualization” or “non-photorealistic rendering (NPR)”
- Applications
  - Industrial design
  - Movies and games
  - Architecture and 3D geospatial data
  - Cultural heritage
- Holy Grail: “Digital Reality”
  - Provide simulated reality that feels “real” – for humans & machines
  - All optical (acoustic, haptic, …) features one would perceive in reality
  - Truly convincing real-time simulated reality (aka “Holo-Deck”)
  - Models allows computers (AI) to understand the world around us

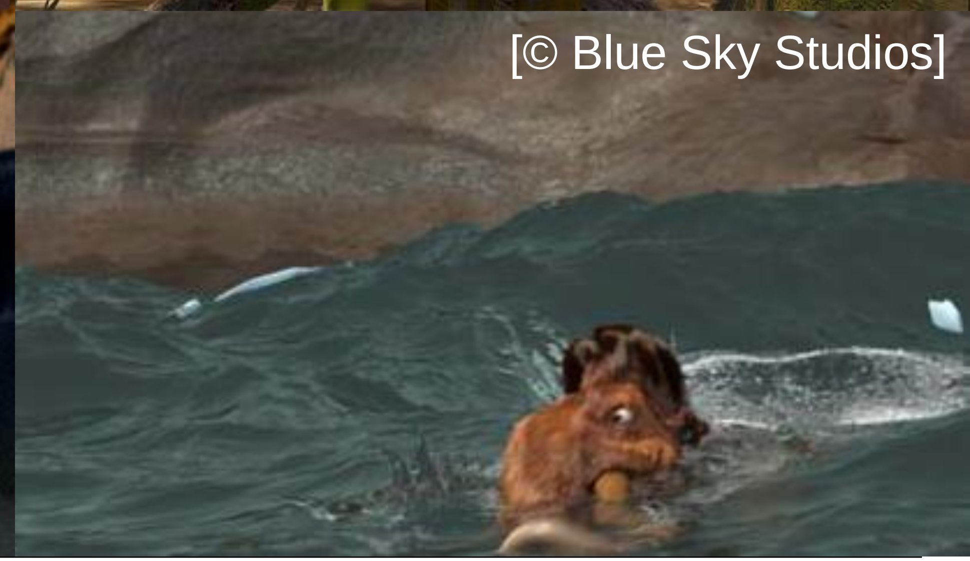
Applications

- Entertainment Industry: Special effects for motion pictures

Applications

- Entertainment Industry: Animated films

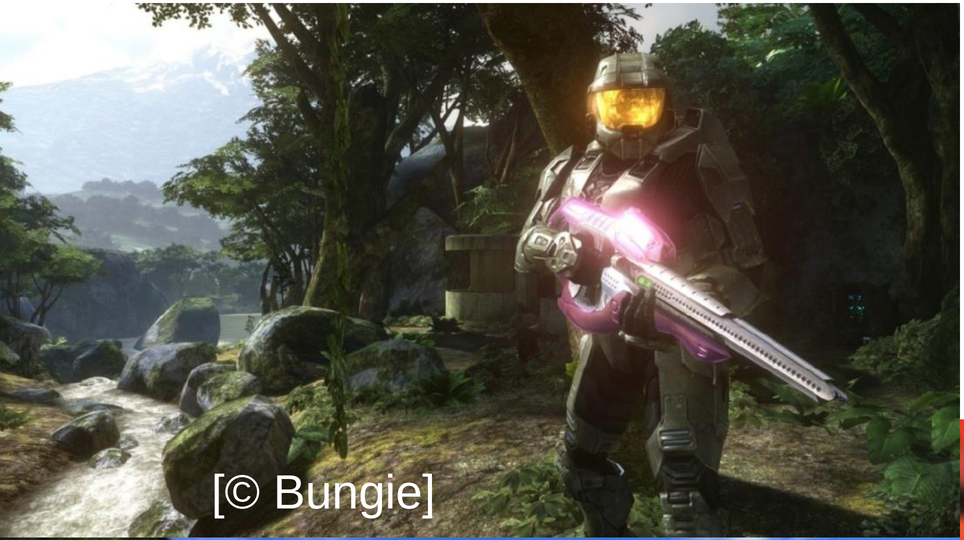




Applications

- Entertainment Industry: Video games


[© Valve]


[© Bungie]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Applications

- Simulation & Augmented Reality

[© NASA]

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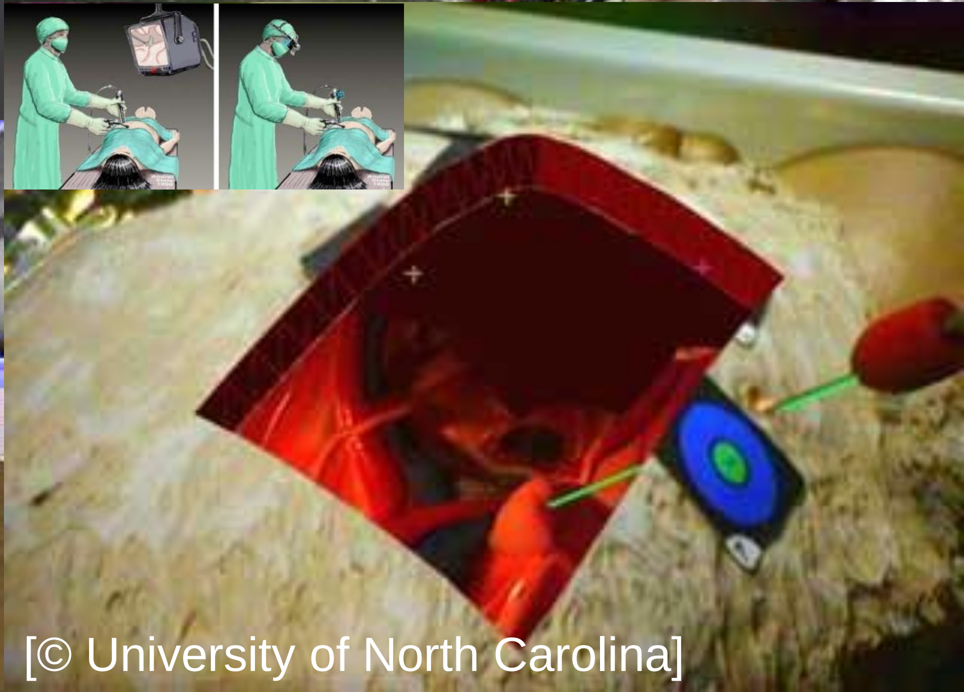

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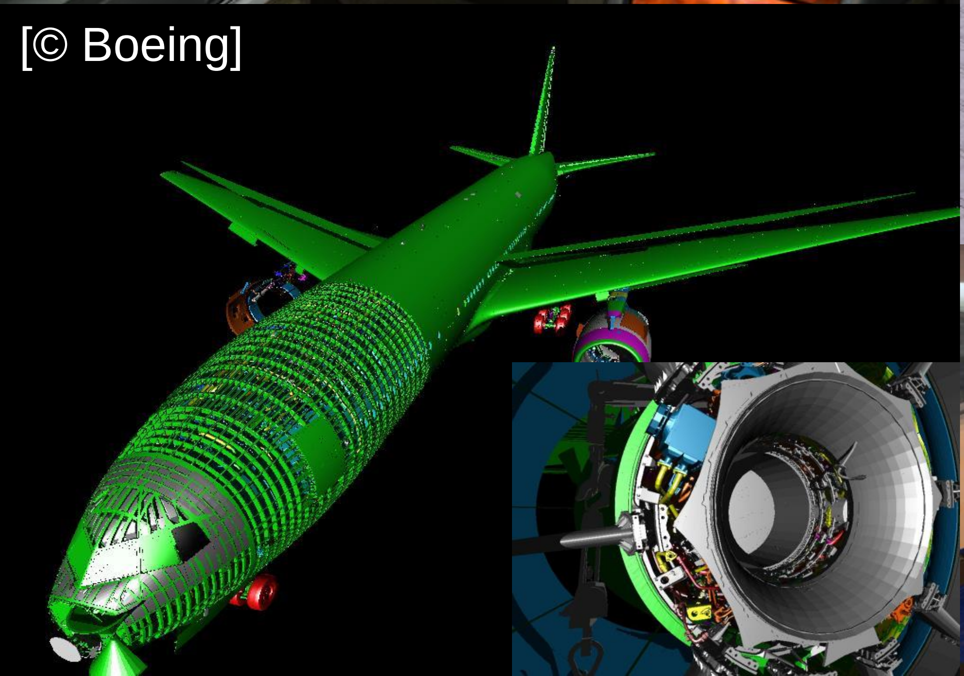
Applications

- Industrial Design & Engineering: Automotive / Aerospatial

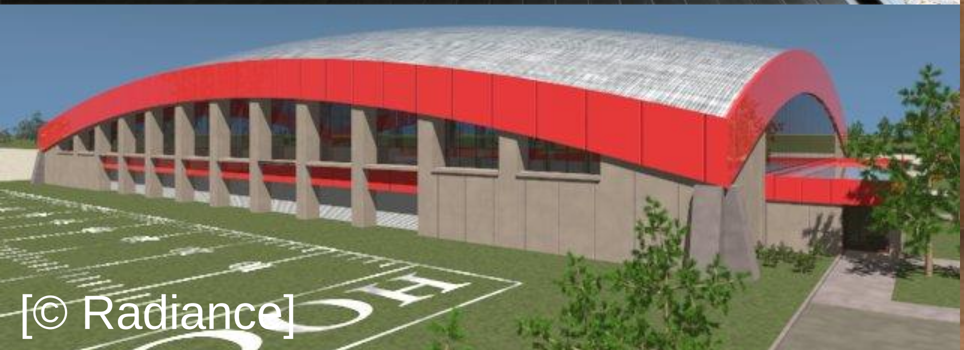


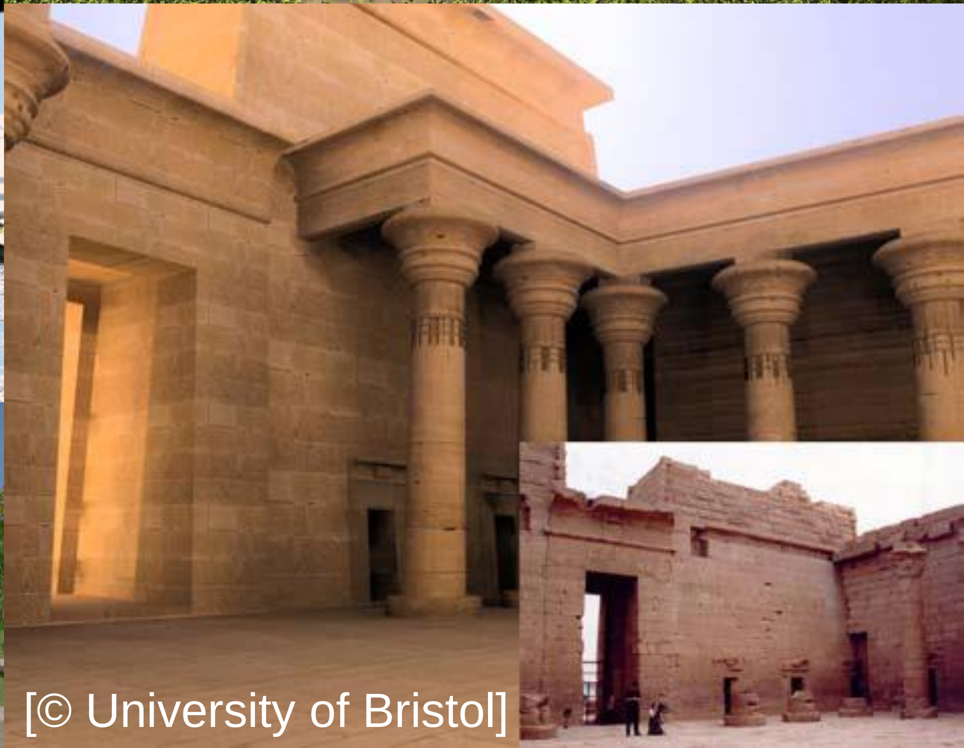
Applications

- Architectural / Interior Design
- Landscape / Urban Planning
- Archeological Reconstruction


[© Saarland University]


[© PBRT]


[© Radiance]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Syllabus

- Rendering Equation
- Finite Elements/Radiosity
- Perception, HDR Imaging, Tone Mapping
- Perception-based Rendering & Display Limitations
- Probability Theory & Monte-Carlo (MC) Integration
- BRDF & Path Tracing
- Density Estimation, Photon Mapping, Merge with MC
- Spatio-Temporal Sampling, Temporal Filtering
- Sampling & Reconstruction
- BiDir Tracing & MCMC
- Volume Techniques
- Interactive GI & HW-Support for Rendering and Lighting

Research From Saarbrücken

- Some examples

Reflection & Refraction

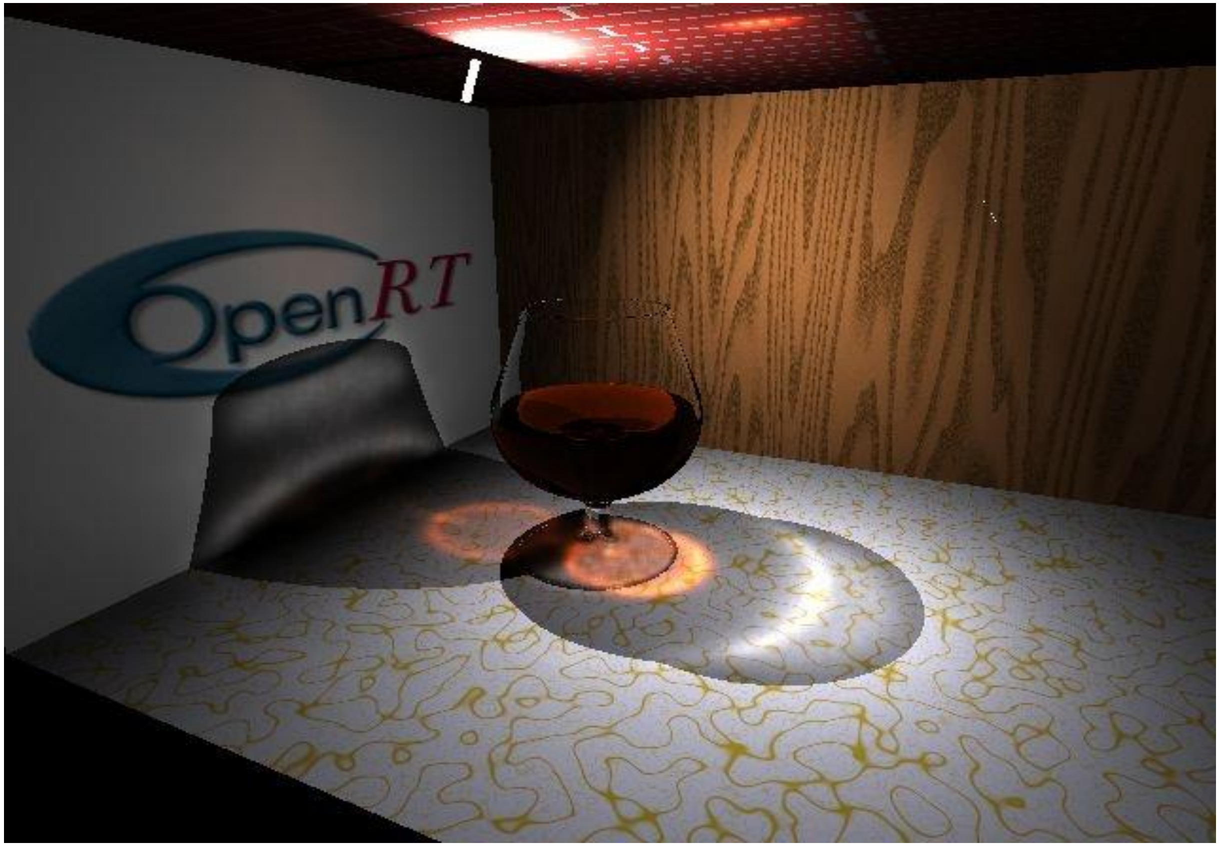
- Visualization of a car headlight
  - It reflects and refracts light almost entirely from the environment. Up to 50 rays per path are needed to render this image faithfully (800k triangles).

Instant Global Illumination

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

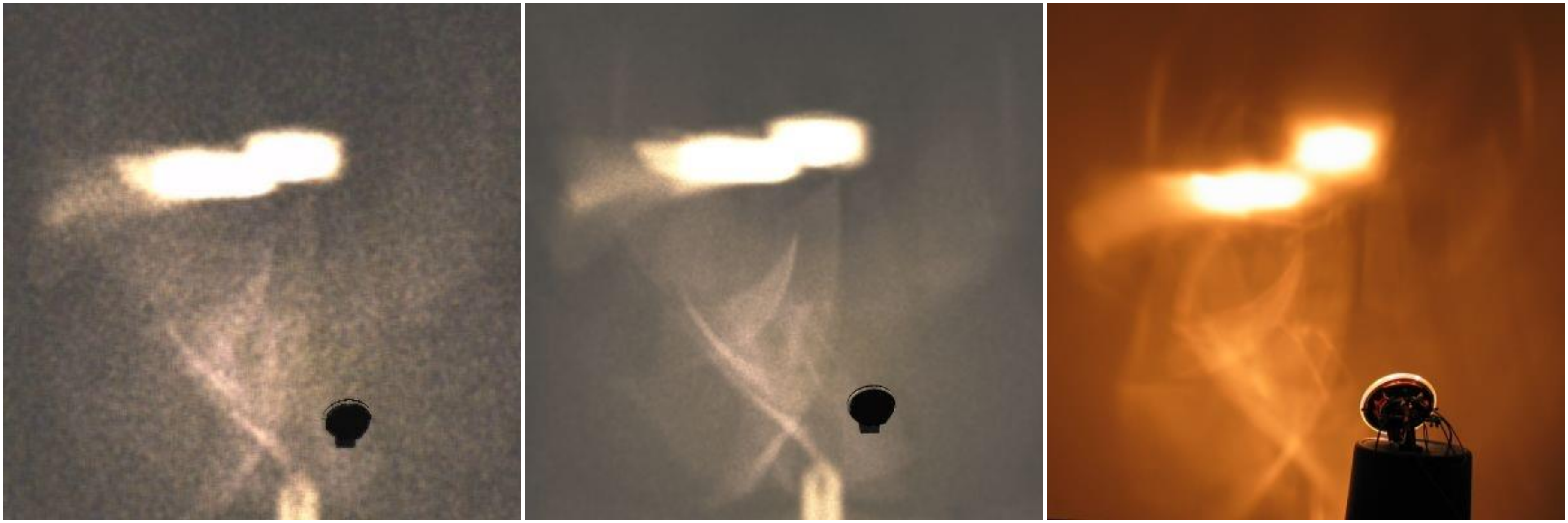
Real-Time Photon Mapping

- 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).



Advanced Materials

- Application to a real car using spline surfaces, realistic paint shaders, BTF shaders in the interior, and realistic environment lighting.

Advanced Materials

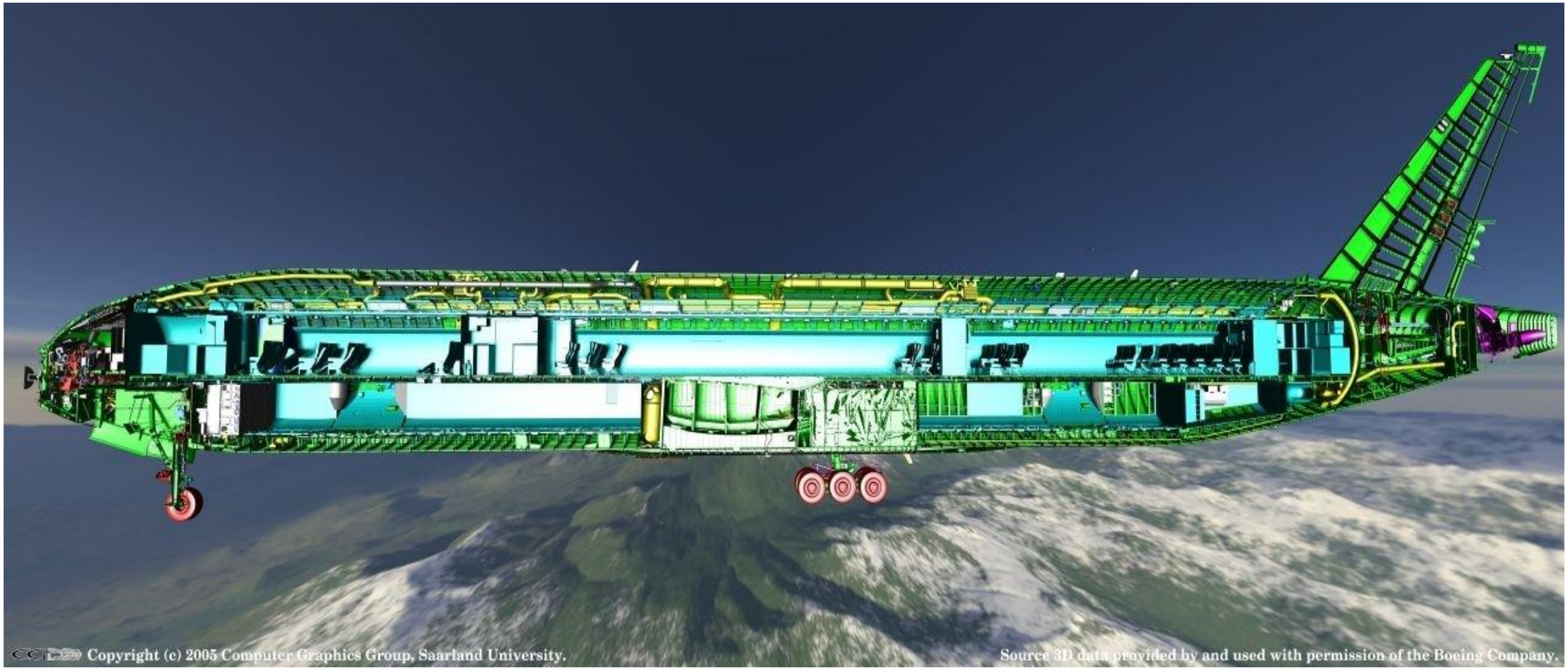
- The use of BTF for realistic materials with optical effects on the meso-scale (e.g. shadows in bumps and creases).

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 (300x300m^2) 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)

Volume Rendering

- Global illumination of iso-surfaces.

Multiple Iso-Surfaces

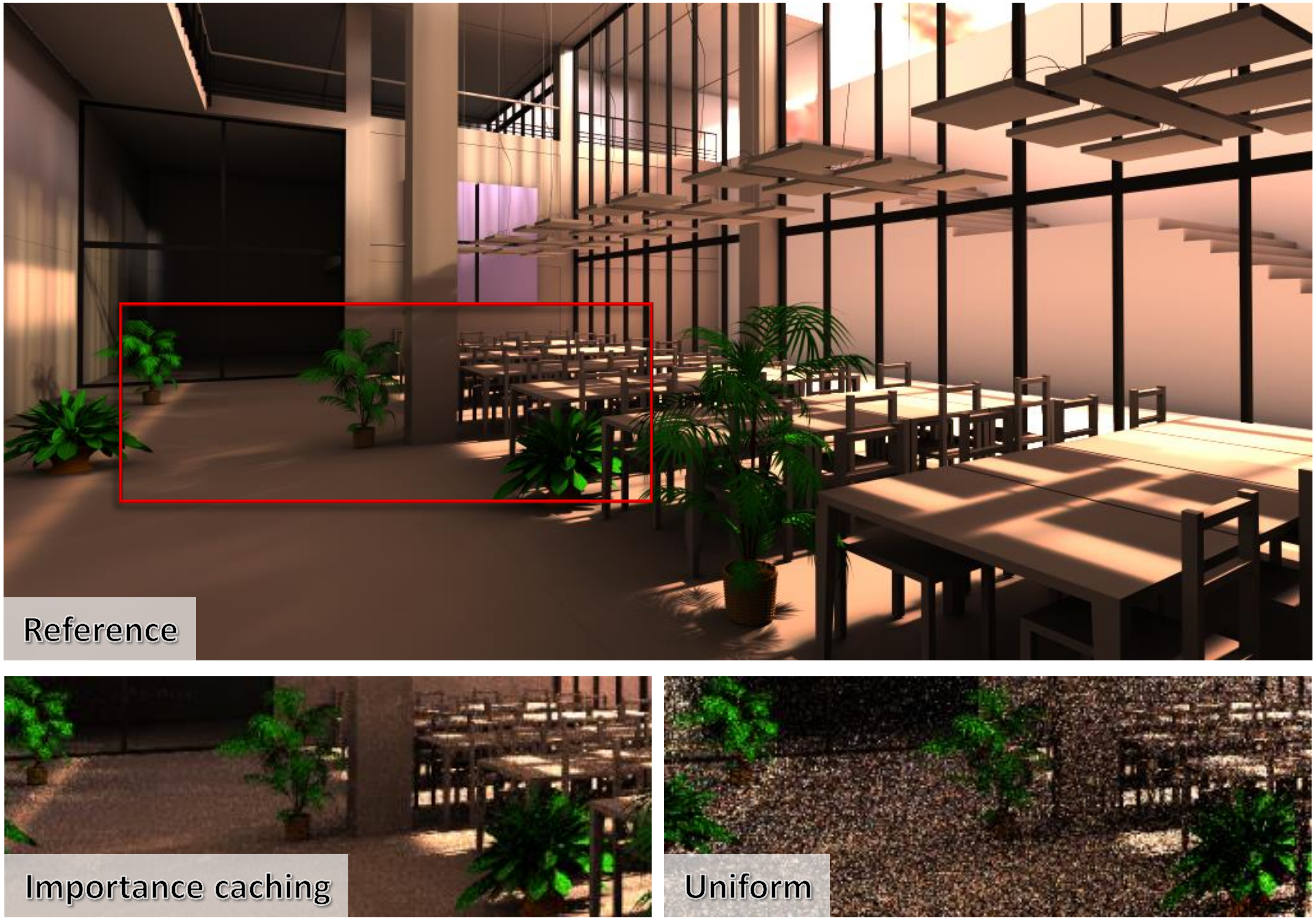
- Ray tracing allows easy integration of multiple modalities into a single rendering framework.

High-Performance Simulation

- Advanced rendering techniques in games

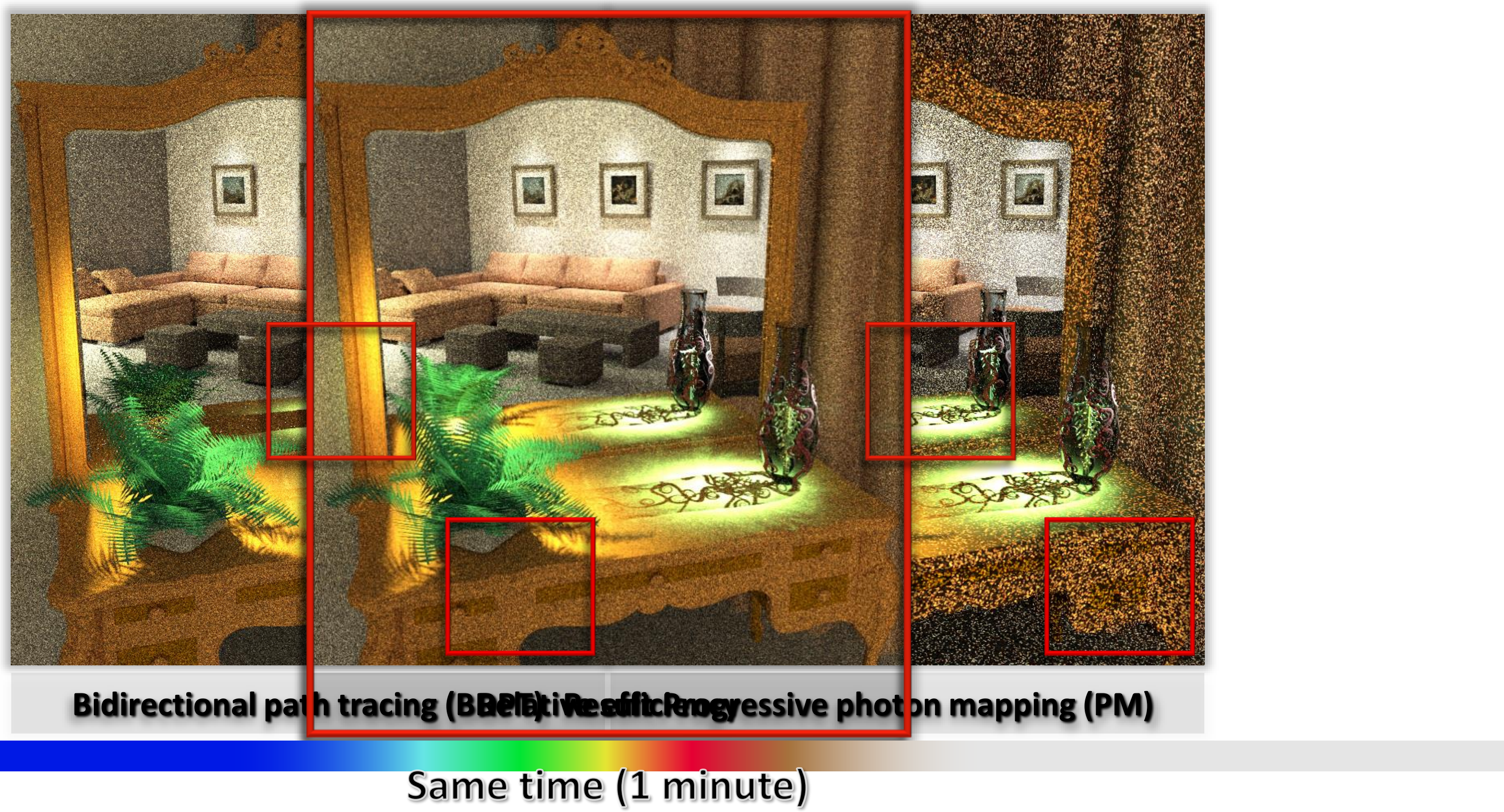
Importance Caching

- Reuse samples based on probability [Eurographics 2012]

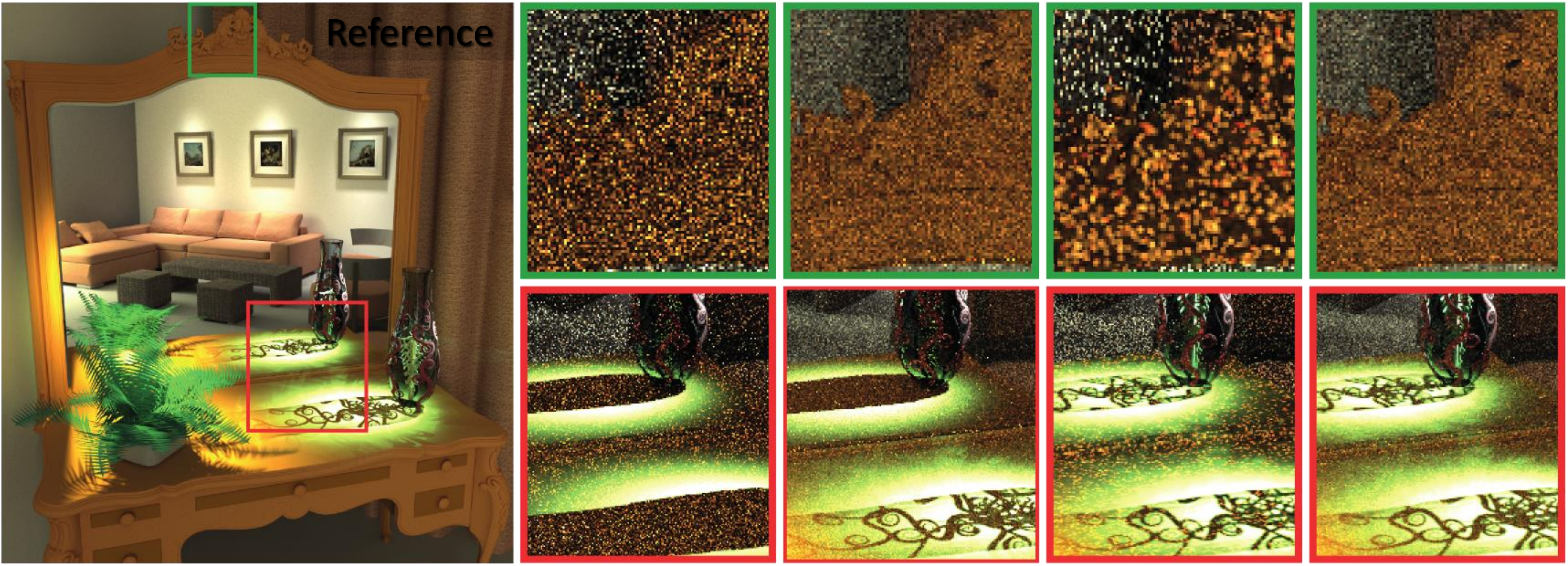


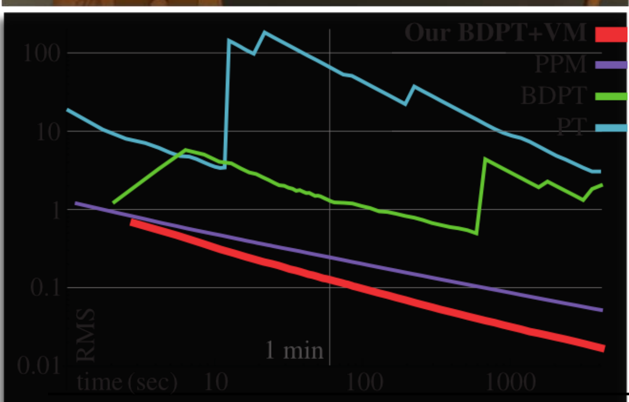
Monte-Carlo vs Density Estimation

- Vertex Connection and Merging [SiggraphAsia 2012]



Order of Convergence





PT	BDPT	PPM	BDPT+VM
$O(N^{-0.5})$	$O(N^{-0.5})$	$O(N^{-0.33})$	$O(N^{-0.5})$

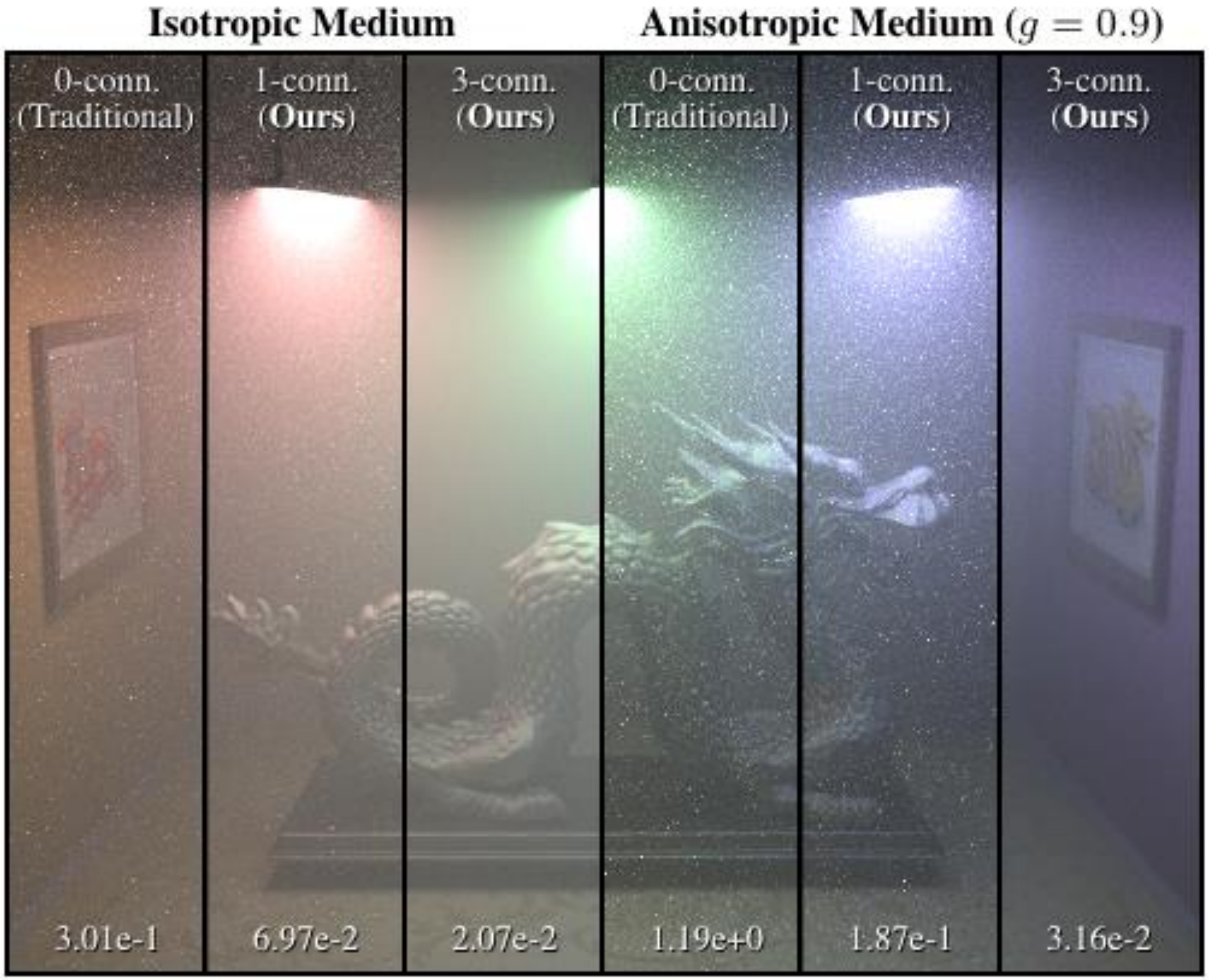
Same time (1 minute)

Monte-Carlo vs Density Estimation

Same time (3 minutes)

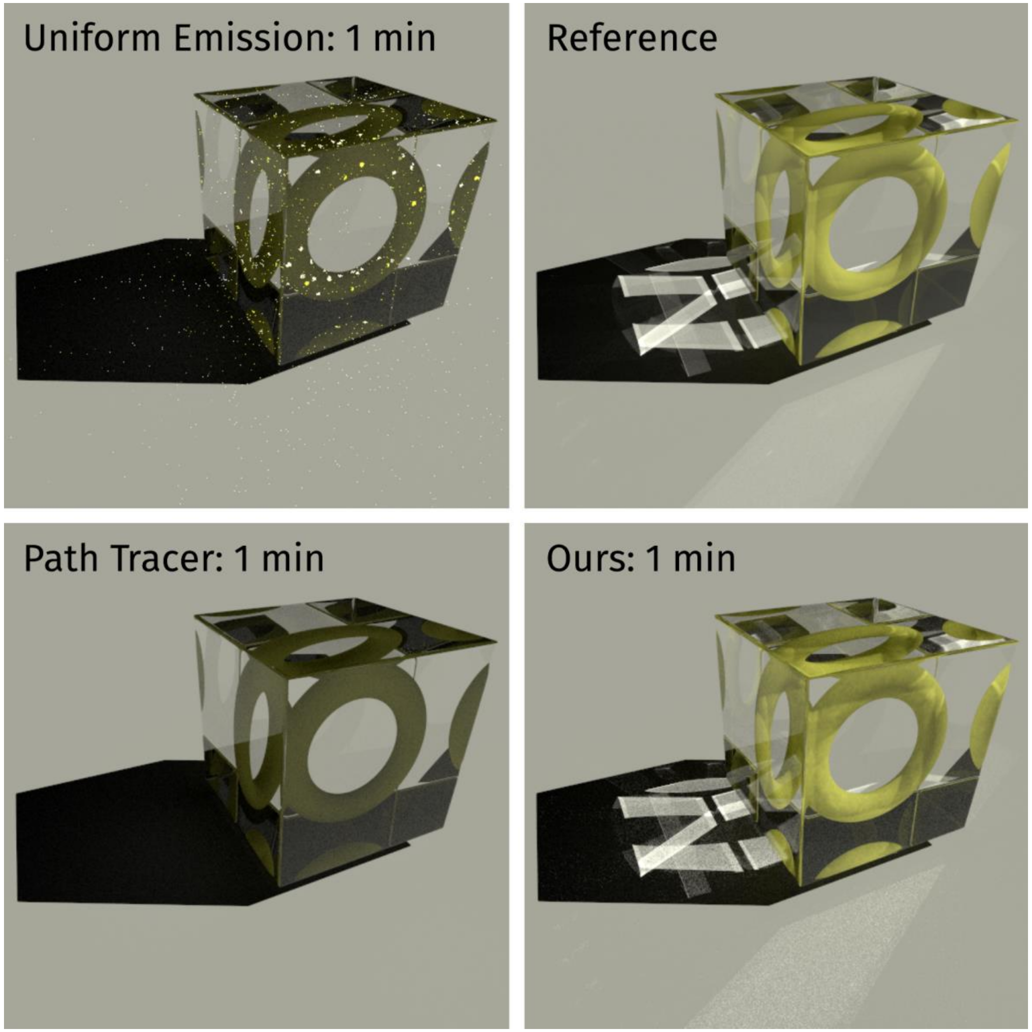
Joint Path Sampling

- Joint sampling of set of next events [SiggraphAsia 2013]



Emission Guiding

- Using Photon Mapping only where it is useful



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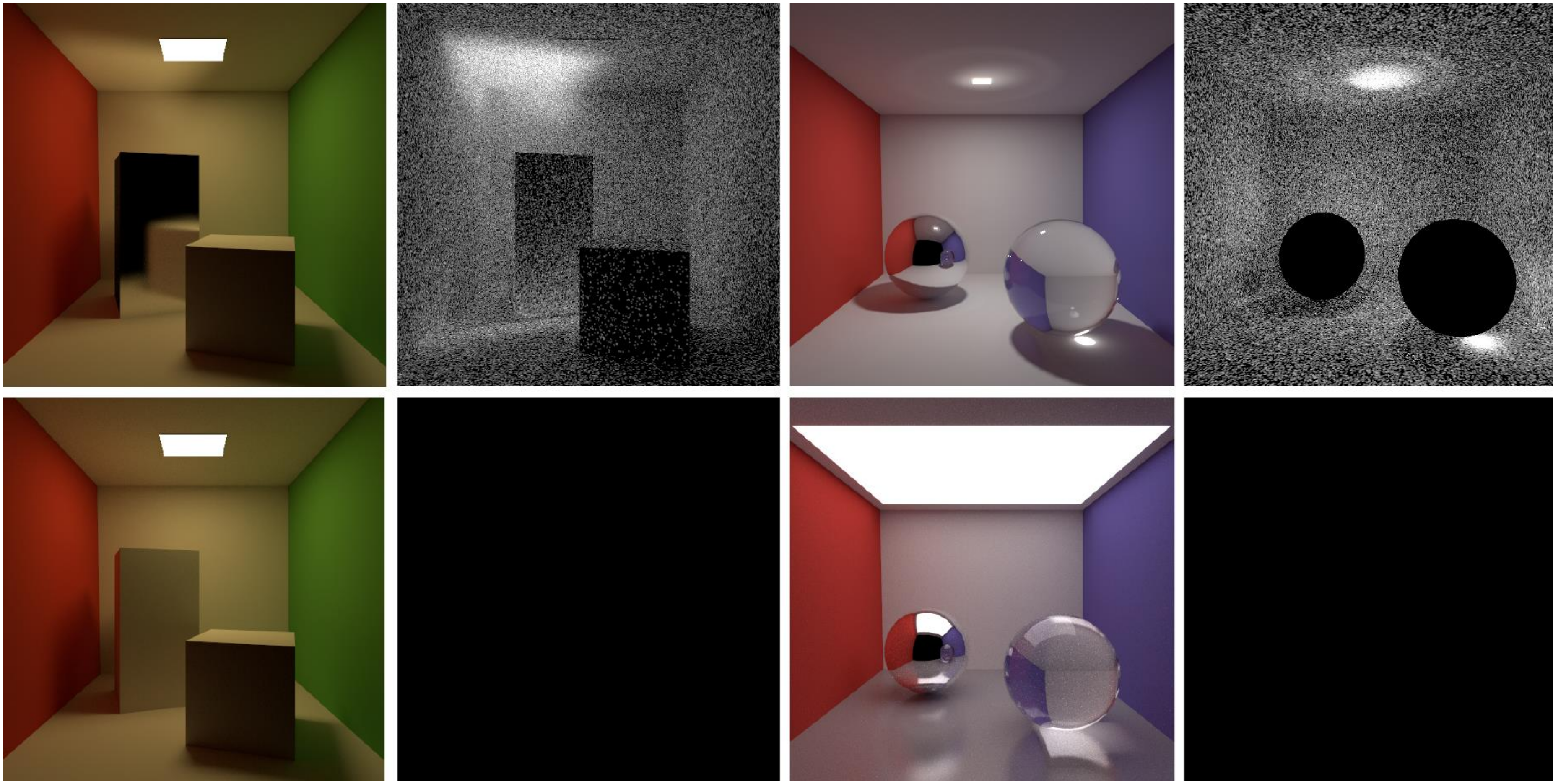
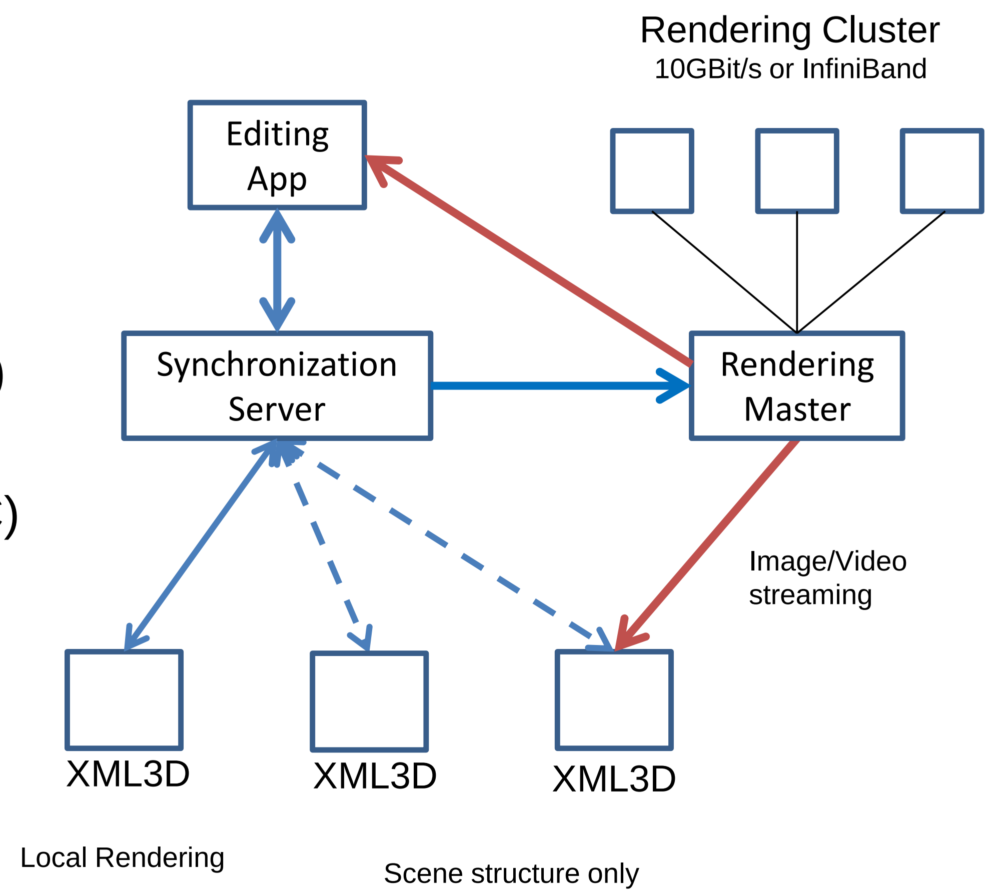


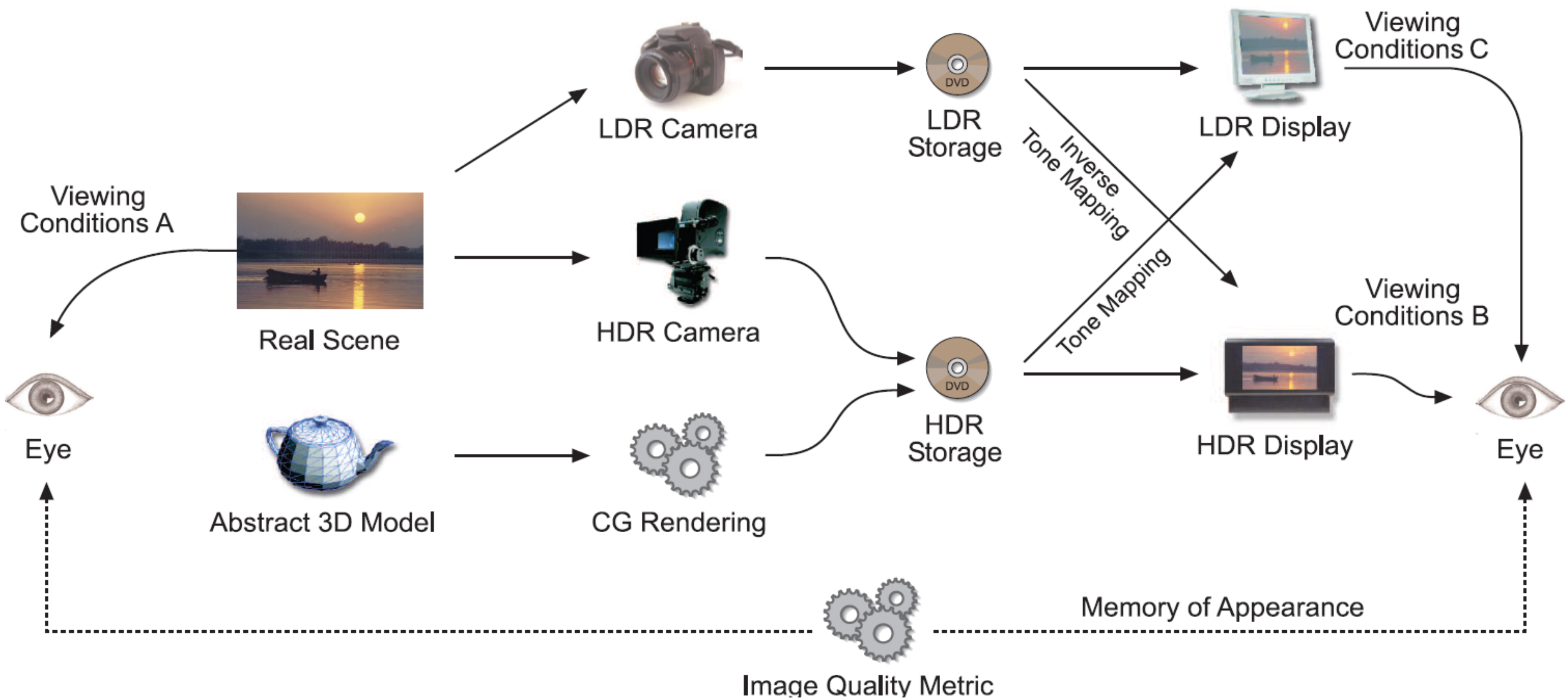
Dreamspace Renderer

Dreamspace Renderer

- Editing App (e.g. Katana)
  - Provides scene data
  - Real-time updates
- Browser with XML3D for visualizing scene
  - XML3D scene (with shade.js)
    - Local rendering (WebGL)
    - Server-based rendering (MC)
  - Enables real-time interaction
- Synchronization Server
  - Synchronizes all changes
- Rendering Master
  - Manages rendering on cluster
  - Streams results as real-time video

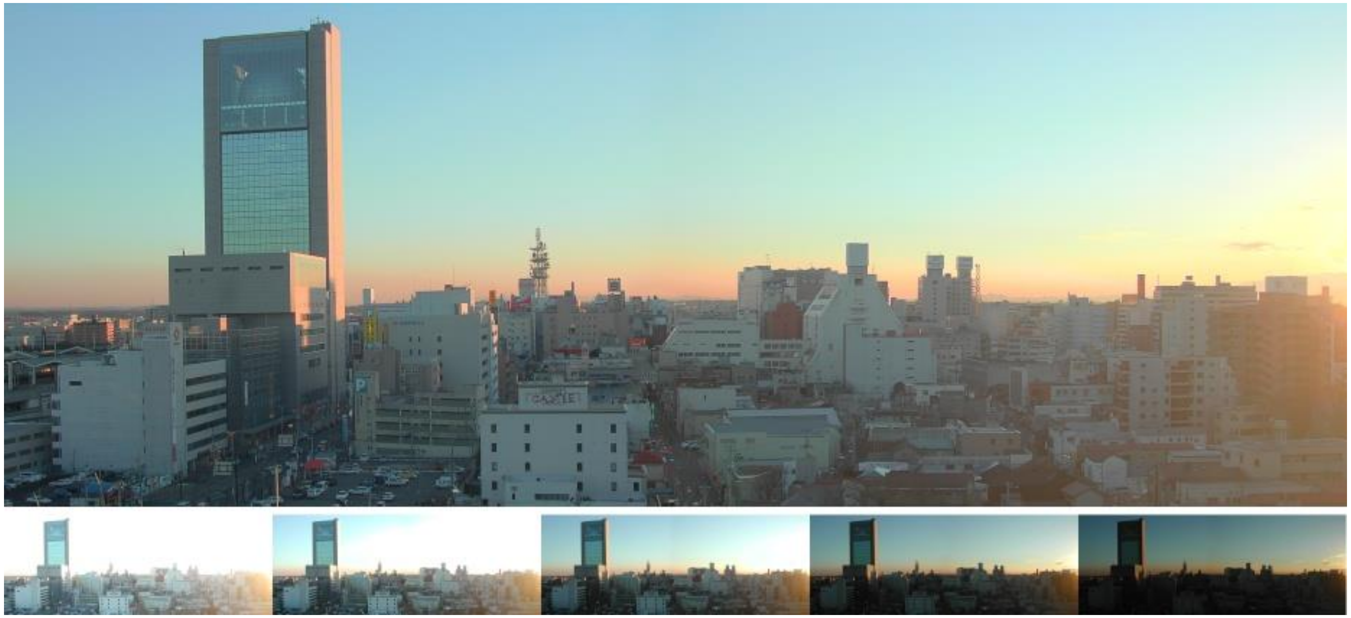


HDR Imaging Pipeline



HDR Photography Radiance Map

- Dynamic range: 394,609:1
- High Dynamic Range image built from 3 stitched photographs taken at 5 different exposures, tone-mapped with adaptive log mapping (Drago et al., EG ’03).



Real-Time HDR Playback

- With Perceptual Effects
  - http://www.mpi-inf.mpg.de/resources/hdr/peffects

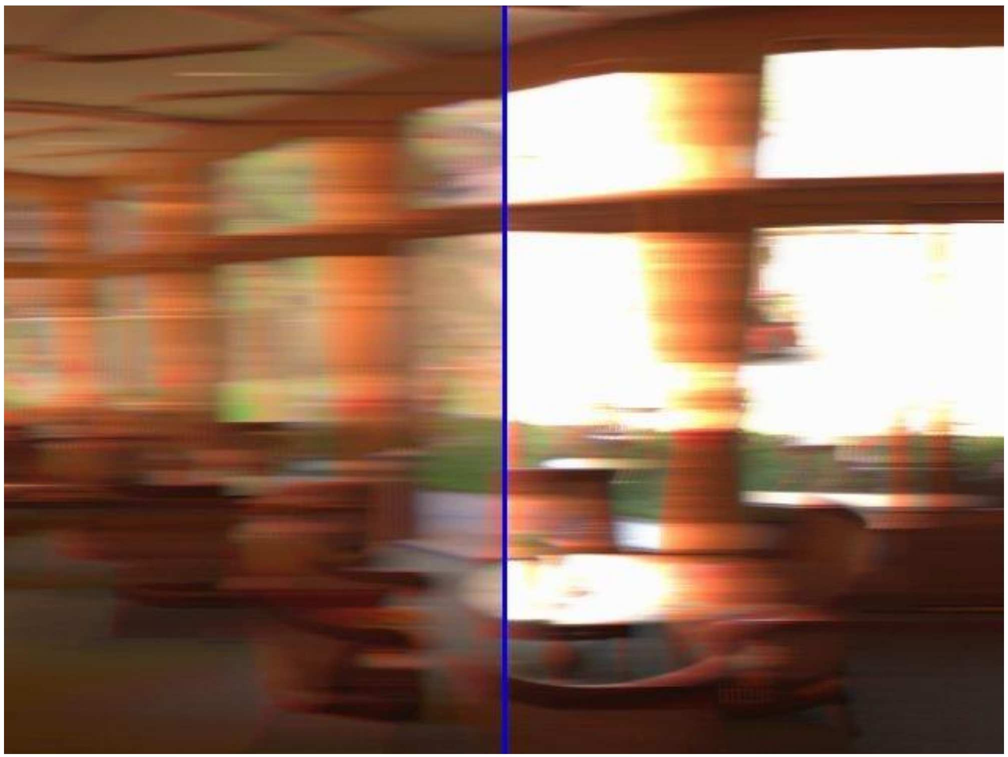
Temporal Luminance Adaptation

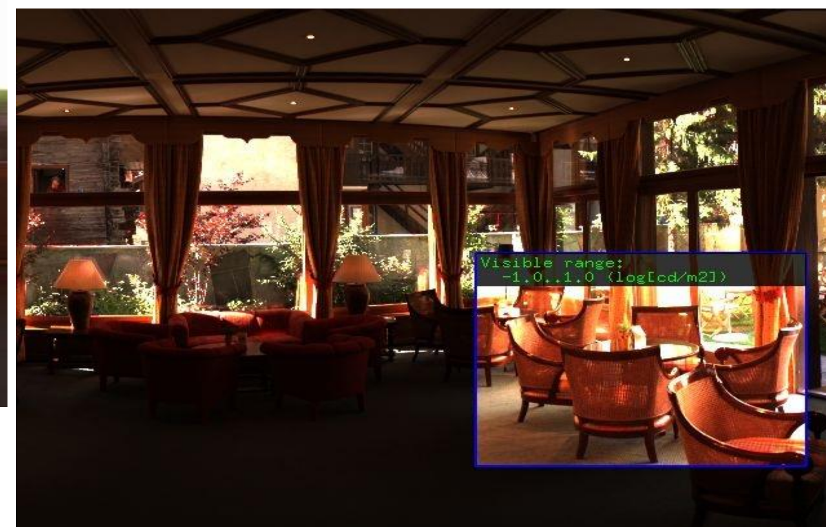
Light adaptation

Tunnel entrance: dark adaptation

Motion Blur

LDR HDR





Tone Mapping in Contrast Domain

Input Image

Luminance to Contrast

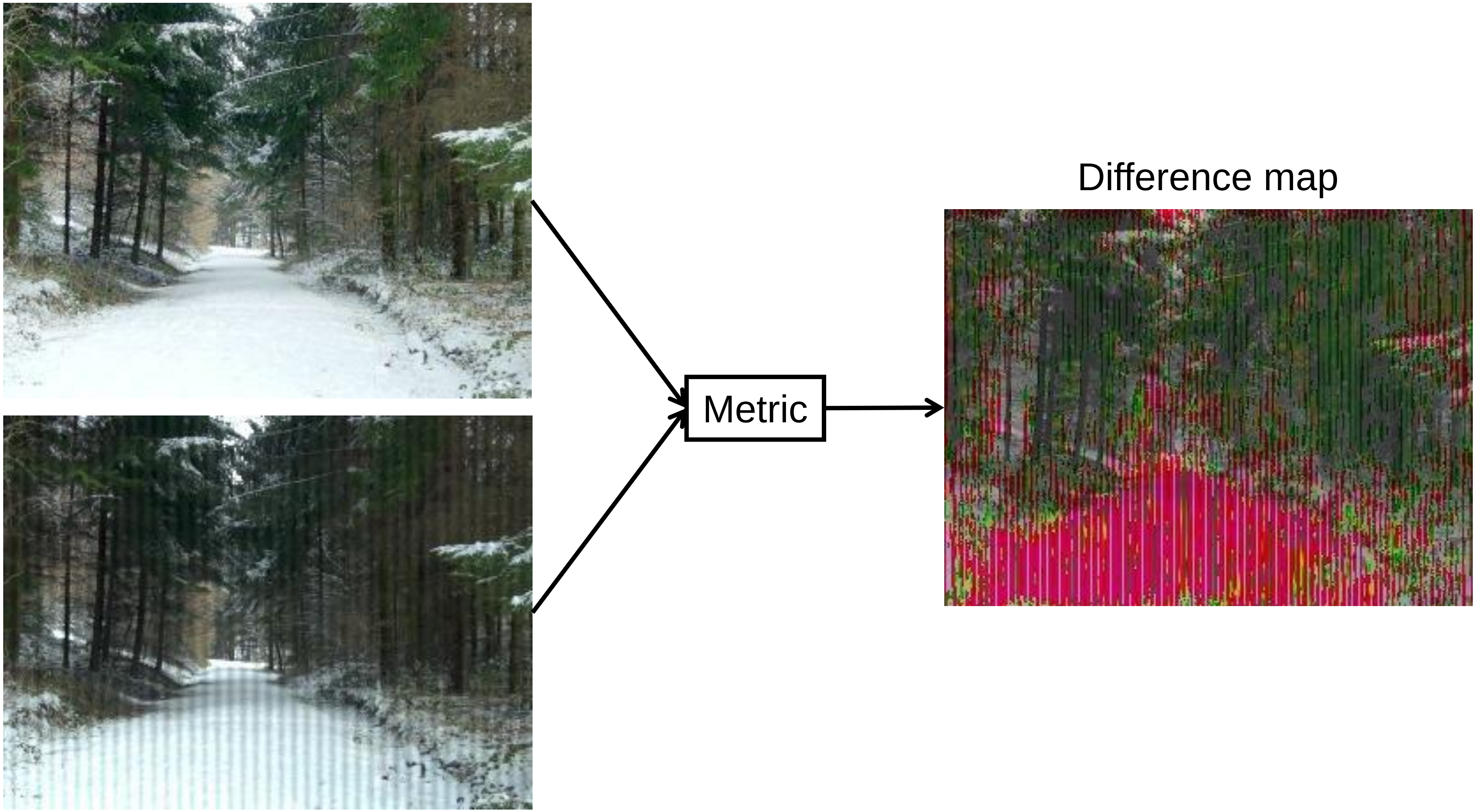
Tone Mapping

Contrast to Luminance

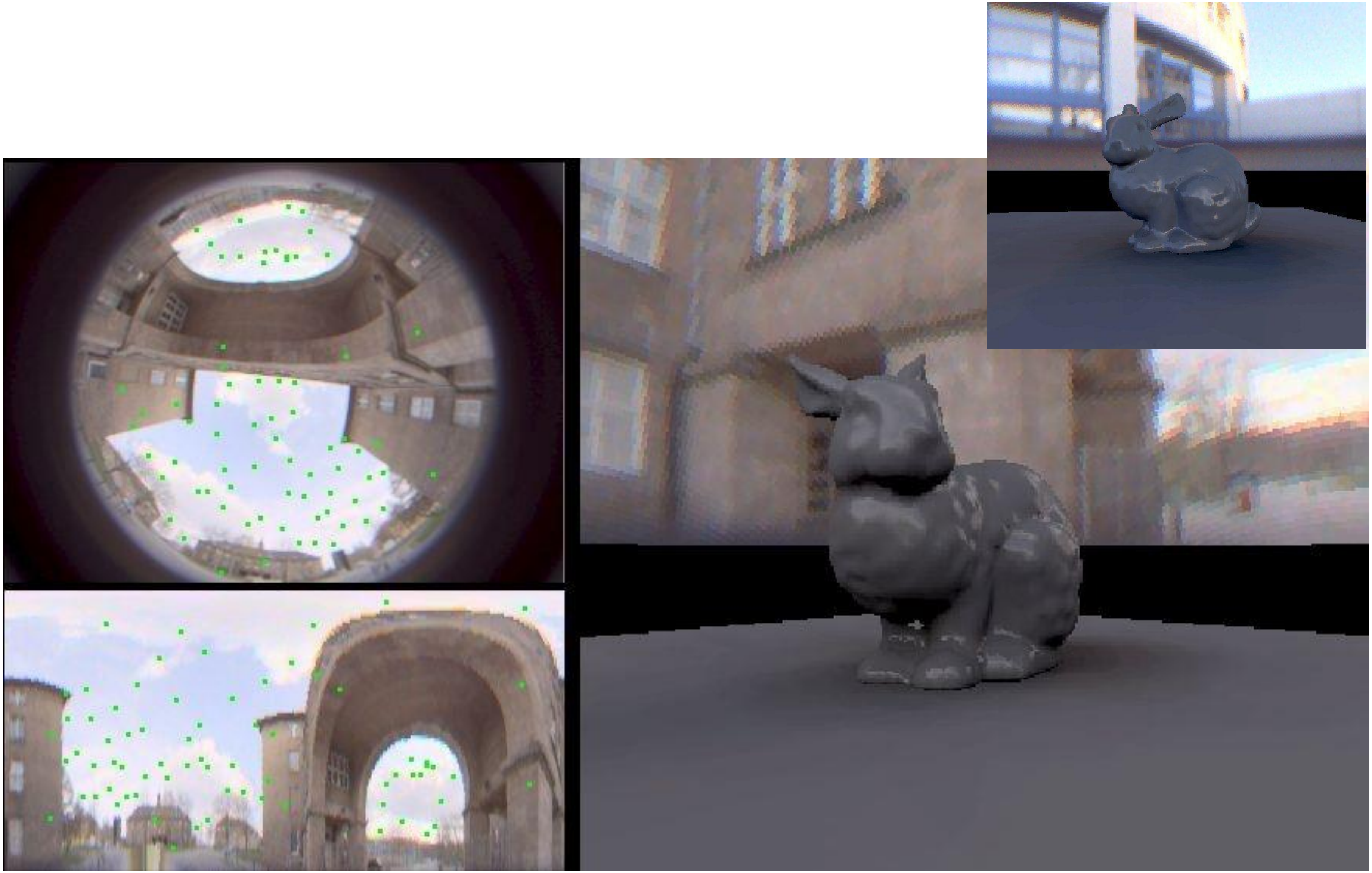
Output Image

HDR Visible Difference Predictor

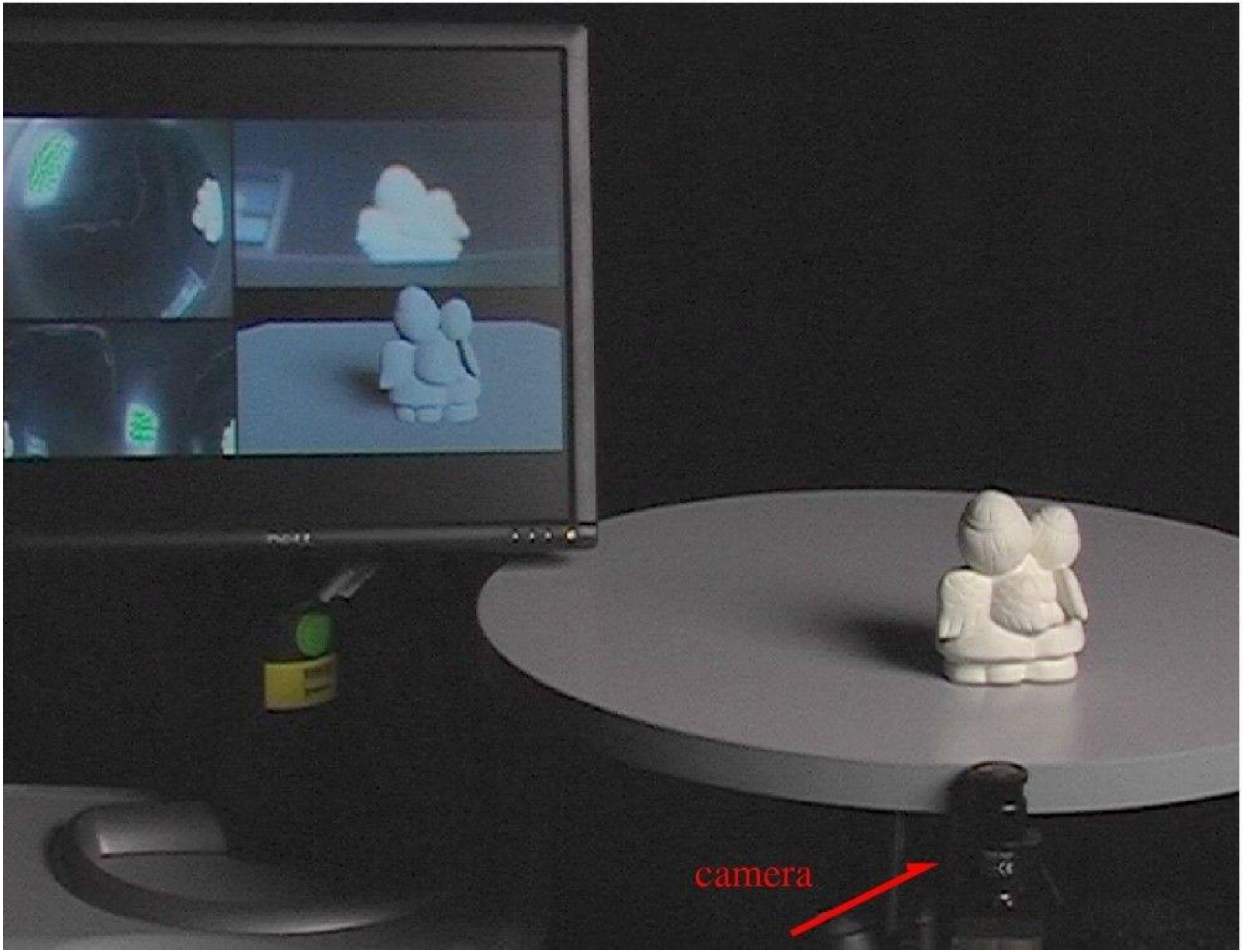
- http://www.mpi-inf.mpg.de/resources/hdr/vdp



Environment Map Sampling

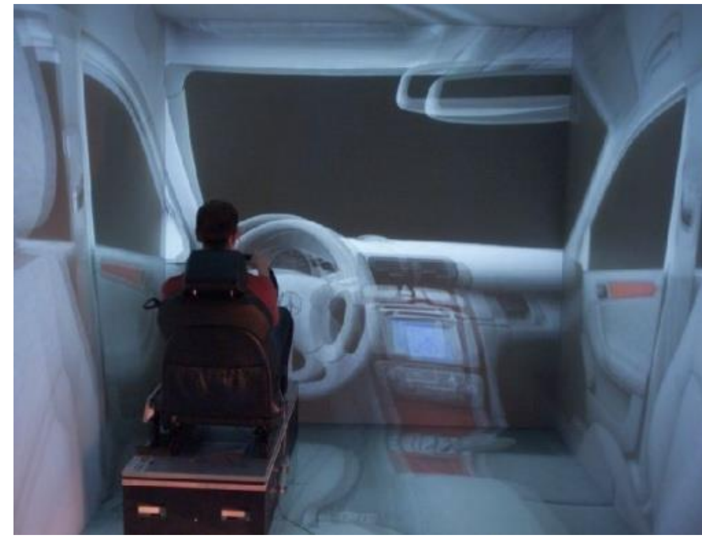


Mixed Reality Applications



PRT Rendering

- Precomputed Radiance Transfer



Modern Displays

Bigger & brighter

More resolution

Higher refresh rates

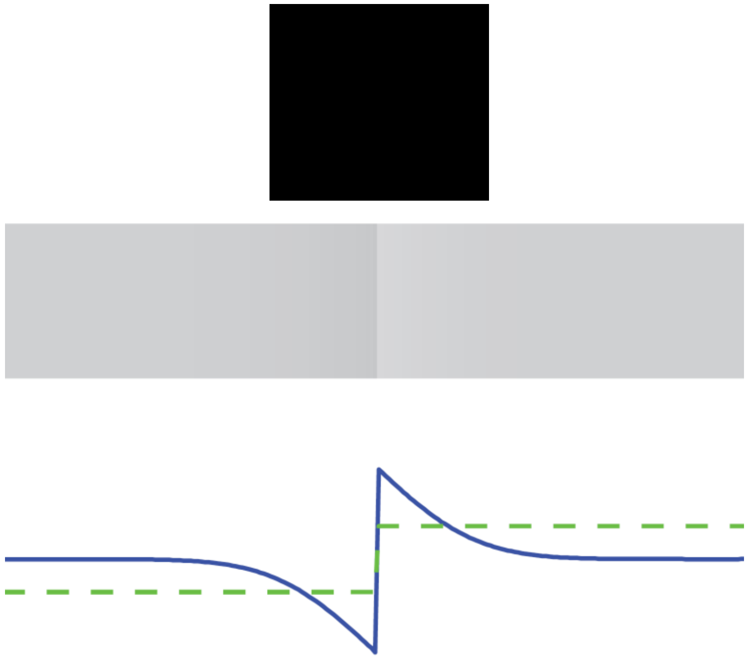
3D

Display Qualities and Human Perception

- Capabilities of displays are limited:
  - Contrast
  - Brightness
  - Temporal resolution
  - Spatial resolution
  - Depth range in stereo 3D

- Idea: take advantage of the visual system properties

Cornsweet Illusion



Unsharp Masking, Countershading and Haloes: Enhancements or Artifacts?

- Same countershading operation is perceived differently, depending on parameter choice
- Some parameters increase sharpness or contrast
- But other choices can introduce haloes

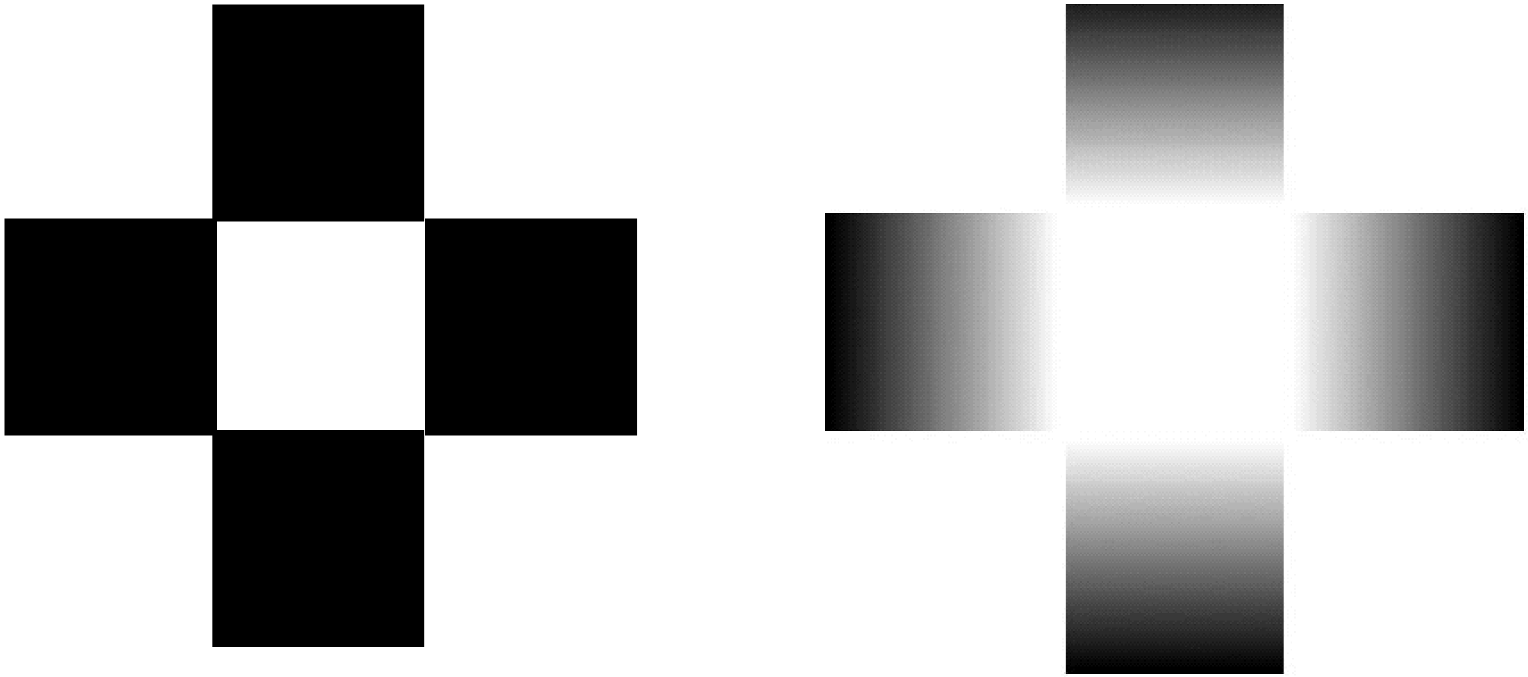
University of British Columbia
Bangor University

Sharpeness

Contrast

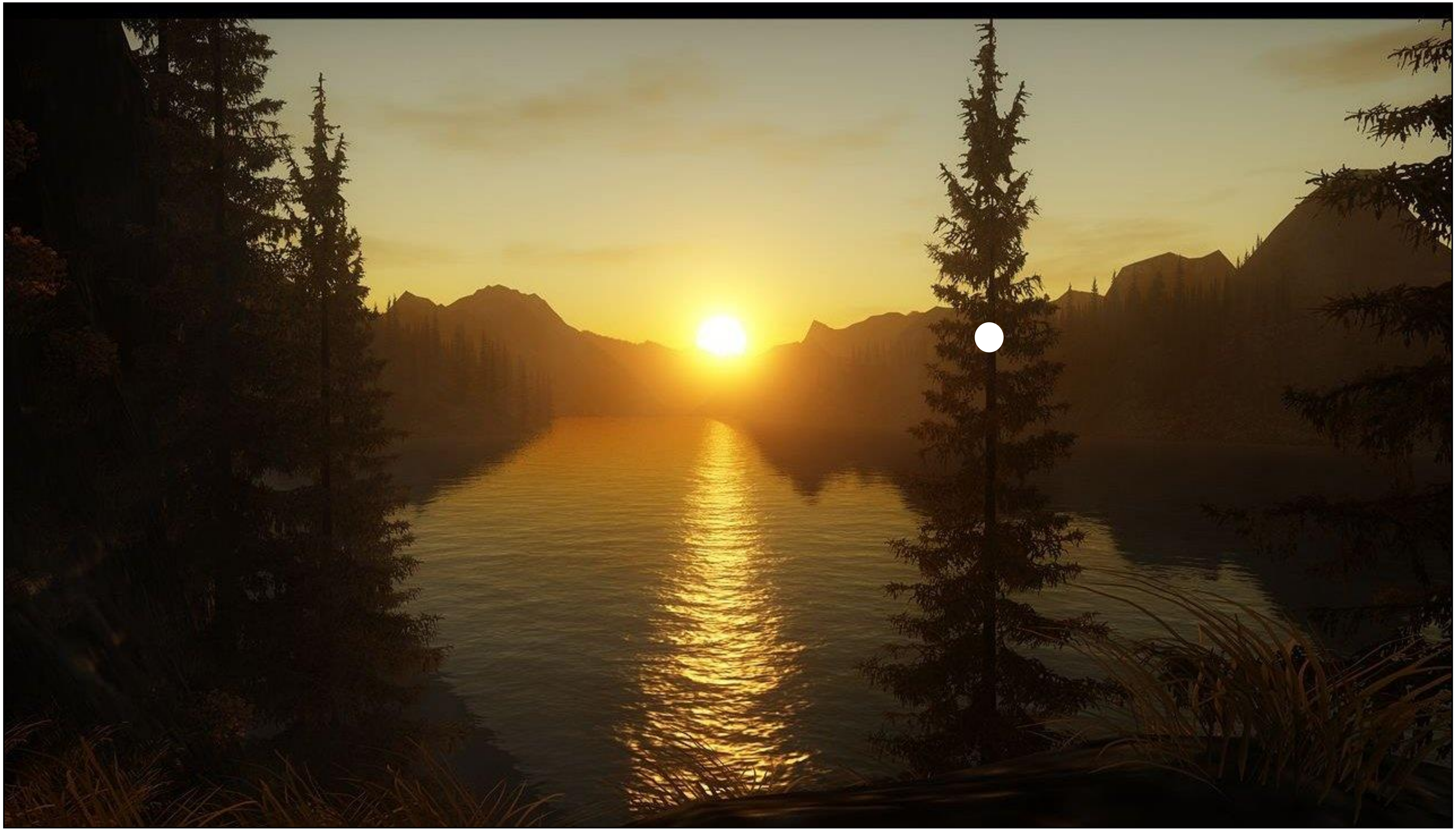
Haloes

Glowing Effect



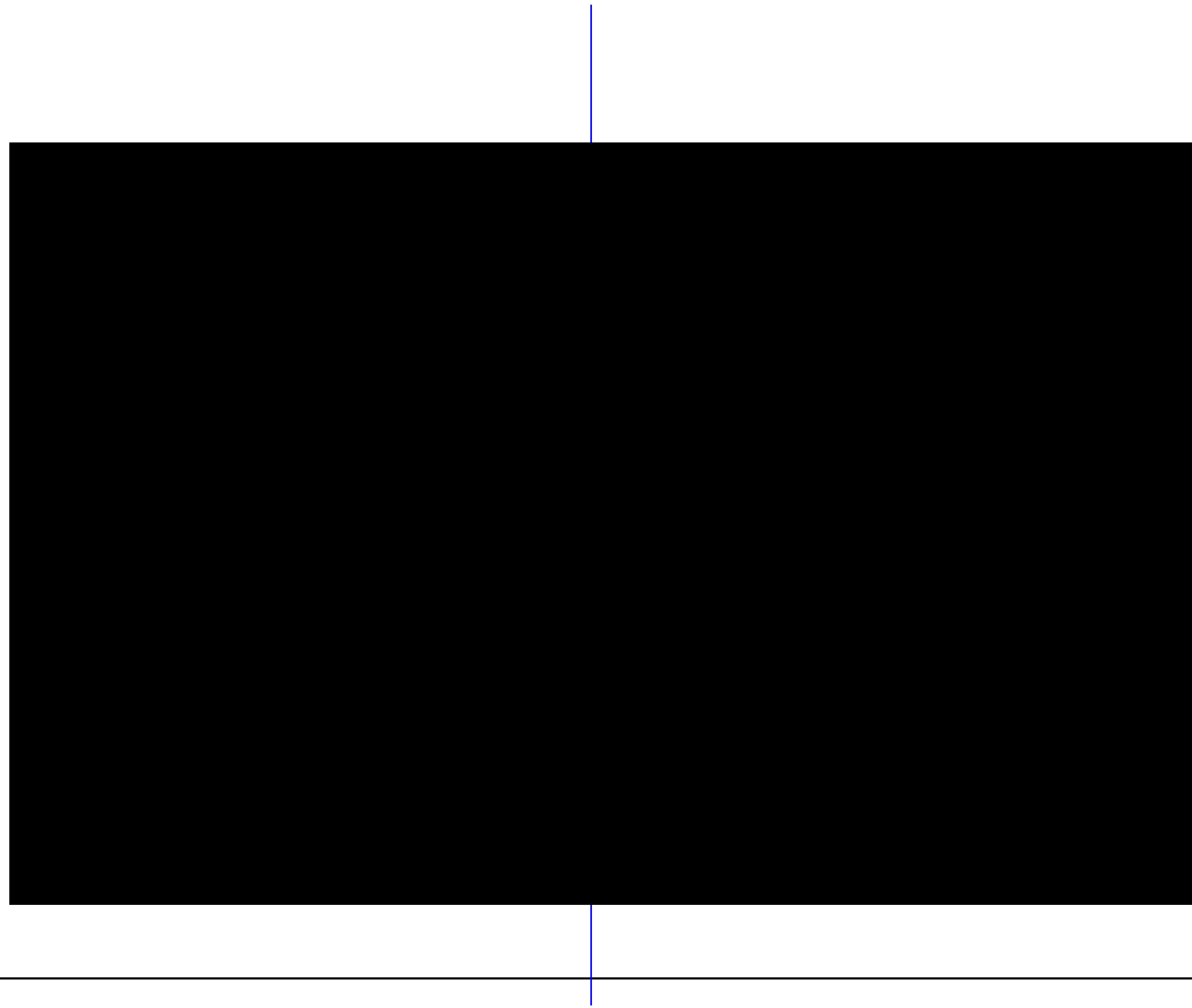
[Zavagno and Caputo 2001]

Glare Illusion



“Alan Wake” © Remedy Entertainment

Hold-type Blur Demo: Eye Tracking Importance



Ultimate Goal

- Reality check
  - Can we render real-time video of such scenes ?