Realistic Image Synthesis

Philipp Slusallek
Karol Myszkowski
Gurprit Singh

Personnel

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

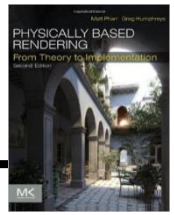
Administrative Information

- 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
  - Tuesday 8-10 & Friday, 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

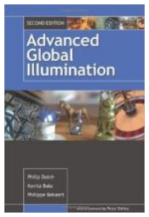
Grading

- 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%

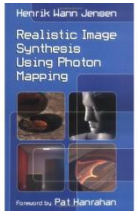
Textbooks



- Pharr & Humphreys, **Physically-Based Rendering: From Theory to Implementation**, Morgan Kaufmann, 3nd Edition (Dec 2016)



- Dutre, Bekaert, Bala, **Advanced Global Illumination**, A.K. Peters, 2006, 2nd Edition.

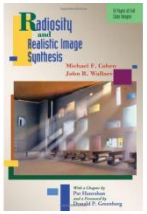


- Jensen, **Realistic Image Synthesis Using Photon Mapping**, A.K. Peters, 2005, 2nd Edition.
- Shirley & Morley, **Realistic Ray Tracing**, A.K. Peters, 2003, 2nd Ed.

- 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

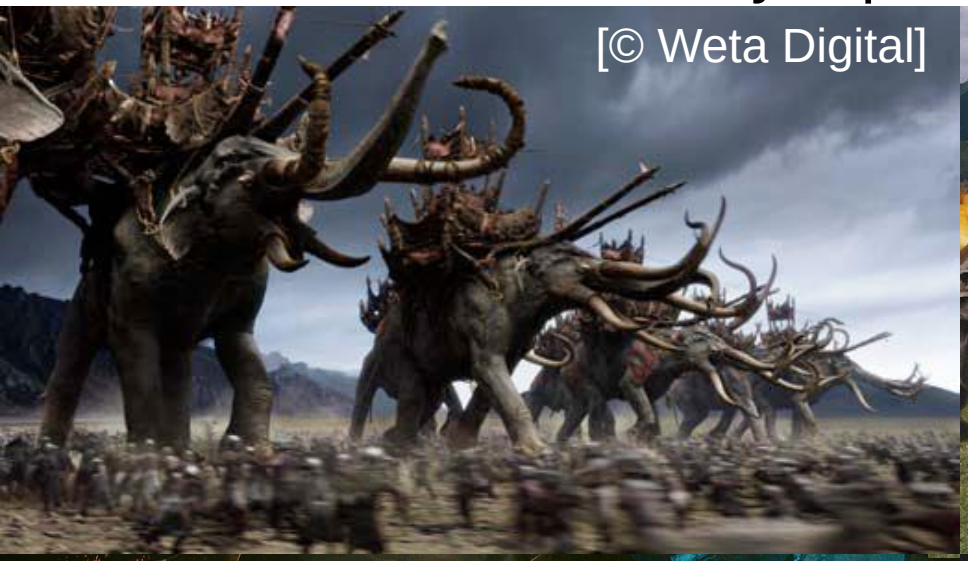
- *Shape* (Geometry)
  - Objects in our scene: surfaces, volumes, points, ...
- *Material* of surfaces & volumes
  - Places of interaction of light with matter
    - Reflection, refraction, scattering, absorption, ...
  - Applied to shapes (“shaders”)
- *Light sources*
  - Sources of light
    - Position, 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)

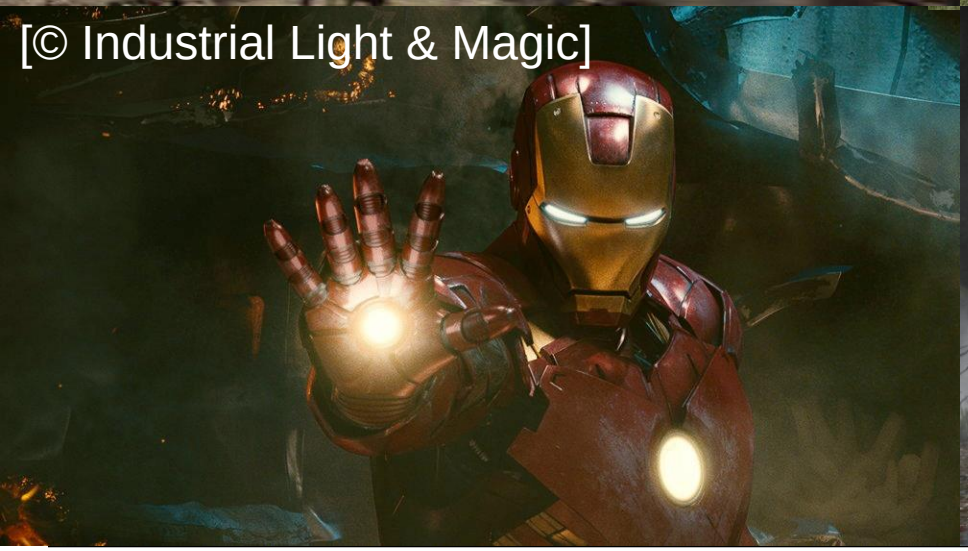
Motivation

- 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 allow computers (AI) to understand the world around us

Applications

- Entertainment Industry: Special effects for motion pictures





Applications

- Entertainment Industry: Special effects for motion pictures

Ready Player One [© Warner Bros. Pictures]

Applications

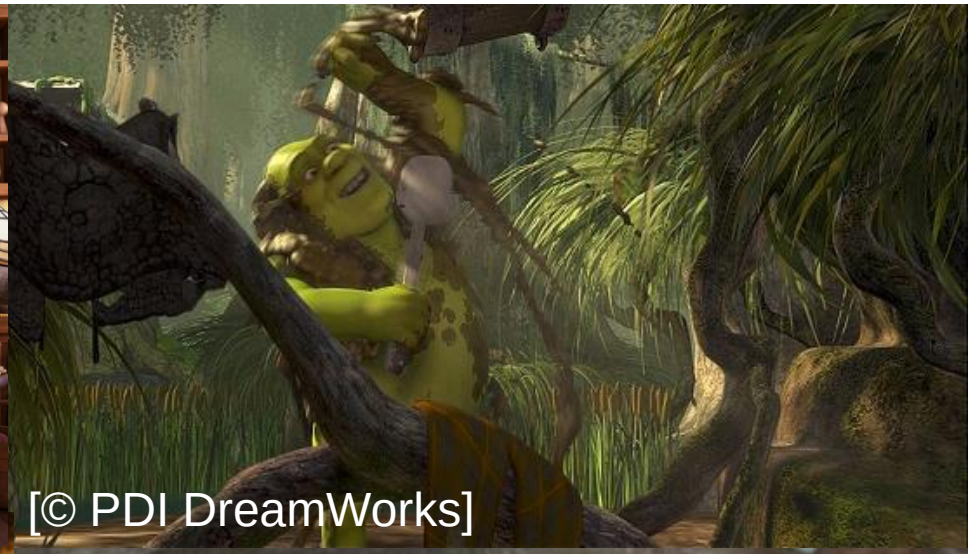
- Entertainment Industry: Special effects for motion pictures

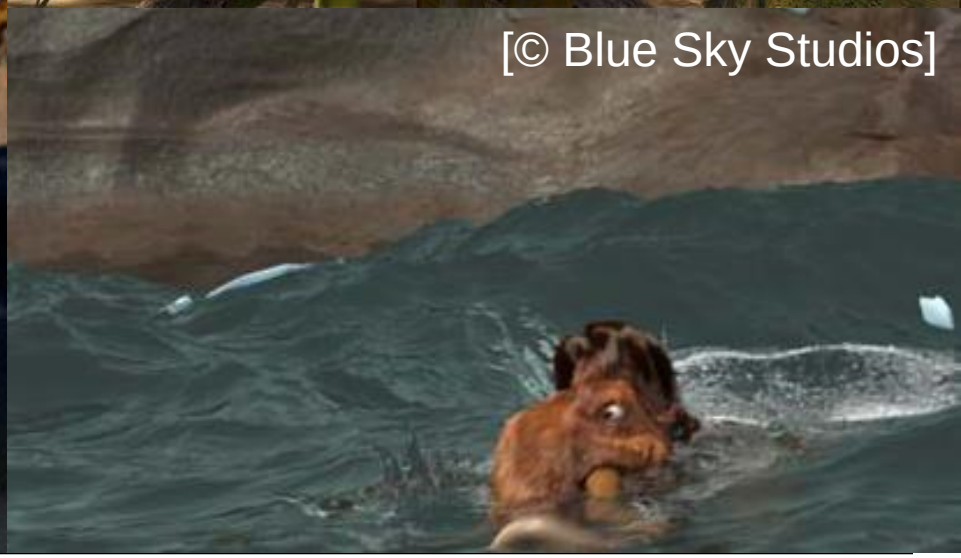
Guardians of the Galaxy 2 [© Marvel Studios]

Avengers: Infinity War [© Marvel Studios]

Applications

- Entertainment Industry: Animated films





Applications

- Entertainment Industry: Animated films

Toy story 4 [© Pixar]

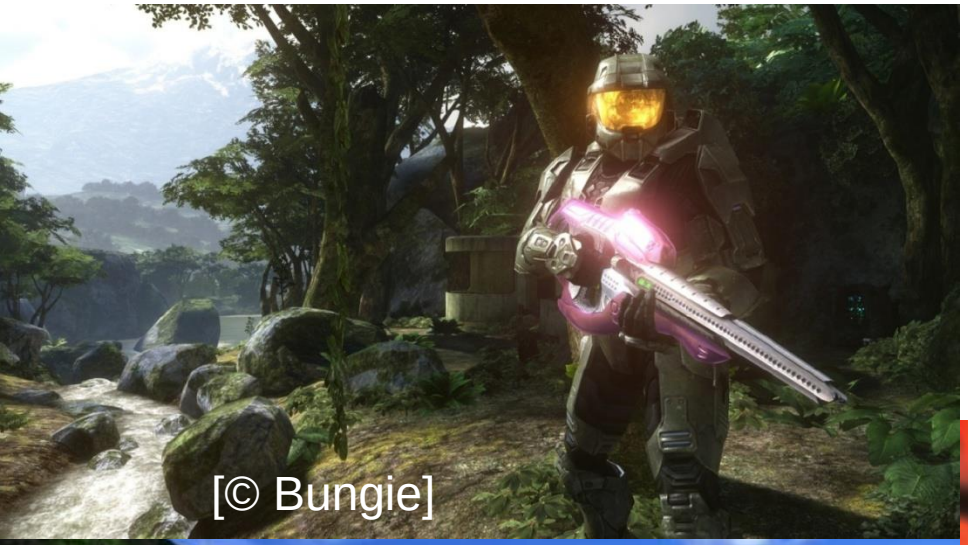
Coco [© Pixar]

How to train your dragon [© DreamWorks]

Big Hero 6 [© Disney]

Applications

- Entertainment Industry: Video games


[© Bungie]


[© Valve]


[© Crytek]


[© Blizzard Entertainment]

Applications

- Entertainment Industry: Video games

Shadow of the Tomb Raider [© Crystal Dynamics]

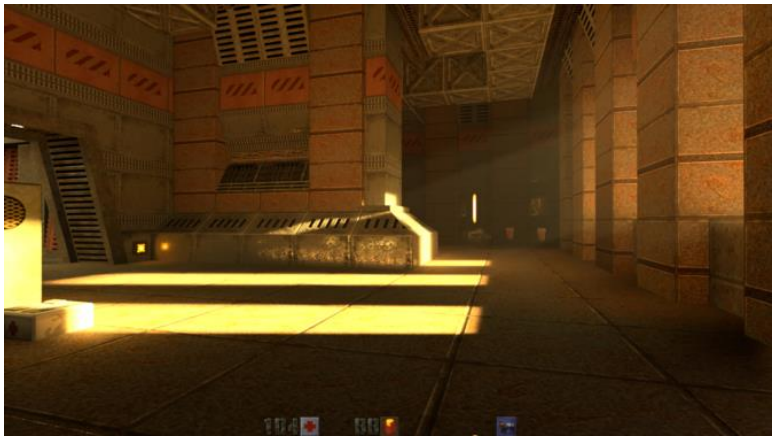
Metro Exodus [© 4A Games]

Applications

- Entertainment Industry: Video games

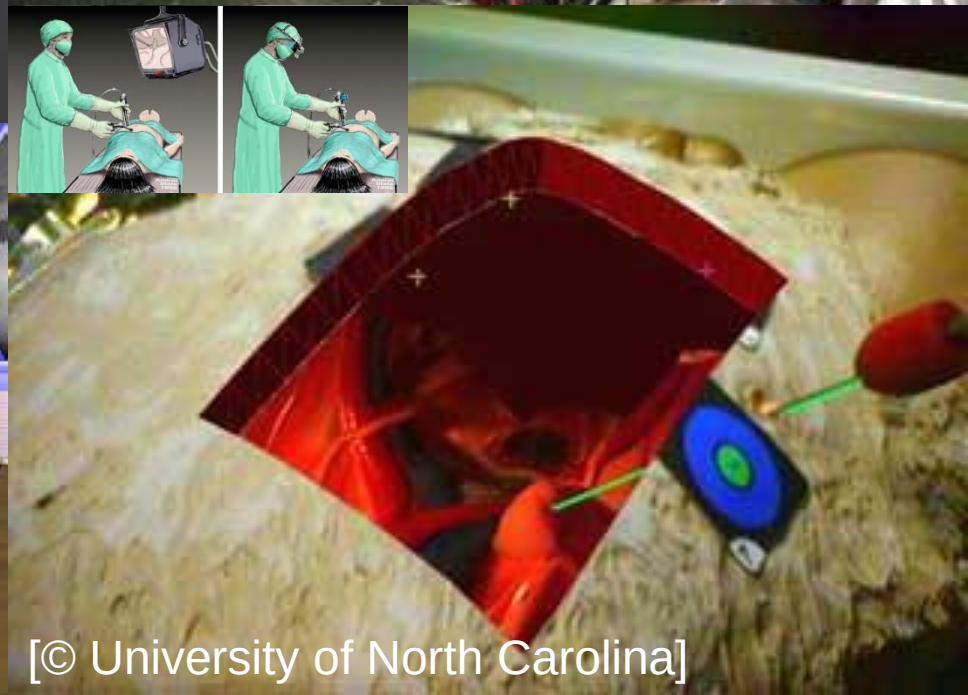
Battlefield V [© EA DICE]

Quake 2 RT remake



Applications

- Simulation & Augmented Reality

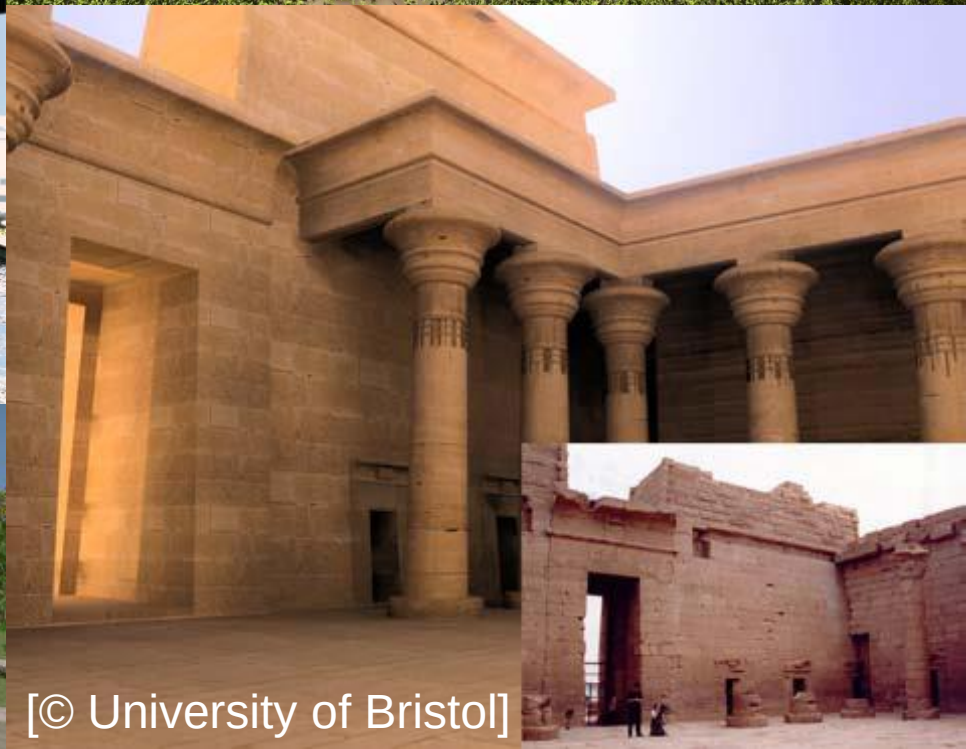


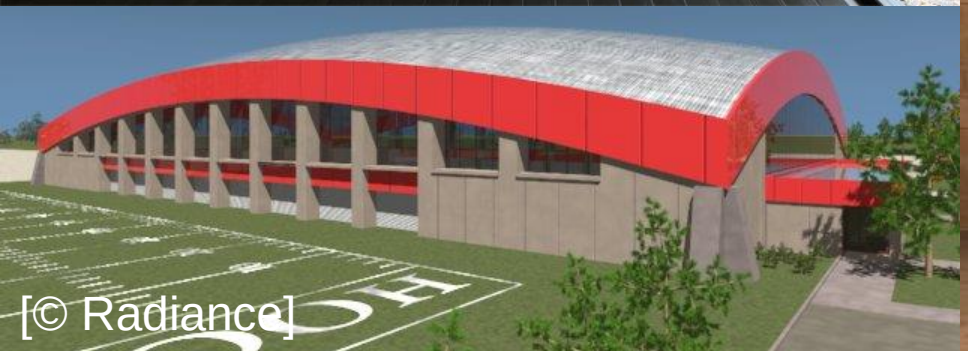
Applications

- Industrial Design & Engineering: Automotive / Aerospatial

Applications

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





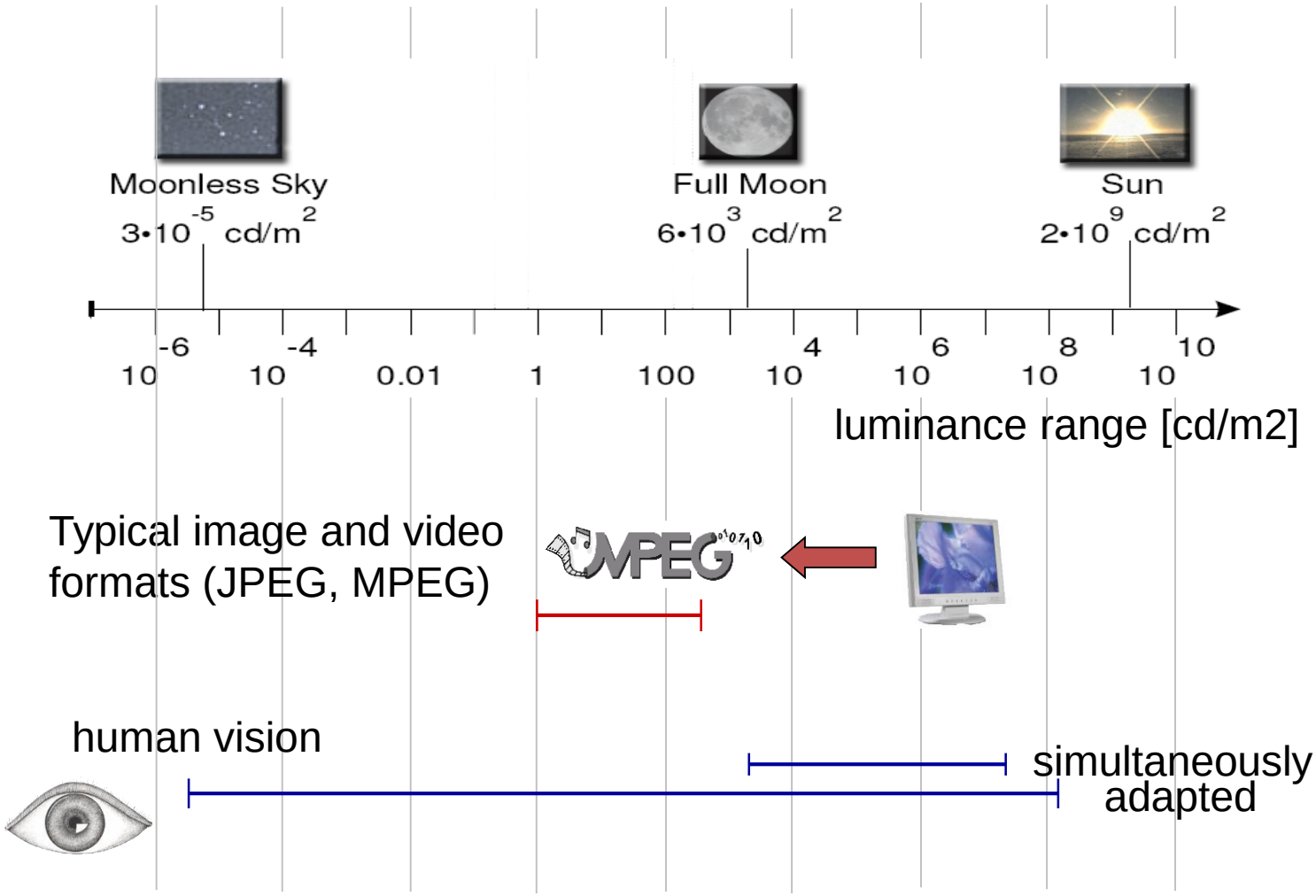
Syllabus

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

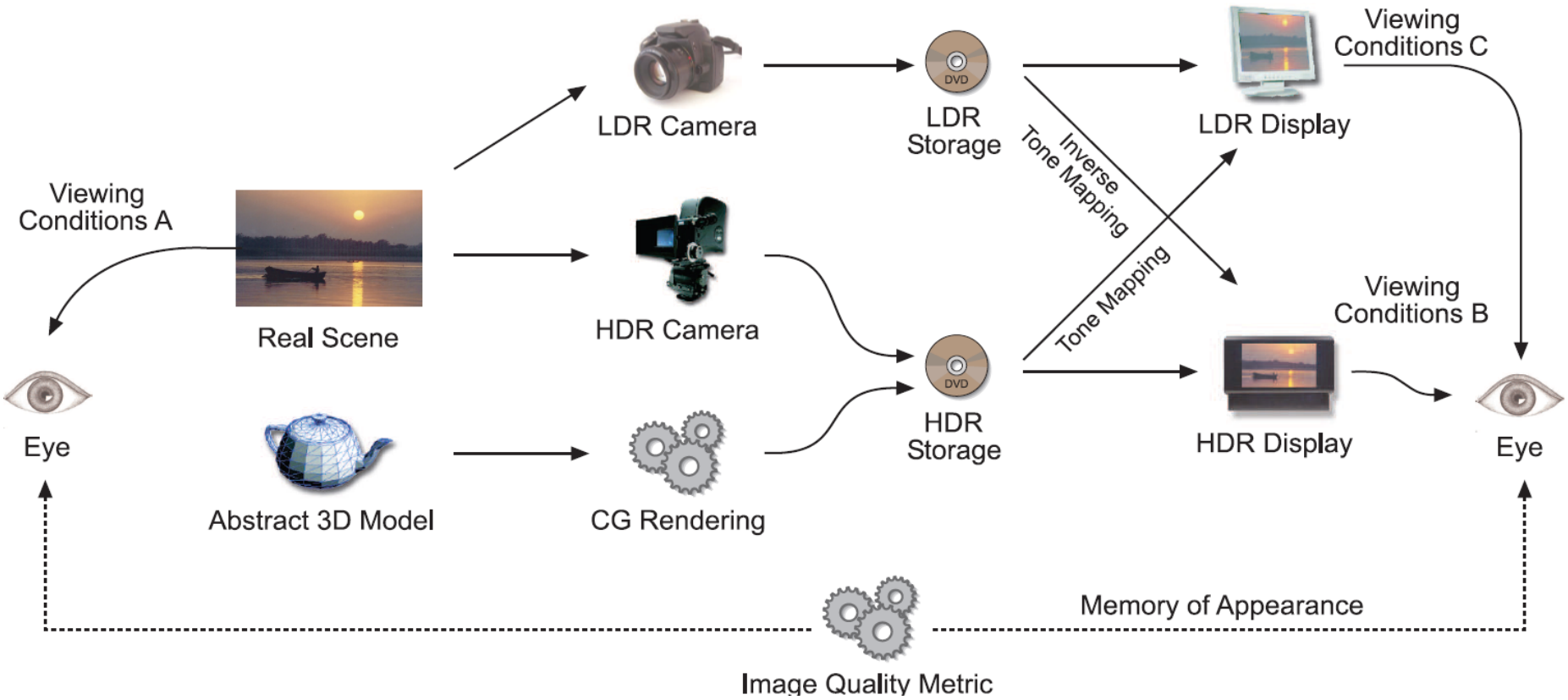
Research From Saarbrücken

- Some examples

High Dynamic Range (HDR) Imaging

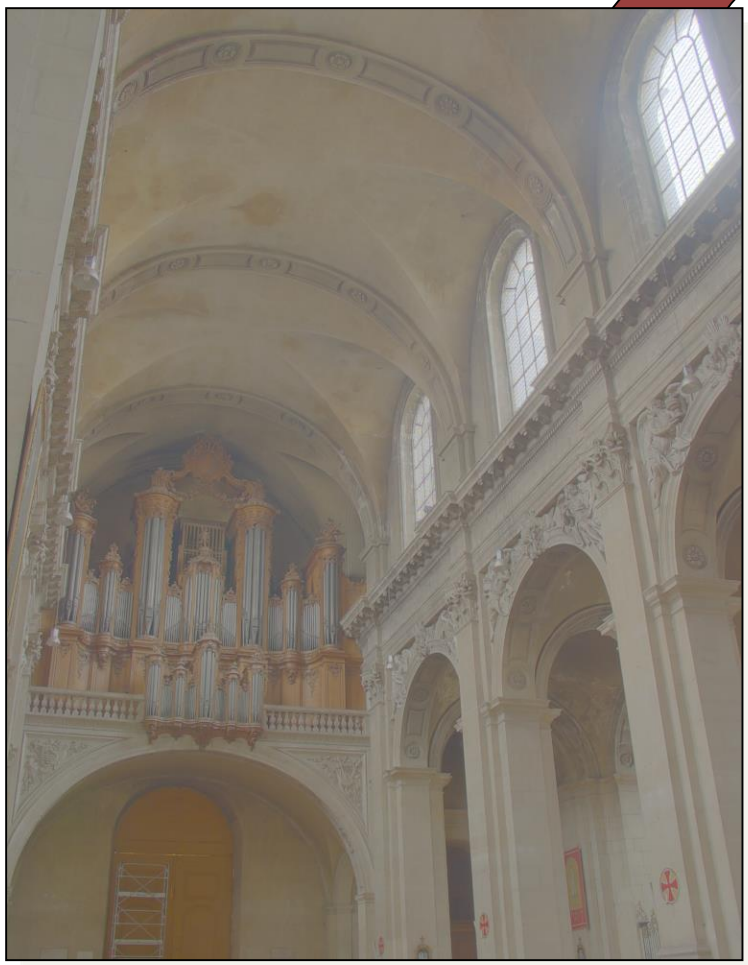


HDR Imaging Pipeline

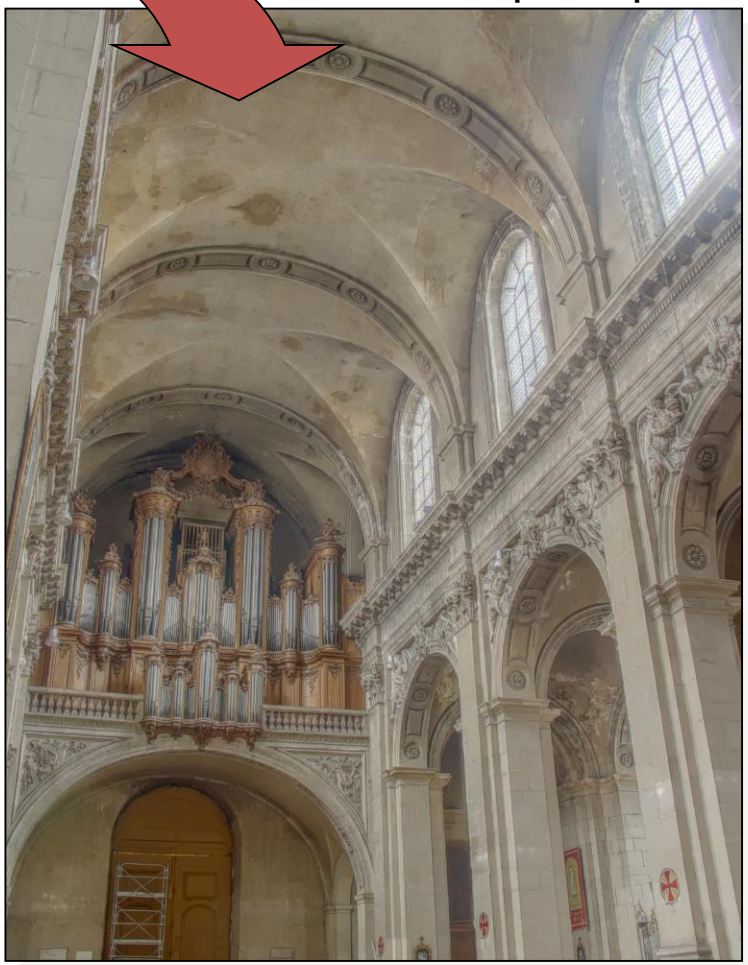


Tone Mapping

Naïve
non-linear compression

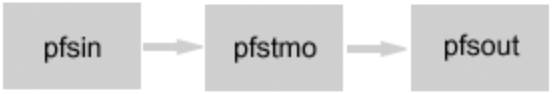


Advanced
contrast perception model



MPI HDR Software

PFSTools
For High Dynamic Range Images and Video



http://pfstools.sourceforge.net/

PFStmo
tone mapping operators

http://www.mpii.mpg.de/resources/tmo/

PFScalibration
Photometric Calibration of HDR and LDR Cameras

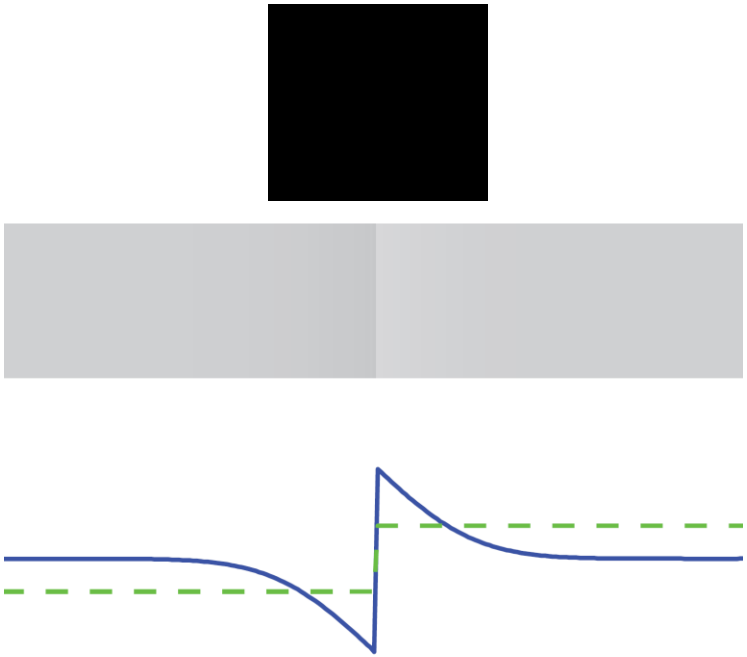
http://www.mpii.mpg.de/resources/hdr/calibration/pfs.html

HDR Visual Difference Predictor

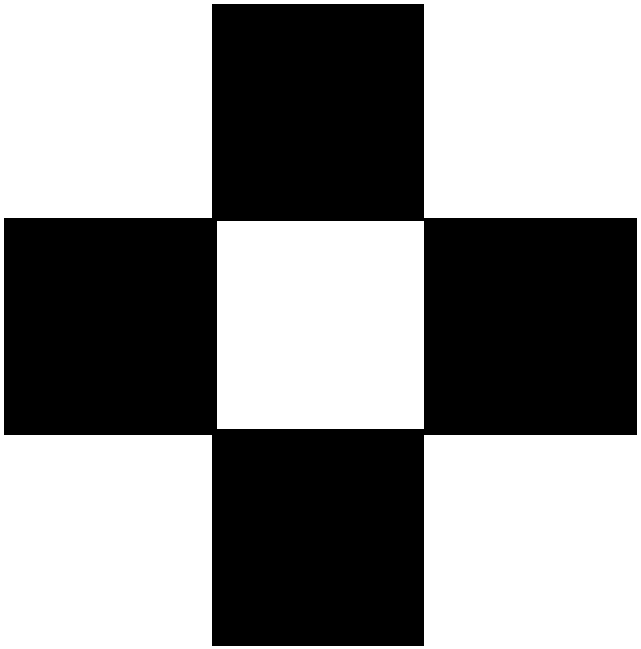
http://www.mpi-sb.mpg.de/resources/hdr/vdp/index.html

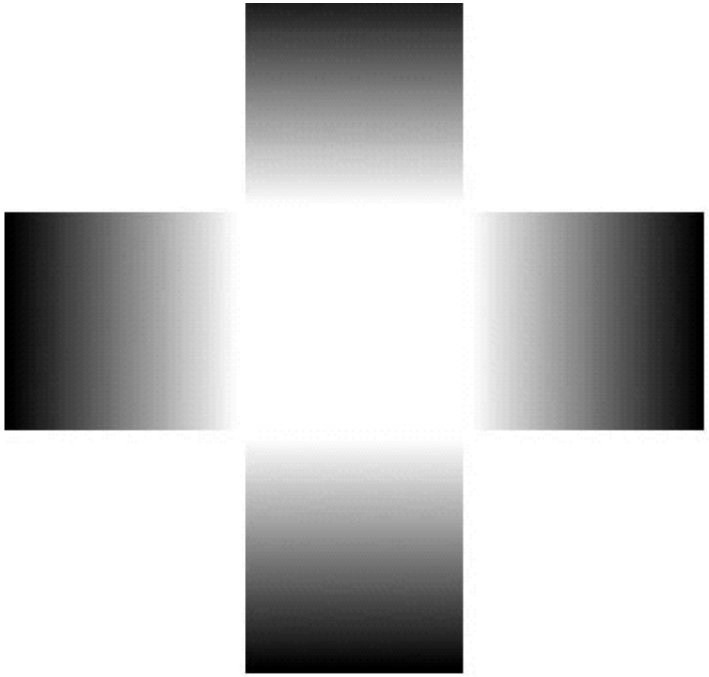
GPL License

Cornsweet Illusion



Glowing Effect

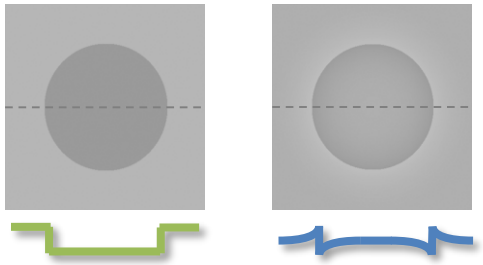


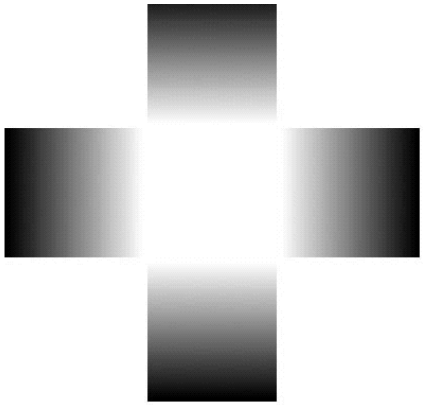


[Zavagno and Caputo 2001]

Overcoming Display Limitations

- Enhancing apparent (perceived) quality rather than improving technical aspects
- Take advantage of the visual system properties

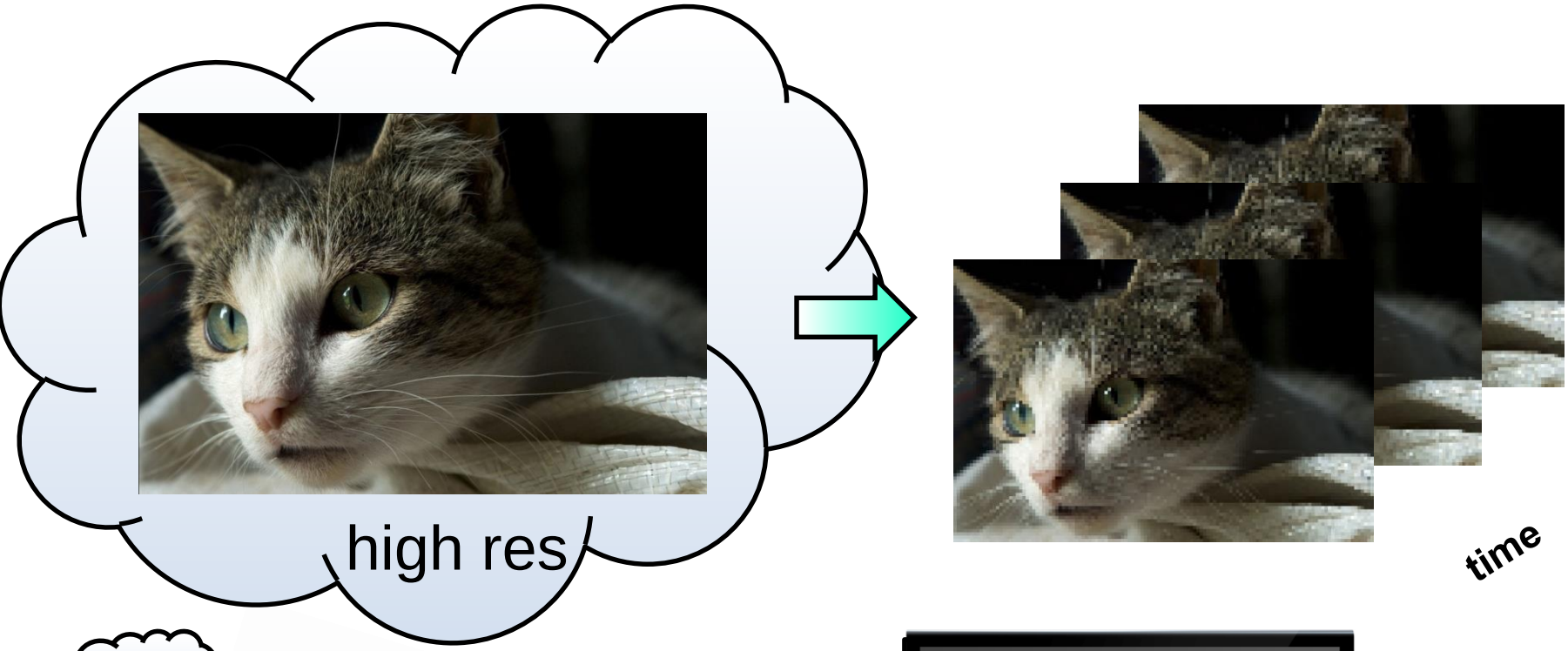


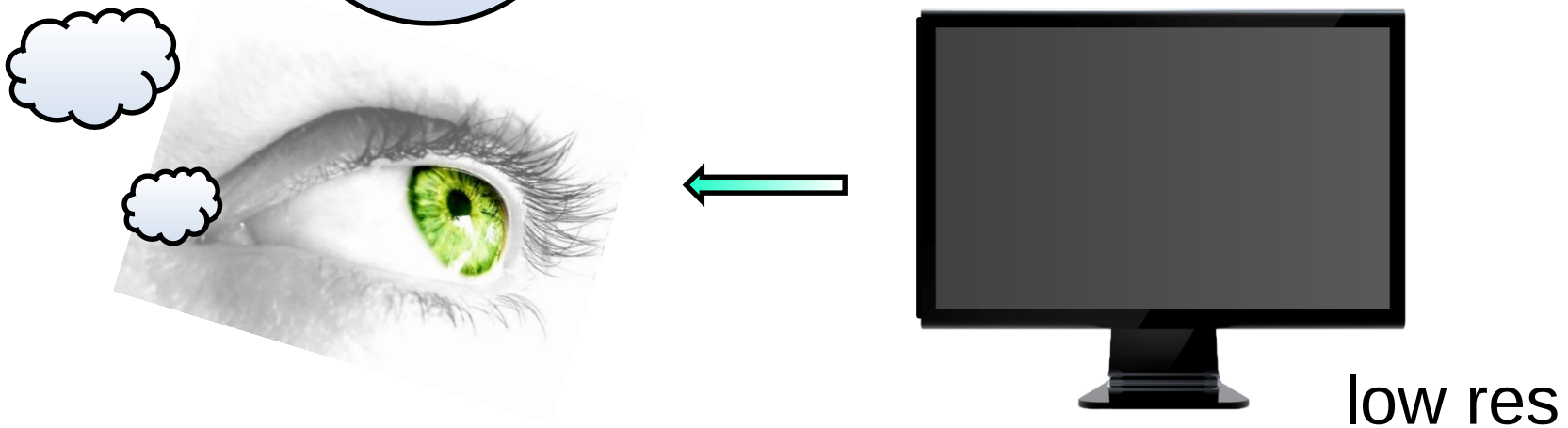


sharpen blur blur

120 Hz

Apparent Resolution Enhancement

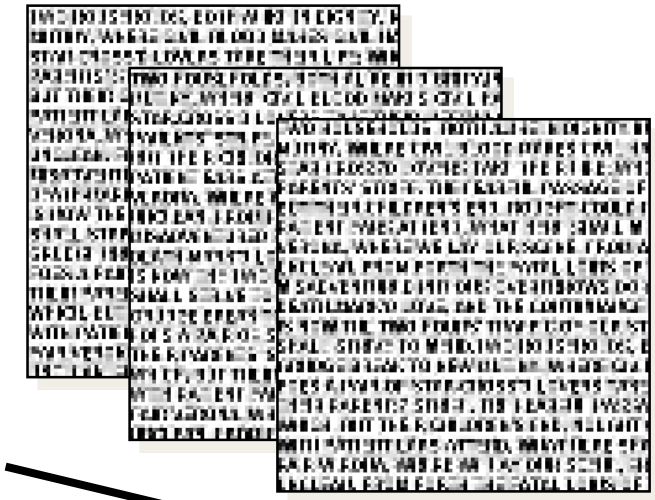




increased apparent resolution

Optimization Result

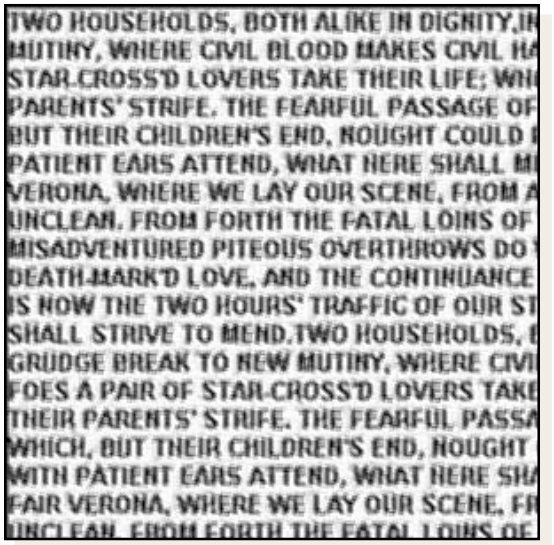
Display



time

integration

Predicted image on the retina



3D Image Retargeting

Input devices

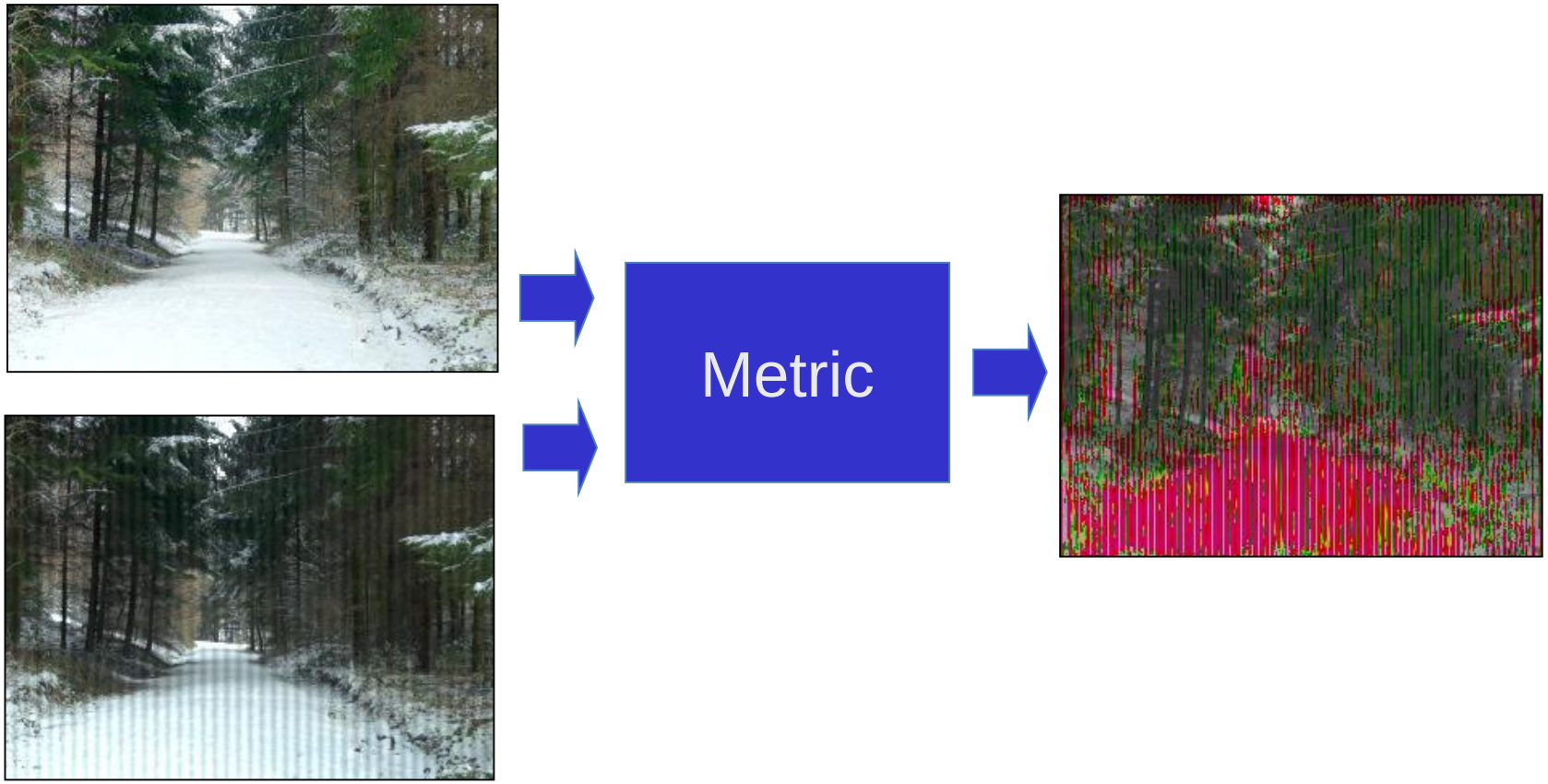
Produce different depth ranges

Output devices

Reproduce different depth ranges

Visible Difference Metric (VDP)

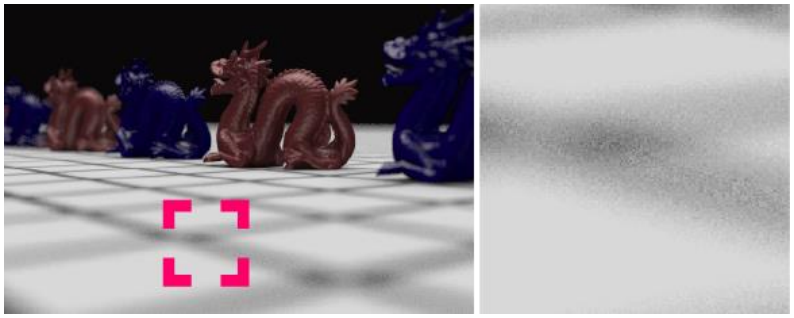
- Can the human eye see the differences between two images?



Dataset of Visible Distortions

Compression

Mixed



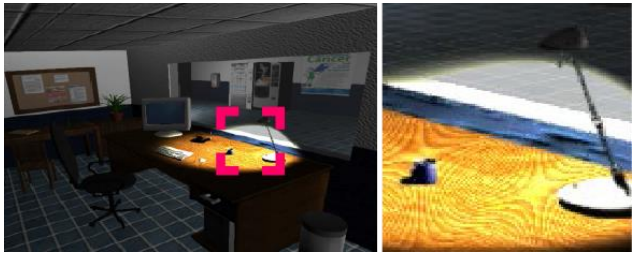
[Čadík et al. 2012]

Dataset of Visible Distortions

Peter Panning

Z-fighting

Shadow acne



Shadowmap downsampling

[Piórkowski et al. 2017]

Dataset of Visible Distortions

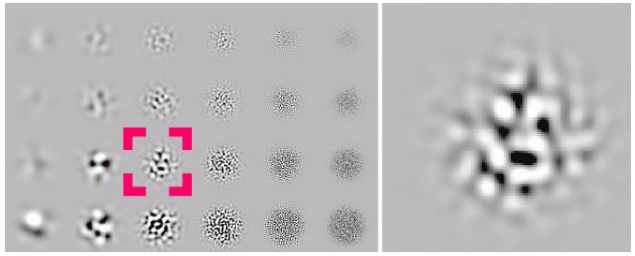
Aliasing

[Piórkowski et al. 2017]

IBR

[Adhikarla et al. 2017]

Perception patterns



[Čadík et al. 2013]

Deghosting

[Karađuzović-Hadžiabdić et al. 2017]

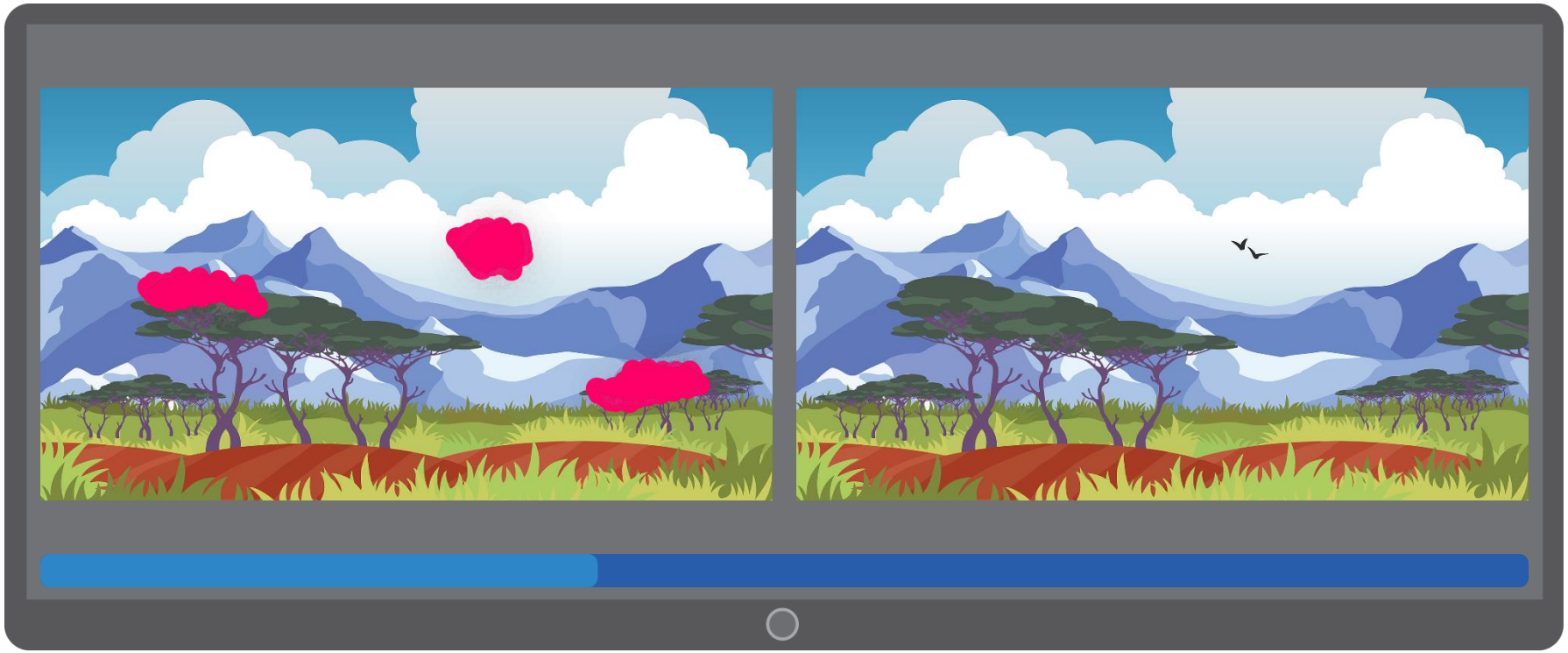
Dataset of Visible Distortions

145
SCENES

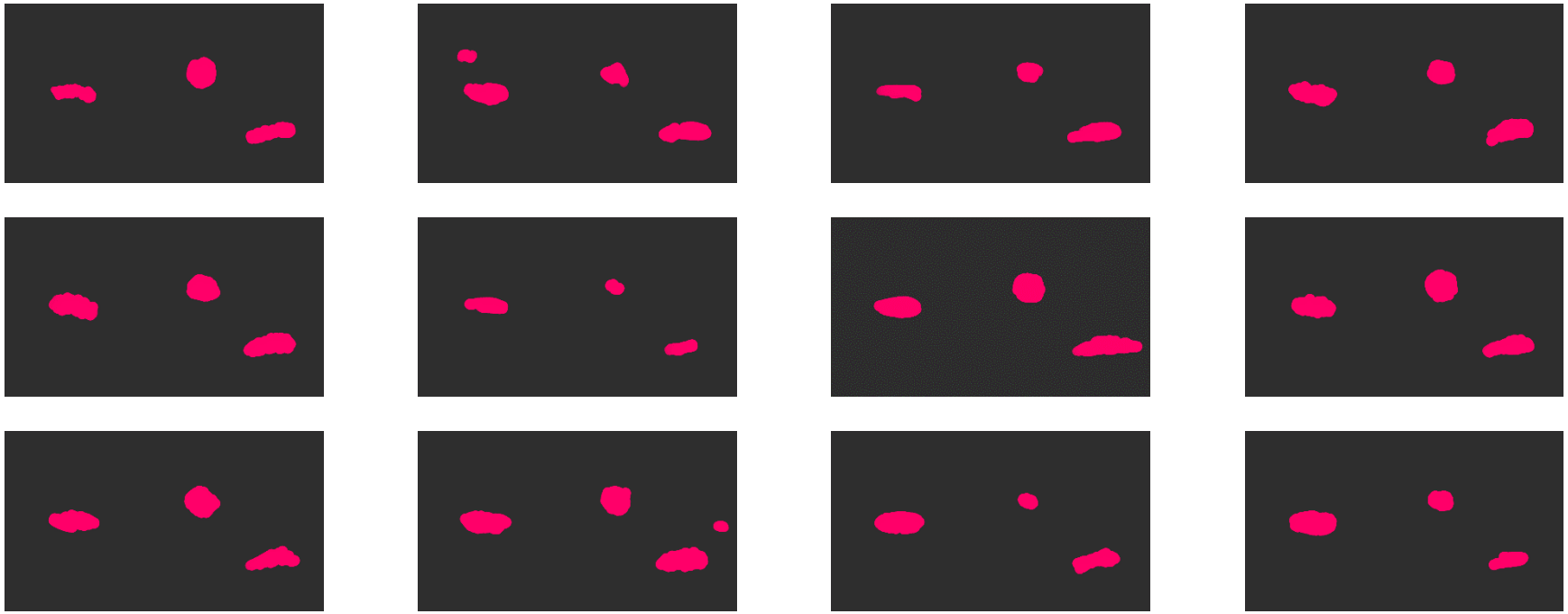
1-3
LEVELS

296!
IMAGES

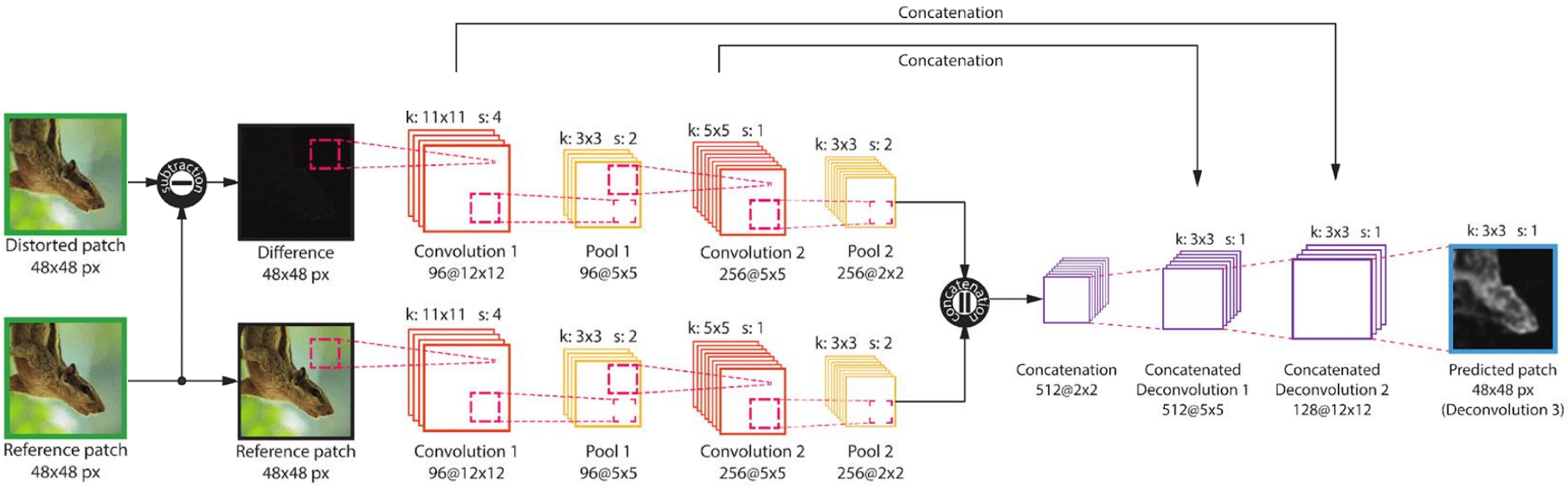
Label Creation



Label Creation



Neural Network Architecture



Multi-material Printing

Stratasys J750 (poly-jetting printer)

Cyan

Magenta

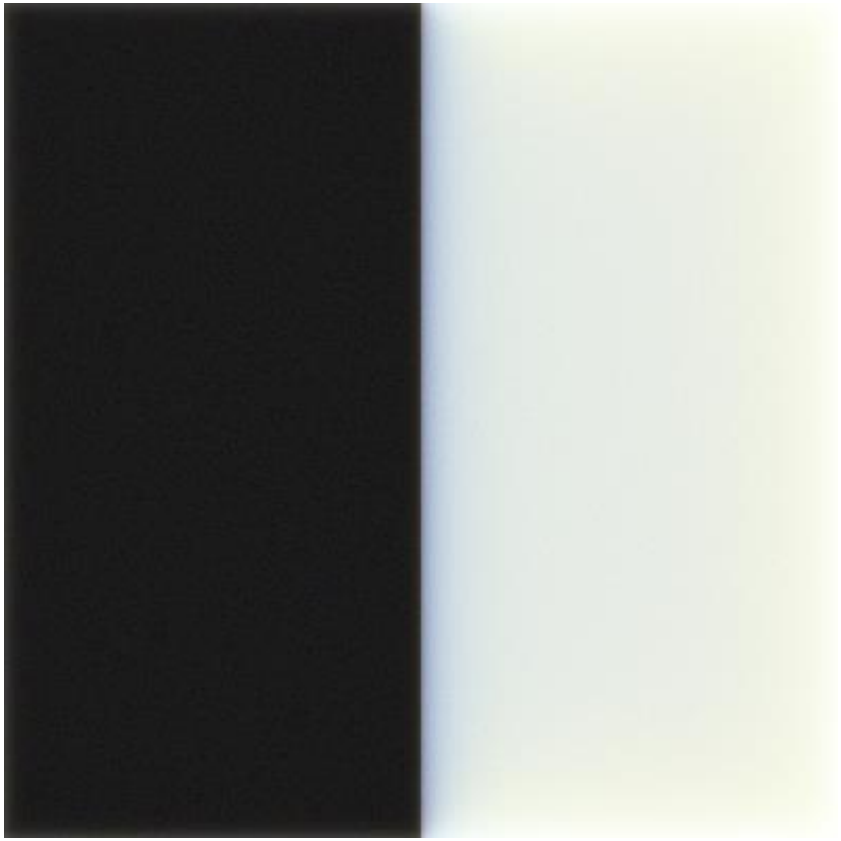
Yellow

blacK

White

Vero Opaque materials
(not actually opaque!)

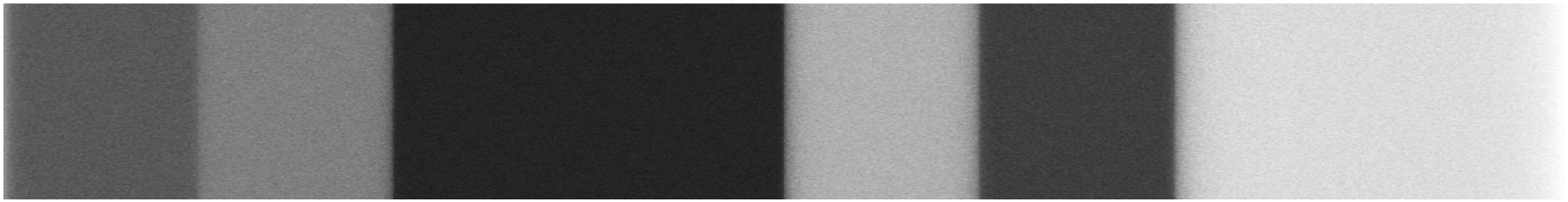
3D Appearance Printing



Goal: Visually Reducing Light Diffusion in the 3D Printed Material

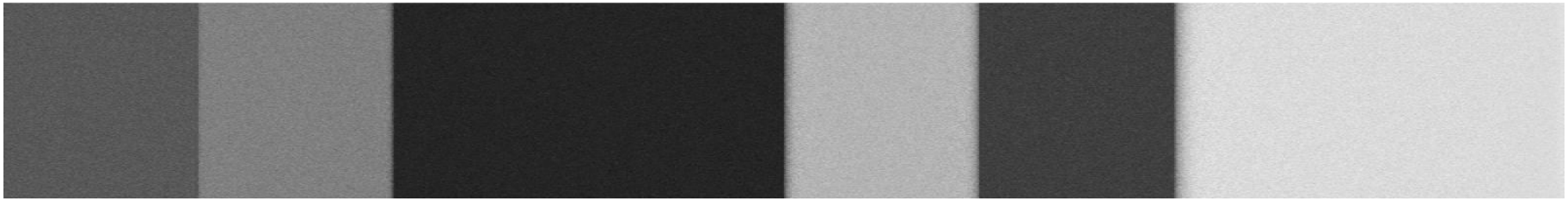
3D Appearance Printing

Without correction (MC simulation)

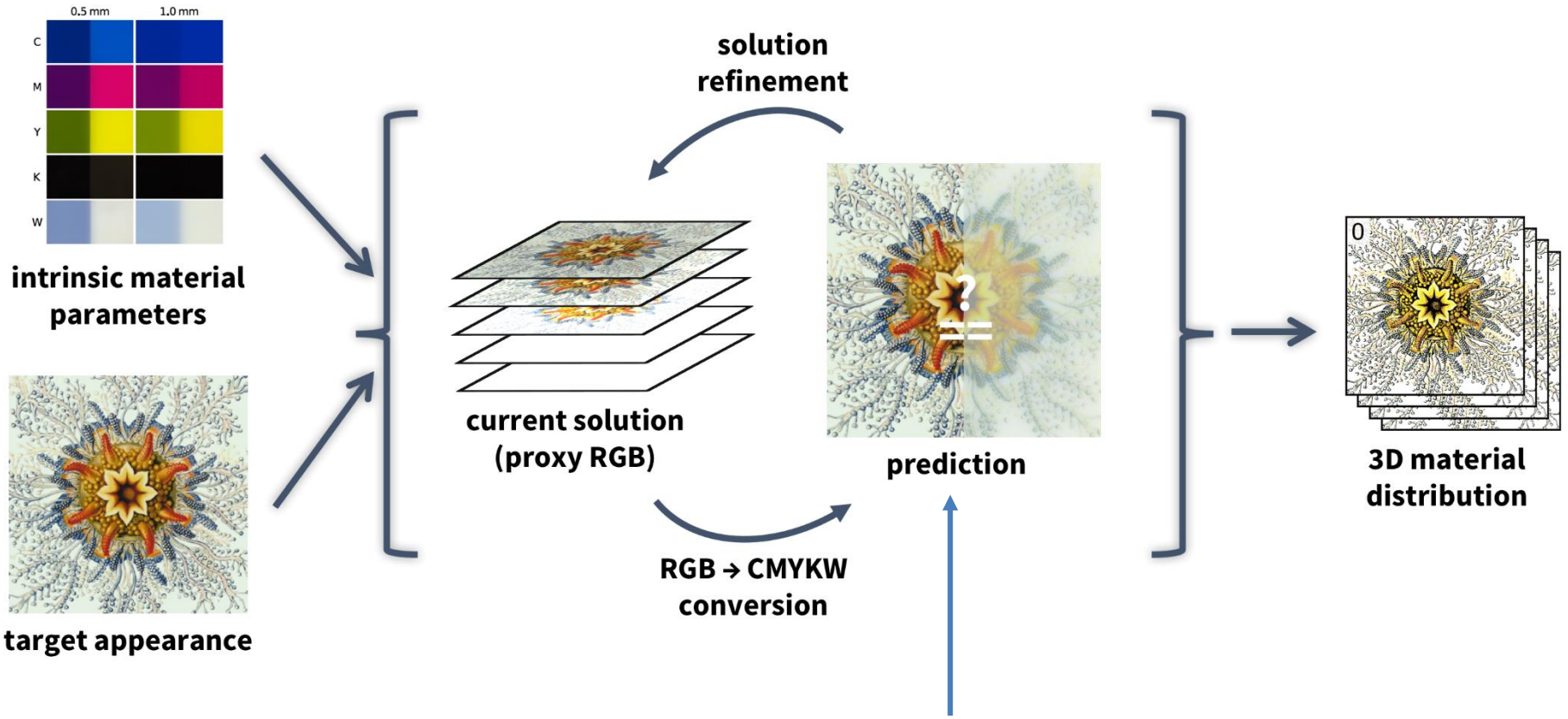


Target texture

With correction (MC simulation)

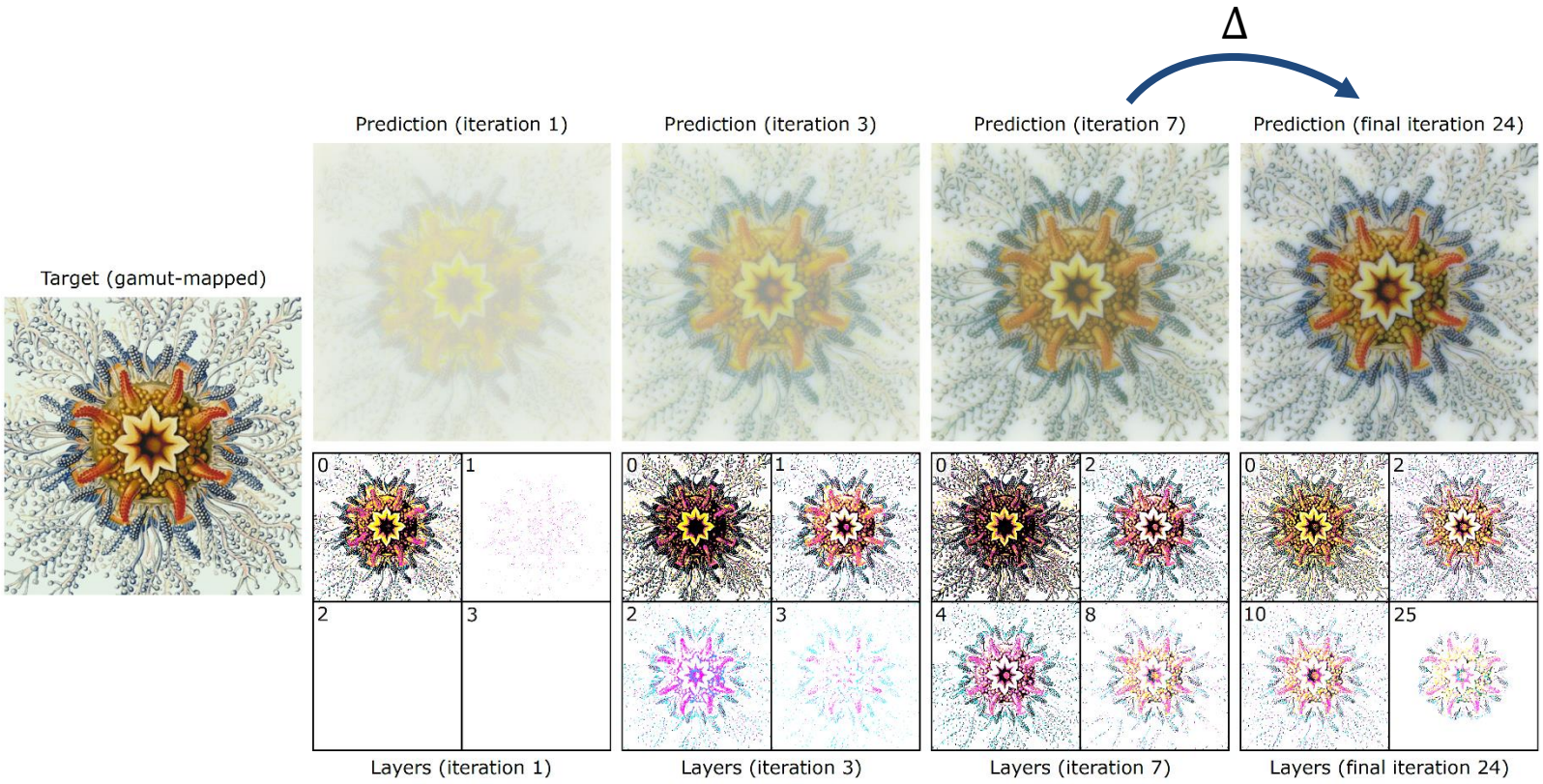


3D Appearance Printing



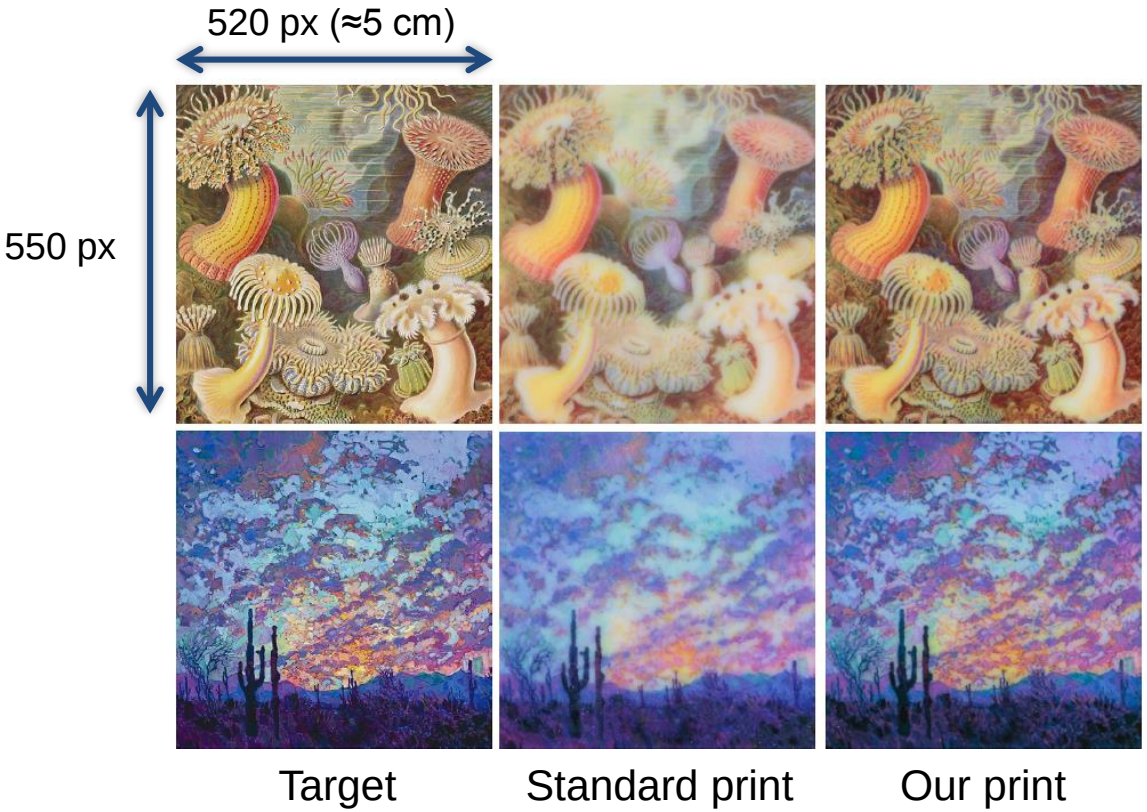
Volumetric MC global illumination simulation

3D Appearance Printing

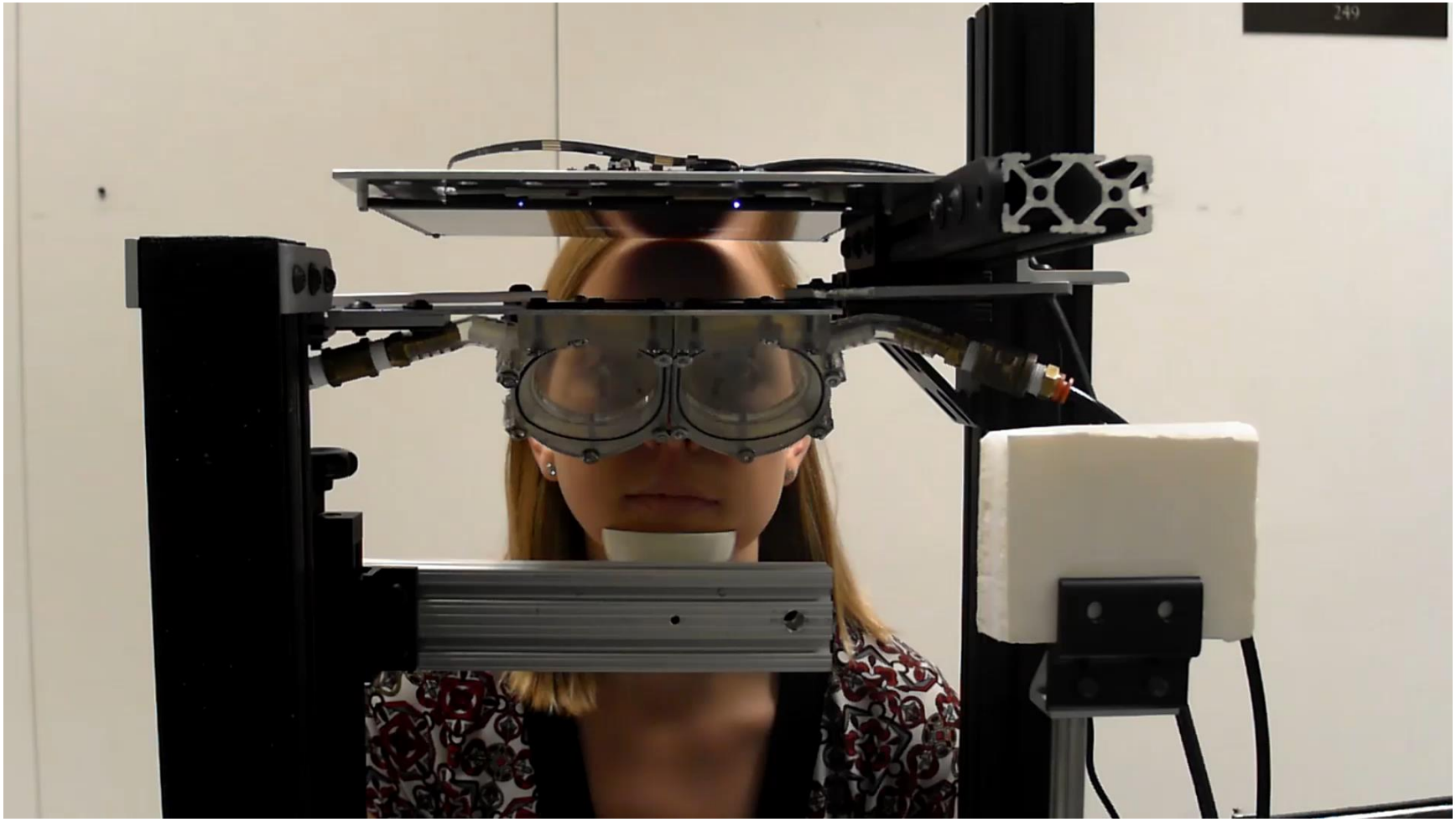


despite the non-linearity of the appearance, it changes monotonically
→ simple residual energy minimization

3D Appearance Printing



Varifocal Displays



Membrane AR – Dunn et al.

Deformable Beamsplitter

Membrane AR – Dunn et al.

Dynamic focal depth: objects at any depth

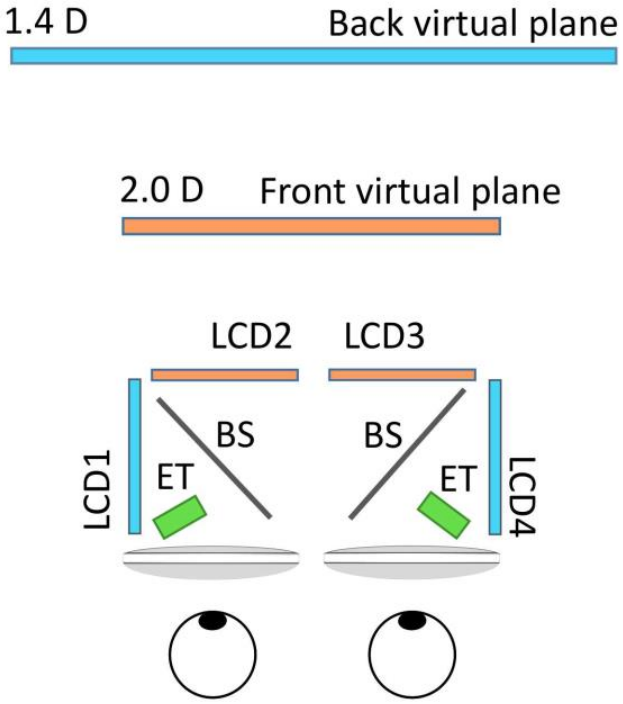
Wide field of view

Optics are simple

Deformable Beamsplitter

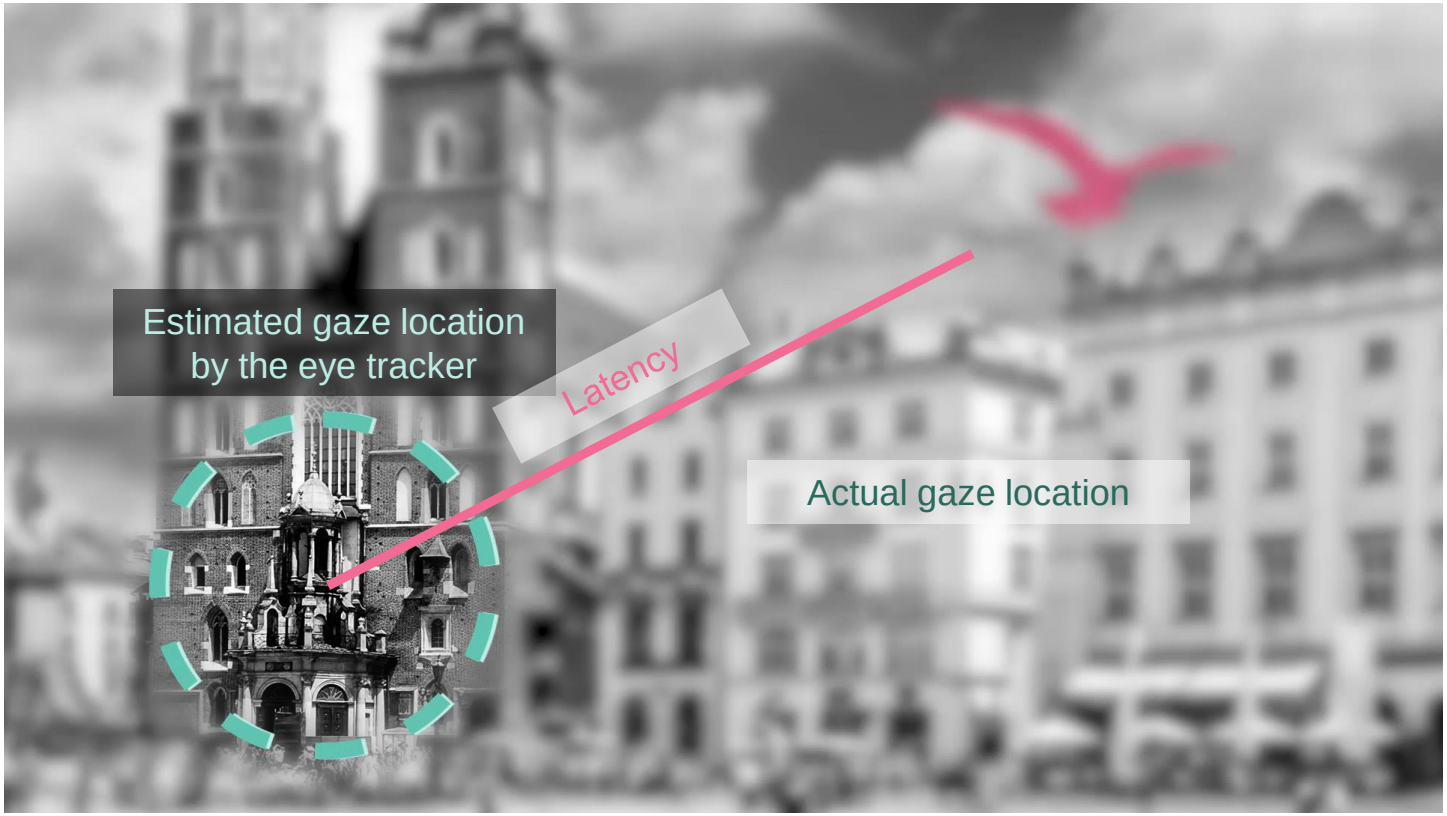
Membrane AR – Dunn et al.

Multi-focal Plane Display



15cpd, 40 deg, 1200x1200 pixels

Saccade in Foveated Rendering



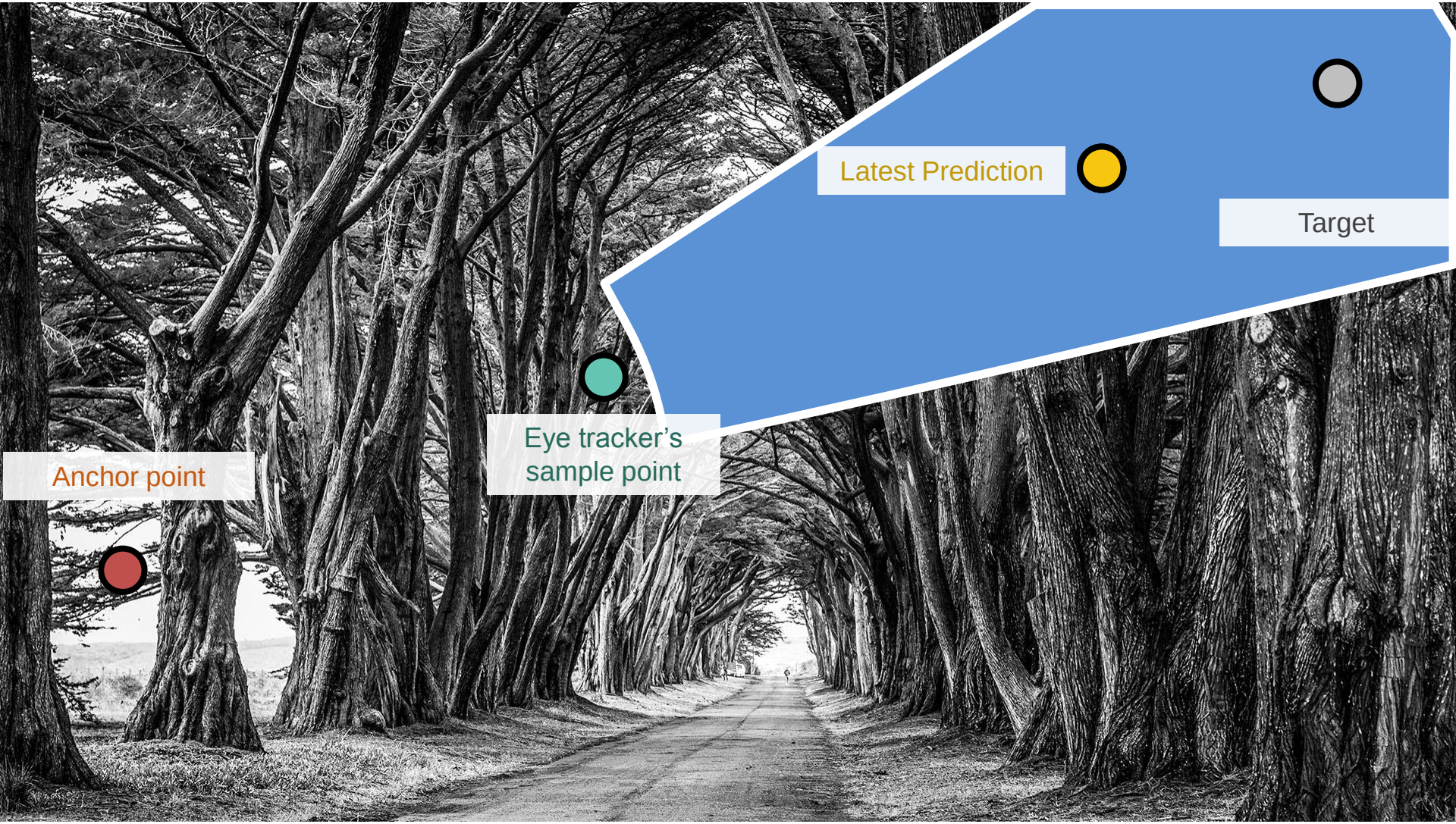
Saccade Landing Position Prediction for Gaze-Contingent Rendering

Saccade in Foveated Rendering

Saccade Landing Position Prediction for Gaze-Contingent Rendering

Eye Tracking: Saccade Landing Prediction

Eye Tracking: Saccade Landing Prediction



Eye Tracking: Saccade Landing Prediction

Eye Tracking: Saccade Landing Prediction

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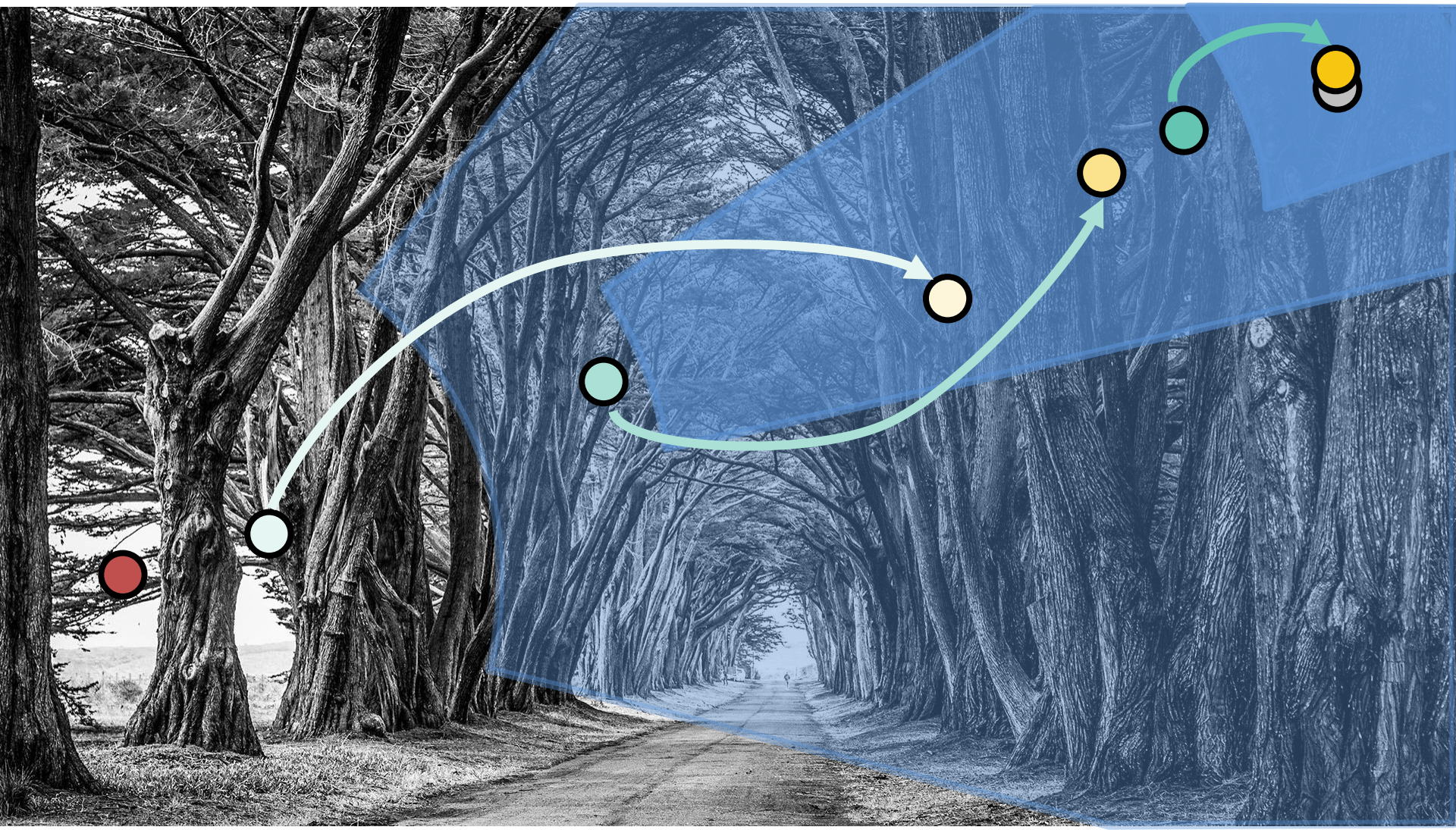
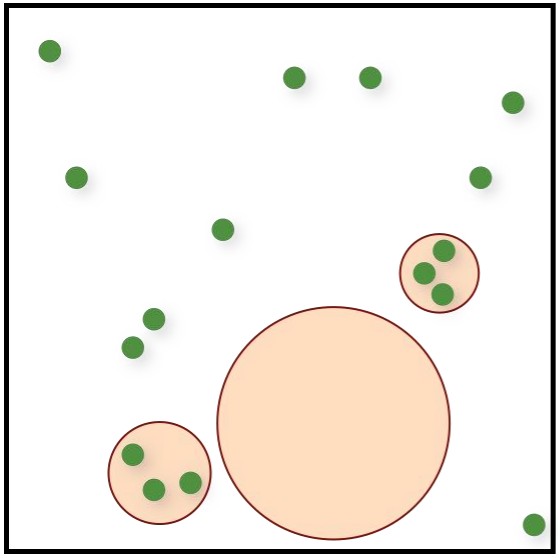
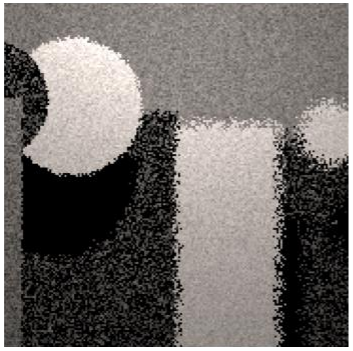


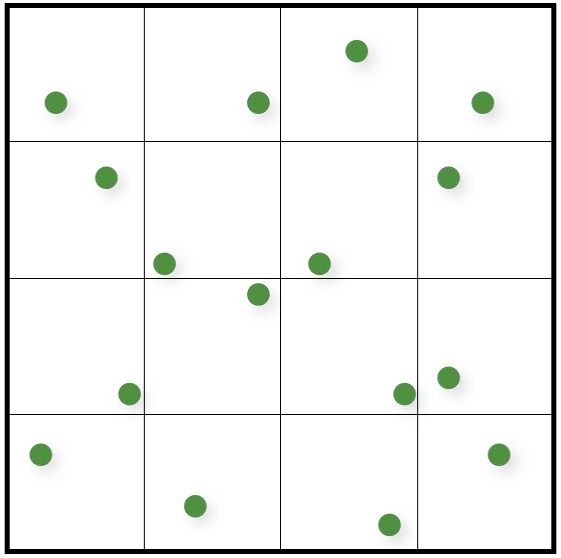
Sampling Patterns

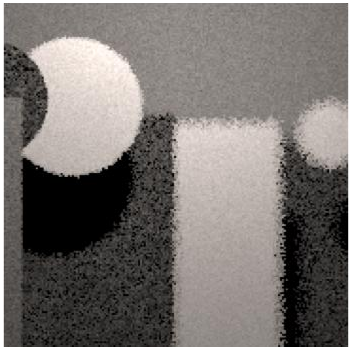
Random



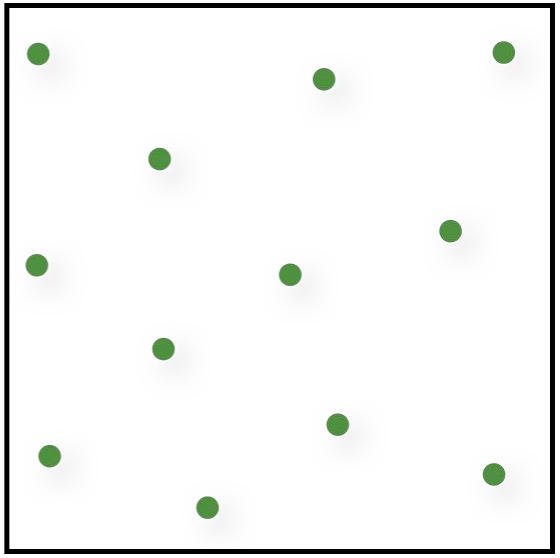


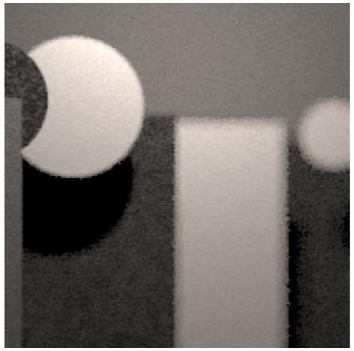
Jitter





Poisson Disk





Advanced Sampling

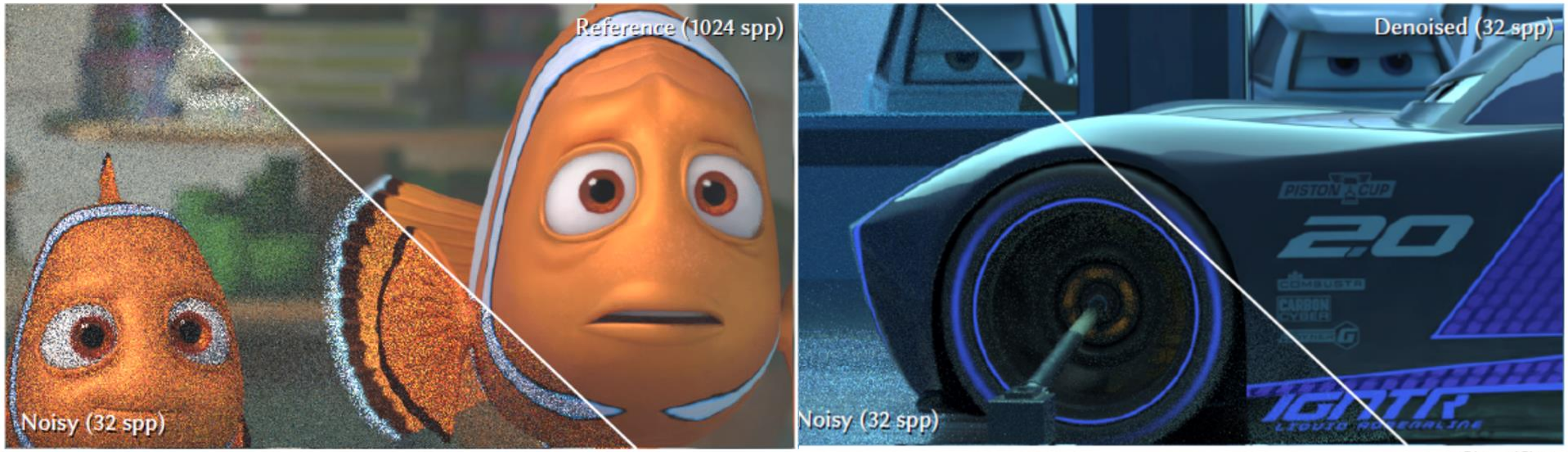
How error in MC integration is affected by different sampling patterns?

Spatial domain statistics: Pair Correlation Function / Discrepancy

Fourier domain statistics

Define Error in terms of Spatial and Fourier domain statistics

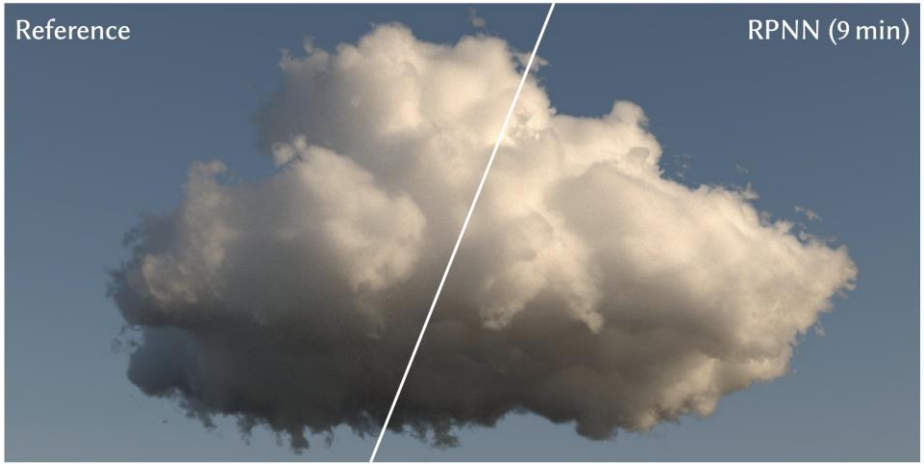
Learn to Render: Path to Neural Networks



Bako et al.[2017]

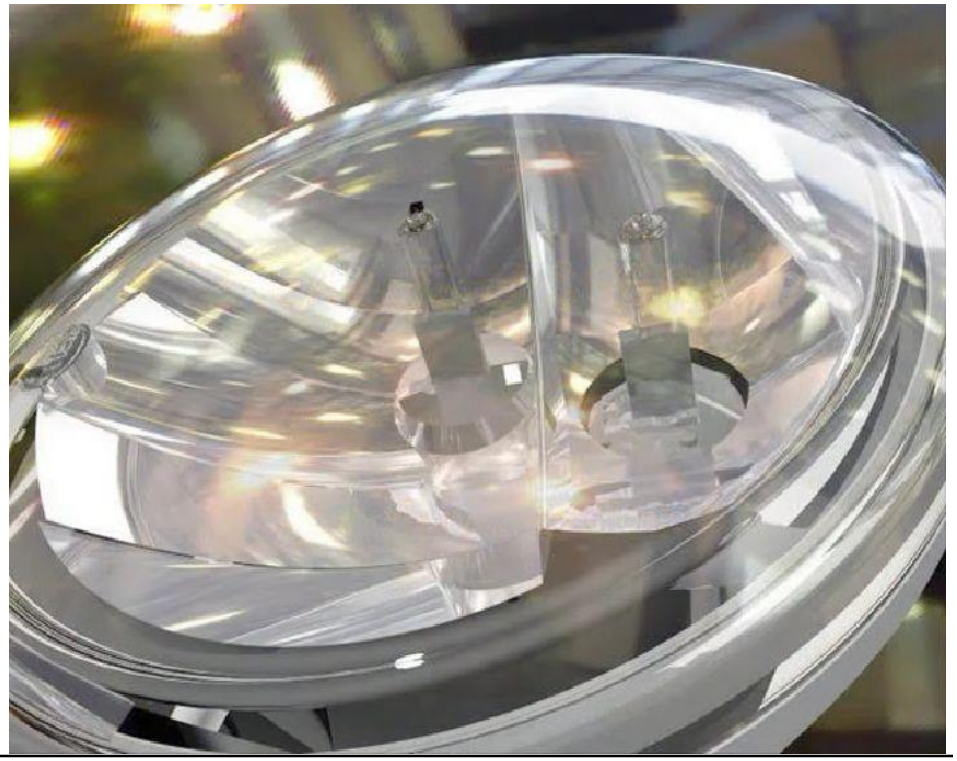
Our Focus: Learn to Render

- ML/NN algorithms for denoising
- CNNs/GANs (unstructured)
- Learning Light Transport the Reinforced Way
- Learning to Importance Sample



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).

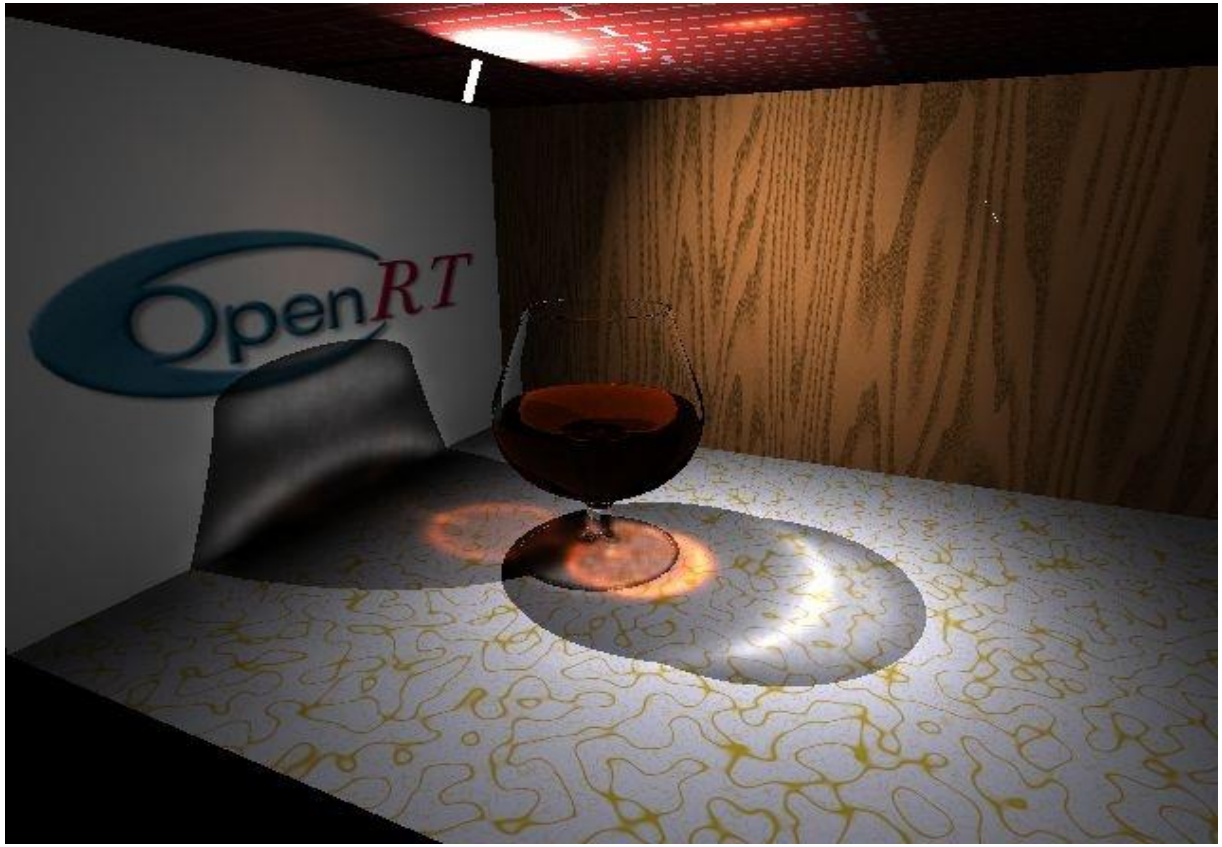


Instant Global Illumination

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

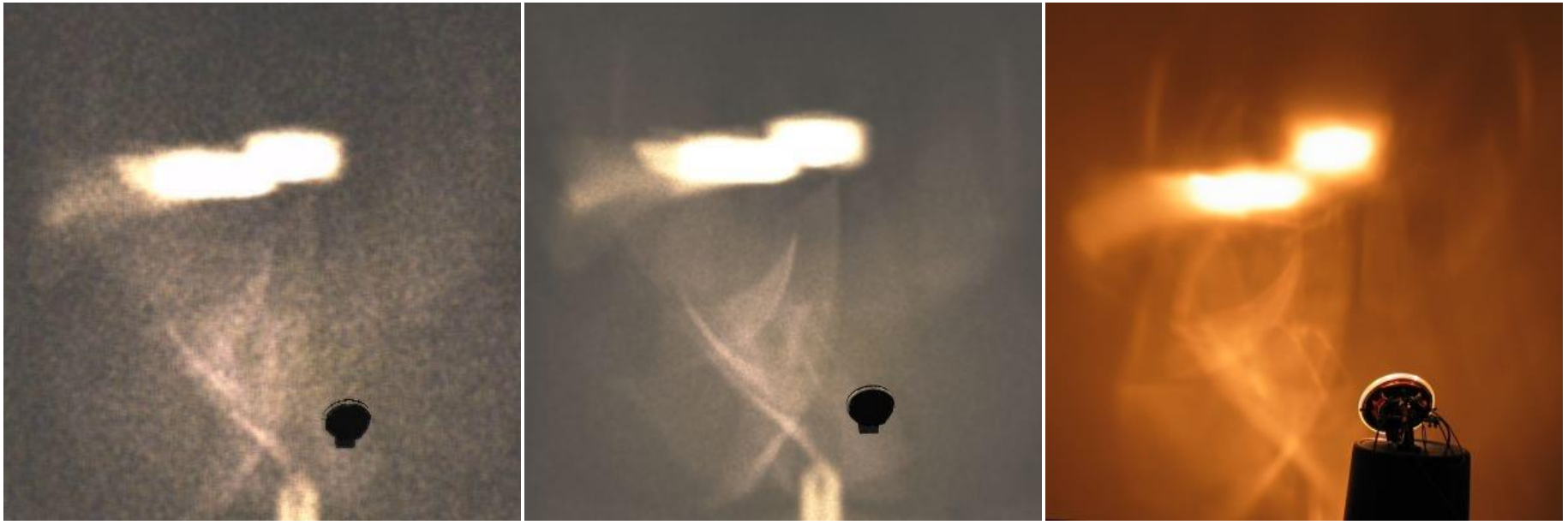
Real-Time Photon Mapping

- 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

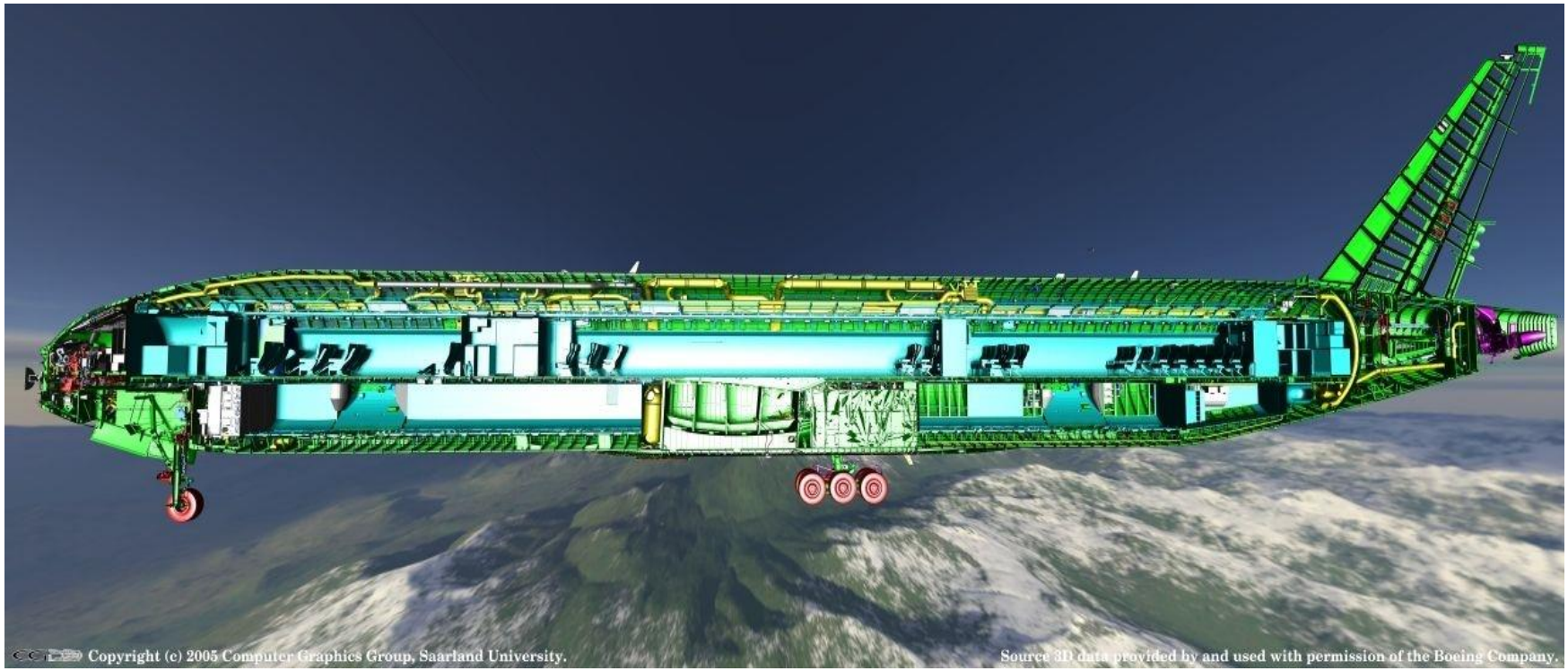
- The use of BTF for realistic materials with optical effects on the meso-scale (e.g. shadows in bumps and creases).

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

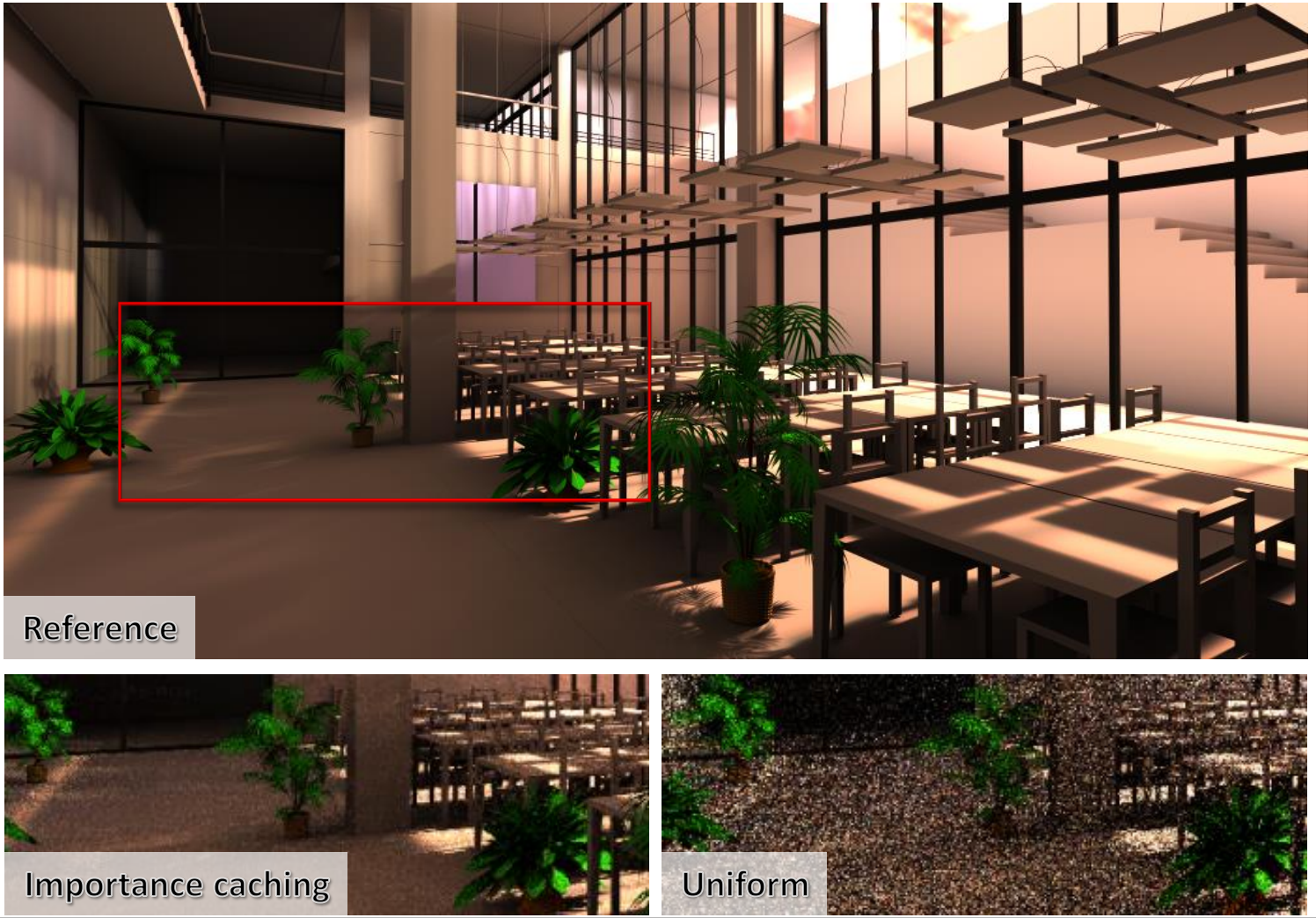
- Ray tracing allows easy integration of multiple modalities into a single rendering framework.

High-Performance Simulation

- Advanced rendering techniques in games

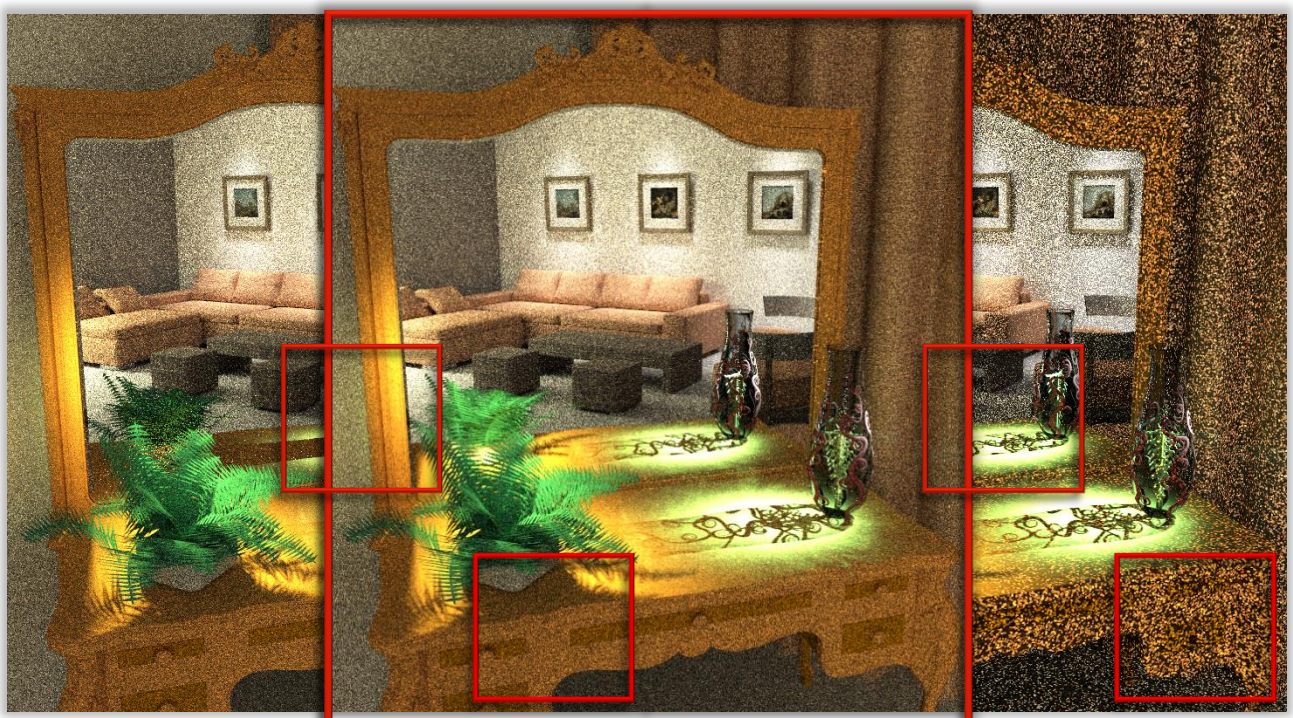
Importance Caching

- Reuse samples based on probability [Eurographics 2012]

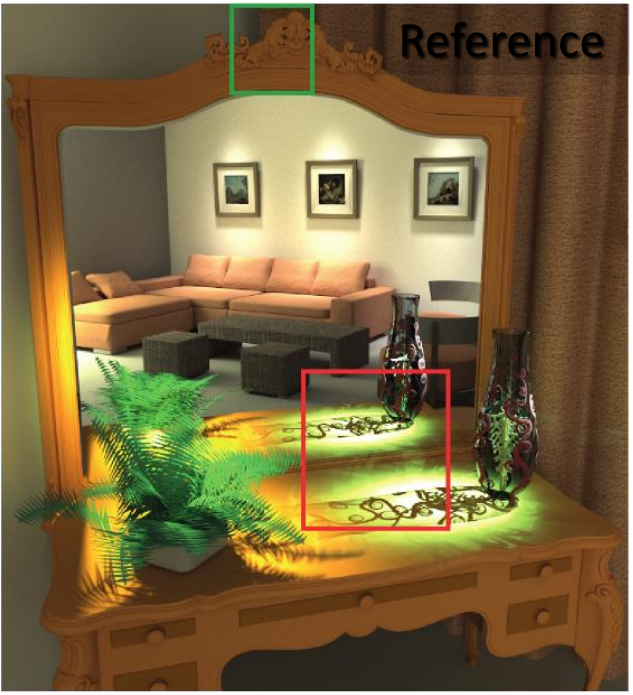


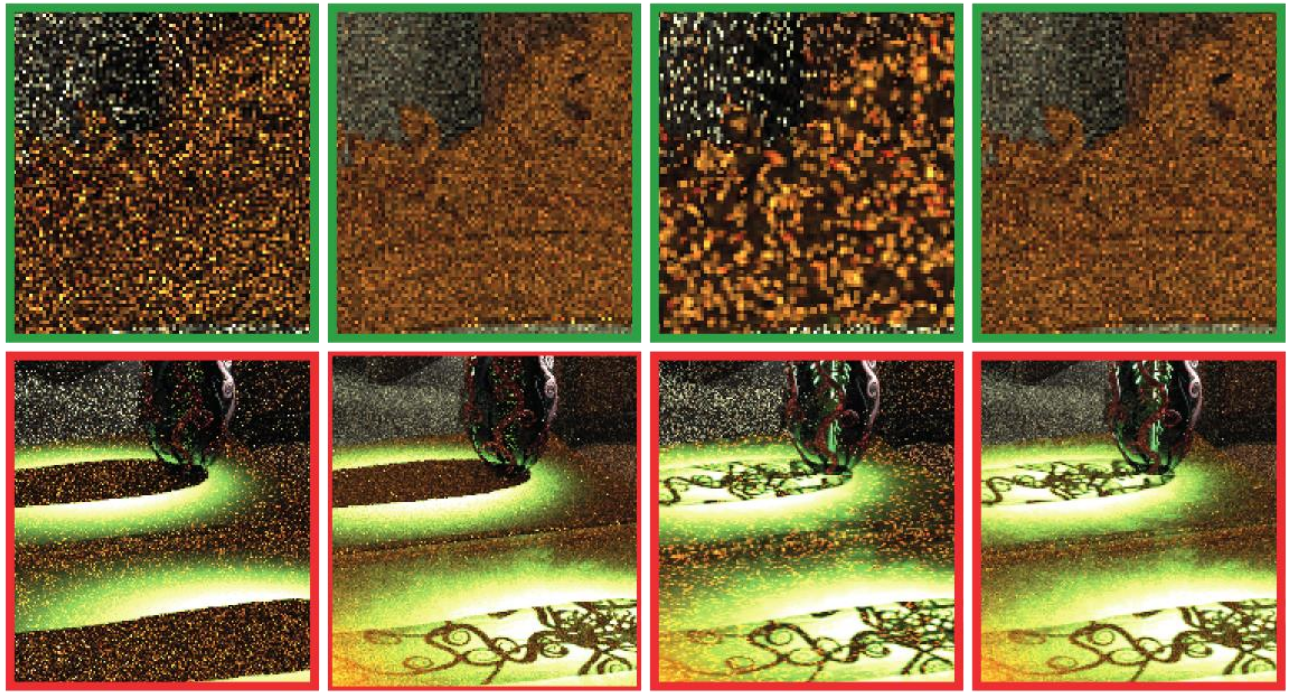
Monte-Carlo vs Density Estimation

- Vertex Connection and Merging [SiggraphAsia 2012]

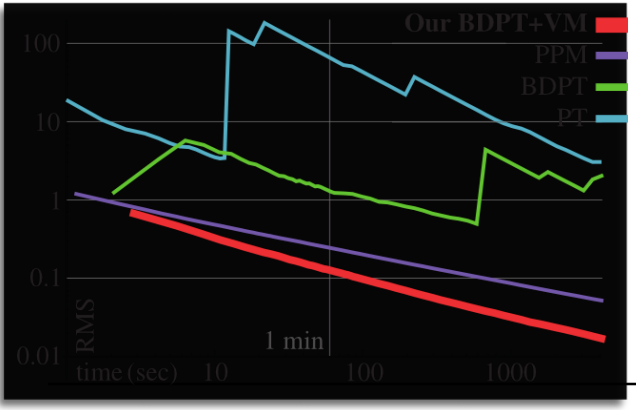


Order of Convergence





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



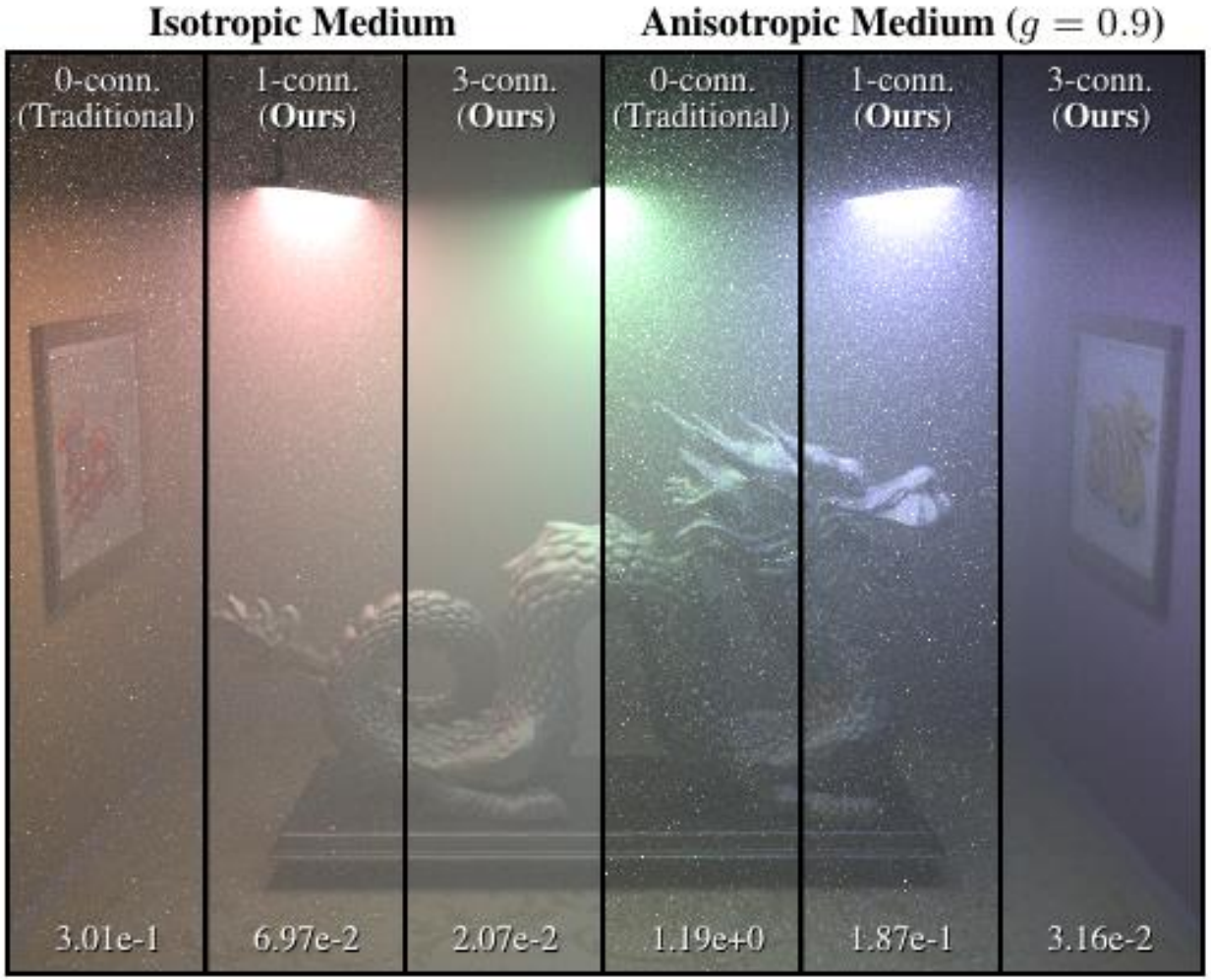
Same time (1 minute)

Monte-Carlo vs Density Estimation

Same time (3 minutes)

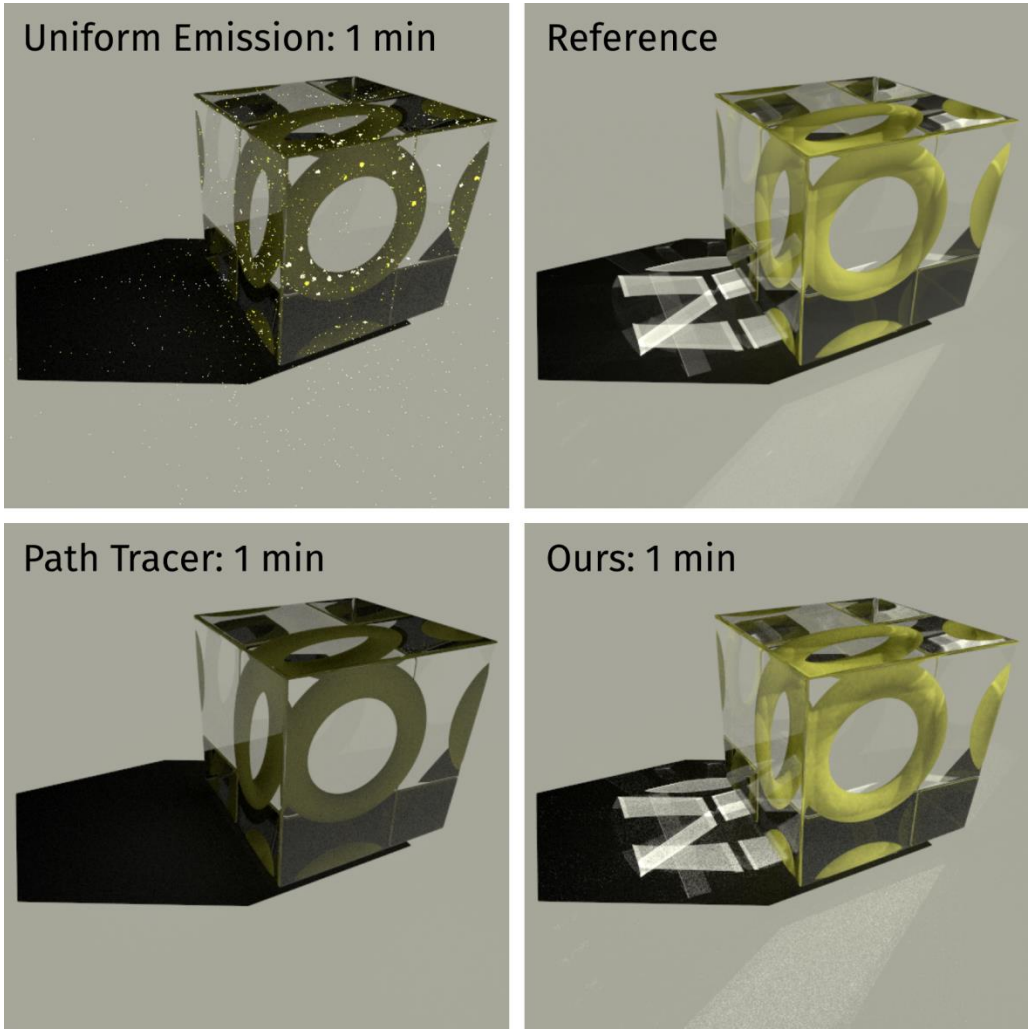
Joint Path Sampling

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



Emission Guiding

- Using Photon Mapping only where it is useful



Emission Guiding

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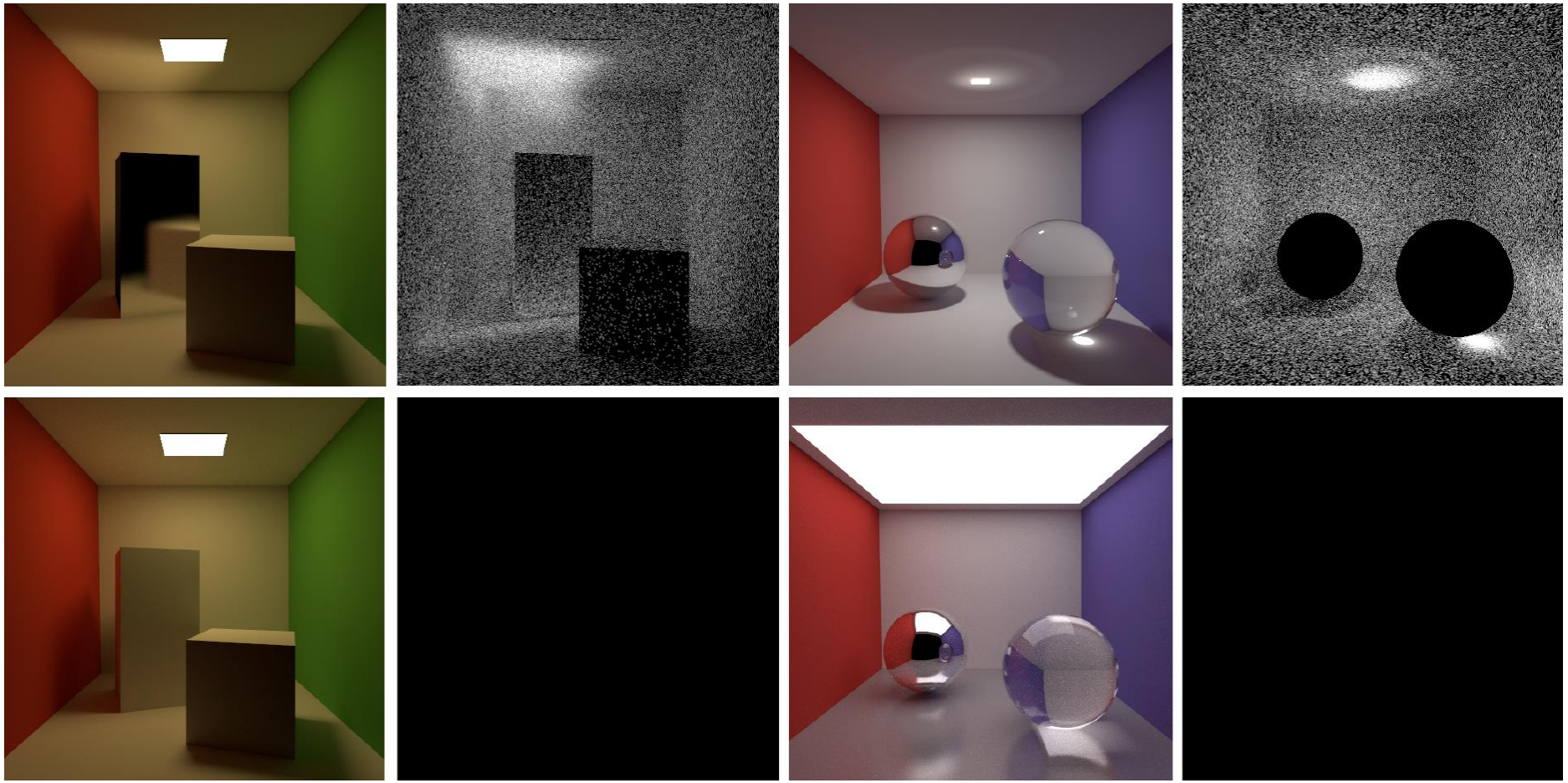
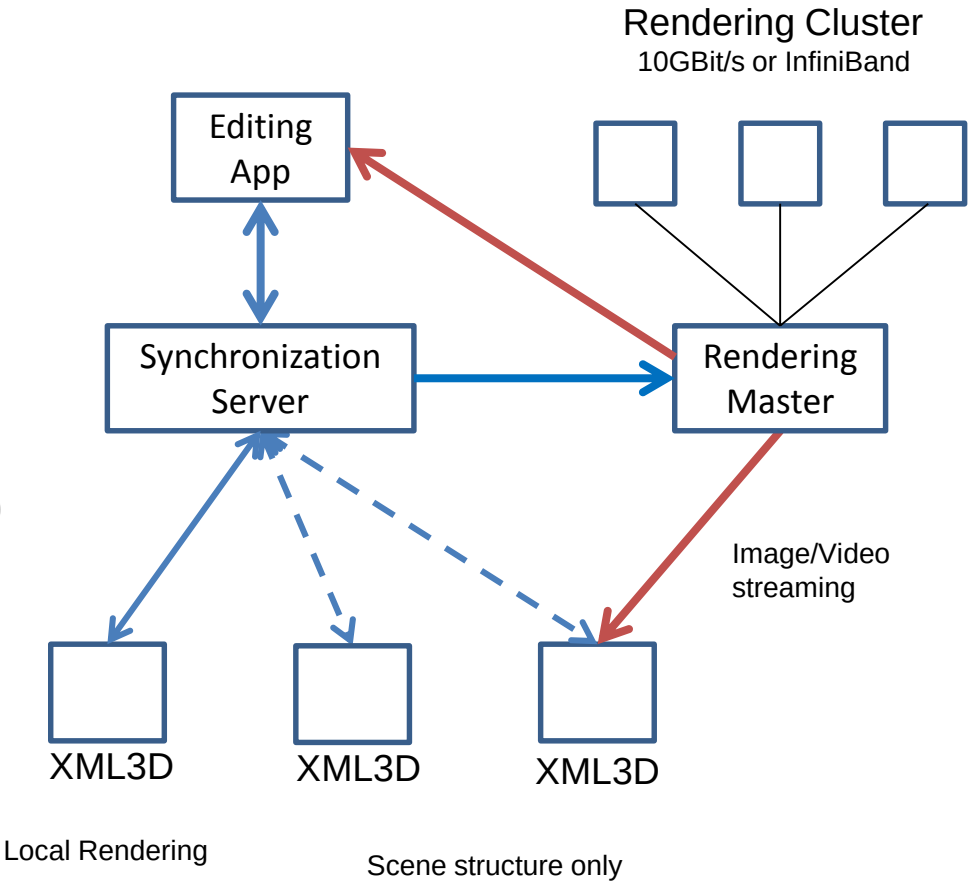


Dreamspace Renderer

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



Ultimate Goal

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