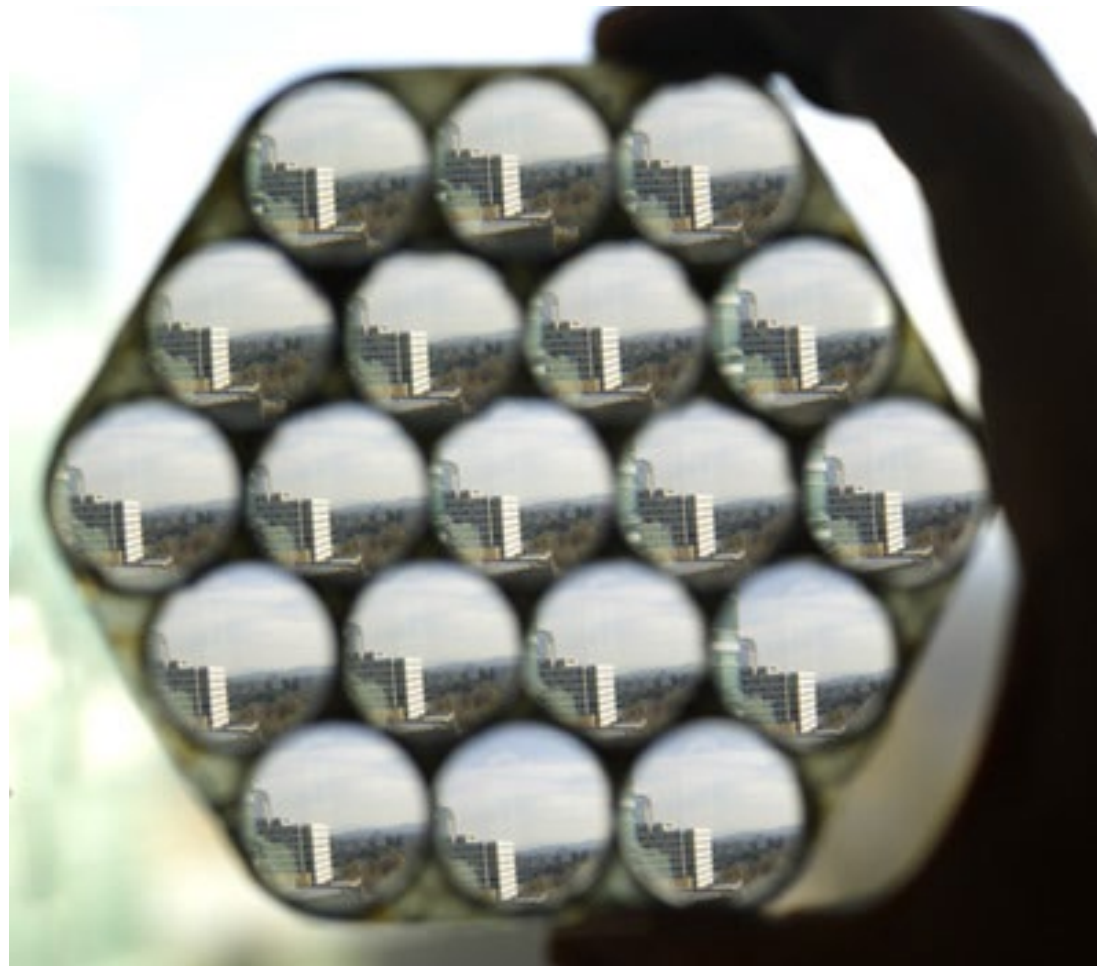


Wrap-up and discussion



15-463, 15-663, 15-862
Computational Photography
Fall 2025, Lecture 20

Course overview

1. Photographic optics and pipeline.	←	Lectures 2 – 4.
2. Exposure, HDR, and noise.	←	Lectures 5 – 7.
3. Color and image editing.	←	Lectures 8 – 10.
4. Focus and coded photography.	←	Lectures 11 – 13.
5. Radiometry and photometric stereo.	←	Lectures 14 – 15.
6. Geometry and stereo.	←	Lectures 16 – 18.
7. Computational light transport.	←	Lectures 19 – 21.

Photographic optics and pipeline

- pinhole and lens cameras
- lenses and other optical elements
- paraxial optics
- aperture
- image processing pipeline



Exposure, HDR, and noise

- exposure control
- high-dynamic-range imaging
- radiometric calibration
- noise modeling
- noise calibration



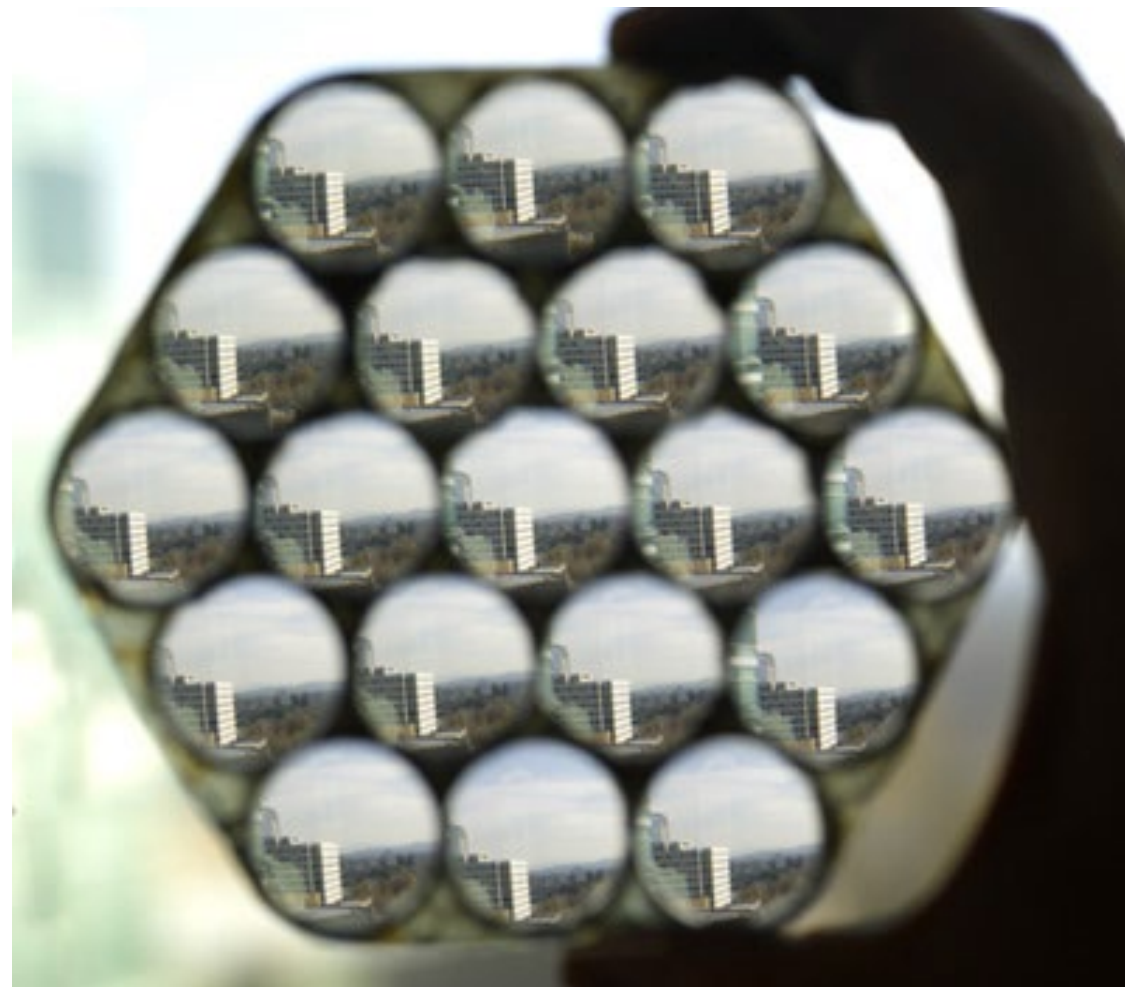
Color and image editing

- tonemapping
- color processing
- color calibration
- edge-aware and bilateral filtering
- gradient-domain processing
- Poisson integration



Focus and coded photography

- focal stacks
- depth from (de)focus and confocal stereo
- lightfields and lightfield processing
- plenoptic camera
- deconvolution and motion deblurring
- coded aperture
- coded exposure



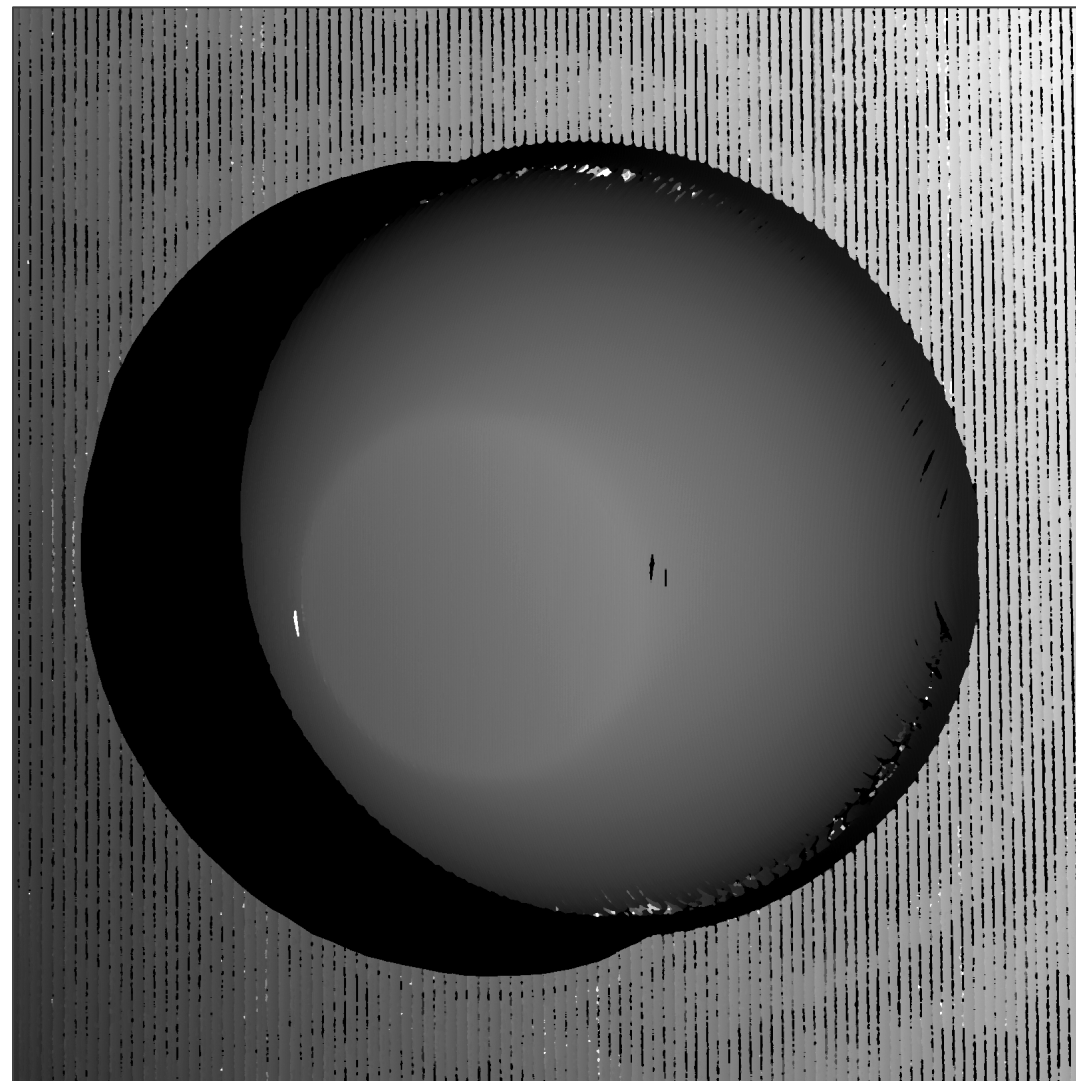
Radiometry and photometric stereo

- radiometry
- reflectance equation
- BRDF models
- illumination models
- calibrated photometric stereo
- uncalibrated photometric stereo



Geometry and stereo

- geometric camera models
- geometric camera calibration
- triangulation
- epipolar geometry
- stereo and disparity
- depth from lightfields
- structured light scanning



Things you should know how to do

1. Build simple pinhole cameras, use DSLR cameras and modern lenses.
2. Write your own LDR and HDR image processing pipelines.
3. Calibrate the radiometric, color, noise, and geometric properties of a camera.
4. Fuse images and perform flash/no-flash photography.
5. Use bilateral and gradient-domain filtering for image editing tasks.
6. Capture and refocus your own lightfields and focal stacks.
7. Build three different types of depth and shape sensing systems: depth-from-focus, photometric stereo, structured light.

Do you plan on taking any other vision/graphics courses?

If you are an undergraduate, check out the **graphics concentration**.

Background courses (ideally you should take both):

- 15-362 or 15-662 computer graphics.
- 16-385 or 16-720 or 16-820 computer vision.

More advanced courses directly relevant for computational photography and imaging:

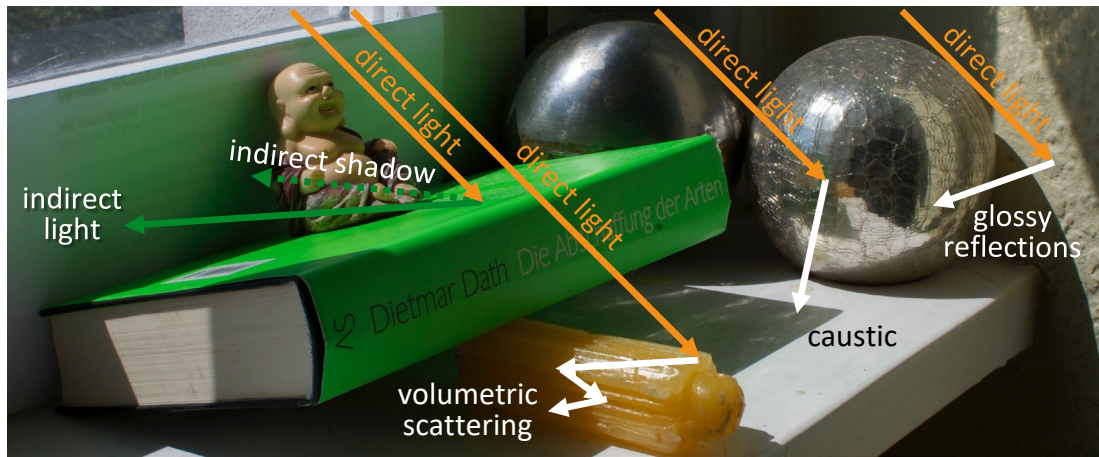
- **15-468 physics-based rendering – modeling, simulating, and inverting light transport.** ← Spring 2025, offered by Yannis
- 15-458 discrete differential geometry – background for 3D geometry processing and geometric optics.
- 16-822 geometry-based methods in vision – all about epipolar geometry.
- 16-825 learning for 3D vision – learning-based methods for 3D reconstruction.
- 16-726 learning-based image synthesis – learning-based variants of computational photography algorithms.
- 16-722 sensing and sensors – background on vision and other sensors and noise modeling.
- 18-453 introduction to XR systems – displays and augmented or virtual reality technologies.
- 33-353 intermediate optics – wave optics, hands-on experience with optical components.
- 18-416 nano-bio-photonics – modern photonics systems and applications to biology.

More general vision (left) and graphics (right):

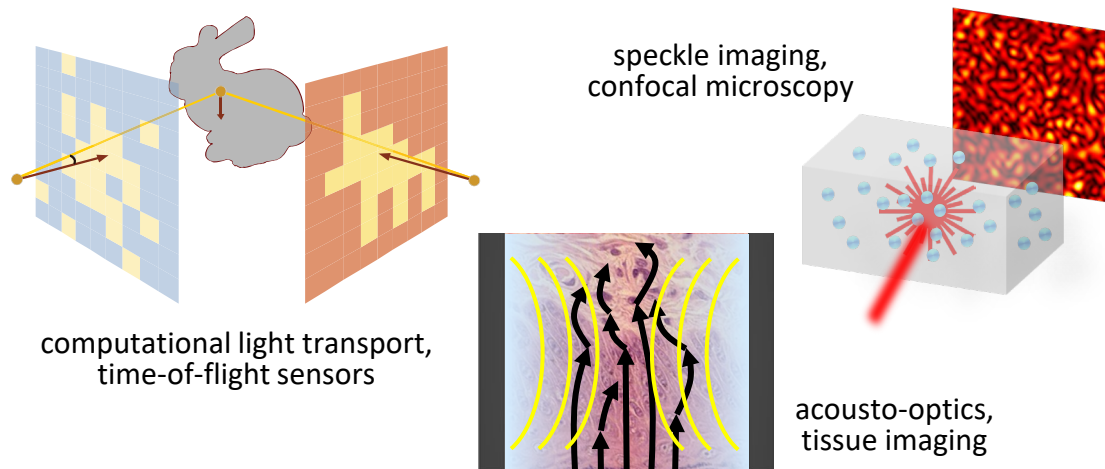
- | | |
|---|---|
| • 16-824 visual learning and recognition | • 15-365 experimental animation |
| • 10-703 deep reinforcement learning | • 15-327 Monte Carlo methods and applications |
| • 16-831 statistical techniques in robotics | • 15-464 technical animation |
| • 16-833 robot localization and mapping | • 15-769 physically-based animation |
| • 16-881 deep reinforcement learning for robotics | • 15-466 computer game programming |
| | • 15-469 algorithmic textiles design |

15-468, 15-668, 15-868 Physics-based Rendering

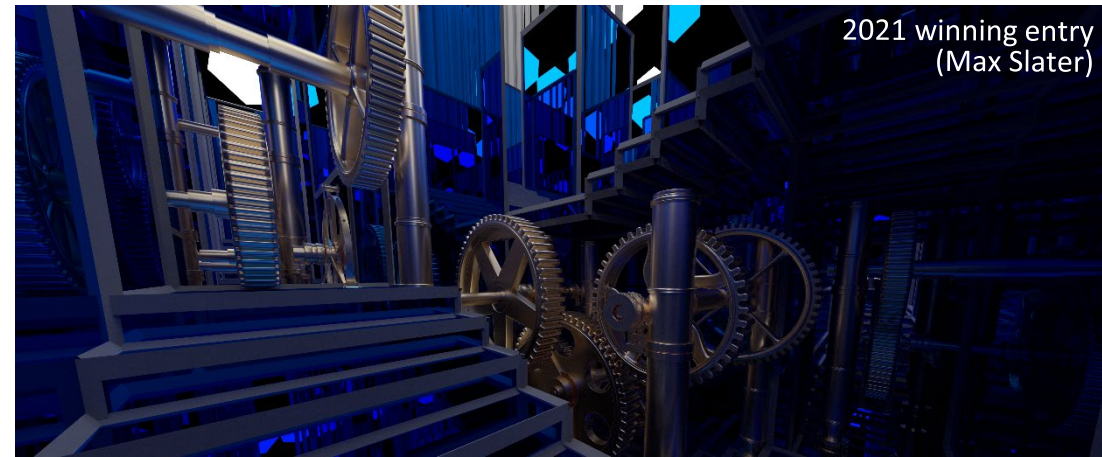
Learn all about modeling, simulating, differentiating, and inverting light!



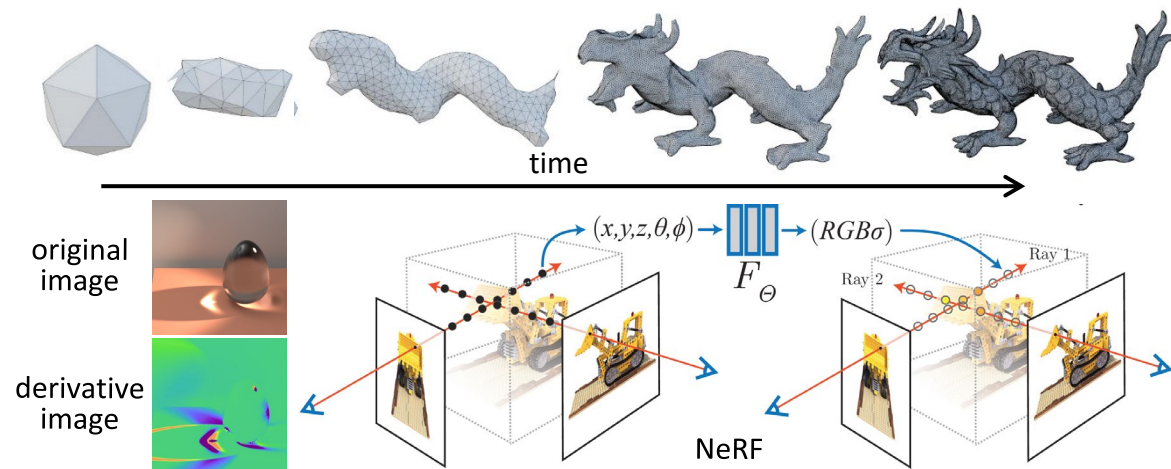
theory and simulation of light transport



scientific imaging applications



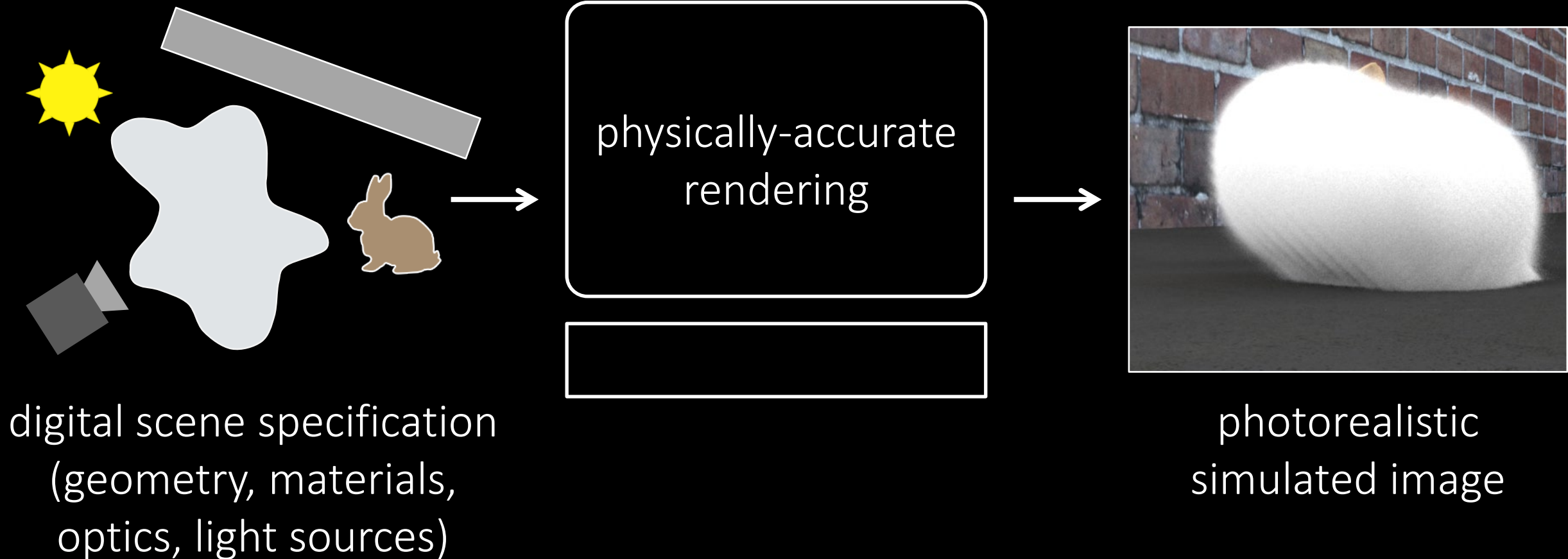
rendering competition (win free SIGGRAPH registrations!)



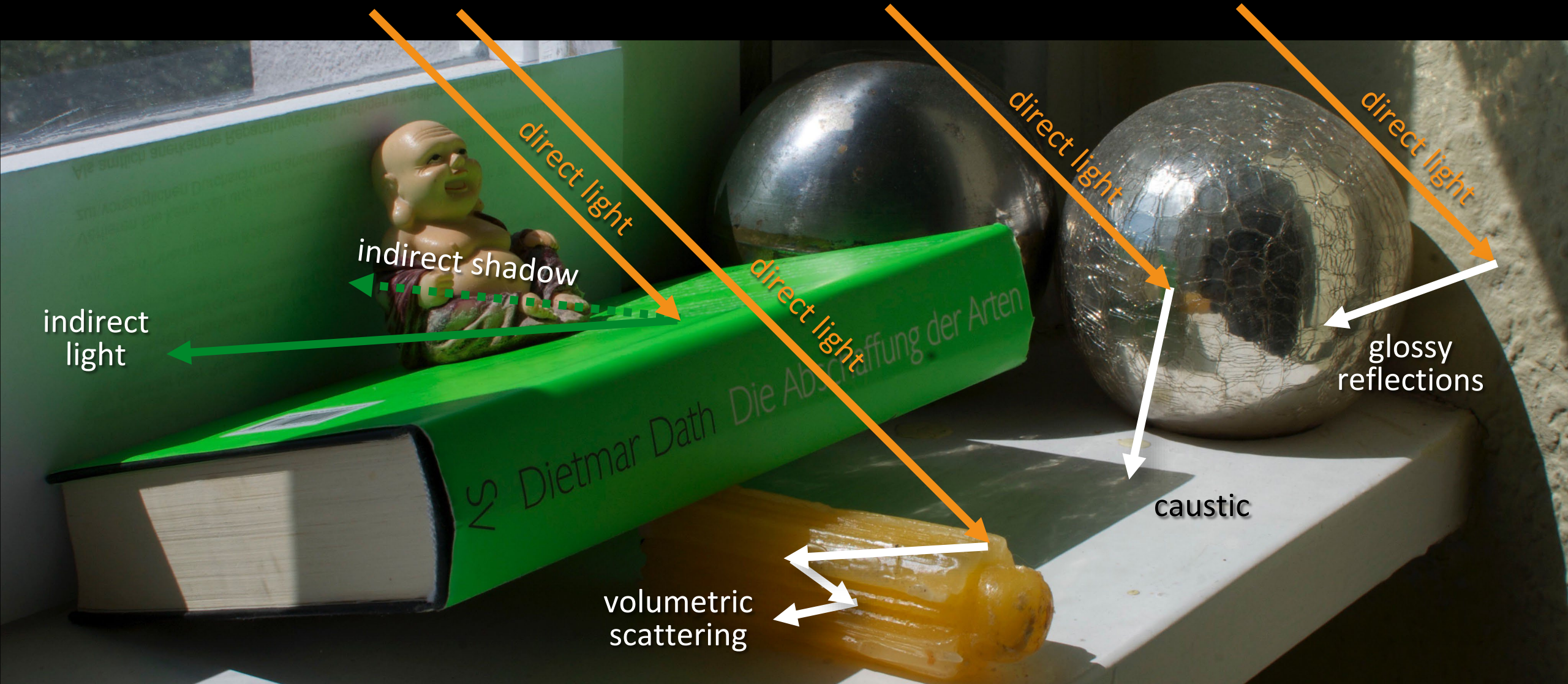
differentiable, inverse, and neural rendering

<http://graphics.cs.cmu.edu/courses/15-468/>

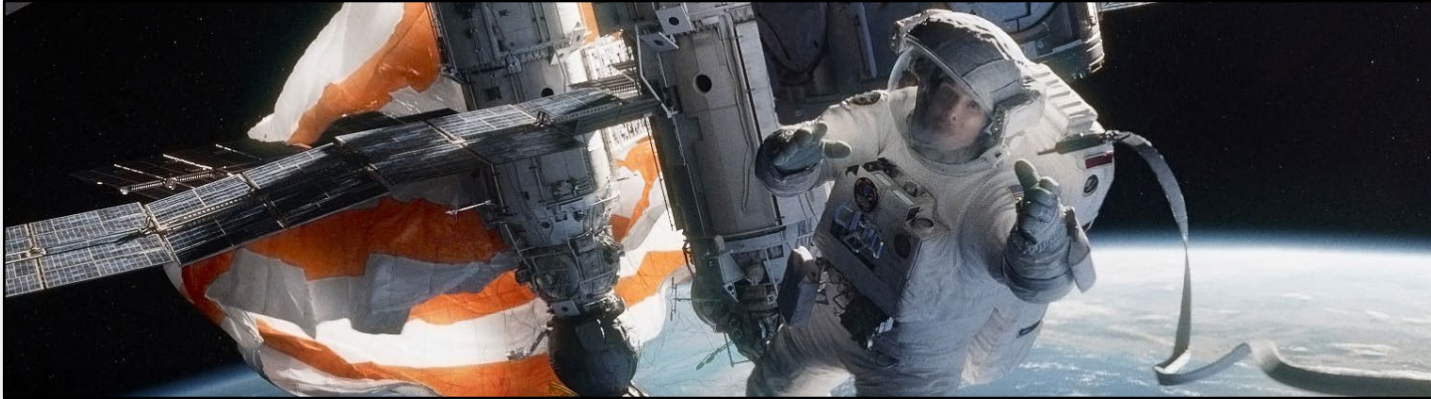
Forward rendering



Light transport in the real world



Ray tracing in production



Arnold Renderer

SOLIDANGLE

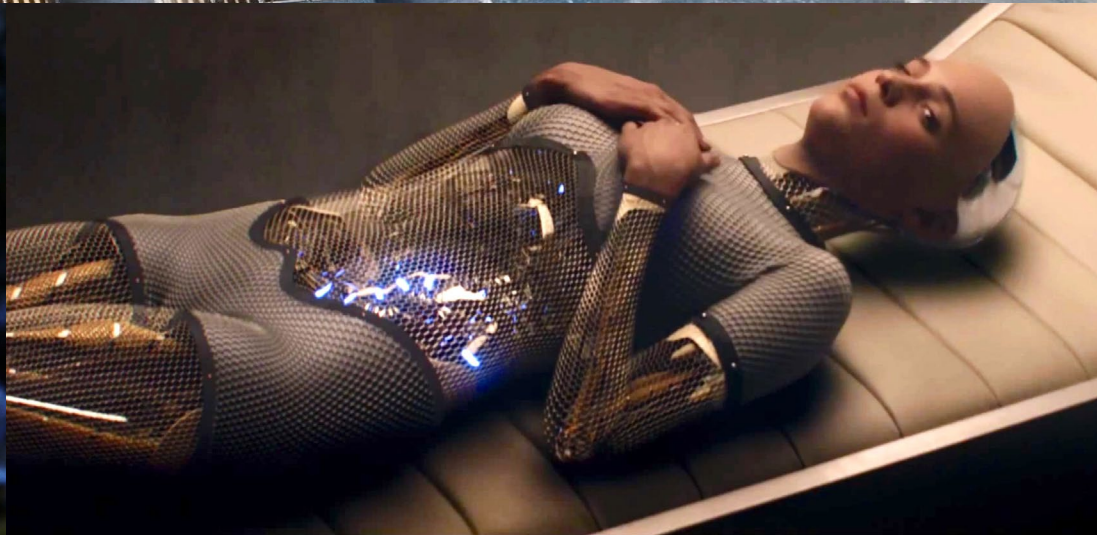


PIXAR's
RenderMan



Hyperion

Visual effects



Animated films



Video games



Architectural visualization



Advertising & E-commerce

VANJA

Dish towel, assorted patterns white/black

\$4.99 / 2 pack

PANNÅ

Place mat, turquoise

\$1.99

RASKOG
Utility cart

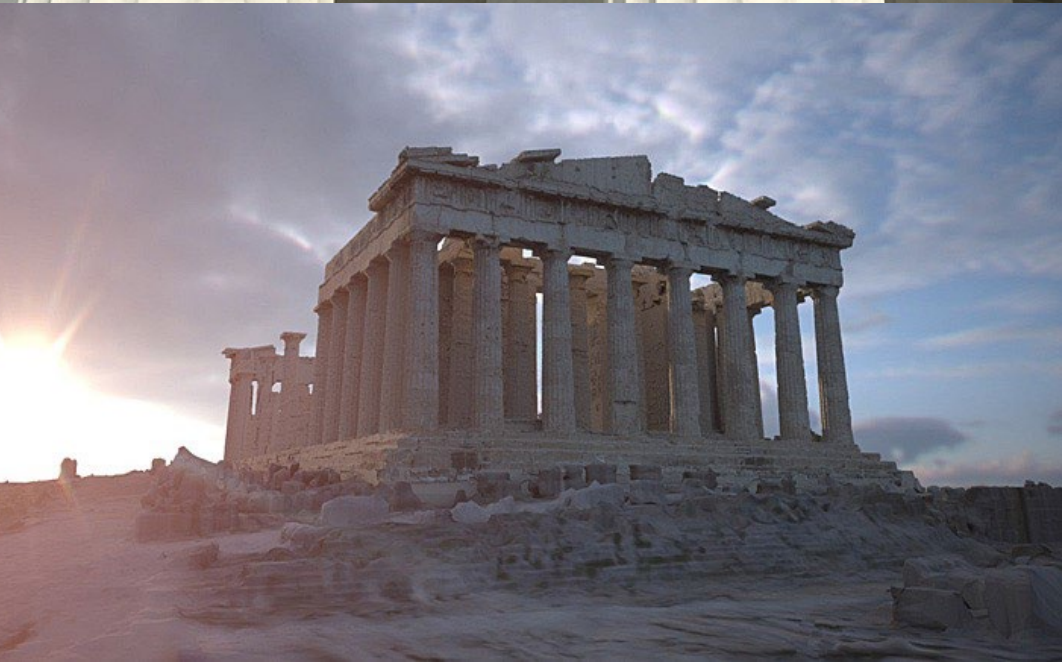
\$29.99

LAPPLJUNG RUTA

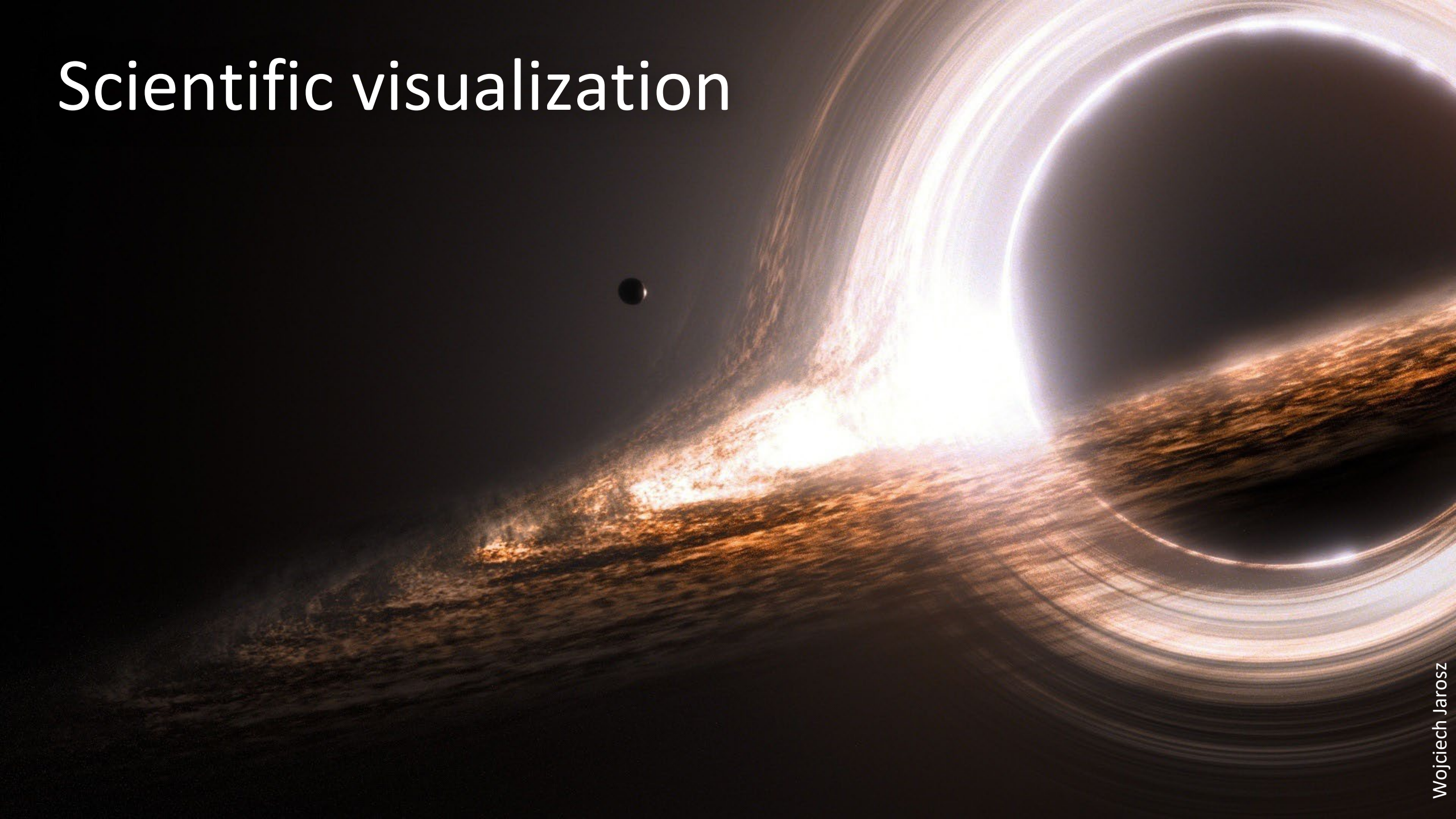
Rug, low pile, white, black

\$79.99



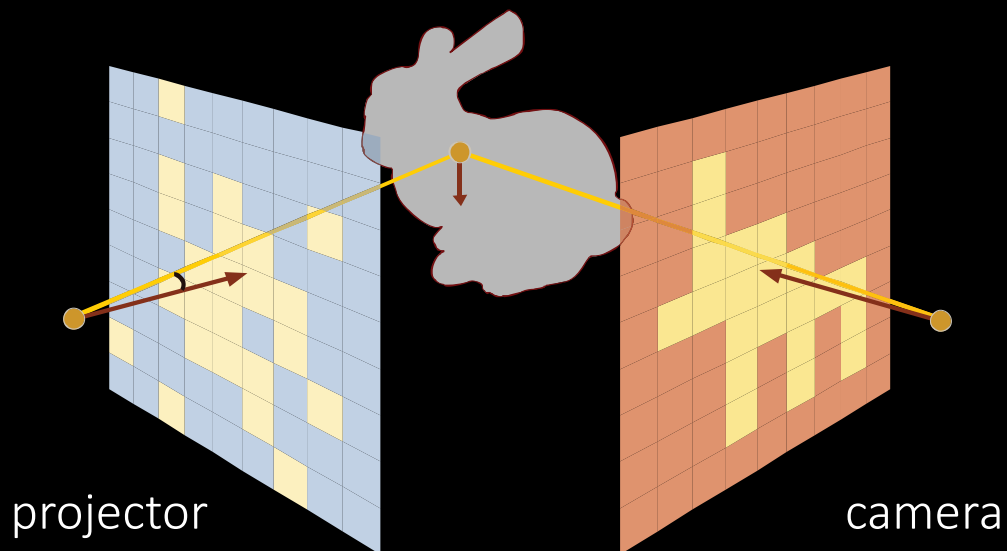


Scientific visualization



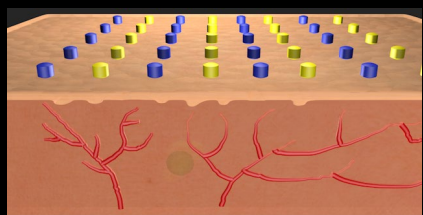
Scientific imaging

rendering computational light transport

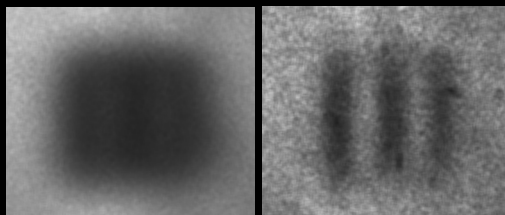


Used by CMU imaging projects:

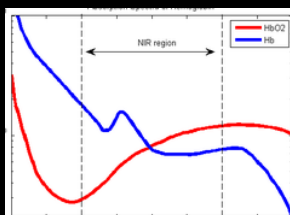
convolutional DOT



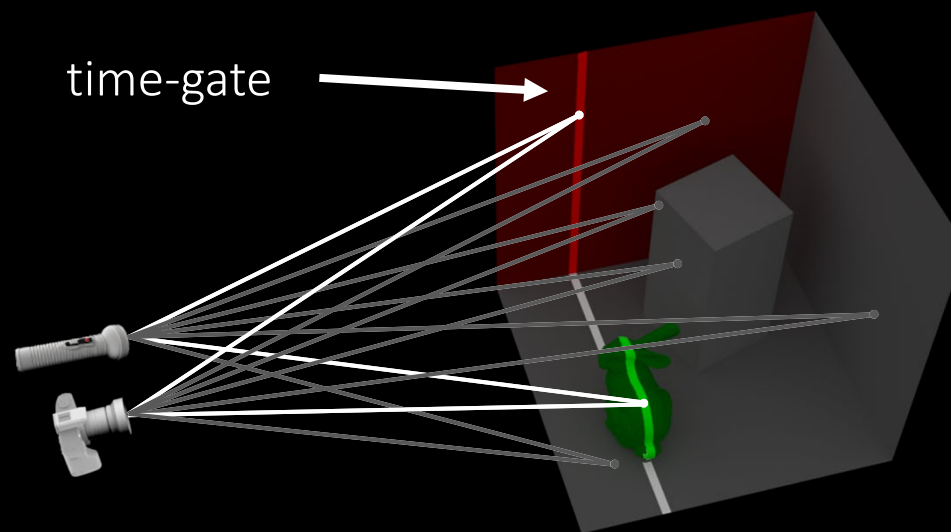
coded coherence



coded spectrum

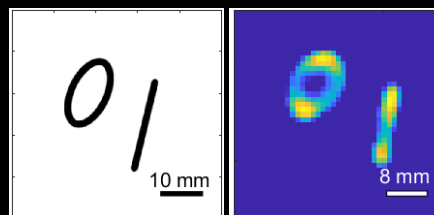


rendering time-of-flight sensors

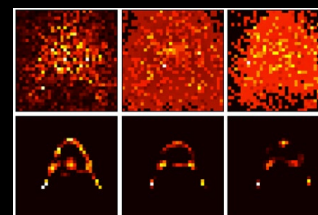


Used by CMU imaging projects:

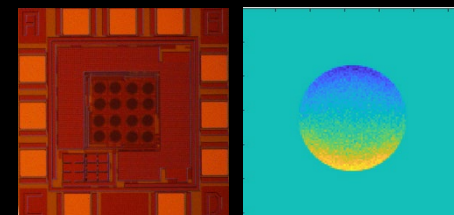
ToF DOT



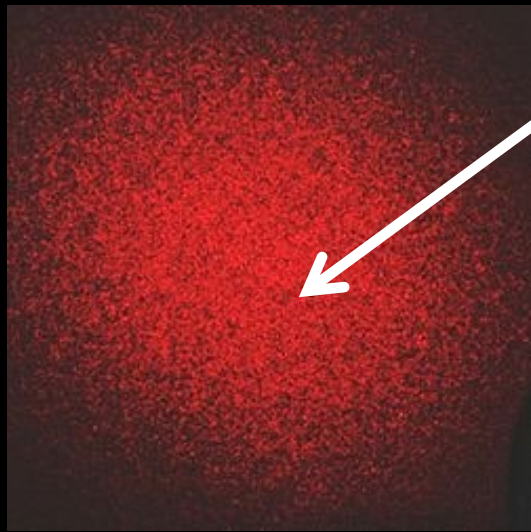
all-photon imag.



differential SPAD

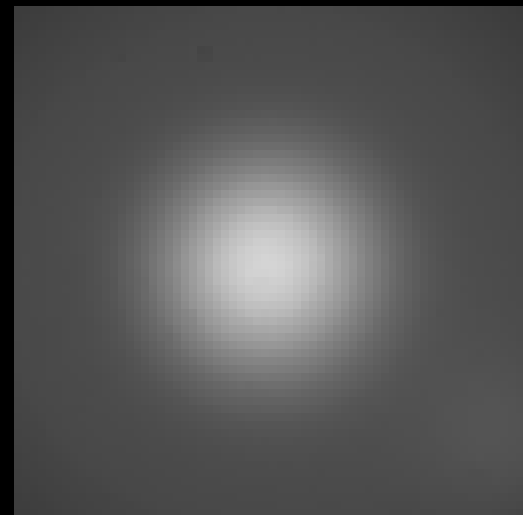


Rendering wave effects

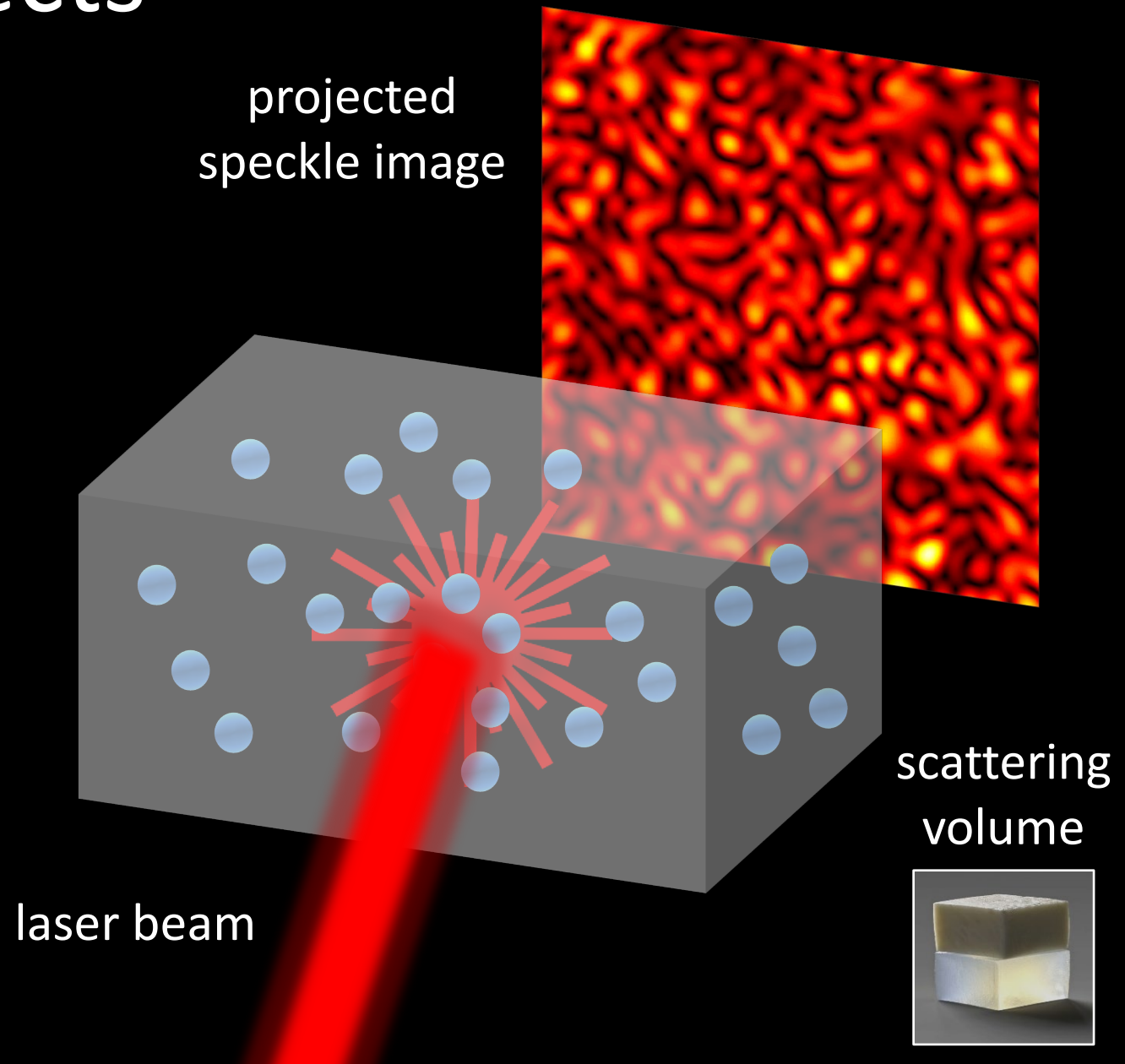


speckle: noise-like pattern

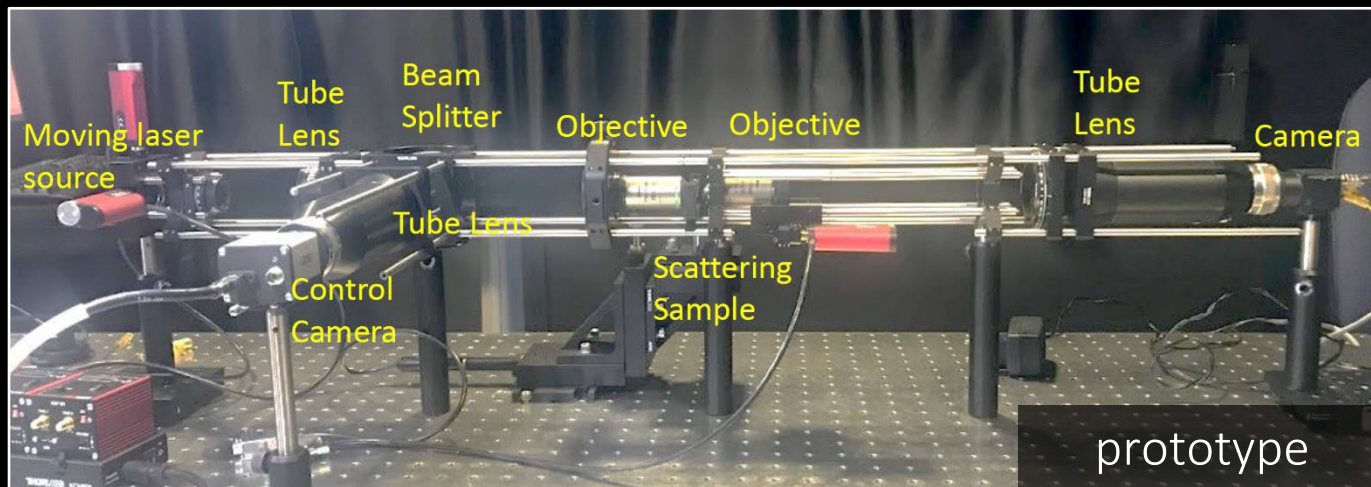
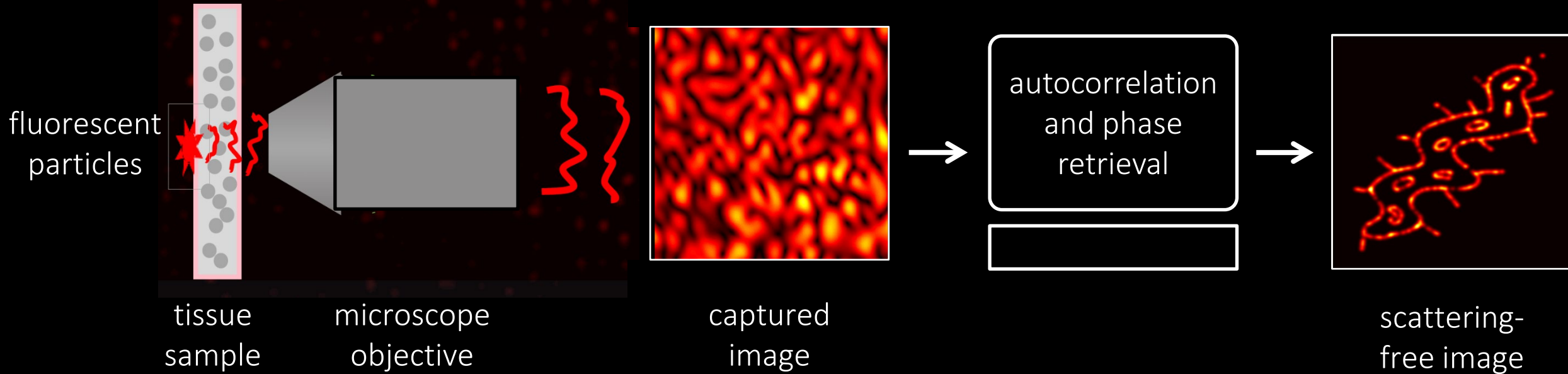
what real laser images look like



what standard rendered images look like



Application: fluorescence Microscopy

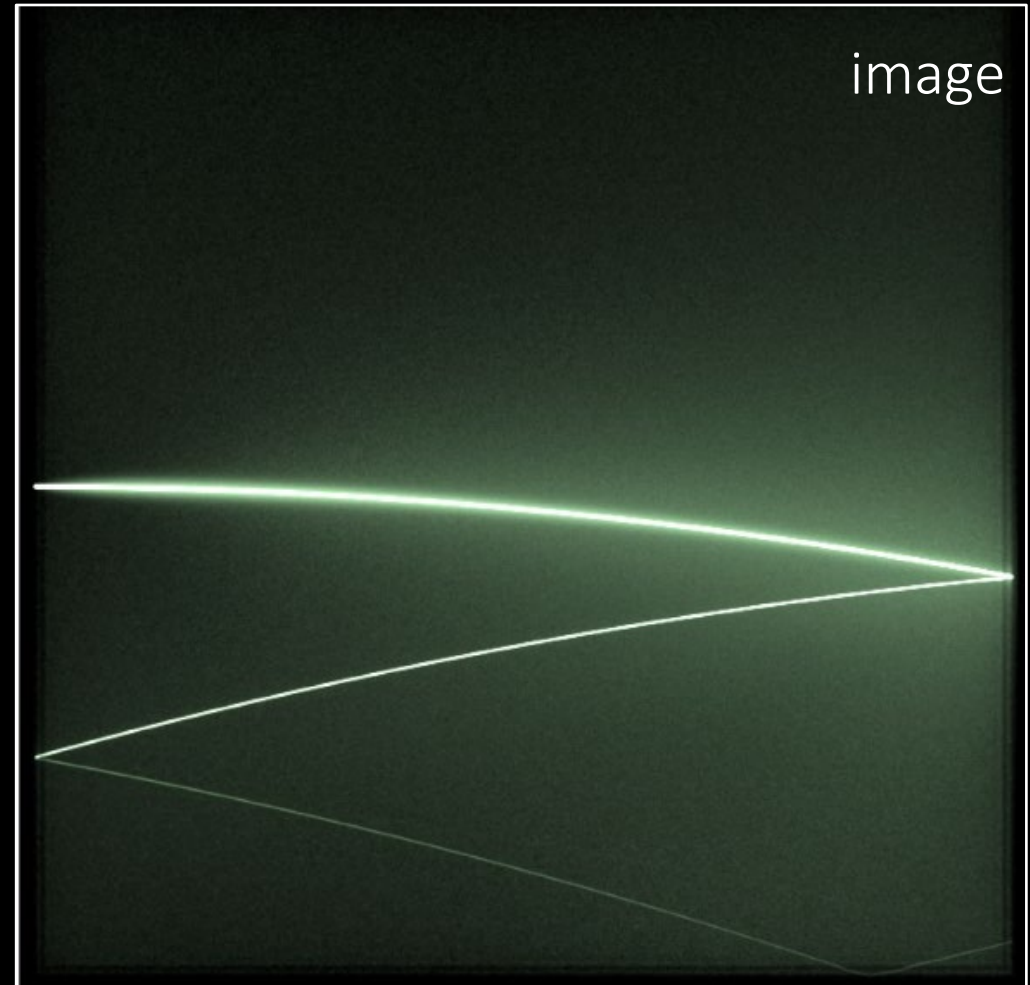
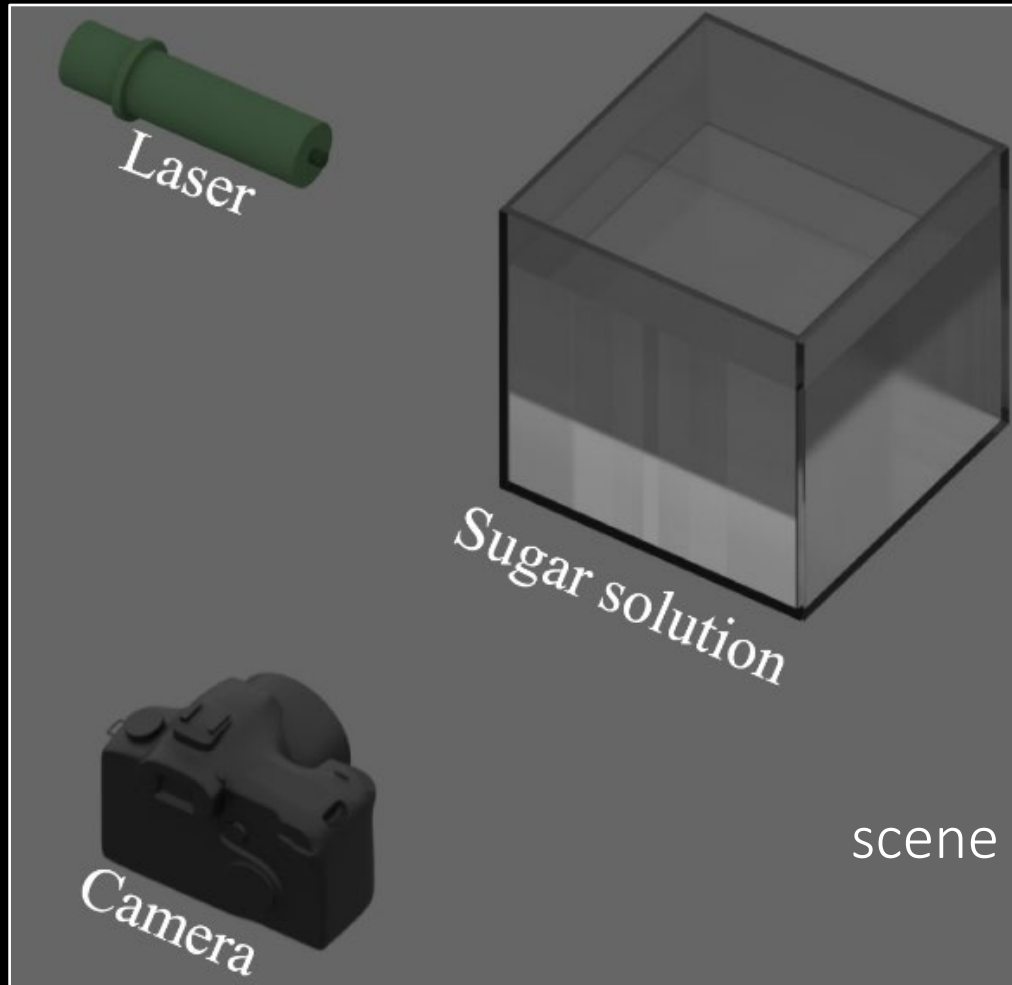


Performance strongly depends on:

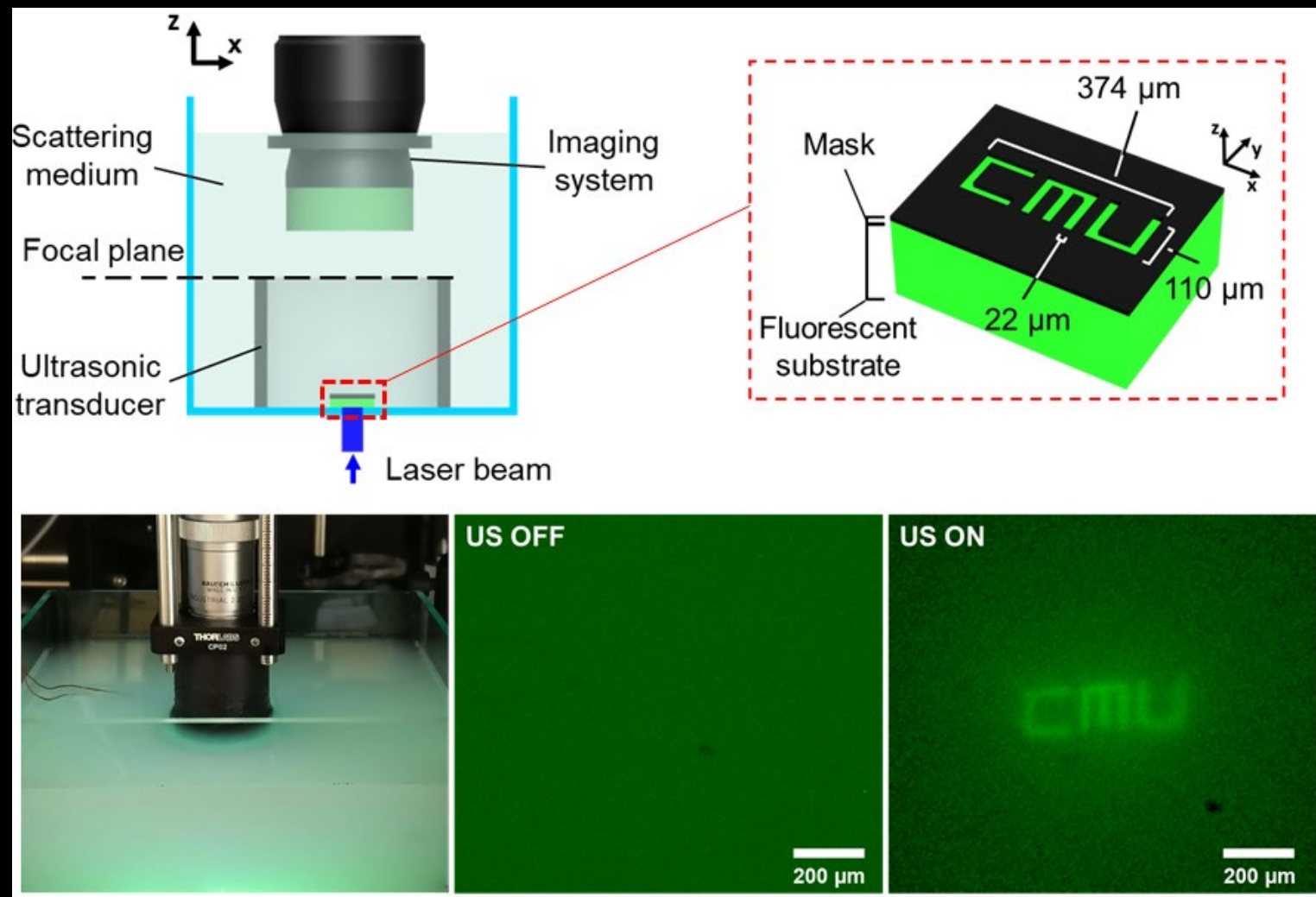
- speckle statistics
- image priors
- tissue parameters

Rendering-assisted exploration and new algorithms!

Rendering eikonal transport



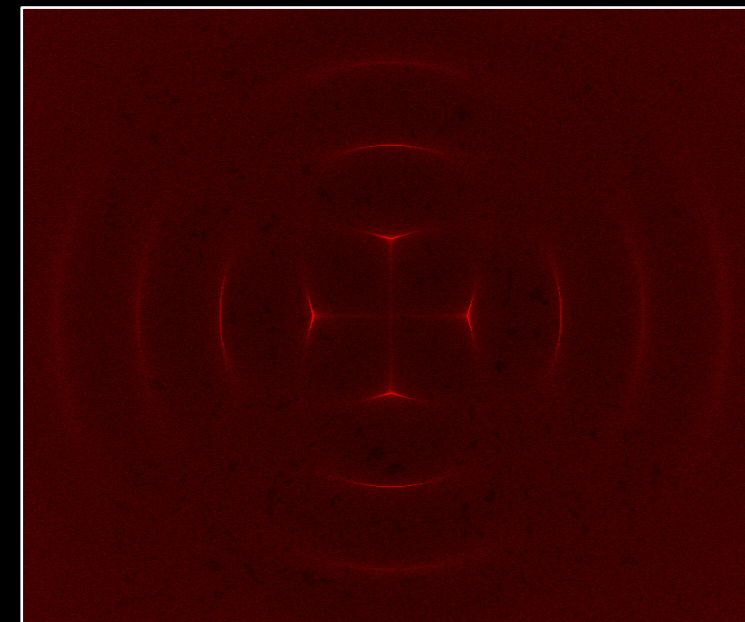
Application: acousto-optics



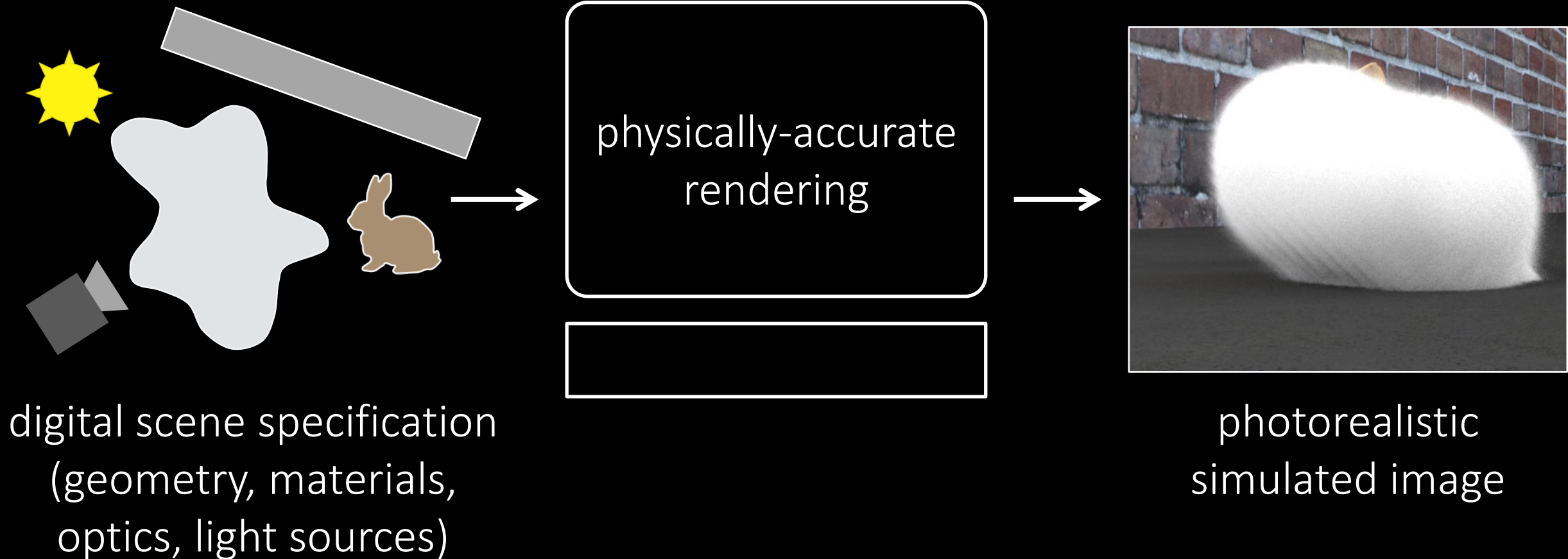
real capture



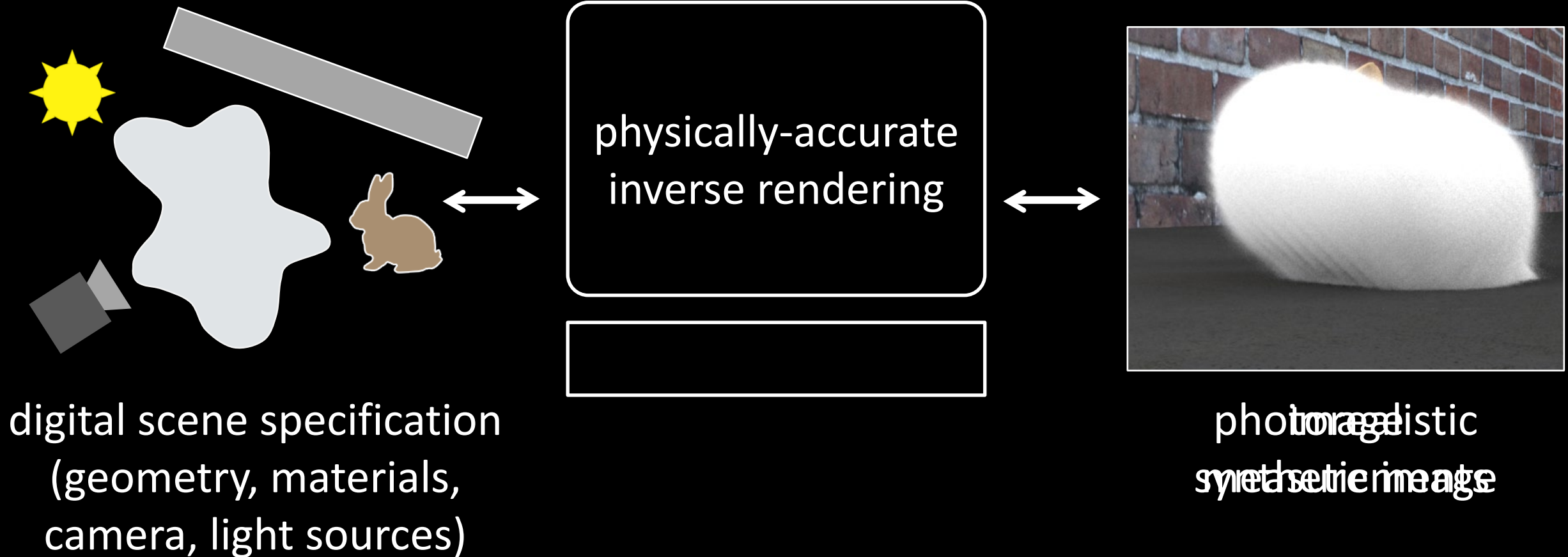
our algorithm



Forward rendering

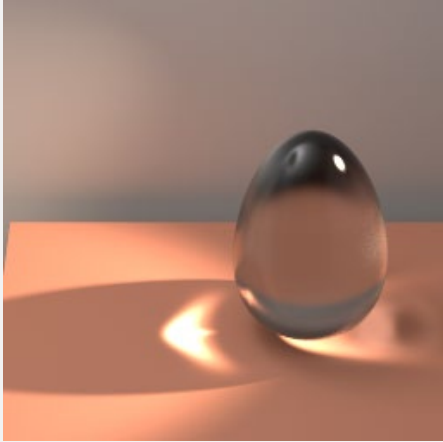


Inverse rendering

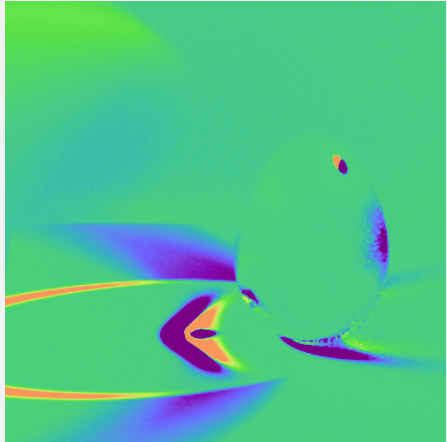


Differentiable rendering

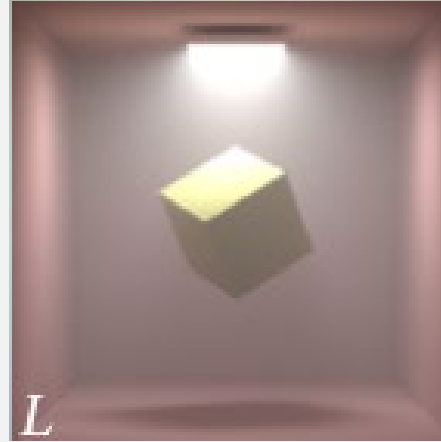
Original image



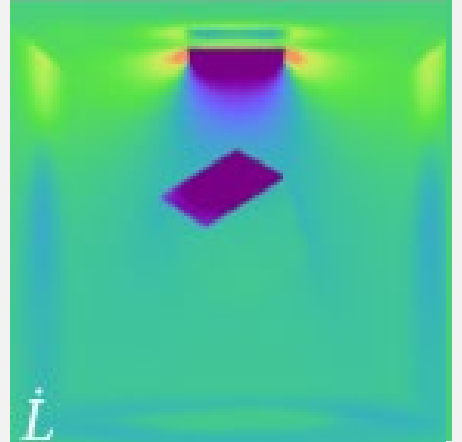
Derivative image



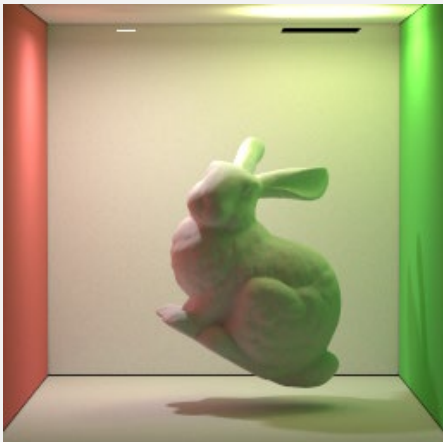
Original image



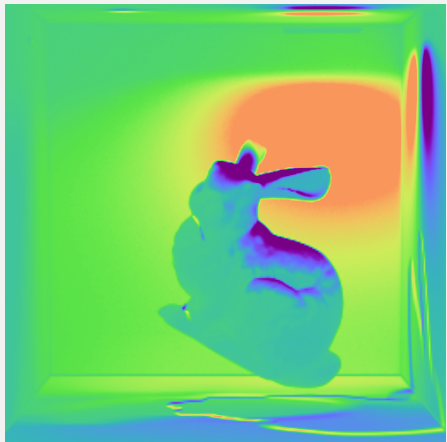
Derivative image



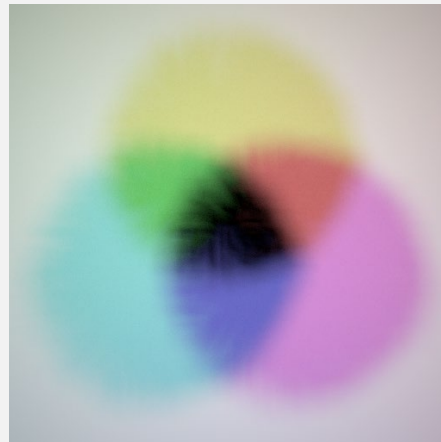
Original image



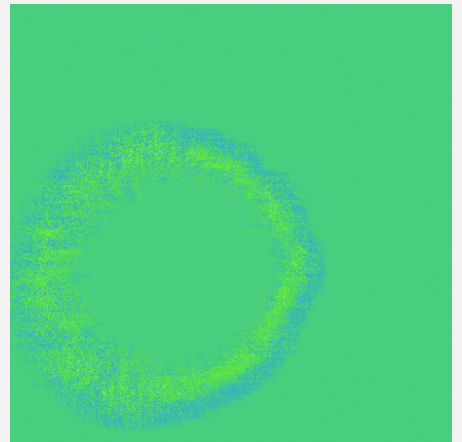
Derivative image



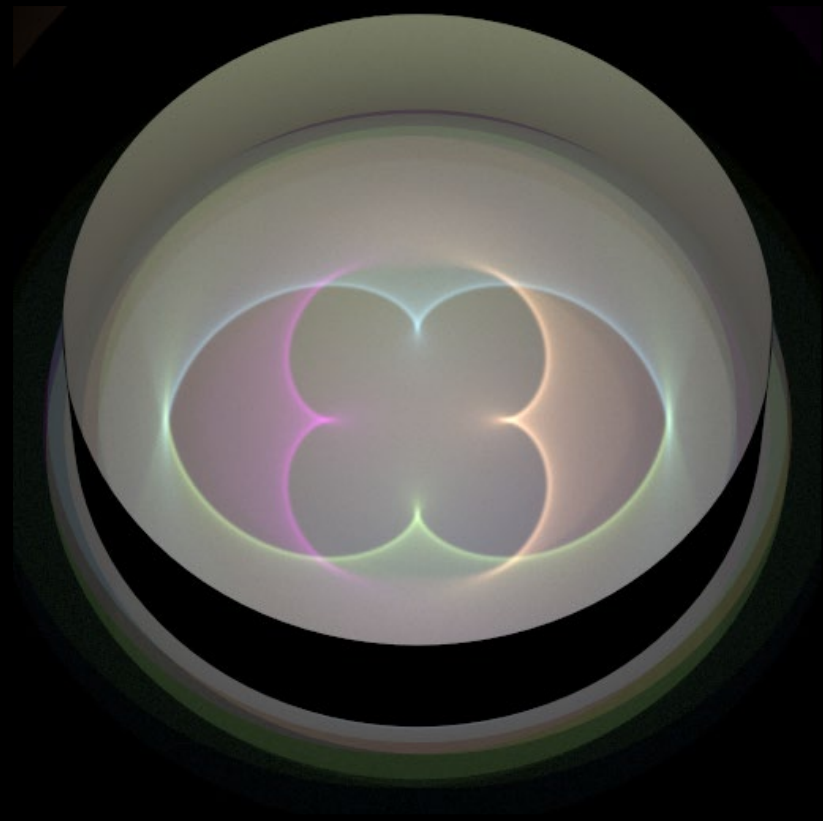
Original image



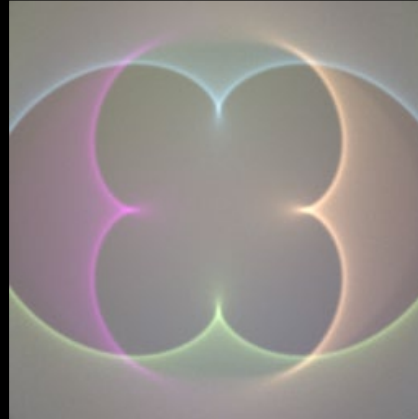
Derivative image



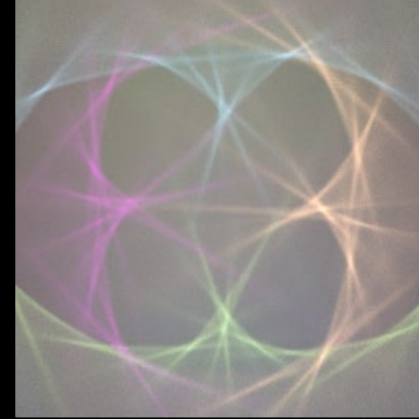
Application: shape optimization



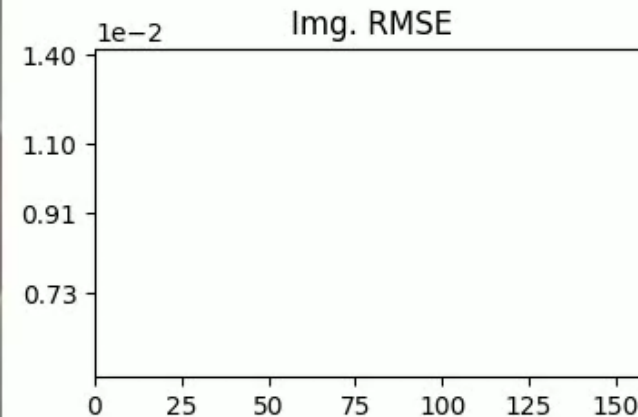
Initial



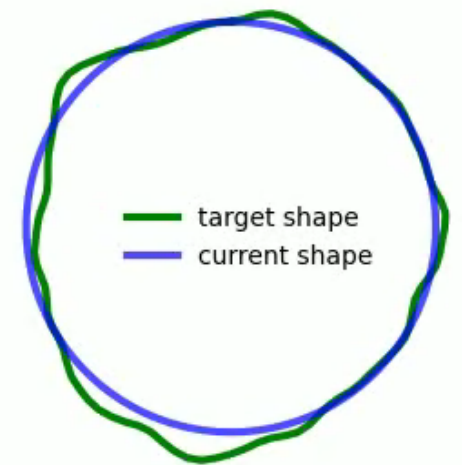
Target image



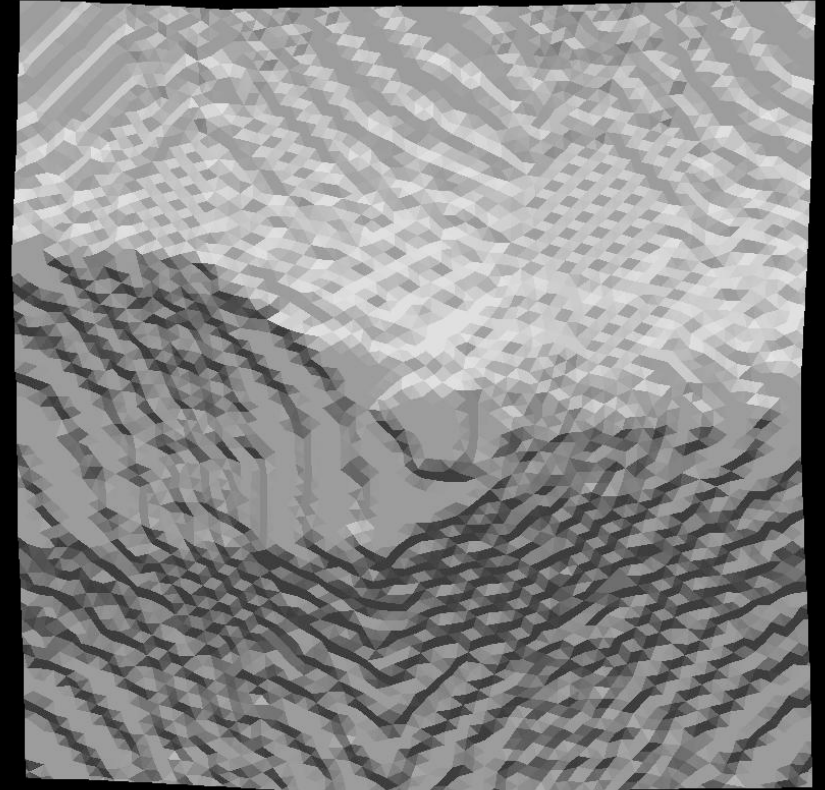
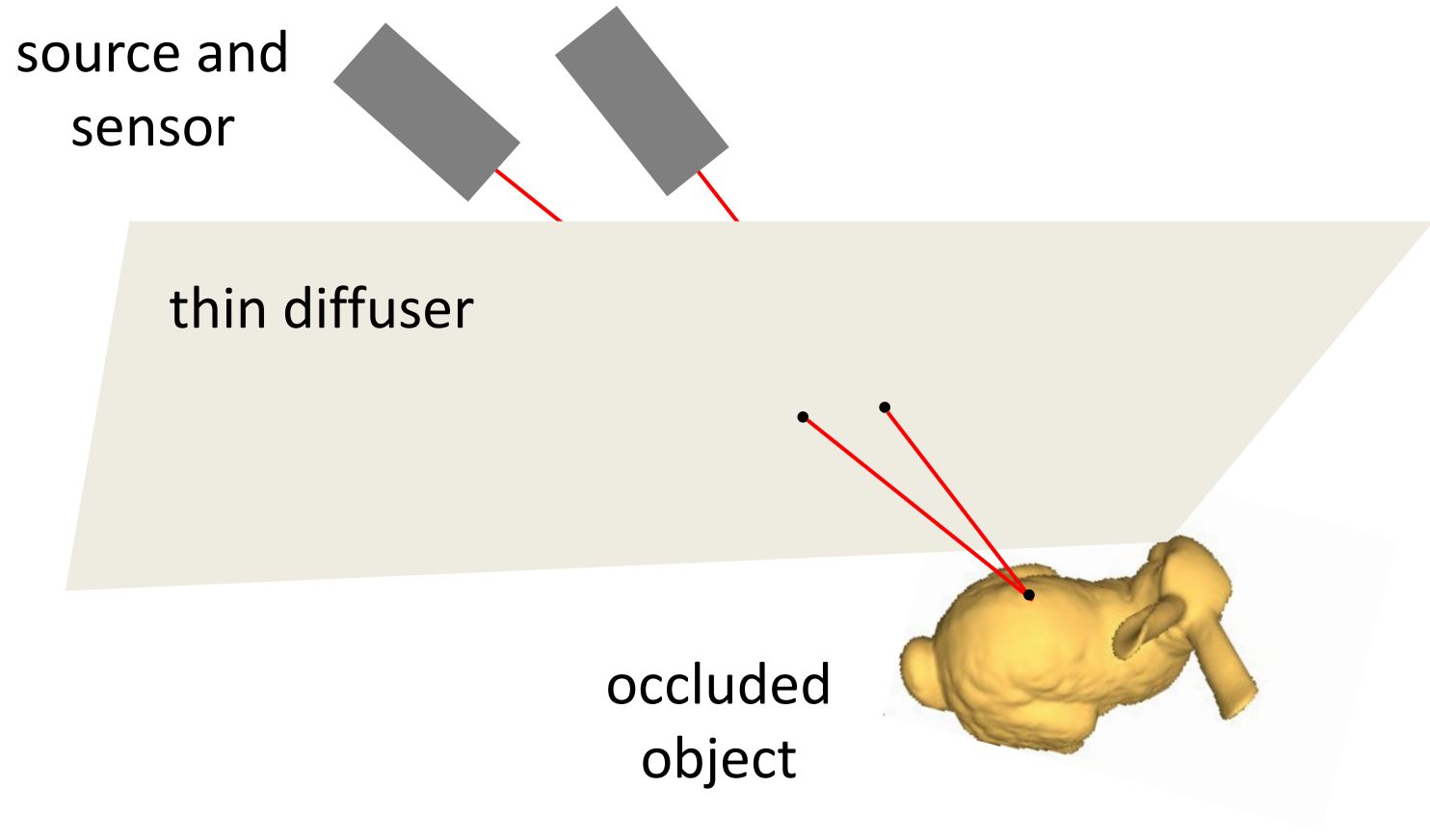
Iter #0



Cross-sectional shape
(displacement $\times 20$)

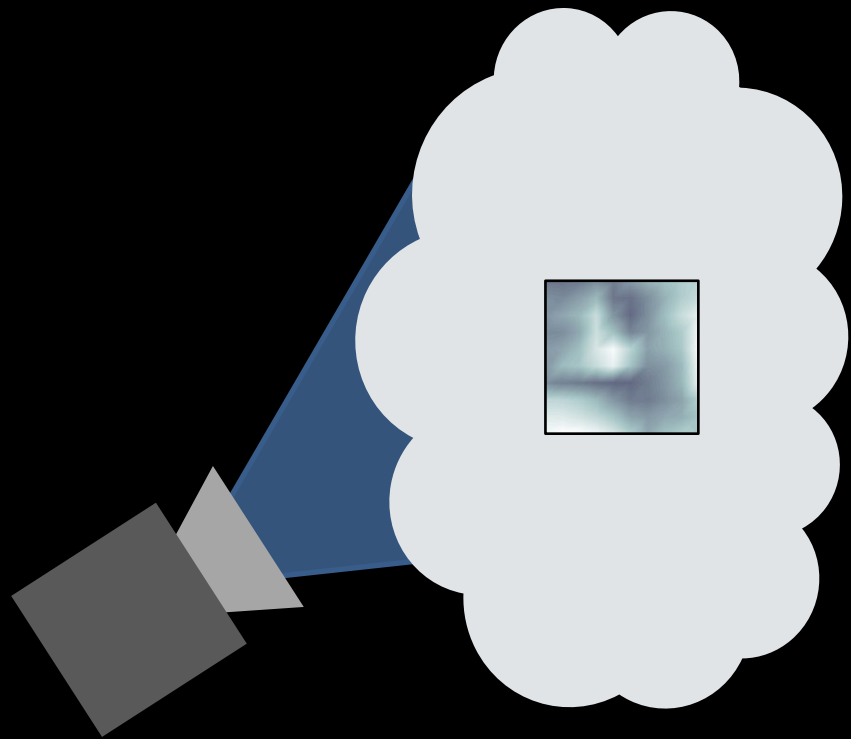


Application: non-line-of-sight imaging



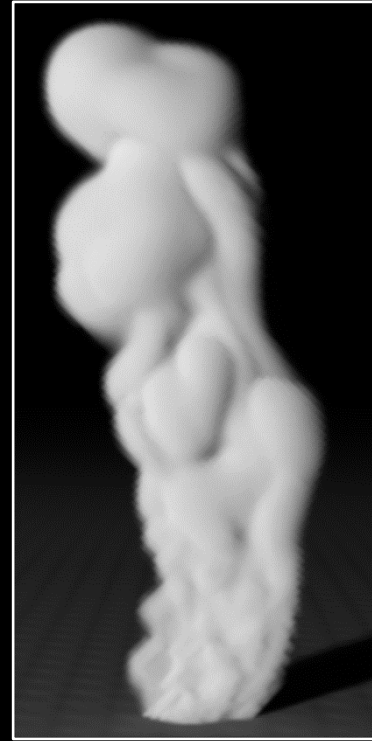
reconstruction evolution

Application: non-invasive tomography



camera

thick smoke cloud



simulated camera
measurements

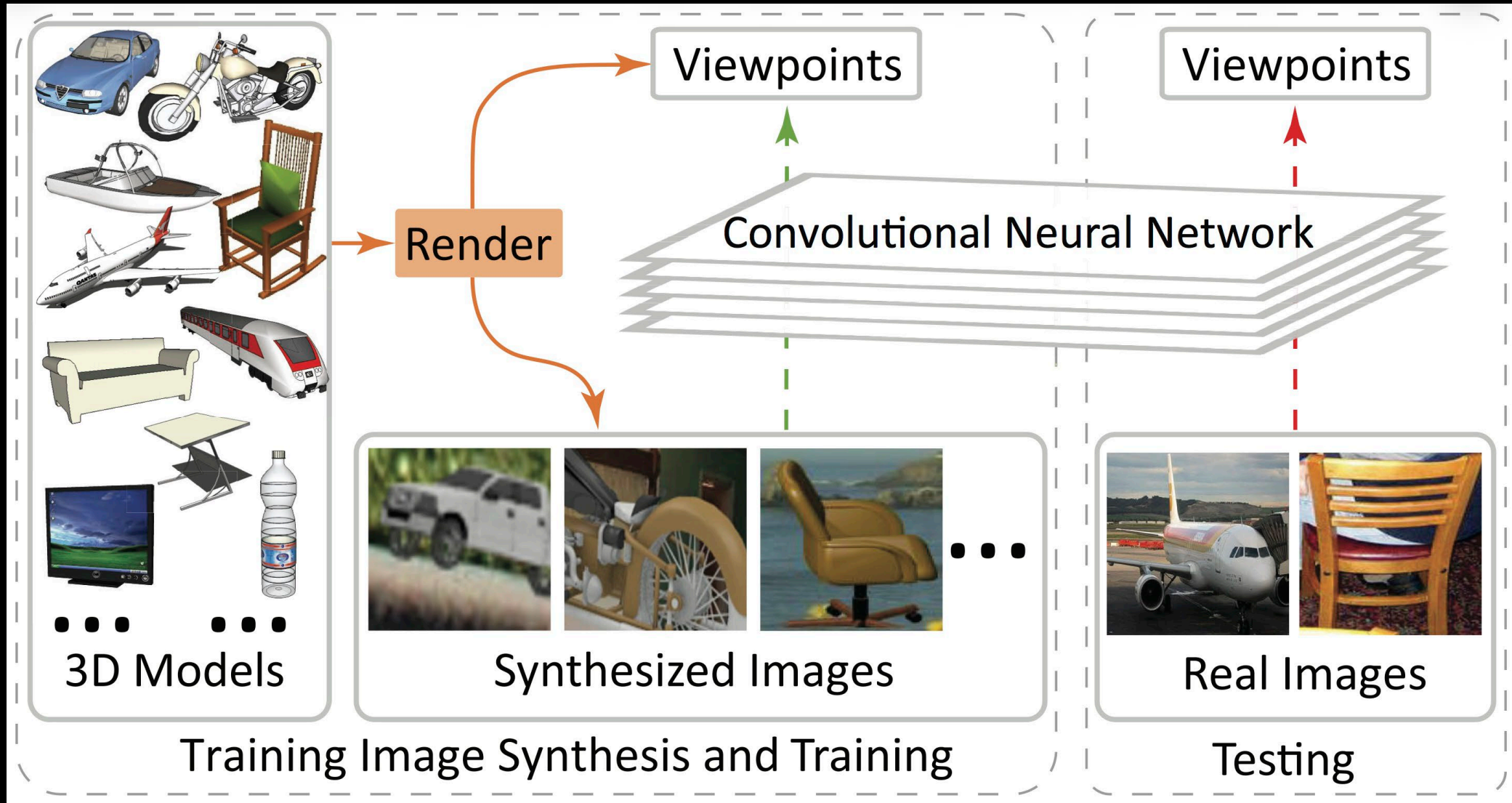


reconstructed cloud
volume



slice through
the cloud

Application: vision and machine learning



Application: neural rendering



Topics to be covered

Basics of ray tracing:

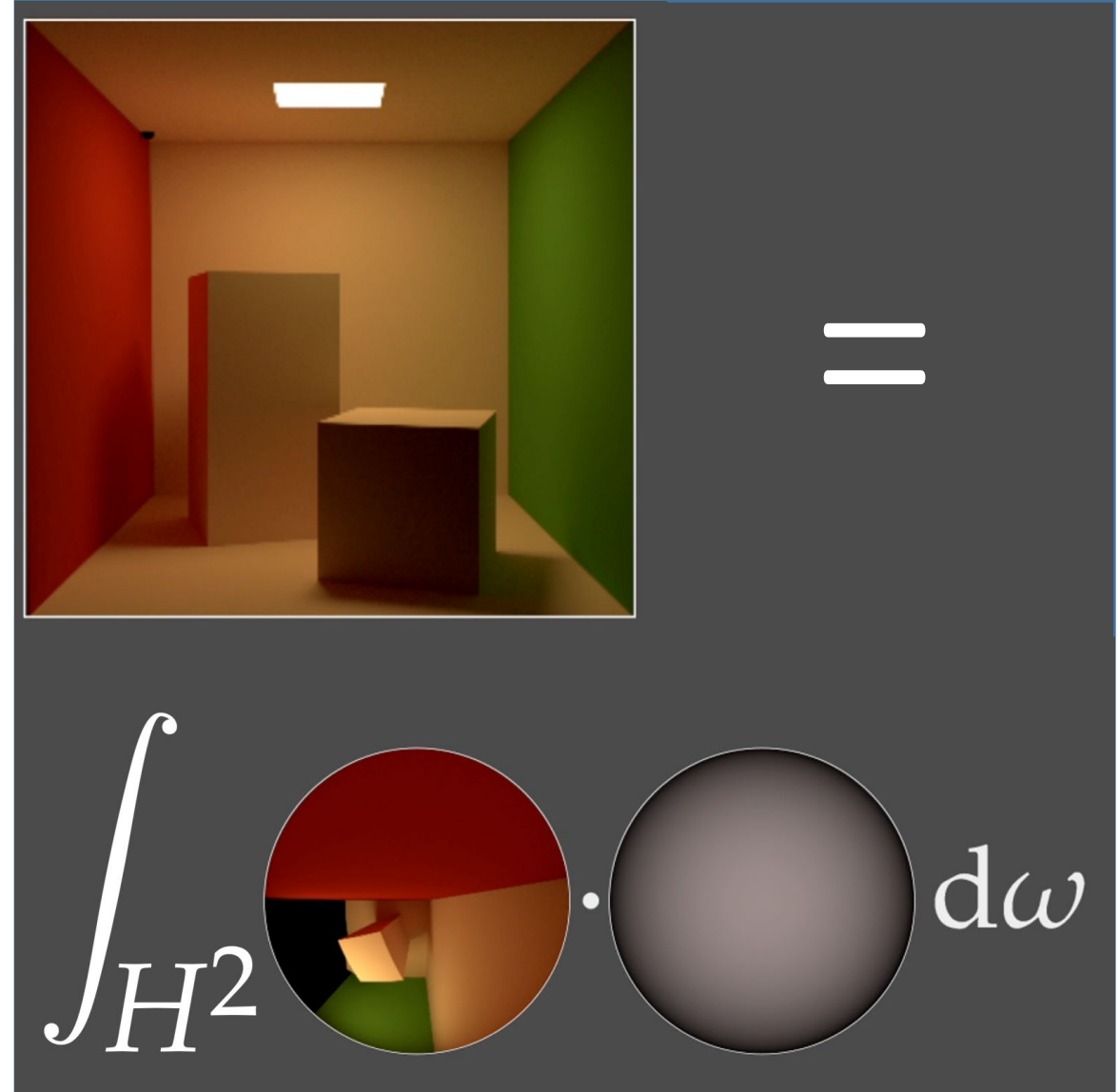
- trace-intersect recursions
- basic camera and illumination models
- shading
- intersection queries
- texture mapping



Topics to be covered

Theory of light transport and materials:

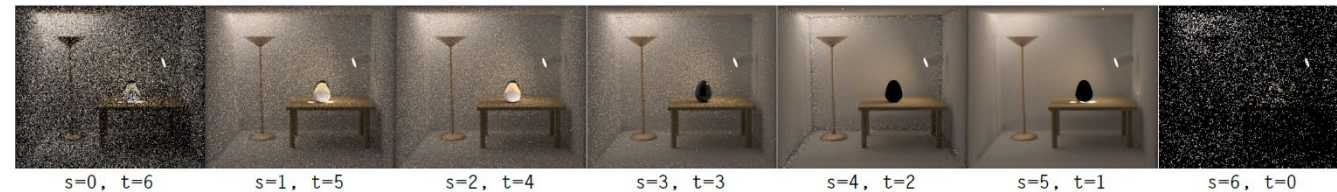
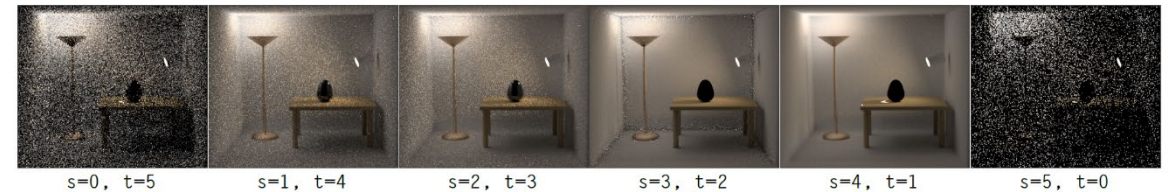
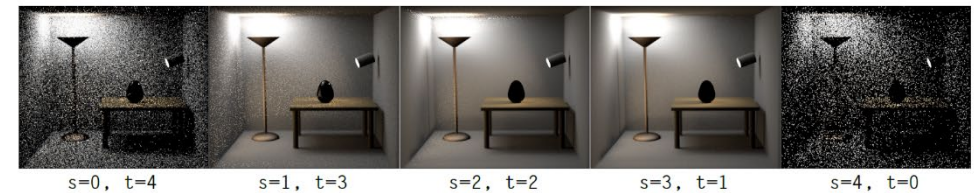
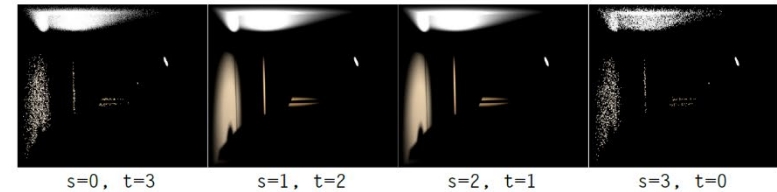
- rendering equation
- radiative transfer equation
- path integral formulations
- microfacet reflectance models
- statistical scattering models



Topics to be covered

Monte Carlo rendering algorithms:

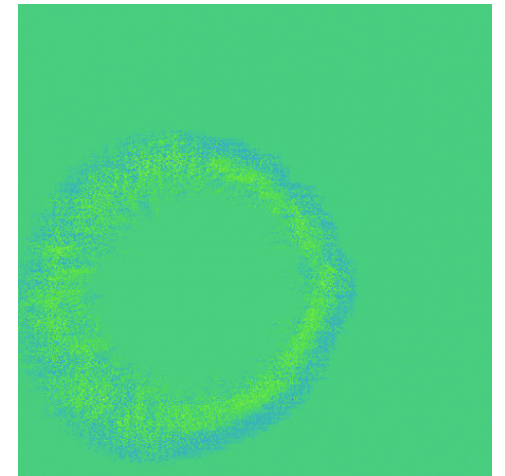
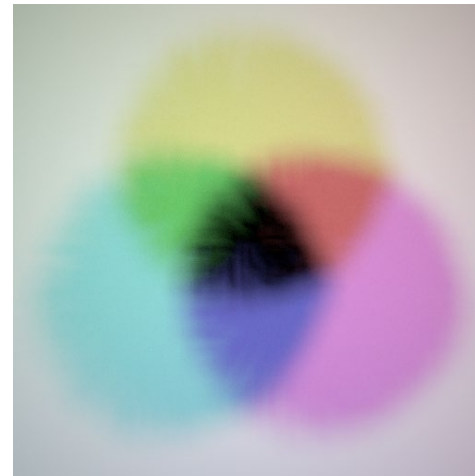
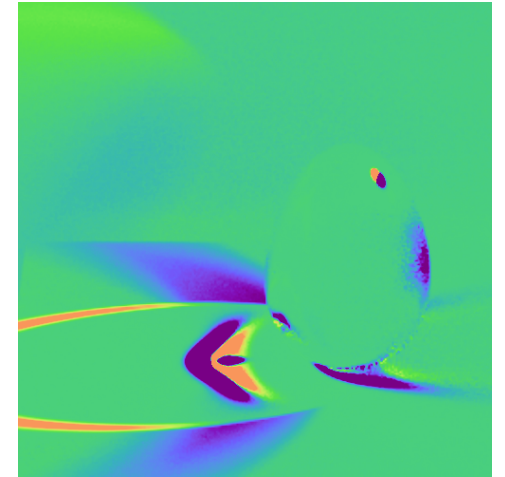
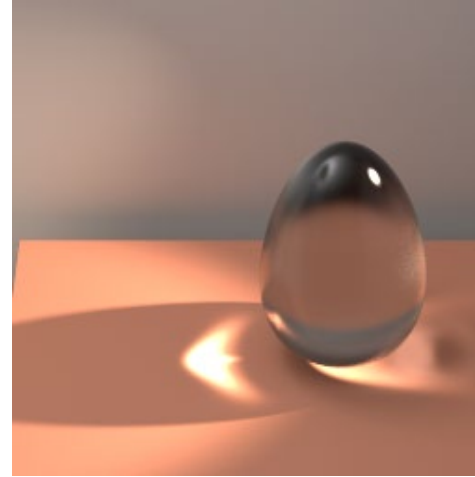
- unidirectional and bidirectional estimators
- Markov chain Monte Carlo techniques
- volumetric rendering
- importance sampling techniques
- quasi-Monte Carlo techniques



Topics to be covered

Advanced topics:

- differentiable rendering
- neural rendering
- rendering wave-optics effects
- rendering specular transport effects
- rendering eikonal transport effects



Interested in doing research in computational imaging or rendering? Talk to me!

40

Many, many possible projects, including:

- Projects on rendering and inverse rendering.
- Projects on theory of light transport.
- Projects on coherent imaging and optical coherence tomography.
- Projects on material inference (reflectance, scattering, refractive fields, particle sizing).
- Projects on tissue imaging.
- Projects on non-line-of-sight imaging.
- Projects on combining physics (rendering) and deep learning.
- Projects on data-driven optimization of imaging systems.
- Projects derived from your final project for a paper publication.

Many 15-463, 15-663, 15-862 alumni have worked on various research projects in my group.

Ideal background:

- Knowledge of (at least one of) graphics, vision, physics, numerical computing.
- If you've taken 15-463, you have the background.



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Alumni



Convolutional Approximations to the General Non-Line-of-Sight Imaging Operator

Byeongjoo Ahn, Akshat Dave, Ashok Veeraraghavan, Ioannis Gkioulekas, and Aswin C. Sankaranarayanan. *ICCV* 2019.



A Differential Theory of Radiative Transfer

Cheng Zhang, Lifan Wu, Changxi Zheng, Ioannis Gkioulekas, Ravi Ramamoorthi, and Shuang Zhao. *ACM SIGGRAPH Asia* 2019.



Ellipsoidal Path Connections for Time-gated Rendering

Adithya Pediredla, Ashok Veeraraghavan, and Ioannis Gkioulekas. *ACM SIGGRAPH* 2019.



Wave-based Non-Line-of-Sight Imaging using Fast f-k Migration

David B. Lindell, Gordon Wetzstein, Matthew O'Toole. *ACM SIGGRAPH* 2019.



A Monte Carlo Framework for Rendering Speckle Statistics in Scattering Media

Chen Bar, Marina Alterman, Ioannis Gkioulekas, Anat Levin. *ACM SIGGRAPH* 2019.



A Theory of Fermat Paths for Non-Line-of-Sight Shape Reconstruction

Shumian Xin, Sotiris Nousias, Kiriakos N. Kutulakos, Aswin C. Sankaranarayanan, Srinivasa G. Narasimhan, and Ioannis Gkioulekas. *CVPR* 2019.



Multispectral Imaging for Fine-Grained Recognition of Powders on Complex Backgrounds

Tiancheng Zhi, Bernardo R. Pires, Martial Hebert, Srinivasa G. Narasimhan. *CVPR* 2019.



Beyond Volumetric Albedo—A Surface Optimization Framework for Non-Line-of-Sight Imaging

Chia-Yin Tsai, Aswin C. Sankaranarayanan, Ioannis Gkioulekas. *CVPR* 2019.



Non-Line-of-Sight Imaging with Partial Occluders and Surface Normals

Felix Heide, Matthew O'Toole, Kai Zang, David B. Lindell, Steven Diamond, Gordon Wetzstein. *ACM Trans. on Graphics* 2019.



Towards Multifocal Displays with Dense Focal Stacks

Rick Chang, Vijaya Kumar, Aswin C. Sankaranarayanan. *ACM SIGGRAPH Asia* 2018.