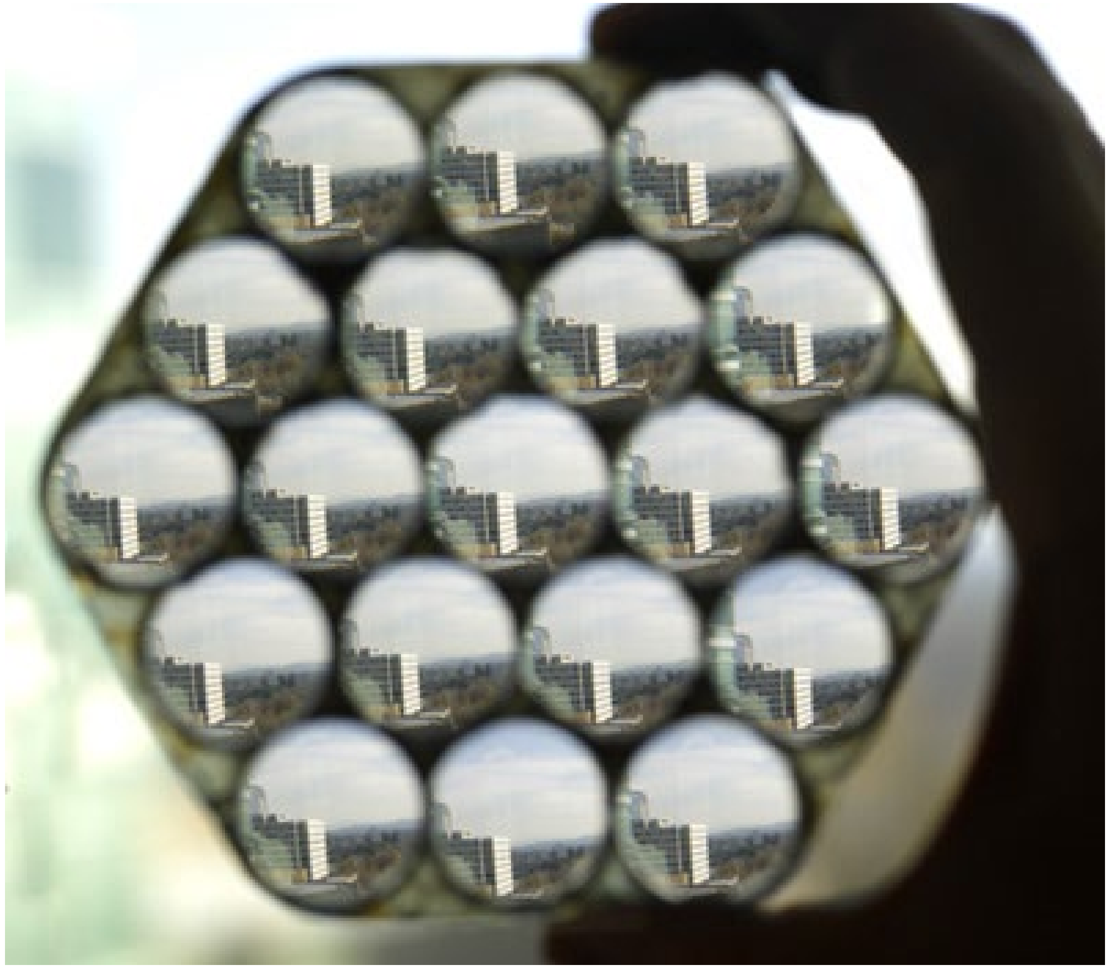
Wrap-up and discussion



15-463, 15-663, 15-862
Computational Photography
Fall 2024, Lecture 20

http://graphics.cs.cmu.edu/courses/15-463

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

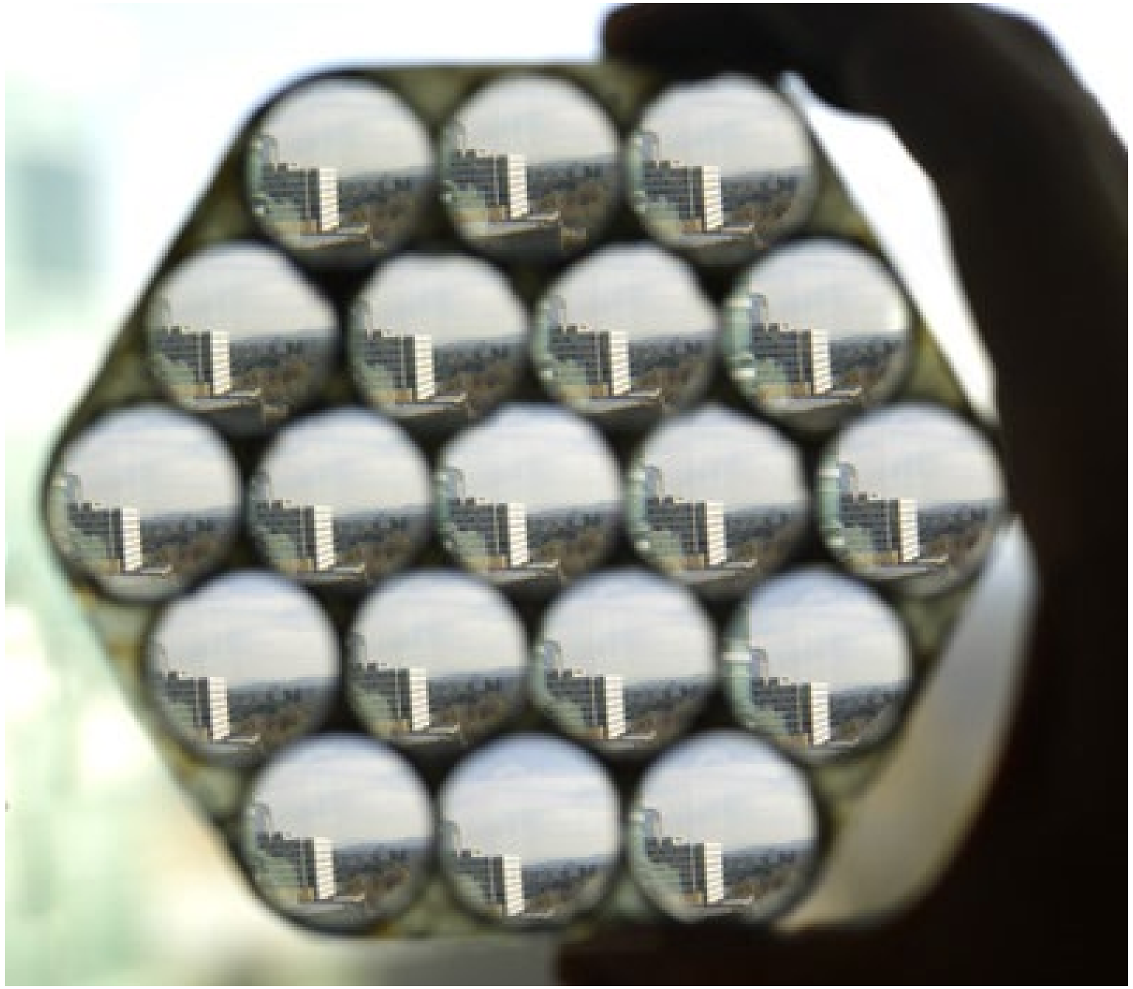
- exposure control
- high-dynamic-range imaging
- radiometric calibration
- noise modeling
- noise calibration

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

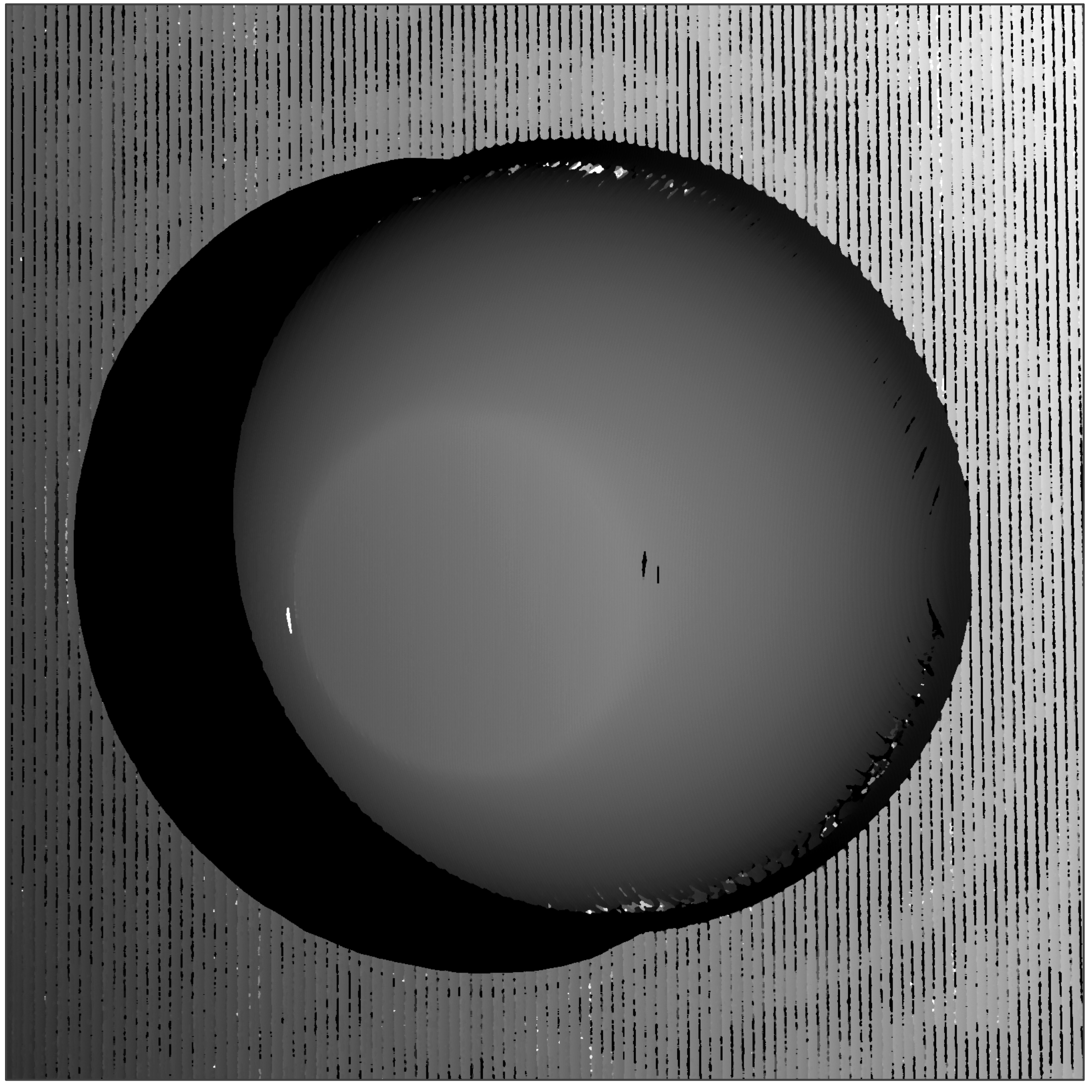


Radiometry and photometric stereo

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

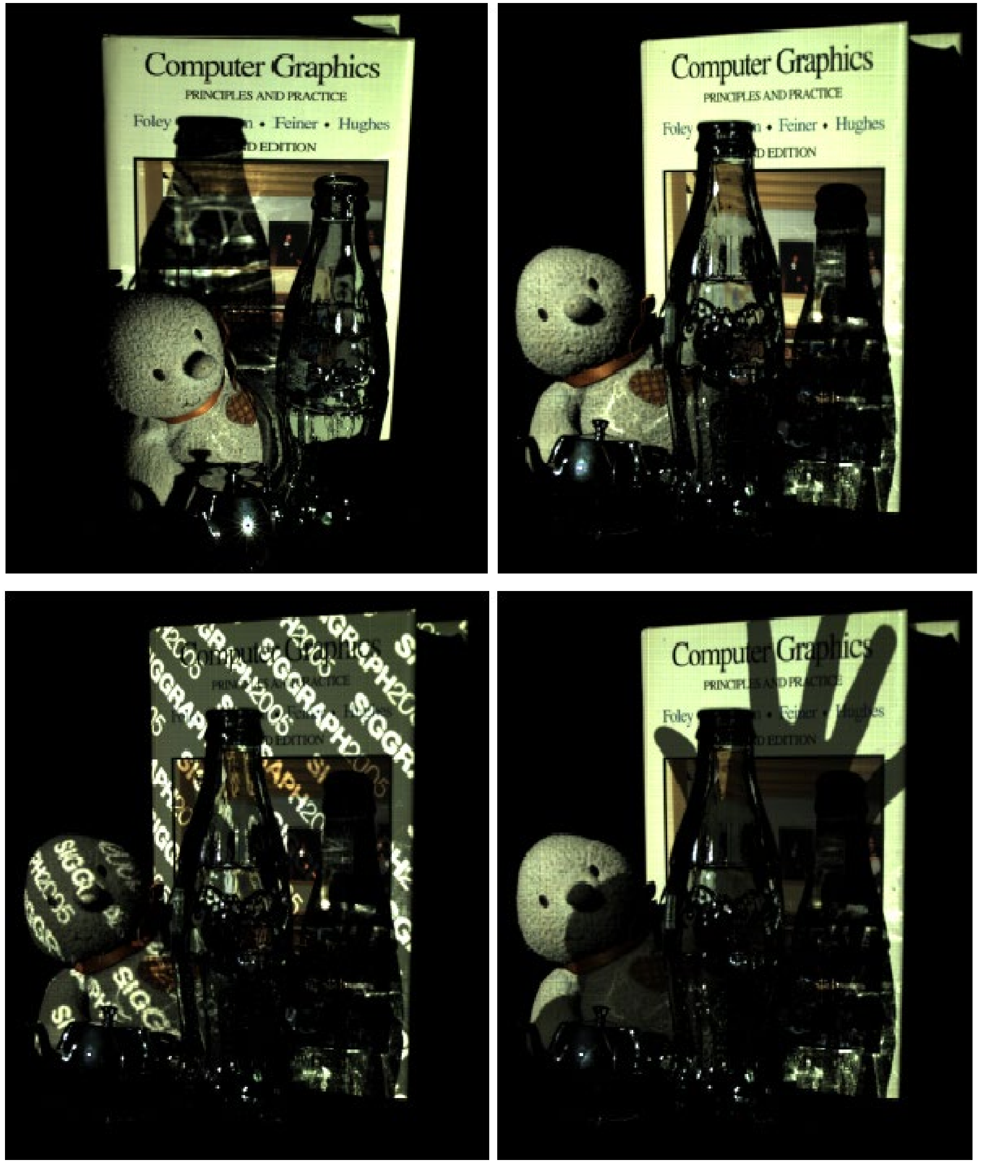

Geometry and stereo

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



Computational light transport

- time-of-flight imaging
- direct and global illumination
- light transport matrices
- dual photography
- optical computing
- probing and epipolar imaging



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-defocus, 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. ← Spring 2025, offered by Yannis and Shubham
- 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.

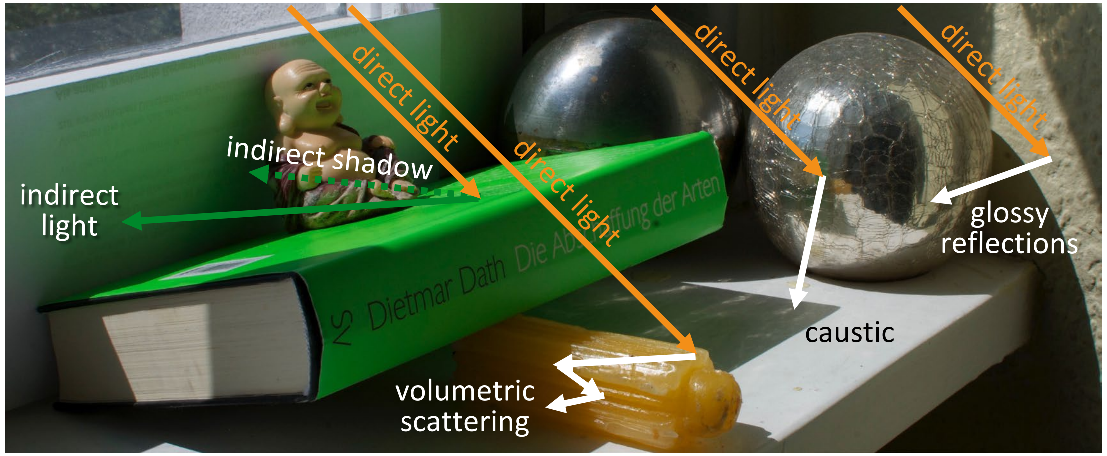
More general vision (left) and graphics (right):

- 16-824 visual learning and recognition
- 10-703 deep reinforcement learning
- 16-831 statistical techniques in robotics
- 16-833 robot localization and mapping
- 16-881 deep reinforcement learning for robotics

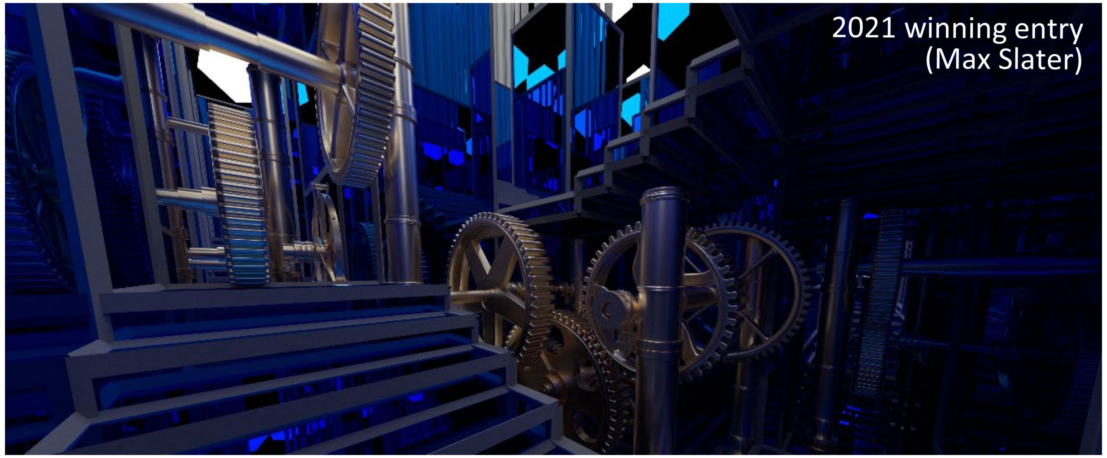
- 15-365 experimental animation
- 15-327 monte carlo methods and applications
- 15-464 technical animation
- 15-769 physically-based animation
- 15-466 computer game programming
- 15-469 algorithmic textiles design

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

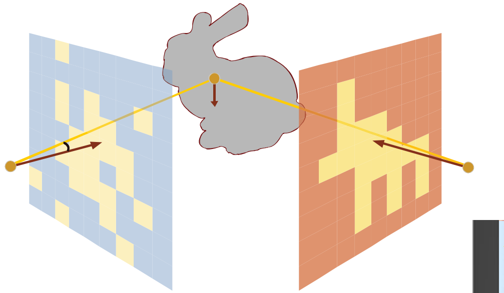
Learn all about modeling, simulating, differentiating, and inverting light!



theory and simulation of light transport

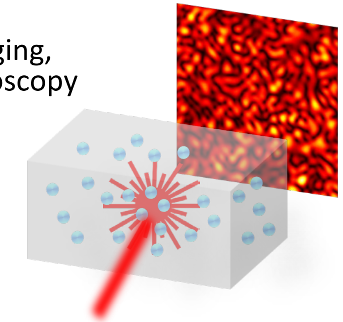


rendering competition (win free SIGGRAPH registrations!)



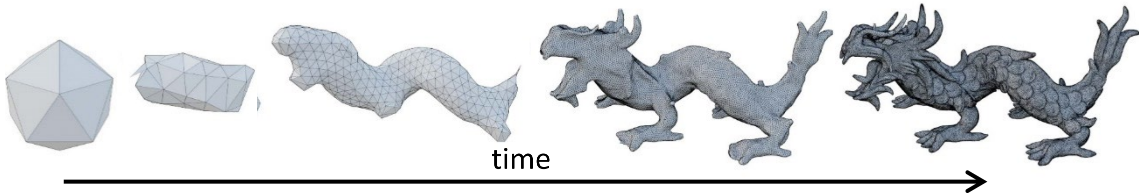
computational light transport,
time-of-flight sensors

speckle imaging,
confocal microscopy



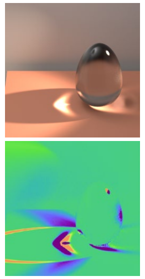
acousto-optics,
tissue imaging

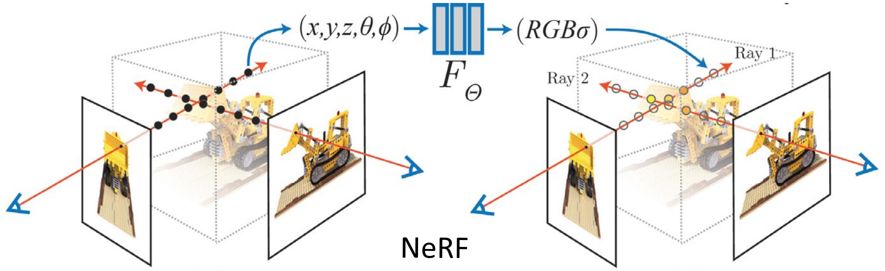
scientific imaging applications



original image

derivative image



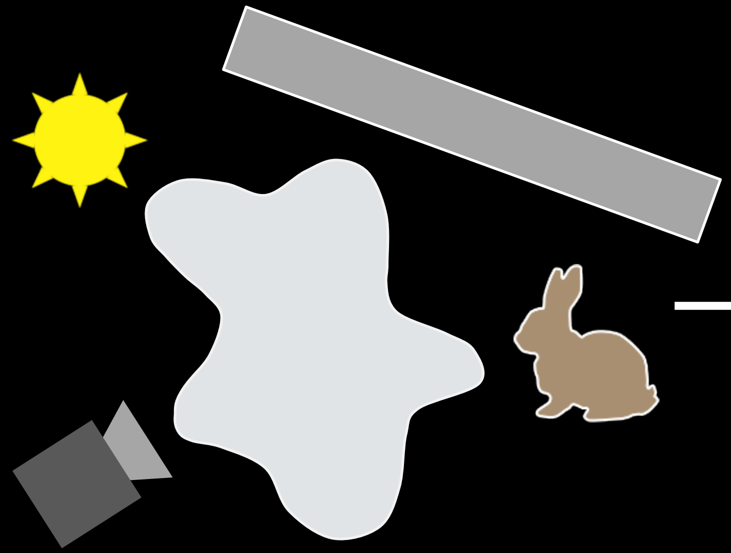


NeRF

differentiable, inverse, and neural rendering

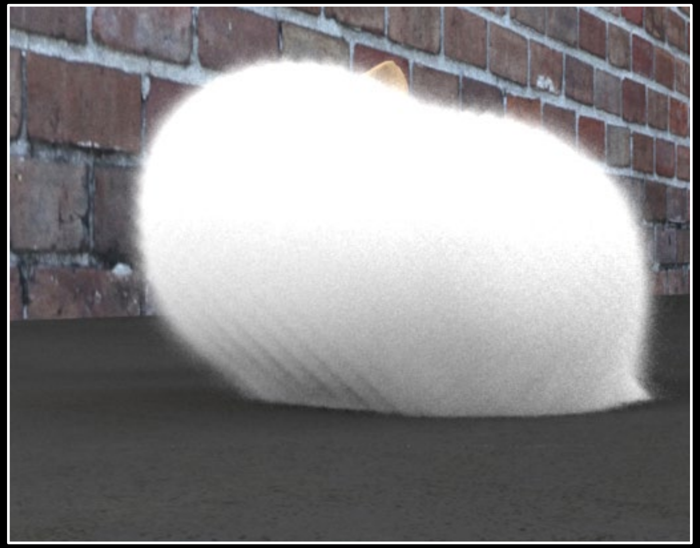
http://graphics.cs.cmu.edu/courses/15-468/

Forward rendering



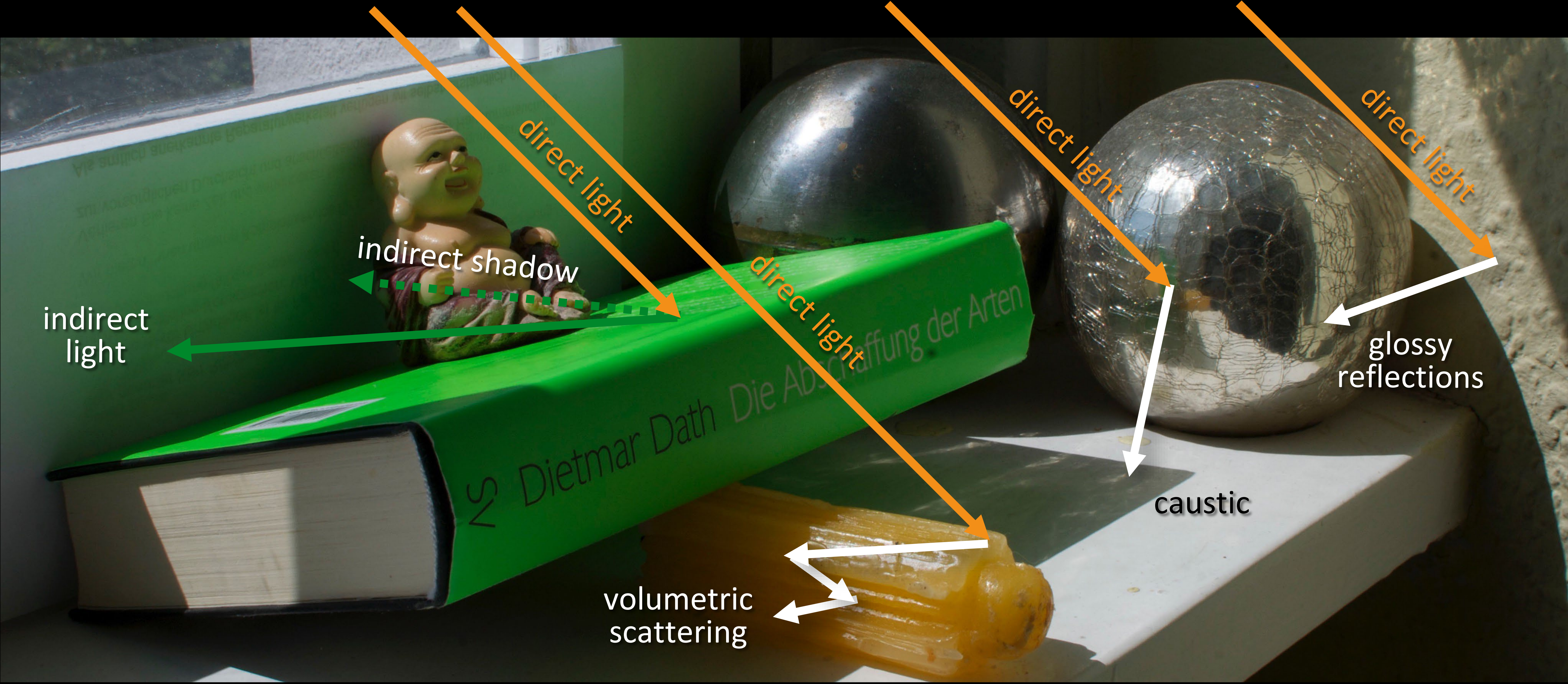
digital scene specification
(geometry, materials,
optics, light sources)

physically-accurate
rendering



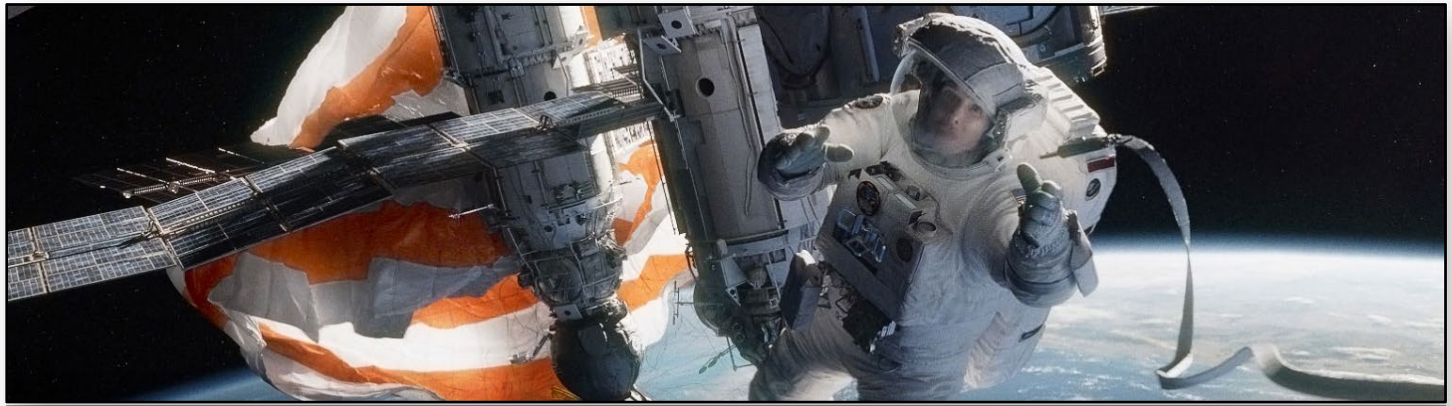
photorealistic
simulated image

Light transport in the real world



After [Ritschel et al 2011]

Ray tracing in production



Arnold Renderer

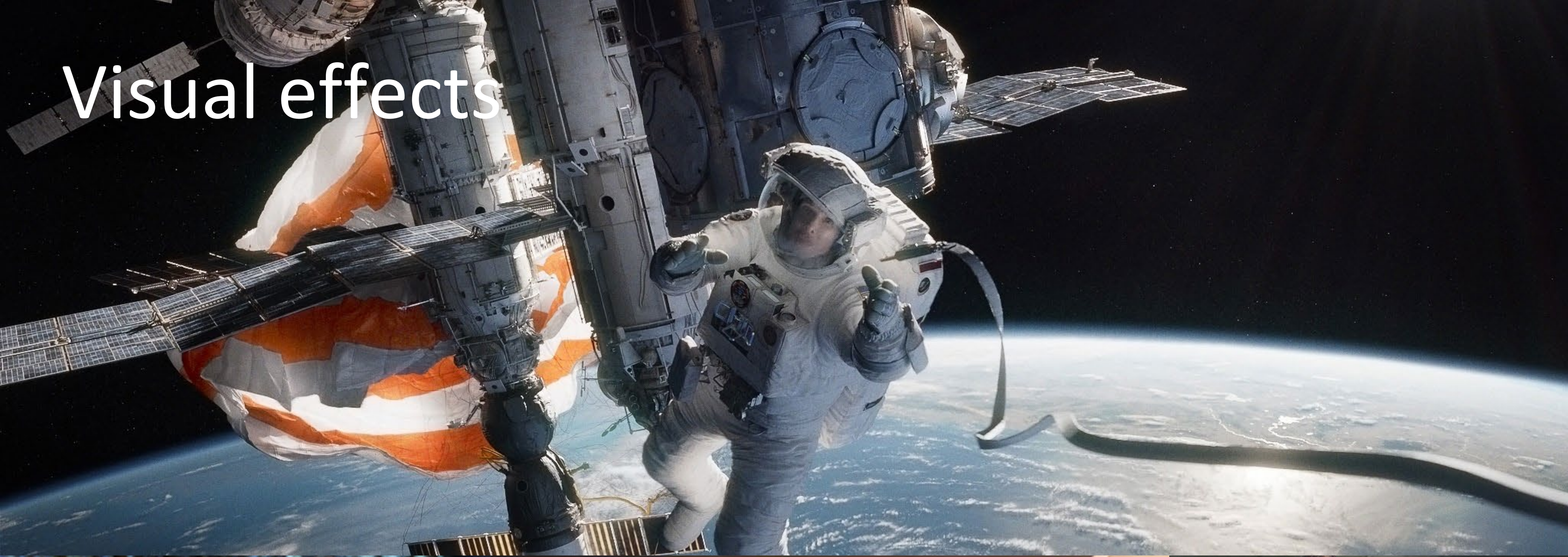
SOLIDANGLE

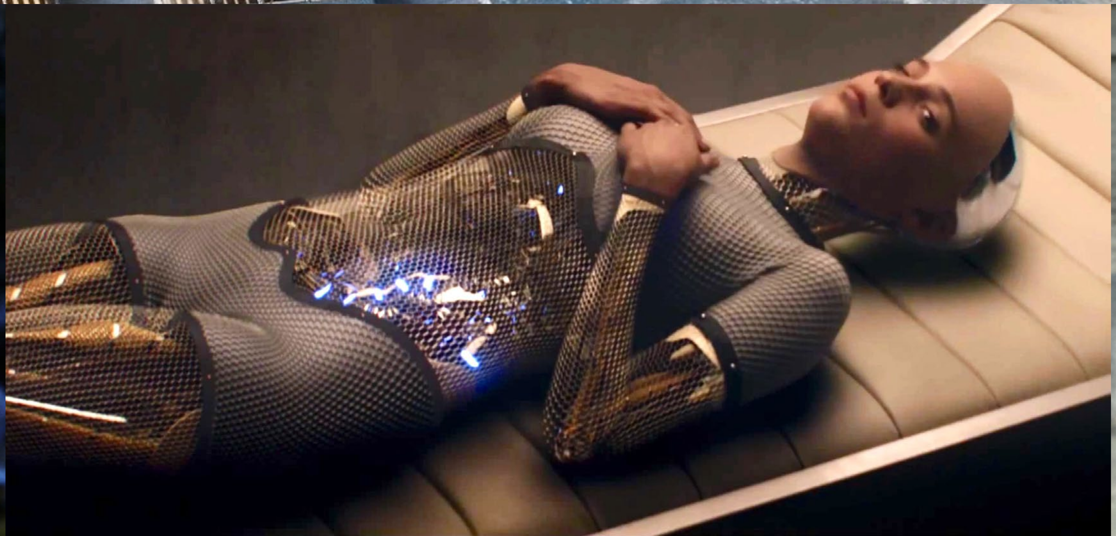
PIXAR's RenderMan

Hyperion

Wojciech Jarosz

Visual effects





Wojciech Jarosz

Animated films

Wojciech Jarosz

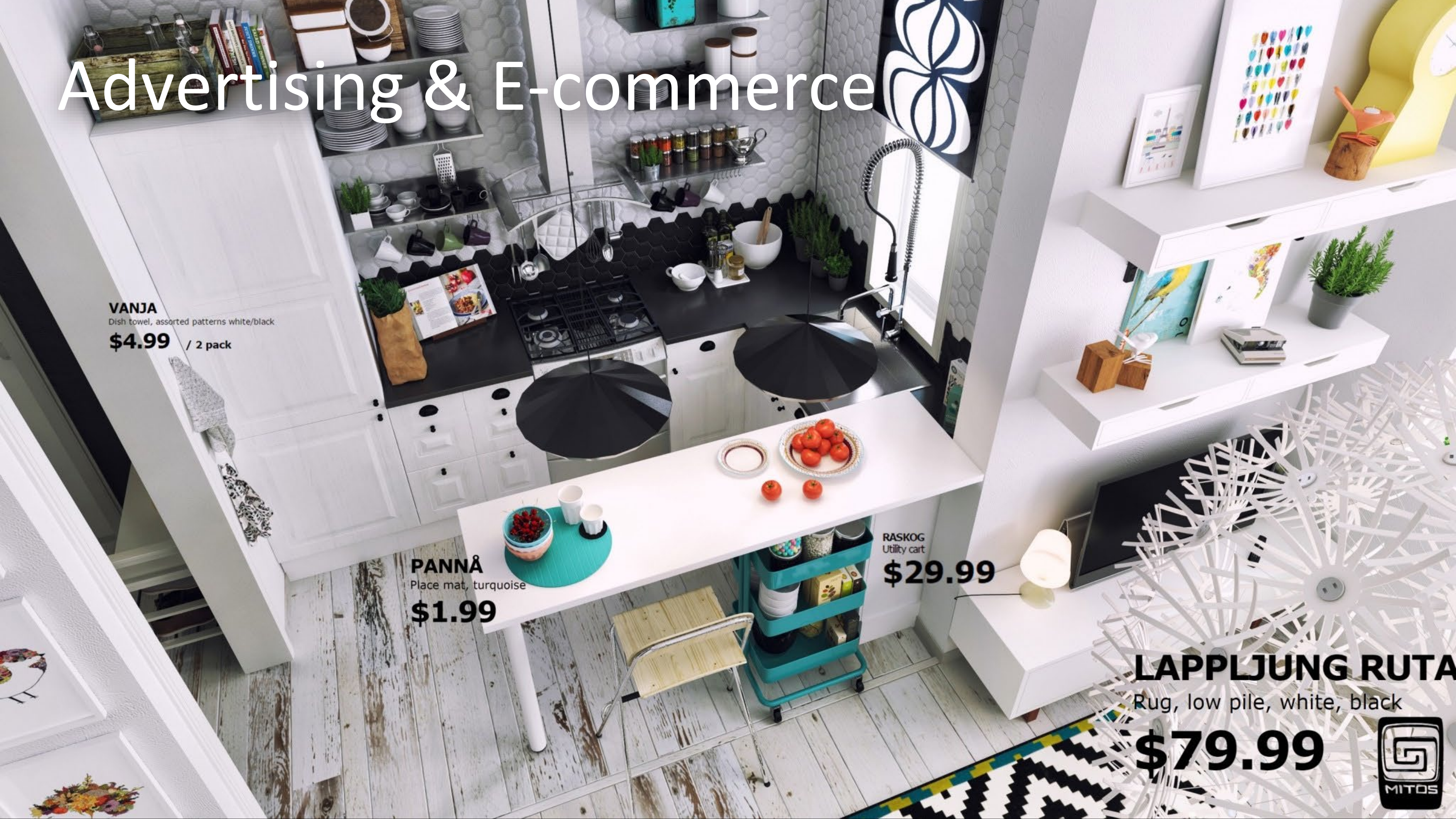
Video games

Wojciech Jarosz

Architectural visualization

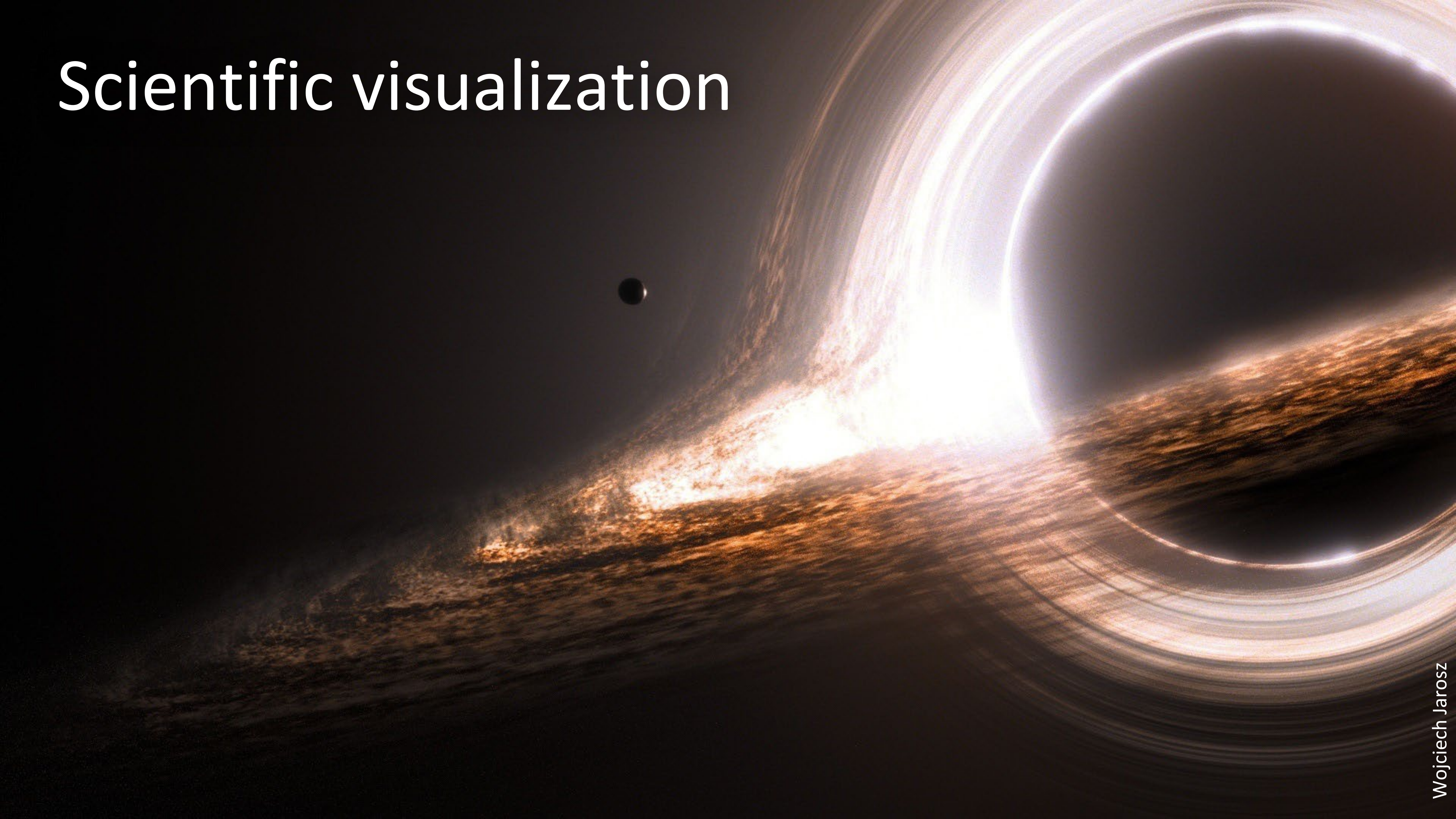
Wojciech Jarosz

Advertising & E-commerce



Cultural heritage

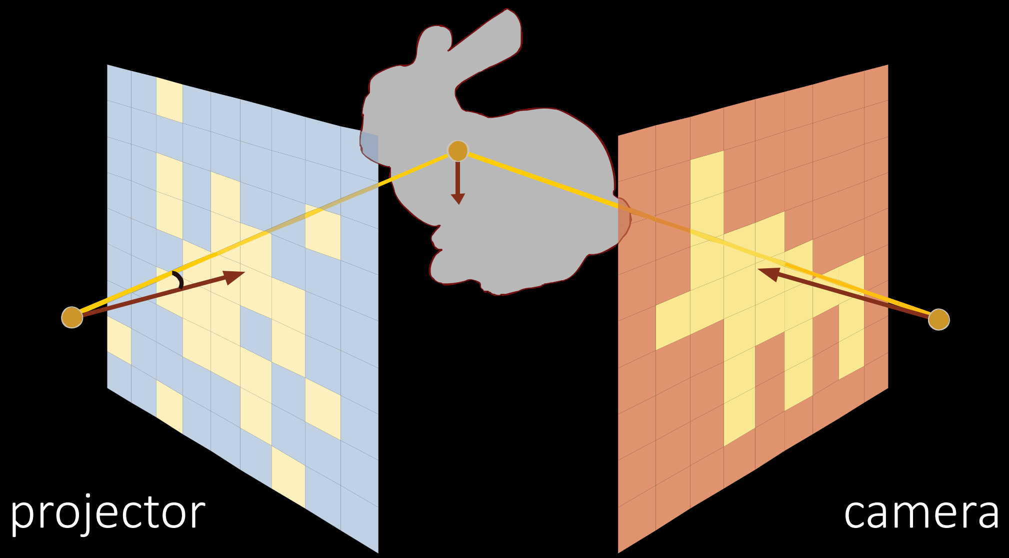
Scientific visualization



Wojciech Jarosz

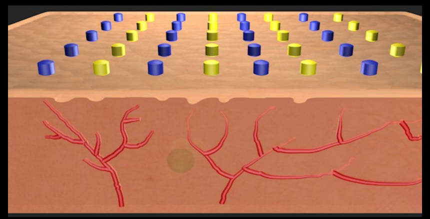
Scientific imaging

rendering computational light transport

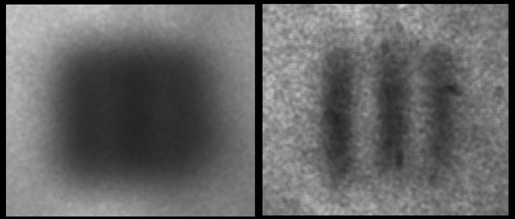


Used by CMU imaging projects:

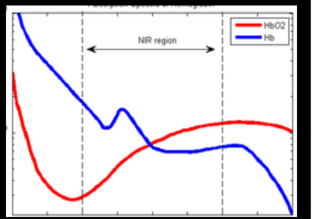
convolutional DOT



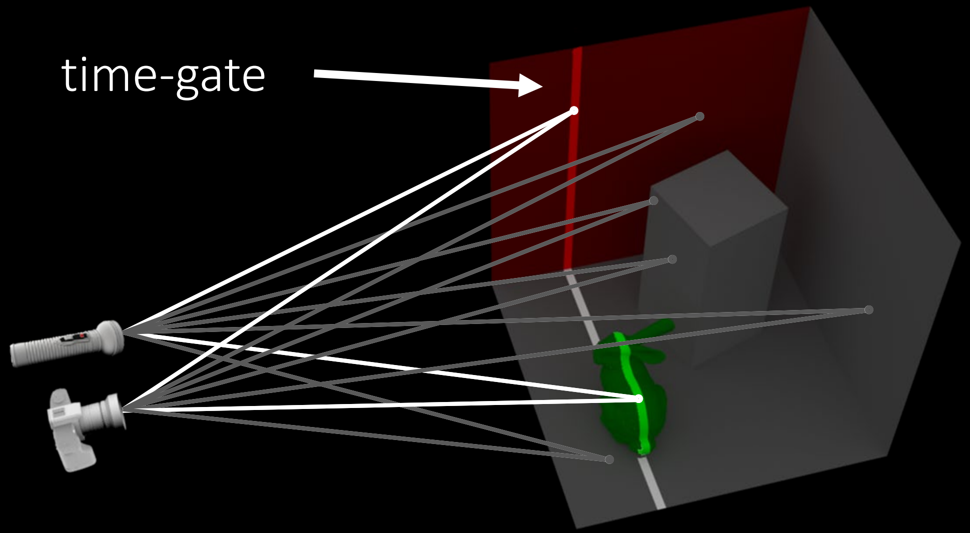
coded coherence



coded spectrum

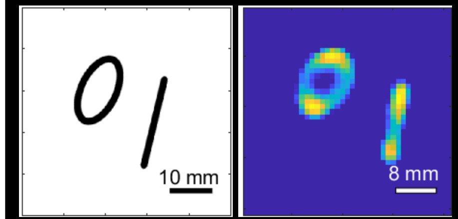


rendering time-of-flight sensors

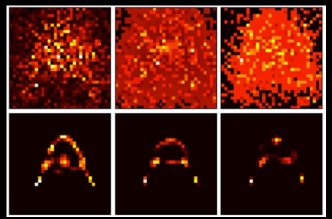


Used by CMU imaging projects:

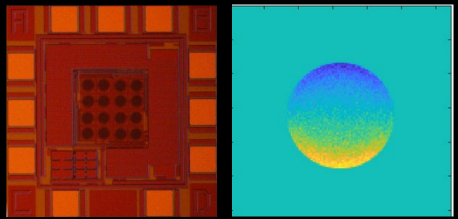
ToF DOT



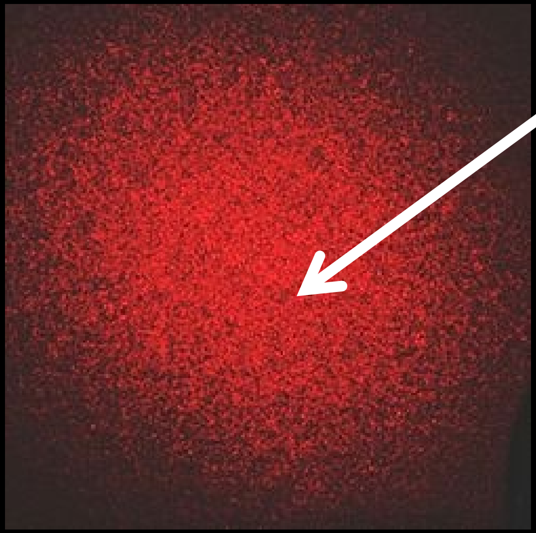
all-photon imag.



differential SPAD

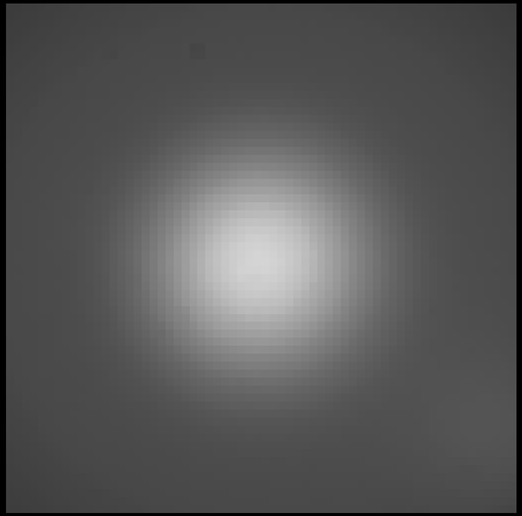


Rendering wave effects



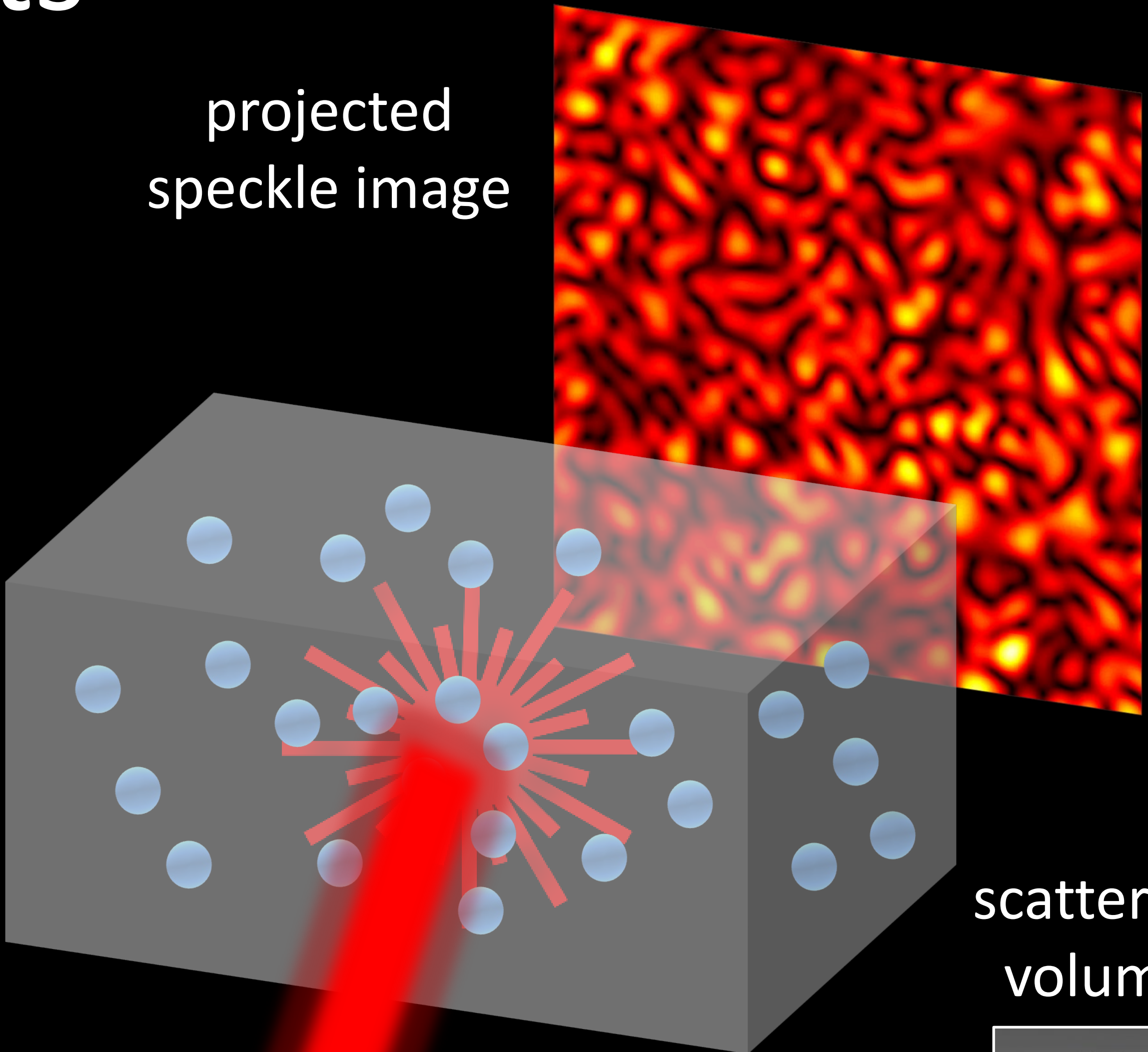
speckle: noise-like pattern

what real laser images look like



what standard rendered images look like

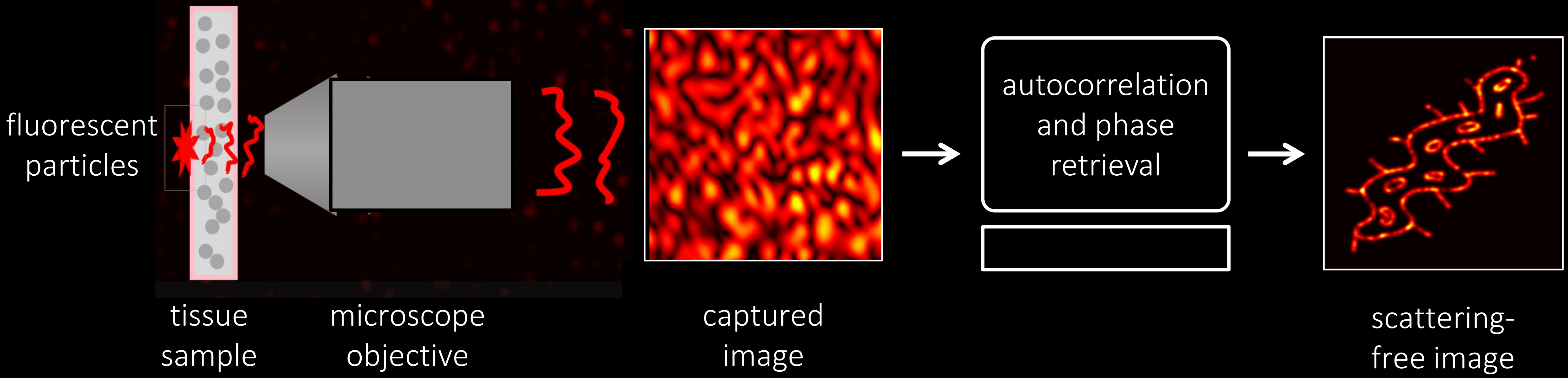
projected speckle image

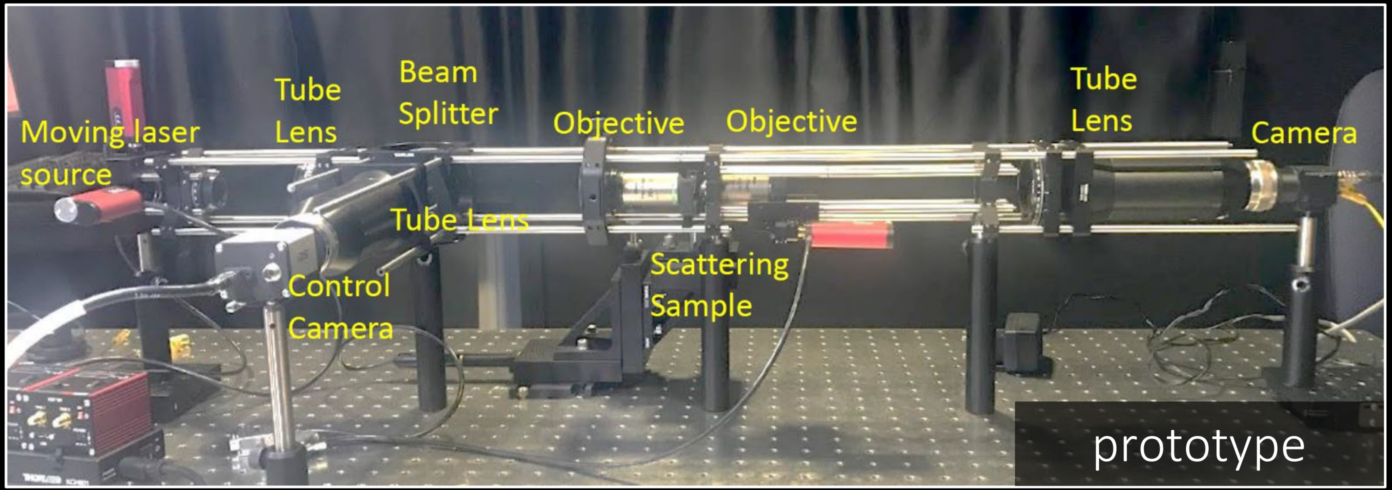


laser beam

scattering volume

Application: fluorescence Microscopy



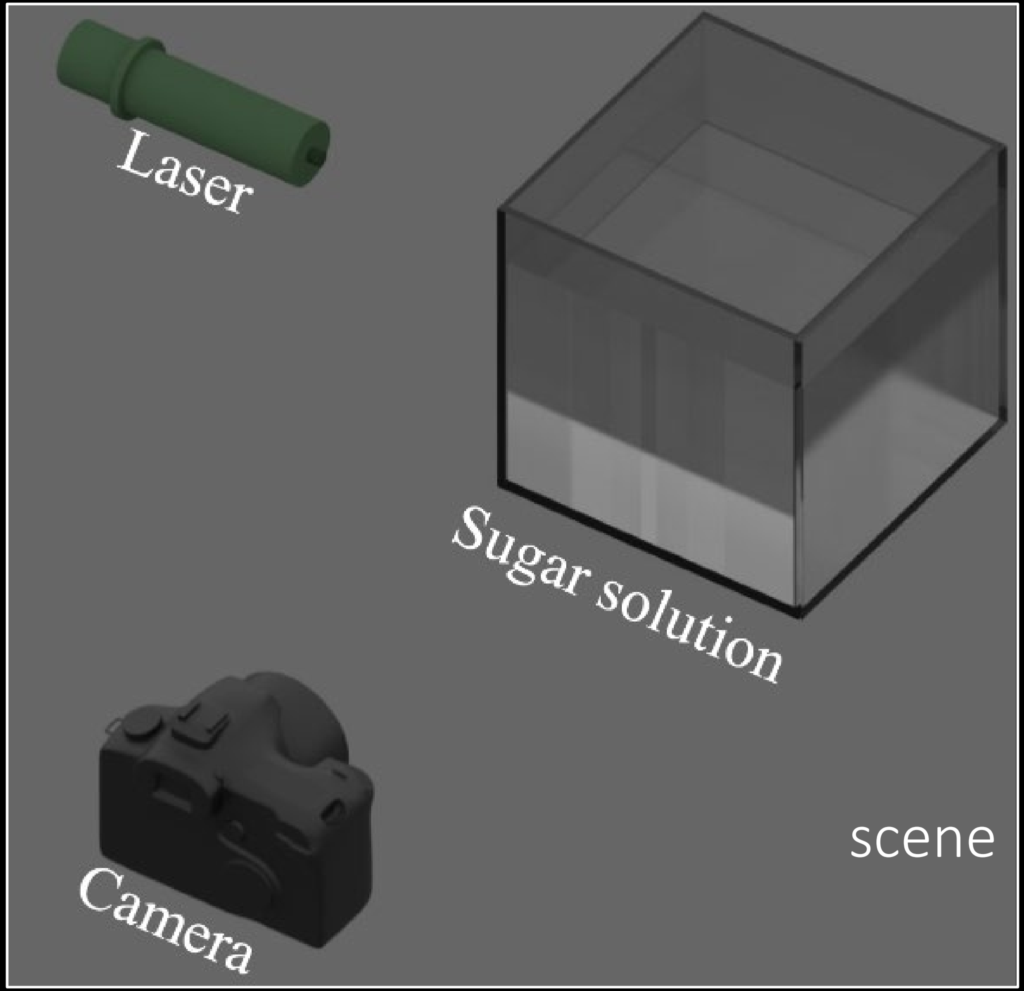


Performance strongly depends on:

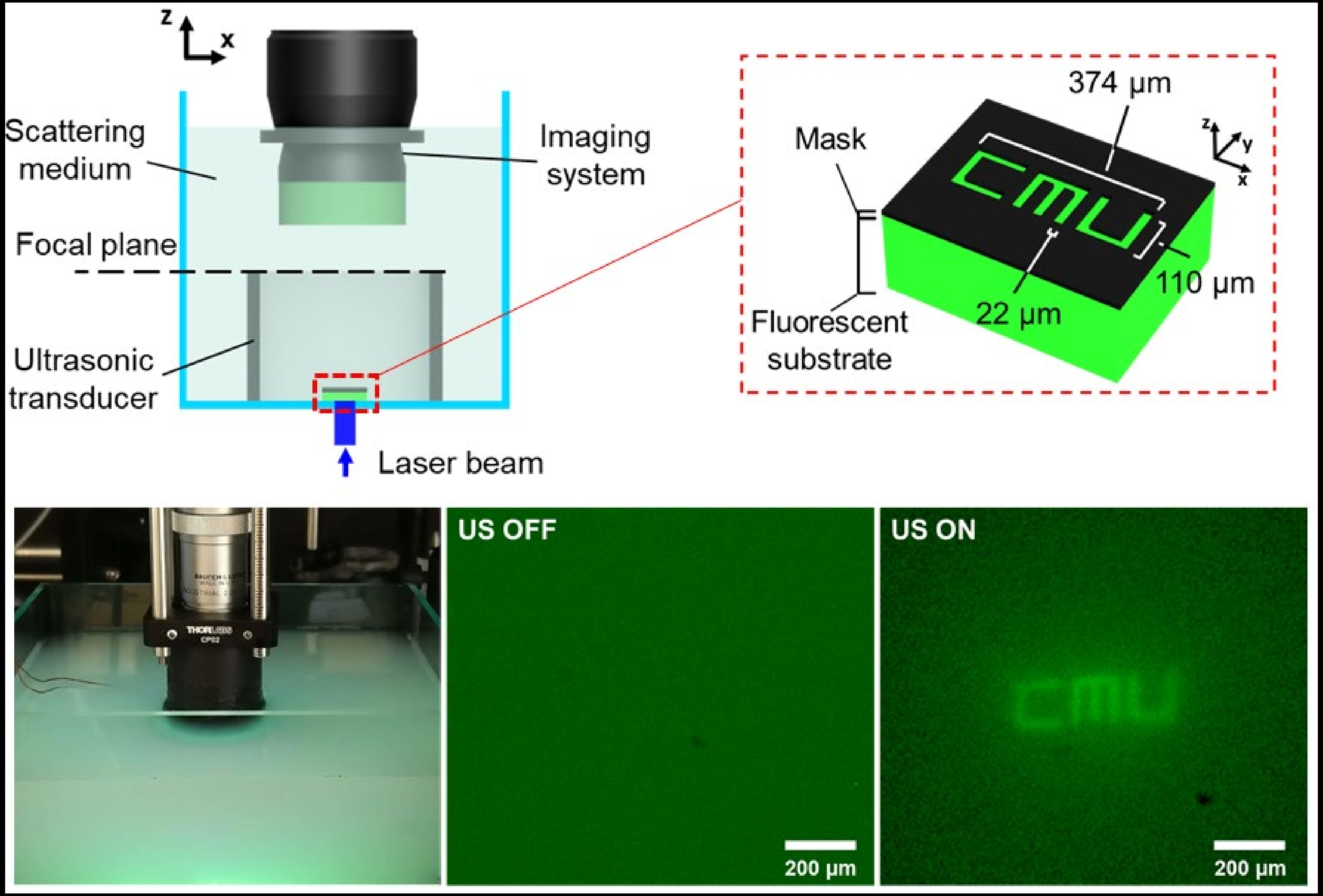
- speckle statistics
- image priors
- tissue parameters

Rendering-assisted exploration and new algorithms!

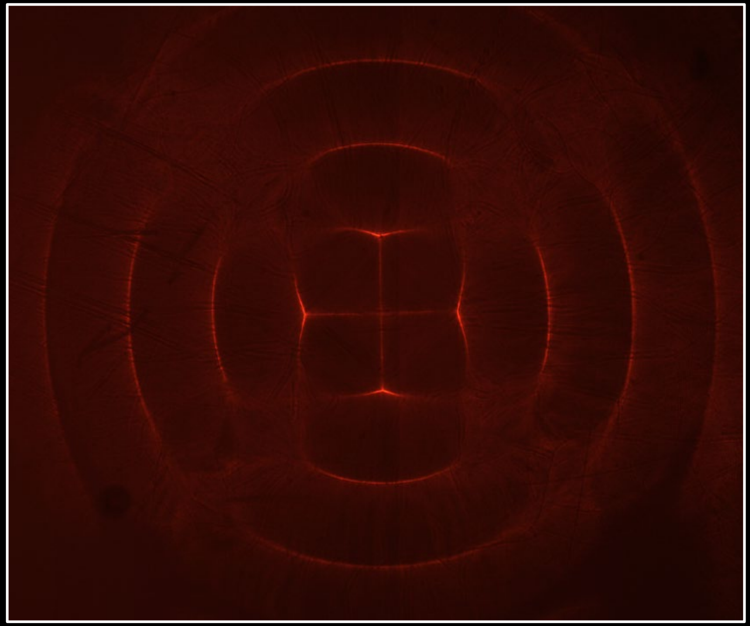
Rendering eikonal transport



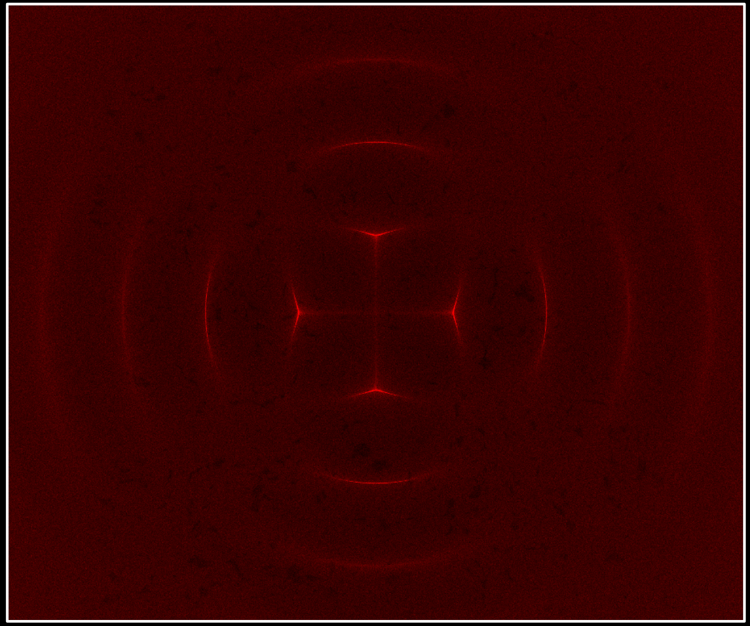
Application: acousto-optics



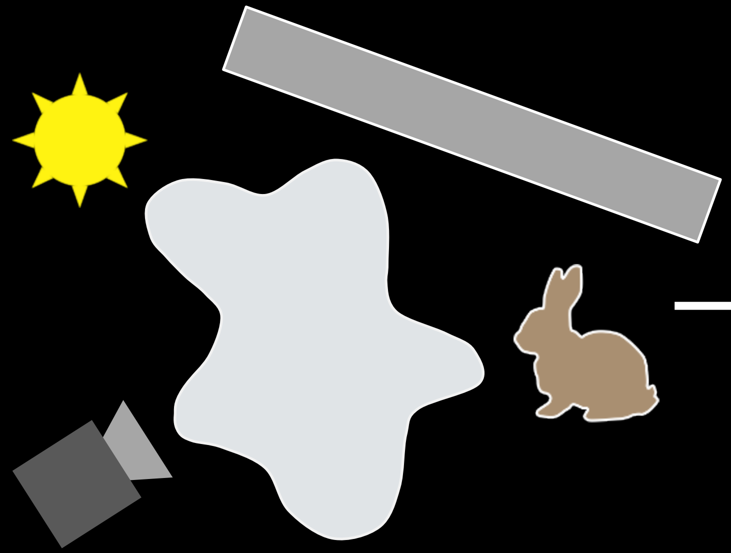
real capture



our algorithm

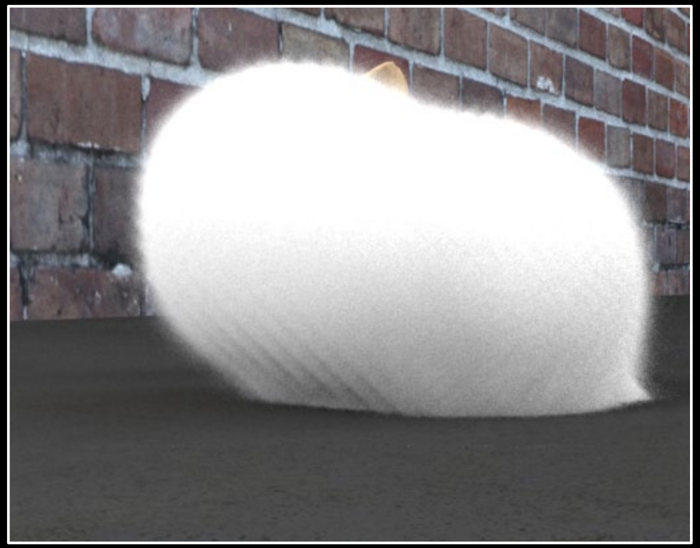


Forward rendering



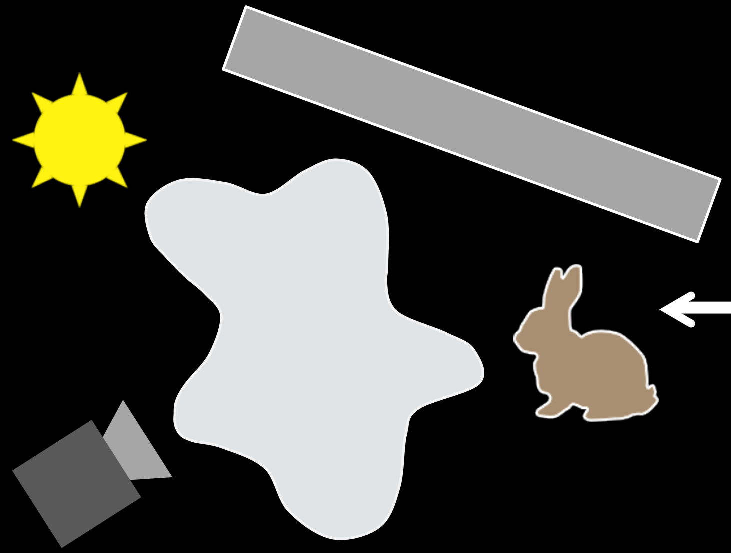
digital scene specification
(geometry, materials,
optics, light sources)

physically-accurate
rendering

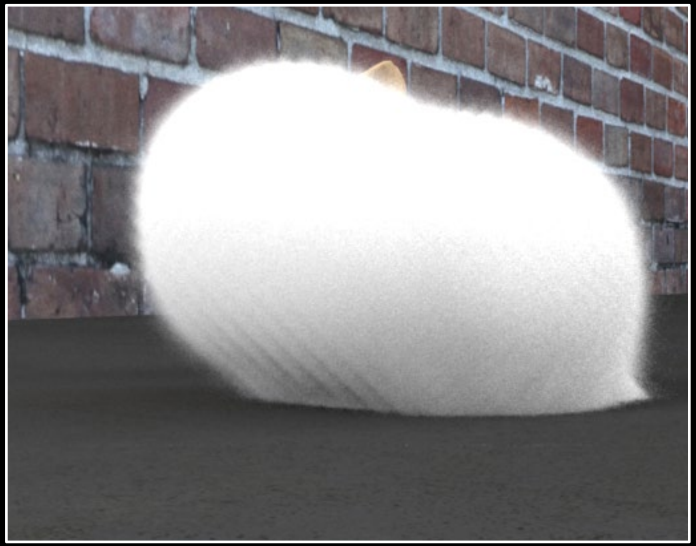


photorealistic
simulated image

Inverse rendering



physically-accurate
inverse rendering

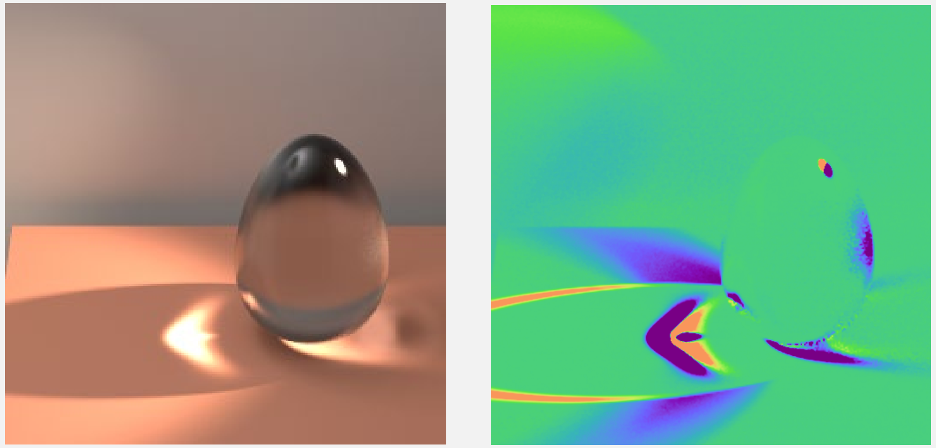


digital scene specification
(geometry, materials,
camera, light sources)

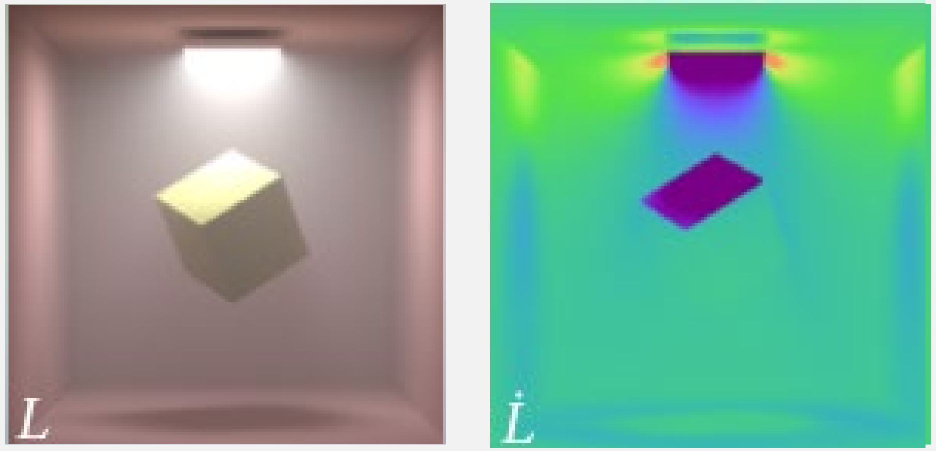
photorealistic
synthetic image

Differentiable rendering

Original image | Derivative image

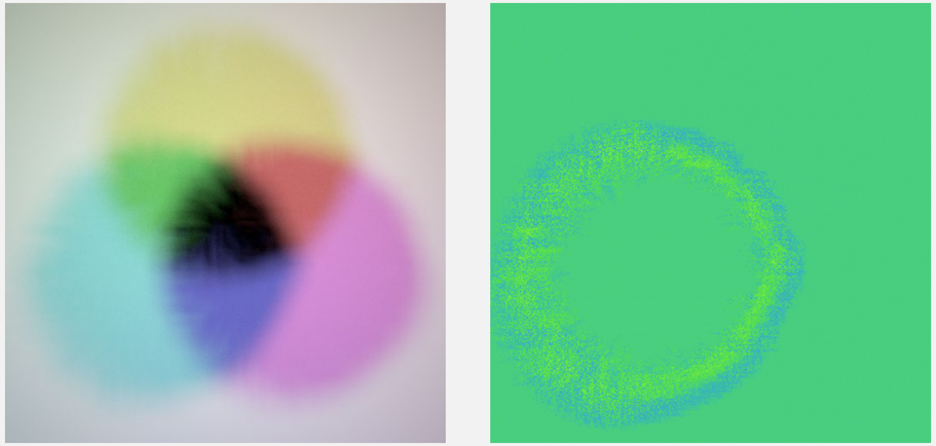


Original image | Derivative image

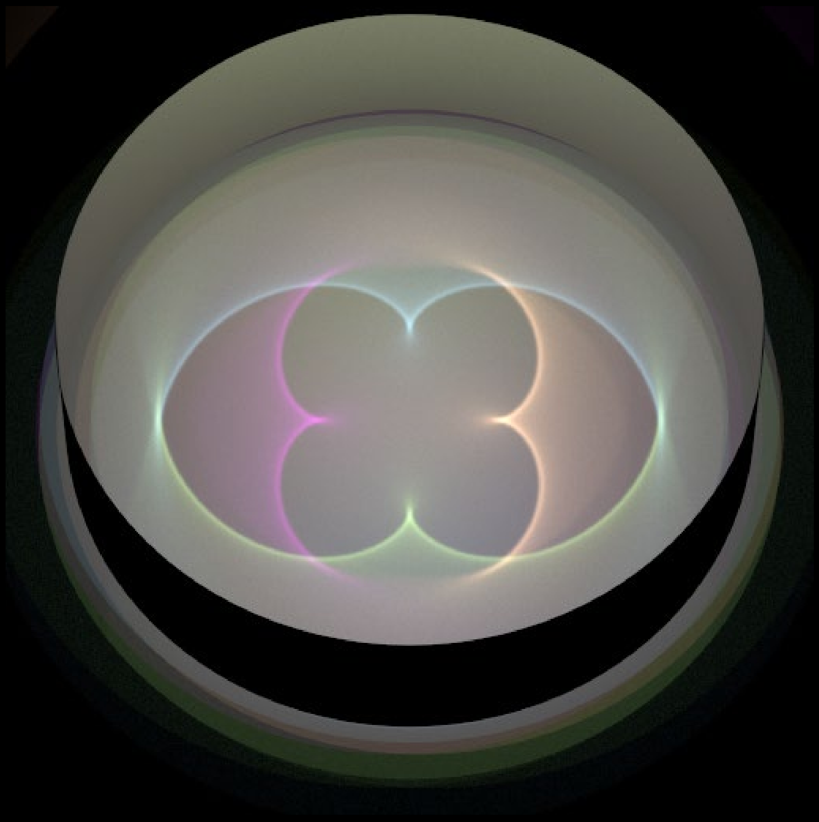


Original image | Derivative image

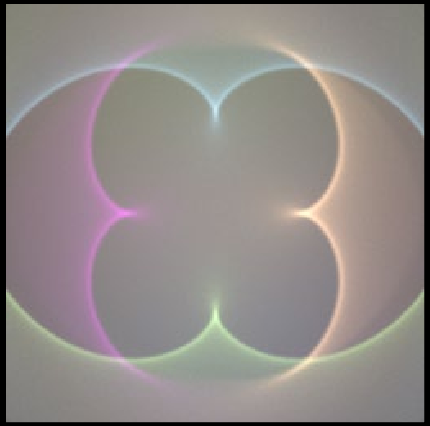
Original image | Derivative image



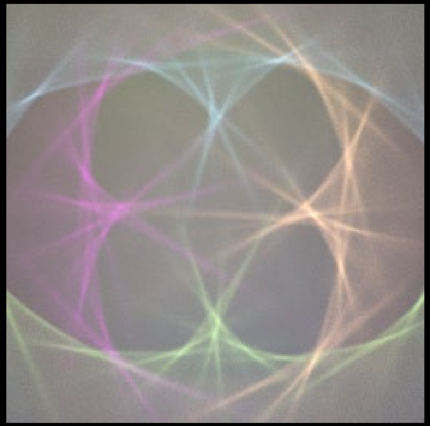
Application: shape optimization

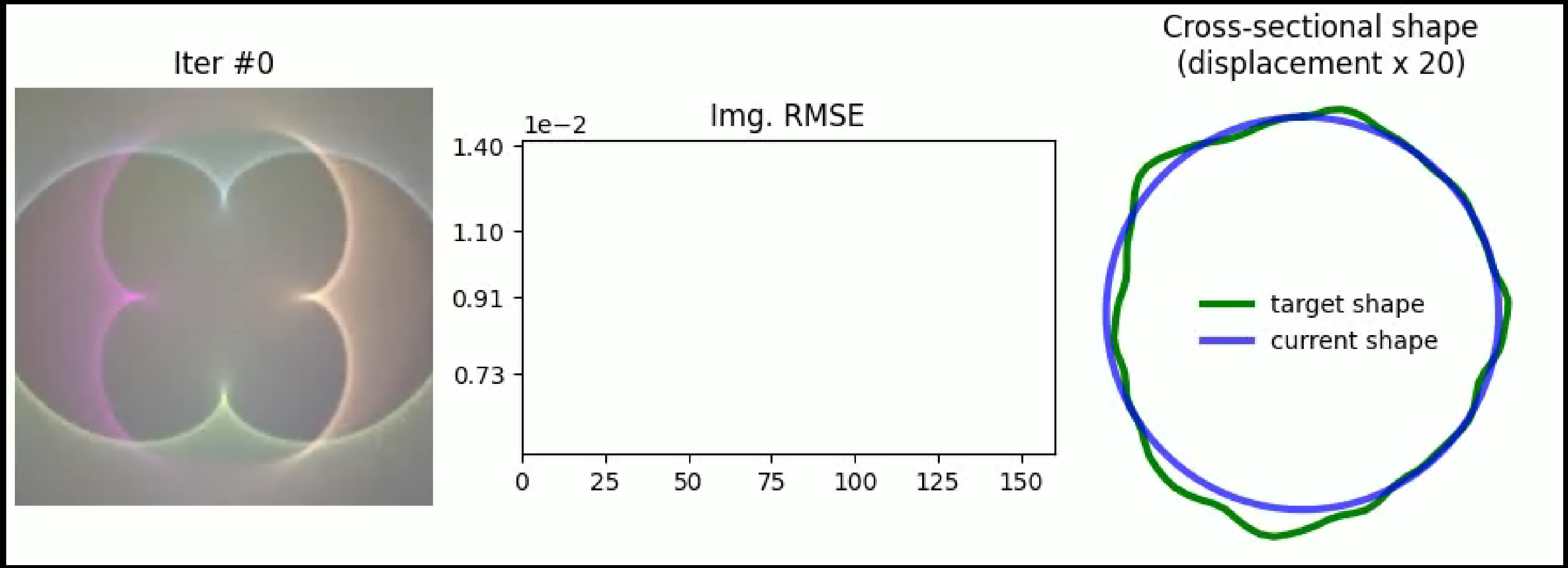


Initial

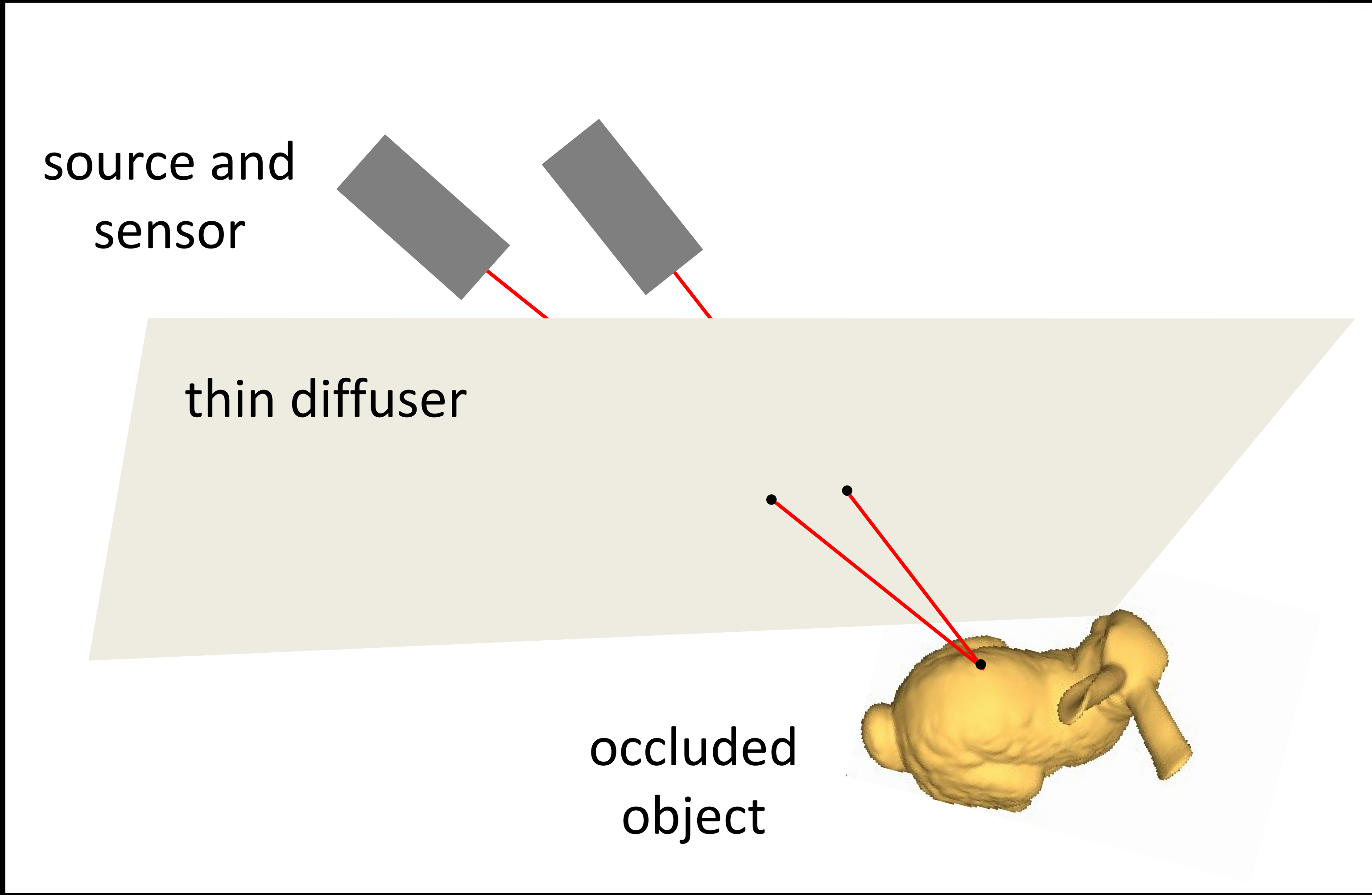


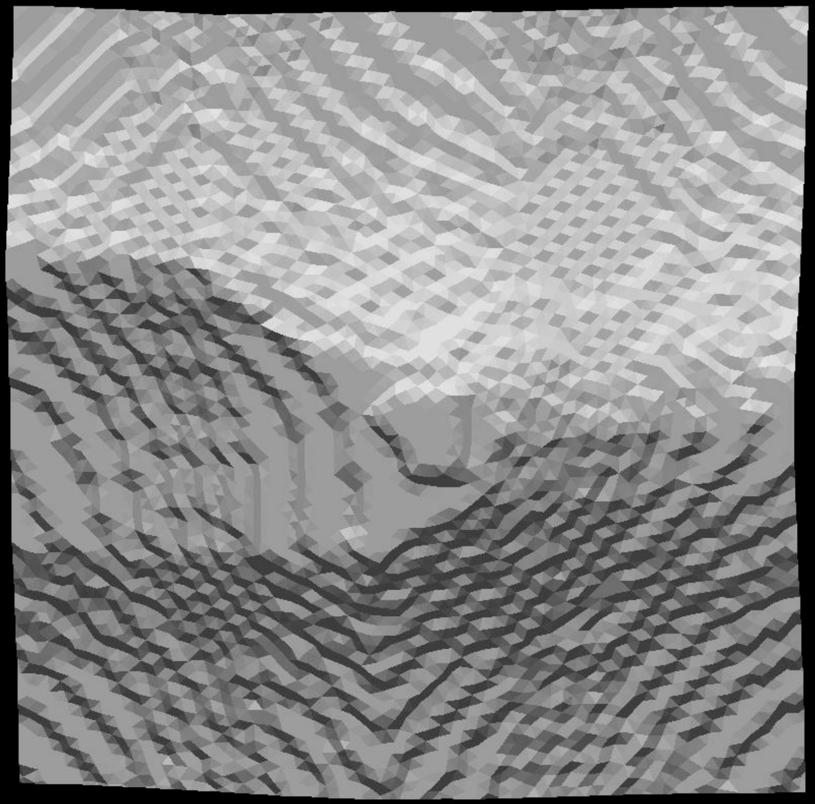
Target image





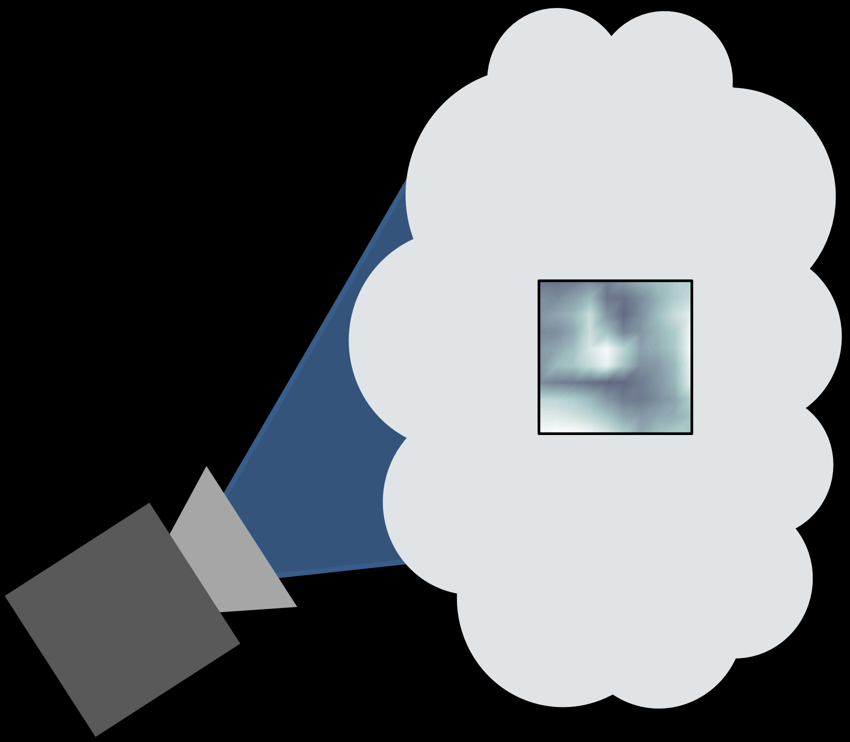
Application: non-line-of-sight imaging





reconstruction evolution

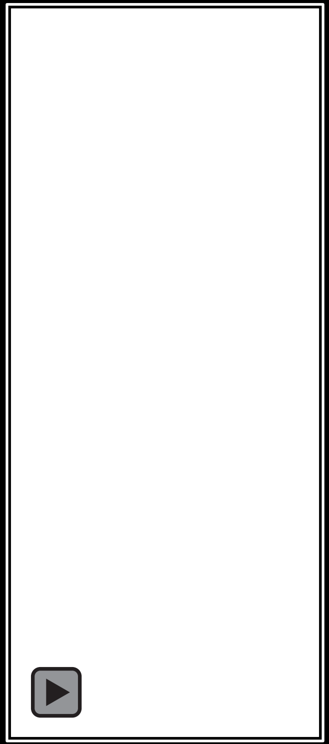
Application: non-invasive tomography



camera

thick smoke cloud

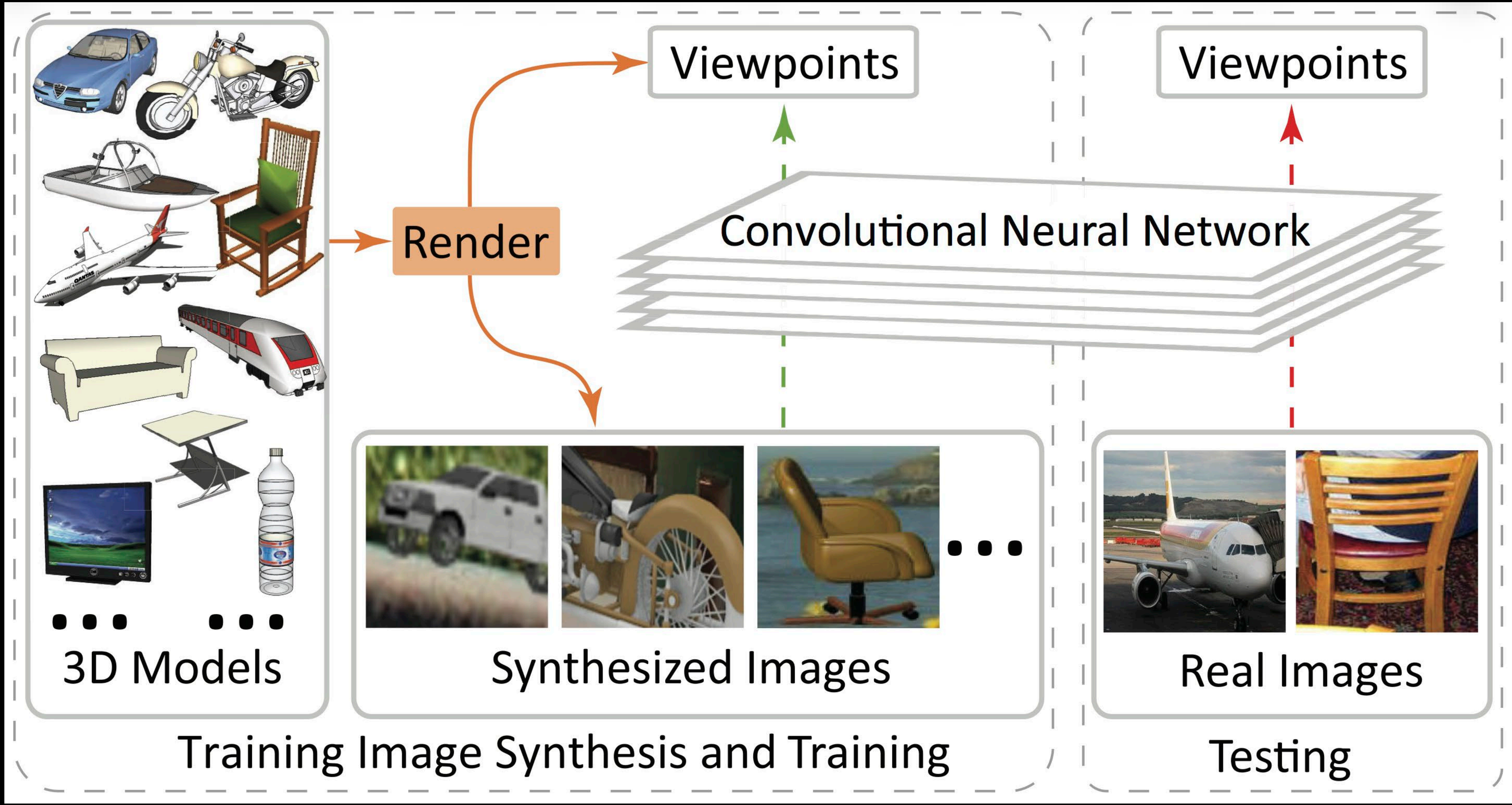
simulated camera measurements



reconstructed cloud volume

slice through the cloud

Application: vision and machine learning



Render for CNN: Viewpoint Estimation in Images Using CNNs Trained with Rendered 3D Model Views [Su et al. ICCV 2015]

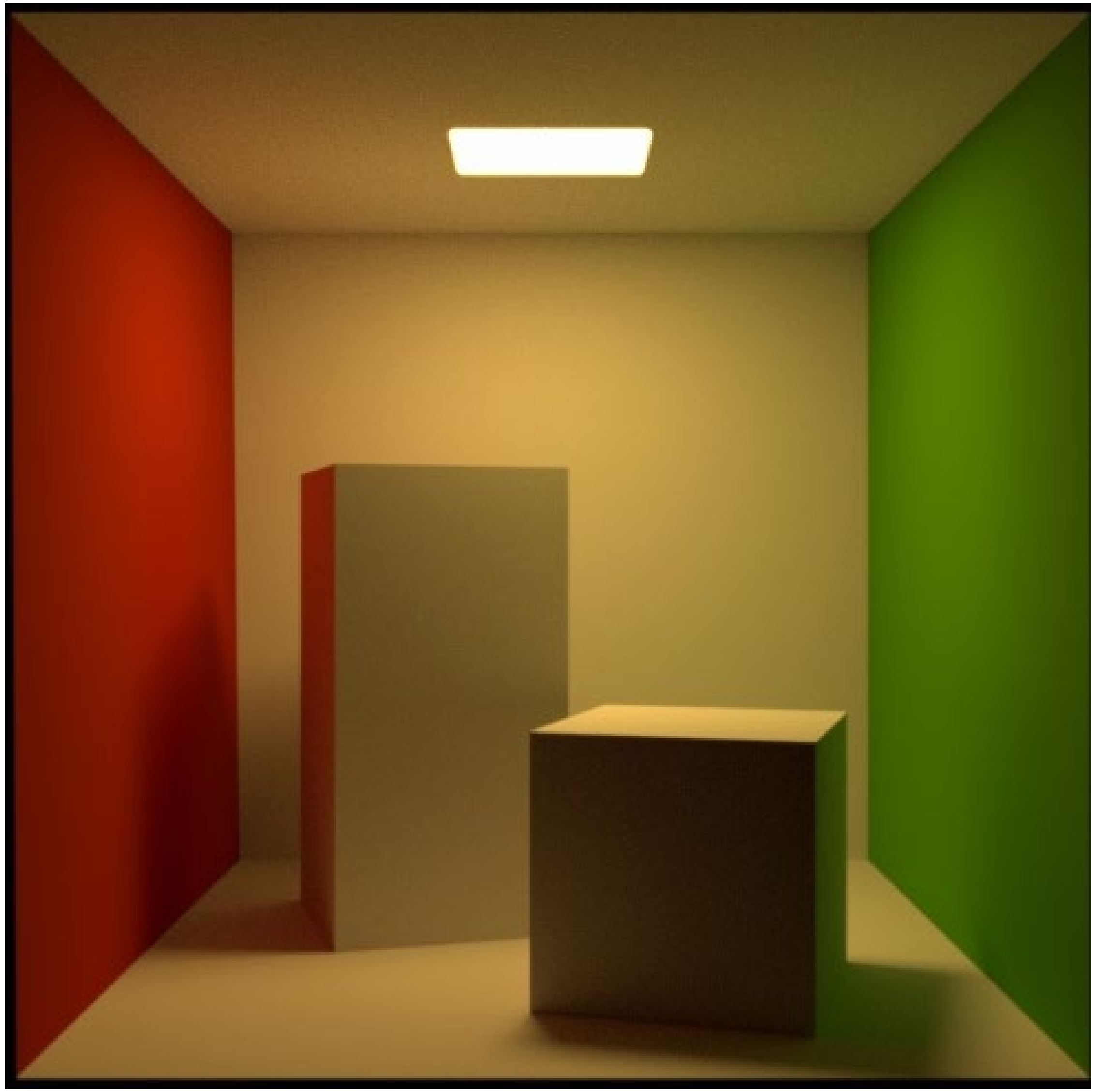
Application: neural rendering

NeRF: Representing Scenes as Neural Radiance Fields for View Synthesis [MildenHall et al. ECCV 2020]

Topics to be covered

Basics of ray tracing:

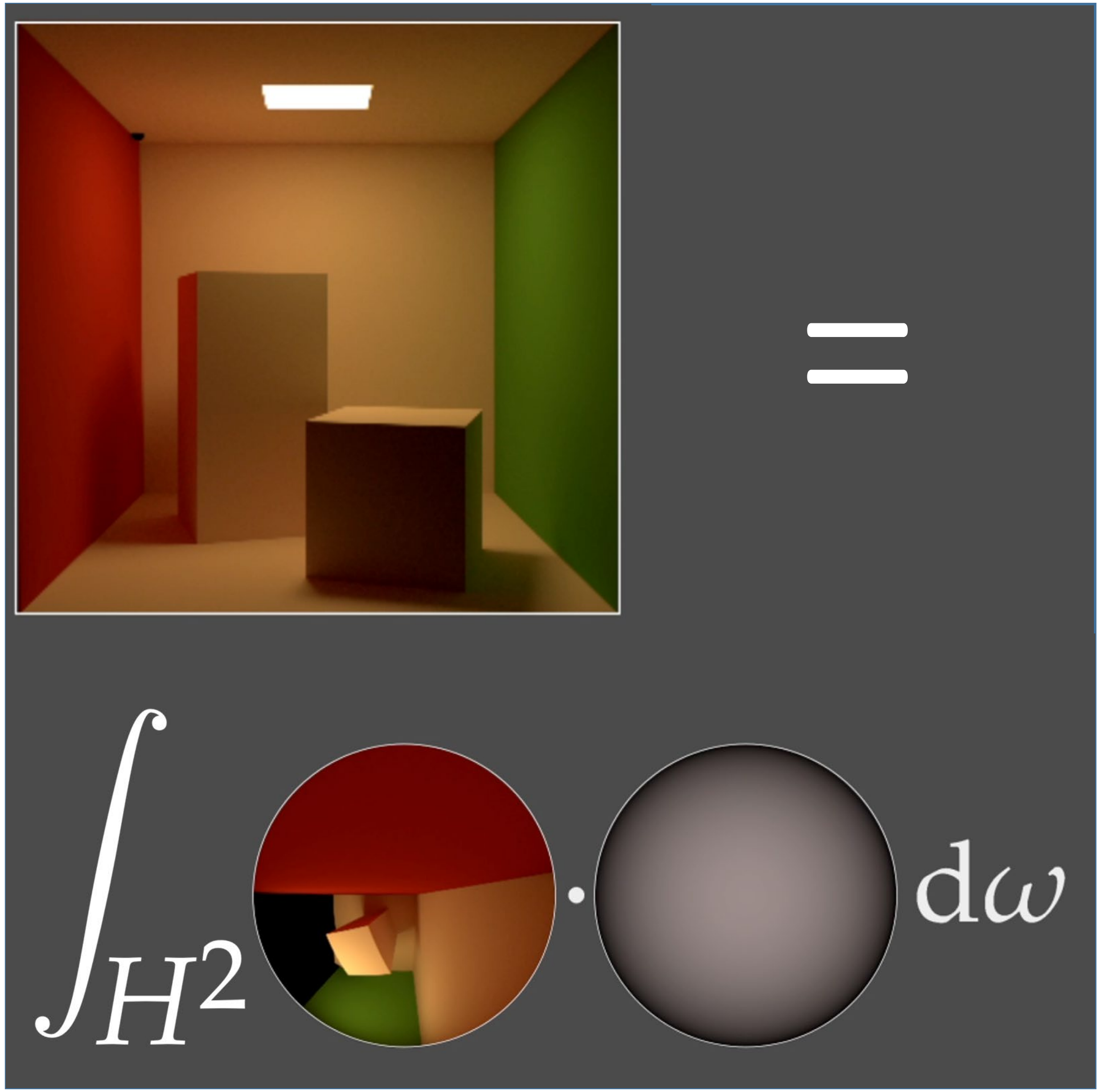
- trace-intersect recursions
- basic camera and illumination models
- shading
- intersection queries
- texture mapping



Topics to be covered

Theory of light transport and materials:

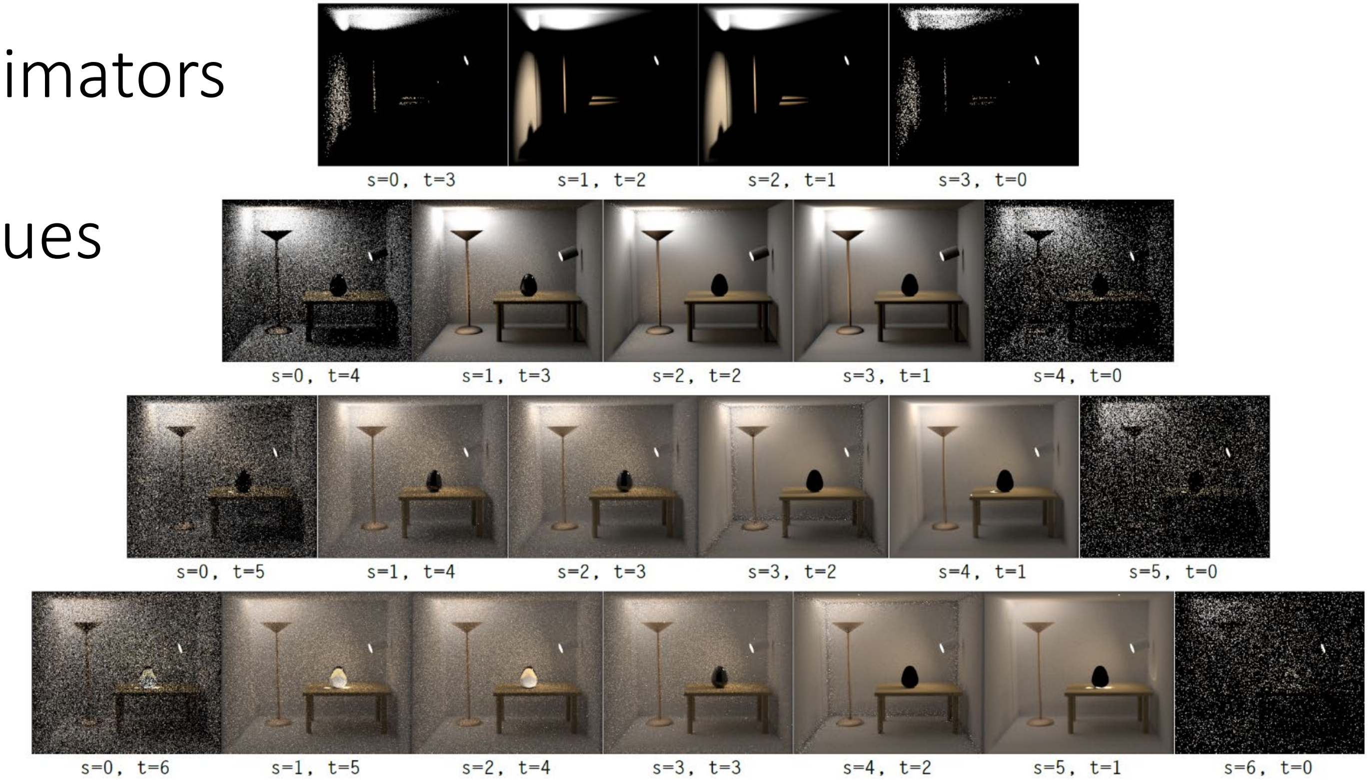
- rendering equation
- radiative transfer equation
- path integral formulations
- microfacet reflectance models
- statistical scattering models



Topics to be covered

Monte Carlo rendering algorithms:

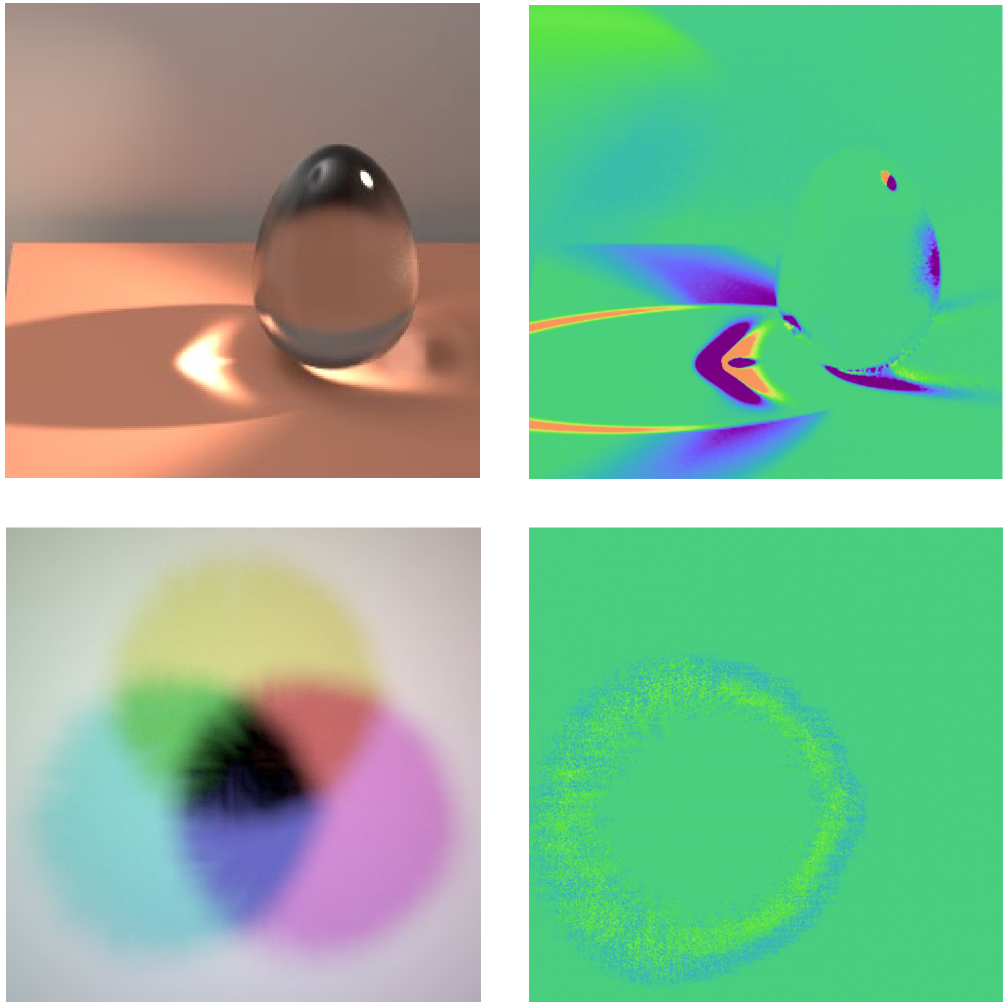
- unidirectional and bidirectional estimators
- Markov chain Monte Carlo techniques
- volumetric rendering
- importance sampling techniques
- quasi-Monte Carlo techniques



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!

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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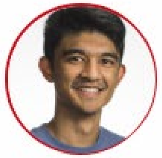
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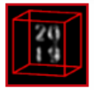
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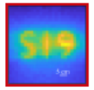
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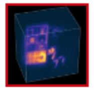
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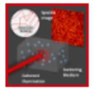
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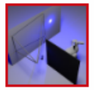
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