Introduction

15-468, 15-668, 15-868
Physics-based Rendering
Spring 2021, Lecture 1

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

Online lecture etiquette

- Lectures **are recorded**, including all discussions. This is to facilitate students that cannot attend the lectures live.

- Recordings become available on **Canvas** a few hours (usually <= 3) after the lecture. Please note that you are **not** allowed to share these recordings with anyone outside this class. This is to protect your FERPA rights and those of your fellow students.

- Please keep your Zoom window muted when you are not speaking.

- You are welcome to keep your camera on or off.

- Feel free to ask questions! Either use the “raise hand” option (preferable), or post in the chat. If I miss you, please repeat. And if I keep missing you, please unmute yourselves and mention that you have a question.

- I’ll be staying around for another 30 minutes after the lecture for additional Q&A.

Overview of today's lecture

- Teaching staff introductions
- What is this course about?
- Course fast-forward and logistics

Teaching staff introductions

Instructor: Ioannis (Yannis) Gkioulekas

I won't hold it against you if you mispronounce my last name

Originally from Greece

National Technical University of Athens (2004-09)

Harvard University (2009-17)

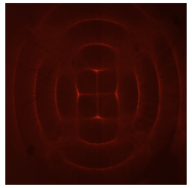
Carnegie Mellon University (2017-now)

Yannis at Harvard in 2011

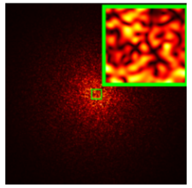
My website: http://www.cs.cmu.edu/~igkioule

See also: http://imaging.cs.cmu.edu/

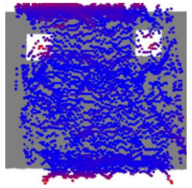
Broadly interested in computational imaging, physics-based vision, and physics-based rendering



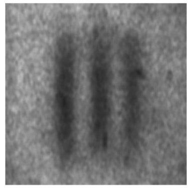
Rendering Near-Field Speckle Statistics in Scattering Media
Adithya Pediredla, Yasin Karimi Chalmiani, Matteo Giuseppe Scopelliti, Maysam Chamanzar, Srinivasa Narasimhan, **Ioannis Gkioulekas**
ACM Transactions on Graphics (SIGGRAPH Asia), 2020
paper | project page



Rendering Near-Field Speckle Statistics in Scattering Media
Chen Bar, **Ioannis Gkioulekas**, Anat Levin
ACM Transactions on Graphics (SIGGRAPH Asia), 2020
paper | project page

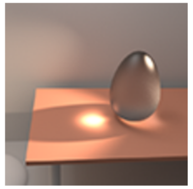


A Theory of Fermat Paths for 3D Imaging Sonar Reconstruction
Eric Westman, **Ioannis Gkioulekas**, Michael Kaess
IEEE International Conference on Intelligent Robots and Systems (IROS), 2020
paper | project page



Interferometric Transmission Probing with Coded Mutual Intensity
Alankar Kotwal, Anat Levin, **Ioannis Gkioulekas**
ACM Transactions on Graphics (SIGGRAPH), 2020
paper | project page

Langevin Monte Carlo Rendering with Gradient-based Adaptation
Fujun Luan, Shuang Zhao, Kavita Bala, **Ioannis Gkioulekas**
ACM Transactions on Graphics (SIGGRAPH), 2020
paper | project page

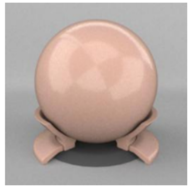


Path-Space Differentiable Rendering
Cheng Zhang, Bailey Miller, Kai Yan, Ioannis Gkioulekas, Shuang Zhao
ACM Transactions on Graphics (SIGGRAPH), 2020
paper | project page

Effect of Geometric Sharpness on Translucent Material Perception
Bei Xiao, Shuang Zhao, **Ioannis Gkioulekas**, Wenyan Bi, Kavita Bala Journal of Vision (JOV), 2020
paper | code

Use rendering to study human perception

A Volumetric Albedo Framework for 3D Imaging Sonar Reconstruction
Eric Westman, **Ioannis Gkioulekas**, Michael Kaess
IEEE International Conference on Robotics and Automation (ICRA), 2020
paper | project page



Towards Reflectometry from Interreflections
Kfir Shem-Tov, Sai Praveen Bangaru, Anat Levin, **Ioannis Gkioulekas**
IEEE International Conference on Computationa Photography (ICCP), 2020
paper | project page

Use rendering to make reflectometry easier

Towards Learning-based Inverse Subsurface Scattering
Chengqian Che, Fujun Luan, Shuang Zhao, Kavita Bala, **Ioannis Gkioulekas**
IEEE International Conference on Computationa Photography (ICCP), 2020
paper | project page

Use rendering to make neural networks better

TA: Bailey Miller

advised by Prof. Ioannis Gkioulekas

personal page: bailey-miller.com

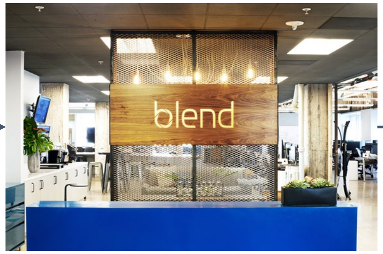
- research interests:
  - physically-based rendering
  - volumetric rendering
  - inverse graphics / differentiable rendering

- current area of research:
  - grid-free methods for solving the reduced wave equation

dartmouth '14 to '18

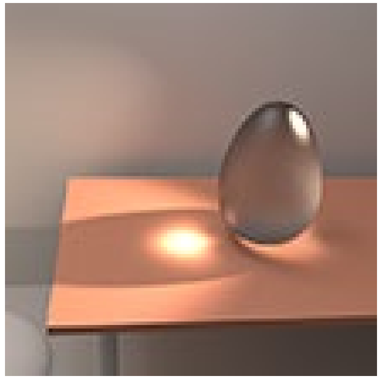
DARTMOUTH
VISUAL COMPUTING LAB

blend '18 to '20



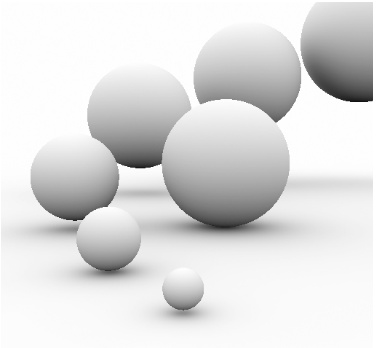
co-founded by a cmu alum!

cmu '20 to present



Zhang et al. '20

Miller et al. '19



Singh et al. '17

What is this course about?

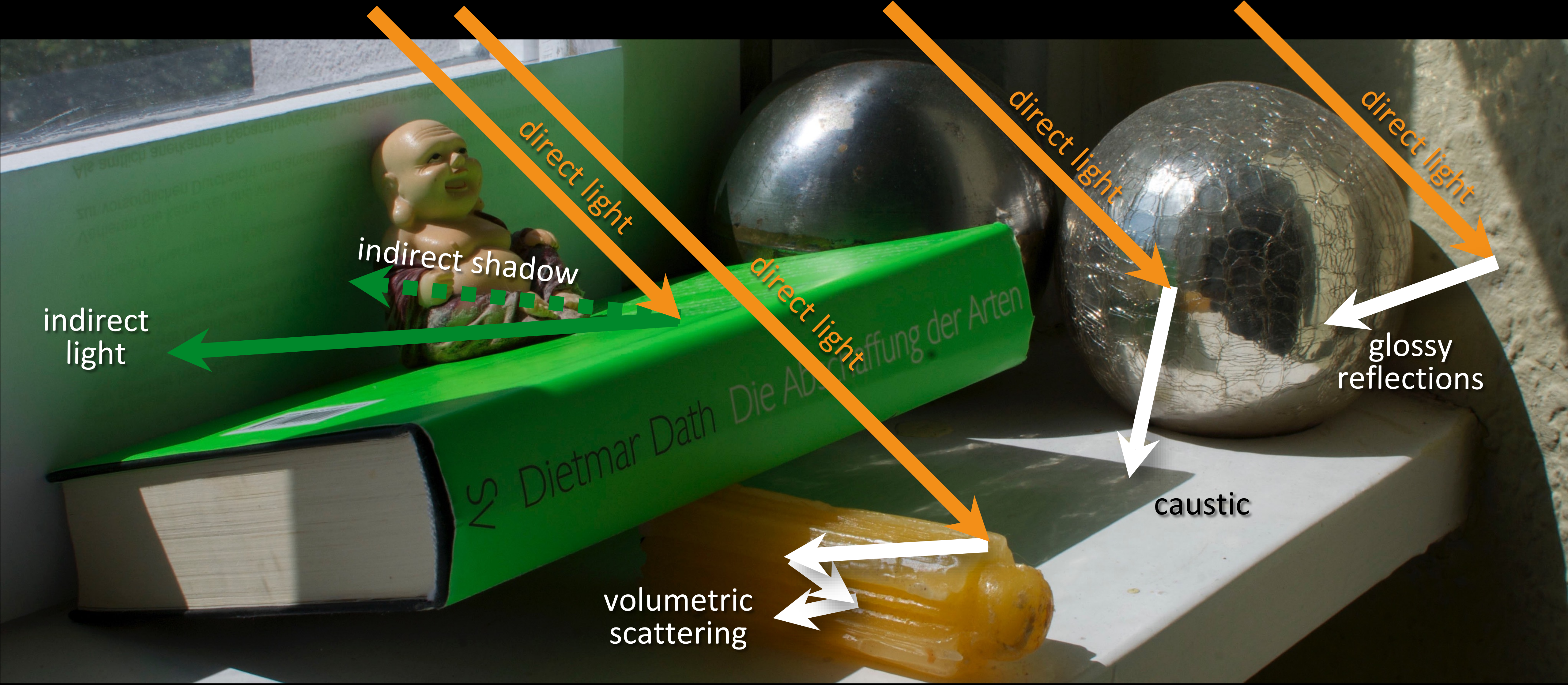
What is this class about?

- How can we generate realistic images?
- Why do things look the way they do?

Motivation

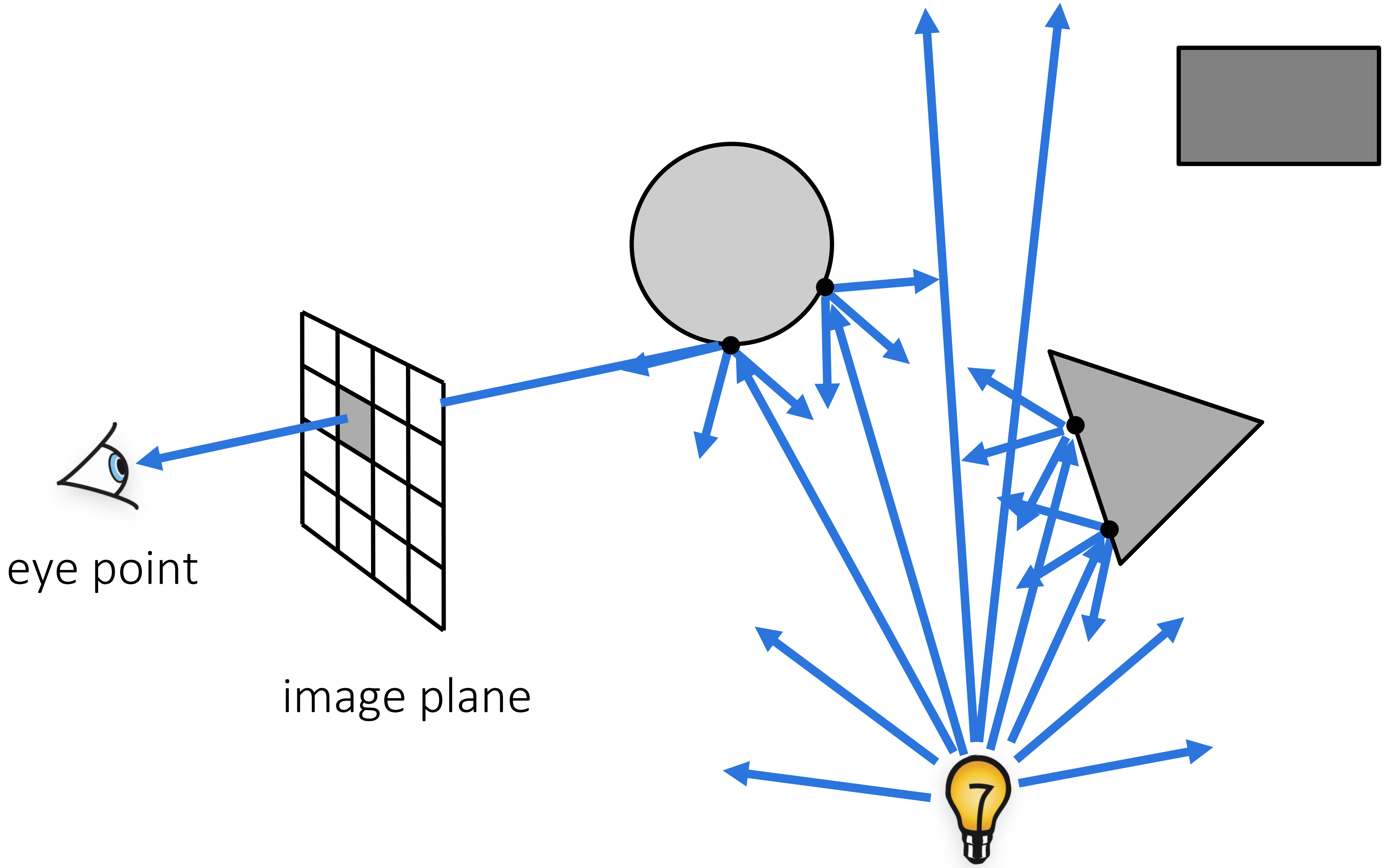
Wojciech Jarosz

Light transport in the real world



After [Ritschel et al 2011]

Physics-based rendering



Mimic the physics of light transport using ray tracing

Wojciech Jarosz

Ray tracing in production

Arnold Renderer

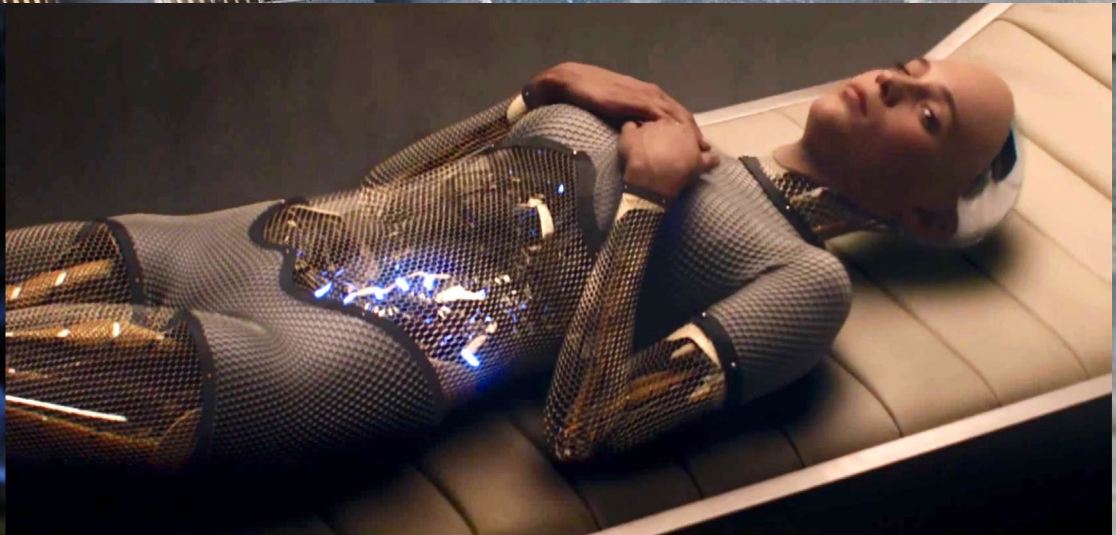
SOLIDANGLE

PIXAR's RenderMan

Hyperion

Wojciech Jarosz

Visual effects



Wojciech Jarosz

Animated films

Wojciech Jarosz

Video games

Wojciech Jarosz

Architectural visualization

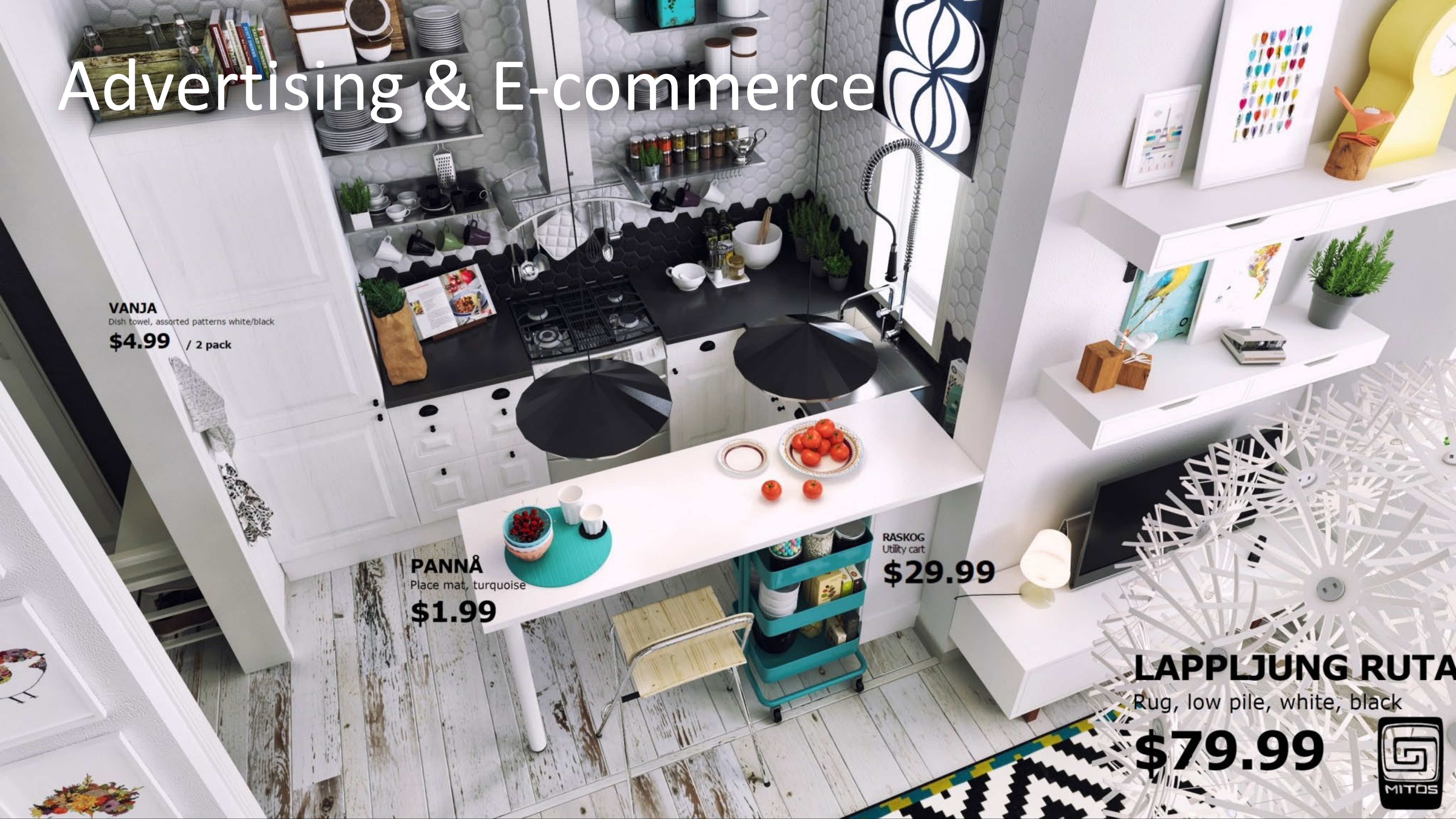
Wojciech Jarosz

Architectural visualization

Advertising/product visualization

Wojciech Jarosz

Advertising & E-commerce



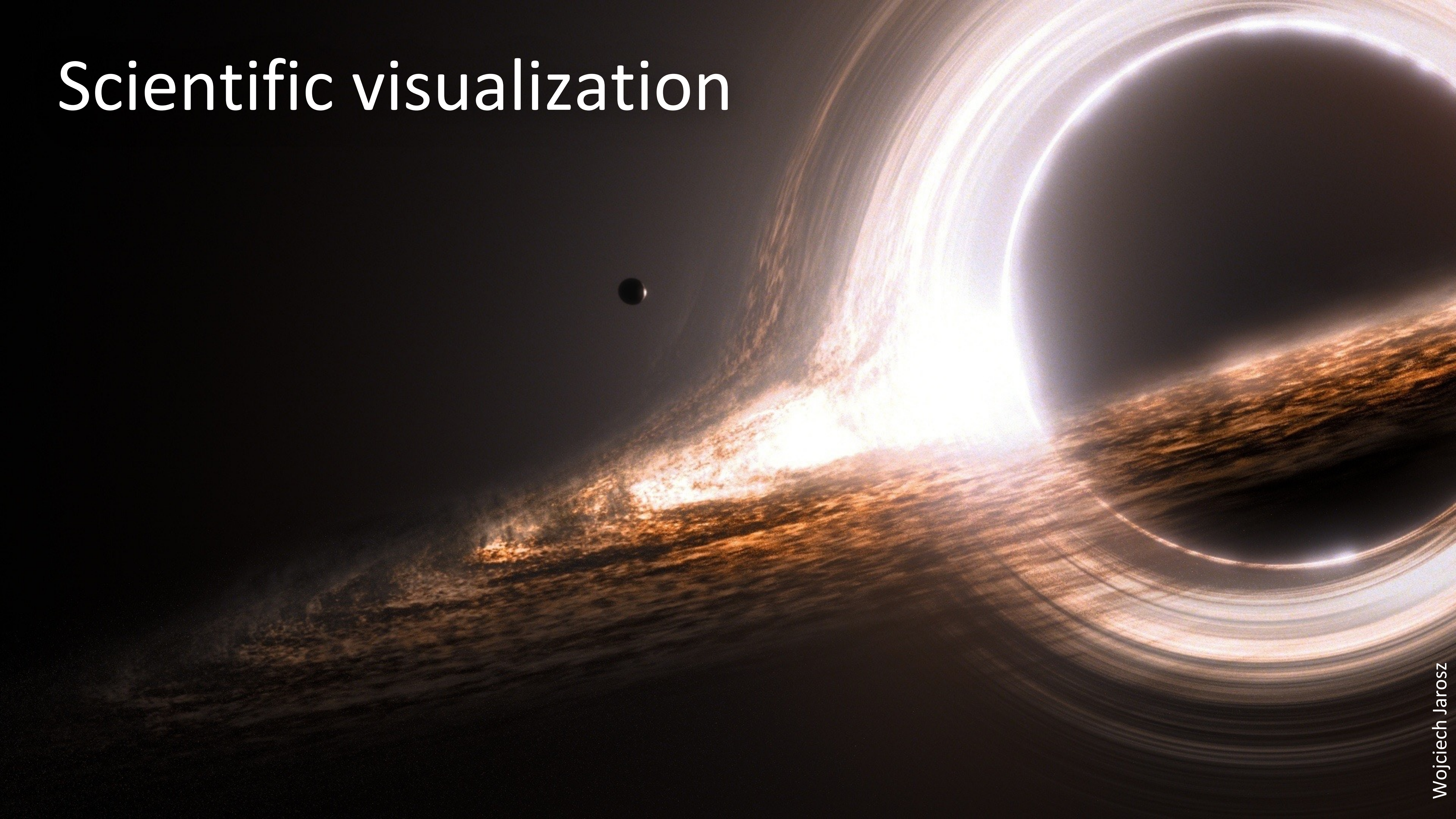
Cultural heritage

Wojciech Jarosz

Digital fabrication

Wojciech Jarosz

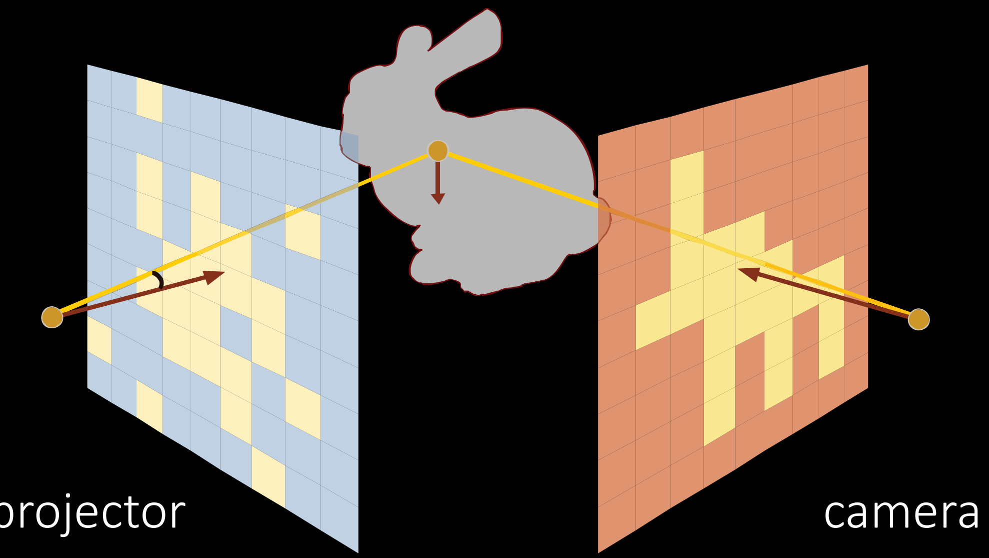
Scientific visualization



Wojciech Jarosz

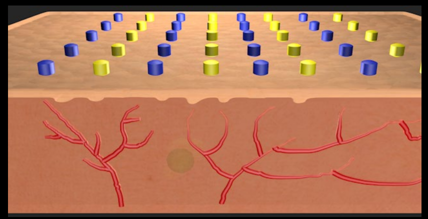
Scientific imaging

rendering computational light transport

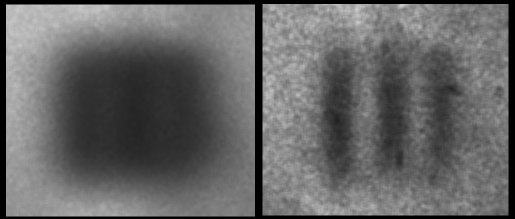


Used by CMU imaging projects:

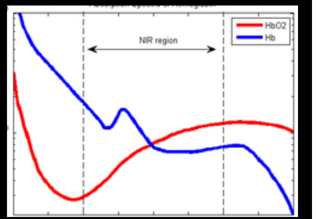
convolutional DOT



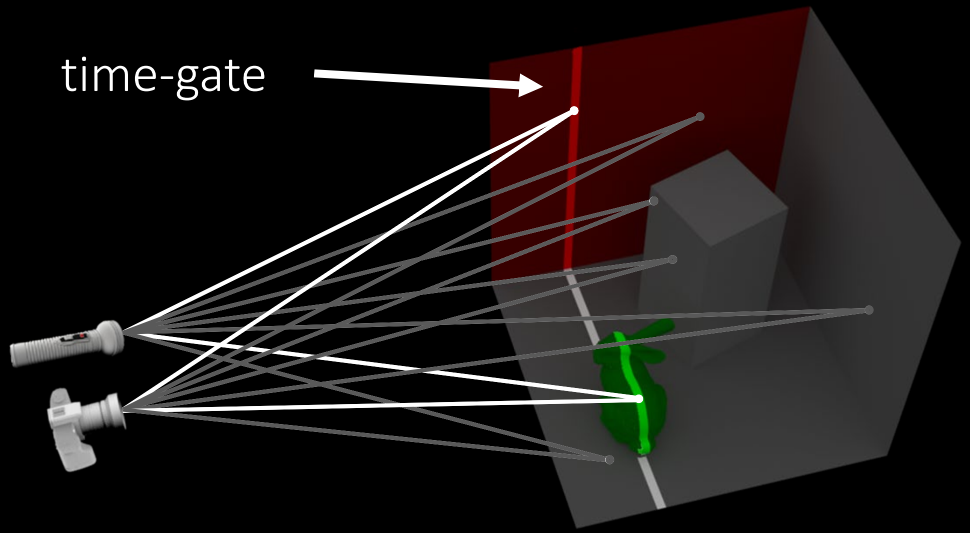
coded coherence



coded spectrum

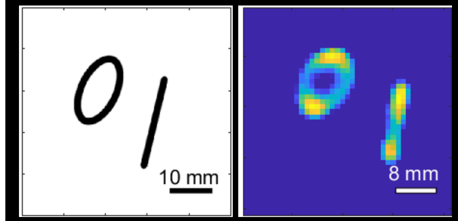


rendering time-of-flight sensors

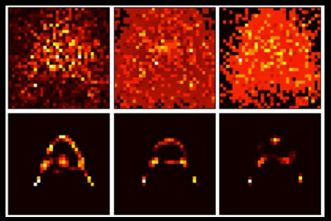


Used by CMU imaging projects:

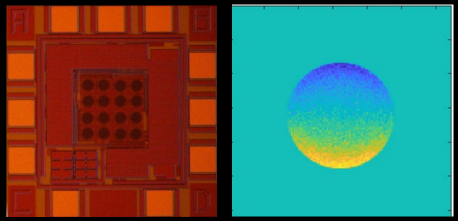
ToF DOT



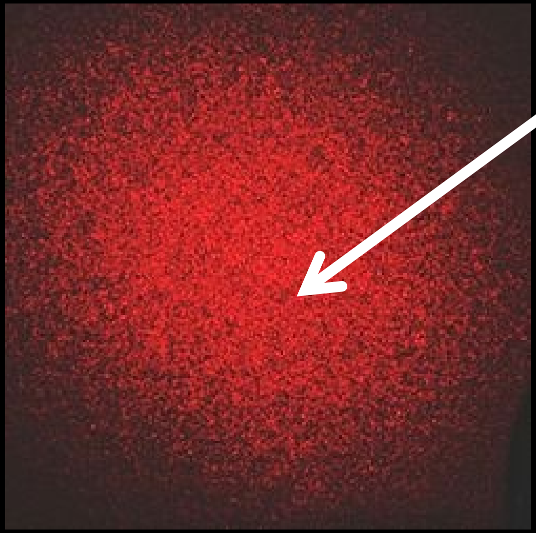
all-photon imag.



differential SPAD

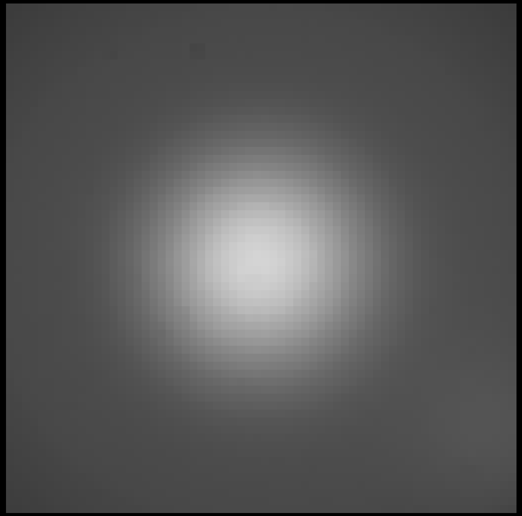


Rendering wave effects



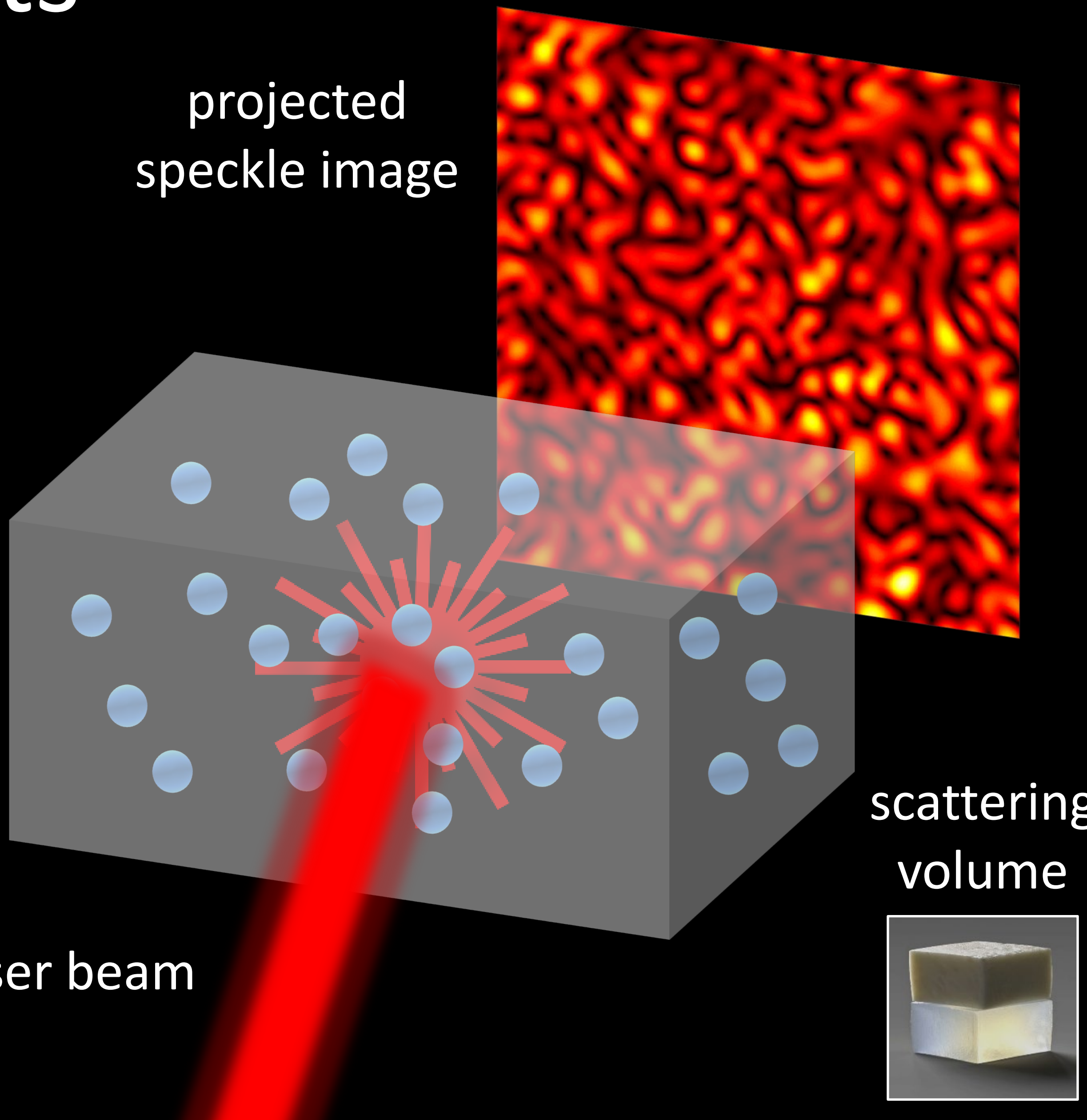
speckle: noise-like pattern

what real laser images look like



what standard rendered images look like

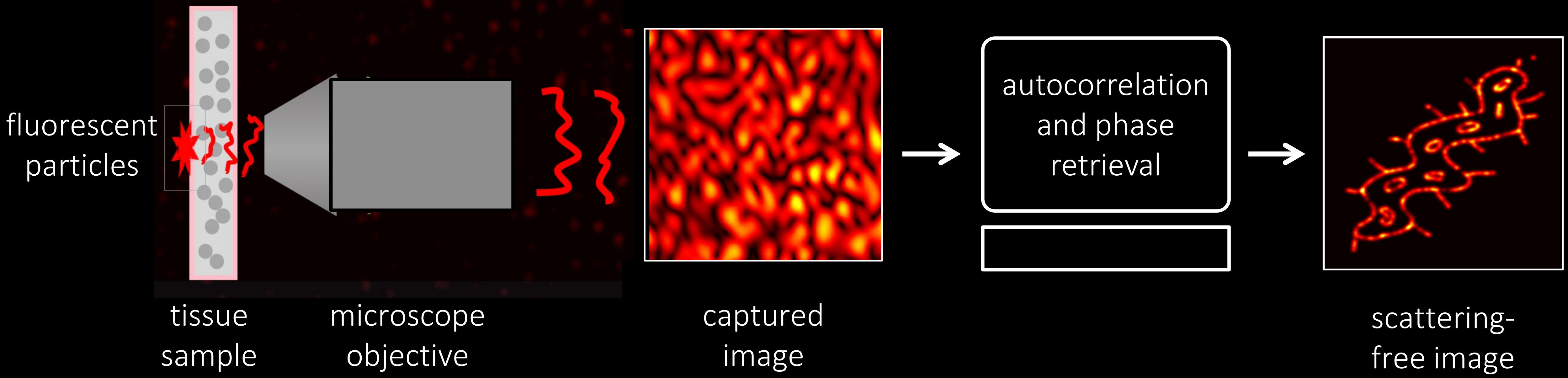
projected speckle image

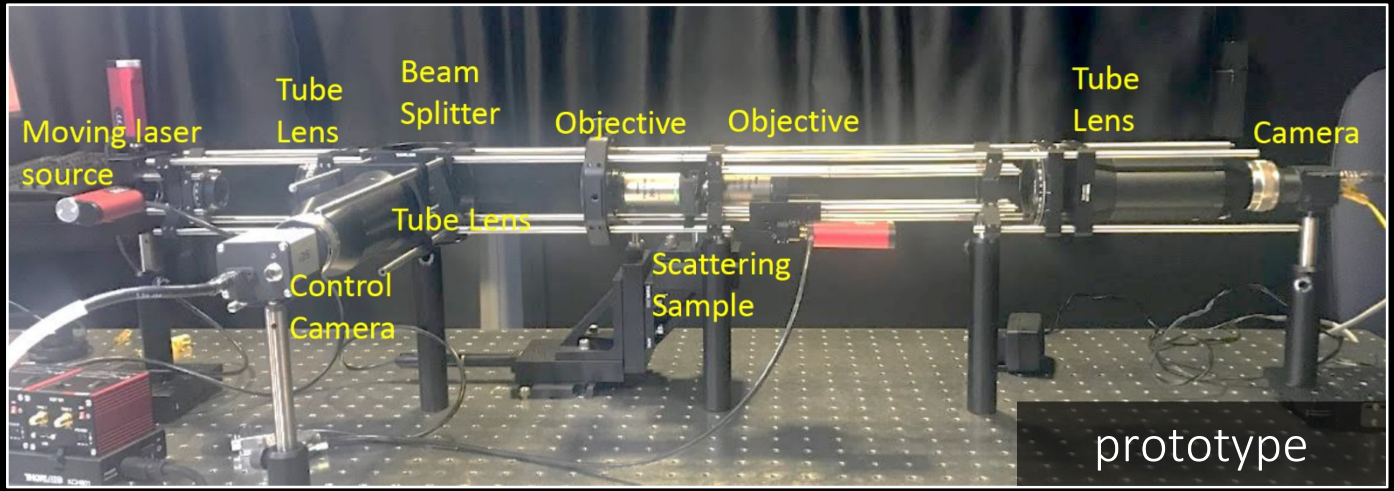


laser beam

scattering volume

Application: fluorescence Microscopy



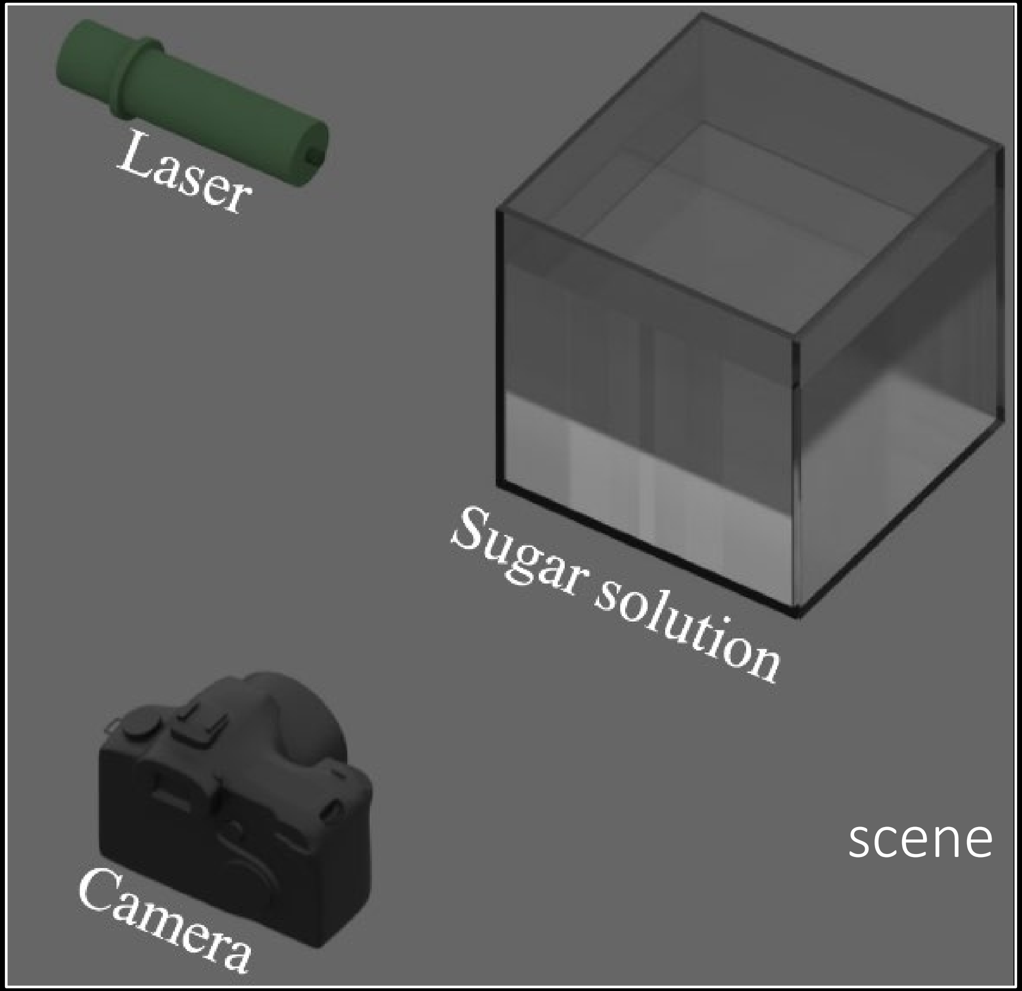


Performance strongly depends on:

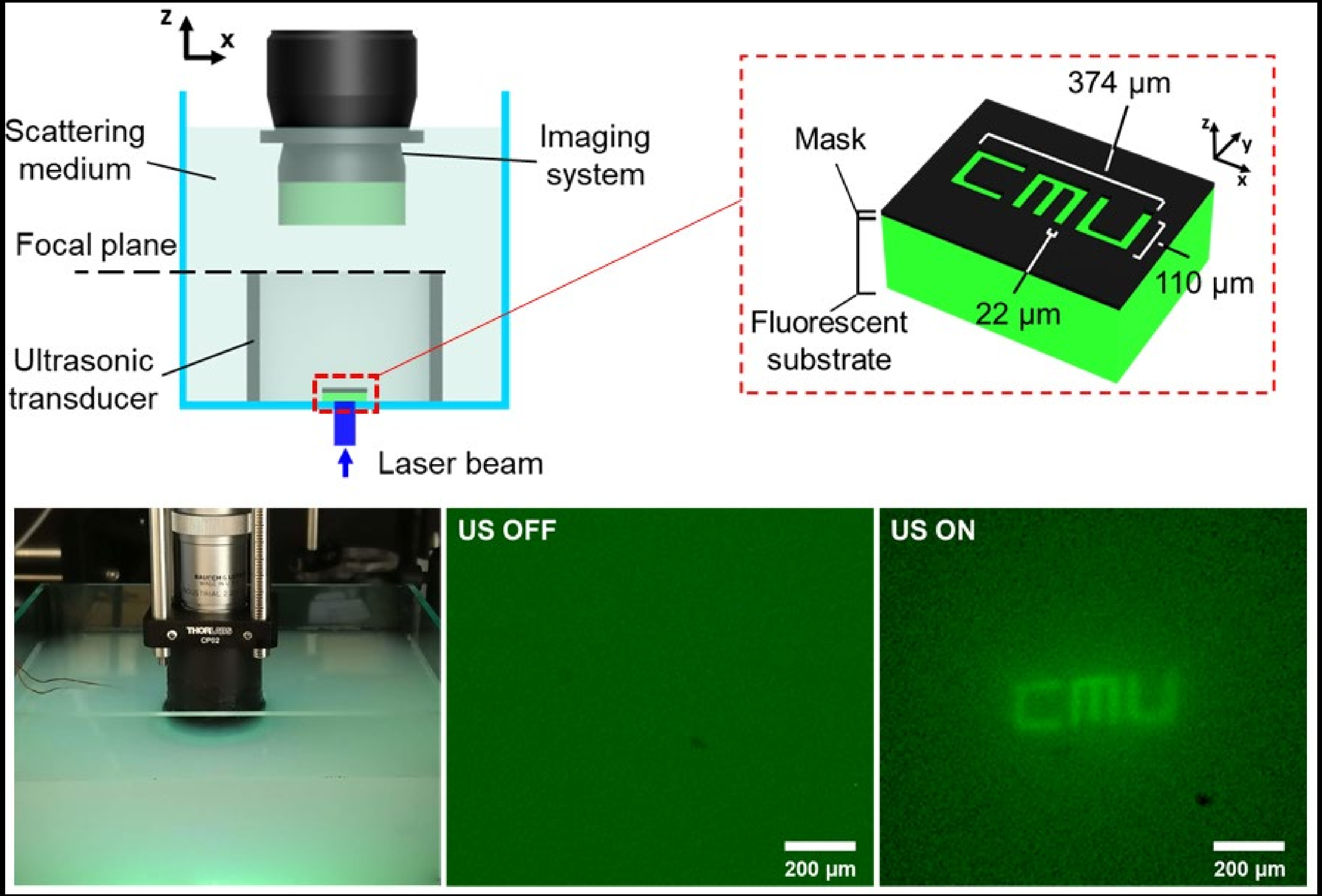
- speckle statistics
- image priors
- tissue parameters

Rendering-assisted exploration and new algorithms!

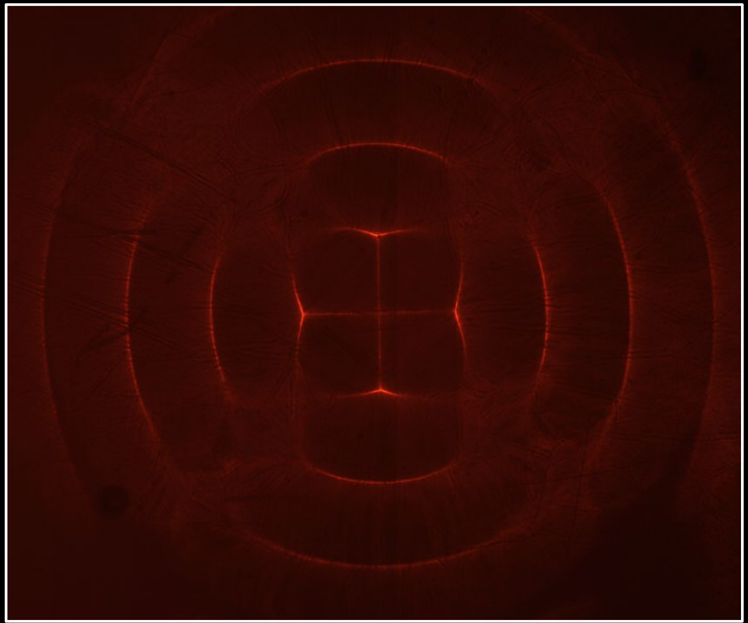
Rendering eikonal transport



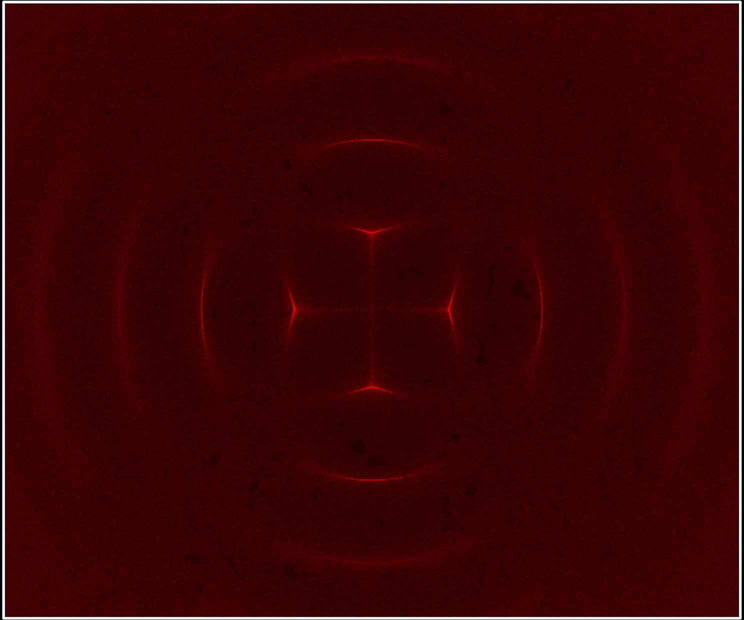
Application: acousto-optics



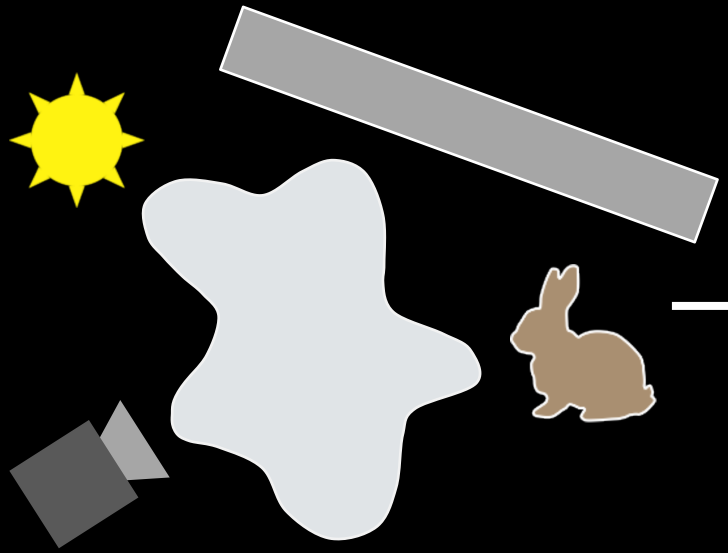
real capture



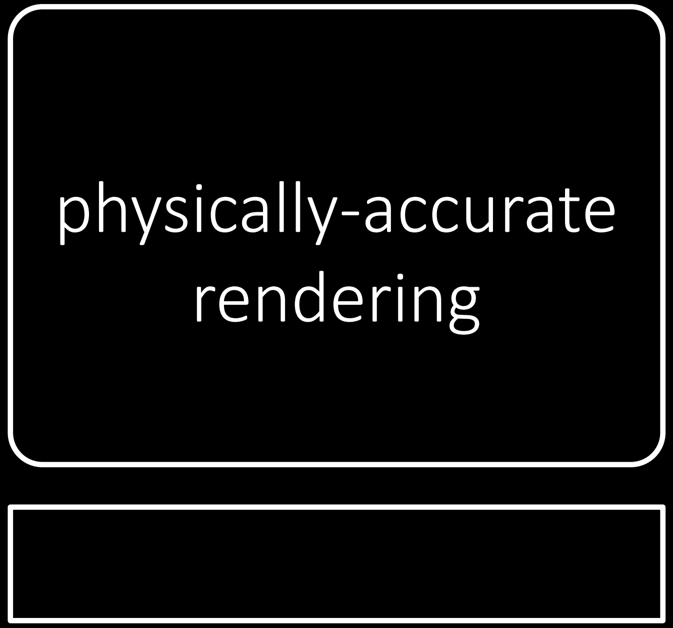
our algorithm

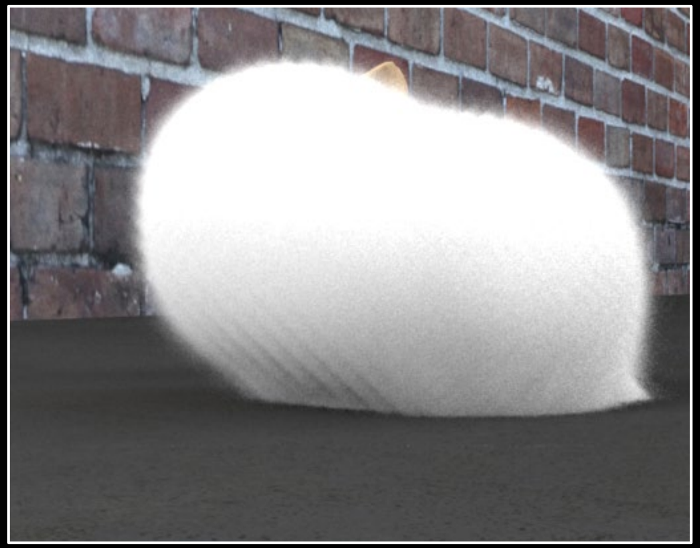


Forward rendering



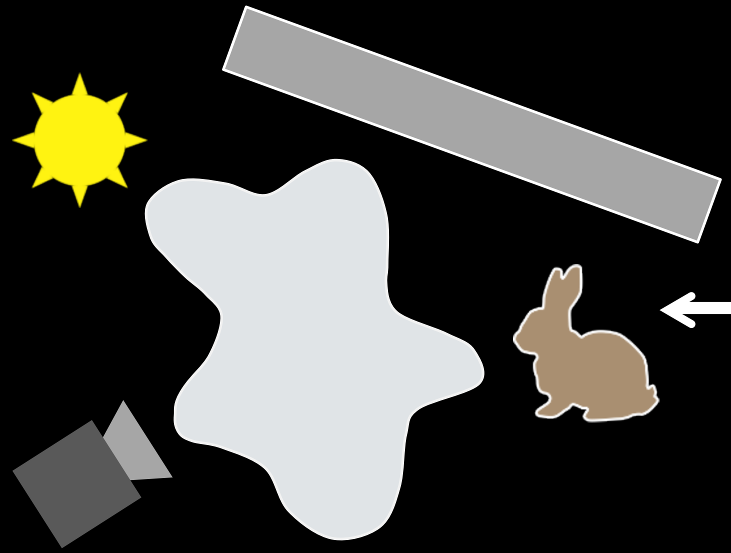
digital scene specification
(geometry, materials,
optics, light sources)



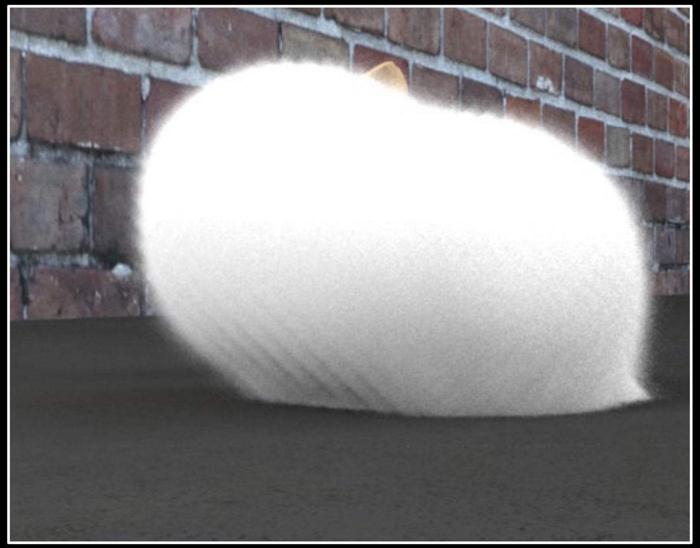


photorealistic
simulated image

Inverse rendering



physically-accurate
inverse rendering



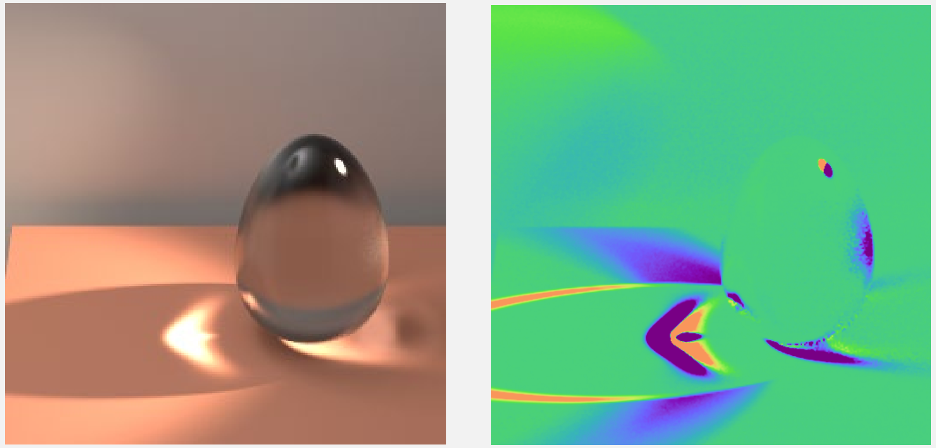
digital scene specification
(geometry, materials,
camera, light sources)

photorealistic
synthetic image

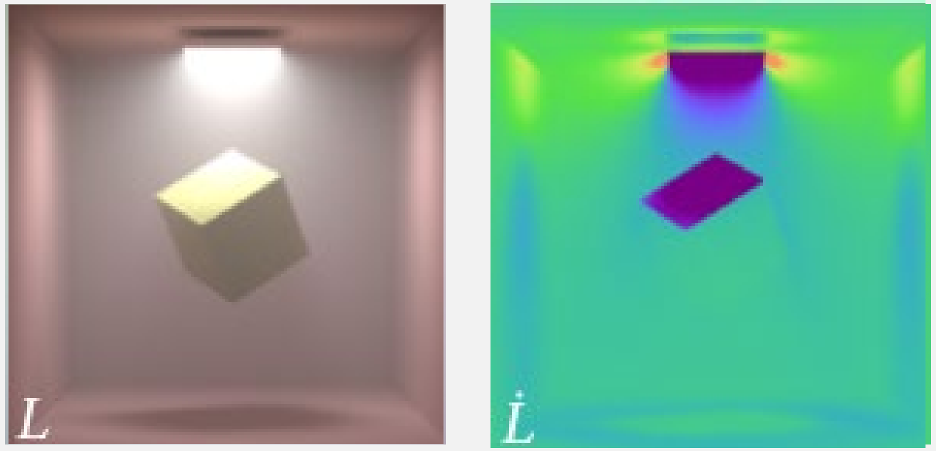
image
measurements

Differentiable rendering

Original image Derivative image

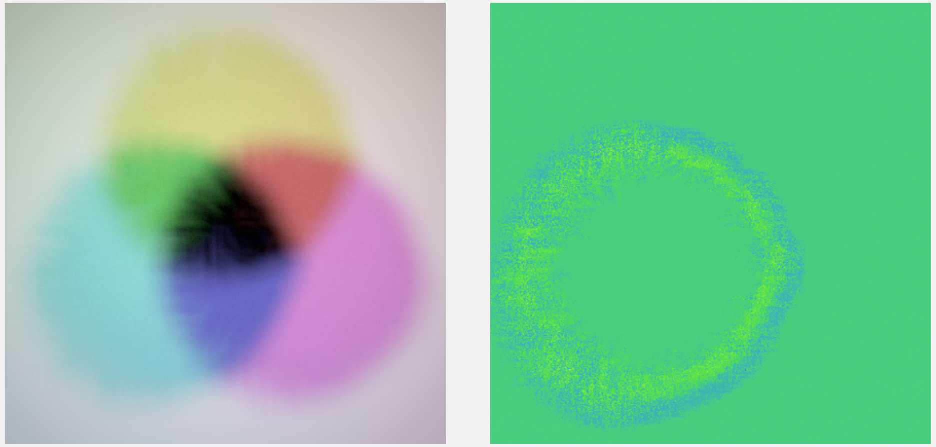


Original image Derivative image

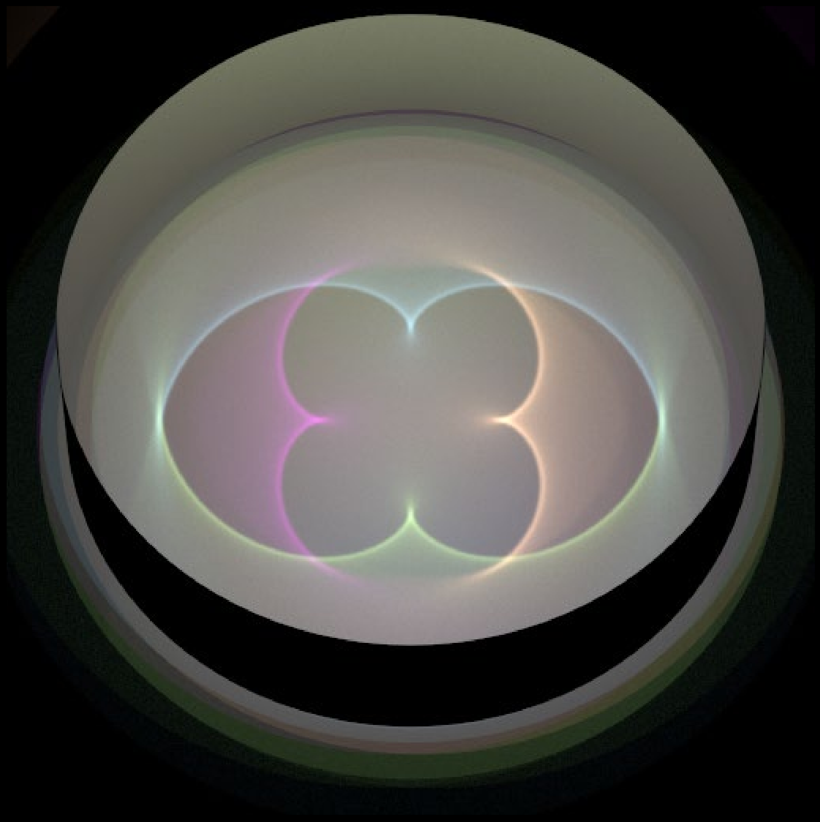


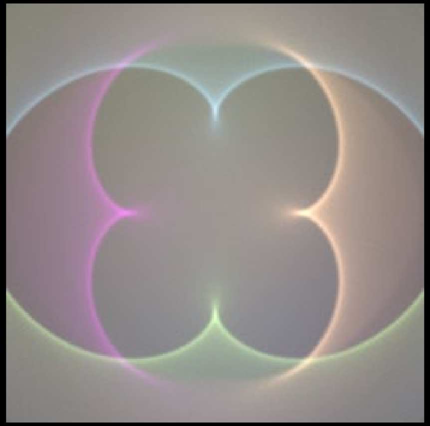
Original image Derivative image

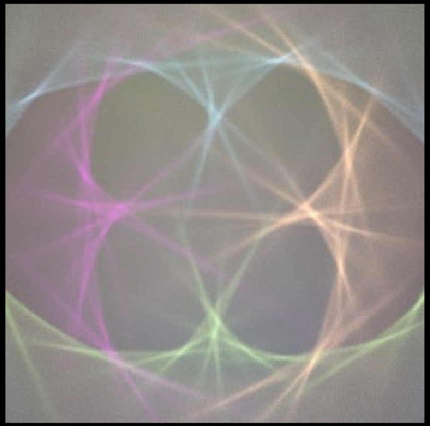
Original image Derivative image

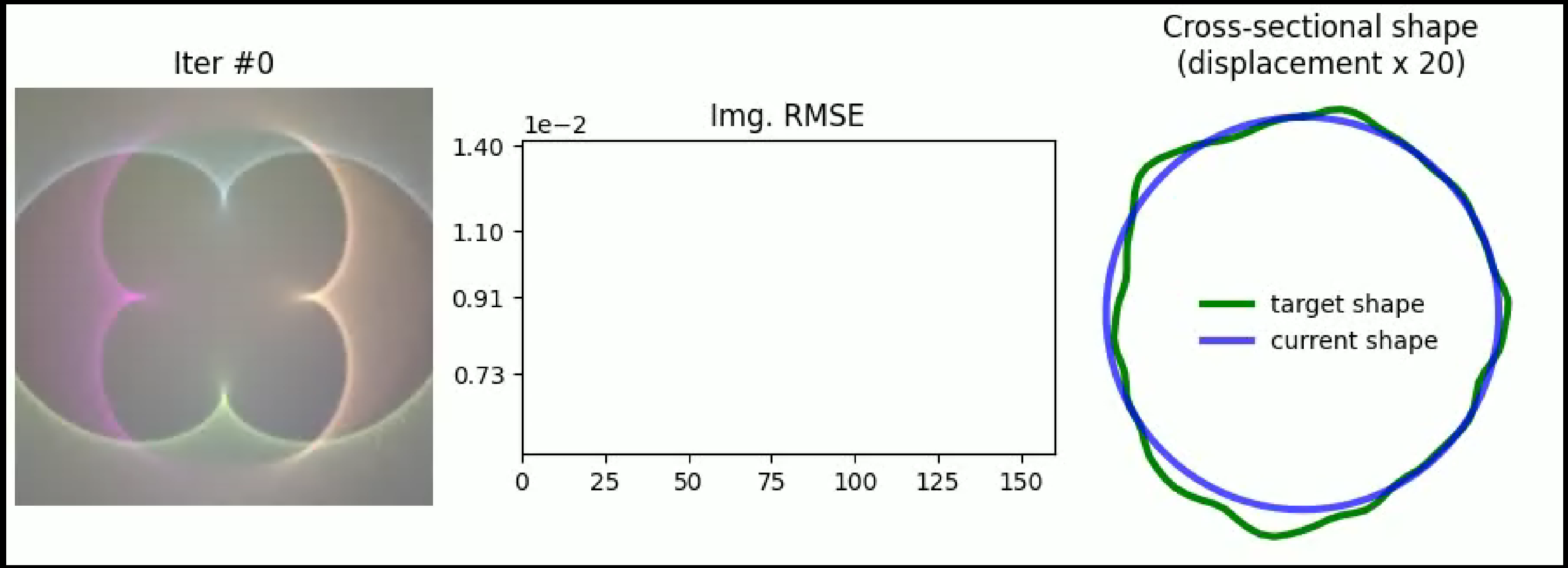


Application: shape optimization

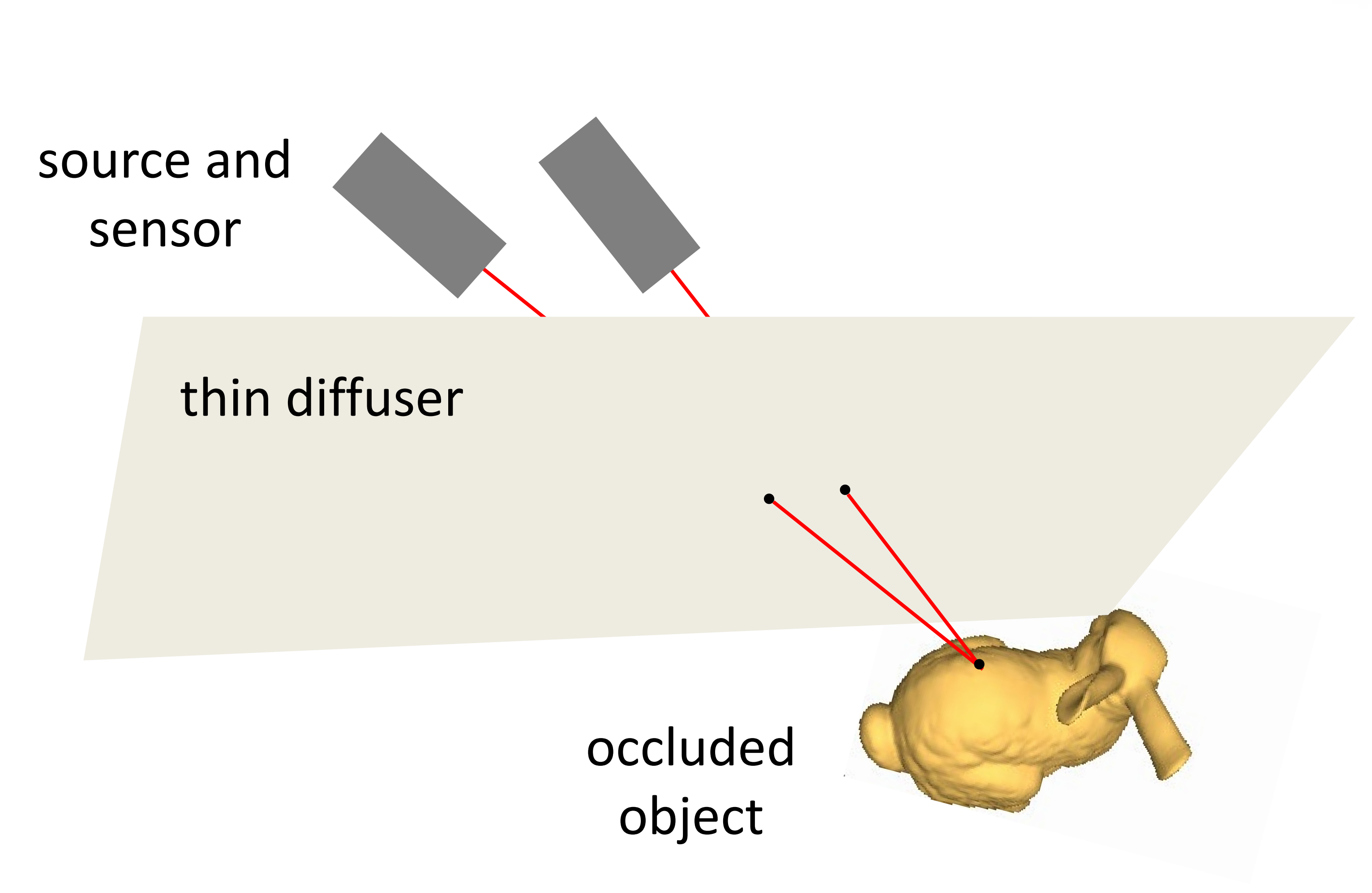


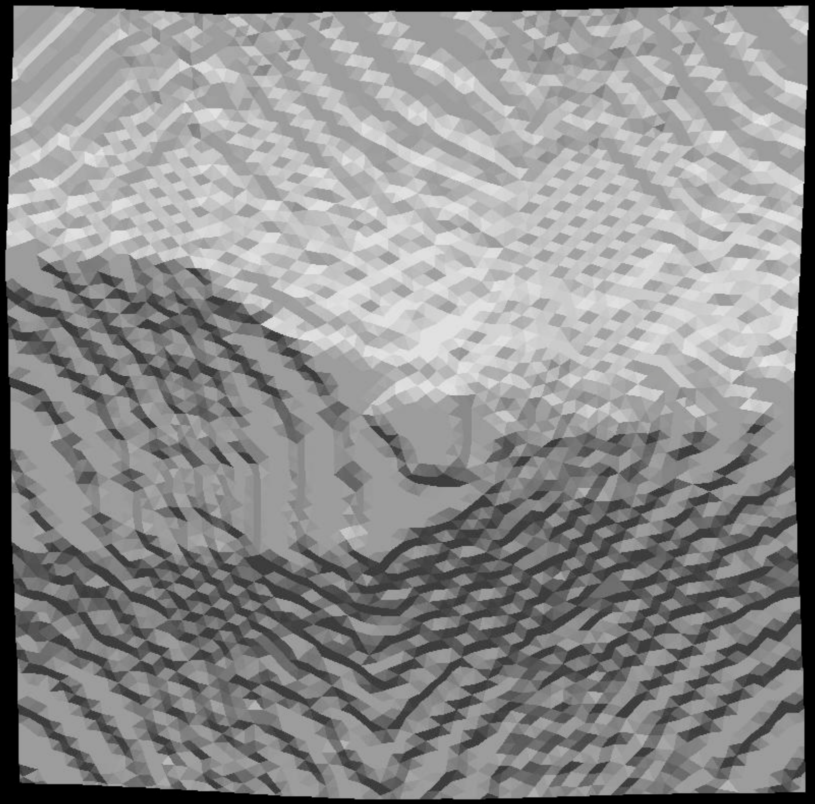






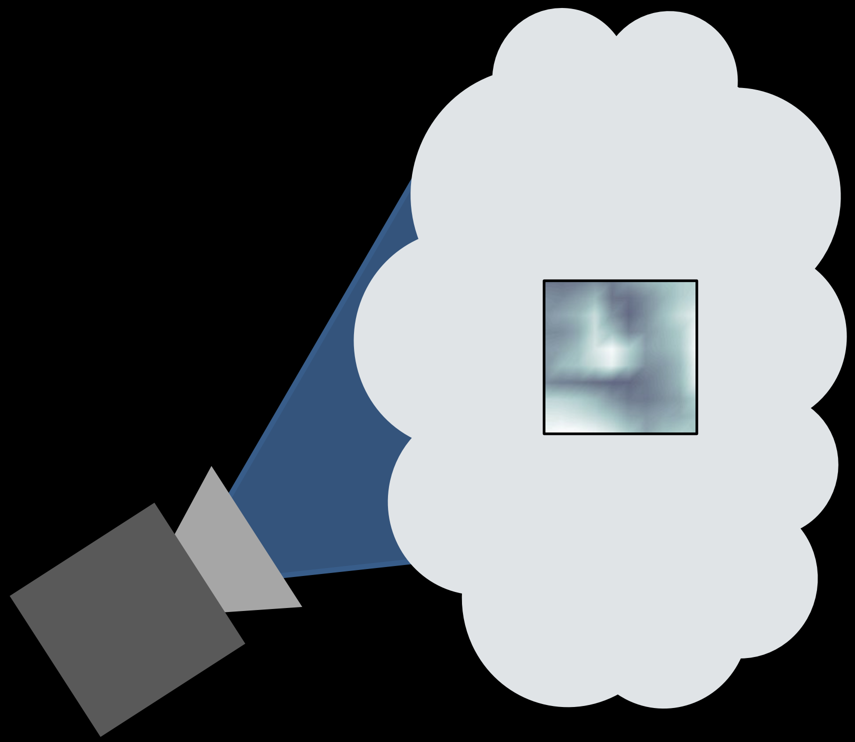
Application: non-line-of-sight imaging





reconstruction evolution

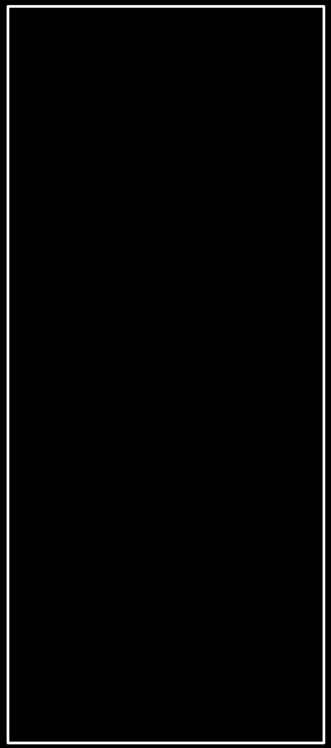
Application: non-invasive tomography



camera

thick smoke cloud

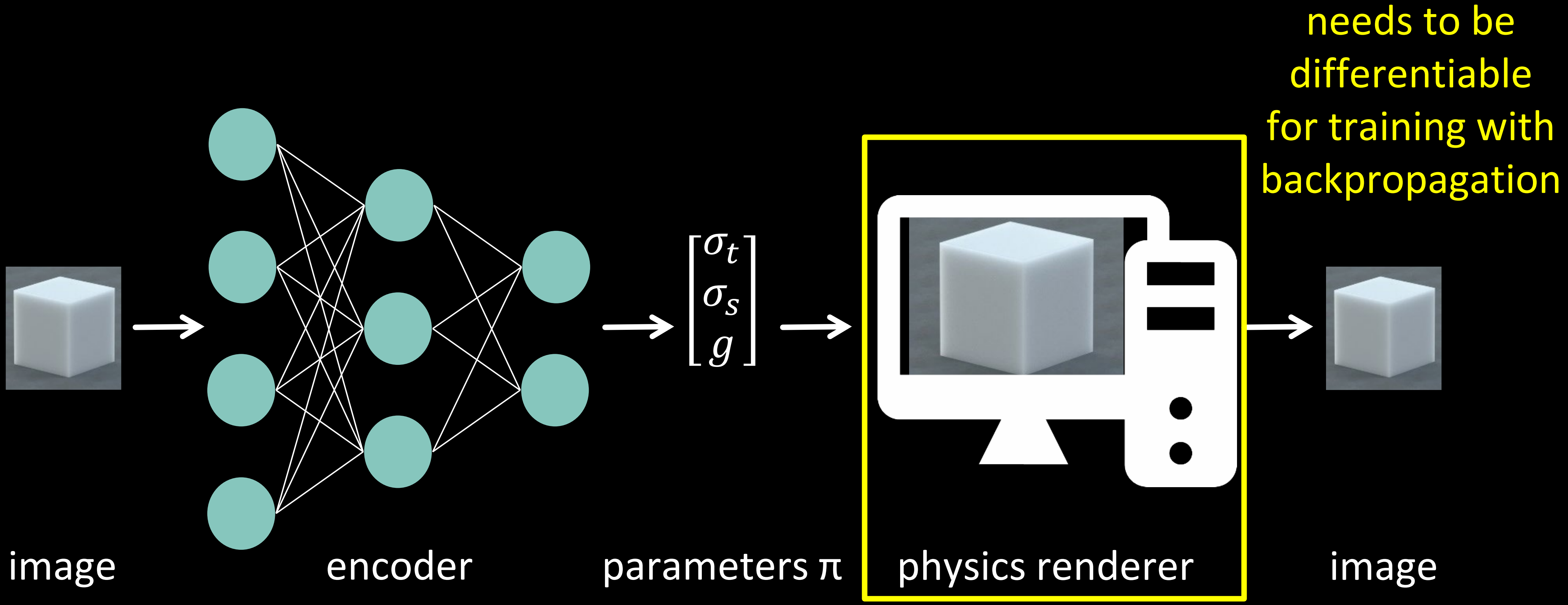
simulated camera measurements



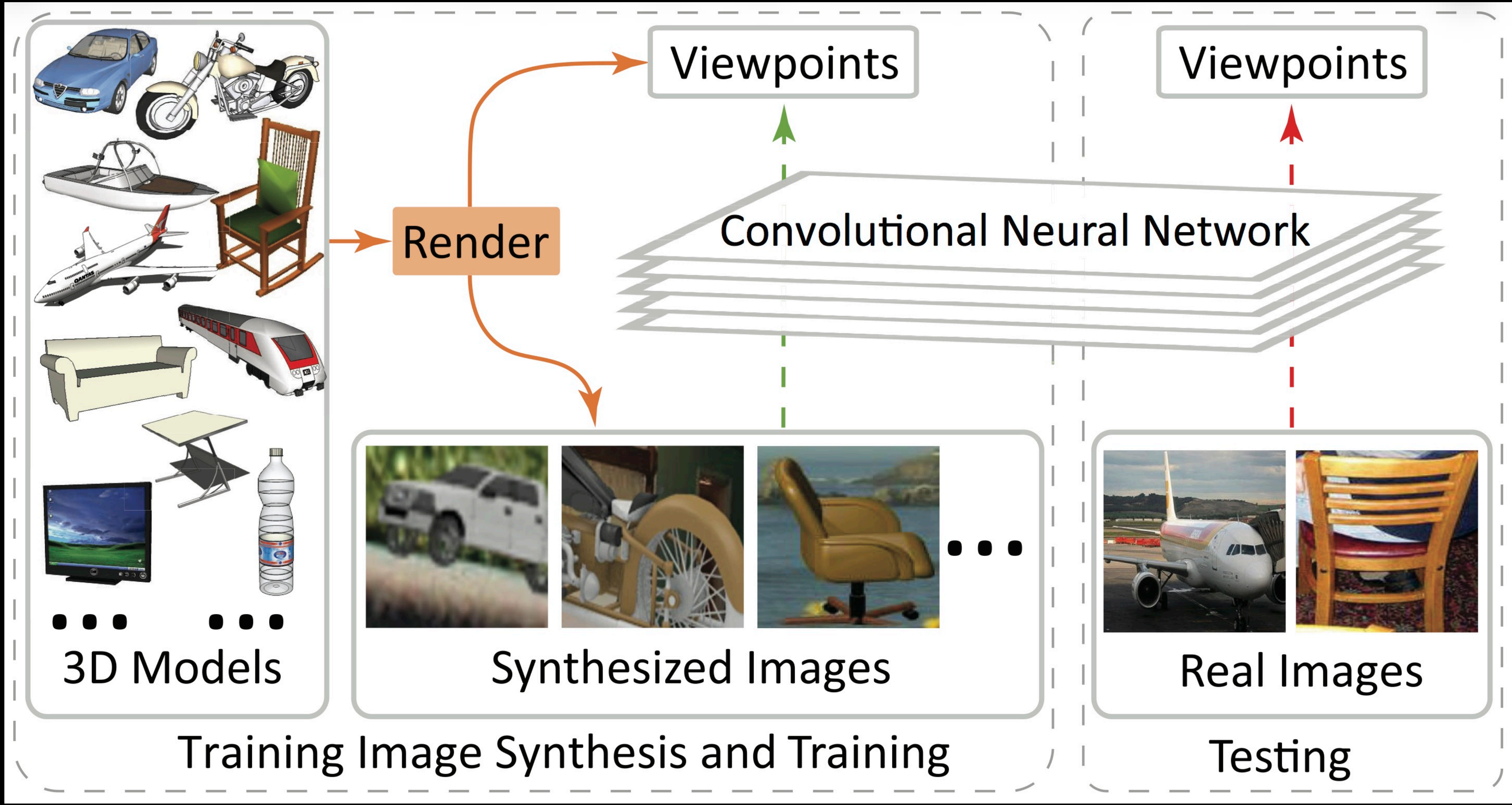
reconstructed cloud volume

slice through the cloud

Application: vision and machine learning



Application: 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]

What is this class about?

Producing realistic images by:

- *simulating* light transport (global illumination)
- *simulating* light's interaction with materials (appearance modeling)

Understanding why things look the way they do:

- Why is the sky blue?
- Why is the grass green?
- Why does metal look different than marble?

Course fast-forward and logistics

Course logistics

- Course website:

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

- Piazza for discussion and announcements (sign up!):

  https://piazza.com/class/kklw0l5me2or4

- Canvas for homework submissions, Zoom links, and recordings:

  https://canvas.cmu.edu/courses/22291

- Slack server for real-time discussion:

  See Piazza for the invite link

Please take the start-of-semester survey!

- Posted on Piazza as well:

  https://docs.google.com/forms/d/e/1FAIpQLScwNSk9hXN61oeohumgsiclifIeHw4ogk9K3ccnPDVKb399cQ/viewform

Course fast-forward

Tentative syllabus at:

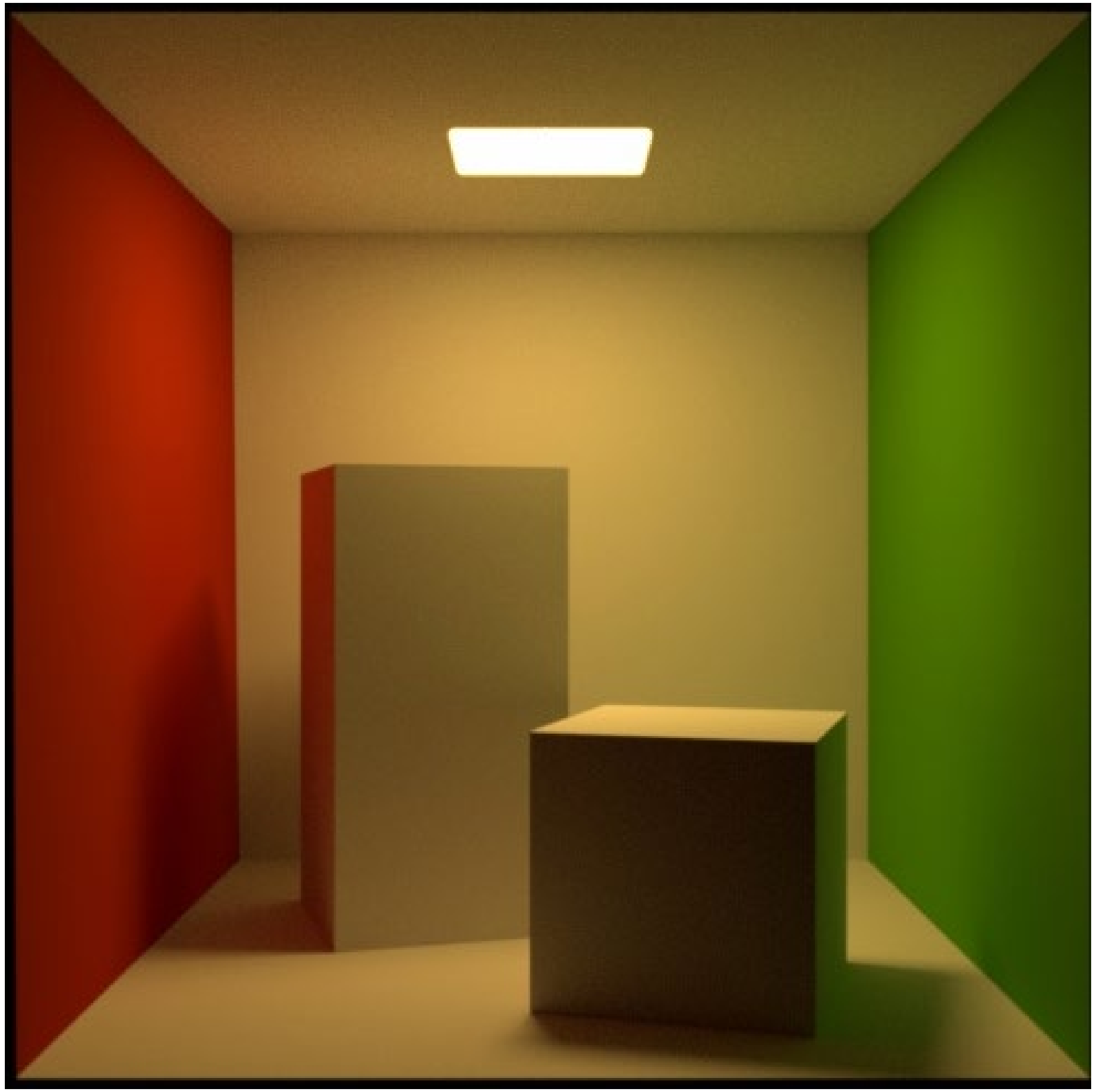
http://graphics.cs.cmu.edu/courses/15-468

- schedule and exact topics will most likely change during semester
- keep an eye out on the website for updates

Topics to be covered

Basics of ray tracing:

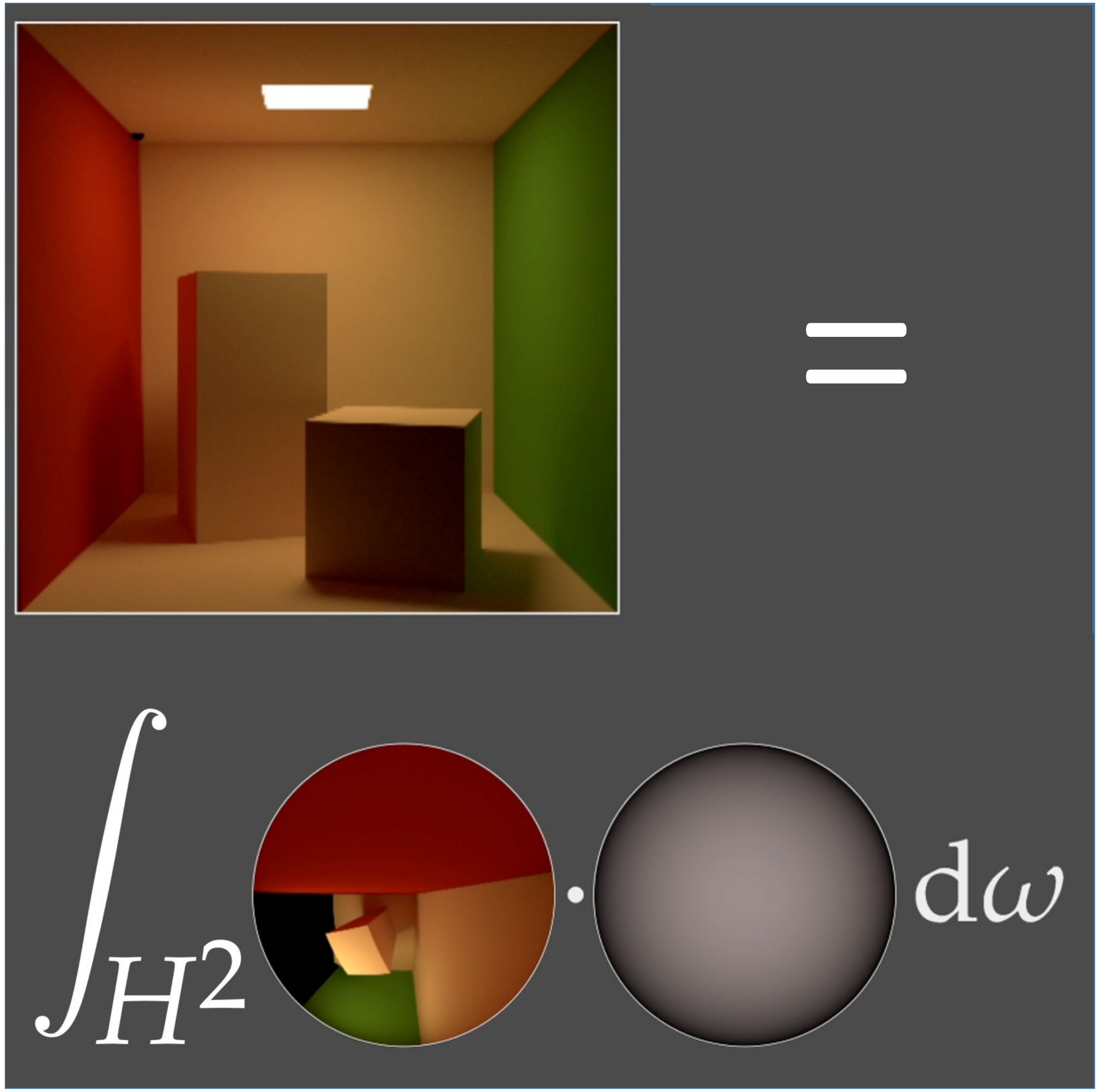
- trace-intersect recursions
- basic camera and illumination models
- shading
- intersection queries
- texture mapping



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

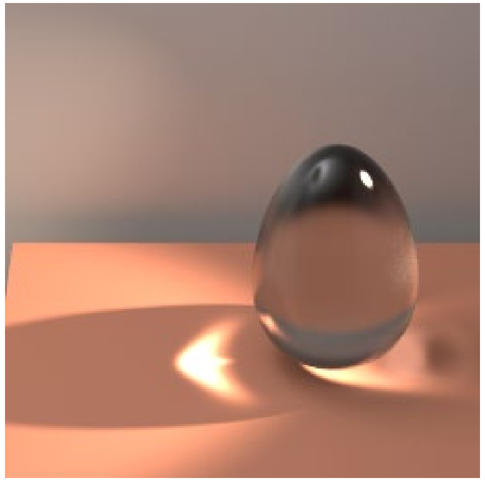
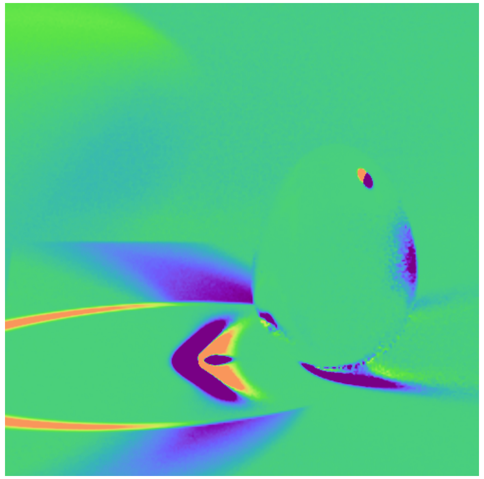
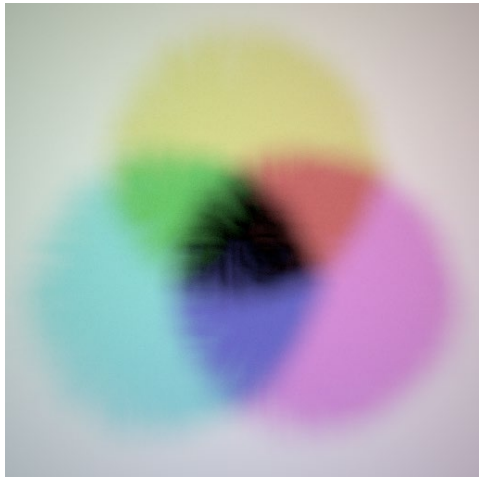
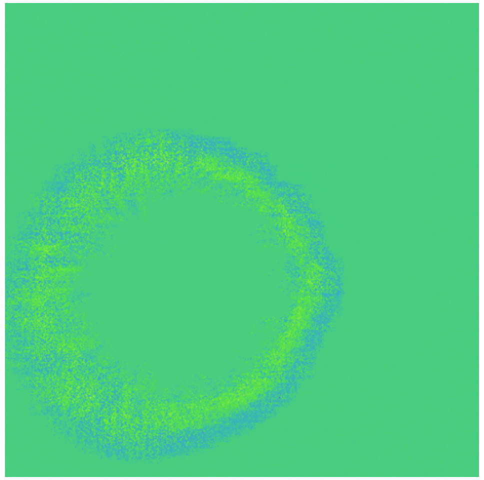
Monte Carlo rendering algorithms:

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

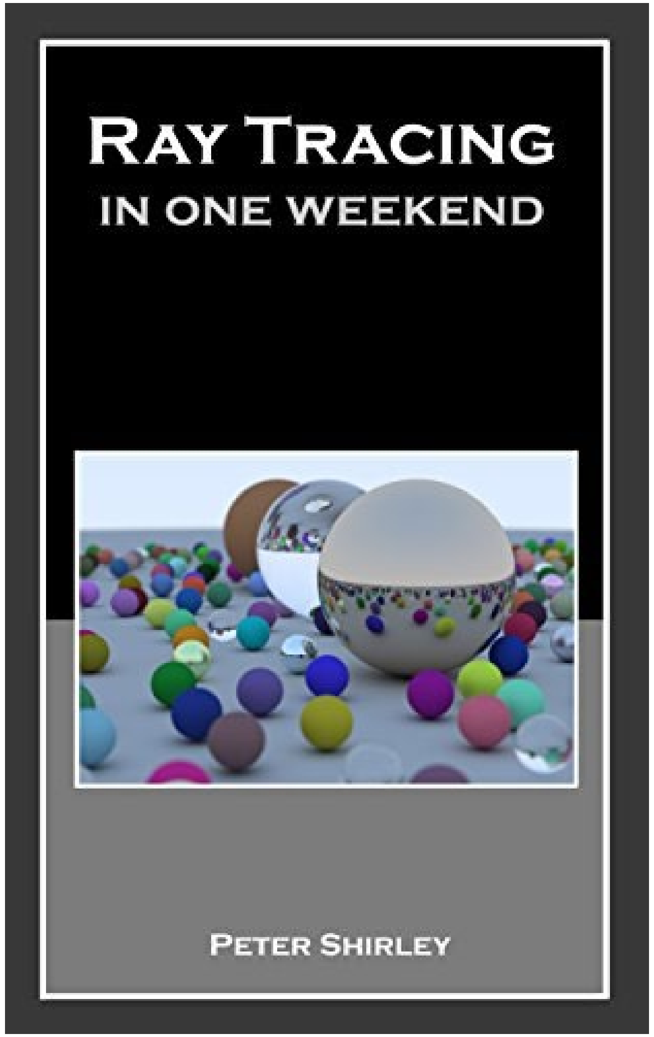
Topics to be covered

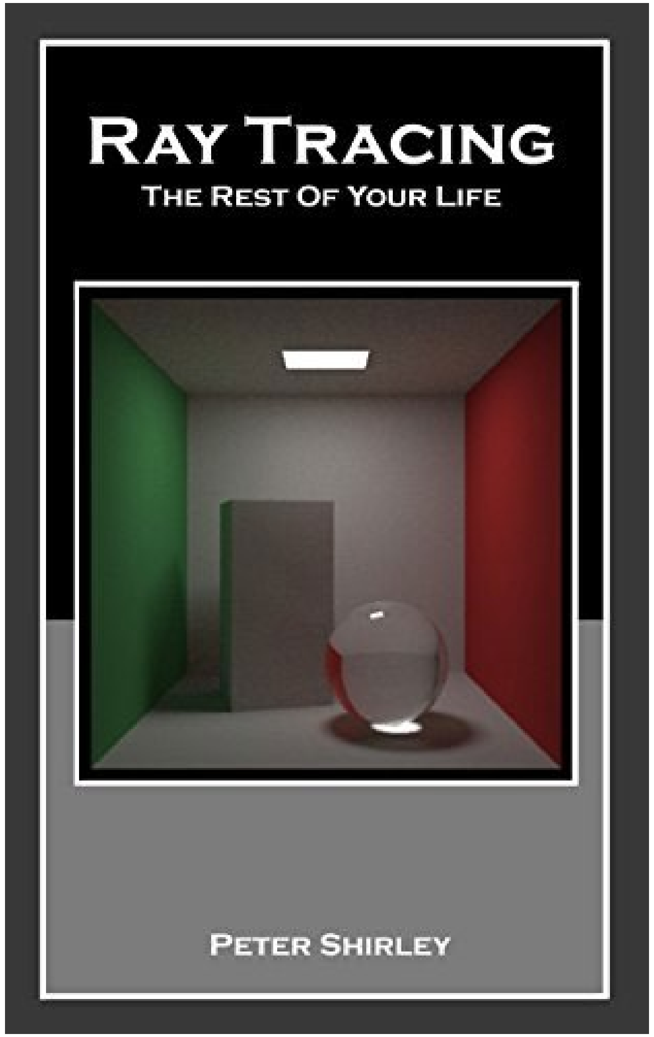
Advanced topics:

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

Books

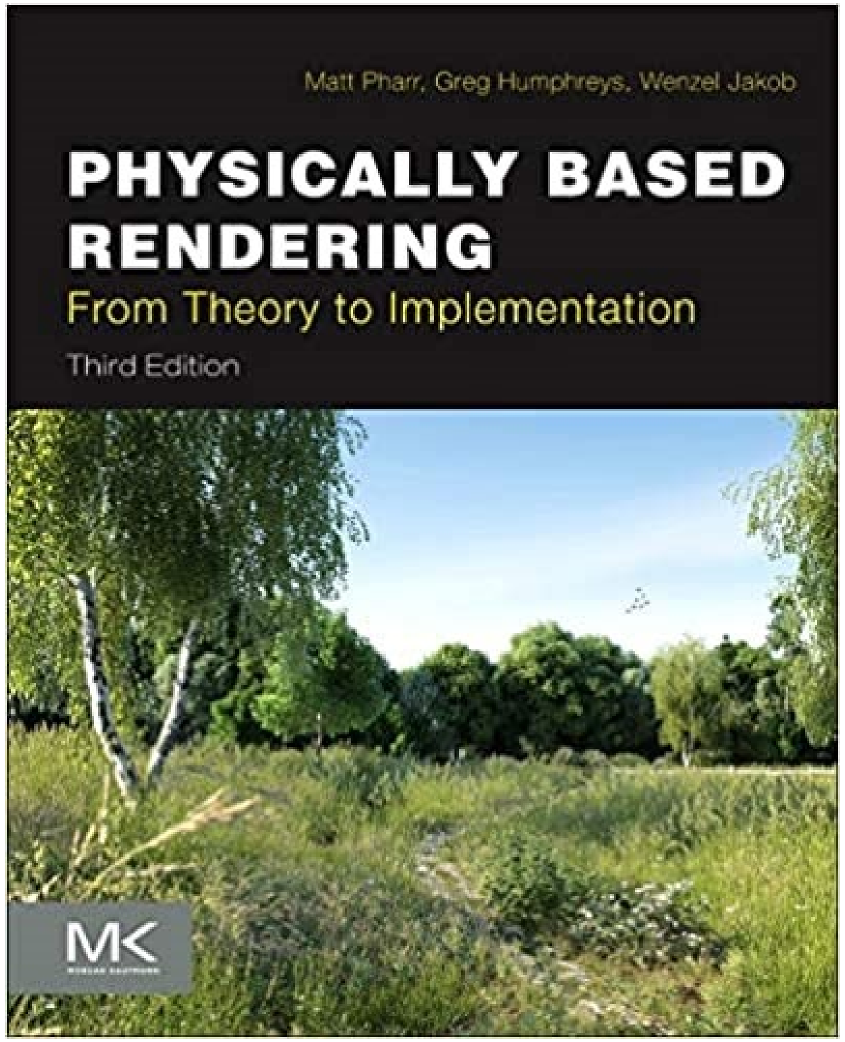




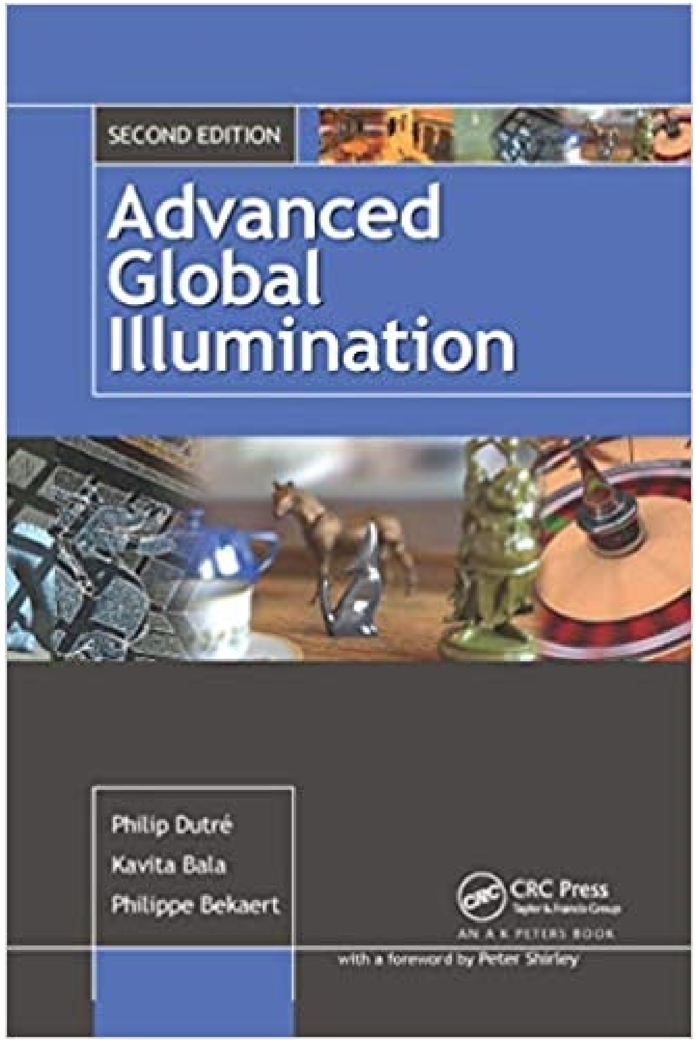
Peter Shirley’s “Ray Tracing” series.

- Great reference material for first and second half programming assignments.

Books



"PBR(T)", great reference for later programming assignments.



"AGI", great reference for theoretical aspects of the course.

Evaluation

- Four (plus one) programming assignments (50%):
    - implement progressively more advanced features within an existing barebones rendering framework.
    - all programming will be in **C++**.
    - 0-th assignment will serve as a gentle introduction to our simplified version of Nori educational renderer.
    - six late days, no more than three per assignment, 10% penalty per additional late day.
- Final project and rendering competition (25%):
    - implement rendering features of your choice and produce compelling imagery.
    - compete for **two free SIGGRAPH registrations (technical award and artistic award)!**
    - we will provide more information near the end of February.
    - 15-668, 15-868 require more substantive project.
    - **no exam, but final project presentations are during the exam period.**
- Ten take-home quizzes (20%):
    - solve 2-3 simple math problems related to each week's lectures.
    - **no late days, we will do solutions in class.**
    - you can skip three out of ten quizzes without penalty.
- Class, Piazza, and Slack participation (5%):
    - be around for lectures and office hours (lenient this semester).
    - participate in Piazza and Slack discussions.
    - ask questions and answer other people's questions.

Submission deadlines will be enforced strictly!

Rendering competition

Look at rendering competitions for similar courses at other universities for inspiration!

- Dartmouth (2019, 2017, 2016)
- EPFL (2019, 2018, 2017)
- ETH Zurich (2017, 2016, Fall 2015, Spring 2015, 2014, 2013, 2012)
- UC San Diego (2011, 2010, 2008, 2007, 2006, 2005, 2004, 2003)
- Stanford.

Contact information, office hours, and discussion

- Feel free to email us about administrative questions.
  - please use [15468] in email title!
- Technical questions should be asked on Piazza or Slack.
  - we won't answer technical questions through email.
  - you can post anonymously if you prefer.
- Office hours will be determined by poll.
  - office hours will be through Zoom.
  - feel free to email Yannis about additional office hours.
  - ~~you can also just drop by Yannis' office (Smith Hall (EDSH) Rm 225).~~
  - you can also post on Piazza or DM on Slack for additional office hours.

  office hours for this week will be announced on Piazza.
- Post-lecture Q&A for 30 minutes.
- We will explore options for study groups and reading groups during the semester.

Prerequisites

At least one of the following:

- A computer vision course at the level of 16-385 or 16-720.
- A computer graphics course at the level of 15-420.

Pop quiz

How many of you know or have heard of the following terms:

- Gaussian and box filtering.
- Convolution and Fourier transform.
- Aliasing and anti-aliasing.
- Homogeneous coordinates.
- Affine transforms and homographies.
- Pinhole, perspective, and orthographic camera.
- Triangular mesh.
- Ray-mesh intersections.
- Texture mapping.
- Radiometry and radiometry.
- Lambertian, diffuse, and specular BRDFs.
- n-dot-l lighting.
- Environment map.
- Point and directional light sources.
- Ray tracing.
- Monte Carlo estimation.
- Refraction and diffraction.

This course is still highly experimental!

- First time this course is offered, so expect things to inevitably change throughout the semester.

Interested in research?

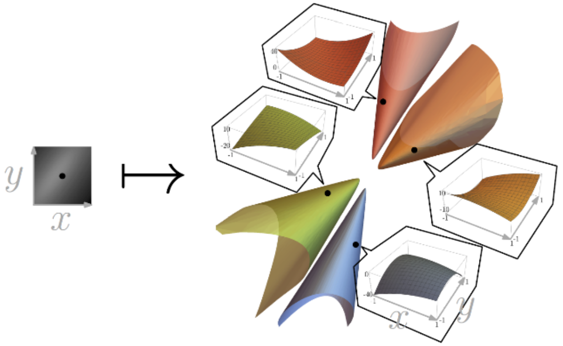
- Visit the graphics lab and imaging group websites:

  http://graphics.cs.cmu.edu/
  https://imaging.cs.cmu.edu/

- Email Yannis if you want to be added to the graphics lab mailing list and attend our weekly meetings (**Tuesdays, 1 – 2 pm ET**).

- We are actively recruiting research assistants for projects relating to **rendering**, imaging, and graphics in general. Please email Yannis if interested.

Today's talk



- Speaker: **Kathryn Heal** (Harvard, Google X)
- Title: **A Lighting-Invariant Approach to Shape from Shading**

- Abstract: Under the conventional diffuse shading model with unknown directional lighting, the set of quadratic surface shapes that are consistent with the spatial derivatives of intensity at a single image point is a 2D algebraic variety embedded in the 5D space of quadratic shapes. We study the geometry of such varieties, and use those insights to prove existence and uniqueness results in the areas of two-shot uncalibrated photometric stereo and co-quadratic shape from shading. Our theory leads naturally to a concise, feedforward model that computes an explicit, differentiable approximation of the variety from the intensity and its derivatives at any single image point. The result is a parallelizable processor that operates at each image point, and produces a lighting-invariant descriptor of the continuous set of compatible surface shapes at that point.

- TL;DR: **How can we combine algebraic geometry, physics, and neural networks to solve shape from shading.**

Please take the start-of-semester survey!

- Posted on Piazza as well:

https://docs.google.com/forms/d/e/1FAIpQLScwNSk9hXN61oeohumgsiclifleHw4ogk9K3ccnPDVKb399cQ/viewform