Introduction

15-468, 15-668, 15-868
Physics-based Rendering
Spring 2025, Lecture 1

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

Lecture etiquette

- Lecture slides (PDF) are posted on the course website before each lecture.
- Lectures are **not** recorded.
- You are expected to attend lectures in person.
- Feel free to ask questions! Please make sure to raise your hand both to ask your own questions and to answer mine.

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)

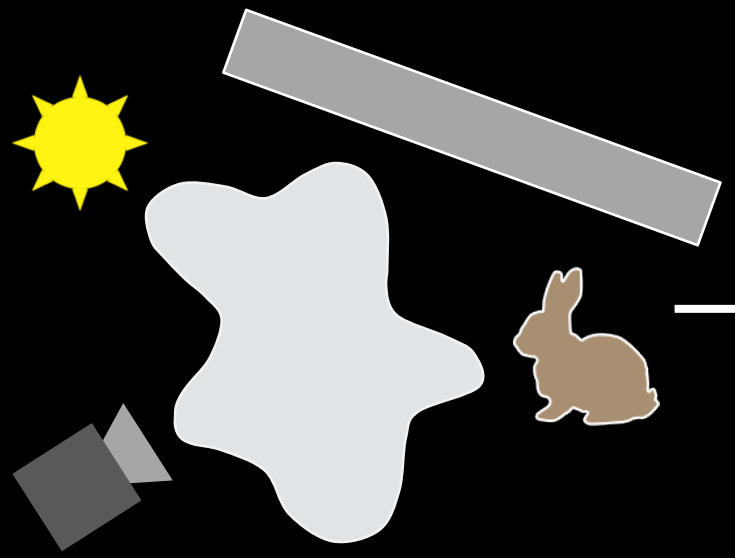
Yannis at Harvard in 2011

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

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

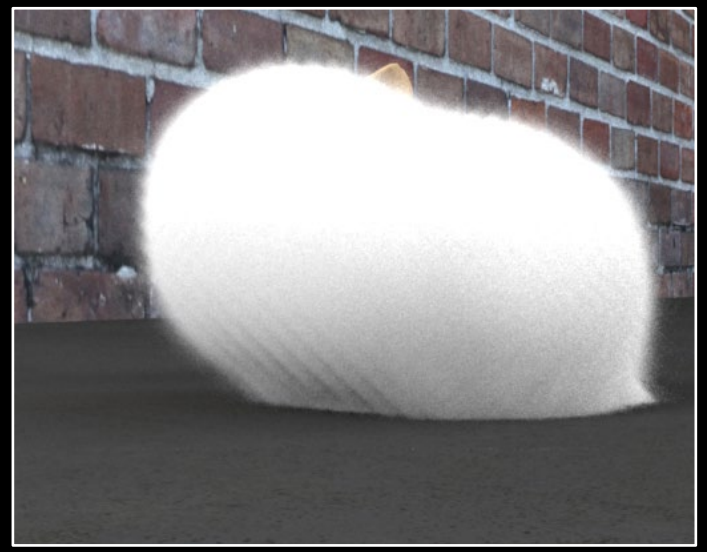
What is this course about?

Forward rendering



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

physically-accurate
rendering



photorealistic
simulated image

What is this class about?

Producing realistic images by:

- *simulating* light transport (global illumination)
- *simulating* light-material interactions (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?

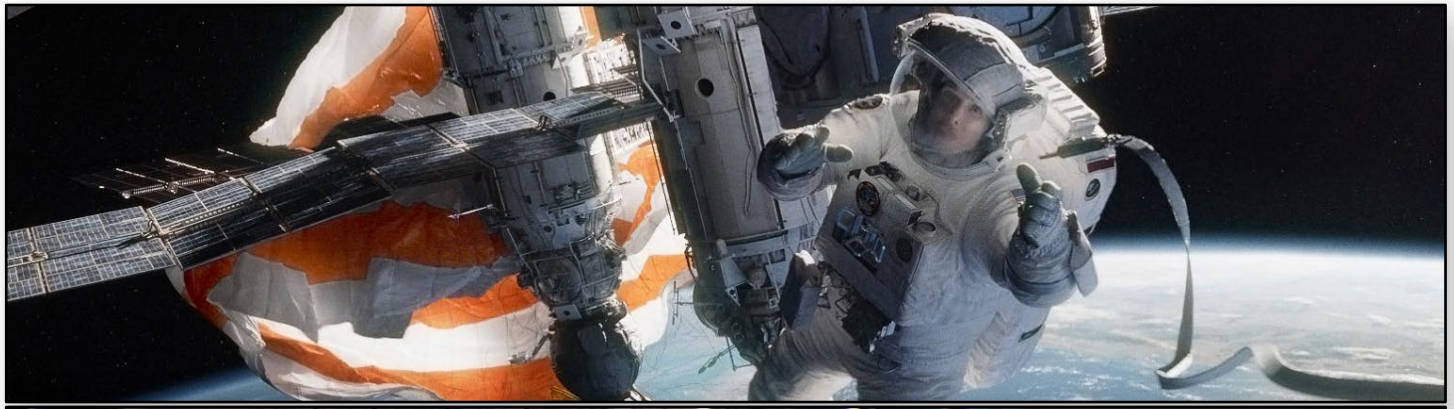
Motivation

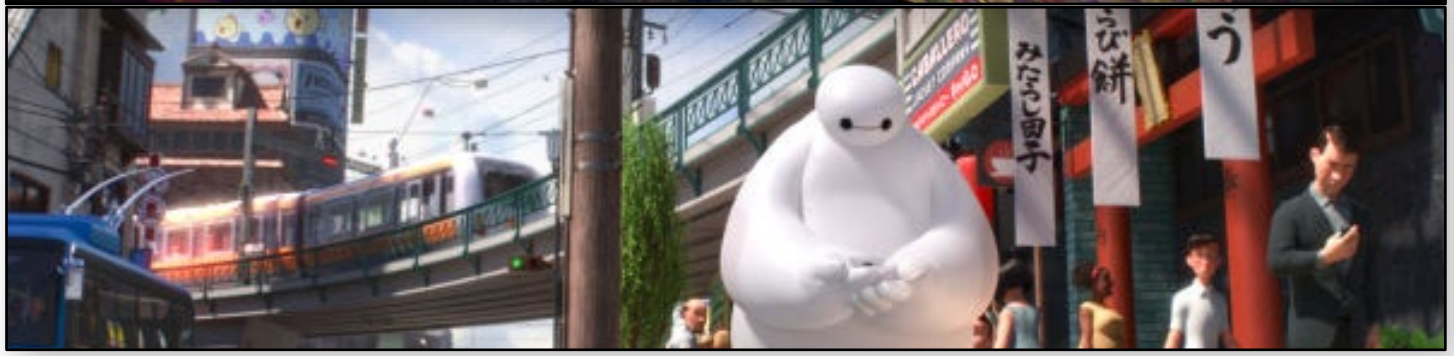
Wojciech Jarosz

Light transport in the real world

After [Ritschel et al 2011]

Ray tracing in production





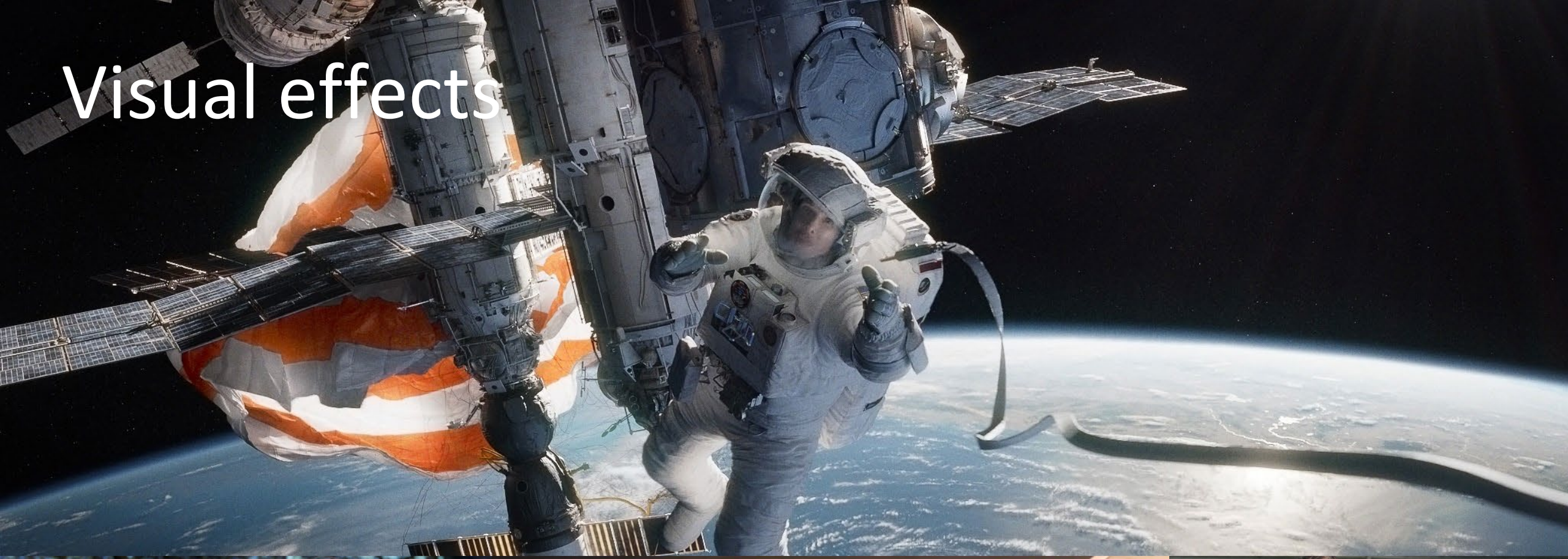
Arnold Renderer

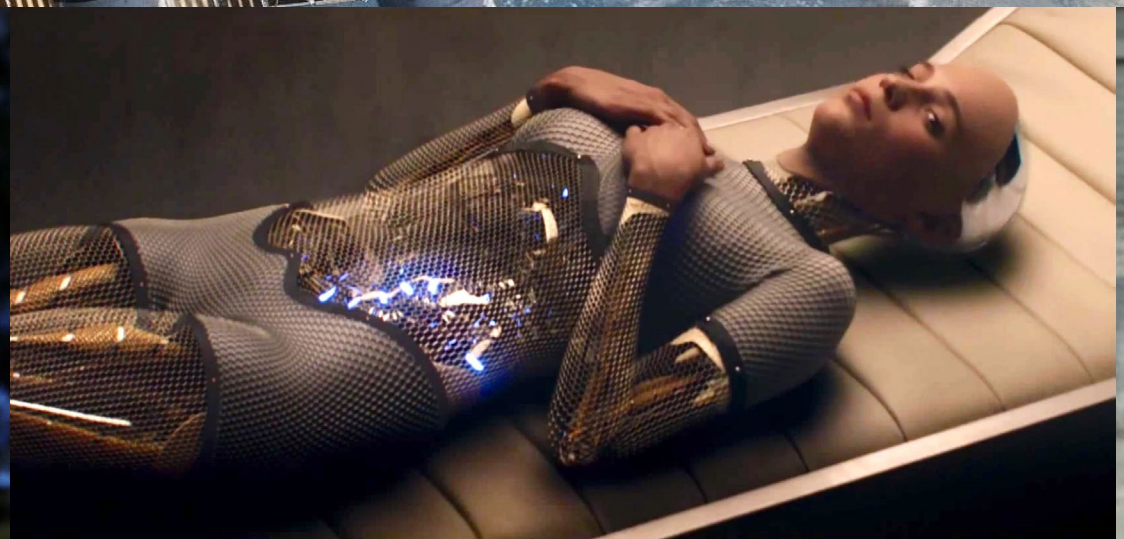
SOLIDANGLE

PIXAR's RenderMan

Hyperion

Visual effects





Wojciech Jarosz

Animated films

Wojciech Jarosz

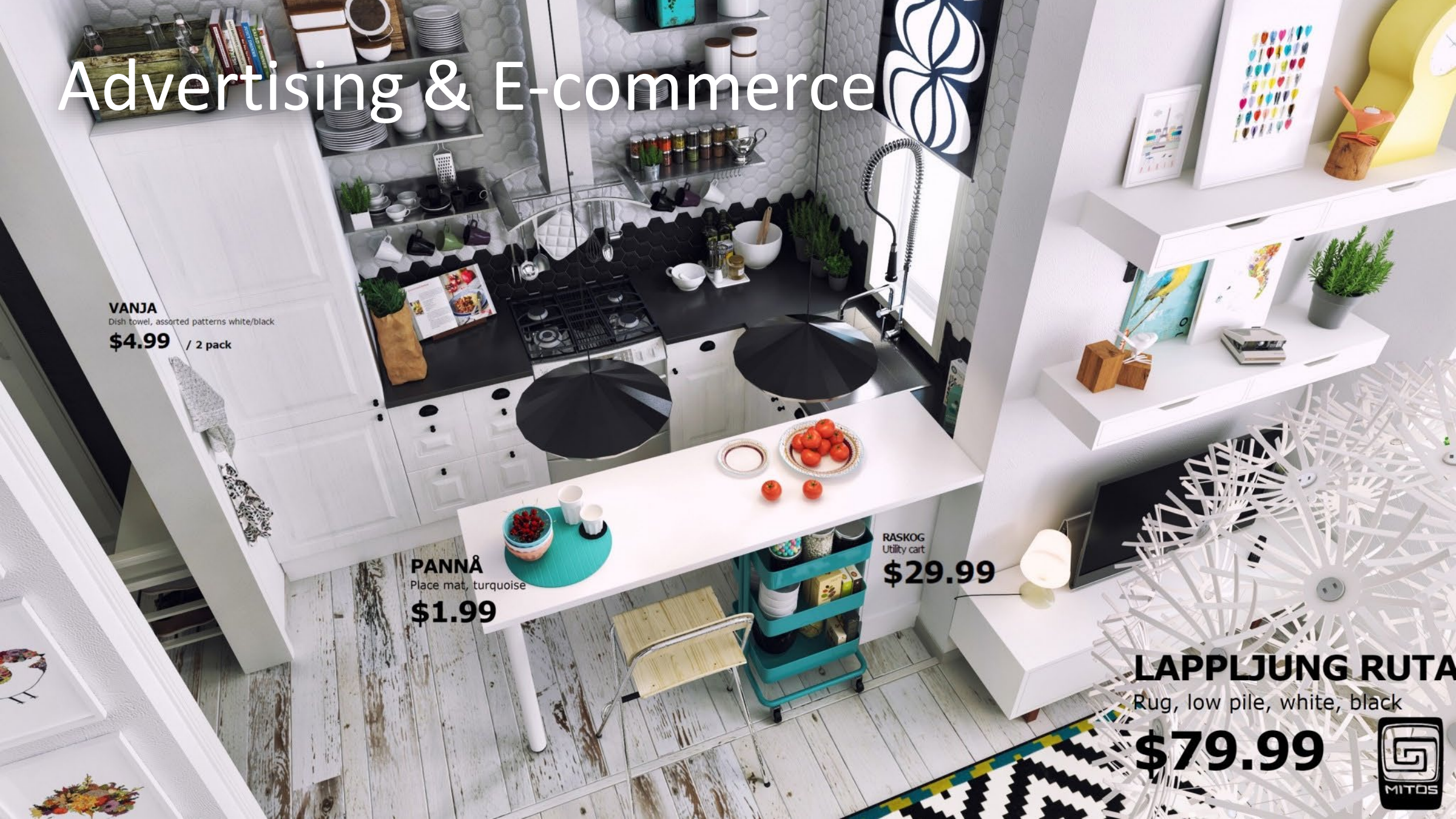
Video games

Wojciech Jarosz

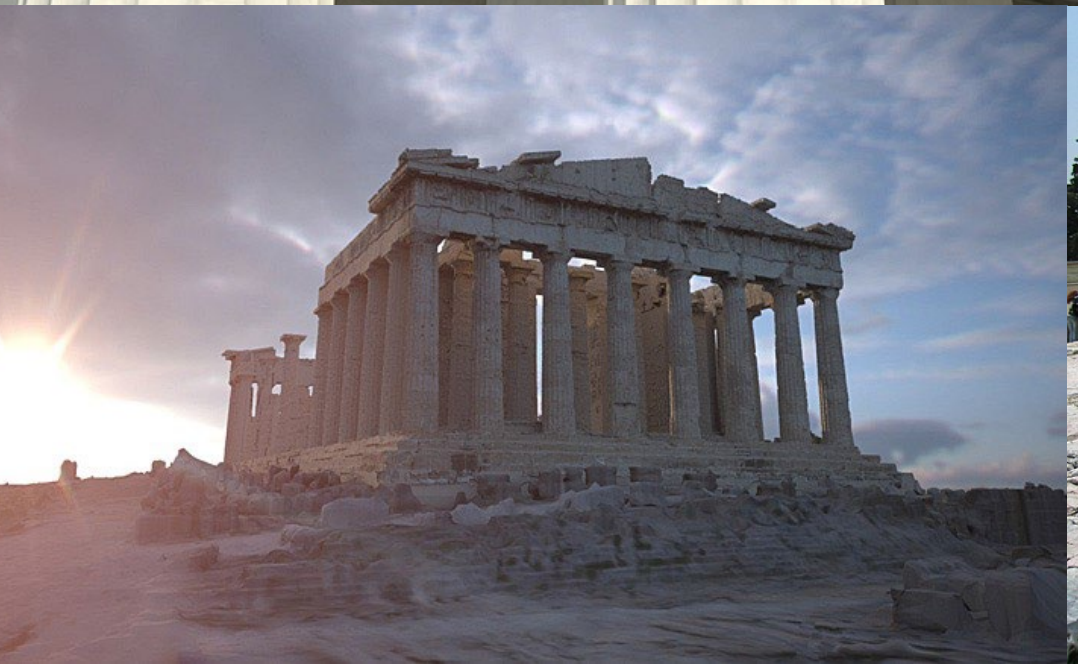
Architectural visualization

Wojciech Jarosz

Advertising & E-commerce



Cultural heritage

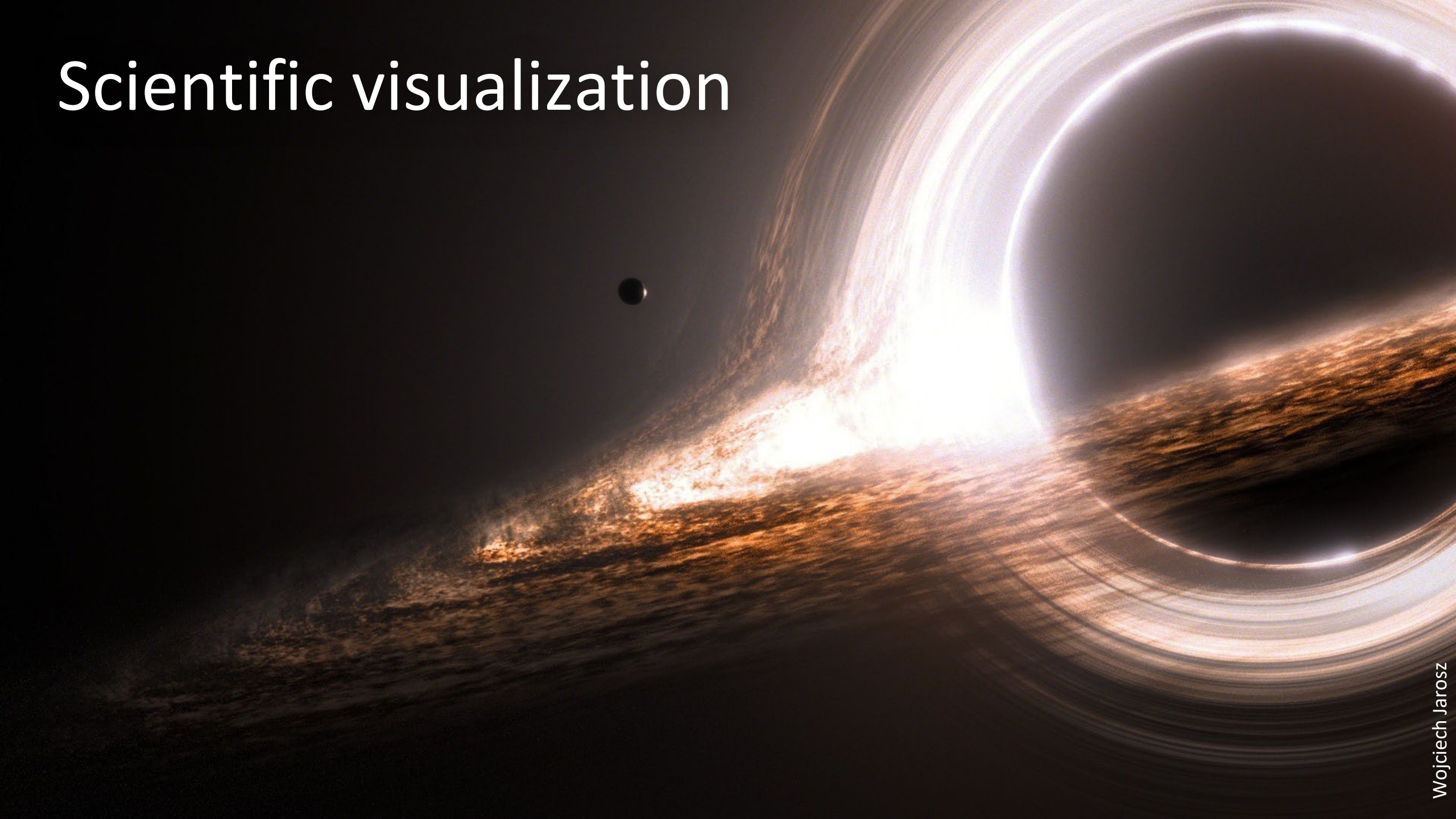


Wojciech Jarosz

Digital fabrication

Wojciech Jarosz

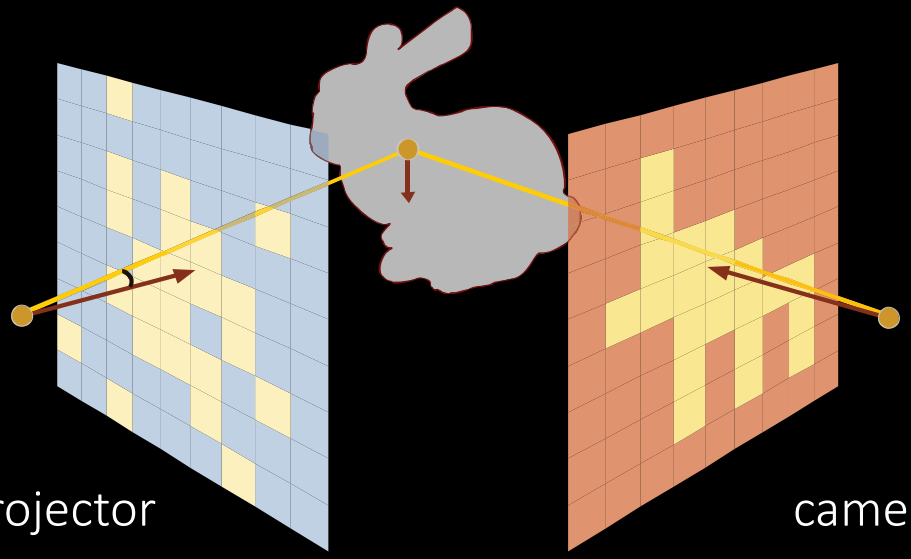
Scientific visualization



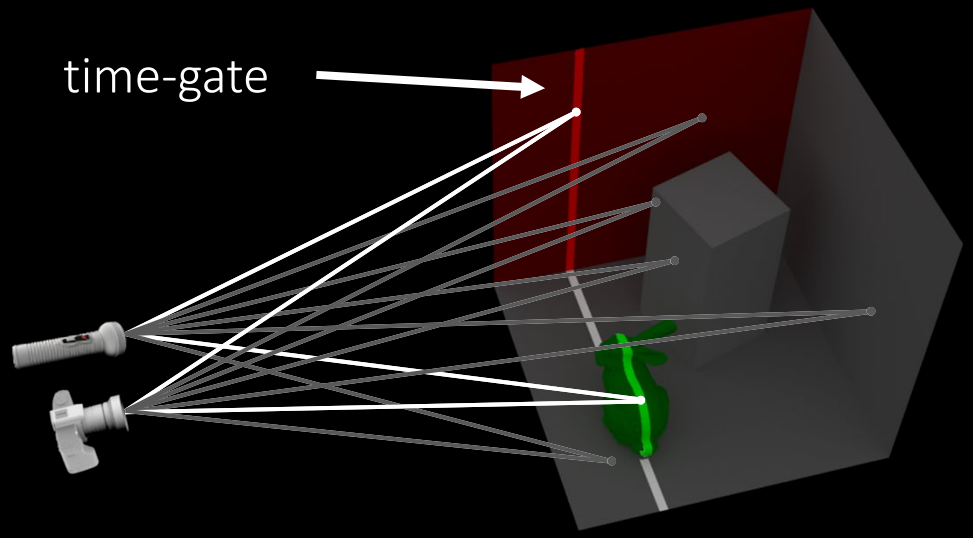
Wojciech Jarosz

Scientific imaging

rendering computational light transport

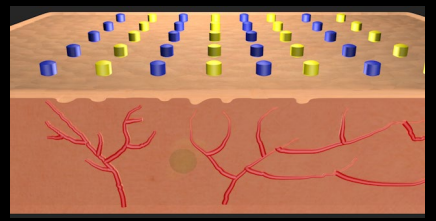


rendering time-of-flight sensors

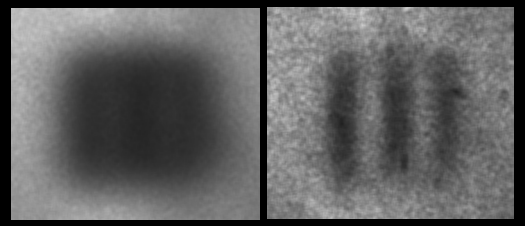


Used by CMU imaging projects:

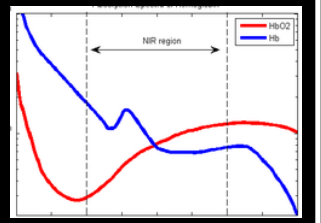
convolutional DOT



coded coherence

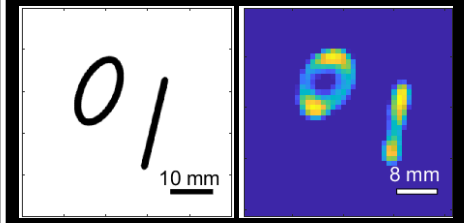


coded spectrum

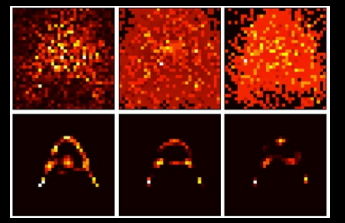


Used by CMU imaging projects:

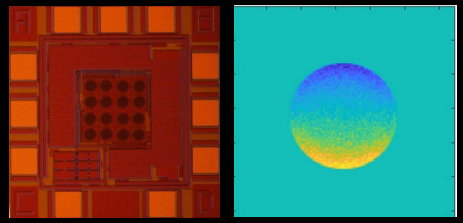
ToF DOT



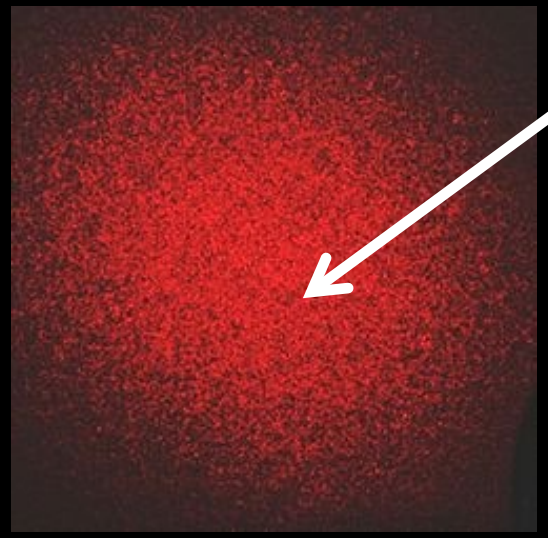
all-photon imag.



differential SPAD

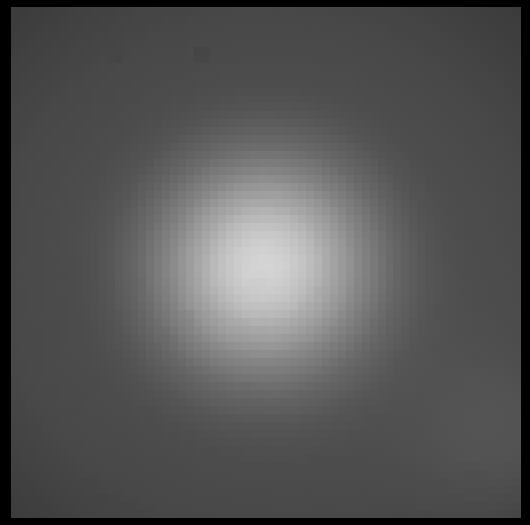


Rendering wave effects



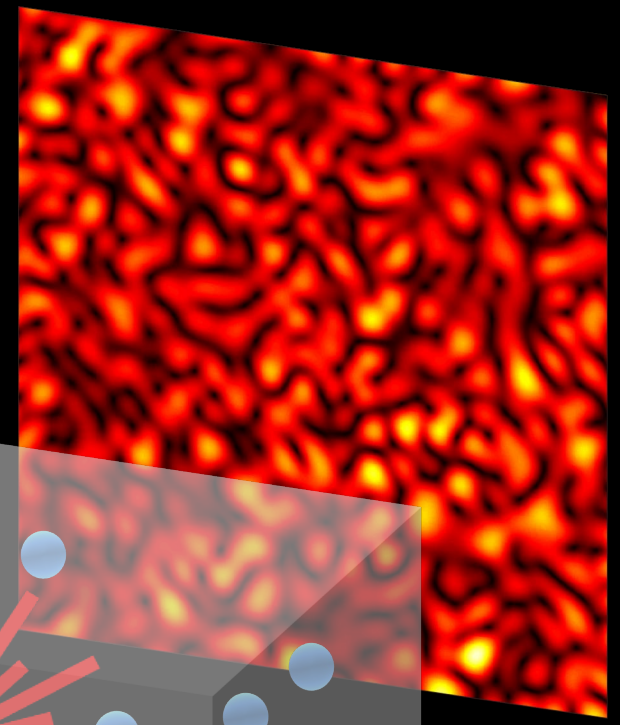
speckle: noise-like pattern

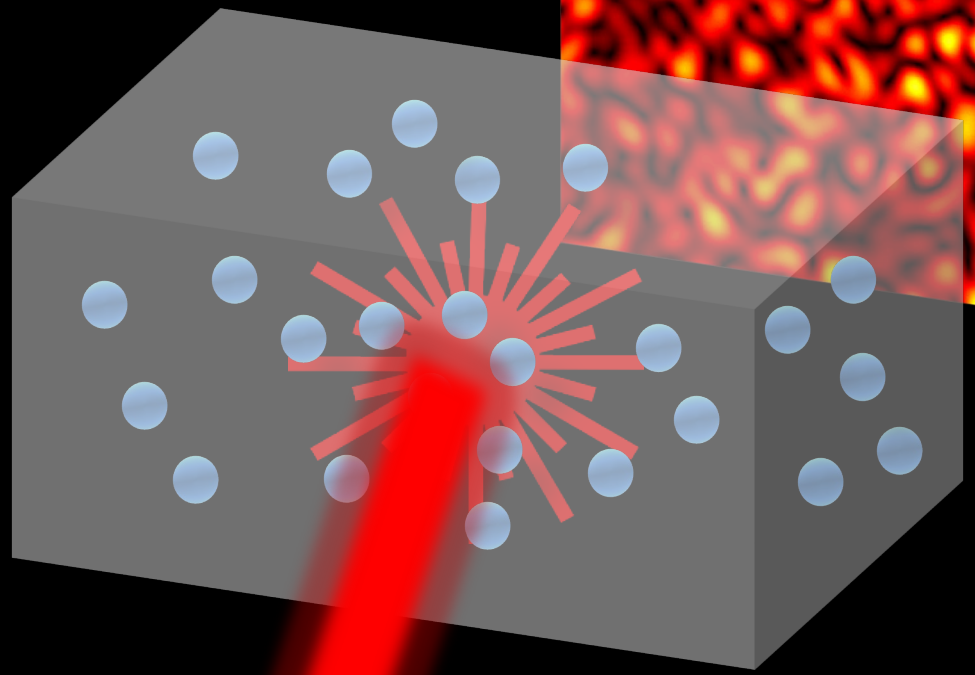
what real laser images look like



what standard rendered images look like

projected speckle image

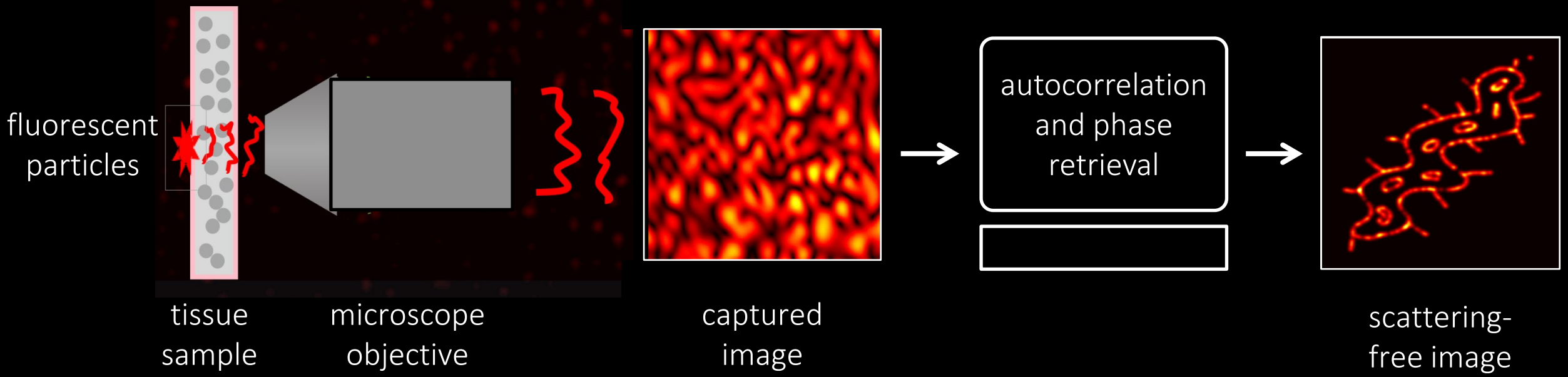


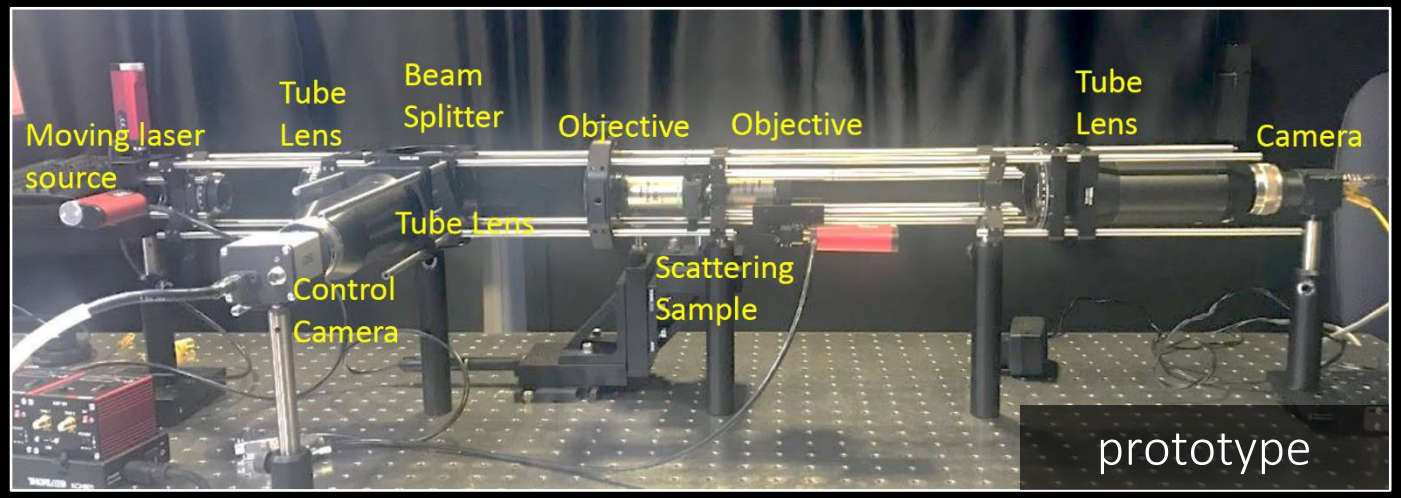


laser beam

scattering volume

Application: fluorescence Microscopy



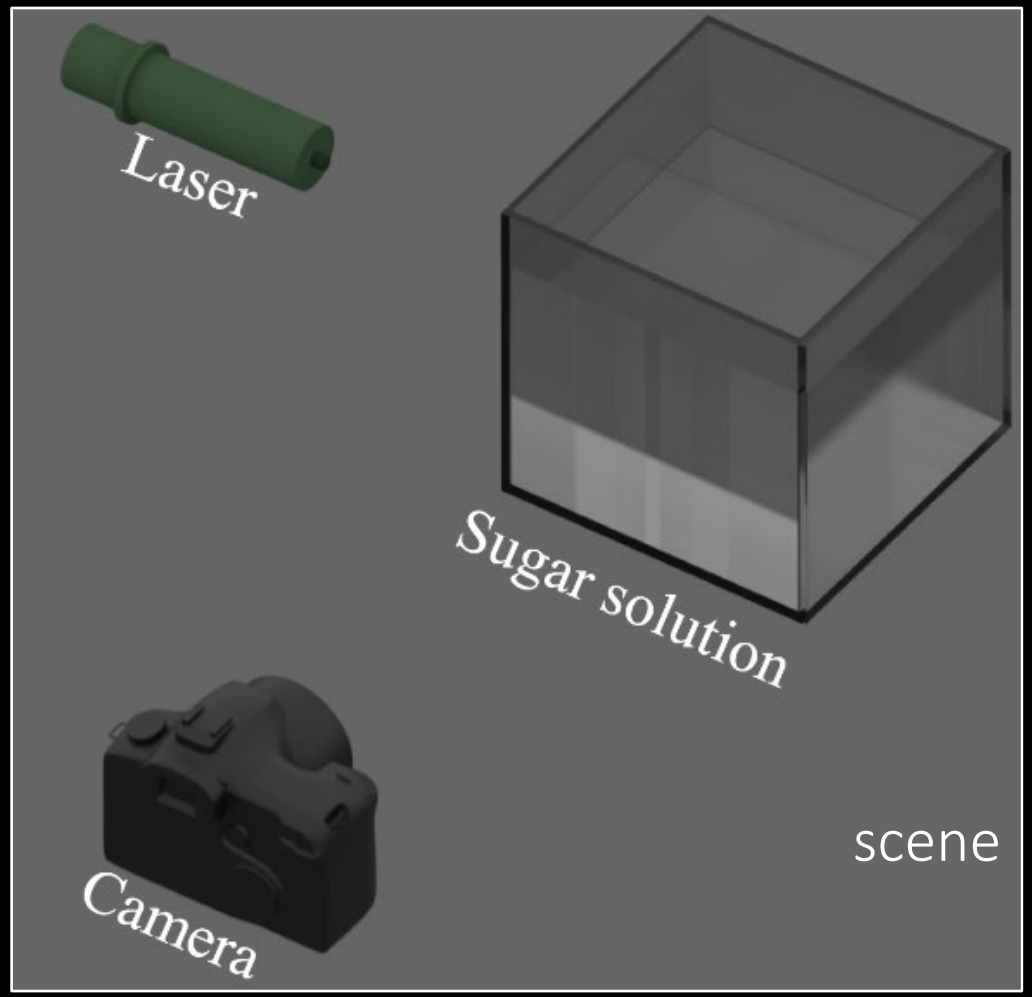


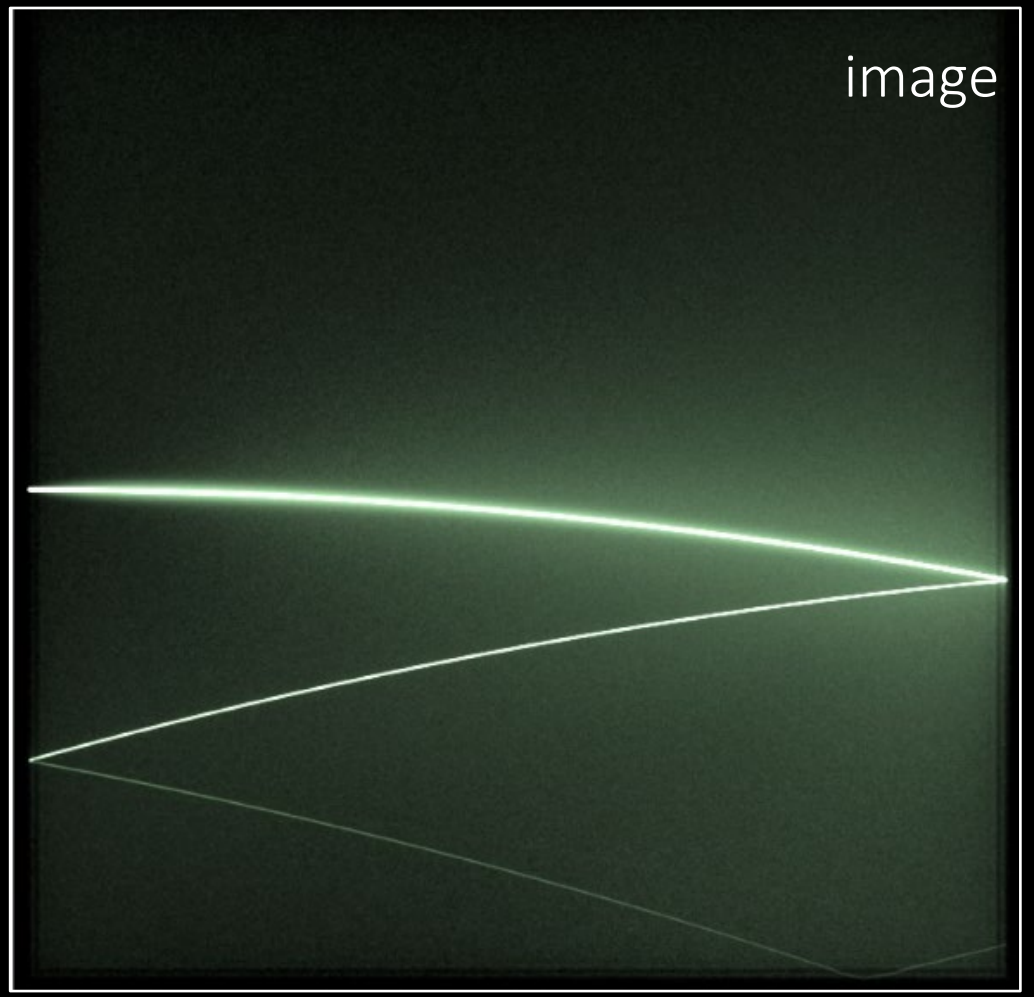
Performance strongly depends on:

- speckle statistics
- image priors
- tissue parameters

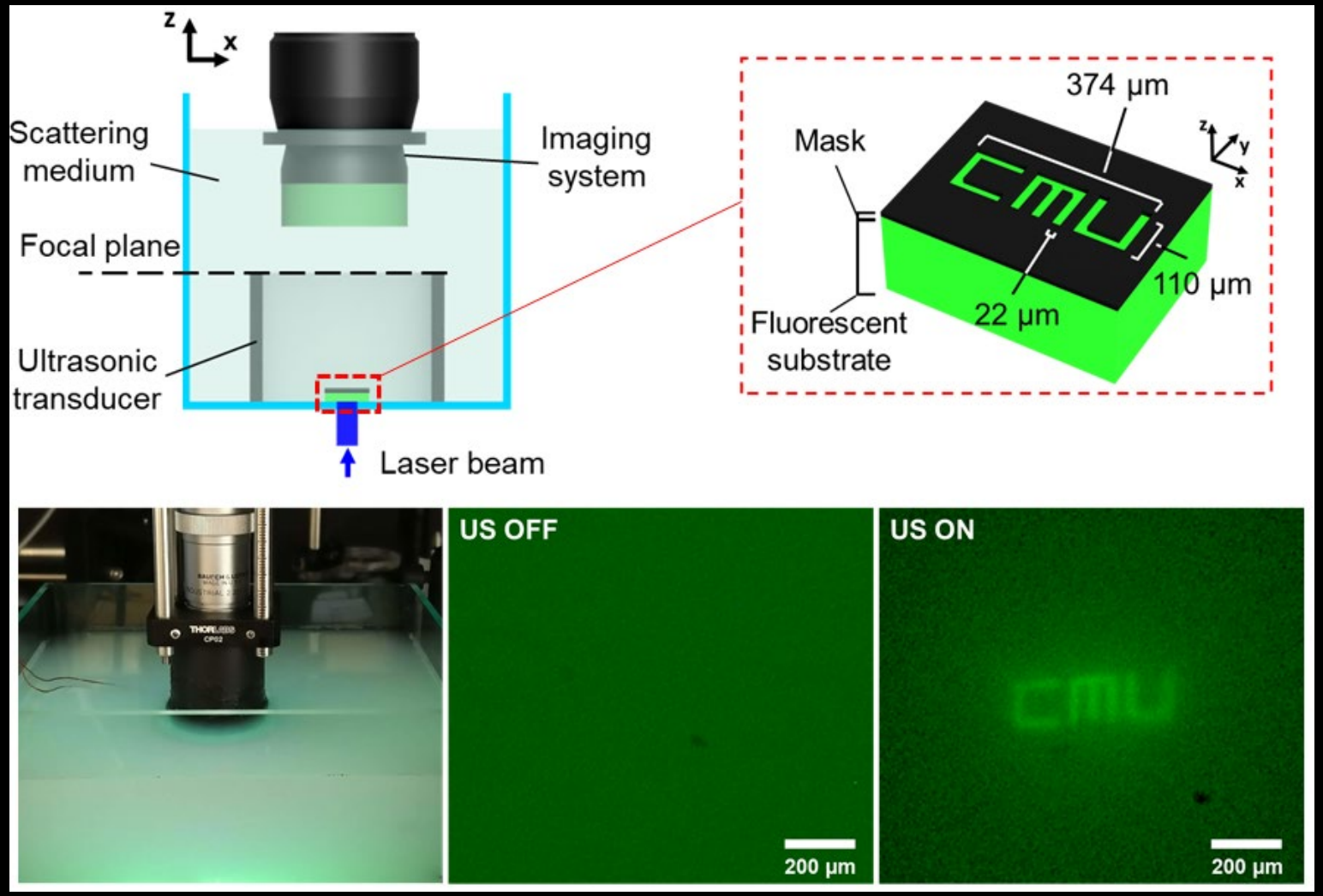
Rendering-assisted exploration and new algorithms!

Rendering eikonal transport

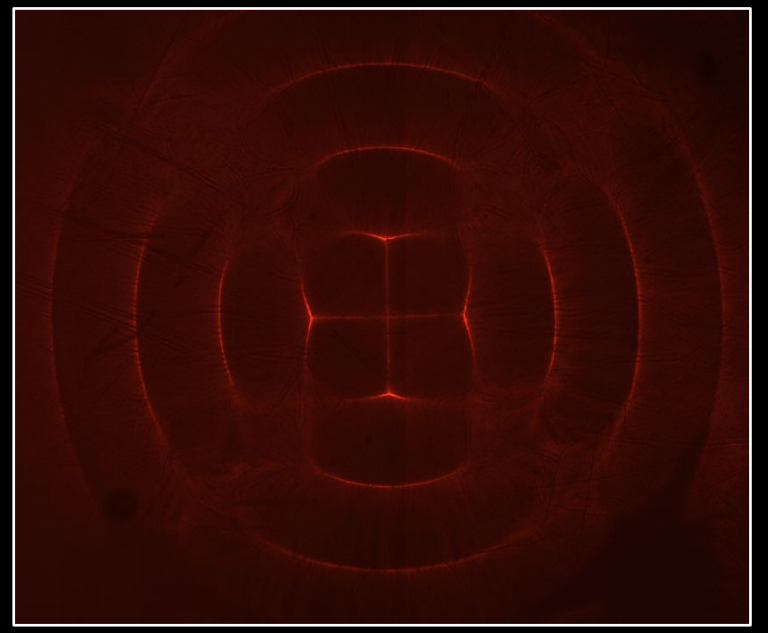




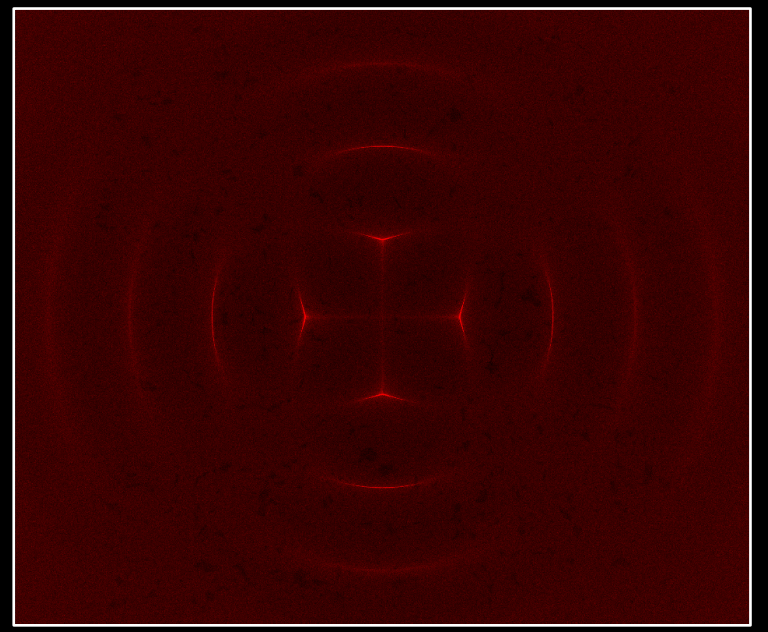
Application: acousto-optics



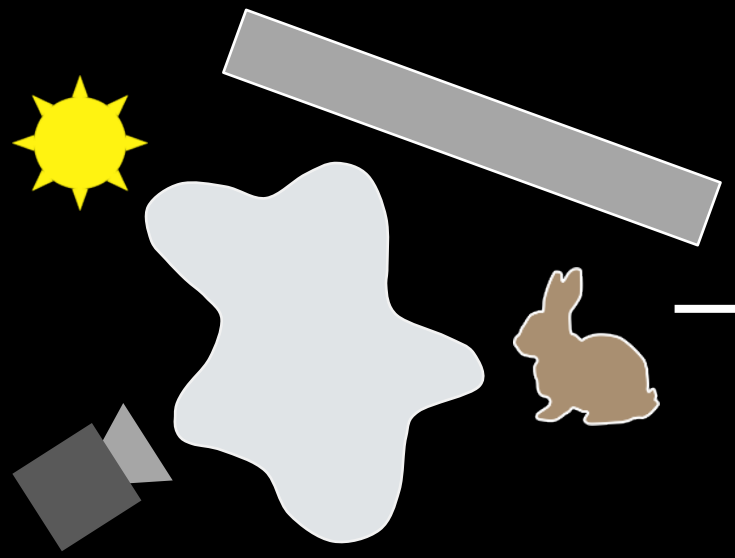
real capture



our algorithm

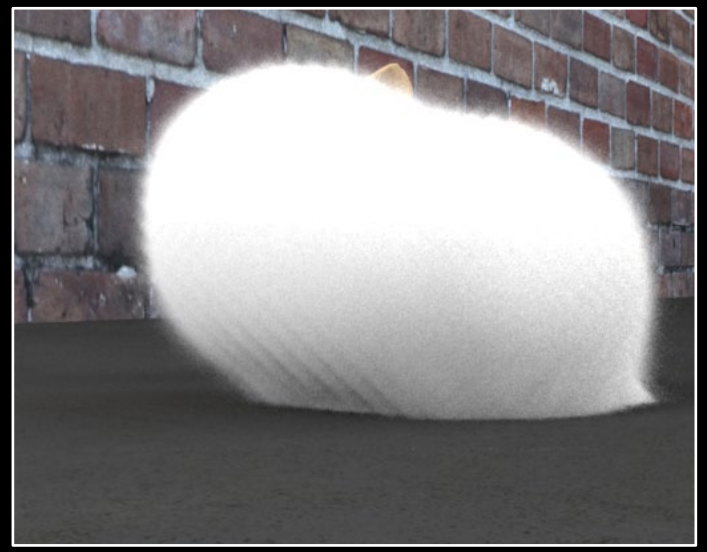


Forward rendering



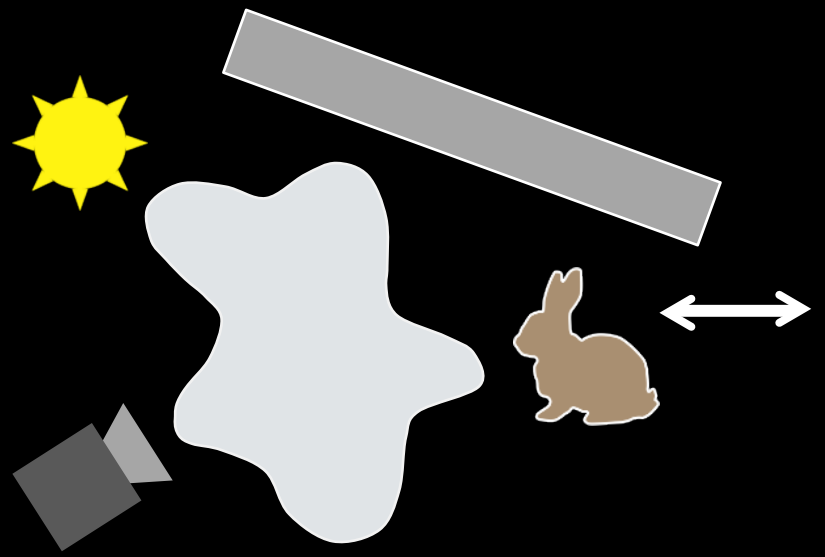
digital scene specification
(geometry, materials,
optics, light sources)

physically-accurate
rendering



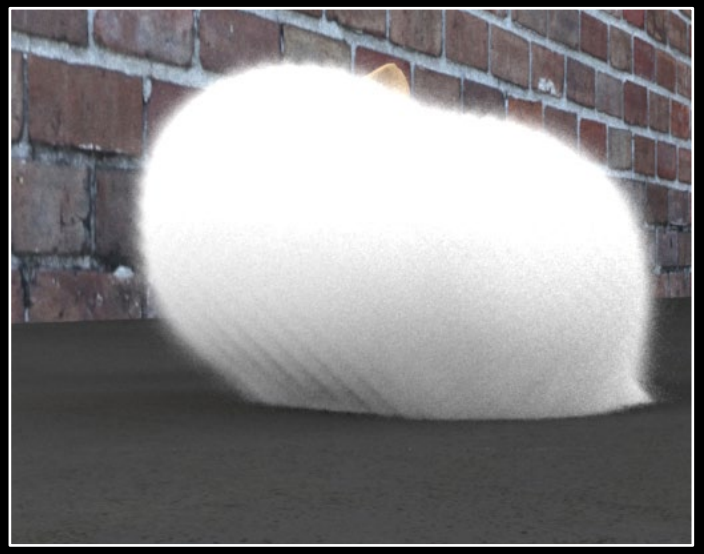
photorealistic
simulated image

Inverse rendering



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

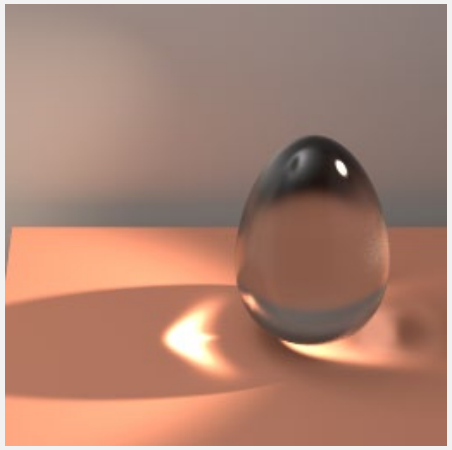
physically-accurate
inverse rendering



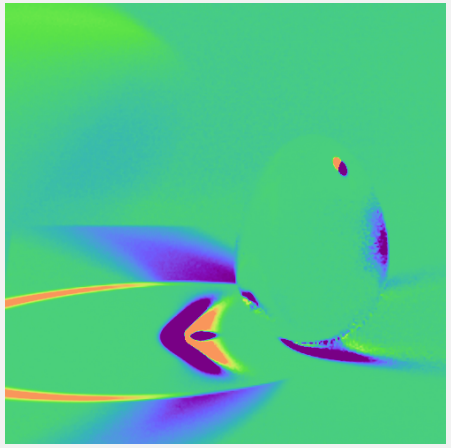
photorealistic
synthetic image

Differentiable rendering

Original image

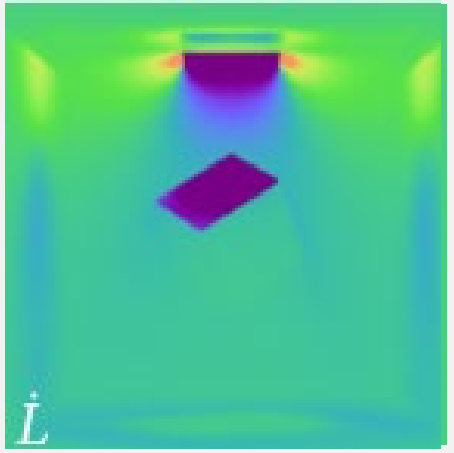


Derivative image

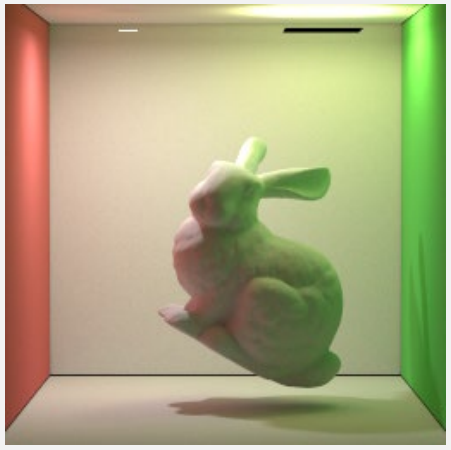


Original image

Derivative image



Original image



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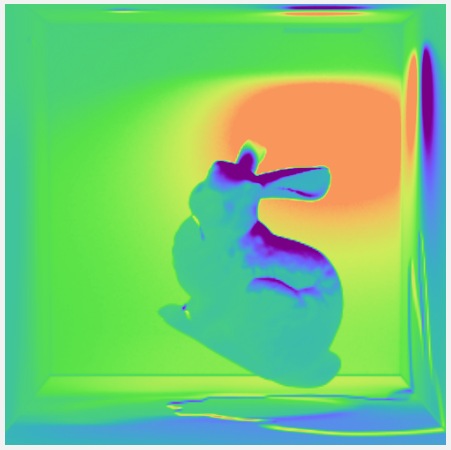
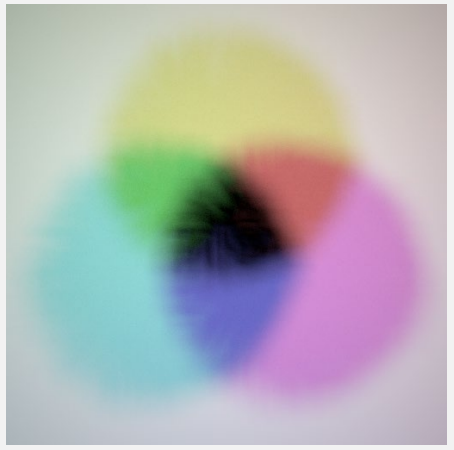
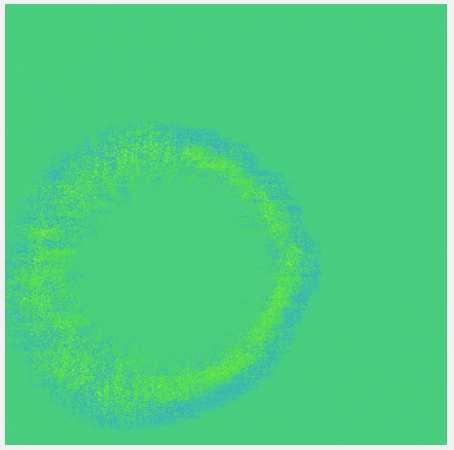


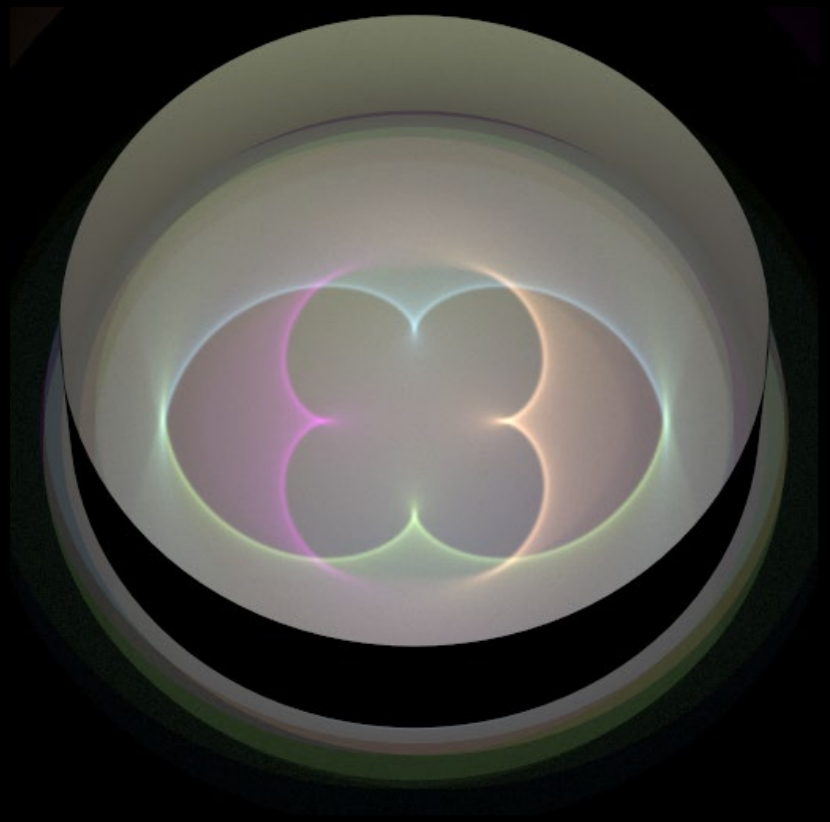
Original image



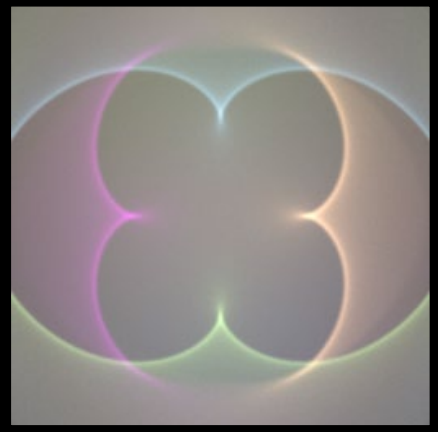
Derivative image



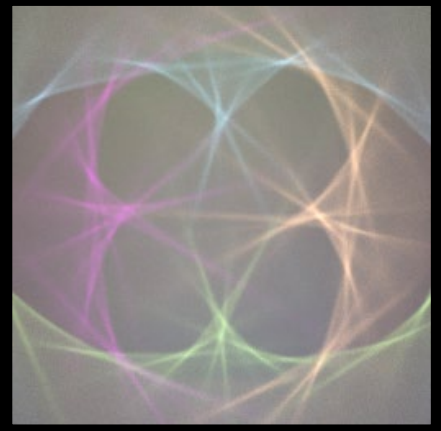
Application: shape optimization

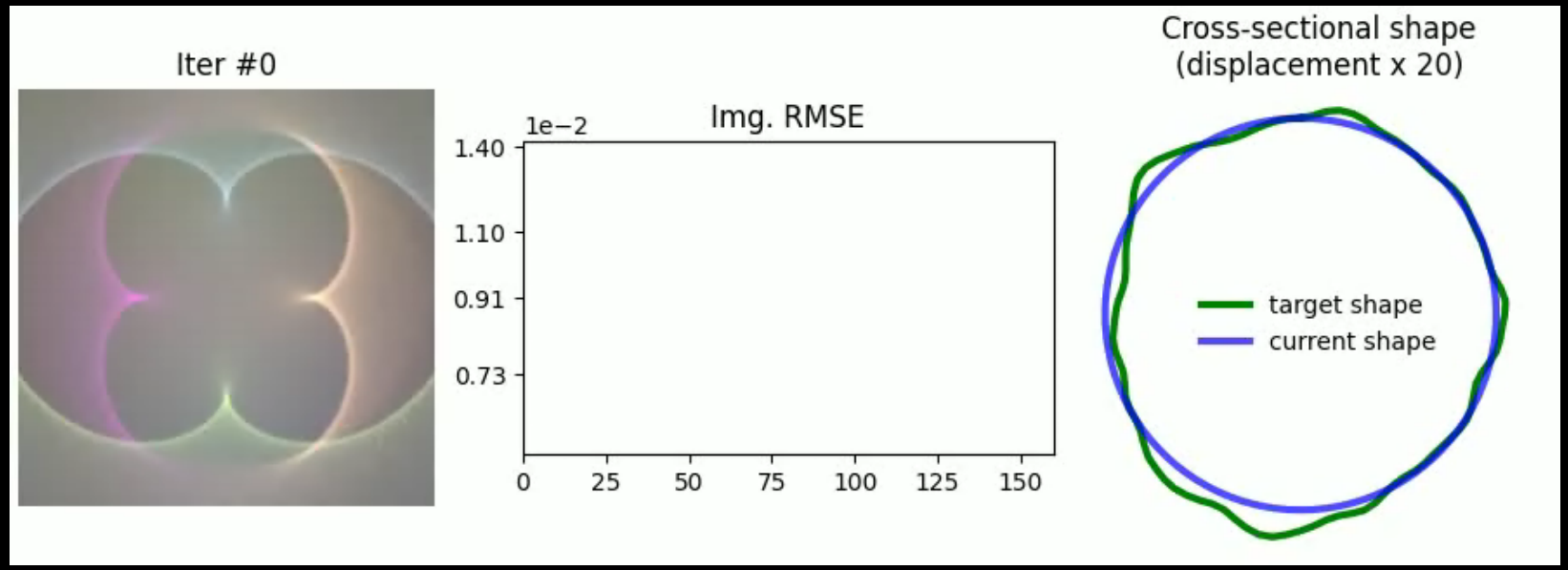


Initial

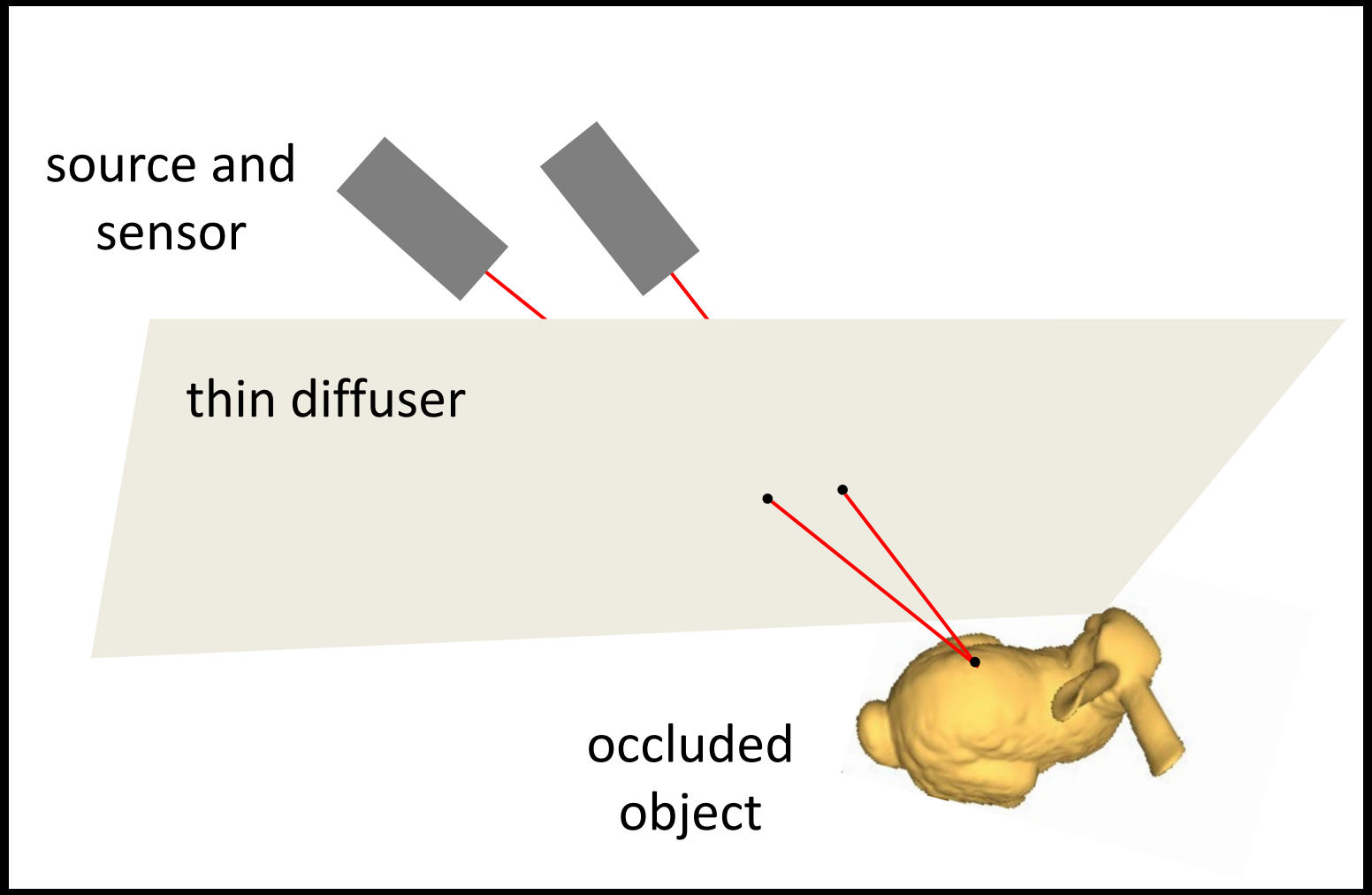


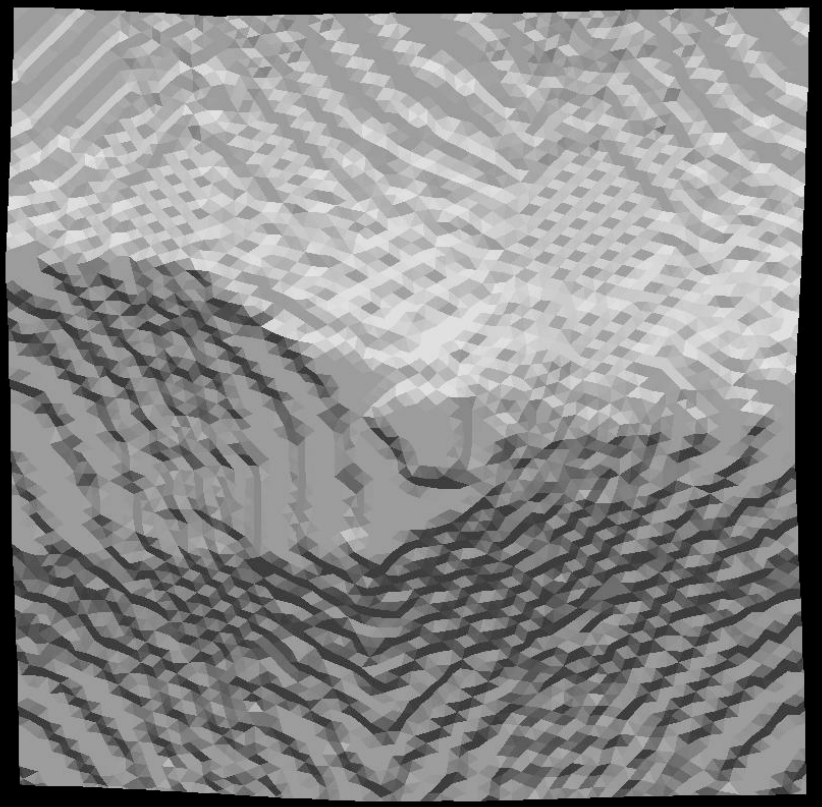
Target image





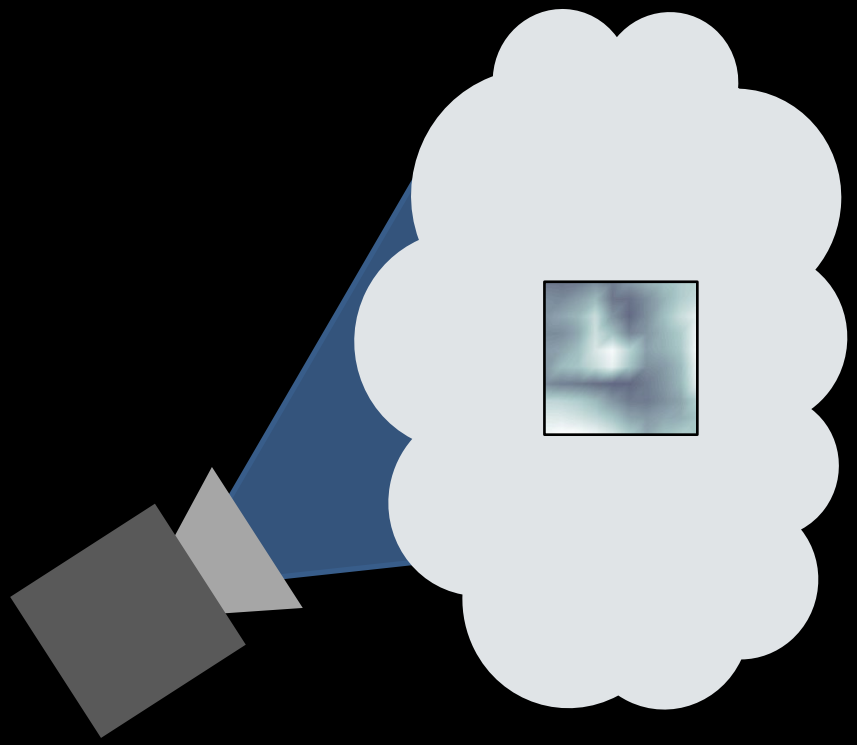
Application: non-line-of-sight imaging





reconstruction evolution

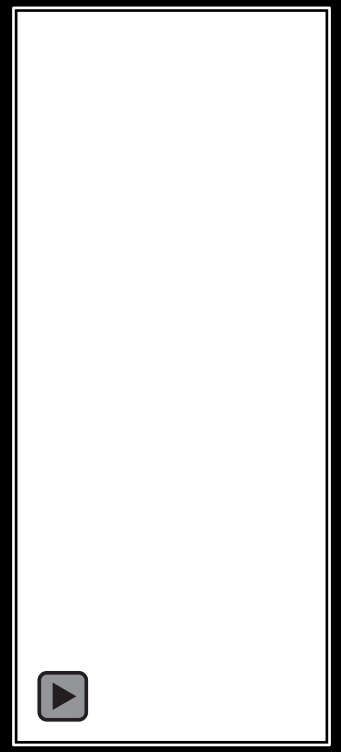
Application: non-invasive tomography



camera

thick smoke cloud

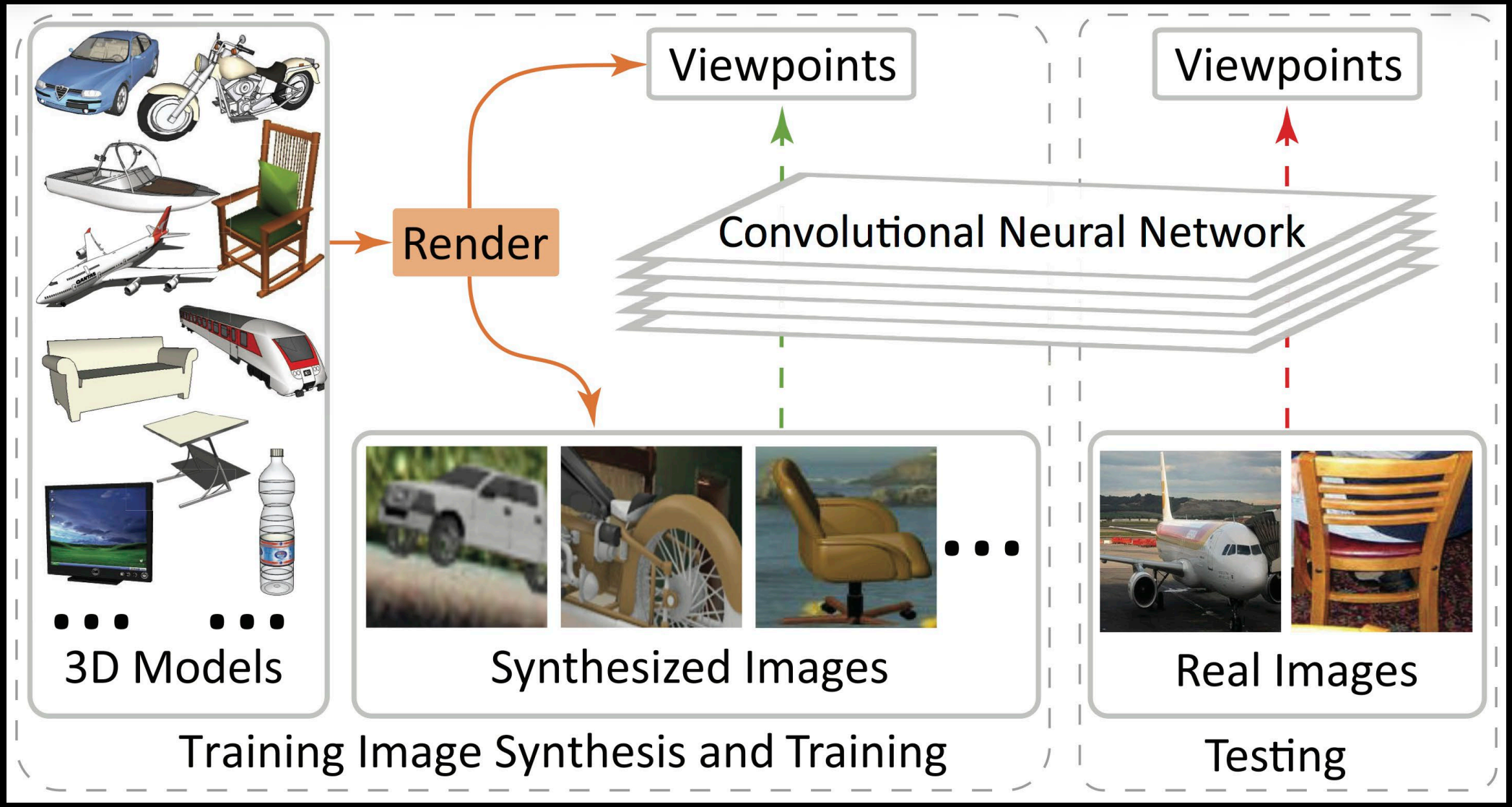
simulated camera measurements



reconstructed cloud volume

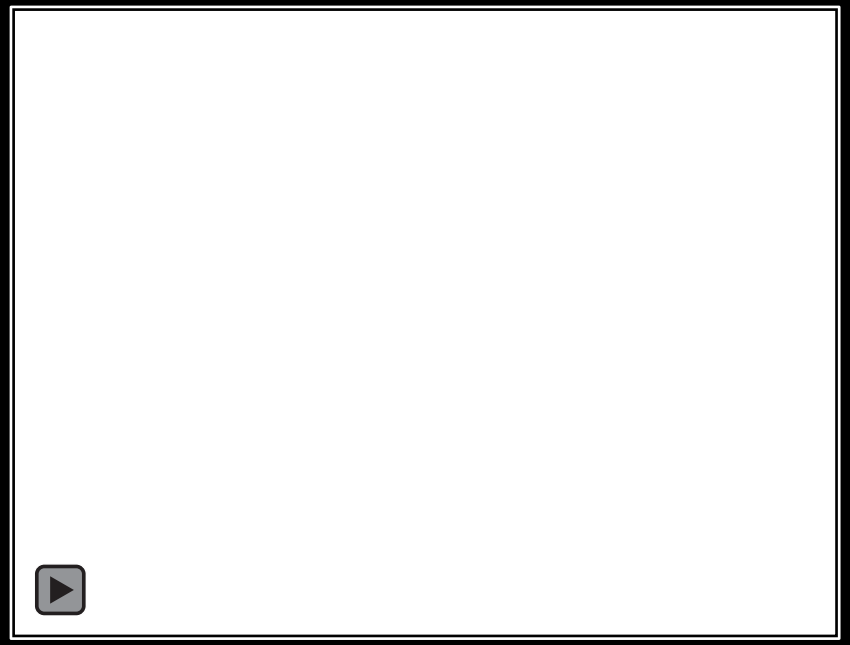
slice through the cloud

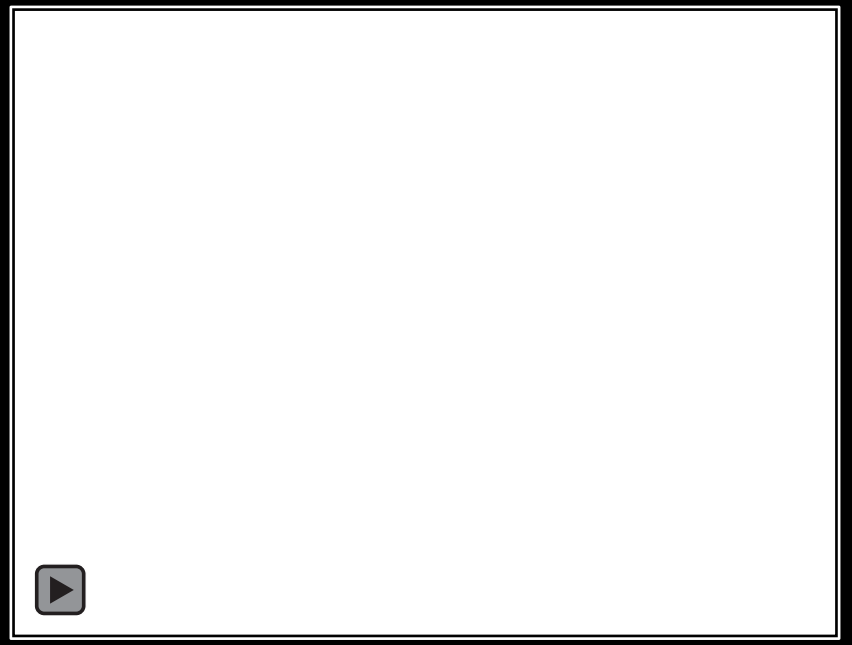
Application: vision and machine learning

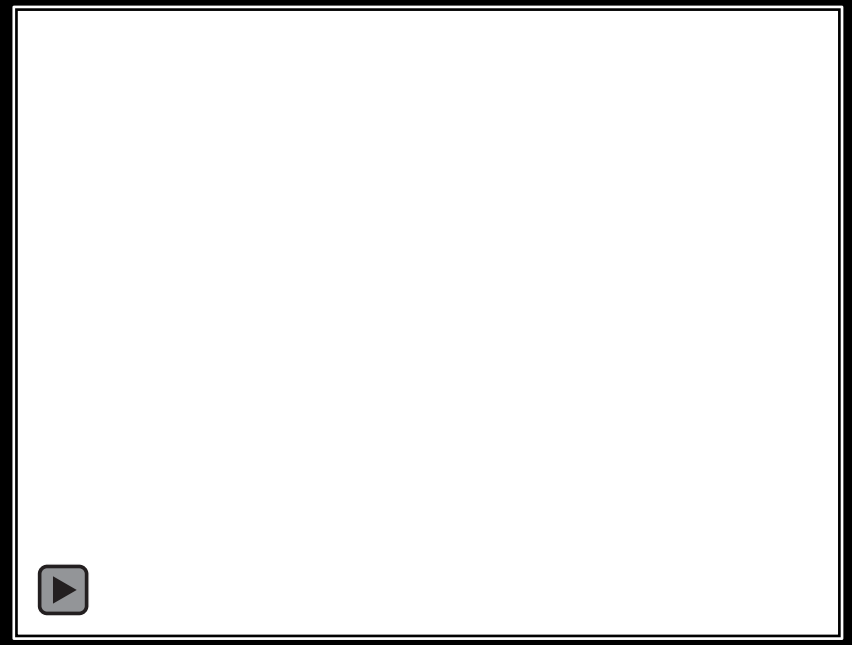


Render for CNN: Viewpoint Estimation in Images Using CNNs Trained with Rendered 3D Model Views [Su et al. ICCV 2015]

Application: neural rendering







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

Course fast-forward and logistics

Course logistics

- Course website:

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

- Github classroom for programming assignments:

https://github.com/cmu-15-468

- Canvas for grades and quiz submission:

https://canvas.cmu.edu/courses/45948

- Slack server for real-time discussion:

https://join.slack.com/t/cmu15-468/shared_invite/zt-2xo8js5tu-5dy2lLGNG~mqtCC4MYVfzw

Please take the start-of-semester survey!

- Posted on Slack as well:

https://docs.google.com/forms/d/e/1FAIpQLScFiQUmTfBm2fah-Ap3fbjFqmwGbdaNl-FUURZBrDP5pkSBvg/viewform

- We use the survey to:
  - Get a better idea of students' background.
  - Decide on day and time of office hours.

Course fast-forward

Tentative syllabus at:

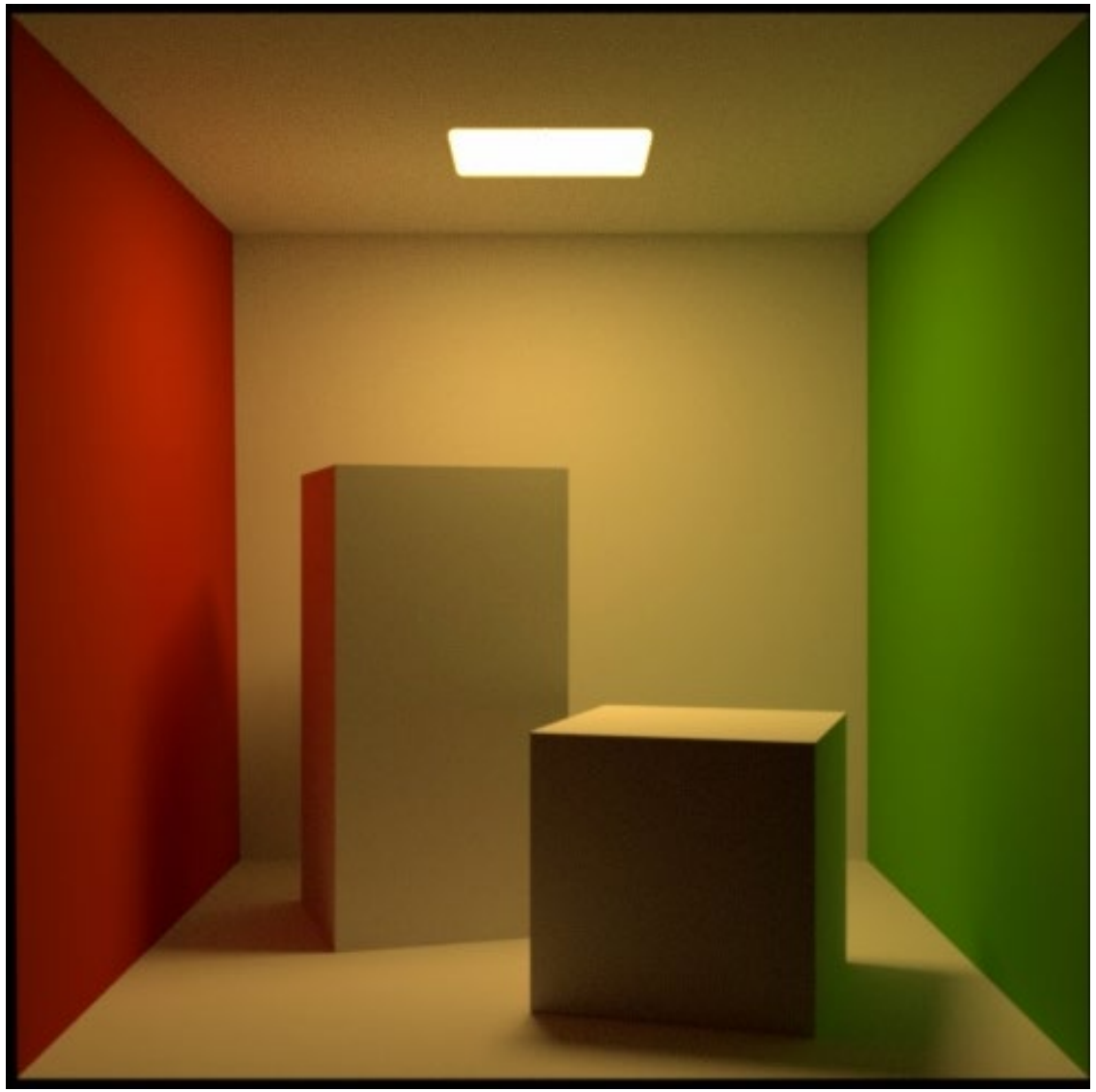
http://graphics.cs.cmu.edu/courses/15-468

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

Topics to be covered

Basics of ray tracing:

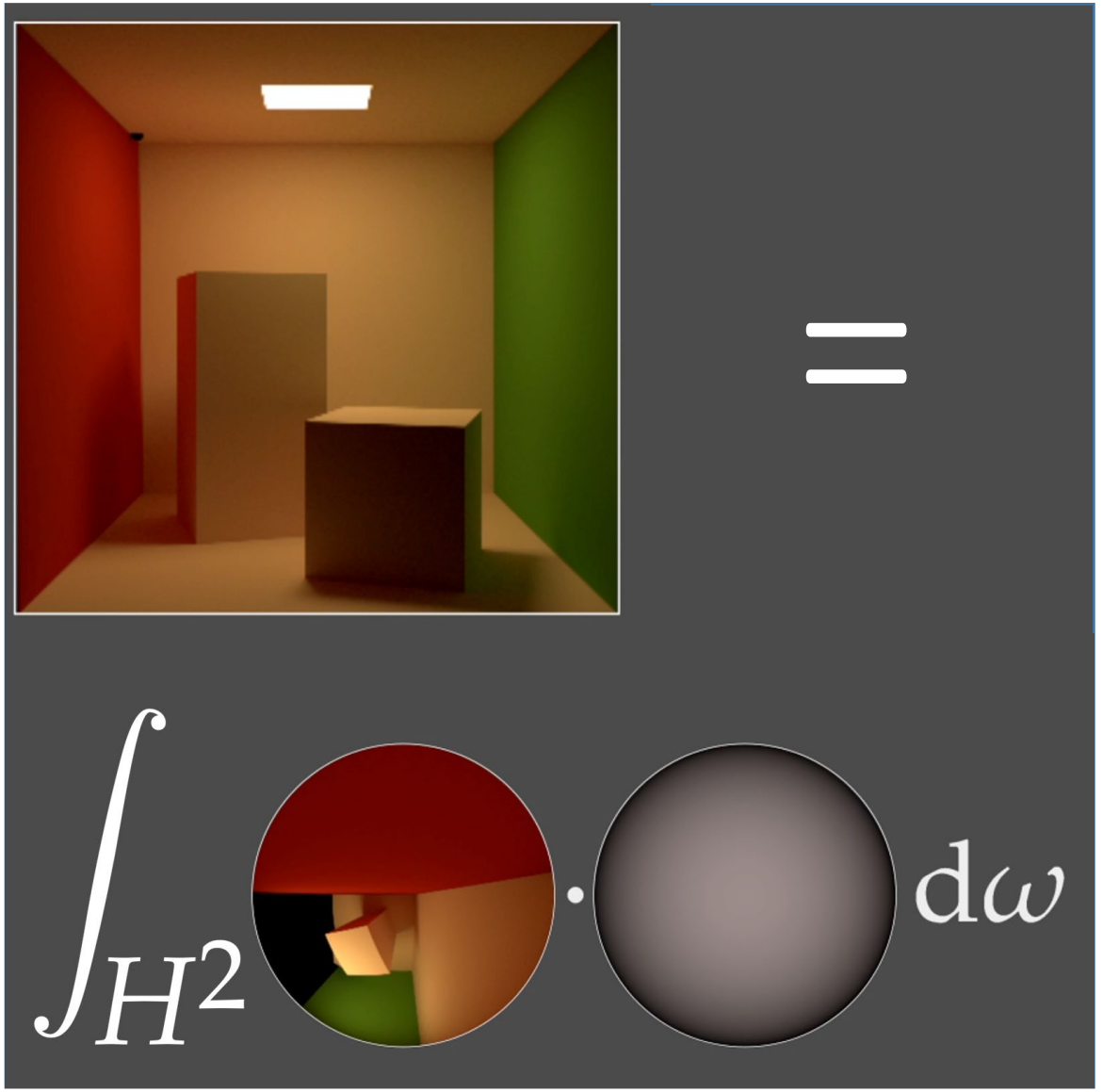
- trace-intersect recursions
- basic camera and illumination models
- shading
- intersection queries
- texture mapping



Topics to be covered

Theory of light transport and materials:

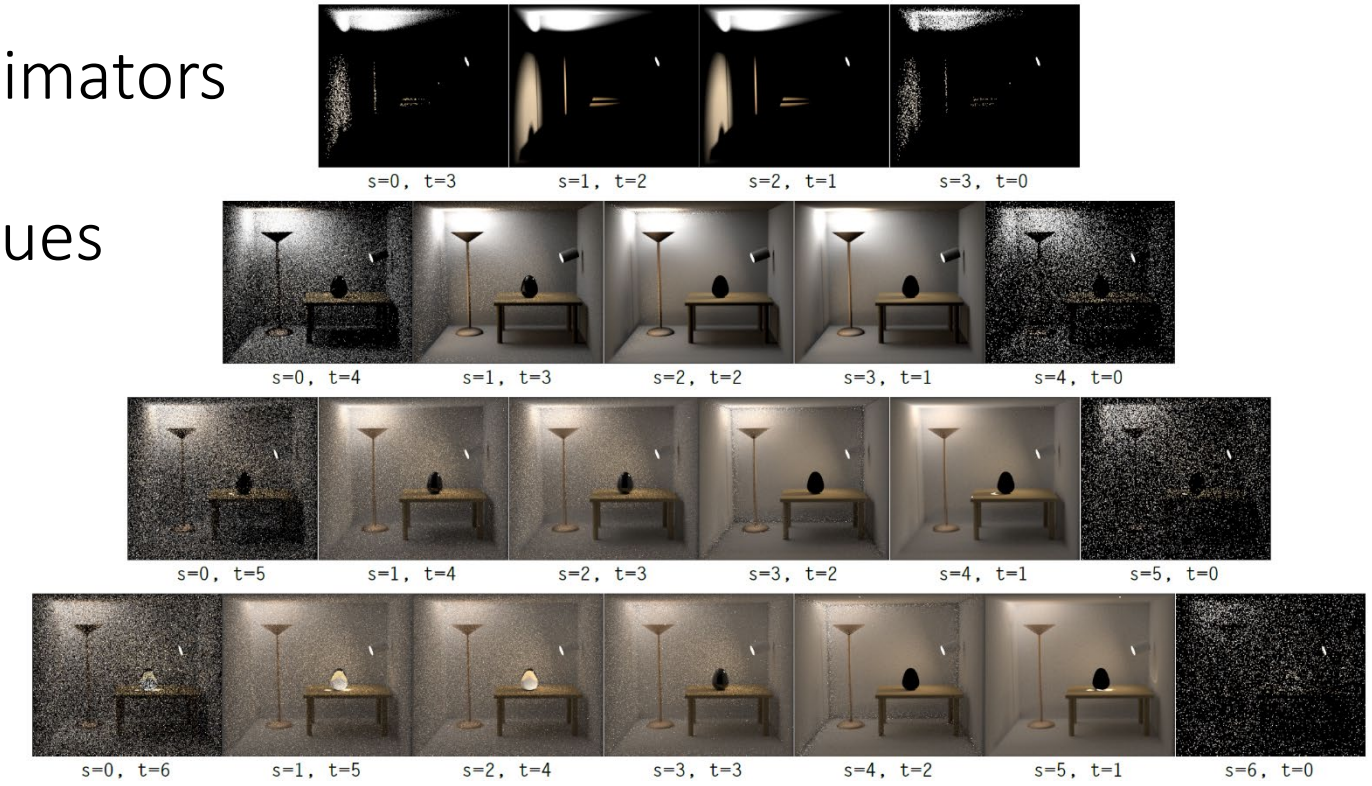
- rendering equation
- radiative transfer equation
- path integral formulations
- microfacet reflectance models
- statistical scattering models



Topics to be covered

Monte Carlo rendering algorithms:

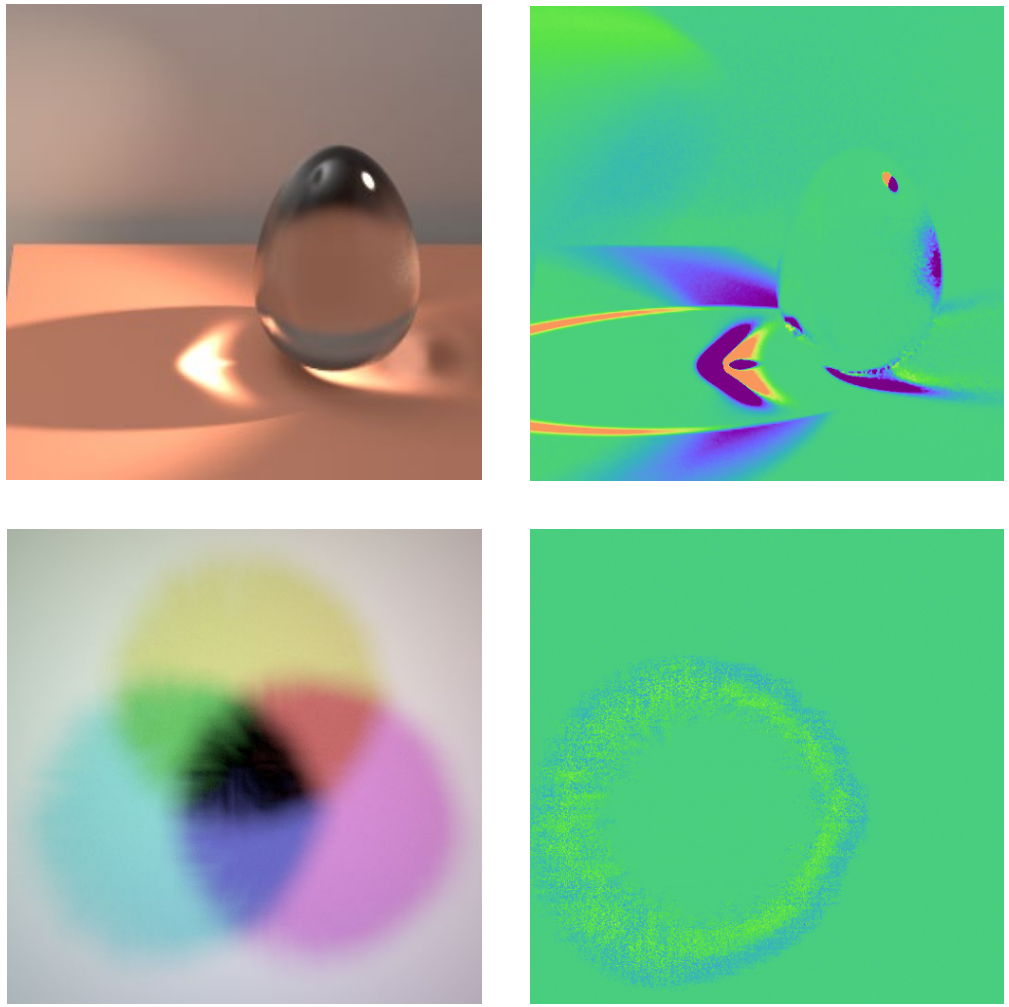
- unidirectional and bidirectional estimators
- Markov chain Monte Carlo techniques
- volumetric rendering
- importance sampling techniques
- quasi-Monte Carlo techniques



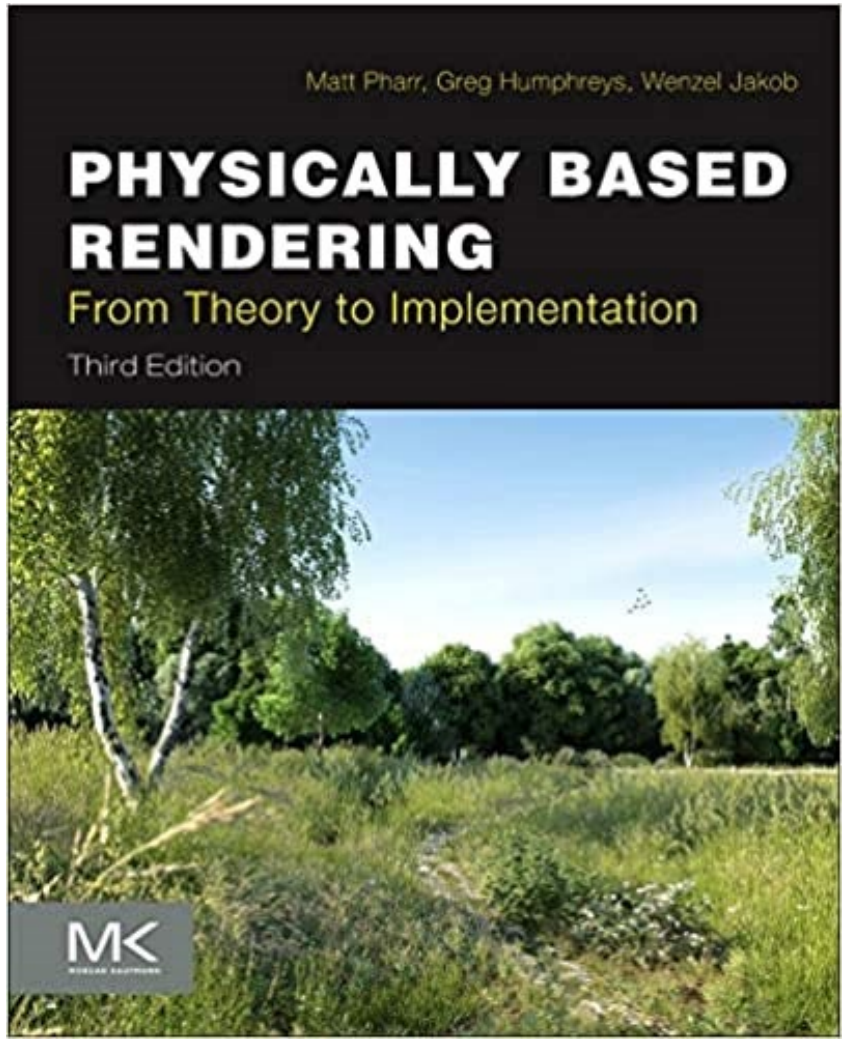
Topics to be covered

Advanced topics:

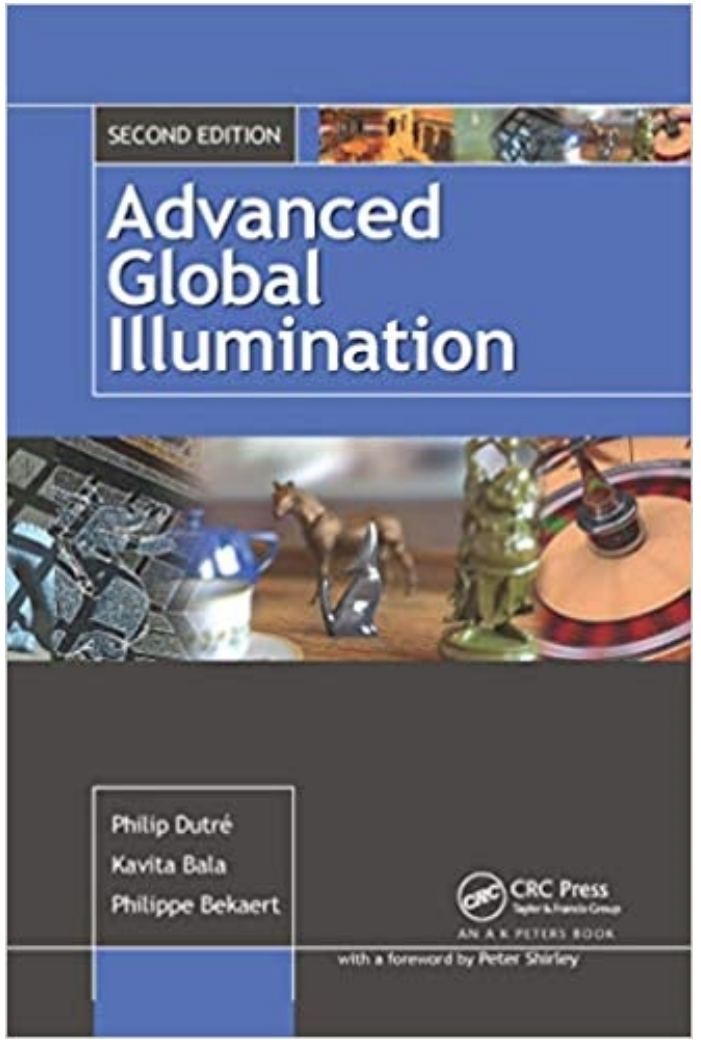
- differentiable rendering
- neural rendering
- rendering wave-optics effects
- rendering specular transport effects
- rendering eikonal transport effects



Books

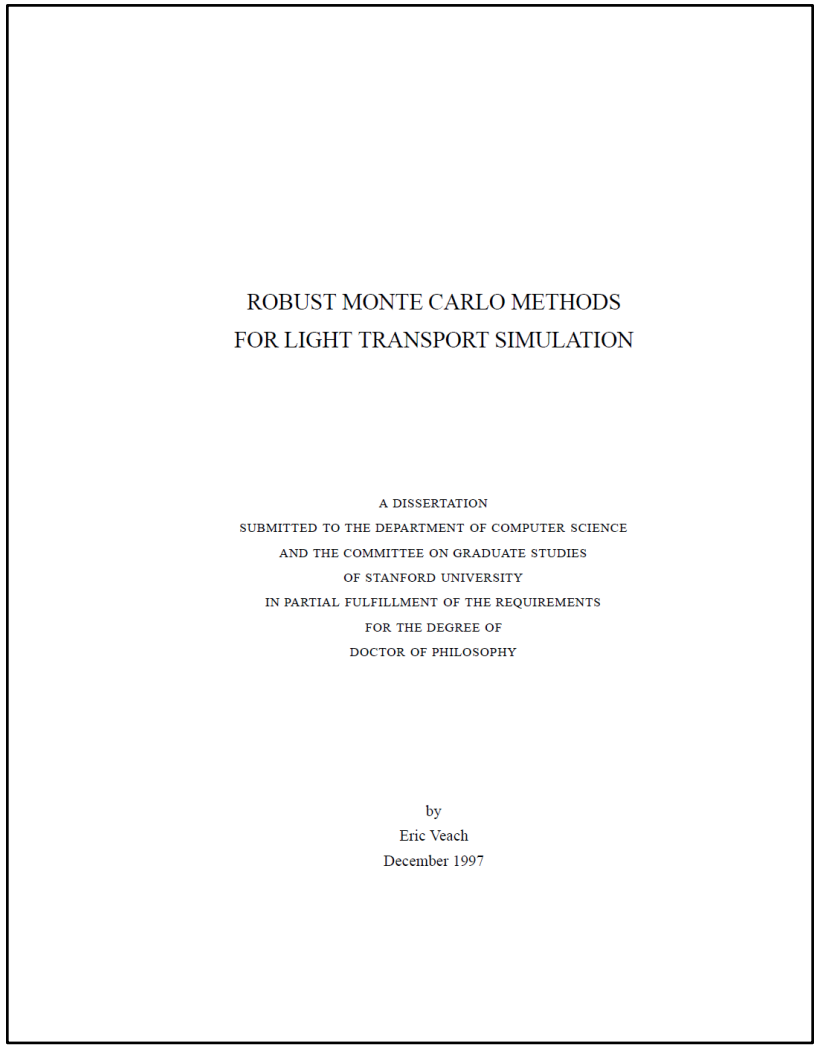


"PBR(T)", great reference for later programming assignments.



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

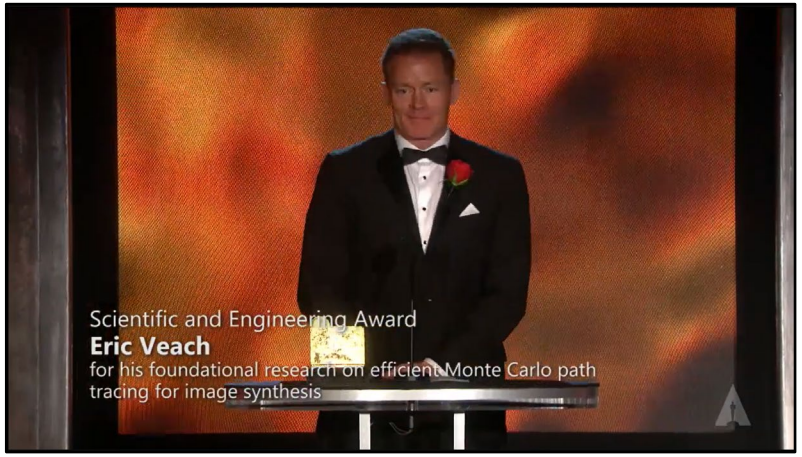
Books



ROBUST MONTE CARLO METHODS
FOR LIGHT TRANSPORT SIMULATION

A DISSERTATION
SUBMITTED TO THE DEPARTMENT OF COMPUTER SCIENCE
AND THE COMMITTEE ON GRADUATE STUDIES
OF STANFORD UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

by
Eric Veach
December 1997



This thesis has won an Oscar!

Eric Veach's thesis, probably the best *technical* reference for physics-based rendering

Prerequisites

At least one of the following:

- A computer vision course at the level of 16-385 or 16-720 or 16-820.
- A computer graphics course at the level of 15-362, 15-662.
- A computational photography course at the level of 15-463, 15-663, 15-862.

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 radiance.
- Lambertian, diffuse, and specular BRDFs.
- n-dot-l lighting.
- Environment map.
- Point and directional light sources.
- Ray tracing.
- Monte Carlo estimation.
- Refraction and diffraction.

Evaluation

- Four 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 educational renderer.
  - five free late days, 10% penalty per additional late day.
  - submissions more than three days late will not be graded.
  - compete for **gift cards to local shops!**

Submission deadlines will be enforced strictly!

- Ten take-home quizzes (25%):
  - solve 2-3 simple math problems related to each week's lectures.
  - **no late days, we will do solutions in recitations.**
  - you can skip two out of ten quizzes without penalty.

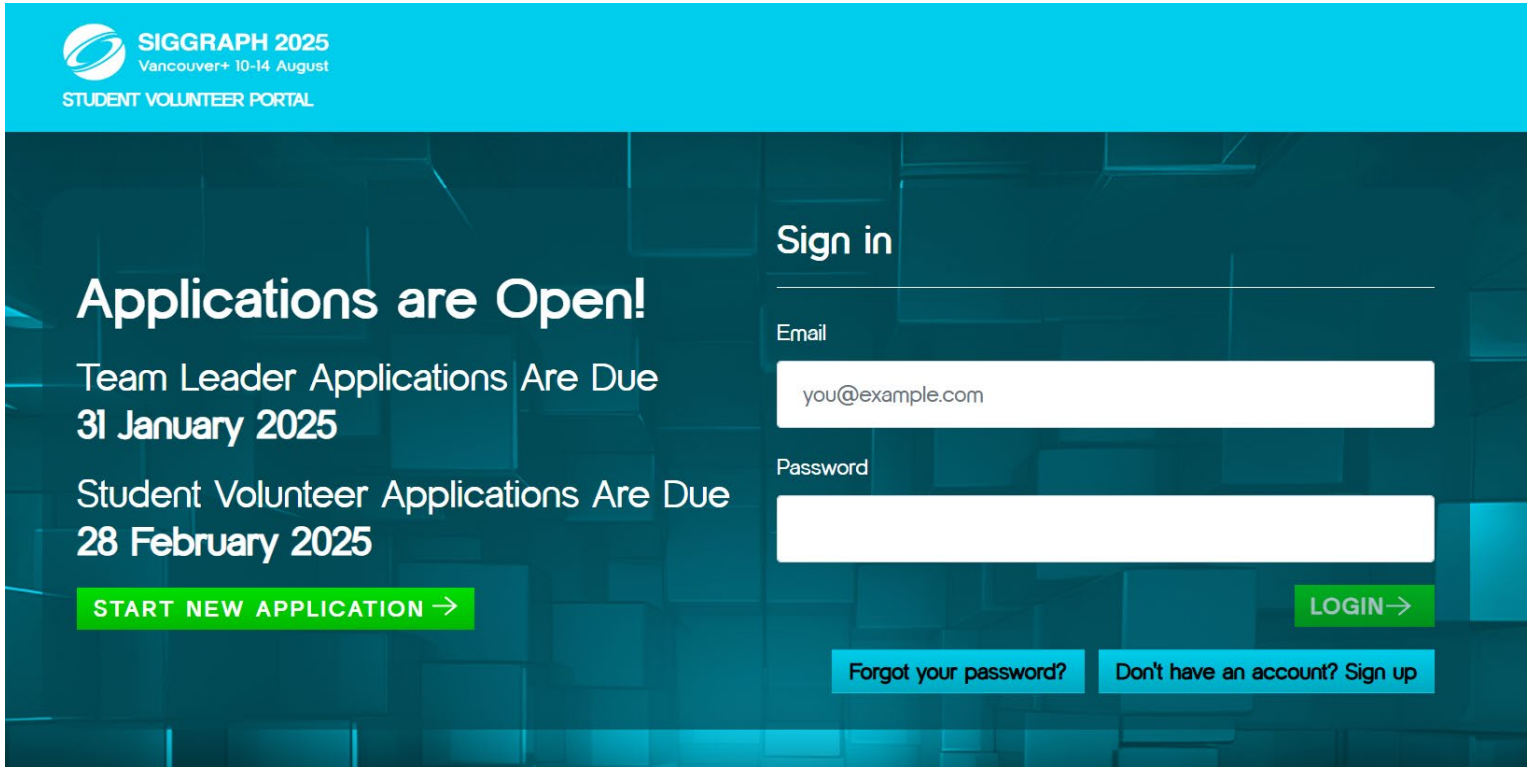
- Final project and rendering competition (25%):
  - implement rendering features of your choice and produce compelling imagery.
  - compete for **two free SIGGRAPH registrations (technical award and artistic award)!**
  - we will provide more information towards the end of February.
  - **no exam, but final project presentations are during the exam period.**

Affordable ways to attend SIGGRAPH

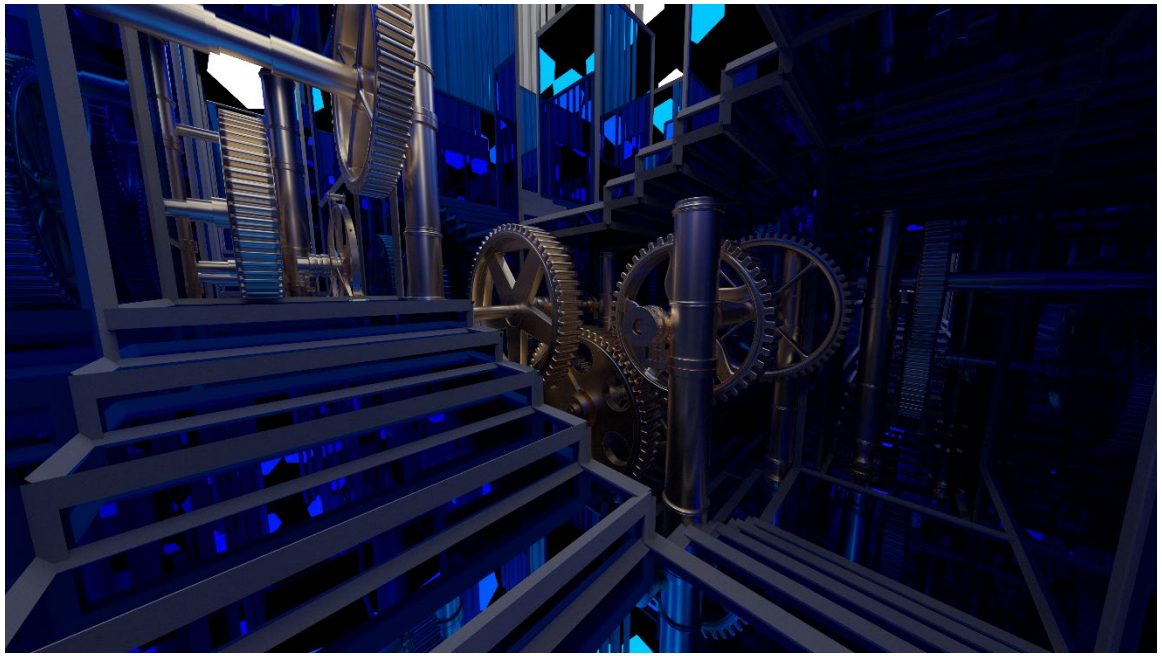
- Work on research with a graphics faculty members and ask them to sponsor you to attend SIGGRAPH. (Ideally, after having a paper accepted.)

- Win the final project competition in this course (and other graphics courses at CMU?).

- Apply to become a SIGGRAPH student volunteer: https://sv.siggraph.org/
  - Deadline to apply: February 28th.



Final project competition, Spring 2021

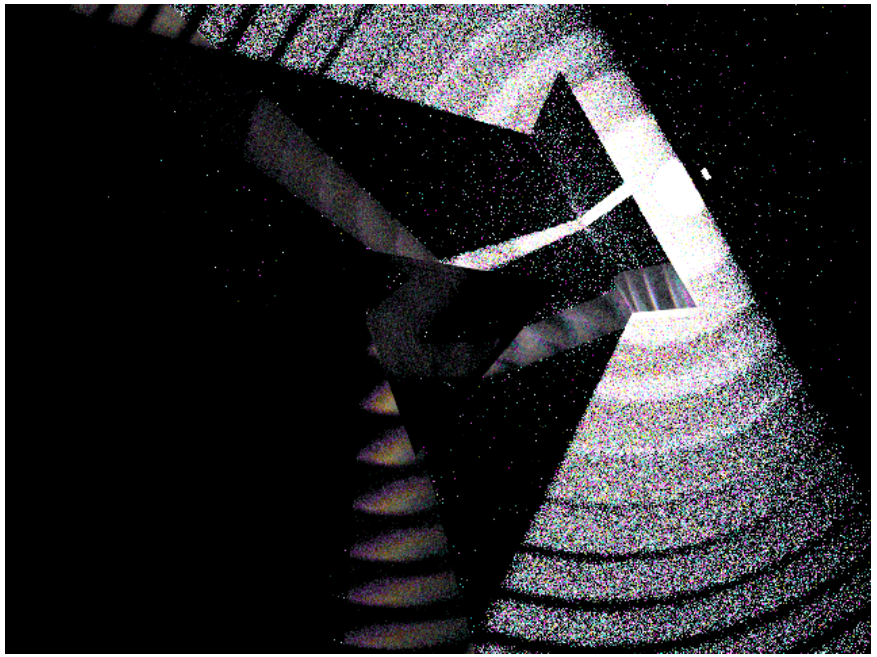


Technical award winner: Max Slater

Art award winner: Arpit Agarwal

- All of Spring 2021's final projects:
  - presentations - https://docs.google.com/presentation/d/1qeFYNXn3Z_pbmvTCtEUOtU8JGy1v8zeaQ9MlUJgCP-8/edit
  - renderings - http://graphics.cs.cmu.edu/courses/15-468/2021_spring/rendering_competition.html

Final project competition, Spring 2022



Technical award winner: George Ralph

Art award winner: Daria Mashanova

- All of Spring 2022's final projects:
  - presentations - https://docs.google.com/presentation/d/1Pjs-Gp3uNeQy4wy-LQrn937t2DGYEJGzShBtXPuJQIM/edit
  - renderings - http://graphics.cs.cmu.edu/courses/15-468/2022_spring/rendering_competition.html

Final project competition, Spring 2023

Technical award winner: Shilin Ma

Art award winner: Gustavo Silvera

- All of Spring 2023's final projects:
  - presentations - https://docs.google.com/presentation/d/1PQo6rtf--uHu-RbULSkcBbhFxE1UIQAYMS7x0a-IqE0/edit
  - renderings - http://graphics.cs.cmu.edu/courses/15-468/2023_spring/rendering_competition.html

Final project competition, Spring 2024

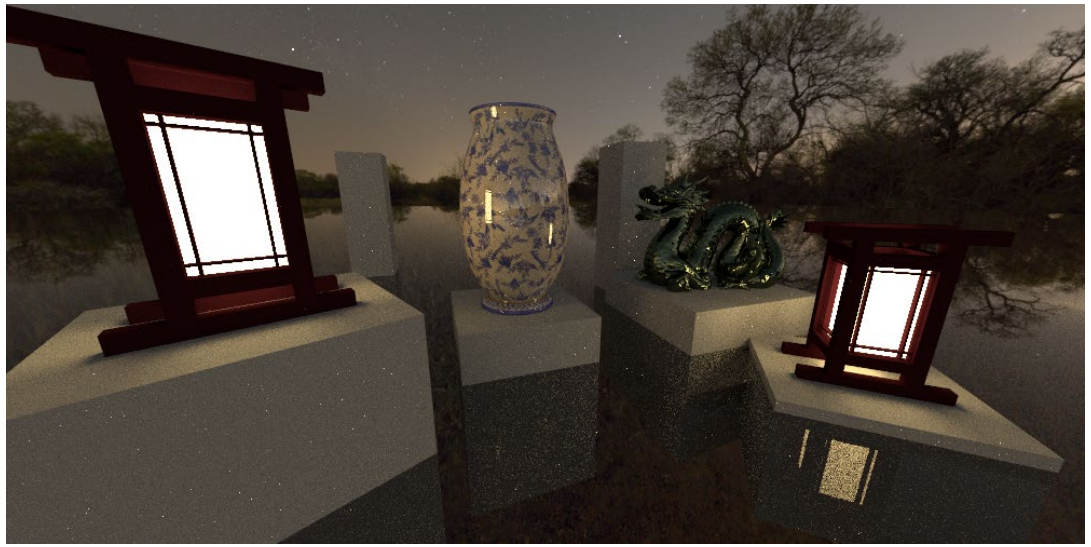
Technical award winners: Robert Fuchs, Junkai Huang

Art award winner: Isa Lie

- All of Spring 2024's final projects:
  - presentations - https://docs.google.com/presentation/d/1vZwe7y7x5AtiyEhkdwkfHt0Hd65YC45Gz-h5VnK9Ydo/
  - renderings - http://graphics.cs.cmu.edu/courses/15-468/2024_spring/rendering_competition.html

Programming assignment competitions, Spring 2023

PA1 winner:
Gustavo Silvera



PA3 winner:
Ruben Partono

PA4 winner:
Ruben Partono

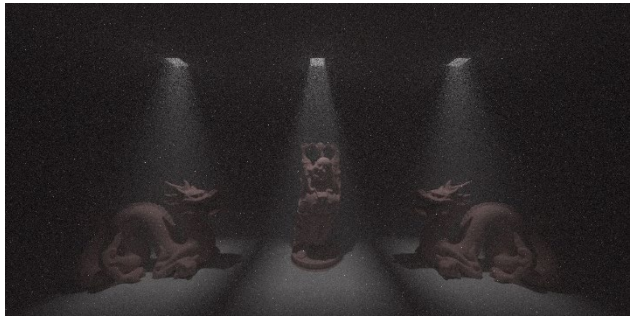
- All of Spring 2023's programming assignment competitions:
  - http://graphics.cs.cmu.edu/courses/15-468/2023_spring/pa1_competition.html
  - http://graphics.cs.cmu.edu/courses/15-468/2023_spring/pa3_competition.html
  - http://graphics.cs.cmu.edu/courses/15-468/2023_spring/pa4_competition.html

Programming assignment competitions, Spring 2024

PA1 winner:
Benran Hu

PA2 winner:
Benran Hu

PA3 winner:
Benran Hu



PA4 winner:
Sahil Jain

- All of Spring 2024's programming assignment competitions:
  - http://graphics.cs.cmu.edu/courses/15-468/2024_spring/pa1_competition.html
  - http://graphics.cs.cmu.edu/courses/15-468/2024_spring/pa2_competition.html
  - http://graphics.cs.cmu.edu/courses/15-468/2024_spring/pa3_competition.html
  - http://graphics.cs.cmu.edu/courses/15-468/2024_spring/pa4_competition.html

Rendering competitions elsewhere

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.

Friday recitations

- Every Friday, there will be a recitation, where we go over the solutions to that week's take-home quiz.

- Typically, recitations take the form of whiteboard derivations, and free-form discussion.

- **Participation is optional but strongly recommended.**
  - Students in prior years suggested adding it in S3 so that students do not overlook or get conflicted with recitations.

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 Slack.
  - we won't answer technical questions through email.
- Office hours will be determined by vote in the start-of-semester survey.
  - office hours will be in person at the Smith Hall (EDSH) graphics lounge.
  - 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 or DM on Slack for additional office hours.
  - office hours for this week will be announced on Slack.
- Post-lecture Q&A for 30 minutes.

Interested in research?

- Visit the graphics lab and imaging group websites:

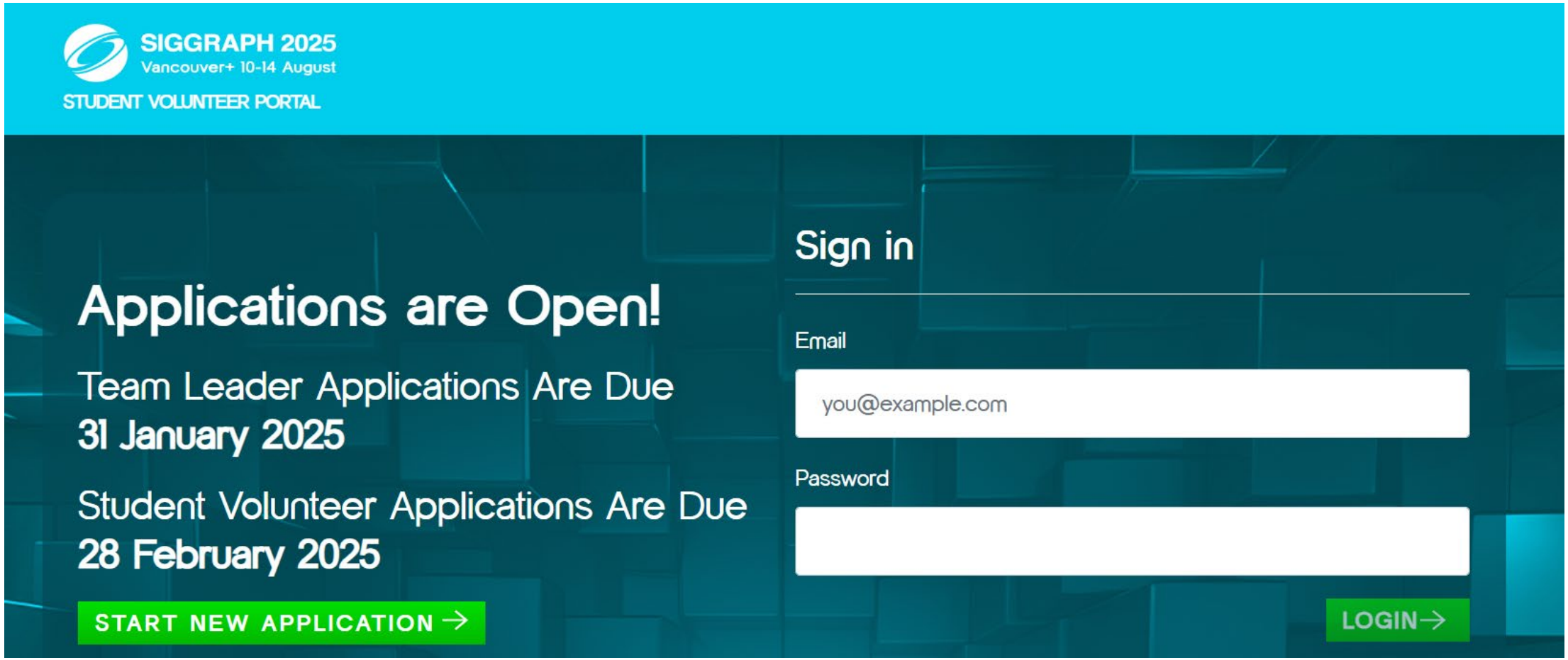
http://graphics.cs.cmu.edu/
https://imaging.cs.cmu.edu/

- Email Yannis if you want to be added to the graphics lab mailing list and attend our weekly meetings (**time TBD**).

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

Apply to become a SIGGRAPH student volunteer!

Website: https://sv.siggraph.org/
Deadline: February 28th



Please take the start-of-semester survey!

- Posted on Slack as well:

https://forms.gle/uNtE1JigWeomPfbb9

- We use the survey to:
  - Get a better idea of students' background.
  - Decide on day and time of office hours.