# Wrap-up and discussion


15-468, 15-668, 15-868
Physics-based Rendering
Spring 2021, Lecture 24

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

# Course announcements

- Take-home quiz 10 posted, due May 11th, 11:59 pm.

- Final project presentations on Tuesday 5/11.
    - Logistics posted on Piazza.

- This week's reading group.
    - We'll cover non-exponential radiative transfer (same topic as last Friday).

- We'll do one more reading group next week.
    - We'll cover a couple of neural rendering papers.

# Take the course evaluation surveys!

- CMU's Faculty Course Evaluations (FCE): https://cmu.smartevals.com/
- CMU's TA Evaluations: https://www.ugrad.cs.cmu.edu/ta/S21/feedback/
- An end-of-semester survey specific to 15-468/668/868: https://docs.google.com/forms/d/e/1FAIpQLSdxnAPIUg-Oy2IUH5OvP7GTRv3XhS0O5P0W4_NlnQp1jQ9X1A/viewform

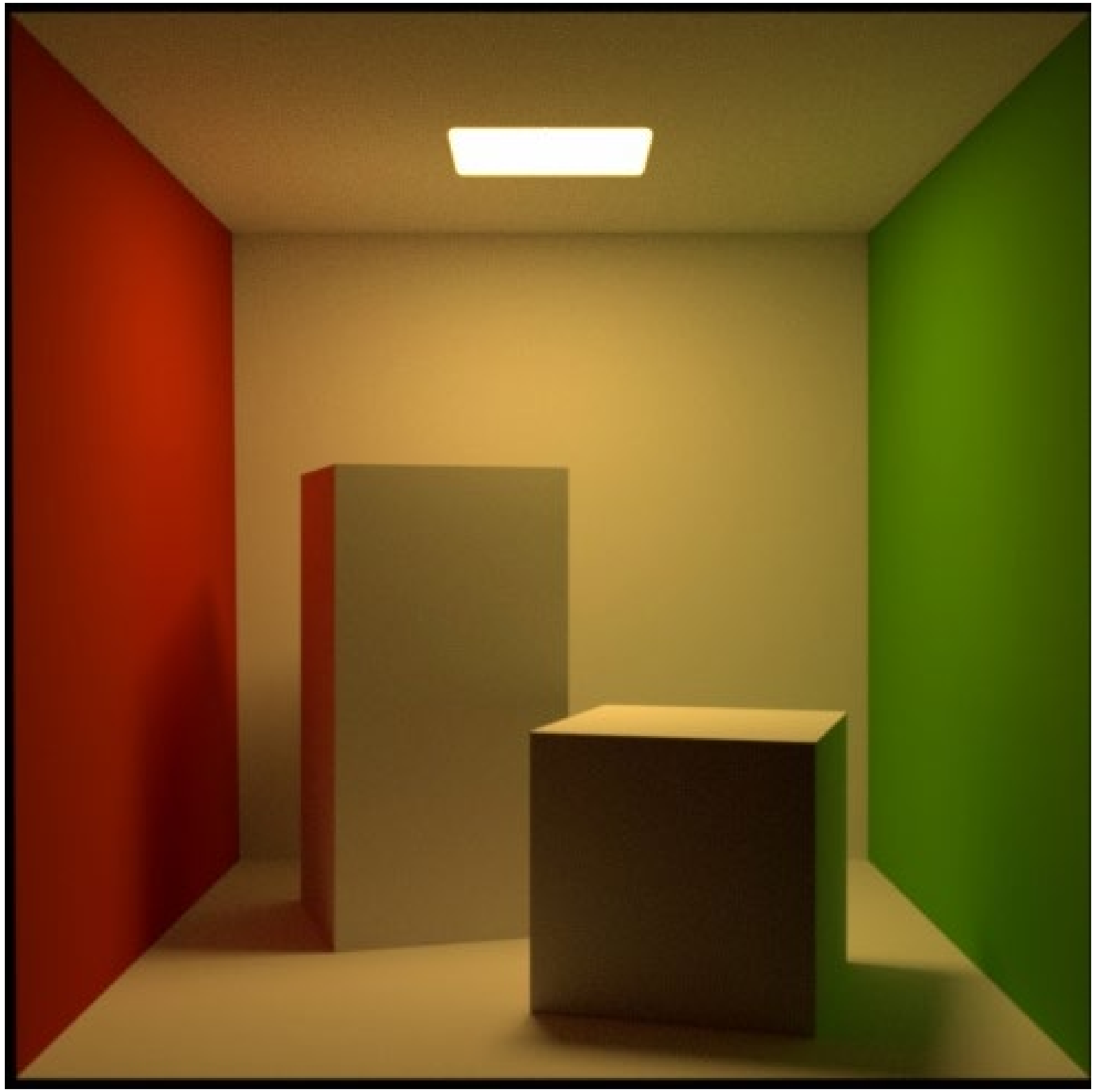
# Overview of today's lecture

- Class wrap-up and discussion.

# Topics we covered

Basics of ray tracing:

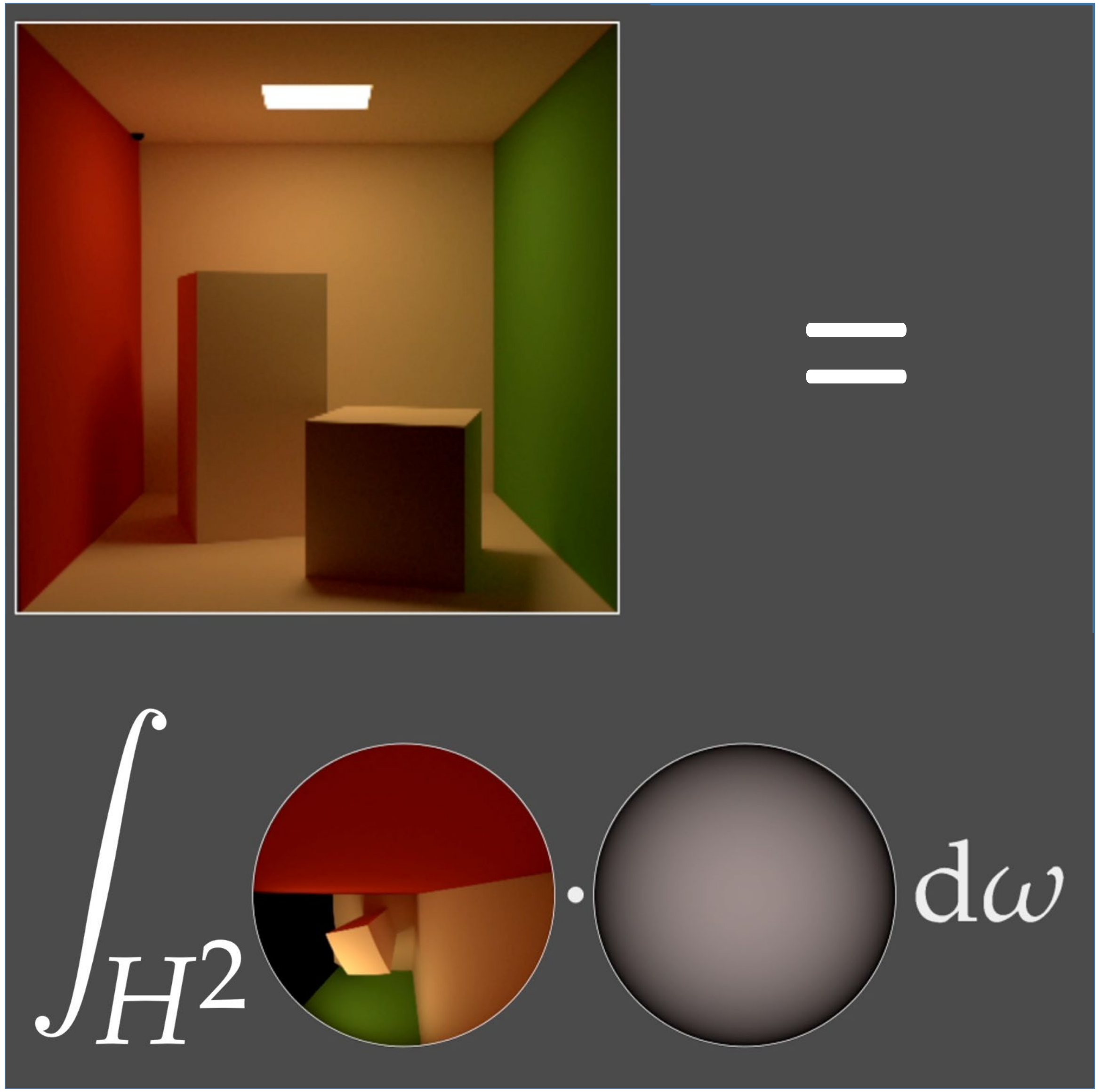
- trace-intersect recursions
- basic camera and illumination models
- shading
- intersection queries
- texture mapping



# Topics we covered

Theory of light transport and materials:

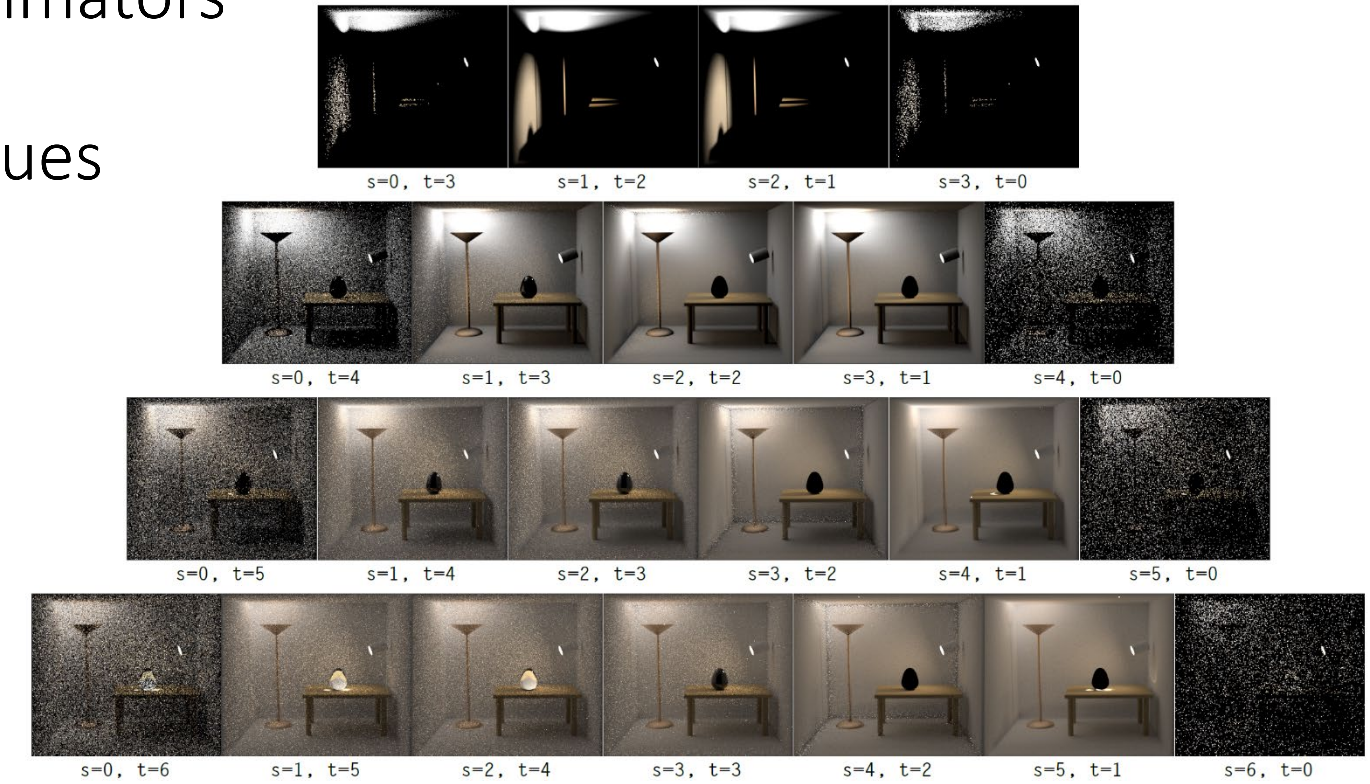
- rendering equation
- radiative transfer equation
- path integral formulations
- microfacet reflectance models
- statistical scattering models



# Topics we covered

Monte Carlo rendering algorithms:

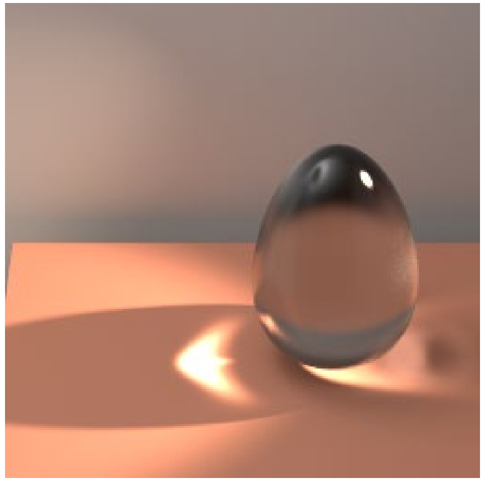
- unidirectional and bidirectional estimators
- Markov chain Monte Carlo techniques
- volumetric rendering
- photon mapping
- importance sampling techniques
- quasi-Monte Carlo techniques

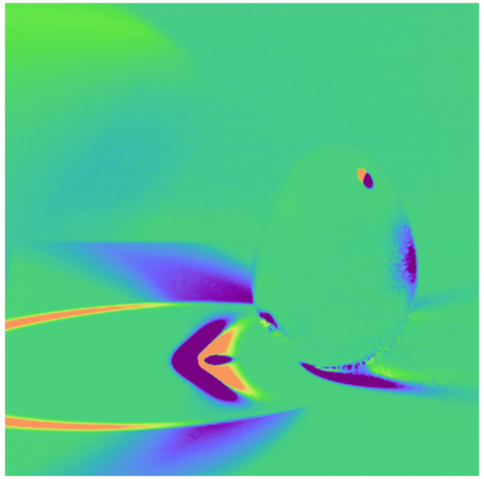


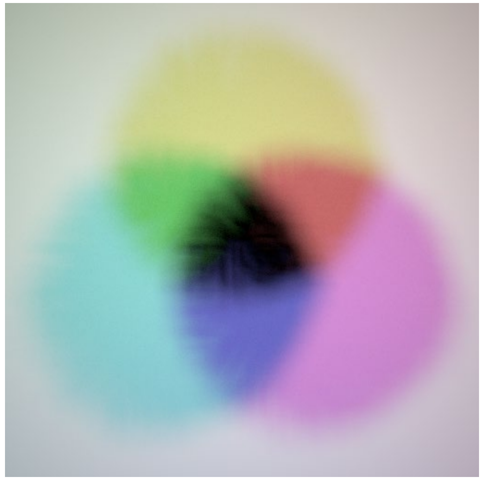
# Topics we covered

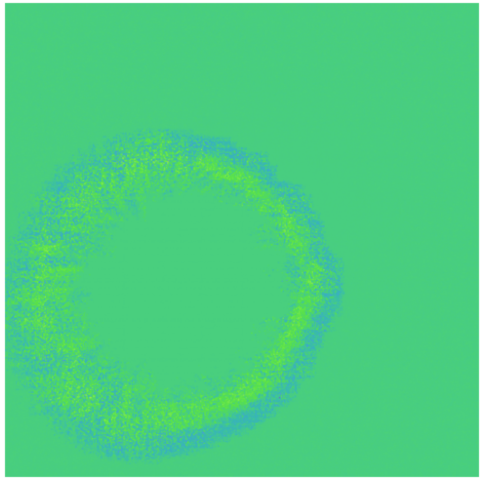
Advanced topics:

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









# Things you should know how to do

1. Implement a ray tracing pipeline.
2. Use different types of textures.
3. Implement different types of light sources.
4. Implement different types of materials.
5. Write integrators for direct illumination, ambient occlusion, and global illumination.
6. Derive complex results about radiometry and light transport.
7. Use an array of statistical techniques to solve integration problems.

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

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

Background courses (ideally you should take both):

- 15-462 computer graphics.
- 16-385 computer vision.

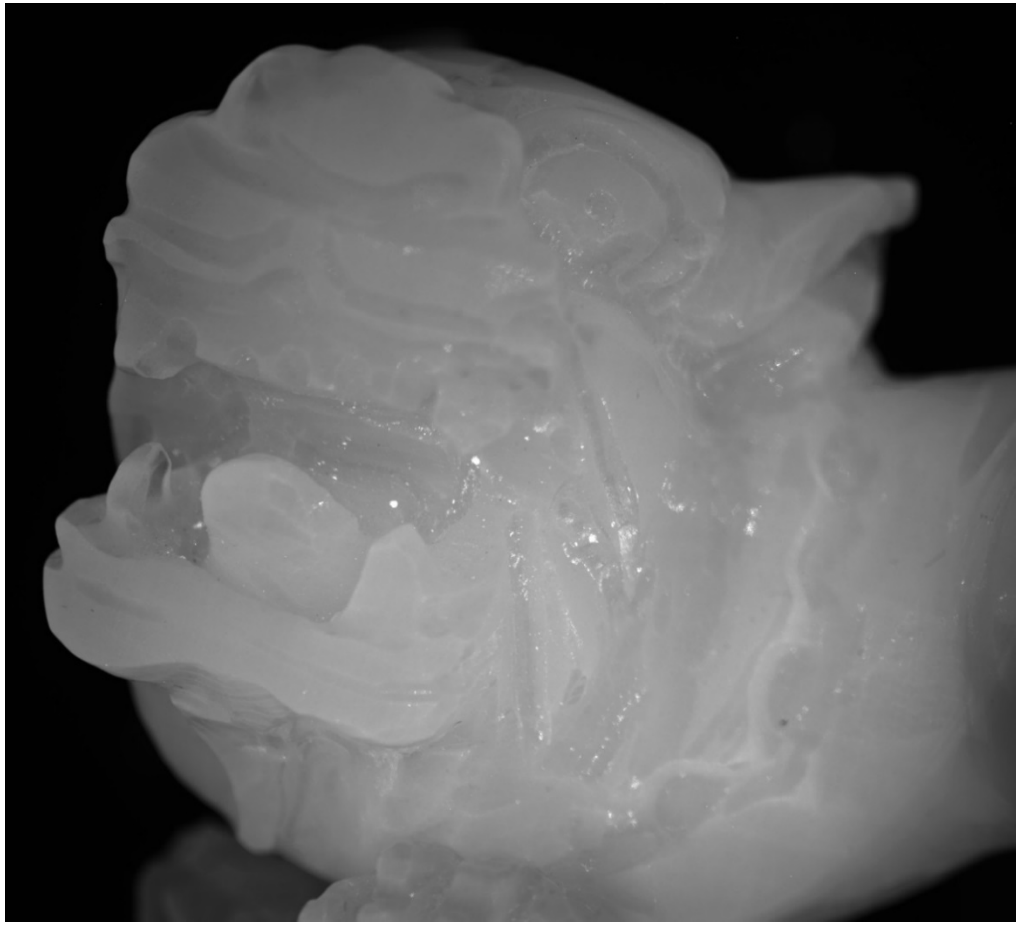
More advanced graphics courses:

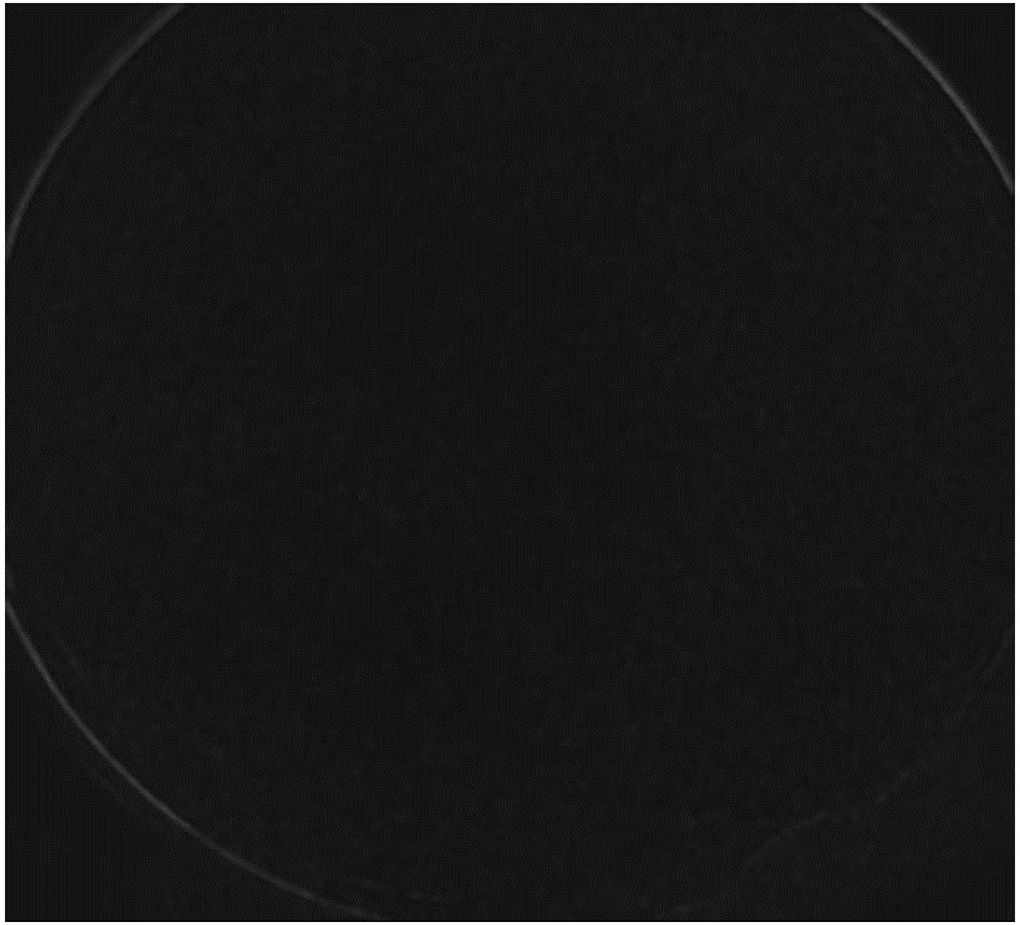
- 15-365 experimental animation
- 15-458 discrete differential geometry
- 15-463 computational photography ← Fall 2021, offered by Yannis
- 15-464 technical animation
- 15-465 animation art and technology
- 15-466 computer game programming
- 15-469 algorithmic textiles design
- 16-726 learning-based image synthesis – learning-based variants of computational photography algorithms.

More advanced vision courses:

- 16-822 geometry-based methods in vision
- 16-823 physics-based methods in vision
- 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

# 15-463/663/862 Computational Photography
# Fall 2021





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

Instructor: Ioannis (Yannis) Gkioulekas

# Topics to be covered

Digital photography:

- optics and lenses
- color
- exposure
- aperture
- focus and depth of field
- image processing pipeline


[Photo from Gordon Wetzstein]

# Topics to be covered

Image manipulation and merging:

- bilateral filtering
- edge-aware filtering
- gradient-domain image processing
- flash/no-flash photography
- high-performance image processing

[Banerjee et al., SIGGRAPH 2014]

# Topics to be covered

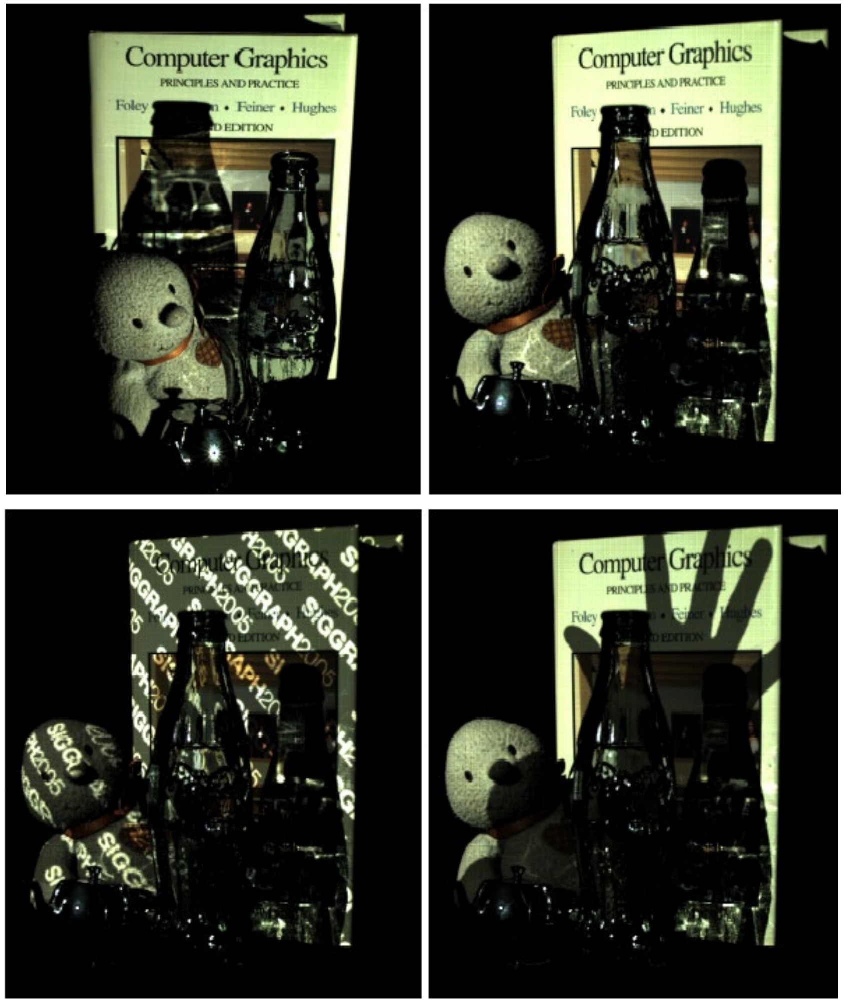
Types of cameras:

- geometric camera models
- light-field cameras
- coded cameras
- lensless cameras
- compressive cameras
- hyperspectral cameras

# Topics to be covered

Active illumination and sensing:

- time-of-flight sensors
- structured light
- computational light transport
- transient imaging
- non-line-of-sight imaging
- optical computing




[Sen et al., SIGGRAPH 2005]

# Evaluation

- Six-plus-one homework assignments (60% + 10%):
  - programming and capturing your own photographs.
  - all programming will be in **Python**
  - first assignment will serve as a gentle introduction to Python.
  - five late days, you can use them as you want.

- Final project (35%):
  - we will provide more information near the end of September.
  - 15-663, 15-862 require more substantive project.
  - if your ideas require imaging equipment, talk to us in advance.
  - **no exam, but final project presentations are during the exam period.**

# Do I need a camera?

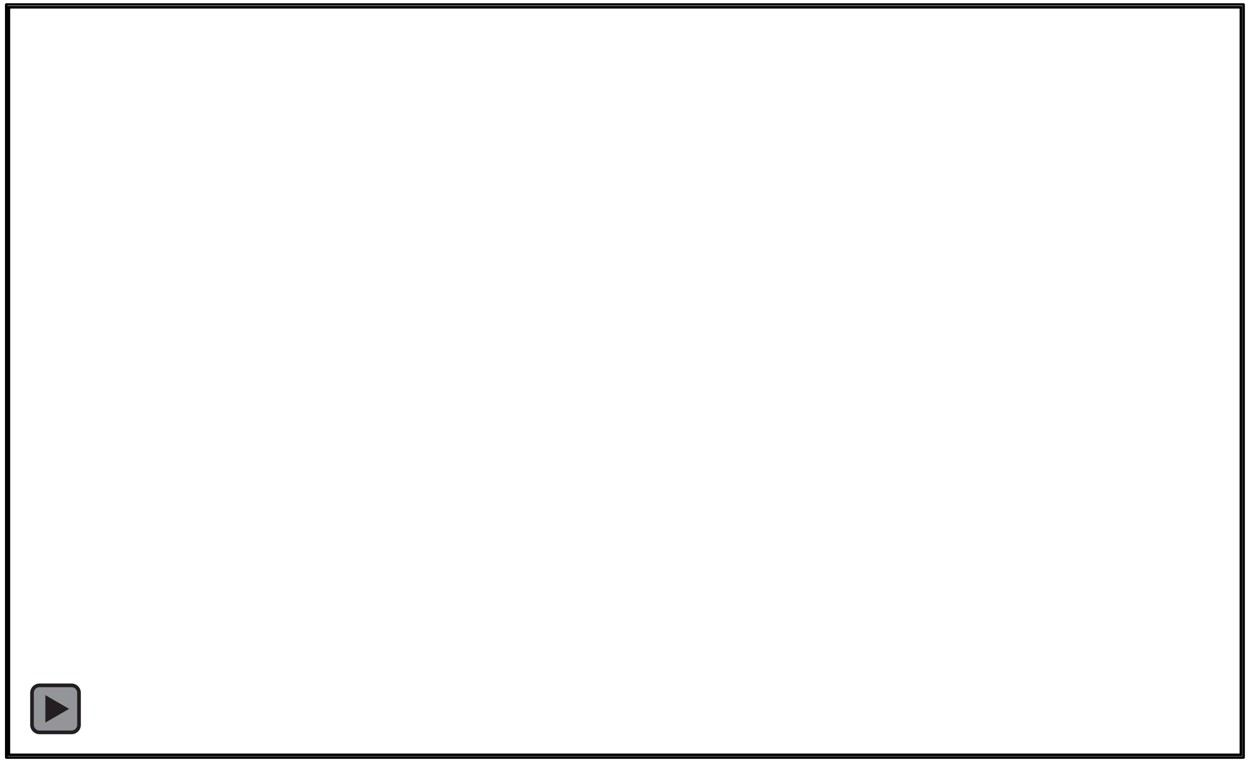
- You will need to take your own photographs for assignments 1-6 (all of them):
  - Assignment 1: pinhole camera – you need a high-sensitivity camera.
  - Assignment 2: HDR – you need a camera with manual exposure controls.
  - Assignment 3: image filtering – you can use your phone camera.
  - Assignment 4: lightfields – you need a camera with manual focus control..
  - Assignment 5: photometric stereo – you need a camera with RAW support.
  - Assignment 6: structured light – you can use your phone camera.
  - Assignment 7: rendering – no camera needed.

- We have 50 Nikon D3X00 kits (camera + lens + tripod) for students.
  - If you have your own camera, please use that!

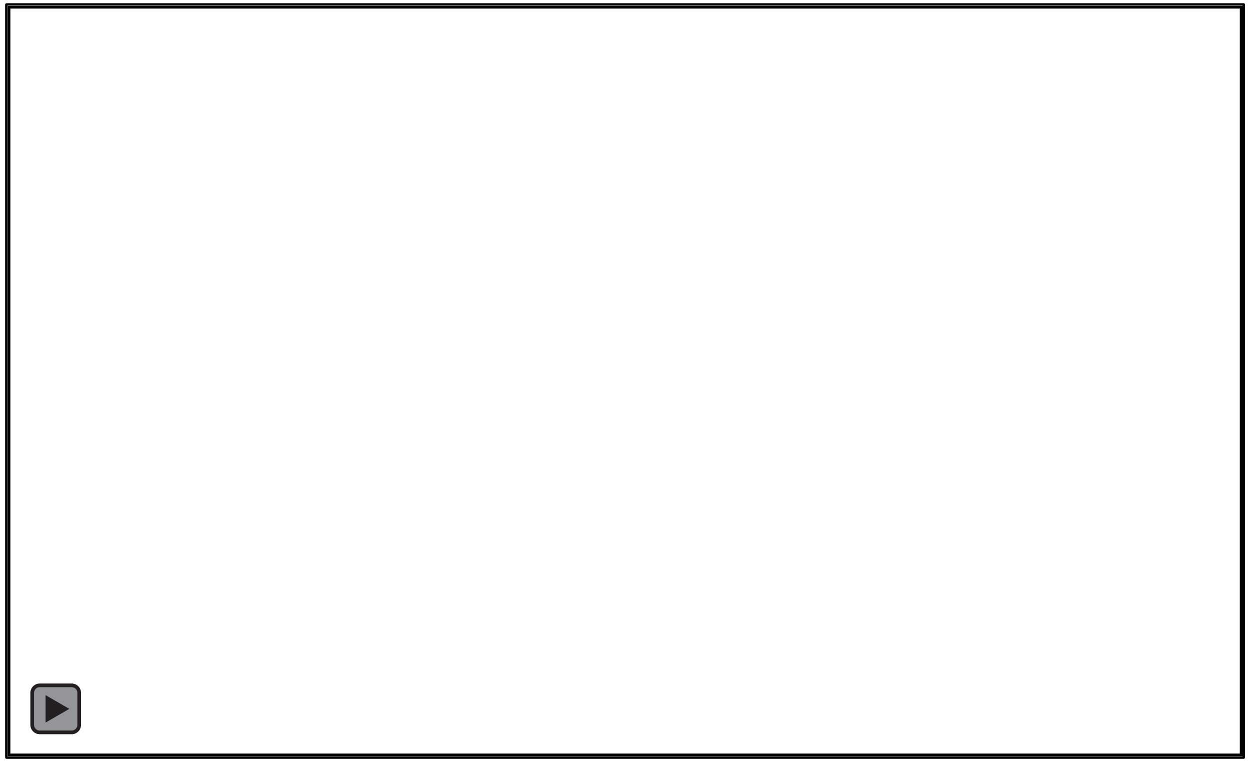
# Interplay between computational imaging and physics-based rendering

- Learn about new types of cameras, optics, and light transport effects → inspiration for new rendering problems to pursue.
- Learn about computational light transport → insights into properties of light transport.
- Learn about challenging imaging problems → opportunities to use rendering to tackle them.

# Separate direct and global illumination

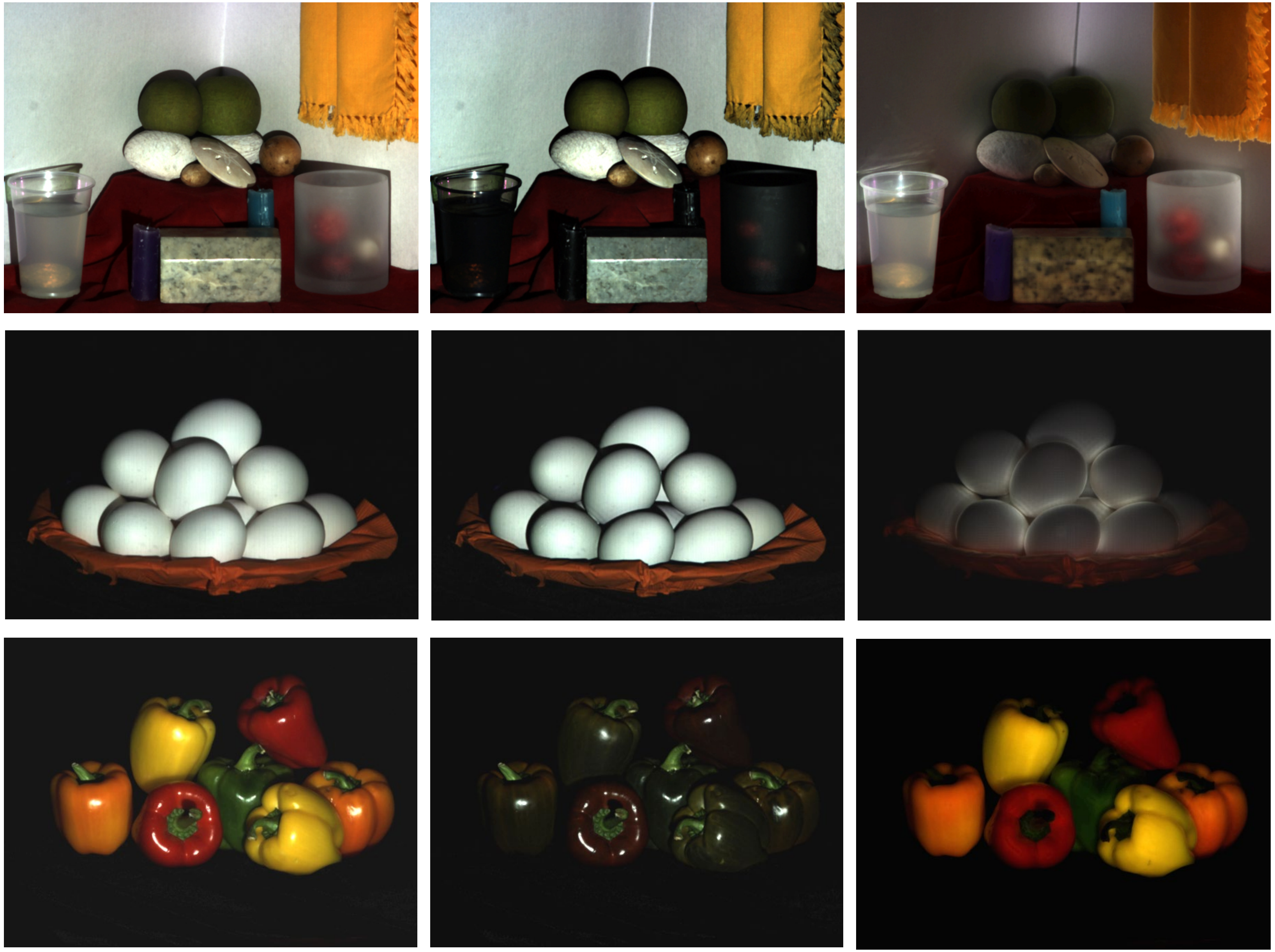


direct-only illumination

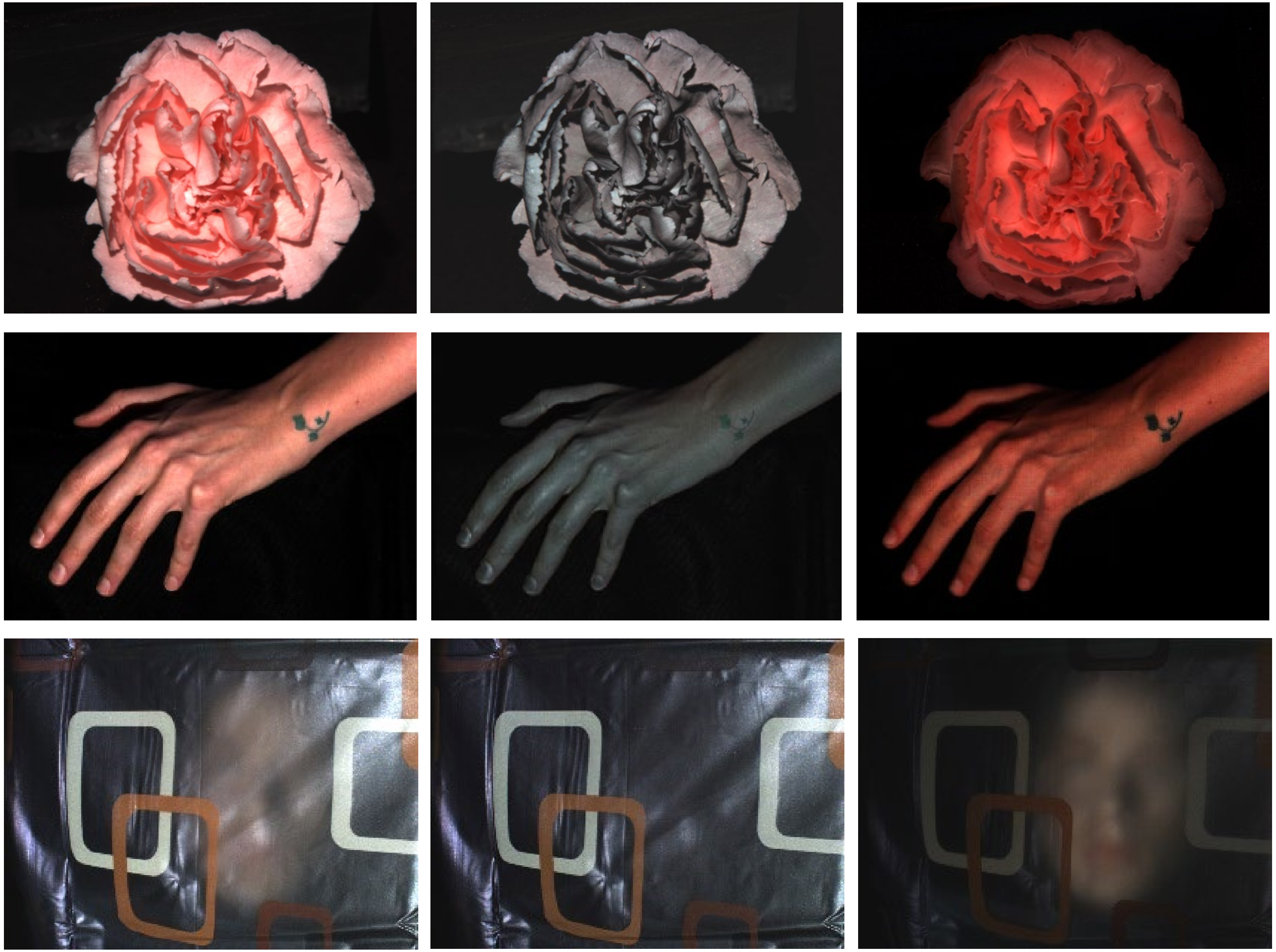


global-only illumination

# Separate direct and global illumination



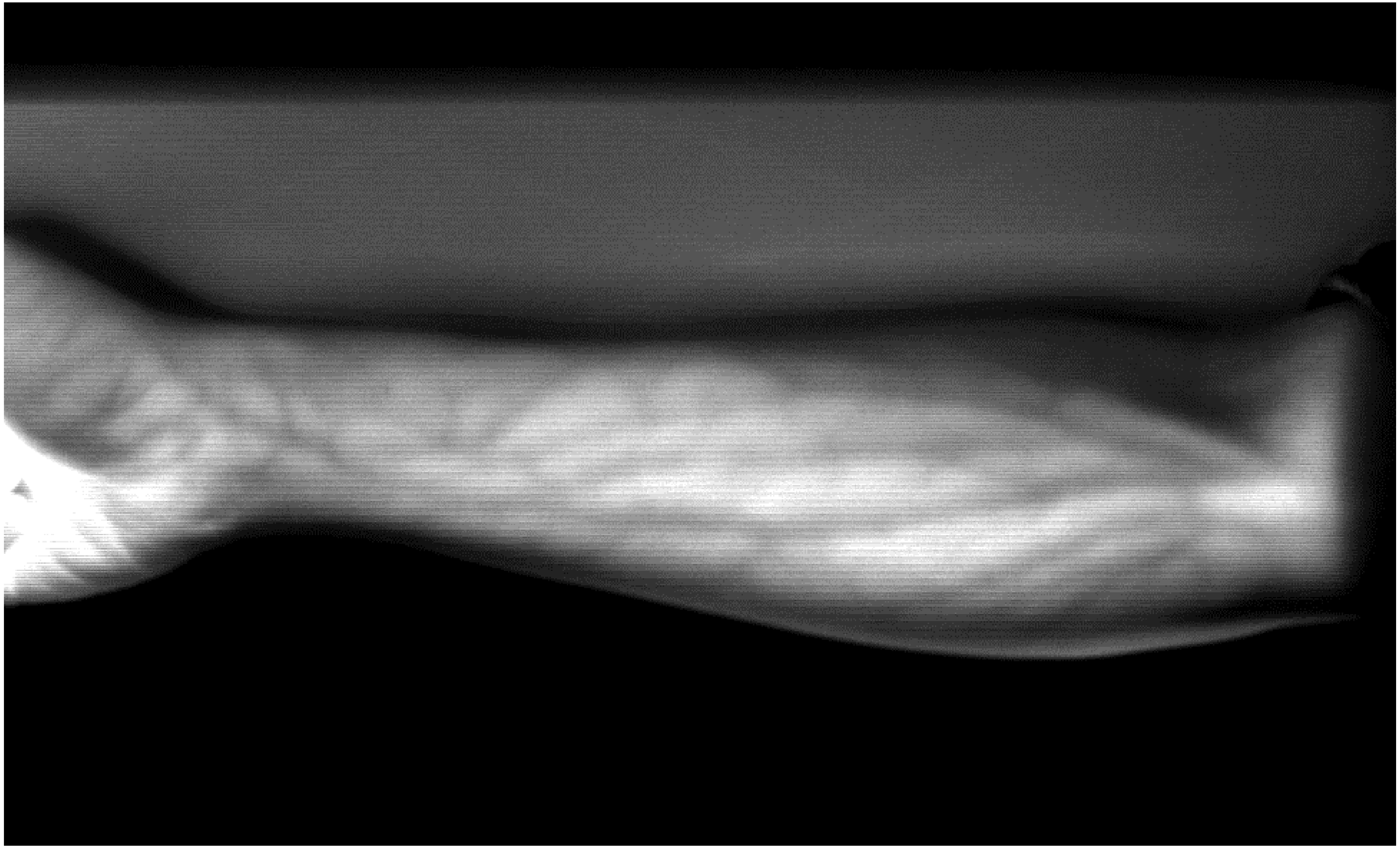
# Separate direct and global illumination



# Separating paths by length

# Looking through the skin

Live vein imaging



[NSF Expedition]

# Dual photography

# 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.

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

Many, many possible projects, including:

- Projects on rendering and inverse rendering.
- Projects on theory of light transport.
- Projects on algorithms for differentiable rendering.
- 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.

Ideal background:
- Knowledge of (at least one of) graphics, vision, physics, numerical computing.
- If you’ve taken 15-468, you have the background.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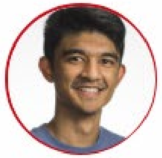
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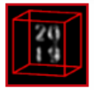
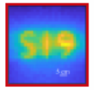
## Alumni


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

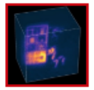
Byeongjoo Ahn, Akshat Dave, Ashok Veeraraghavan, Ioannis Gkioulekas, and Aswin C. Sankaranarayanan. *ICCV 2019.*


**A Differential Theory of Radiative Transfer**

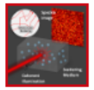
Cheng Zhang, Lifan Wu, Changxi Zheng, Ioannis Gkioulekas, Ravi Ramamoorthi, and Shuang Zhao. *ACM SIGGRAPH Asia 2019.*


**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**

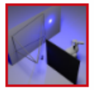
Shumian Xin, Sotiris Nousias, Kiriakos N. Kutulakos, Aswin C. Sankaranarayanan, Srinivasa G. Narasimhan, and Ioannis Gkioulekas. *CVPR 2019.*


**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.*

**http://imaging.cs.cmu.edu/**

# This class is still evolving, so your feedback is invaluable.

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- Please take all three of them, super helpful for developing future offerings of the class.
- Thanks in advance!

# Questions?

# Which parts of the course did you like the most?

# Which parts of the course did you like the least?

# Any topics you wanted to learn more about?

# Any topics you wanted to learn less about?

# Any topics you would cover in a different order?

# How should we change the programming assignments?

# Would you prefer to use a different codebase/renderer for programming assignments?

# How should we change the take-home quizzes?

# Should we replace take-home quizzes with a final exam?

# Were the recorded recitations for take-home quizzes OK?

# How does homework difficulty compare to other classes?

# Any kind of homework you would have liked to see?

# Would it be better if the final projects were more open-ended and/or research-oriented?

# Should we continue reading groups?