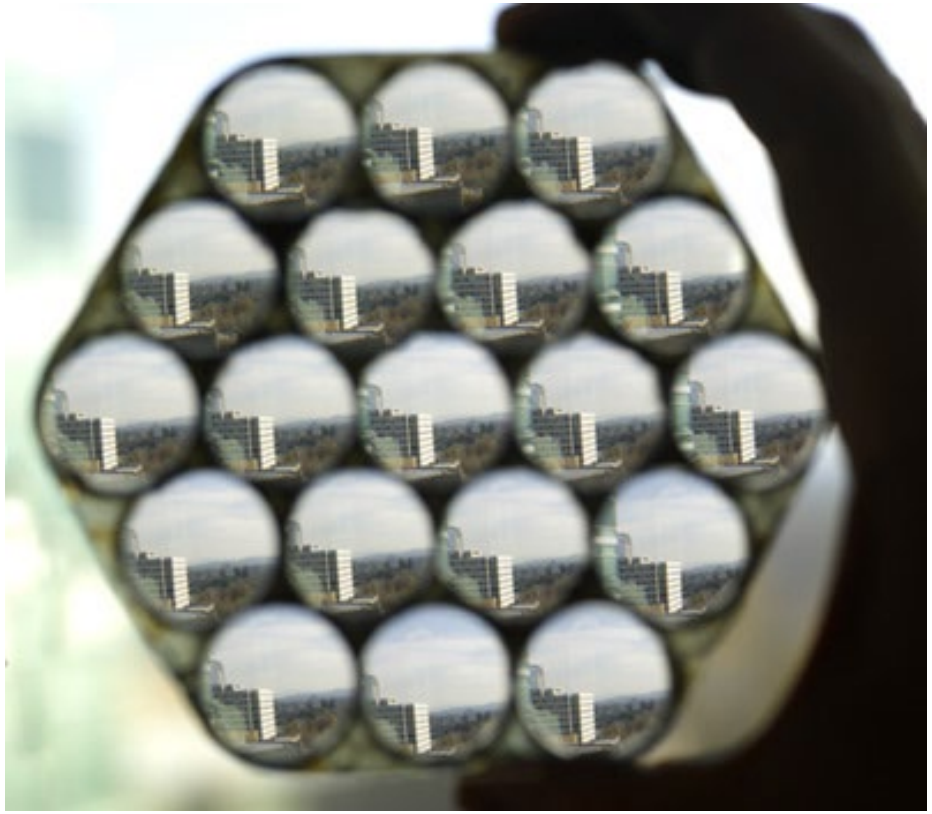
# Introduction



15-463, 15-663, 15-862
Computational Photography
Fall 2022, Lecture 1

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

# Lecture etiquette

- Lecture slides (PPTX and PDF) are posted on the course website before each lecture.
- Lectures, including all discussions, **are recorded** using Zoom. This is to facilitate students that **occasionally** cannot attend the lectures live, or that want to revisit the lecture material.
- You are expected to attend lectures in person. You are **not** allowed to attend lectures over Zoom, unless you have explicit permission.
- Recordings become available on **Canvas** a few hours (usually <= 3) after the lecture. You are **not** allowed to share these recordings with anyone outside this class. This is to protect your and your fellow students' FERPA rights.
- 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 computational photography?
- Course fast-forward and logistics

# Teaching staff introductions

# Instructor: Ioannis (Yannis) Gkioulekas

You can call me Yannis.

Originally from Greece

National Technical University of Athens (2004-09)

Harvard University (2009-17)

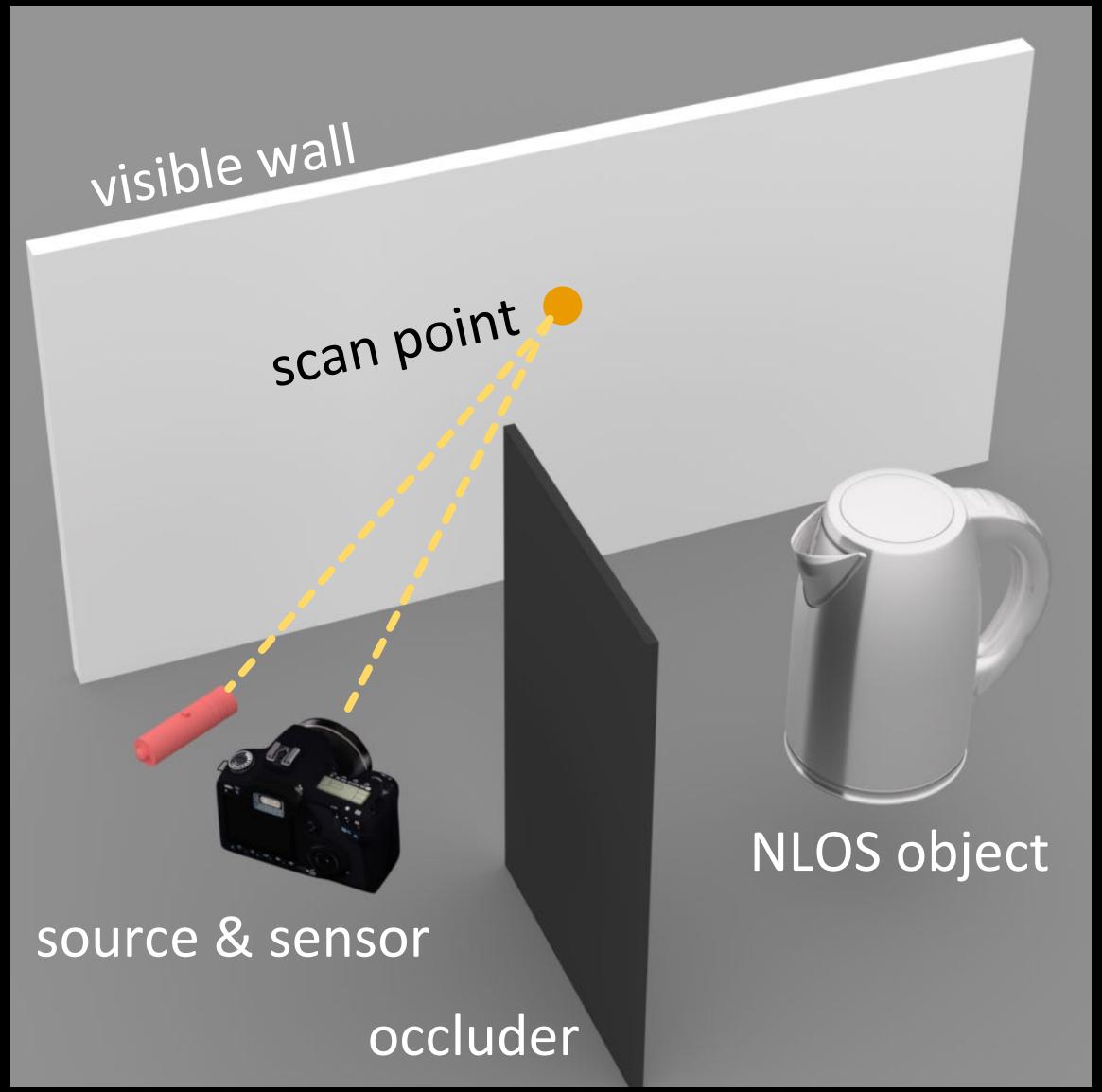
Carnegie Mellon University (2017-now)

Yannis at Harvard in 2011

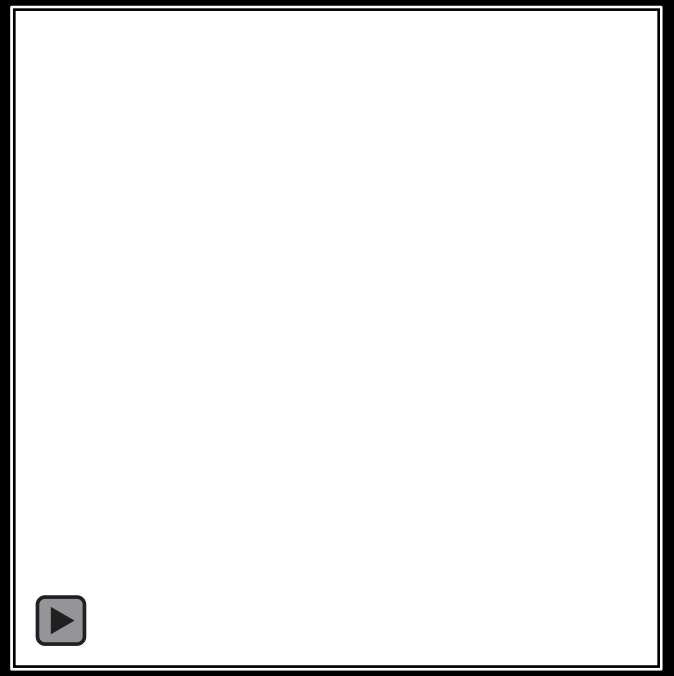
My website: http://www.cs.cmu.edu/~igkioule

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

# Looking around corners



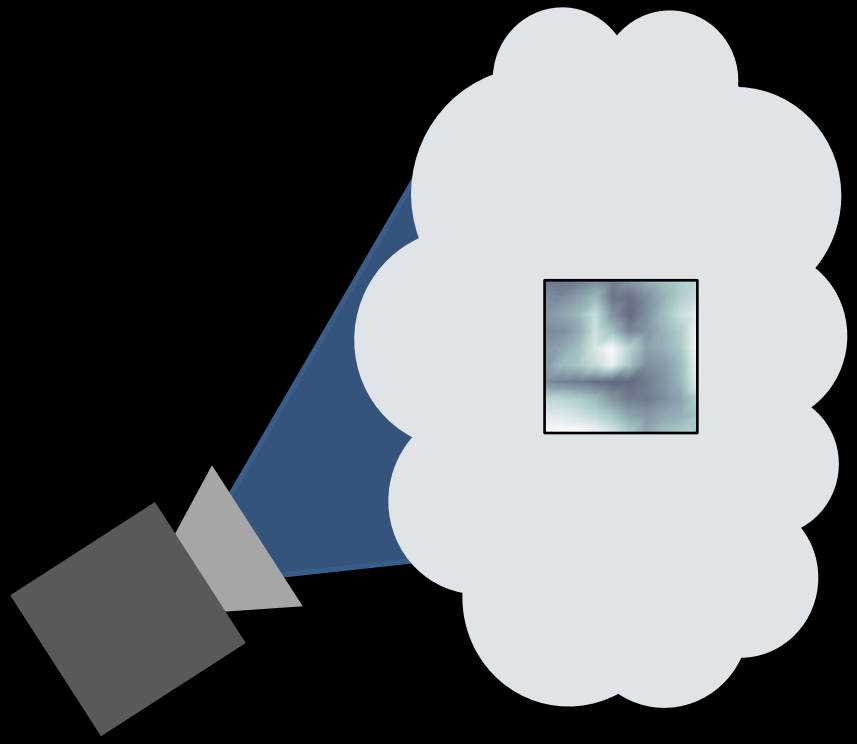

what a regular camera sees



what we can reconstruct

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

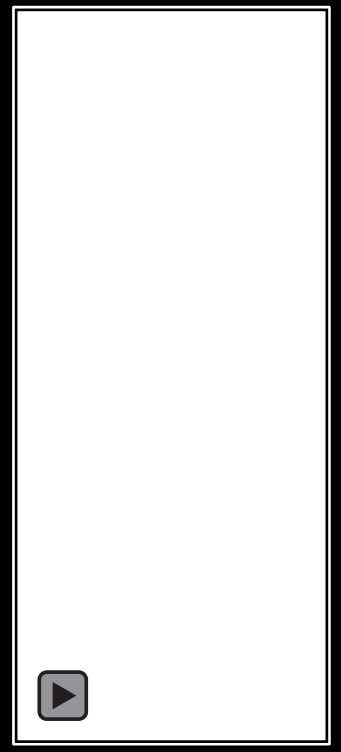
# Looking inside deep scattering objects



camera

thick smoke cloud

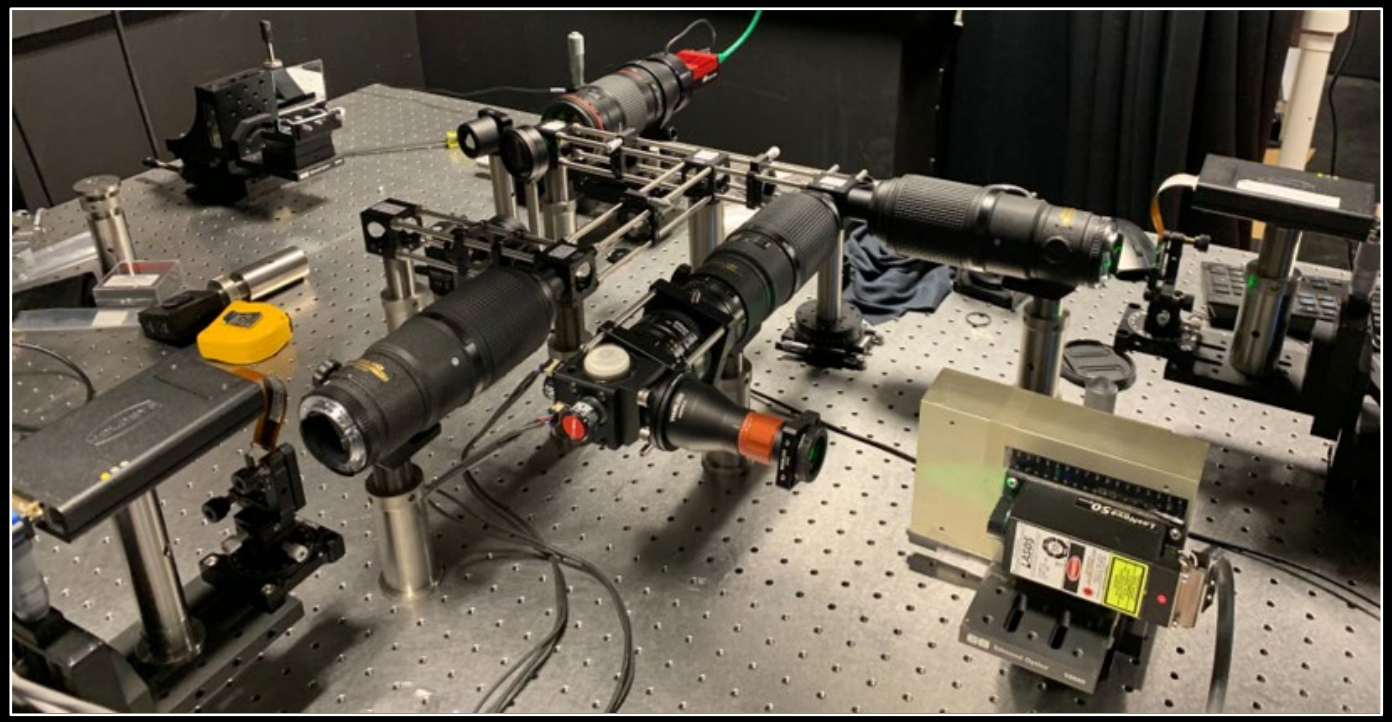
simulated camera measurements



reconstructed cloud volume

slice through the cloud

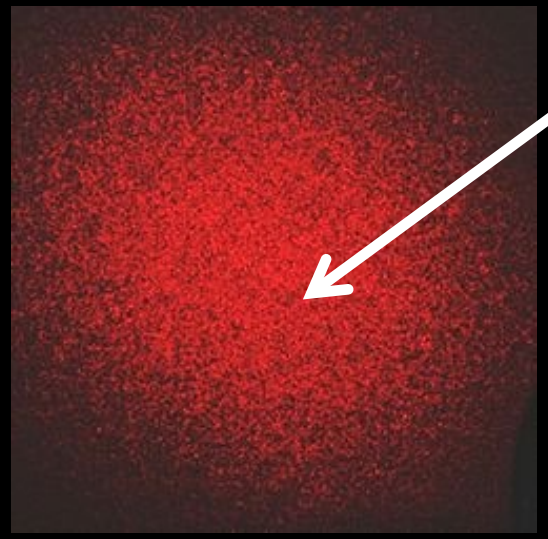
# Seeing light in flight



camera for capturing video at $10^{15}$ frames per second

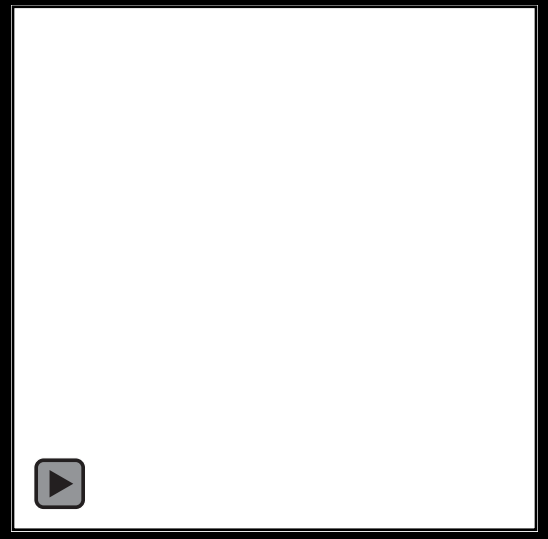
http://imaging.cs.cmu.edu/

# Rendering wave effects

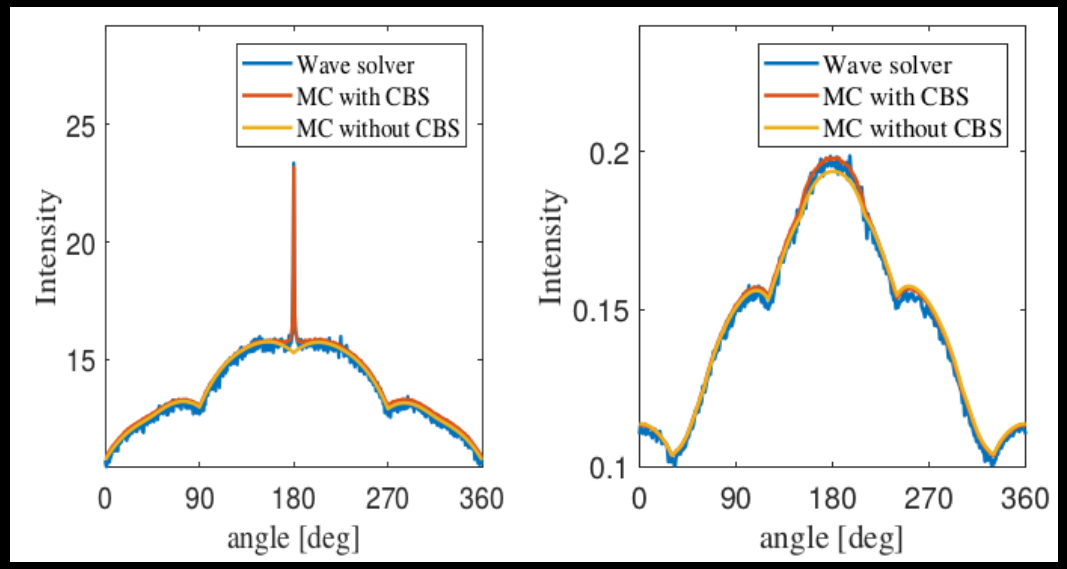


speckle: noise-like pattern

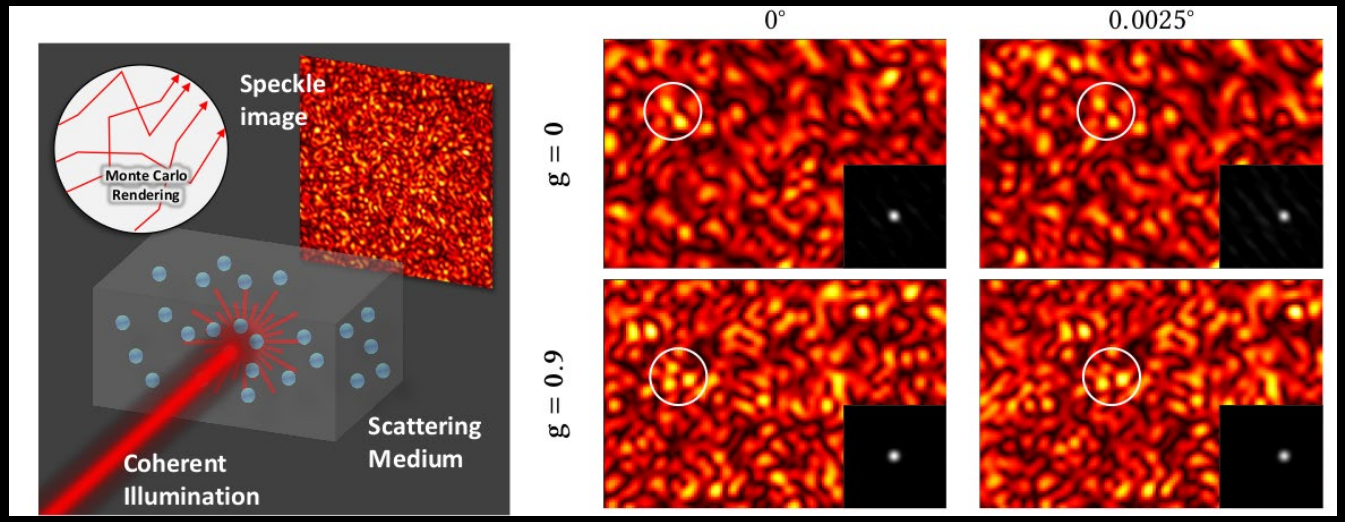
what real laser images look like



what real laser videos look like



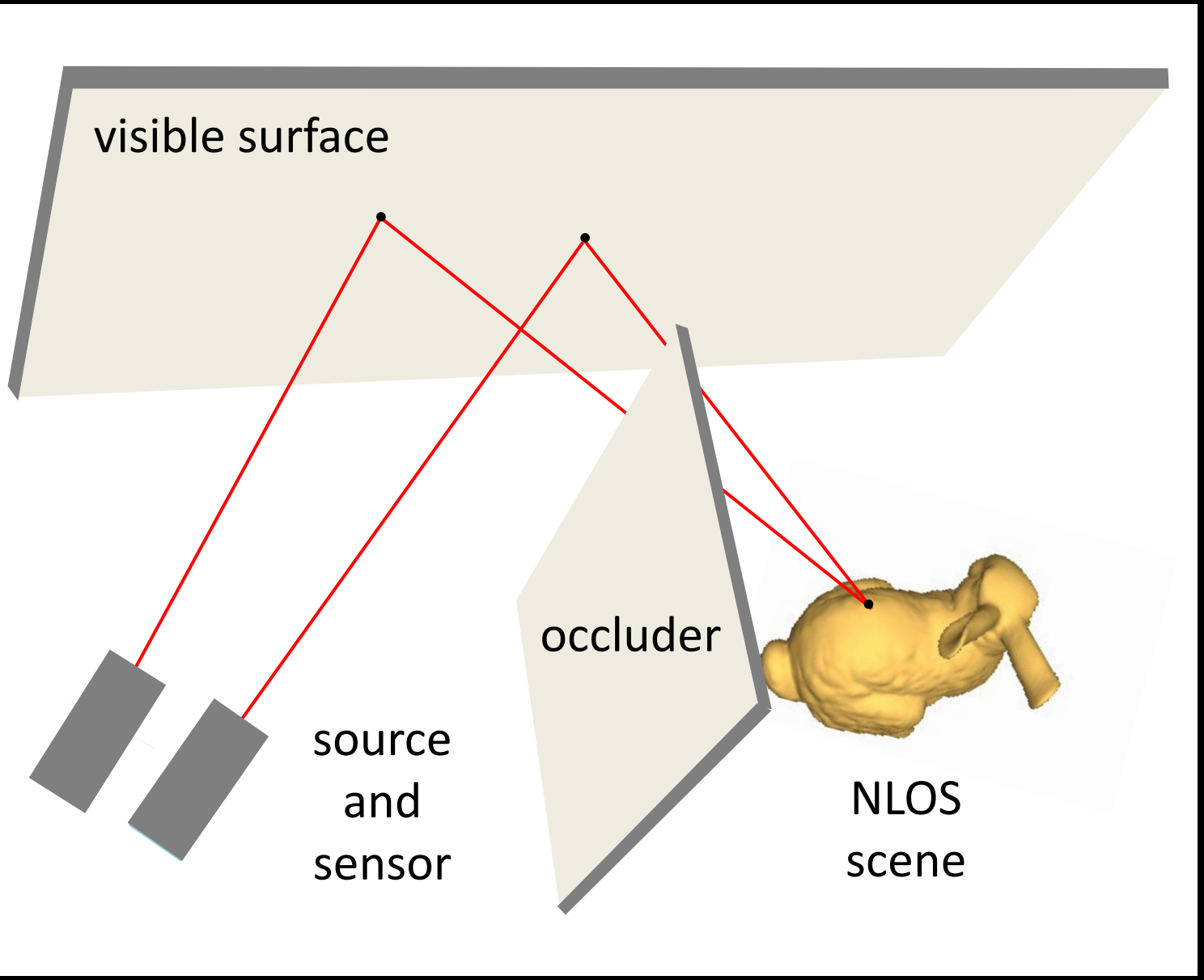

match wave equation solvers, **$10^5$x faster**

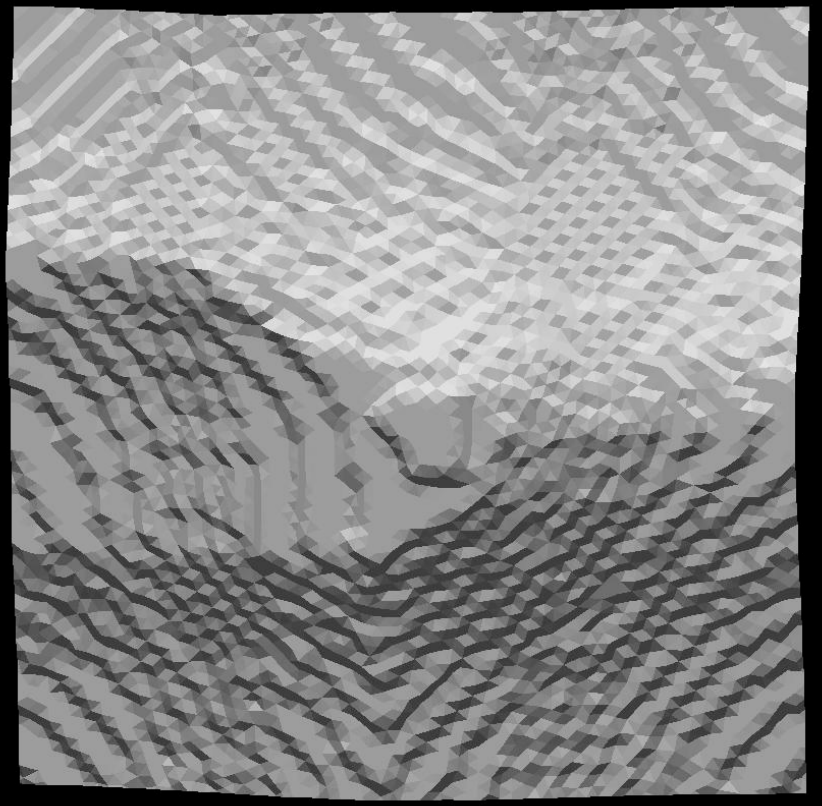



reproduce physical effects like memory effect

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

# Differentiable rendering



reconstruction evolution

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

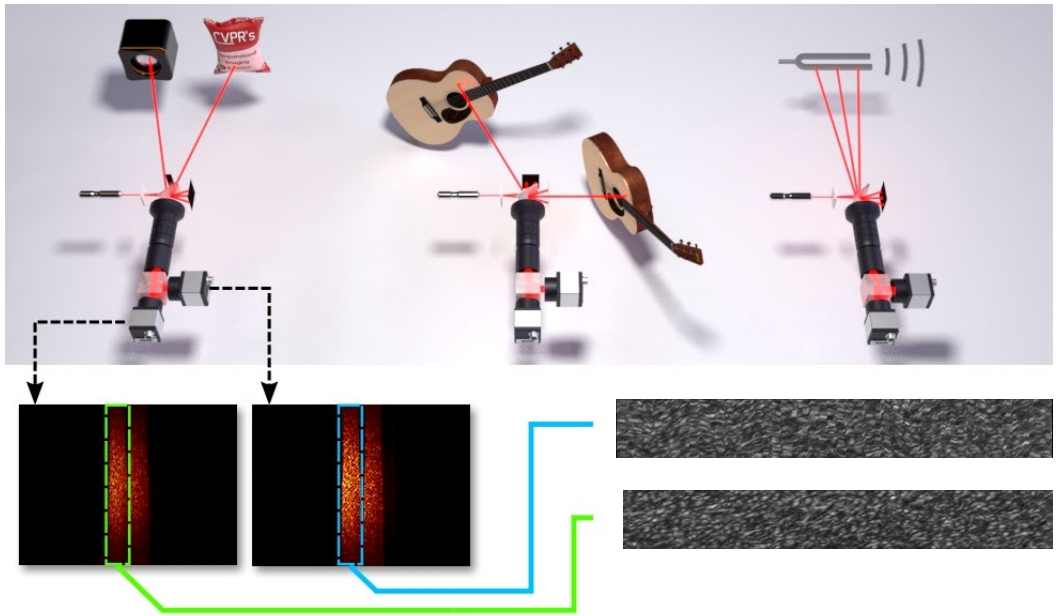

# TA: Dorian Chan

CSD PhD Student: Advised by Matthew O'Toole

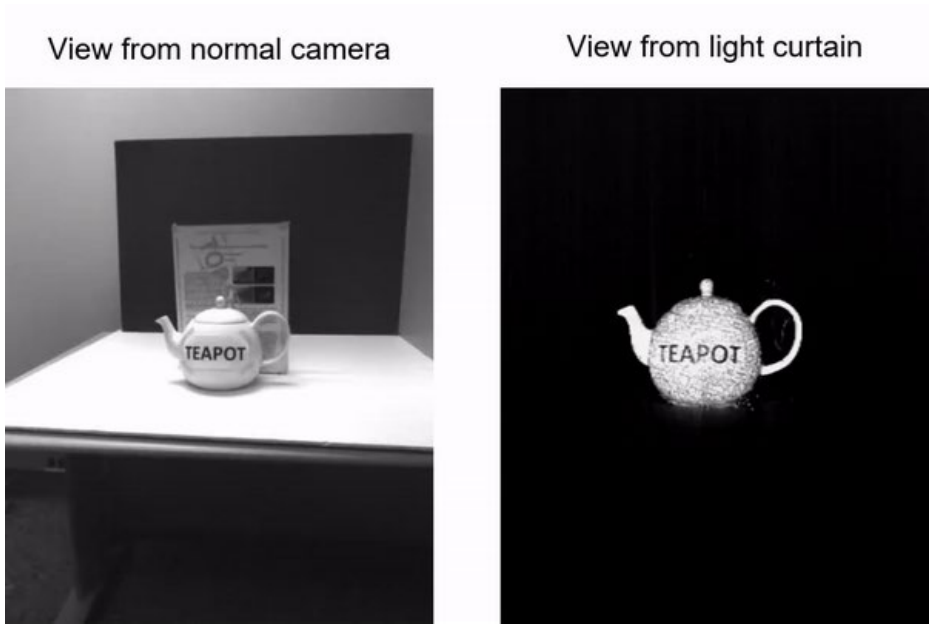
Current focus: wave optics for computational imaging

Contact me: dychan@andrew.cmu.edu

## Optical vibration sensing




## 3D Flash



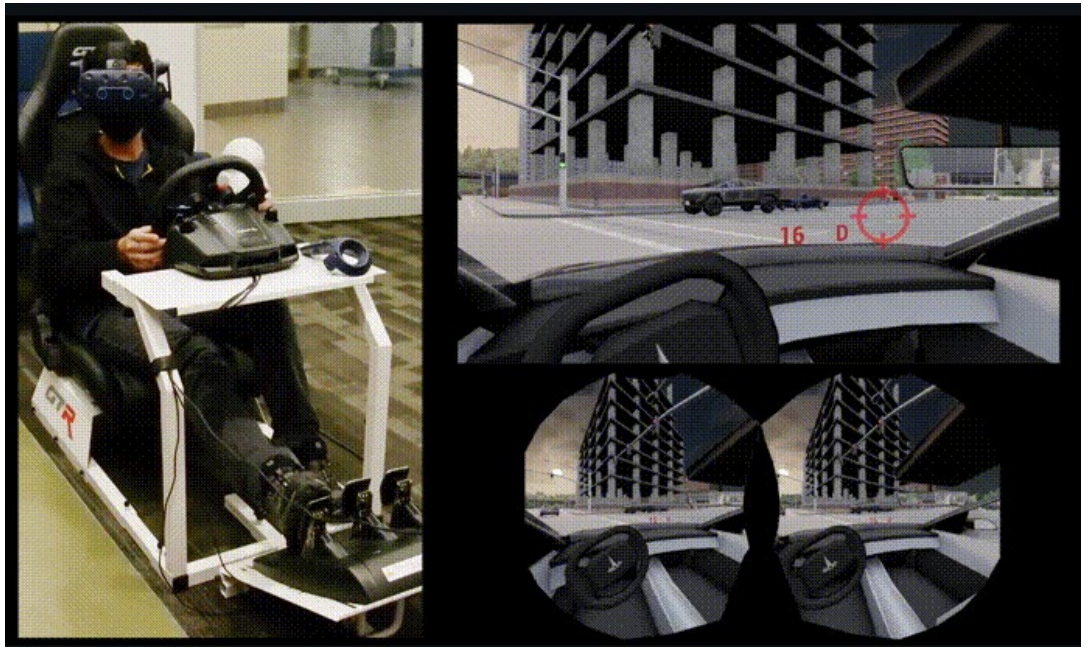
# TA: Gustavo Silvera

HRI @ HARP Lab
Advised by Dr. Henny Admoni

Personal page: https://www.andrew.cmu.edu/user/gsilvera/

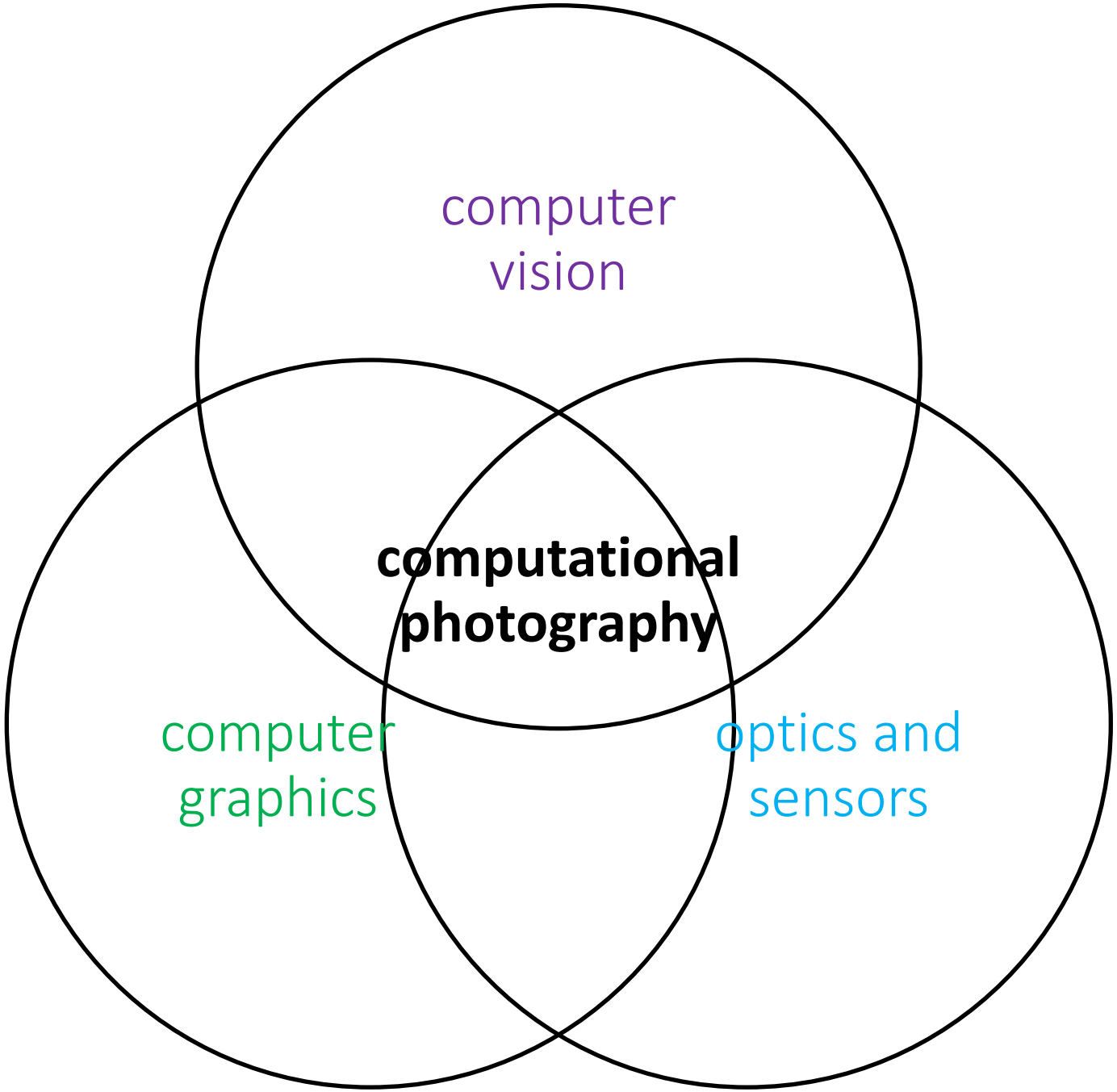
General Interests:

- Improving vehicle autonomy with eye gaze
- Human-in-the-loop driving assistance
- Photorealistic VR driving simulation



gsilvera@andrew.cmu.edu

# What is computational photography?




[Slide credit: Kris Kitani]

# Analog photography

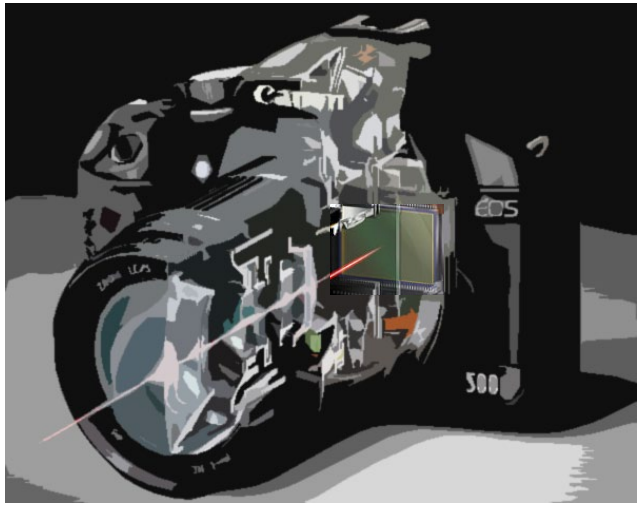

optics to focus light on an image plane

film to capture focused light (chemical process)

dark room for limited post-processing (chemical process)

# Digital photography


optics to focus light on an image plane

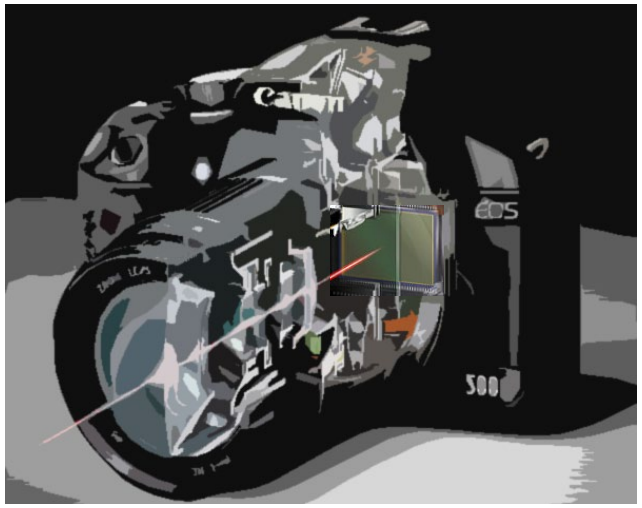



digital sensor to capture focused light (electrical process)


on-board processor for post-processing (digital process)

# Computational photography


optics to focus light on an image plane



digital sensor to capture focused light (electrical process)


arbitrary computation between sensor and image

# Overcome limitations of digital photography

## Image enhancement and photographic look

camera output

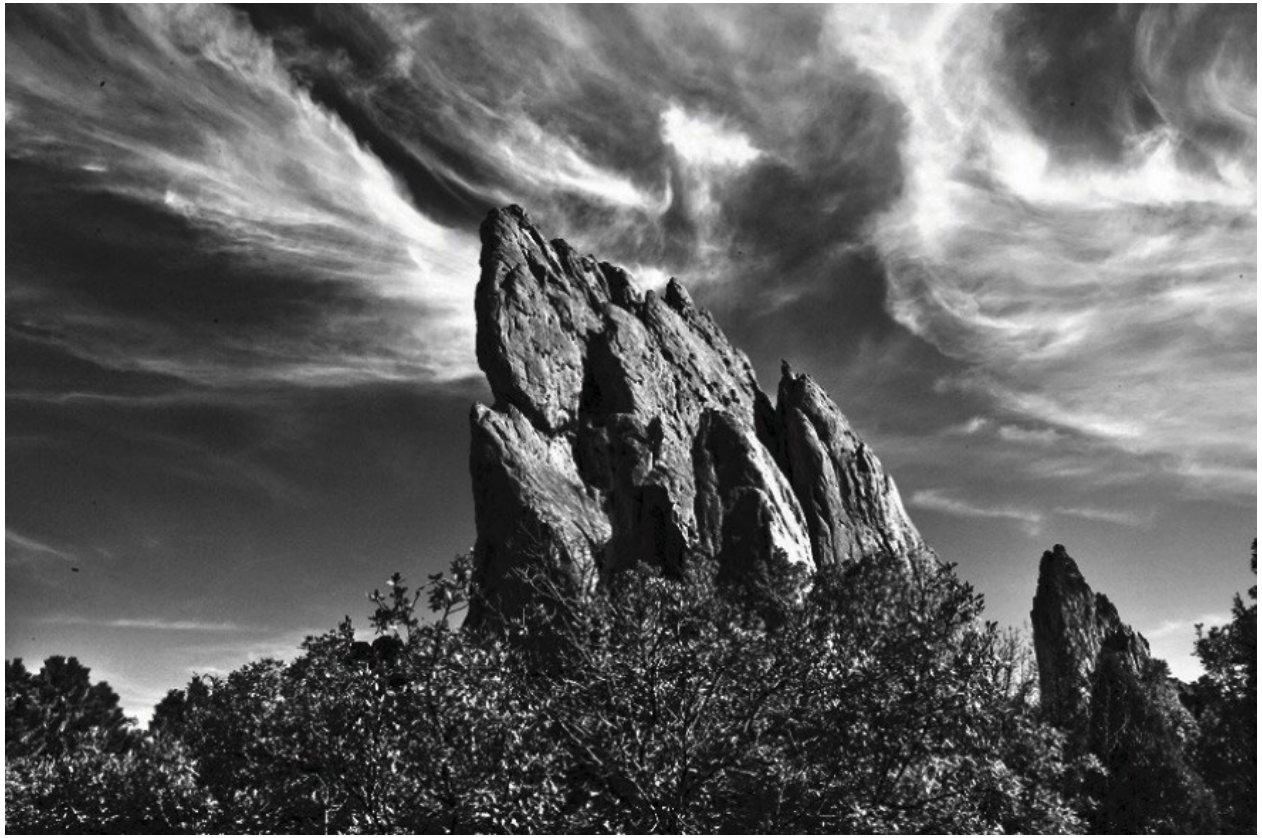
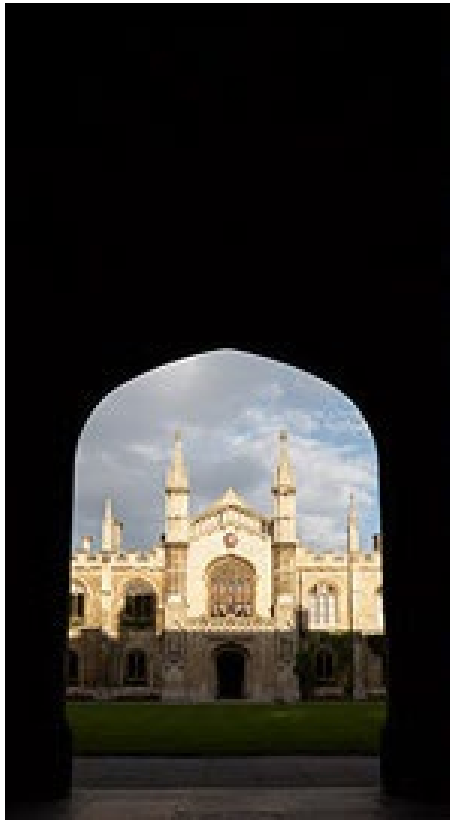


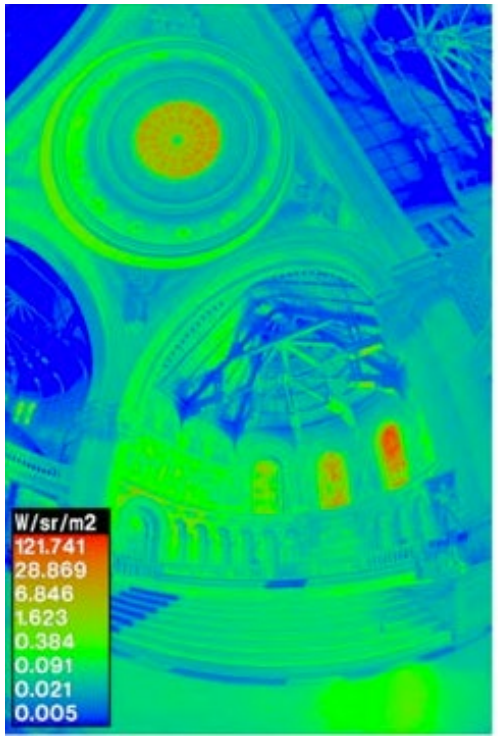
image after stylistic tonemapping

[Bae et al., SIGGRAPH 2006]

# Overcome limitations of digital photography

## High dynamic range (HDR) imaging



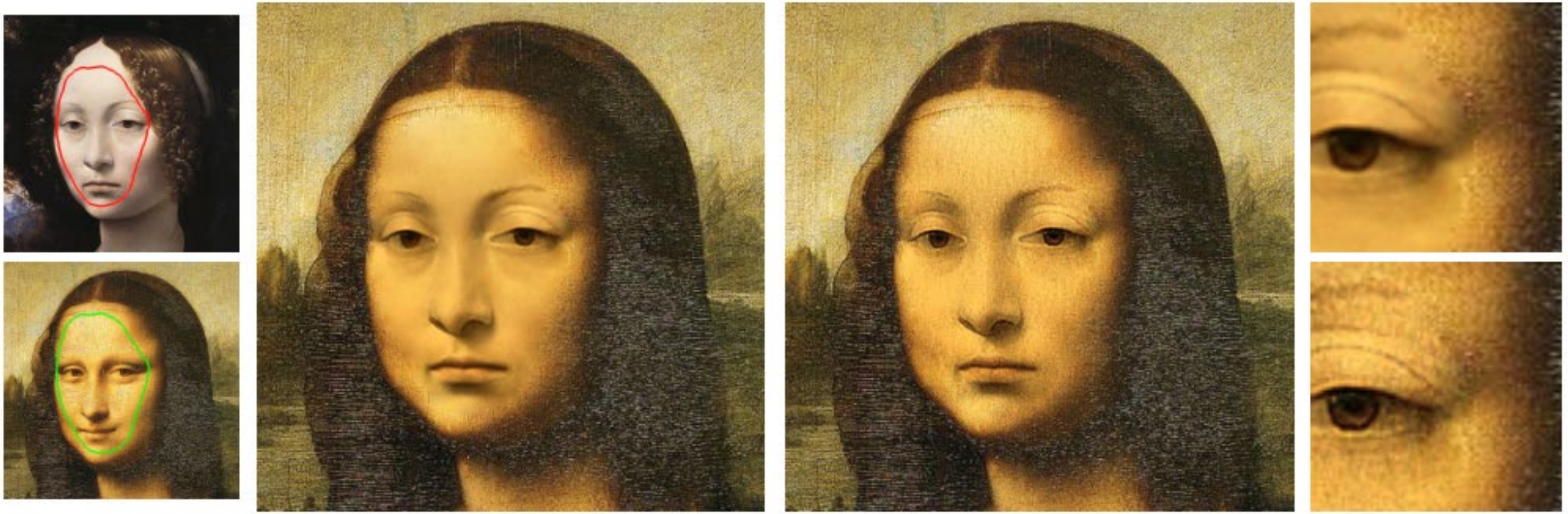



One of your homeworks!

[example from www.dpreview.com] [Debevec and Malik, SIGGRAPH 1997]

# Create realistic new imagery

## Image blending and harmonization



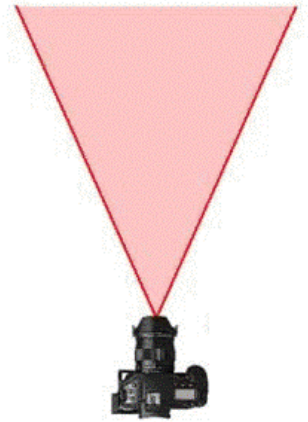
One of your homeworks!

[Sunkavalli et al., SIGGRAPH 2010]

# Post-capture image compositing

## Computational zoom

images captured at three zoom settings

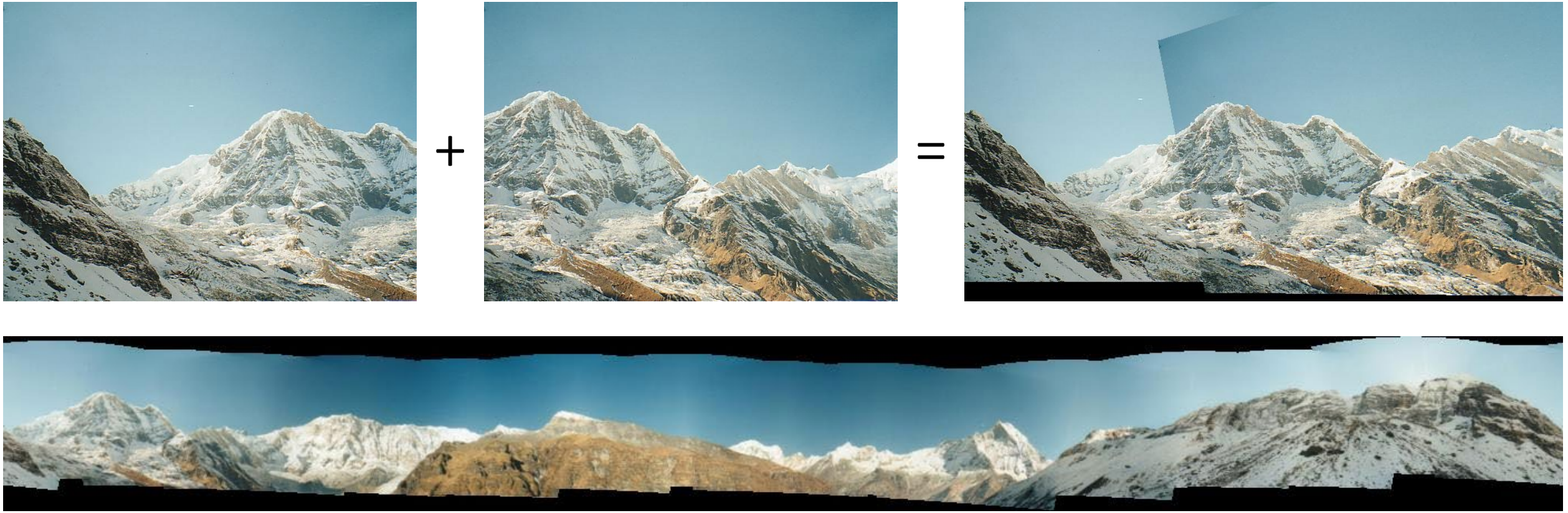


post-capture synthesis of new zoom views

[Badki et al., SIGGRAPH 2017]

# Process image collections

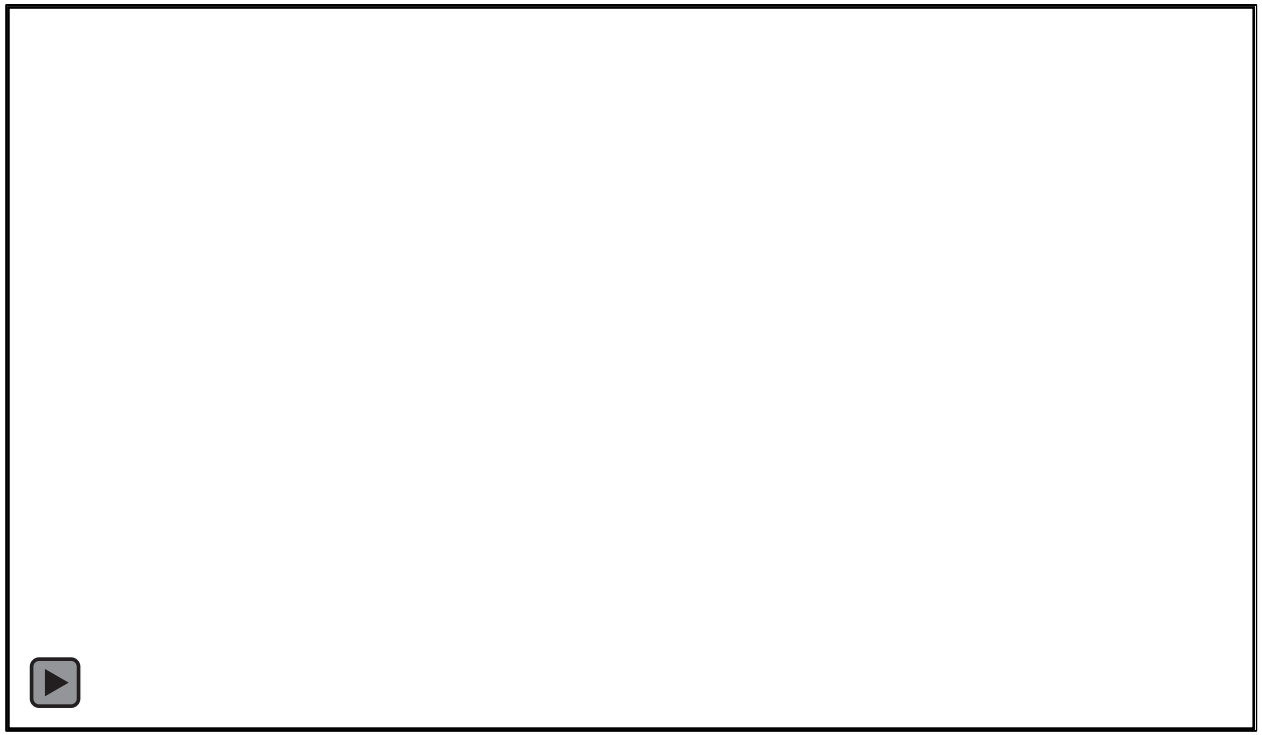
Auto-stitching images into panoramas



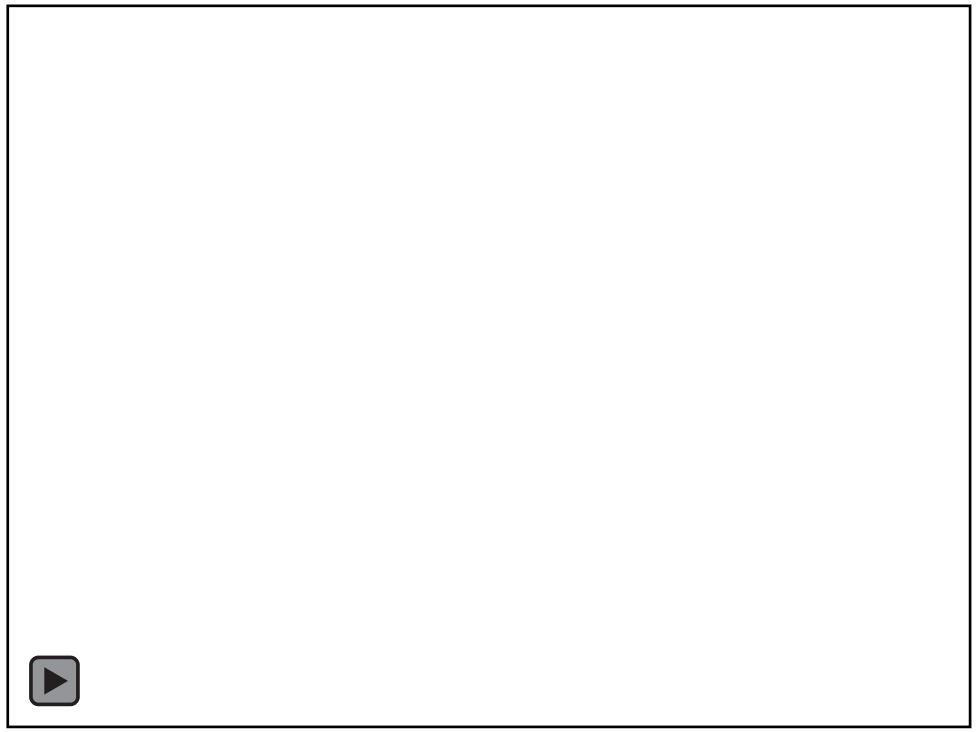
[Brown and Lowe, IJCV 2007]

# Process (very) large image collections

Using the Internet as your camera



reconstructing cities from Internet photos

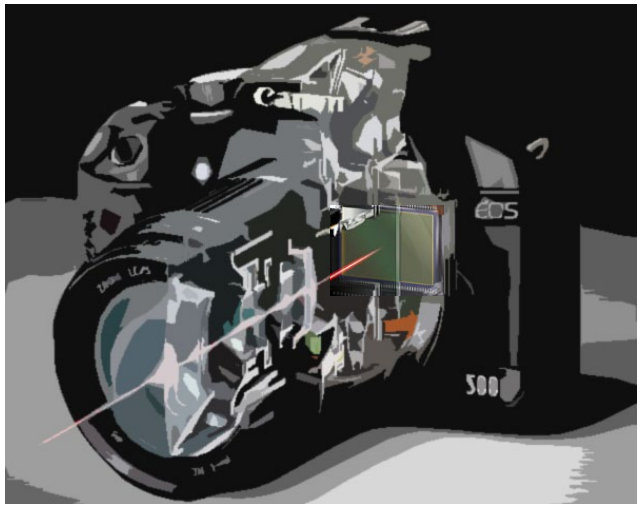


time-lapse from Internet photos

[Agarwal et al., ICCV 2009] [Martin-Brualla et al., SIGGRAPH 2015]

# Computational photography


optics to focus light on an image plane



digital sensor to capture focused light (electrical process)


arbitrary computation between sensor and image

# Computational photography


generalized optics
between scene and sensor

digital sensor to capture focused
light (electrical process)

arbitrary computation
between sensor and image

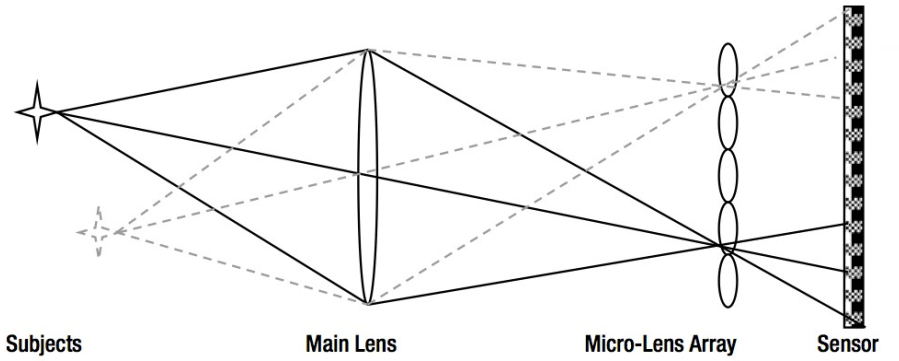
*Sometimes people discriminate between *computational photography* and *computational imaging*. We use them interchangeably.

# Capture more than 2D images

Lightfield cameras for plenoptic imaging

post-capture refocusing

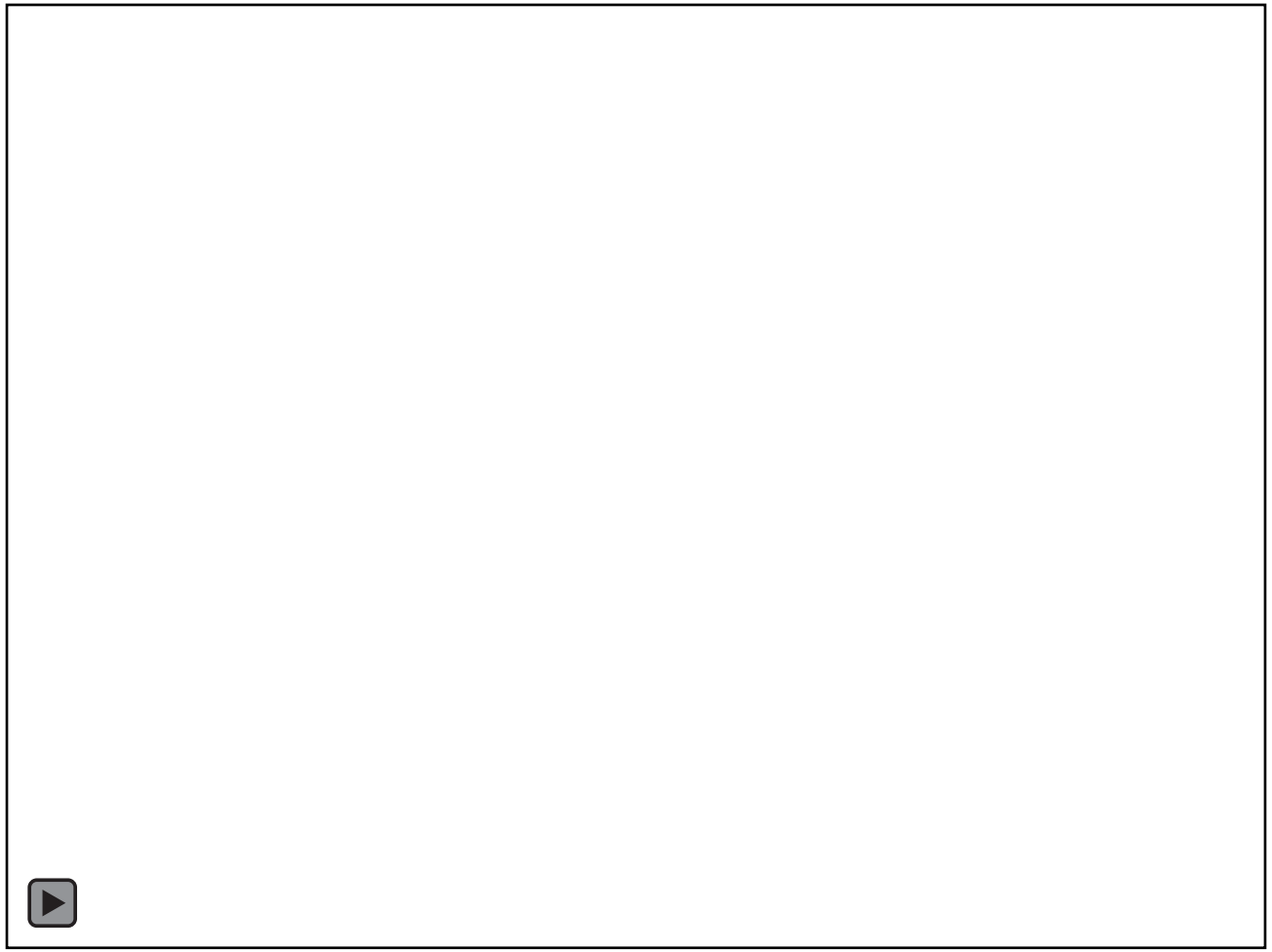
One of your homeworks!




[Ng et al., SIGGRAPH 2005] [Lytro Inc.]

# Capture more than 2D images

Lightfield cameras for plenoptic imaging

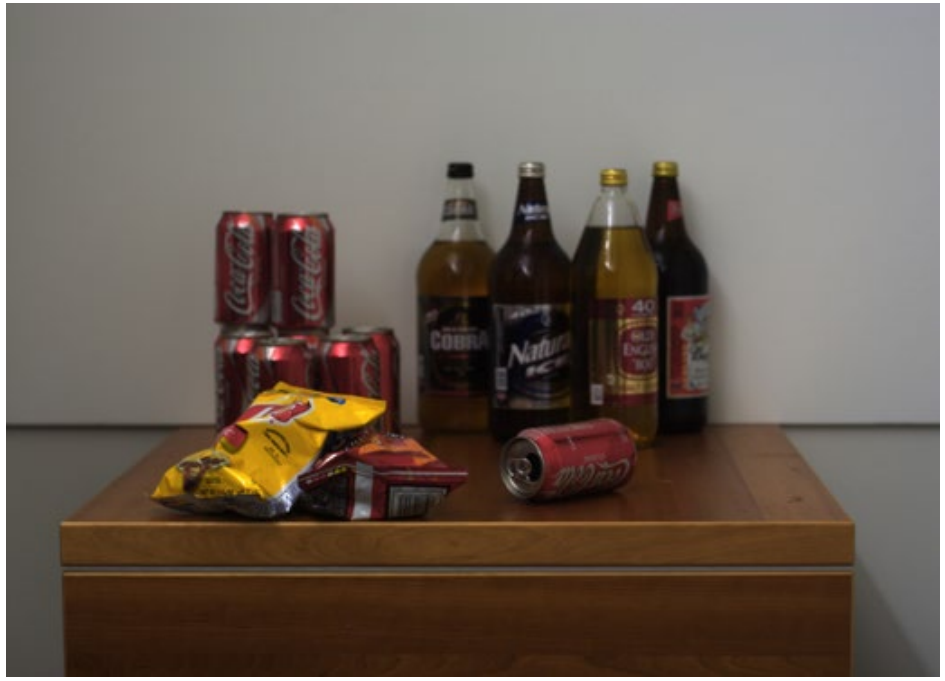


[Ng et al., SIGGRAPH 2005] [Lytro Inc.]

# Measure 3D from a single 2D image

Coded aperture for single-image depth and refocusing


conventional vs coded lens



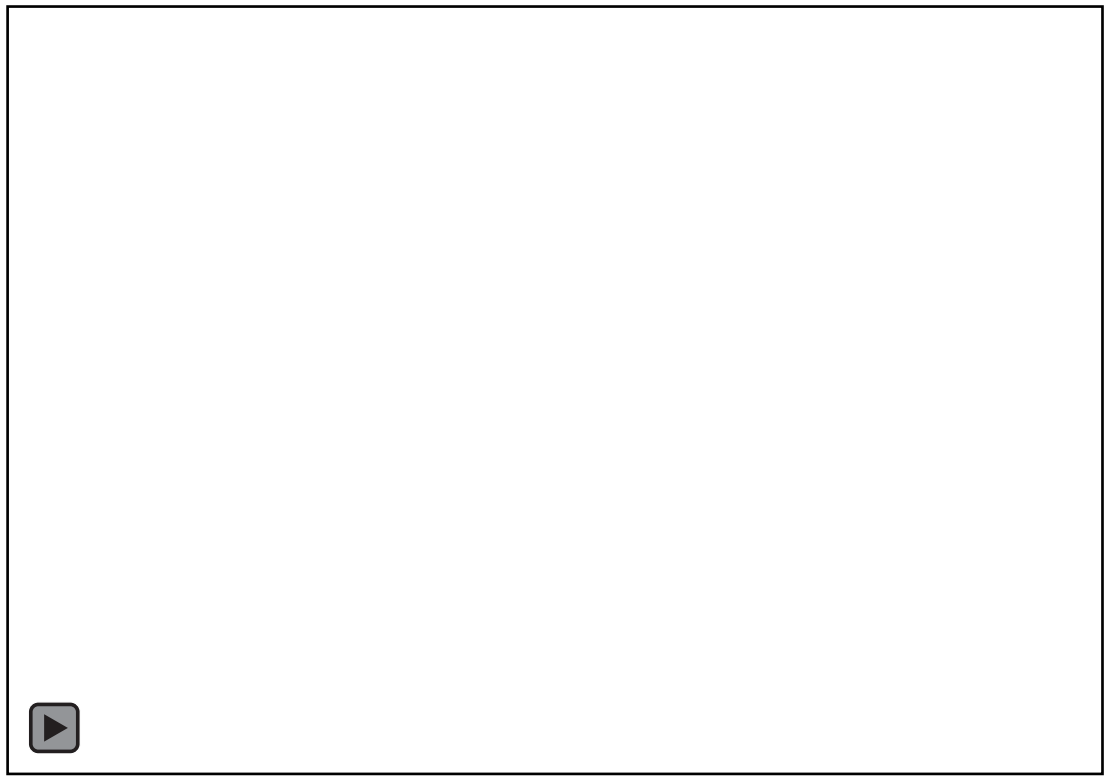
input image

inferred depth

[Levin et al., SIGGRAPH 2007]

# Measure 3D from a single 2D image

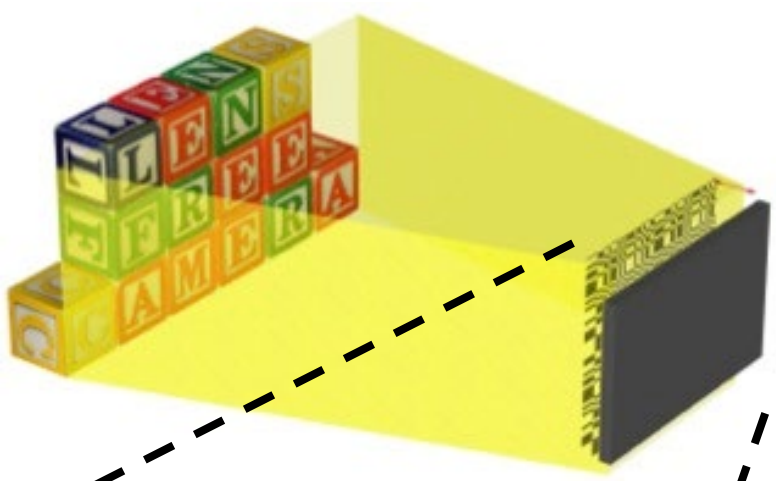
Coded aperture for single-image depth and refocusing

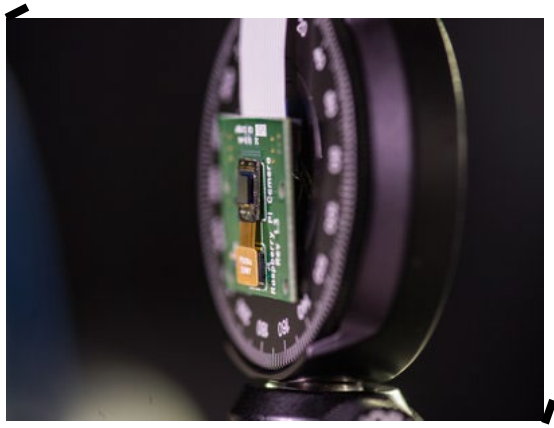



[Levin et al., SIGGRAPH 2007]

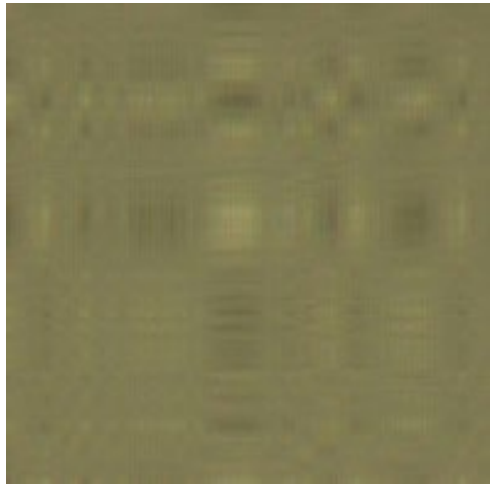
# Remove lenses altogether

FlatCam: replacing lenses with masks



prototype



sensor measurements

reconstructed image

[Asif et al. 2015]

# Computational photography

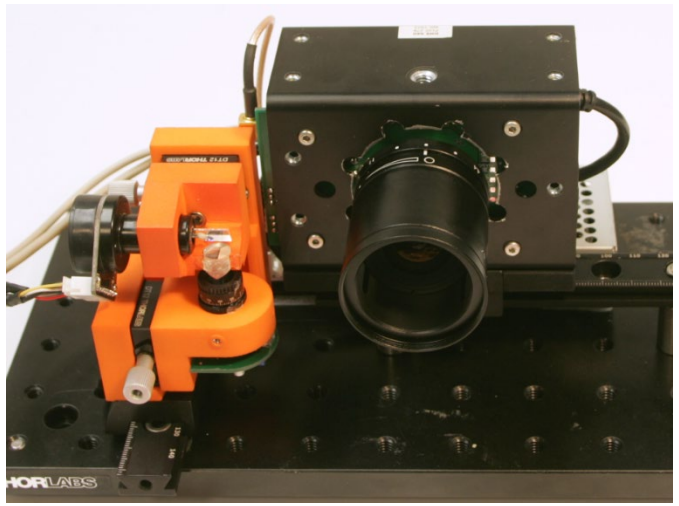

generalized optics
between scene and sensor

digital sensor to capture focused
light (electrical process)

arbitrary computation
between sensor and image

# Computational photography


generalized optics
between scene and sensor

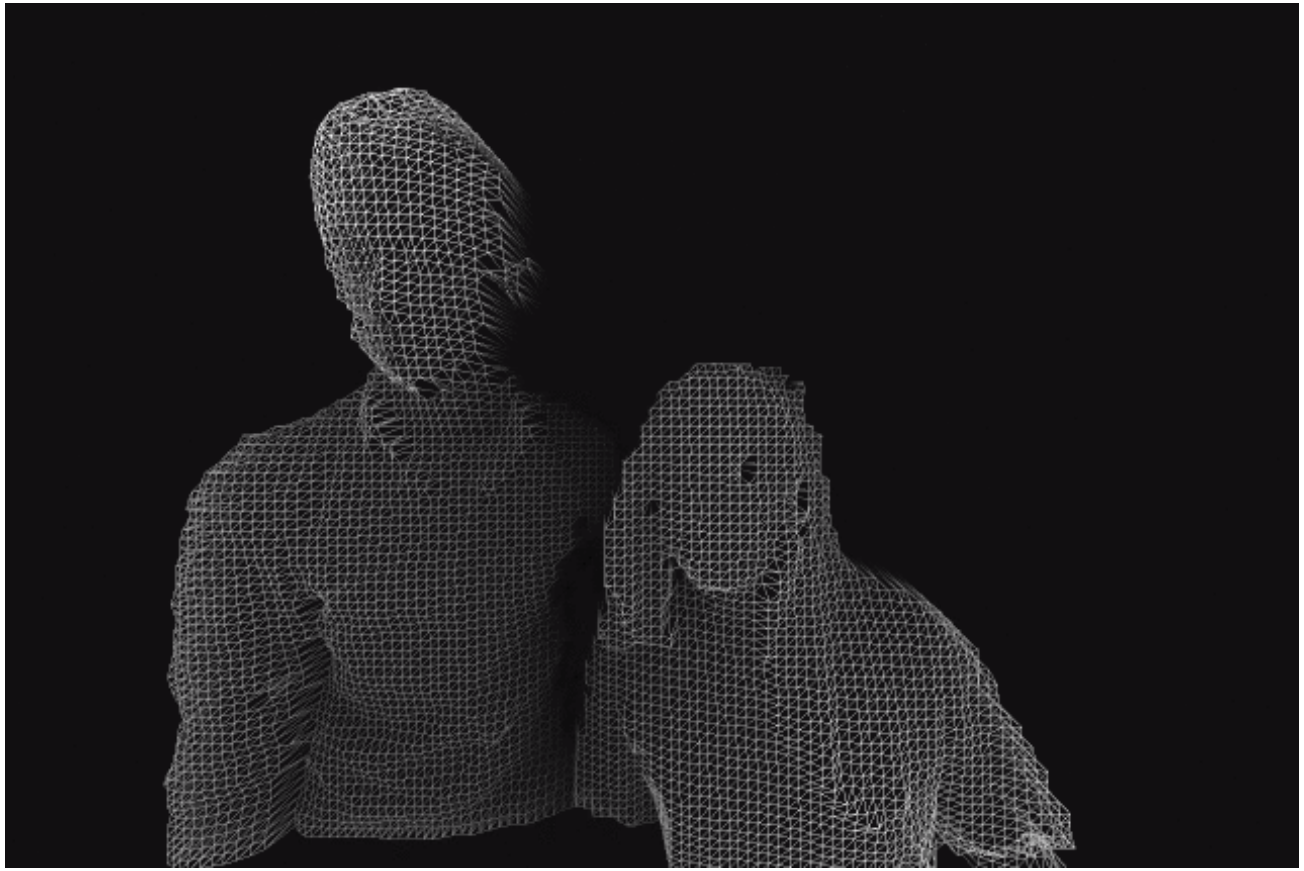


unconventional sensing
and illumination

arbitrary computation
between sensor and image

# Measure depth

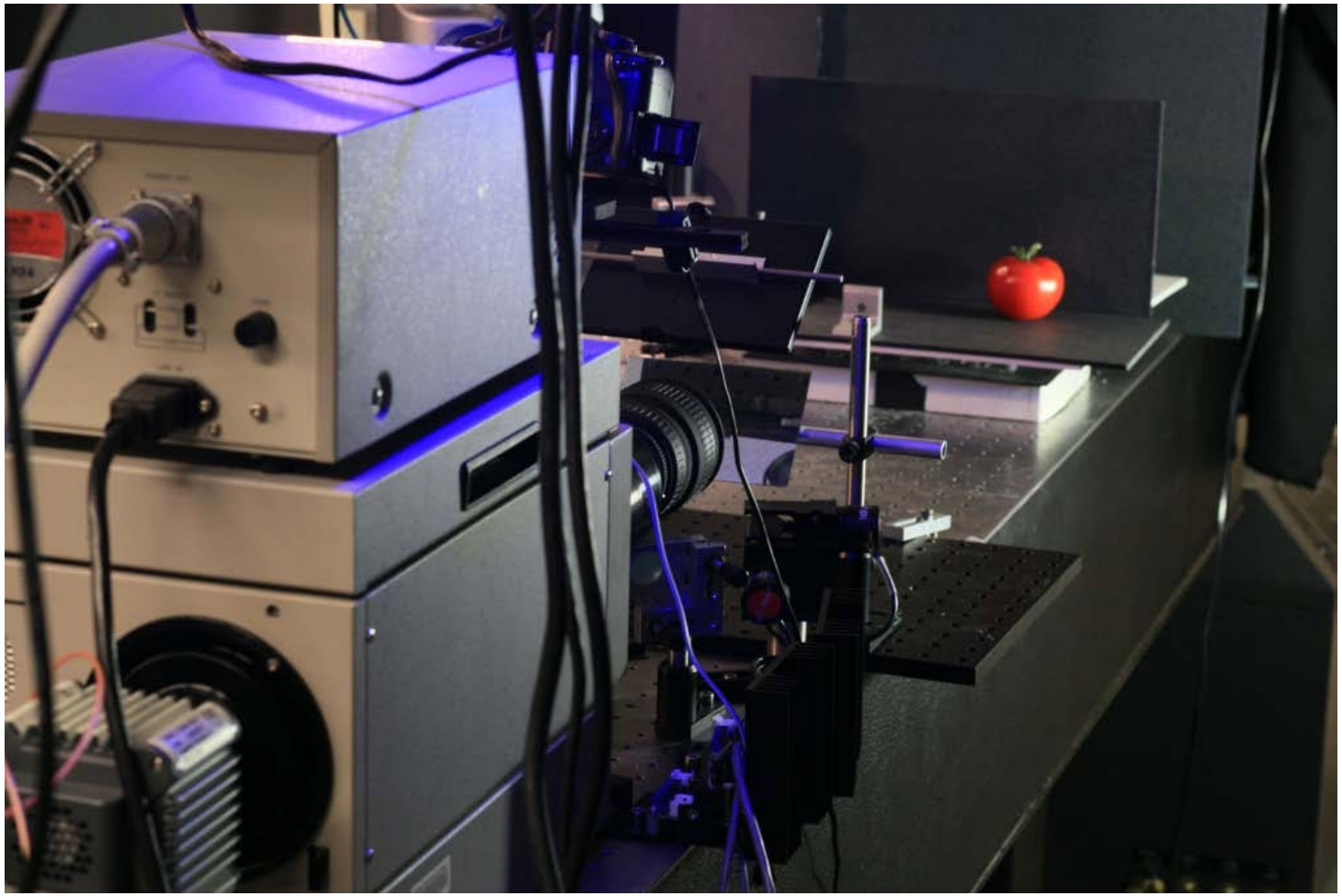
Time-of-flight sensors for real-time depth sensing



[Microsoft Inc.]

# Measure light in flight

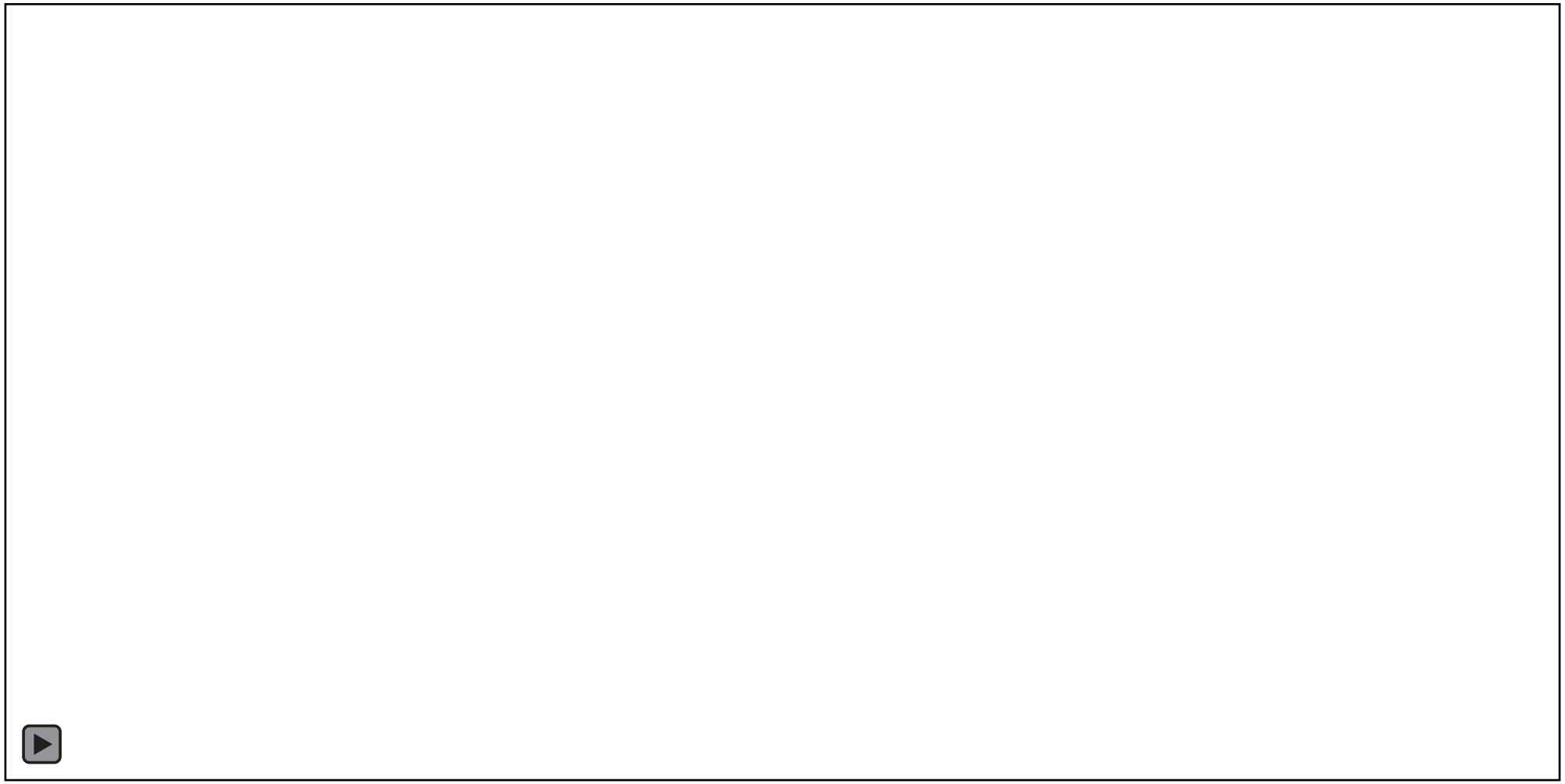
Streak camera for femtophotography



[Velten et al., SIGGRAPH 2013]

# Measure light in flight

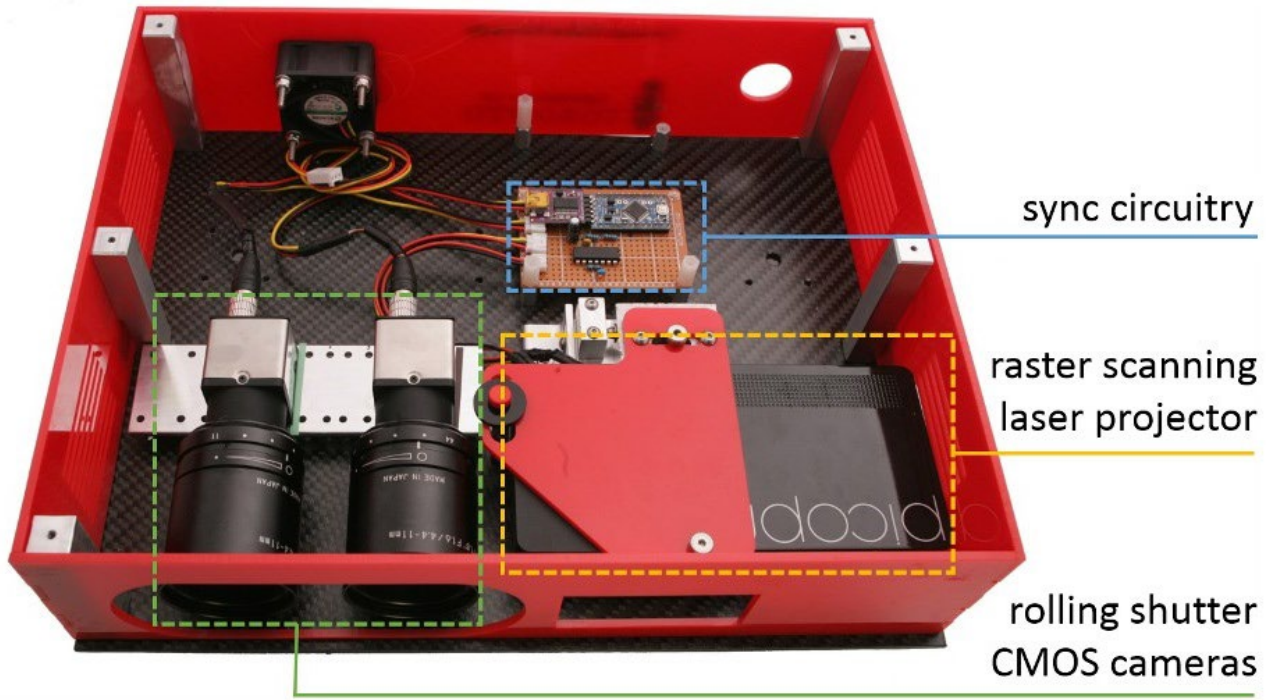
Streak camera for femtophotography



[Velten et al., SIGGRAPH 2013]

# Measure photons selectively

Structured light for epipolar imaging

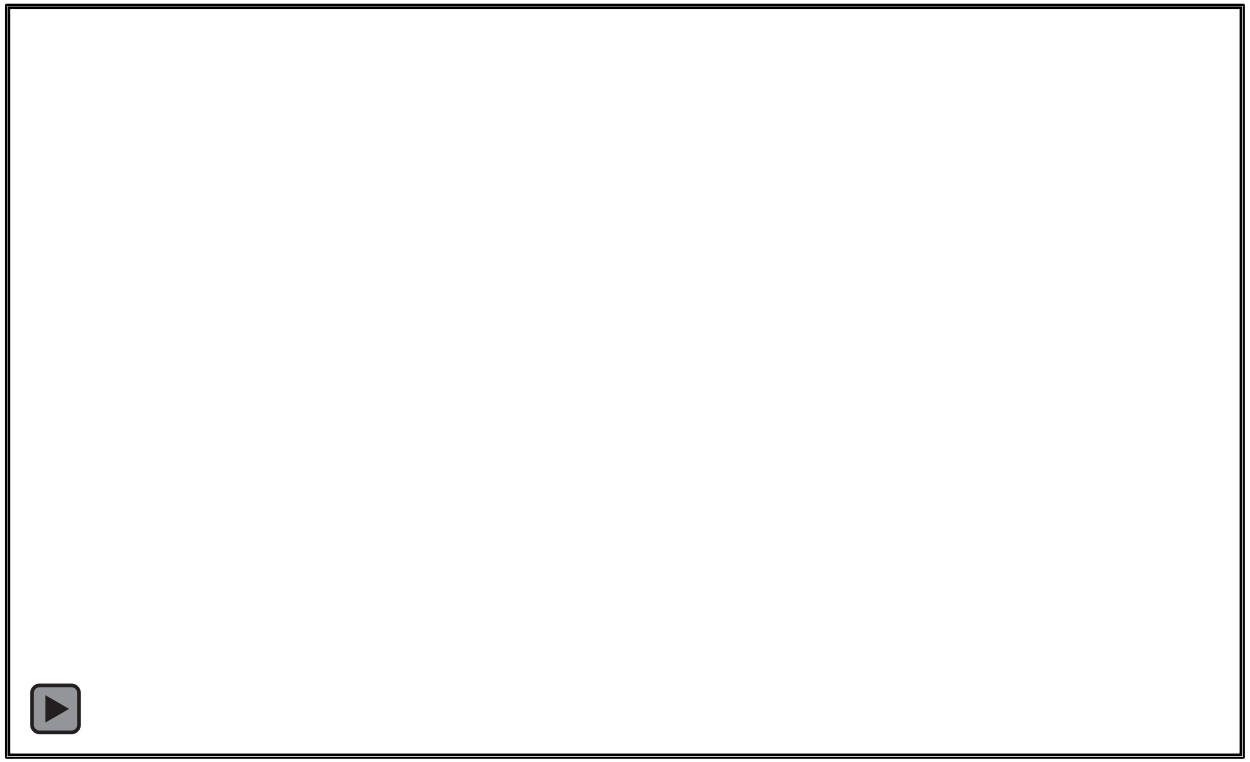



[O'Toole et al., SIGGRAPH 2015]

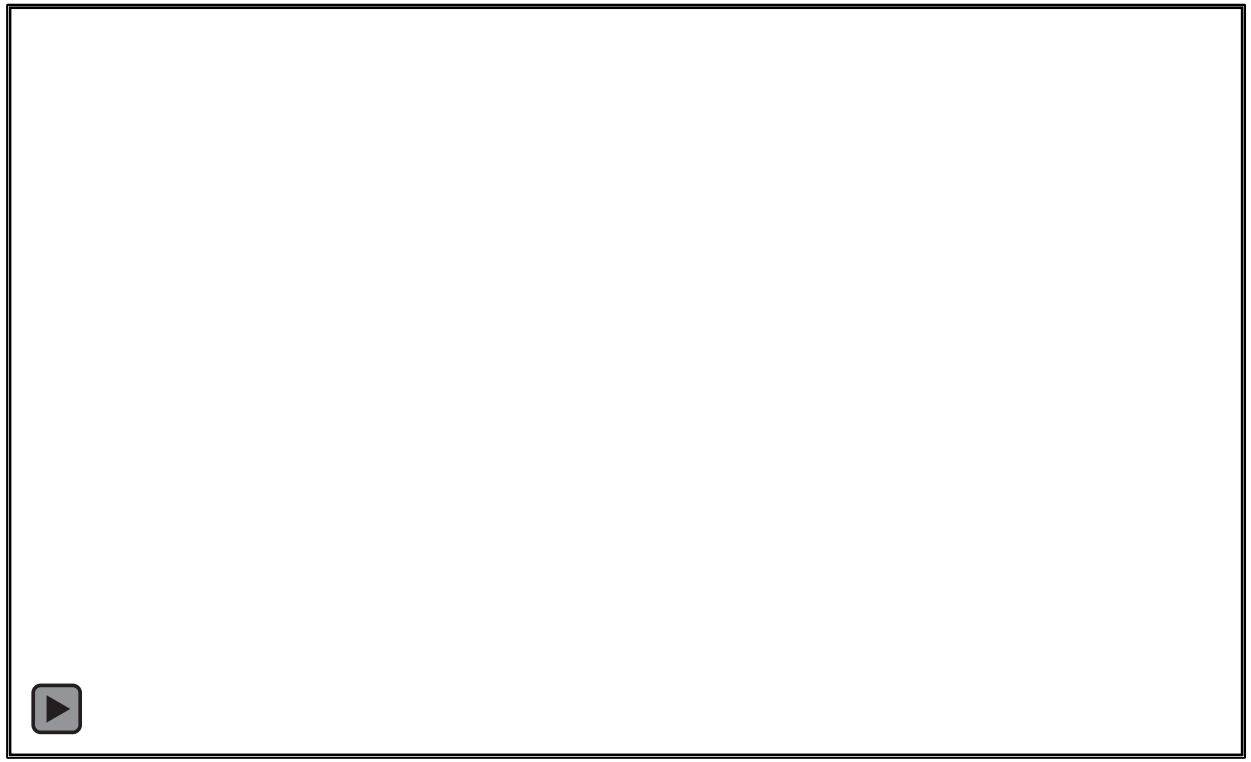
# Measure photons selectively

Structured light for epipolar imaging

One of your homeworks!



direct photons

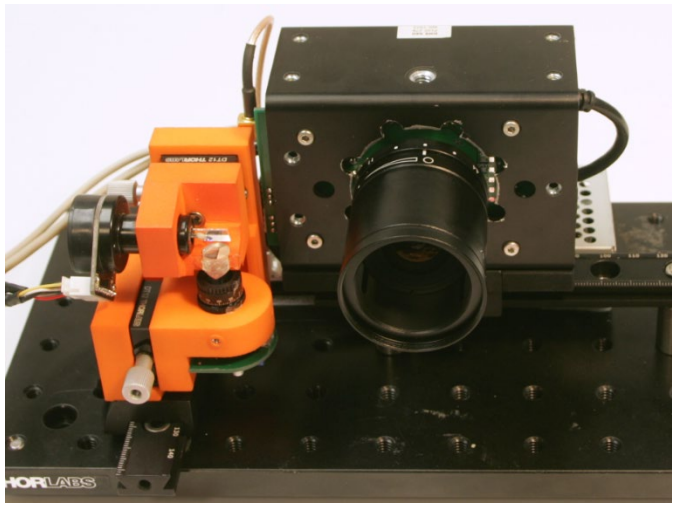


indirect photons

[O'Toole et al., SIGGRAPH 2015]

# Computational photography


generalized optics
between scene and sensor

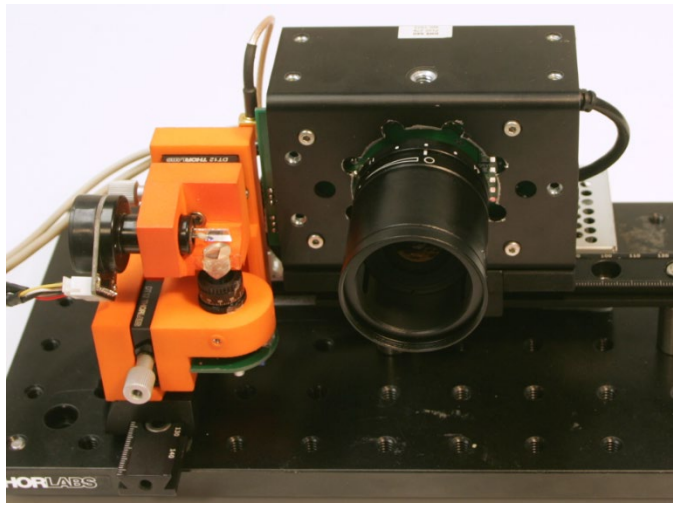


unconventional sensing
and illumination

arbitrary computation
between sensor and image

# Computational photography


generalized optics
between scene and sensor



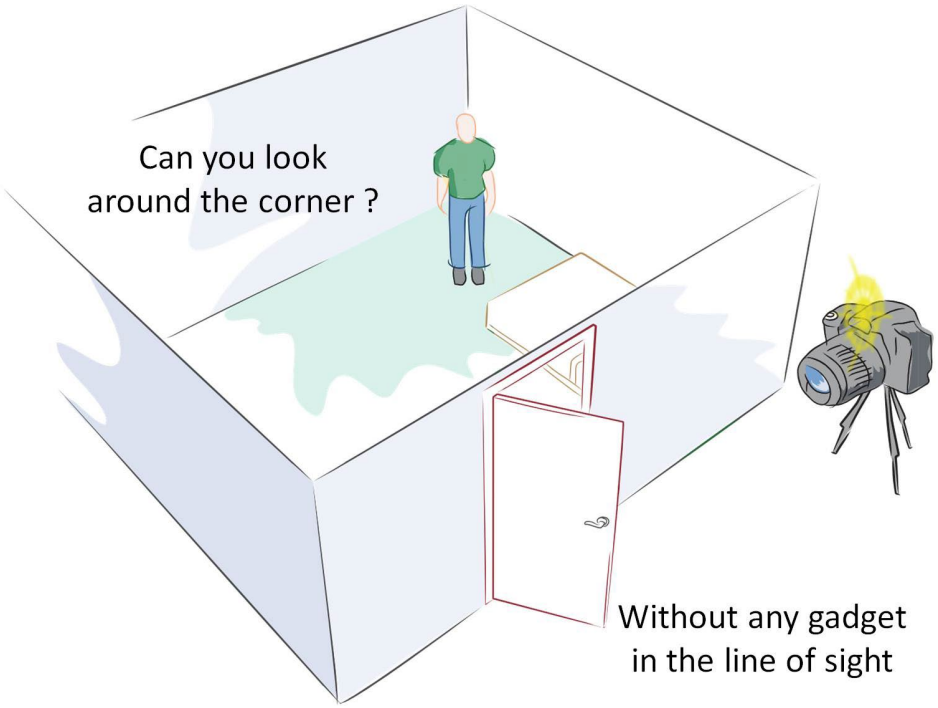
unconventional sensing
and illumination

arbitrary computation
between sensor and image

joint design of optics, illumination, sensors, and computation

# Putting it all together

## Looking around corners

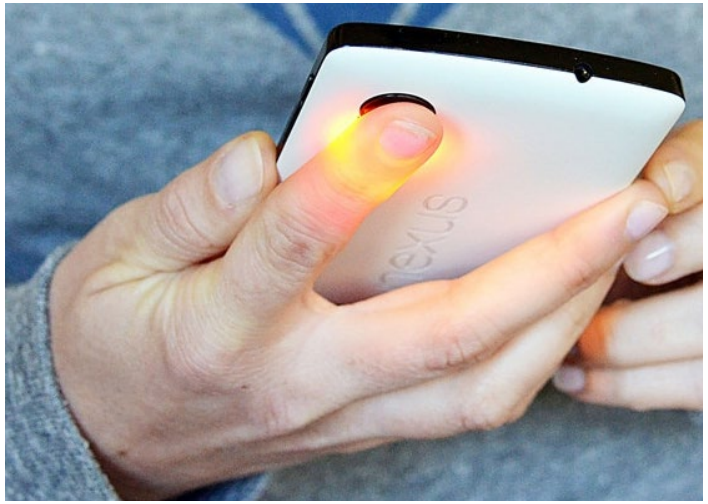



[MIT Media Lab, DARPA REVEAL]

# Putting it all together

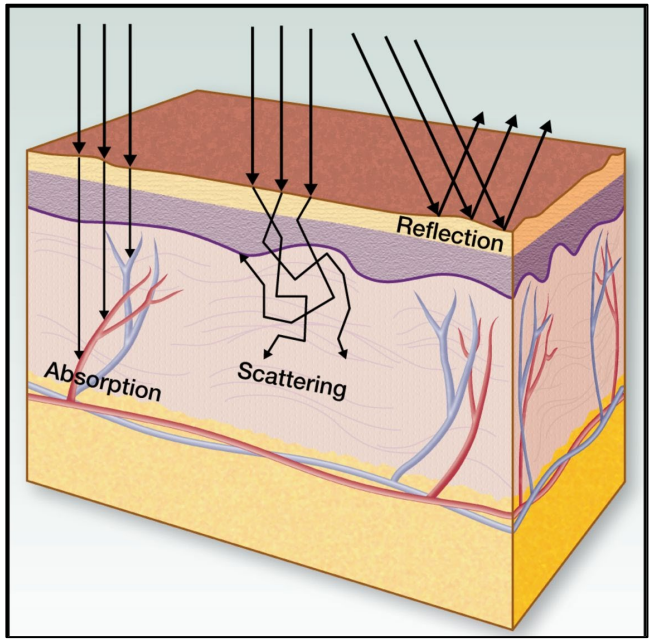
## Looking through tissue

**Opportunity**



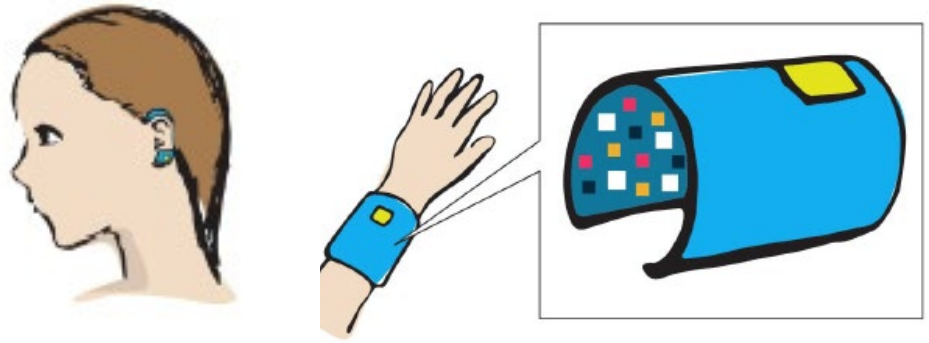
+ Light travels deep inside the body
+ It is non-ionizing (400-1100nm)
+ Cheap to produce and control

**Scattering Barrier**

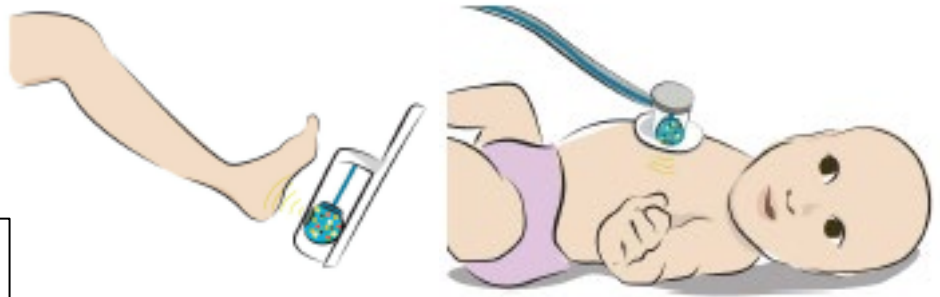



− Most pass-through photons are scattered
− Avg 10 scattering events per mm
− By 50mm, avg 500 scattering events !
− Large-scale inverse problem with low SNR

## Practical imaging up to 50mm



Wearables (1-10mm)

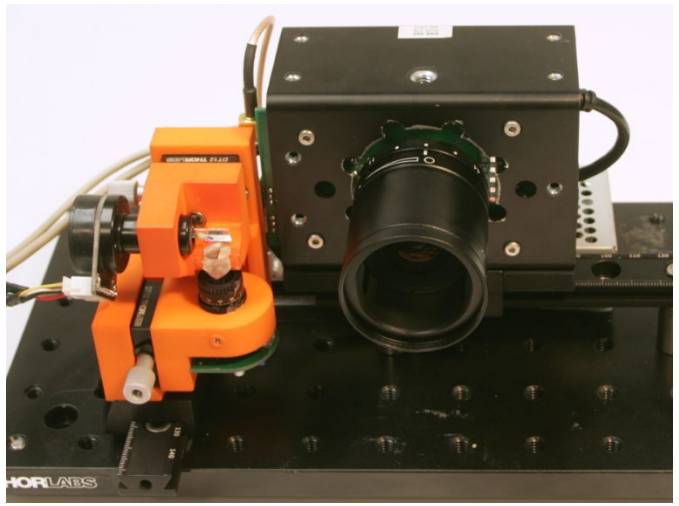


Non-invasive point of care devices (10-50mm)

[NSF Expedition]

# Computational photography


generalized optics
between scene and sensor



unconventional sensing
and illumination

arbitrary computation
between sensor and image

joint design of optics, illumination, sensors, and computation

# Course fast-forward and logistics

# Course fast-forward

Tentative syllabus at:

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

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

# 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 fusion:

- high-dynamic-range imaging
- 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

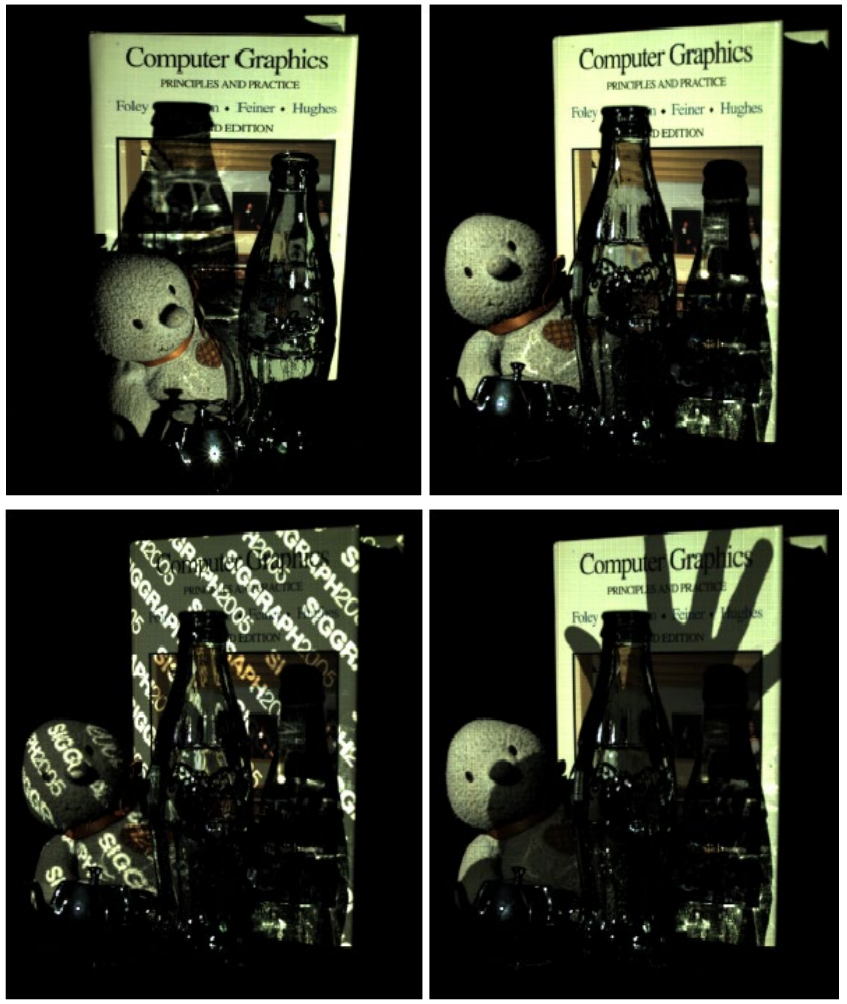
Types of cameras:

- geometric camera models
- lightfield 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]

# Course online platforms

- Course website:

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

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

  https://piazza.com/class/l6v87t7gf9f69a/

- Canvas and Gradescope for homework submissions, grading, and recordings:

  https://canvas.cmu.edu/courses/30775/

- Slack server (see Piazza for access instructions).

# Please take the start-of-semester survey!

- Posted on Piazza as well:

  https://docs.google.com/forms/d/e/1FAIpQLSeUx7mw3twz8s_VySxJfx4wBAttllgmG26u2LH_ZOEBhW_9Ow/viewform

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

# 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 15-462.
- An image processing course at the level of 18-793.

# 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.
- Laplacian pyramid.
- Poisson blending.
- Homogeneous coordinates.
- Homography.
- RANSAC.
- Epipolar geometry.
- XYZ space.
- Multi-view stereo.
- Radiance and radiometry.
- Lambertian, diffuse, and specular reflectance.
- n-dot-l lighting.
- Thin lens, prime lens, and zoom lens.
- Demosaicing.
- Refraction and diffraction.

# Evaluation

- Six two-week homework assignments (75%):
  - Programming in **Python** and capturing your own photographs.
  - Generous extra credit components to help you catch up on missed credit.
  - Released and due every second Friday (see course website for schedule).
  - Five late days, you can use them as you want. Penalty 10%/day after that.
  - **Submission deadlines are enforced strictly.**
- Final project (20%):
  - 15-663, 15-862 require more substantive project.
  - See final project page on course website for detailed logistics (some dates TBD).
  - If your ideas require imaging equipment, talk to us in advance.
  - **No exam, but final project presentations are during the exam period.**
- Class and Piazza participation (5%):
  - Be around for (at least one of) lectures, office hours, and reading groups.
  - Participate in Piazza and Slack discussions.
  - Ask questions.

# 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 if it has video.
  - 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.

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

- Sign up for a camera (distributed in the second week of classes):

https://docs.google.com/spreadsheets/d/1Q1dpYlhBEUupQVw6pOM7fST--JSsEFEWZVE0ipgGx3I/edit#gid=0

# Final project competition

- At the end of the semester, we will ask other computational photography faculty at CMU (Srinivasa Narasimhan, Matthew O'Toole, Aswin Sankaranarayanan, Jun-Yan Zhu) to join the final project presentations and vote on the two best final projects.
- The two winning students will receive a **free DSLR camera kit** (same as the one provided for homework).
- Previous year's projects for inspiration: Fall 2021, Fall 2022.

# Homework assignment competitions

- After each homework assignment, the teaching staff will select one of the submissions that produced the most compelling result in the “capture your own images” part.

- The winning student will receive a **free camera-related gift.** Tentative list:
  - Assignment 1: Thingify pinhole "lens“.
  - Assignment 2: Colorchecker passport.
  - Assignment 3: flash.
  - Assignment 4: Lytro camera.
  - Assignment 5: telecentric lens.
  - Assignment 6: pocket projector.

# Friday reading groups

- Every second Friday, there will be a reading group to go over an advanced topic or paper in detail.
- Typically, reading groups take the form of a review of a group of papers, whiteboard derivations, and free-form discussion.
- **Participation is completely optional.** Reading groups will be recorded.
- Time will be decided by vote in the start-of-semester survey.
- Topics covered last year: Fermat paths, non-line-of-sight imaging, Helmholtz stereopsis, dual photography, optical stochastic gradient descent, NeRF, novel view synthesis.

# Contact information and office hours

- Feel free to email us about administrative questions.
  - Please use [15463] in email title!
- Technical questions should be asked on Piazza or Slack.
  - We won't answer technical questions through email.
  - You can post anonymously on Piazza if you prefer.
- Office hours will be determined by vote in the start-of-semester survey.
  - Office hours will be in person in Smith Hall (EDSH) Rm 236 (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 on Piazza or Slack for additional office hours.
  - Office hours for this week will be announced on Piazza.

# Interested in research?

- Visit the imaging group website:

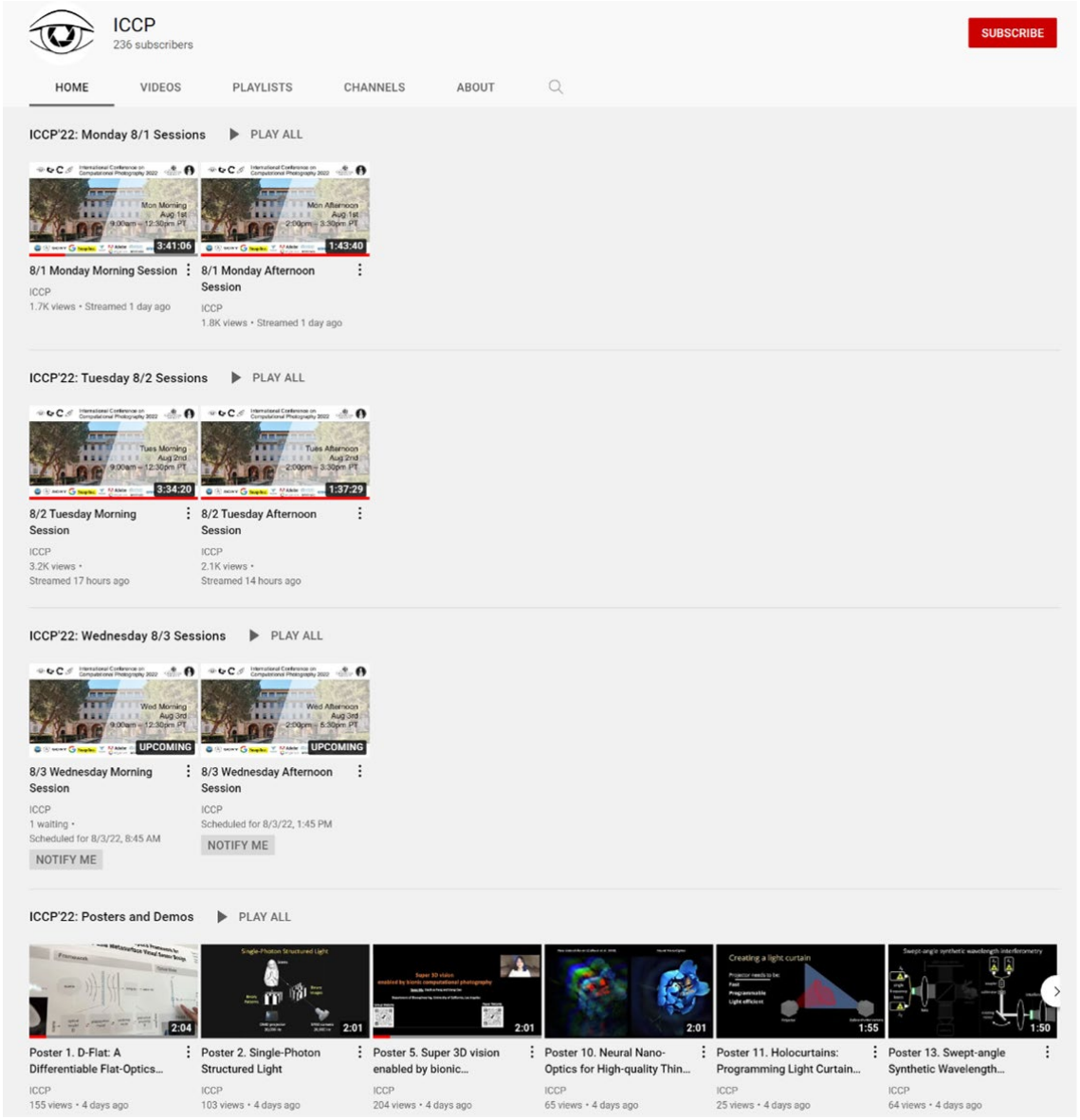
https://imaging.cs.cmu.edu/

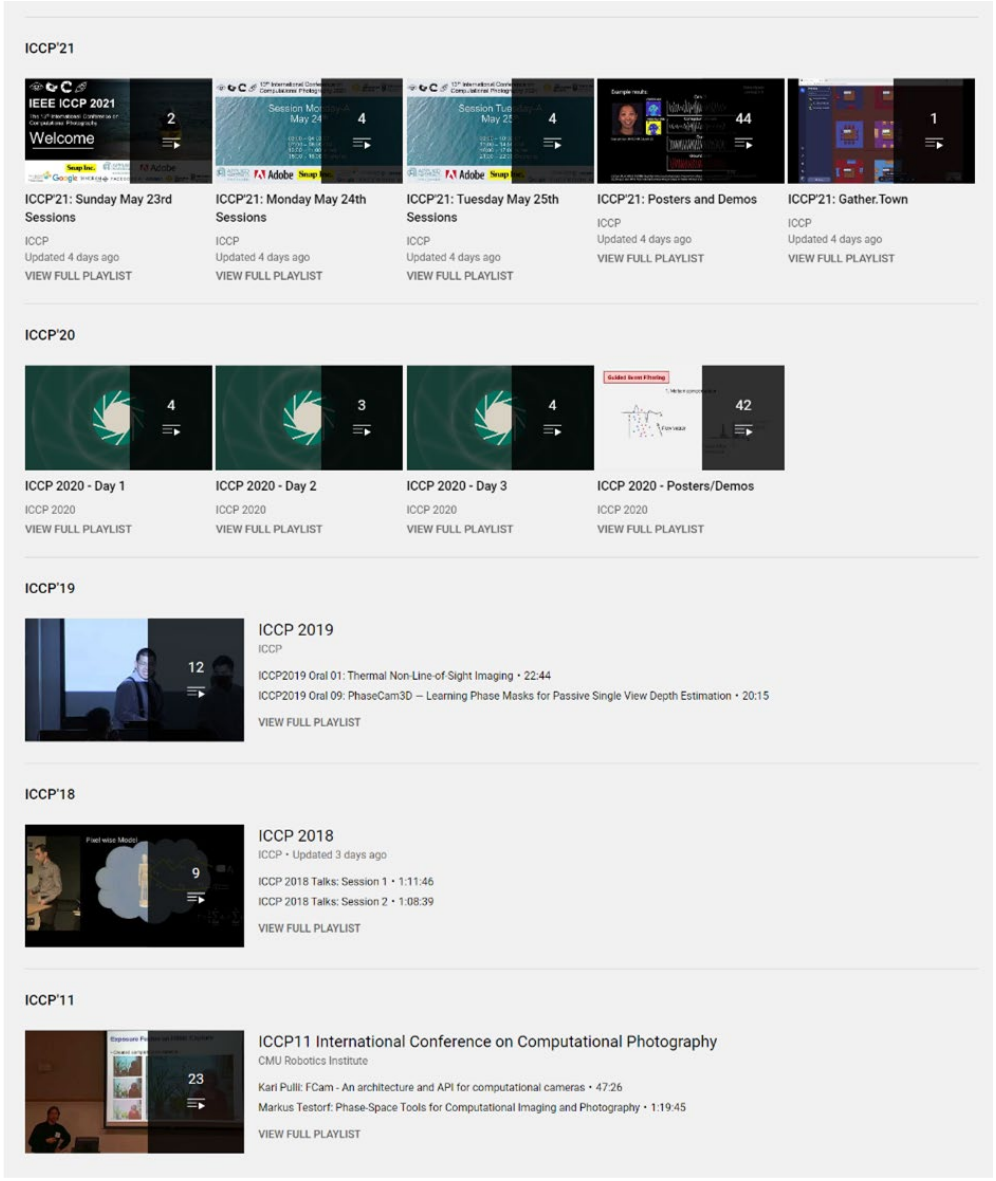
- Email Yannis if you want to be added to the imaging group mailing list and attend our weekly meetings (day and time for the semester TBD).

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

# International Conference on Computational Photography YouTube channel

https://www.youtube.com/channel/UClptqae8N3up_bdSMzlY7eA

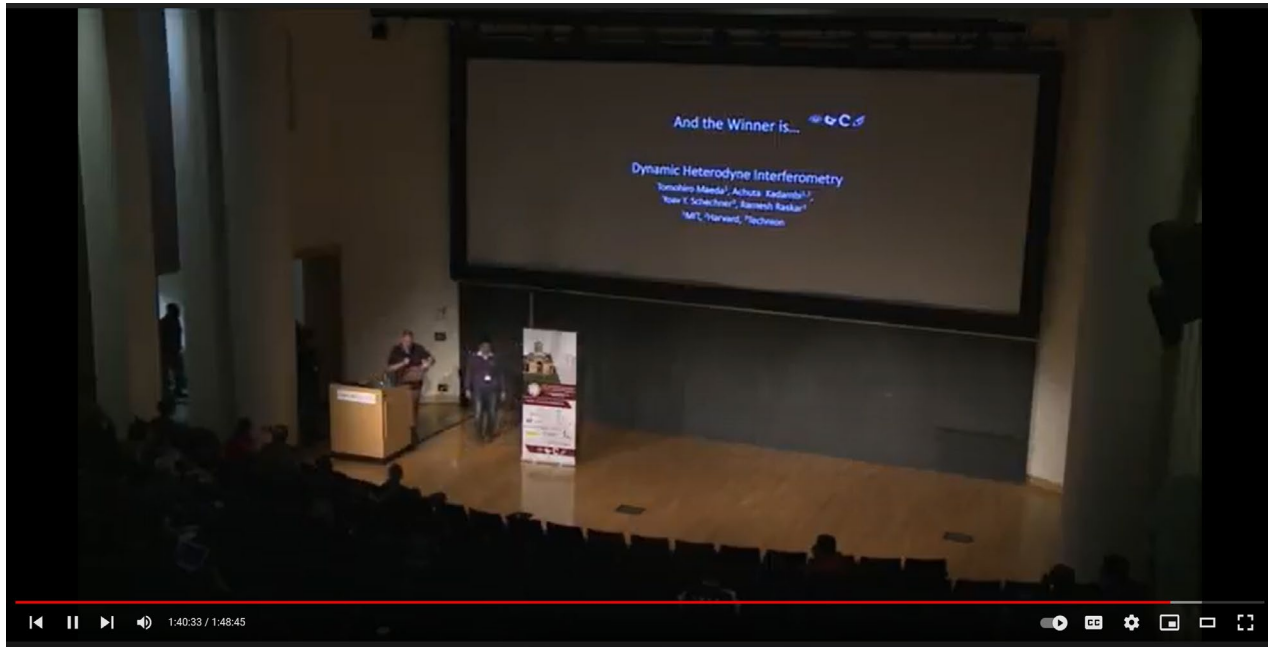


# CMU has a strong presence at ICCP


ICCP 2011

ICCP 2018



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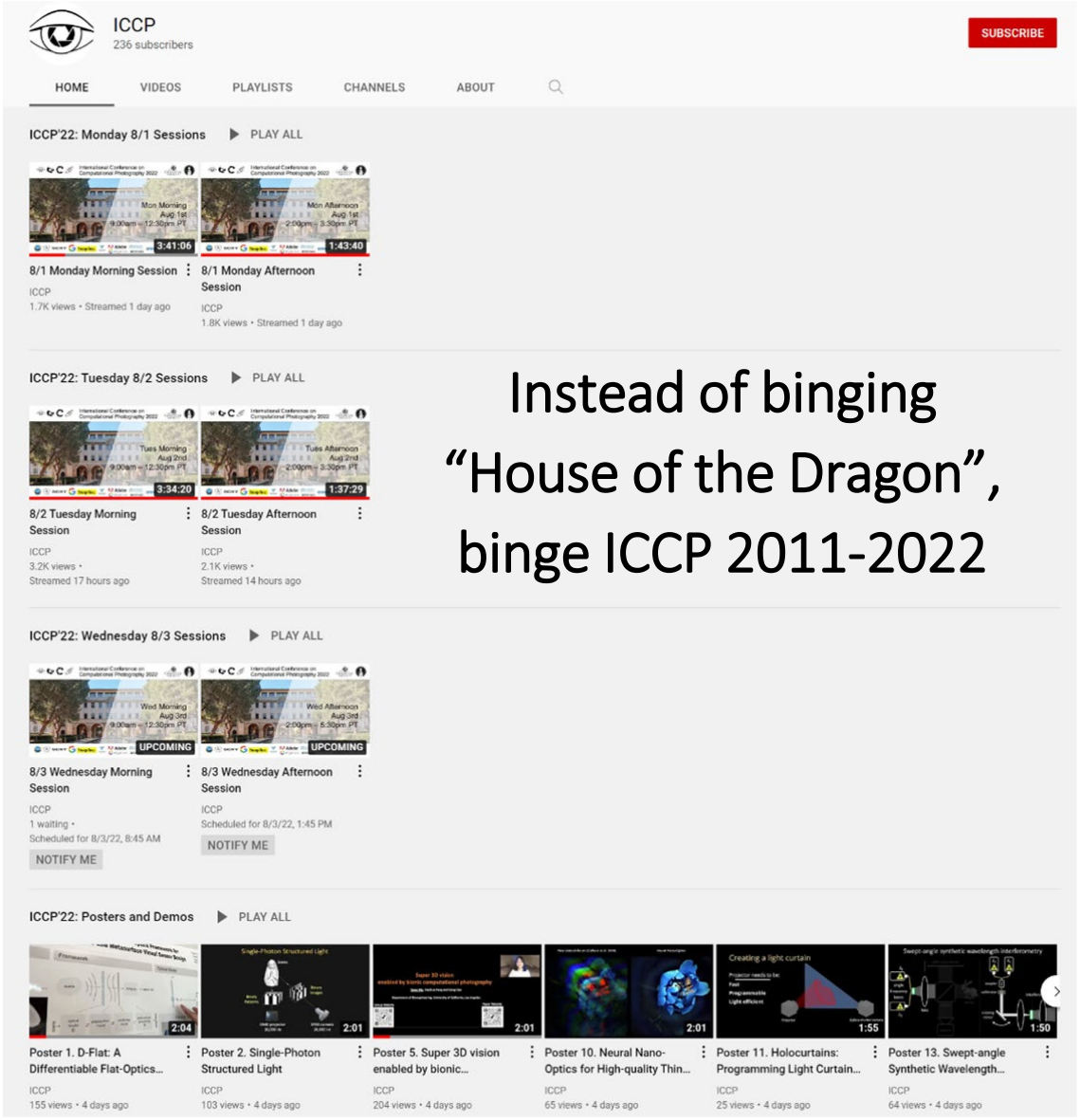
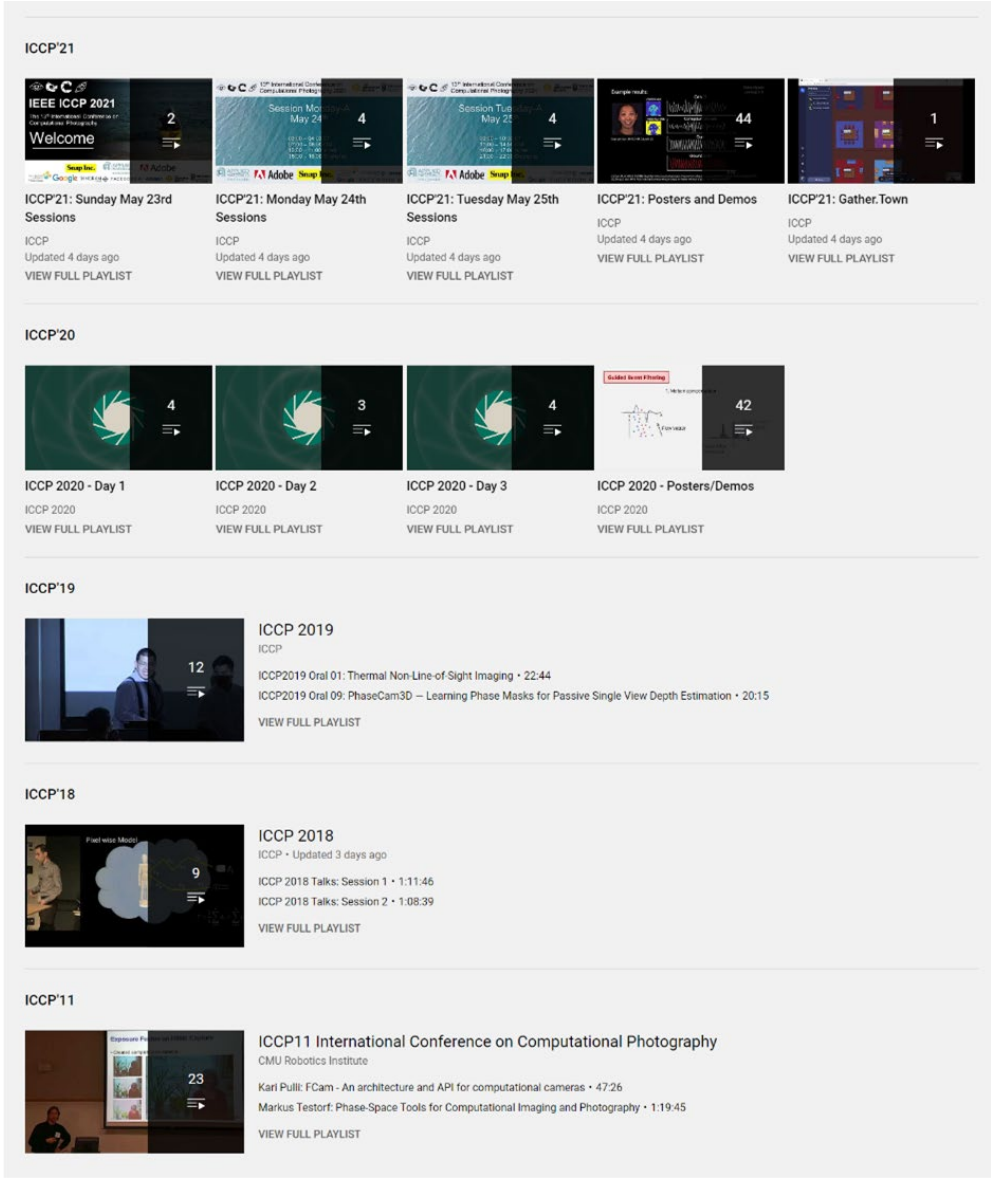



Instead of binging
"House of the Dragon",
binge ICCP 2011-2022



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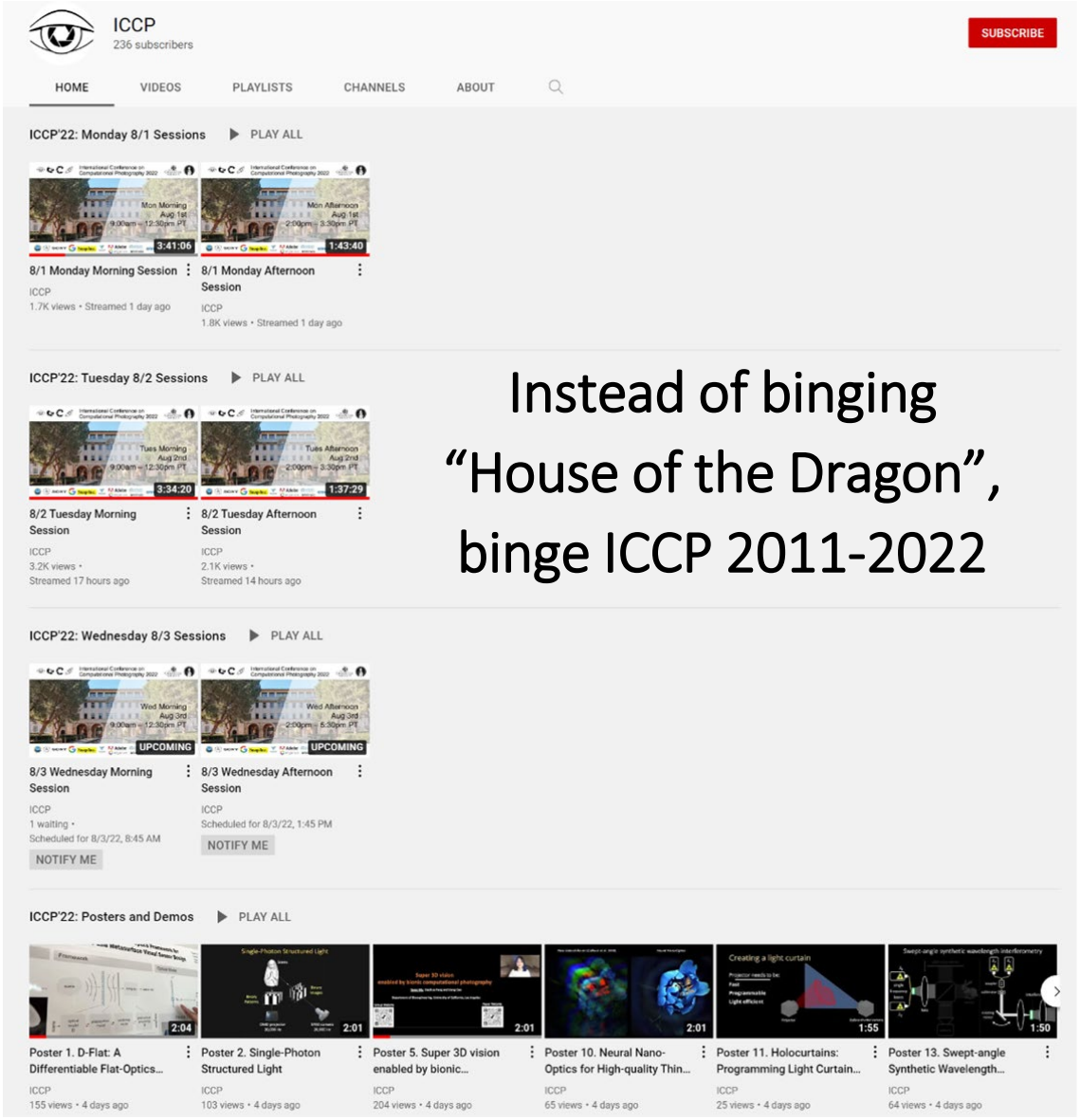


Instead of binging
“House of the Dragon”,
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**smash that subscribe button**

# Please take the start-of-semester survey and sign up for a camera before the next lecture!

Survey link:

https://docs.google.com/forms/d/e/1FAIpQLSeUx7mw3twz8s_VySxJfx4wBAttllgmG26u2LH_ZOEBhW_9Ow/viewform

Camera sign up:

https://docs.google.com/spreadsheets/d/1Q1dpYlhBEUupQVw6pOM7fST--JSsEFEWZVE0ipgGx3I/edit#gid=0

Both links available on Piazza.