Introduction

Computational Photography (CSCI 3240U)

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A bit about me

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Important questions

- Will I get an A+ in this course?
- What is computational photography anyways?

Acknowledgments

- These slides borrow and adapt materials developed by others, including
  - Michael Brown
  - Kyros Kutulakos
  - Ioannis Gkiouleka
  - David Lindell
  - Gordon Wetzstein
  - Marc Levoy
  - Fredo Durand
  - Paul Debevec
  - Ramesh Raskar

Traditional (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)

Slide credit: I. Gkioulekas

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)

Slide credit: I. Gkioulekas

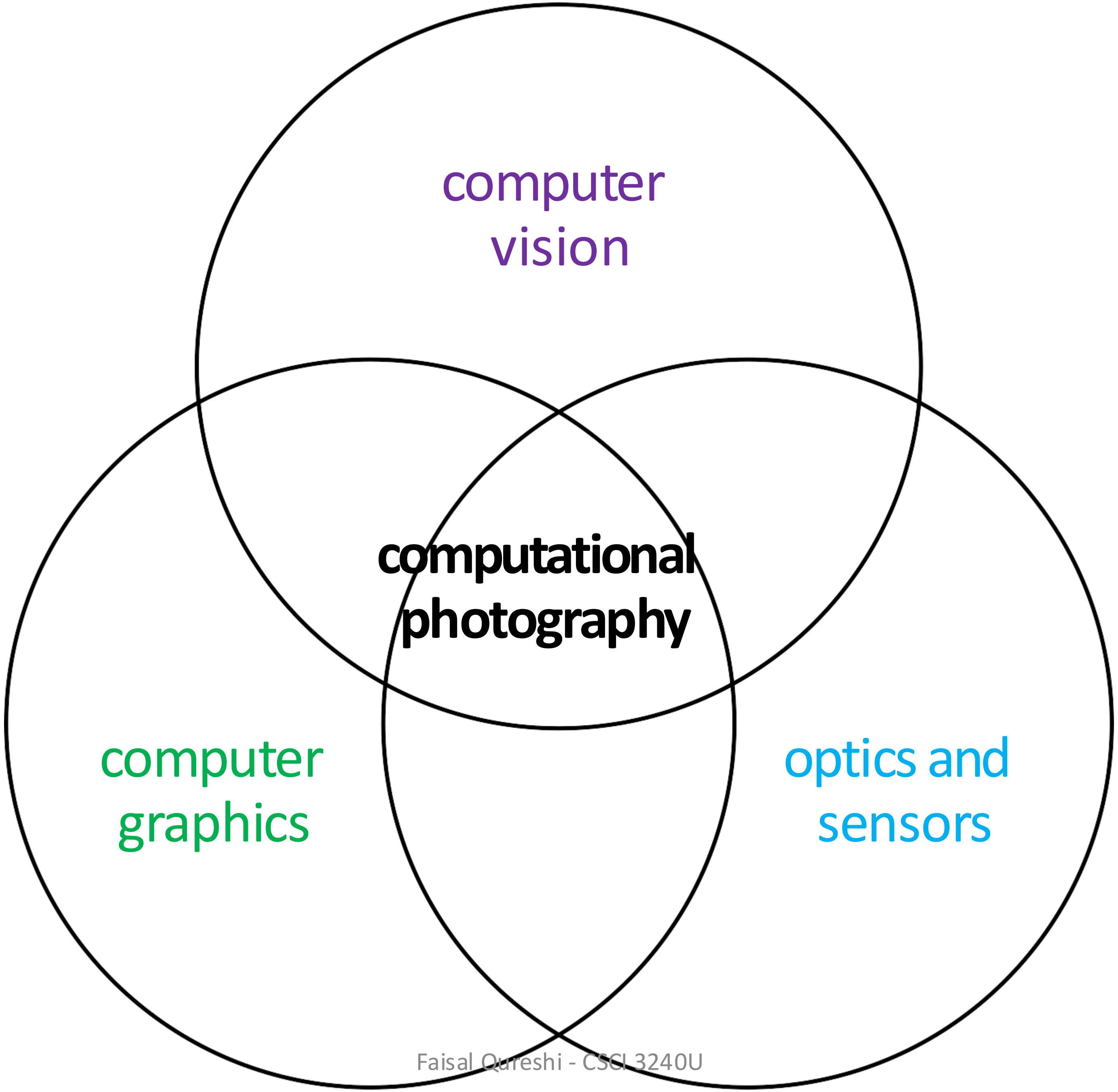
Computational photography

optics to focus light on an image plane

digital sensor to capture focused light (electrical process)

arbitrary computation between sensor and image

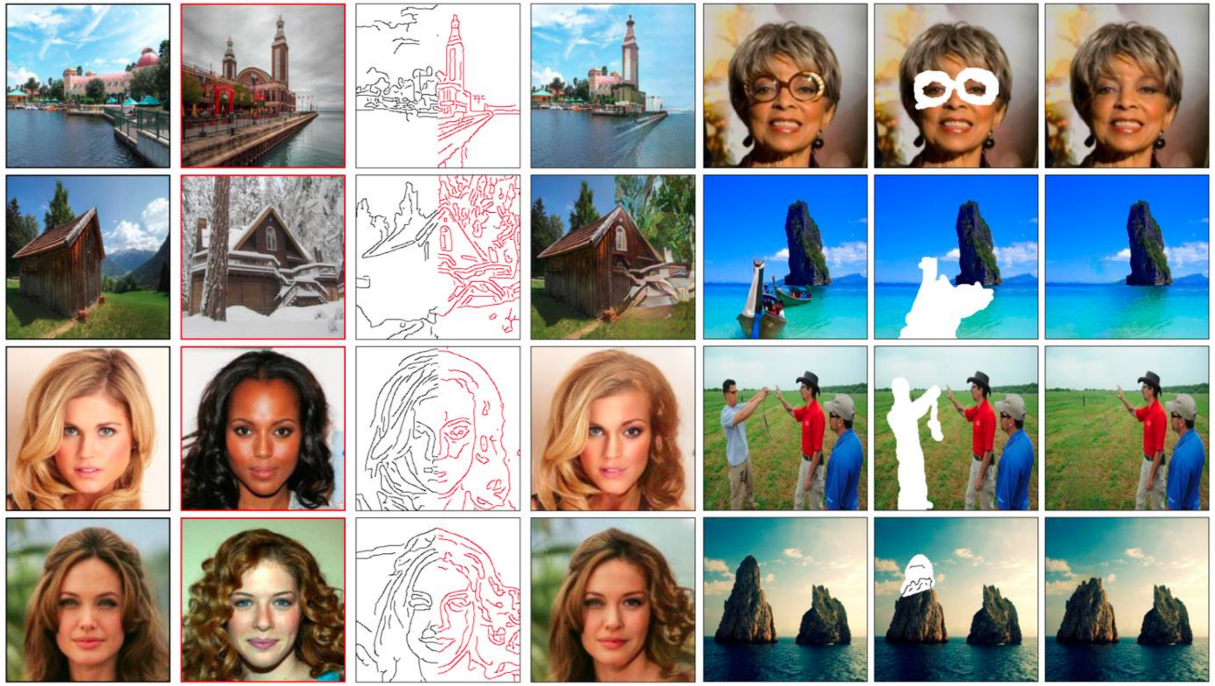
Slide credit: I. Gkioulekas



Slide credit: K. Kitani

Computational Photography

- The use of imagery to create new content
  - Image-based rendering
  - Fake images!
- The use of computational techniques to overcome the limitations of traditional photography



[Nazeri et al 2019]

Computational photography

Computer Graphics

+ easy to create new worlds

+ easy to manipulate objects/ viewpoint

- very hard to look realistic

Realism
Manipulation
Ease of capture

Photography

+ instantly realistic

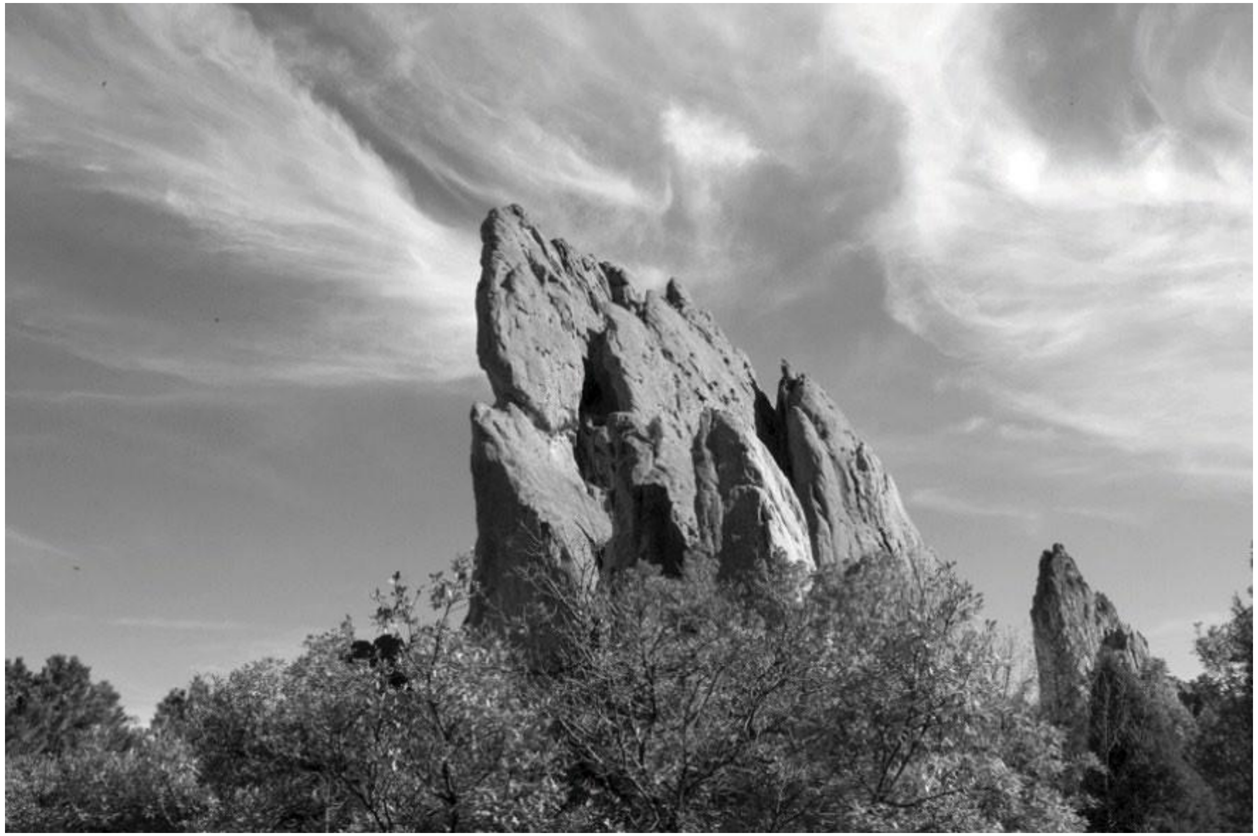
+ easy to acquire

- very hard to manipulate objects/viewpoint

Slide credit: A. Efros

Photographic look

[Bae et al. SIGGRAPH 2006]



camera output

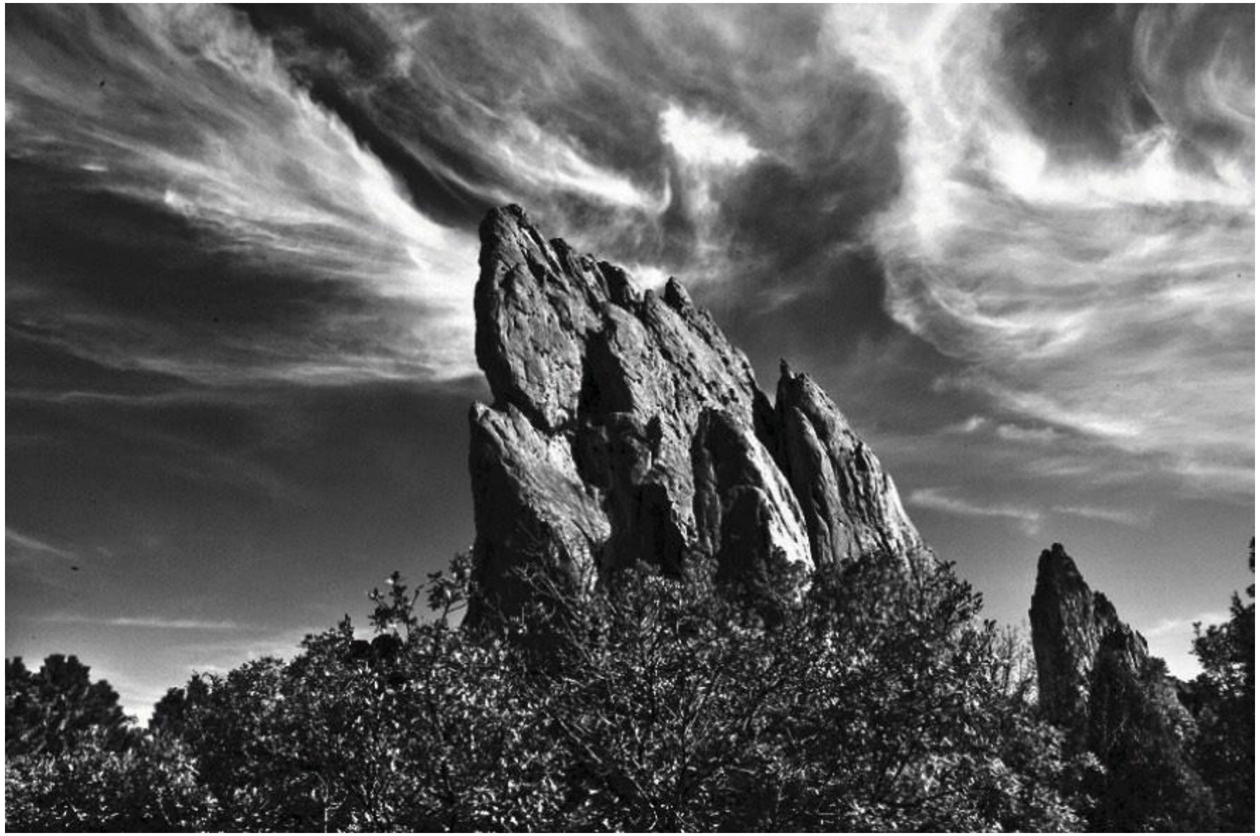
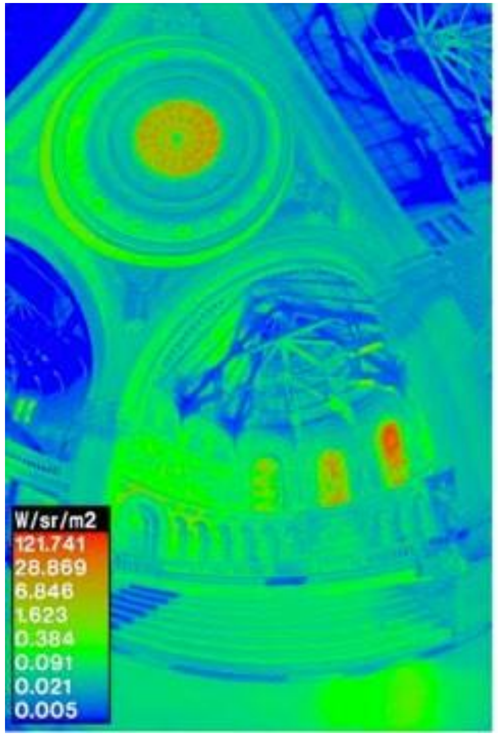


image after stylistic tonemapping

Slide credit: I. Gkioulekas

High-dynamic range imagery

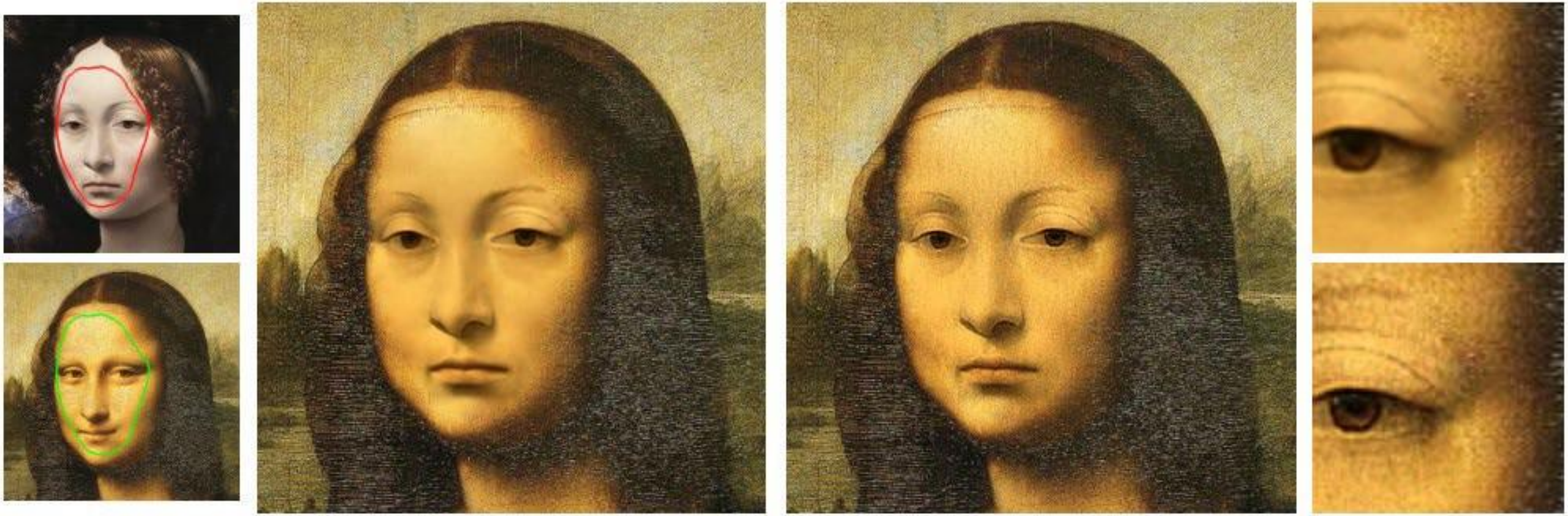
[Debevec and Malik, SIGGRAPH 1997]



Slide credit: I. Gkioulekas

Image blending & harmonization

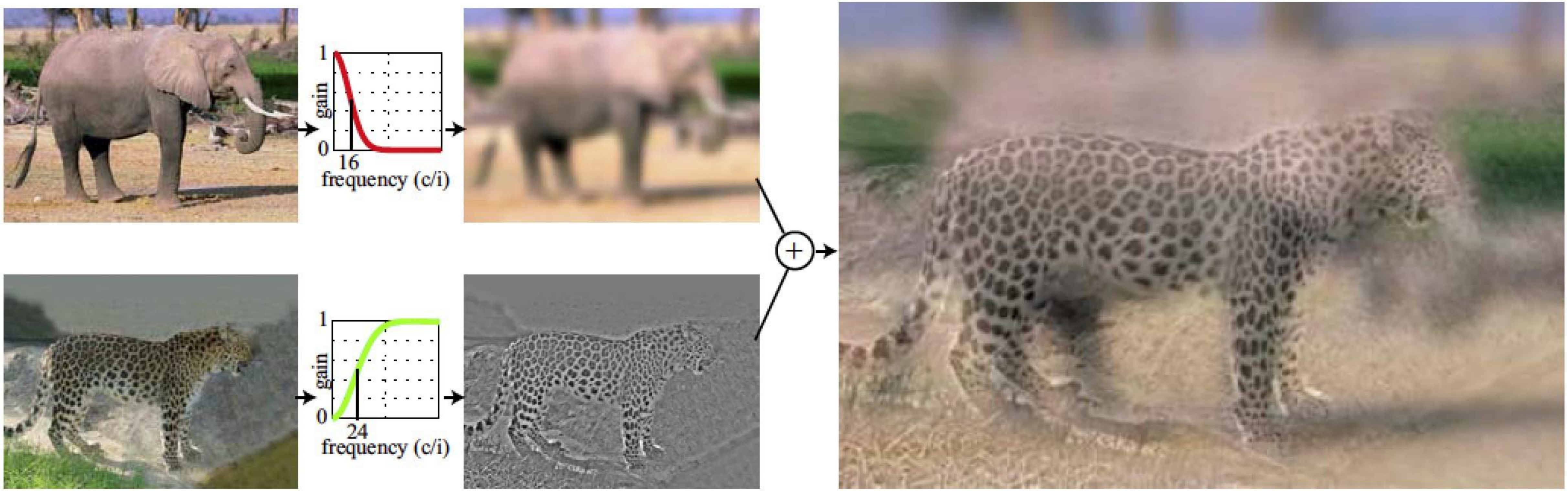
Creating new imagery



[Sunkavalli et al. SIGGRAPH 2010]

Slide credit: I. Gkioulekas

Hybrid images



Oliva, Torralba, & Schyns, 2006, ACM SIGGRAPH

Slide credit: D. Lindel

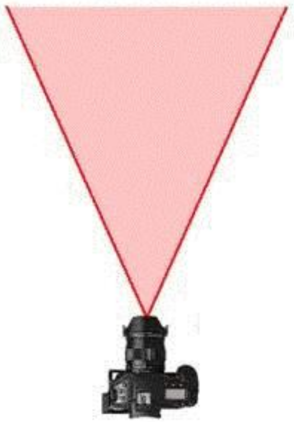
Limitations of Conventional Photography

- Single viewpoint
- Static picture
- No 3D information

Post-capture image compositing

Computational zoom

images captured at three zoom settings



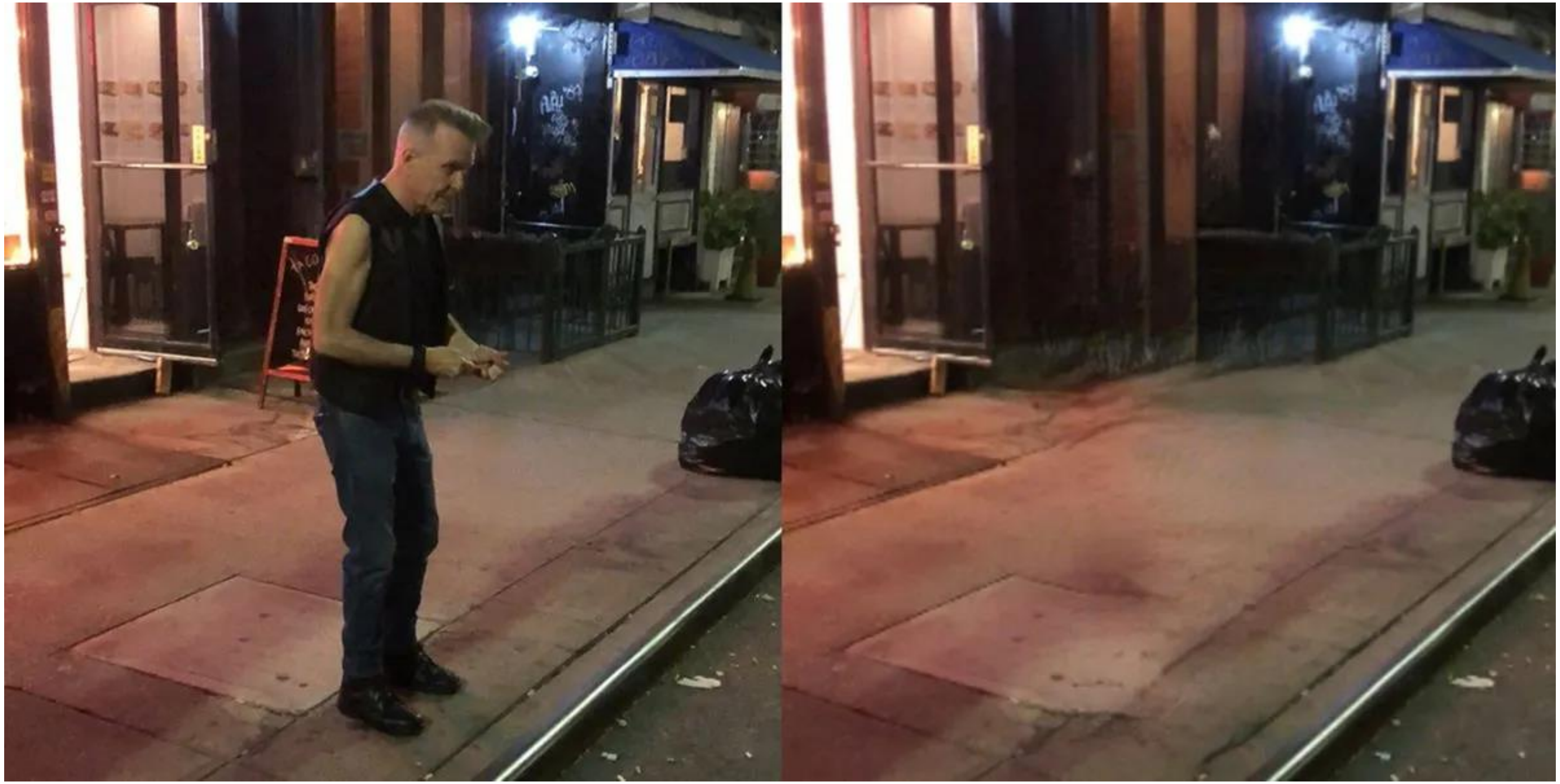
post-capture synthesis of new zoom views

[Badki et al., SIGGRAPH 2017]

Slide credit: I. Gkioulekas

Post-capture image compositing

Person removal



Post-capture image compositing

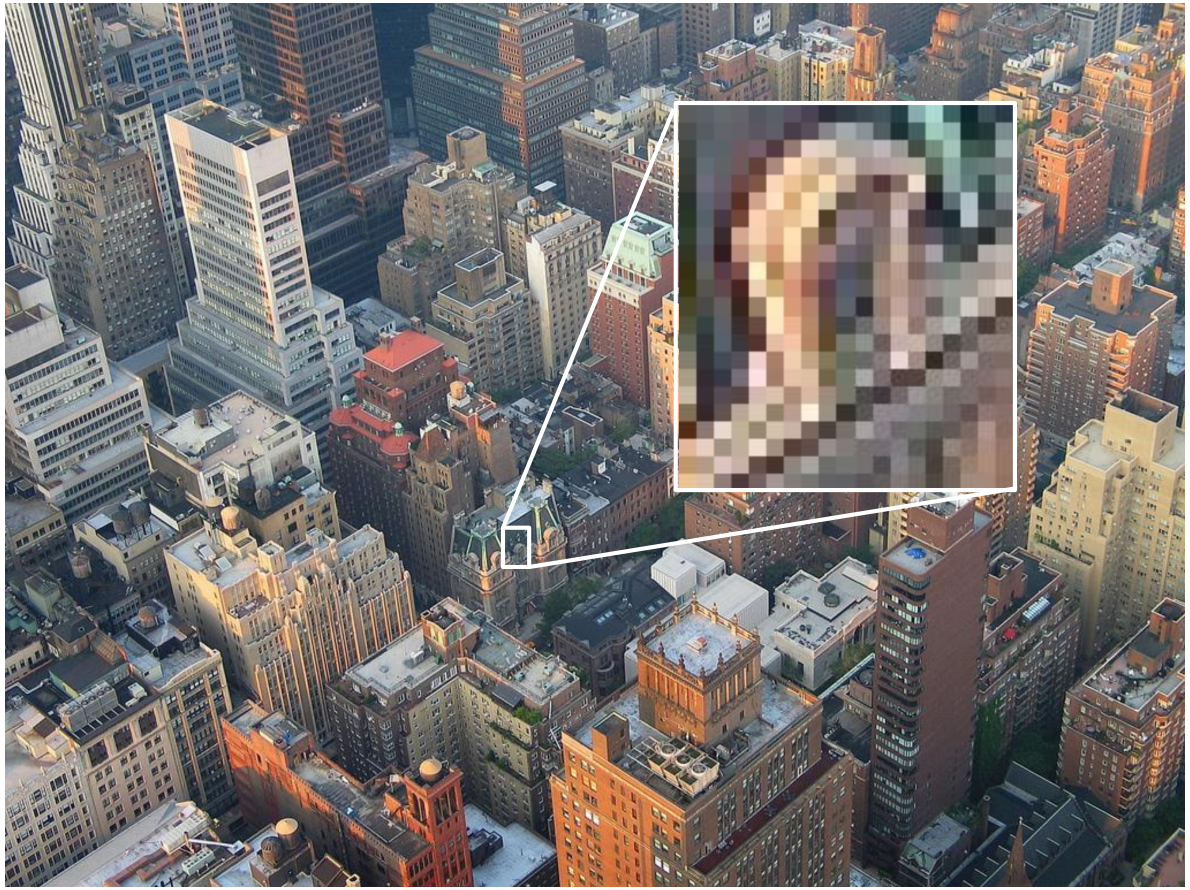
Re-focus

Slide credit: M. Brown

Fix blur, camera shake, noise, damage

Slide credit: M. Brown

Resolution enhancement



Slide credit: M. Brown

Color correction and colorization

Slide credit: M. Brown

Image stitching

Panorama generation

+

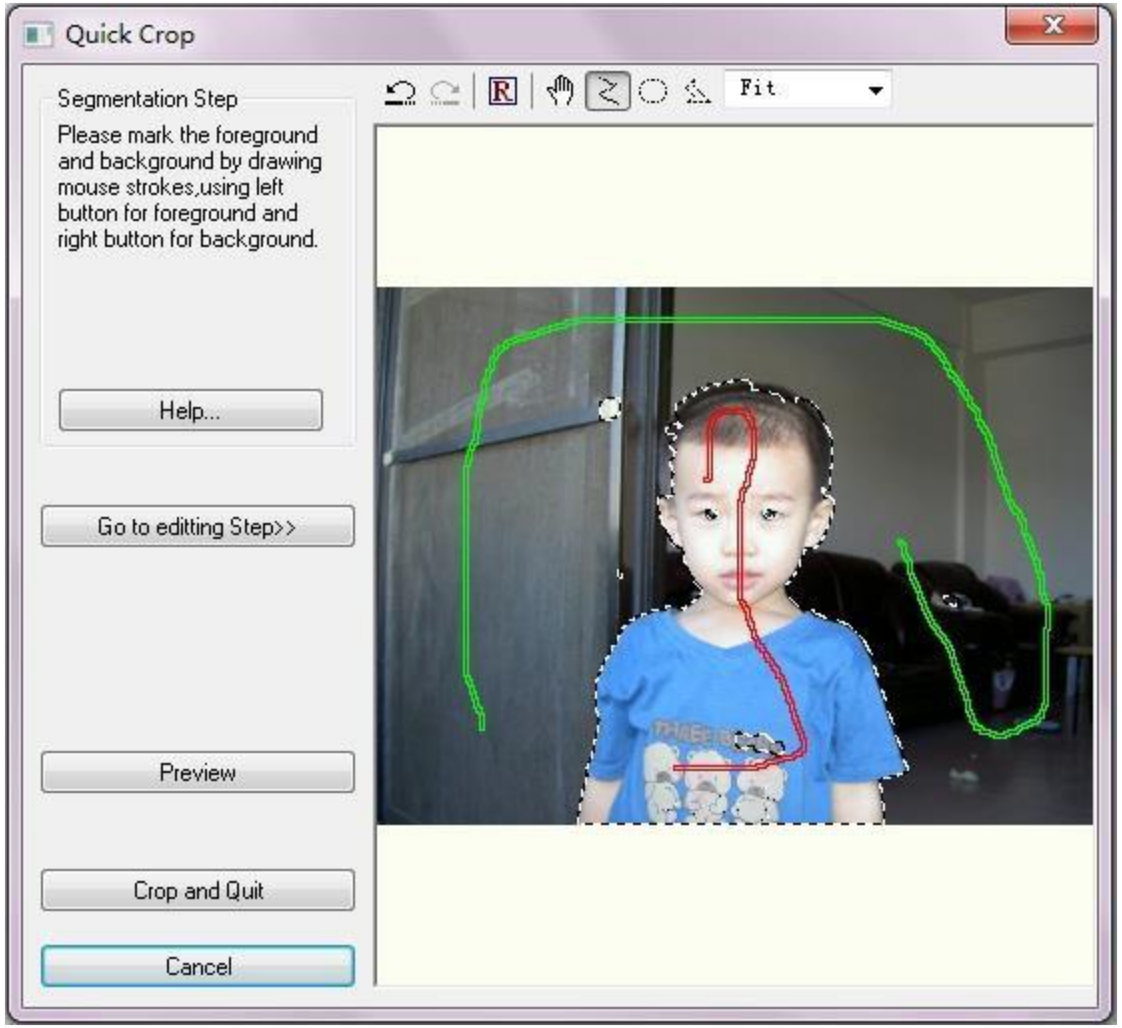
=

[Brown and Lowe IJCV 2007]

Processing very large number of images

[Agarwal et al., SIGGRAPHY 2011]

Interactive Editing



Put the “human in the loop” when editing photographs.

Slide credit: M. Brown

Computational photography

optics to focus light on an image plane

digital sensor to capture focused light (electrical process)

arbitrary computation between sensor and image

Slide credit: I. Gkioulekas

Computational photography or Computational Imaging

generalized optics
between scene and sensor

digital sensor to capture focused
light (electrical process)

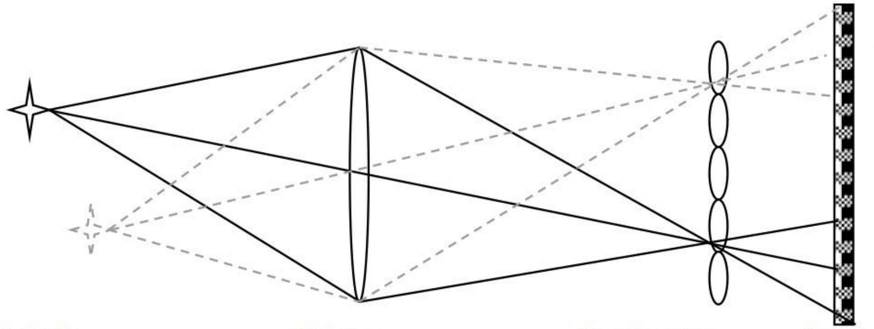
arbitrary computation
between sensor and image

Slide credit: I. Gkioulekas

Capture more than 2D images

Lightfield cameras for plenoptic imaging

post-capture refocusing

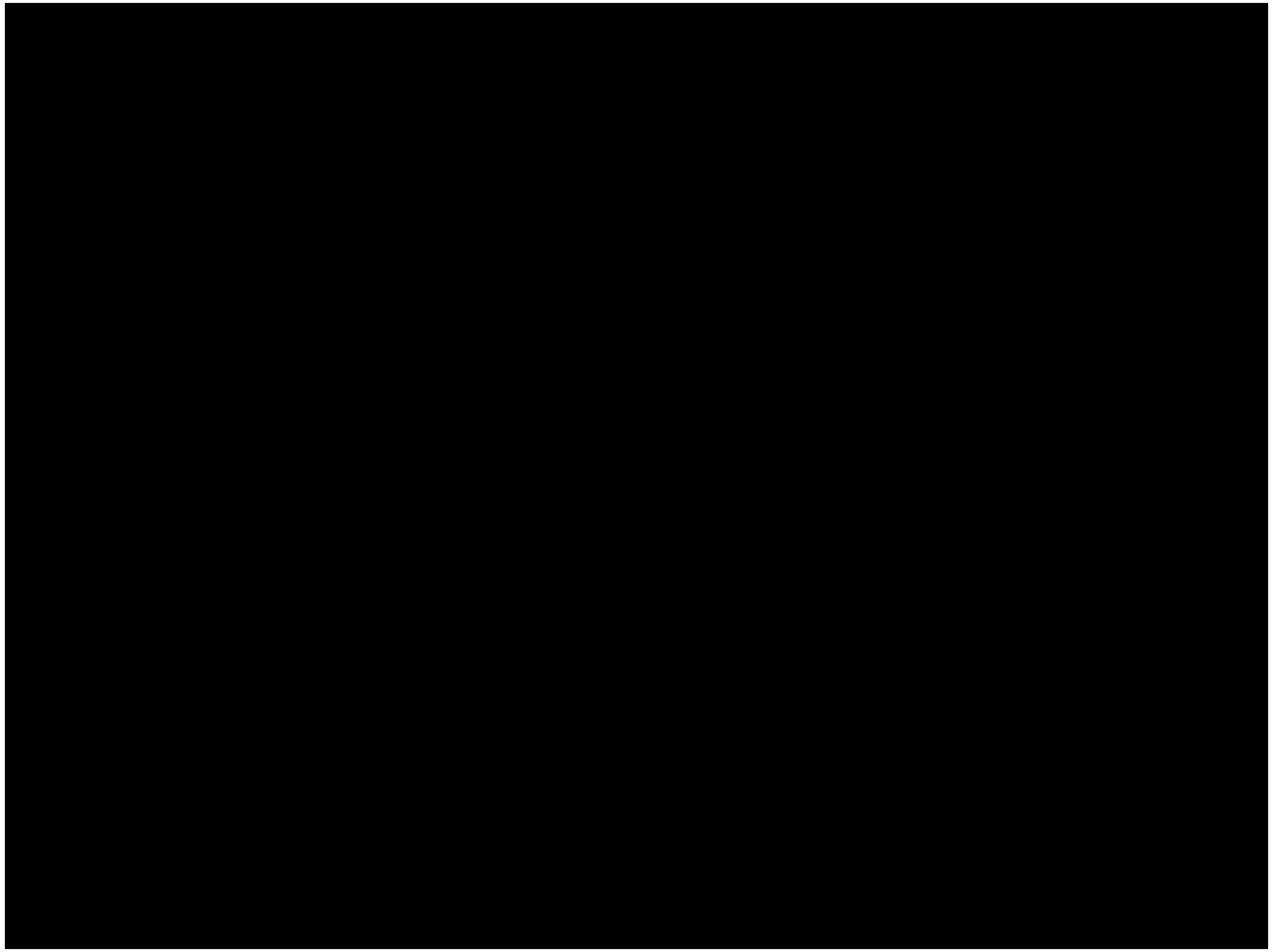


[Ng et al., SIGGRAPH 2005]

Slide credit: I. Gkioulekas

Capture more than 2D images

Lightfield cameras for plenoptic imaging

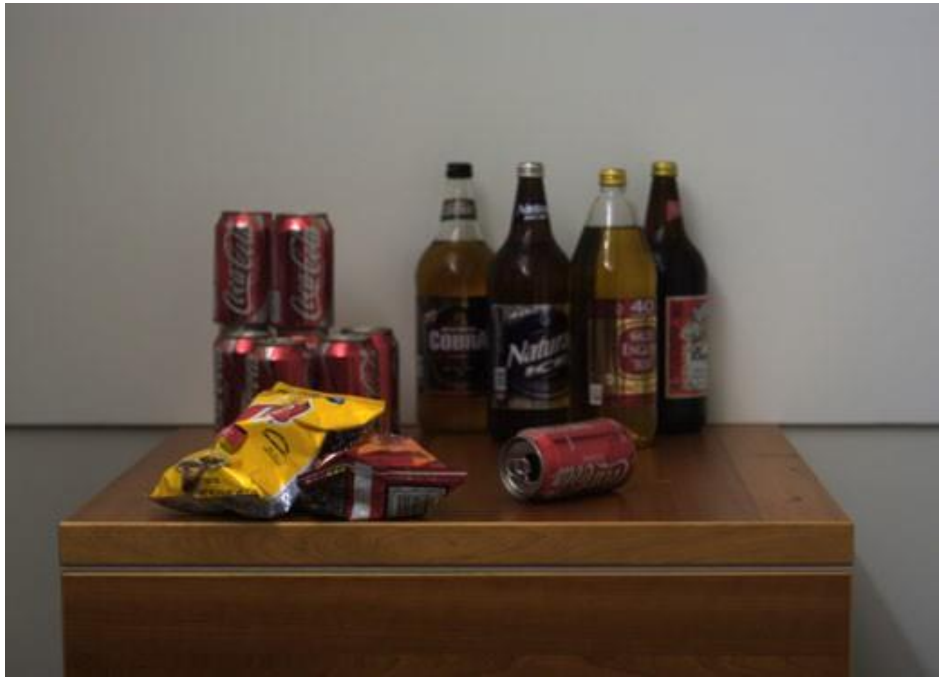


[Ng et al., SIGGRAPH 2005]

Measure 3D from a single 2D image

Coded aperture for single-image depth and refocusing

conventional vs coded lens



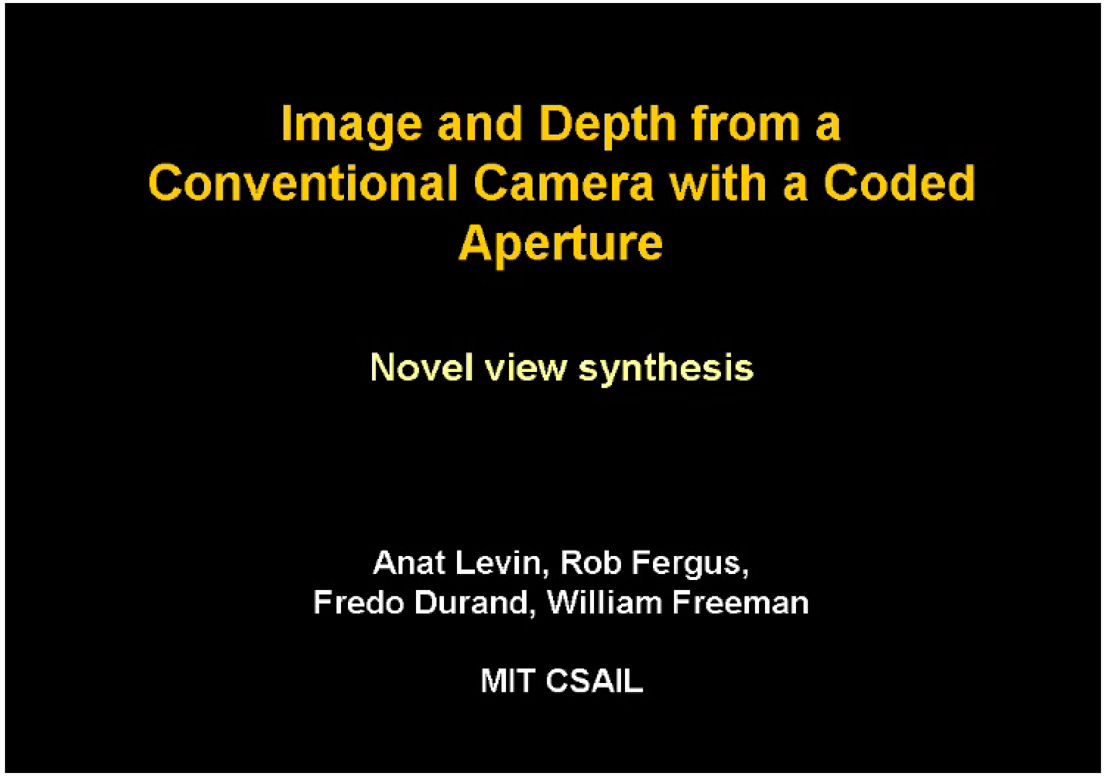
input image

inferred depth

[Levin et al., SIGGRAPH 2007]

Measure 3D from a single 2D image

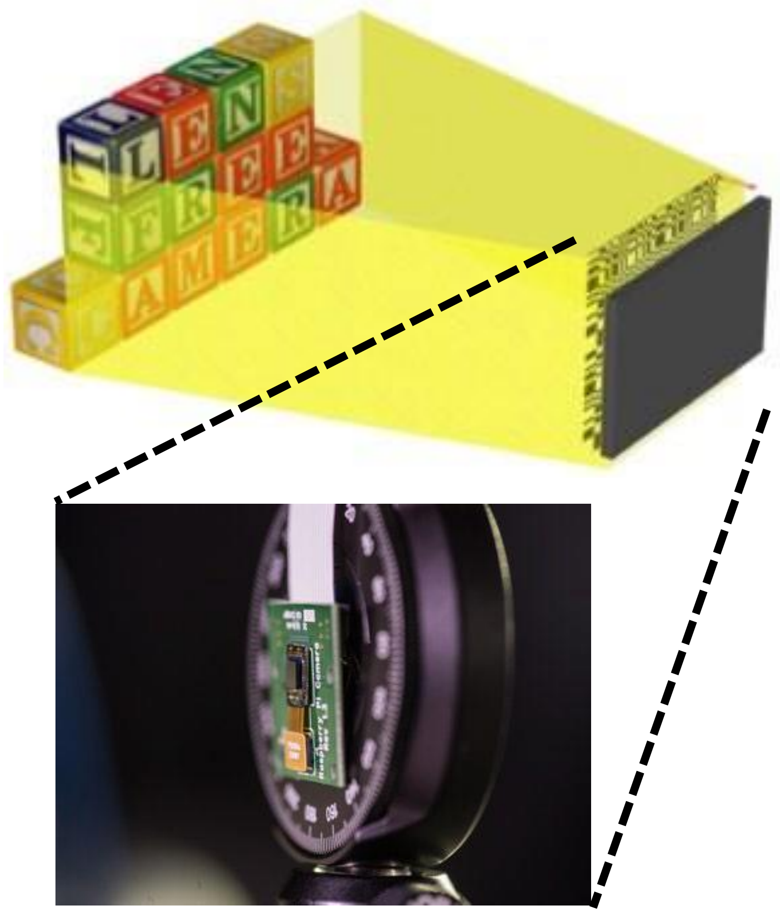
Coded aperture for single-image depth and refocusing



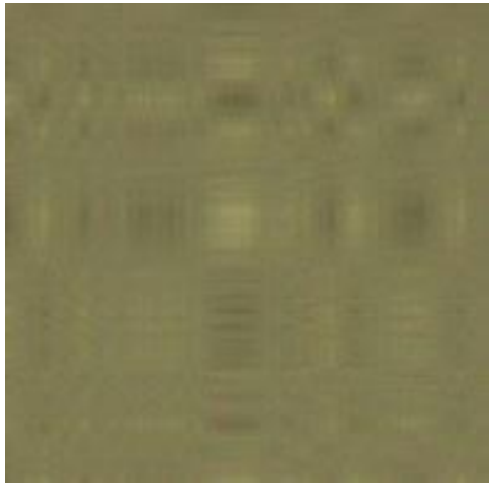
[Levin et al., SIGGRAPH 2007]

Remove lenses altogether

FlatCam: replacing lenses with masks



prototype



sensor measurements

reconstructed image

[Asif et al., 2015]

Computational Imaging

generalized optics
between scene and sensor

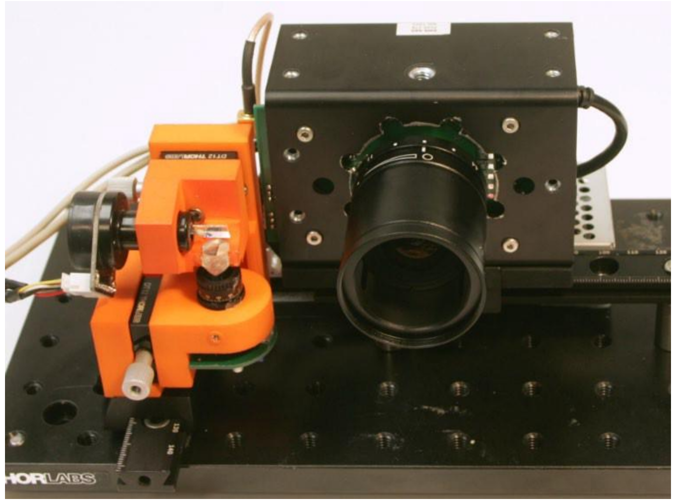
digital sensor to capture focused
light (electrical process)

arbitrary computation
between sensor and image

Slide credit: I. Gkioulekas

Unconventional sensing and illumination

generalized optics
between scene and sensor



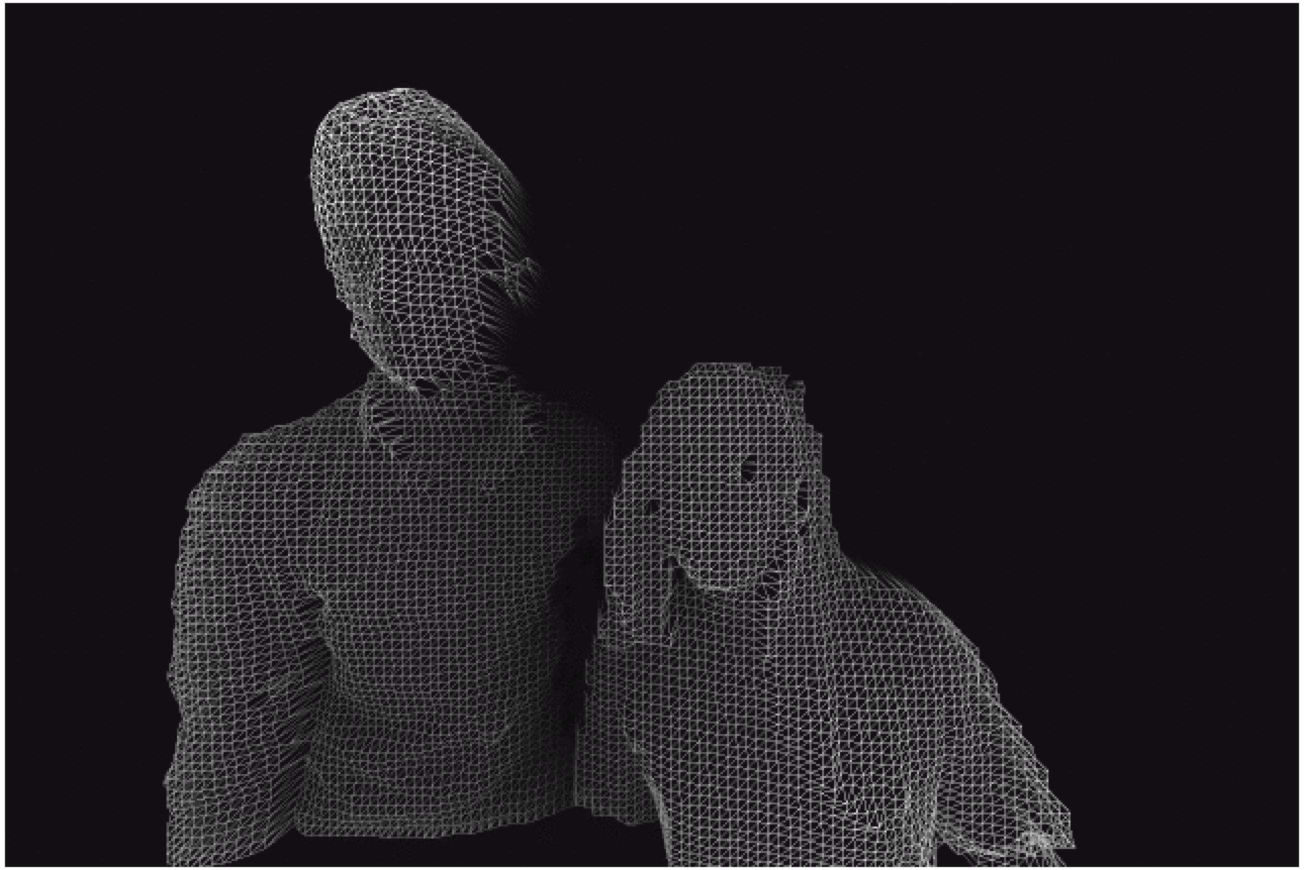
unconventional sensing
and illumination

arbitrary computation
between sensor and image

Slide credit: I. Gkioulekas

Measure depth

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

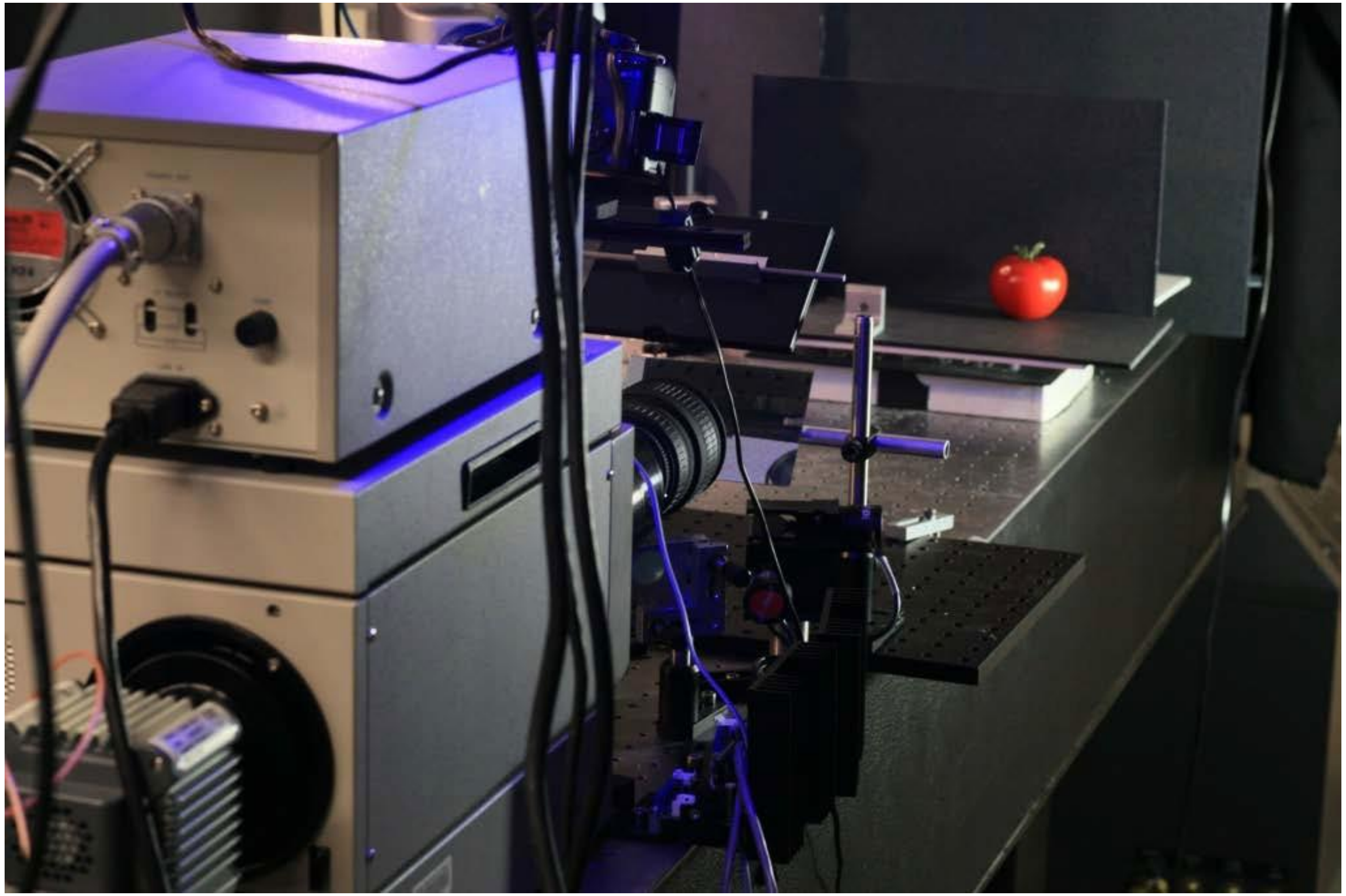


[Microsoft]

Slide credit: I. Gkioulekas

Measure light in flight

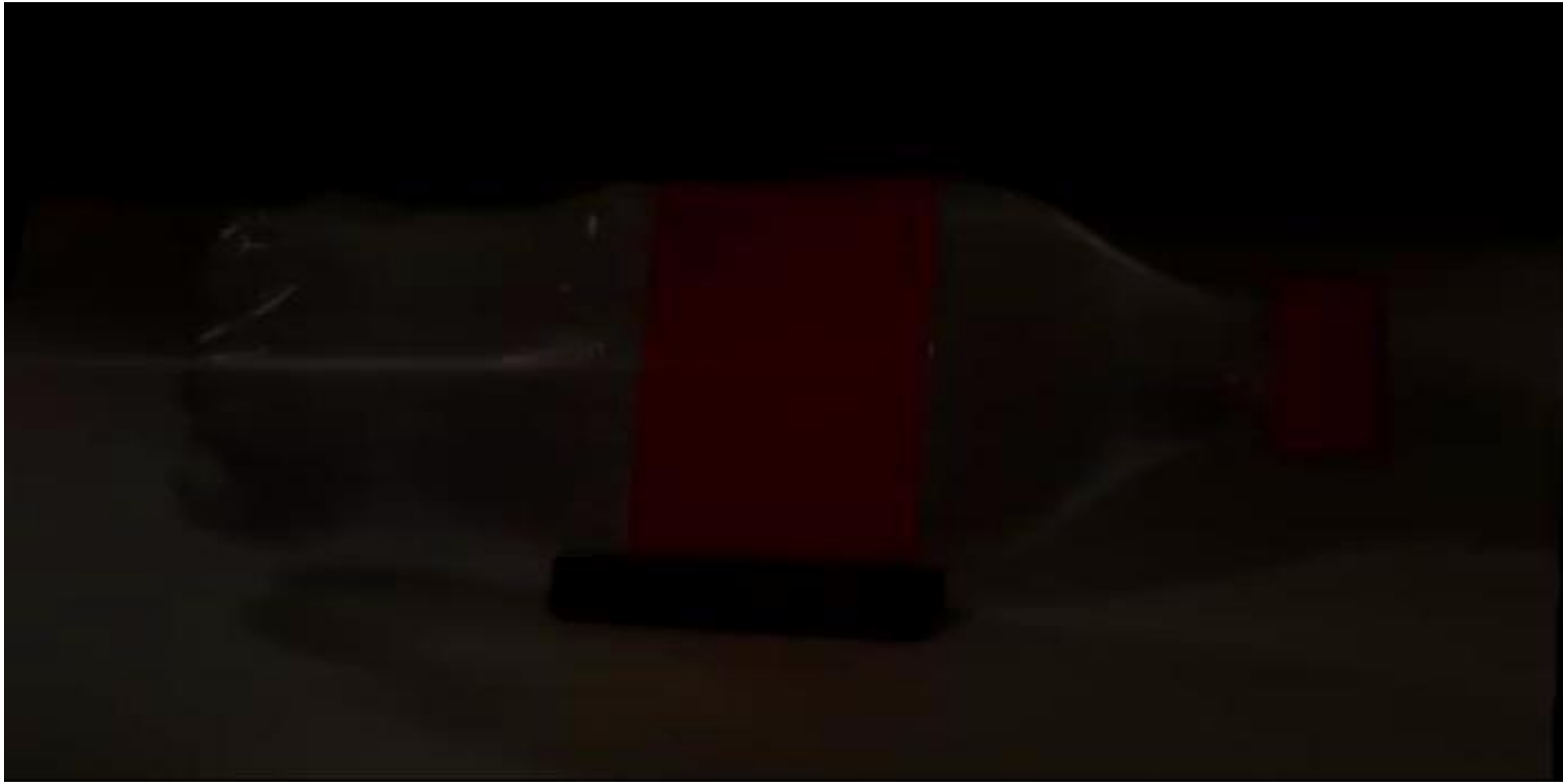
Streak camera for femtophotography



[Velten et al., SIGGRAPH 2013]

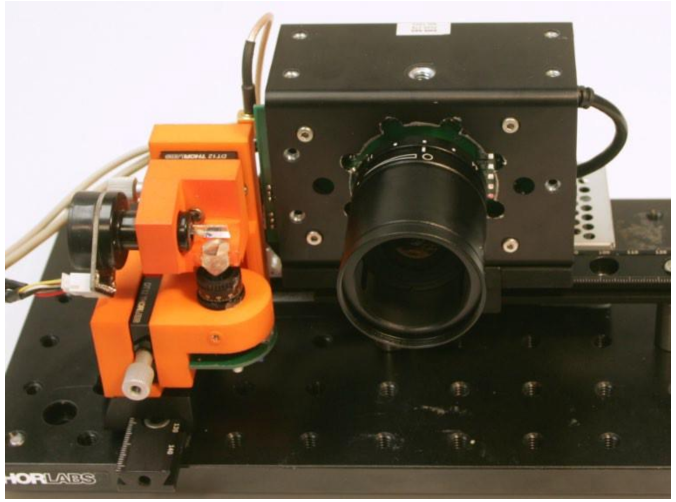
Measure light in flight

Streak camera for femtophotography



Computational photography

generalized optics
between scene and sensor



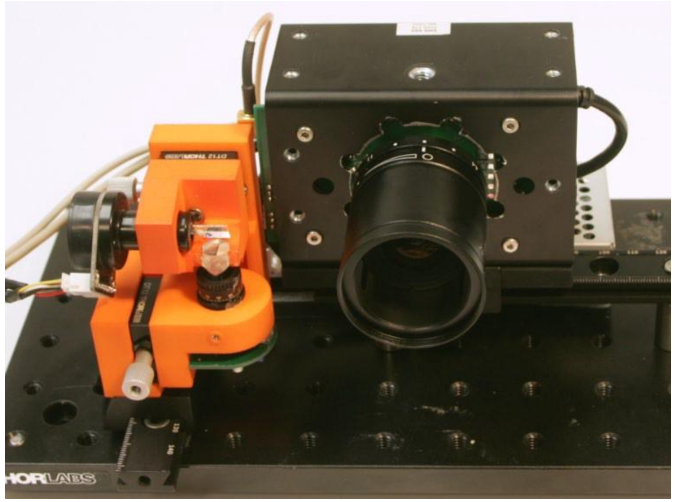
unconventional sensing
and illumination

arbitrary computation
between sensor and image

Slide credit: I. Gkioulekas

Computational photography going forward

generalized optics
between scene and sensor



unconventional sensing
and illumination

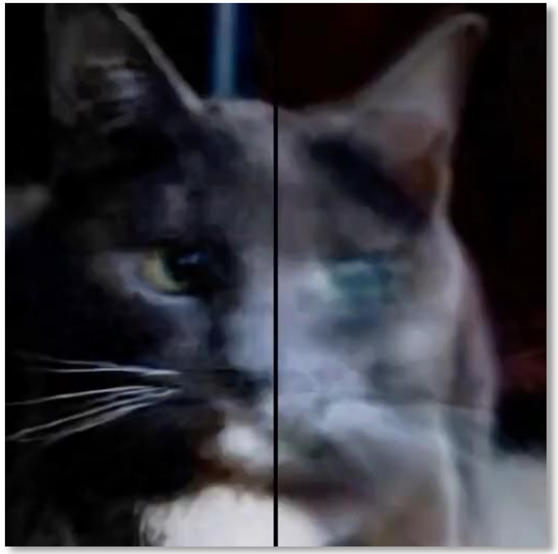
arbitrary computation
between sensor and image

joint design of optics, illumination, sensors, and computation

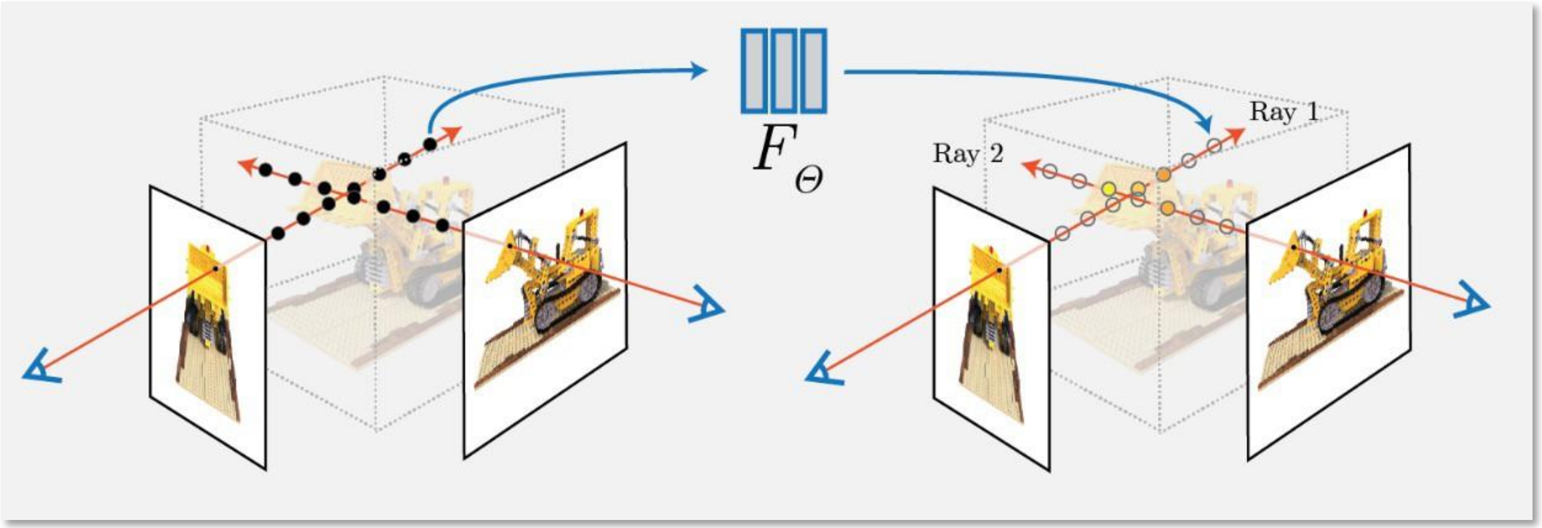
Slide credit: I. Gkioulekas

Neural Signal Representations

- Coordinate networks
- Radiance fields
- Multiview image reconstruction
- …



[Sitzmann et al. 2020]



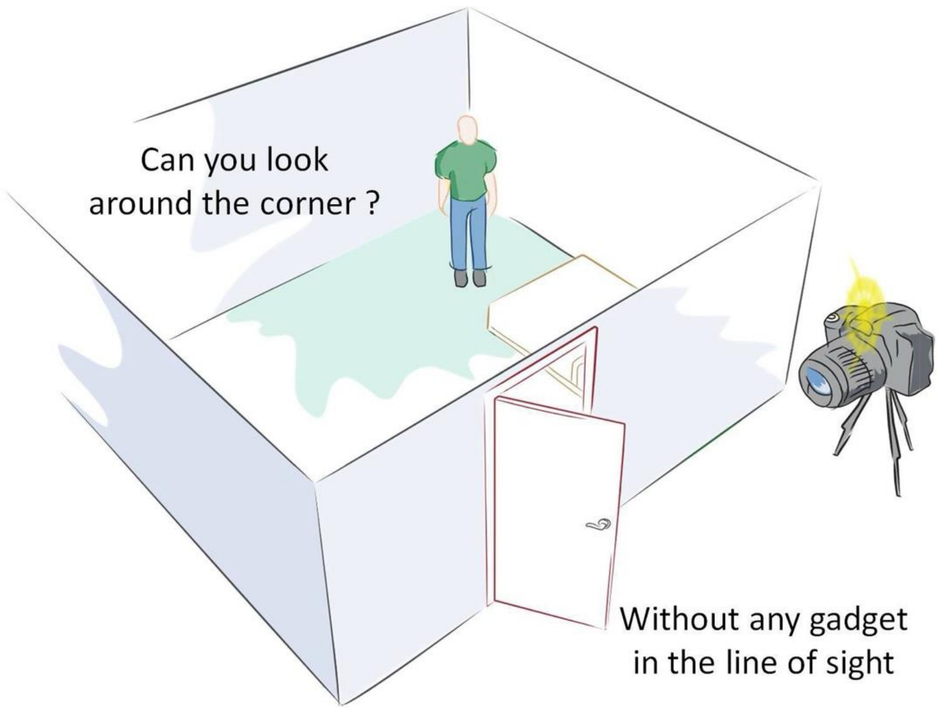
Slide credit: D. Lindel

[Mildenhall et al. 2020]

[Mildenhall et al. 2022]

Putting it all together

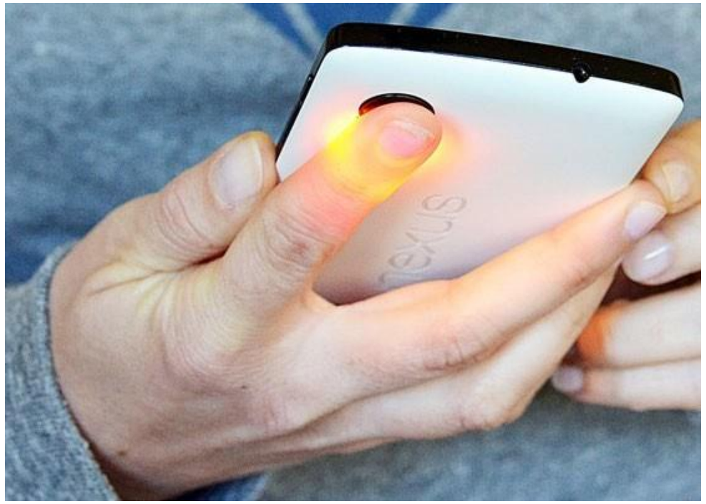
Looking around corners



[MIT Media Lab, DARPA Reveal]

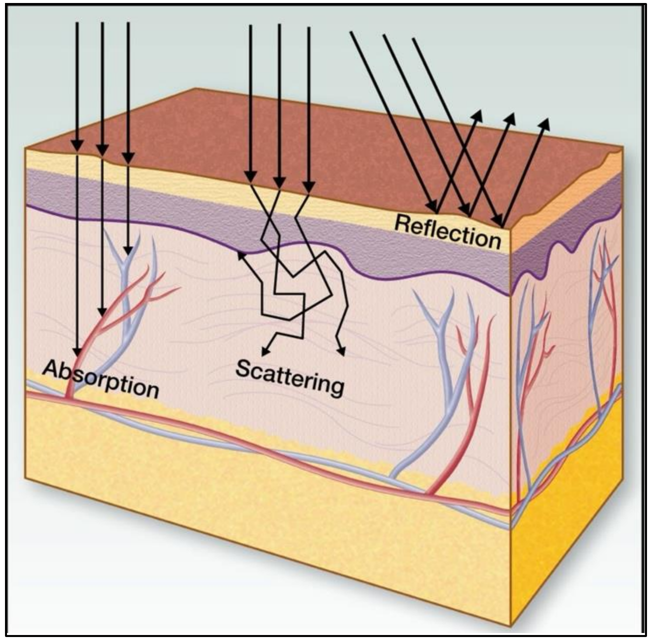
Looking through tissue

Opportunity



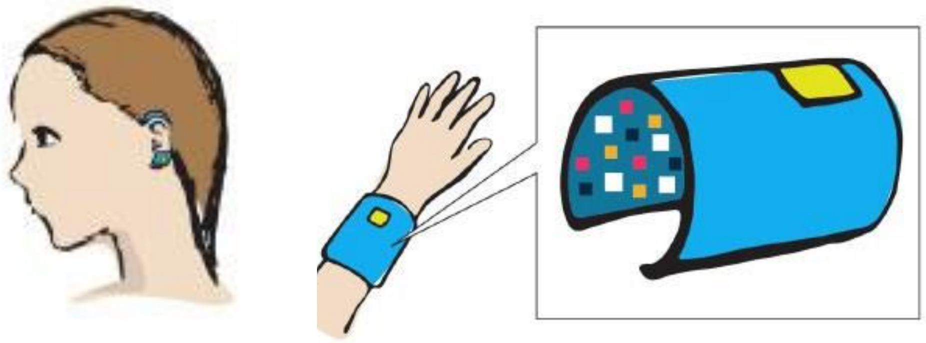
- + Light travels deep inside the body
- + It is non-ionizing (400-1100nm)
- + Cheap to produce and control

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]

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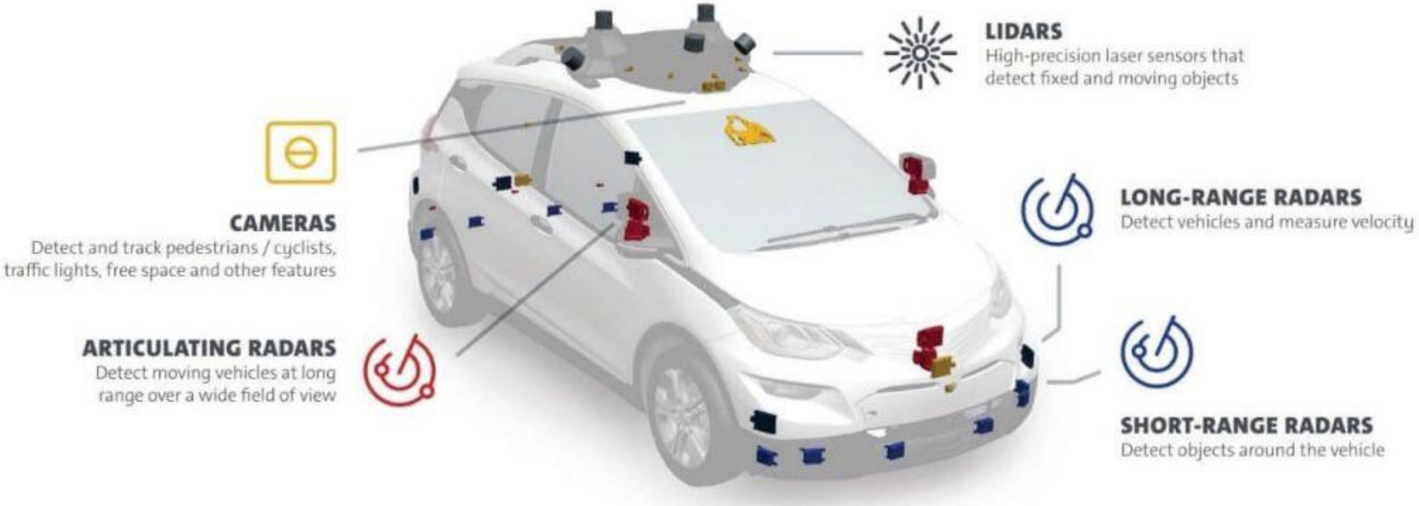

Slide credit: D. Lindel

Topics

A tentative list

- Imaging pipeline
- Linear filtering, edge detection
- Fourier transform, image pyramids
- Color processing, demosaicing, deconvolutions
- Image denoising, non-linear filtering
- Image segmentation
- Image pasting, colorization
- Deblurring
- High-dynamic range images
- Linear systems, gradient descent
- Ethics and social impact

Skills Acquired

- Technical skills
  - Programming
  - Image processing
  - Computer vision
- Algorithmic understanding
  - Image enhancement
- Mathematical foundations
  - Linear algebra, calculus, and statistics as these apply to image manipulation
- Soft skills
  - Critical thinking, problem solving and communication

Course syllabus

http://csundergrad.science.uoit.ca/courses/csci3240u/syllabus/syllabus.pdf

Course Organization

http://csundergrad.science.uoit.ca/courses/csci3240u/

Grading

- In-class quizzes 10%
- Lab and assignment participation and completion 20%
- Midterm exams 50%
- Course project 20%

A student must get 50% in the course project to pass the course.
Furthermore, a student must get 50% in the two midterms to pass the course.
*Class attendance is **not** optional.*

Course project

- The course project is an independent exploration of a specific problem within the context of this course.
- Project will consist of implementing one or more papers
- Project grade will depend on the ideas, how well you present them in the report, how well you position your work in the related literature, how thorough are your experiments and how thoughtful are your conclusions.
- *Teams of up to two students are allowed.*
- *You are required to prepare a three-minutes video that provides an overview of your project.*
- You are also required to prepare a final project writeup.

Important dates

- Midterm 1 on Oct 7
- Study break during the week of Oct 14
- Midterm 2 on Nov 18
- Project selection due by Oct 18
  - *You may lose up to 10% of the course project grade if project selection isn't finalized by Oct 18. You may lose up to an additional 20% of the course project grade if the project selection isn't finalized by Oct 25.*
- Project report due on Dec 8, by 11:59 pm
  - *You may be asked to record a 3 minutes long project presentation that will be submitted before the last week of lectures.*

Course syllabus

- Please consult course syllabus available at the course website for policies regarding conduct, late submissions, remarking, etc.

Labs

- Tuesday
  - 9:40 am, UB 2058
- Wednesday
  - 11:10 am, SHA 248
- Thursday
  - 2:10 pm, SHA 362

- First lab next week
  - Setting up the computational environment
  - Loading images
  - Playing with pixels
  - Reducing image size

First lab during the week of Sep 9

- First lab next week
  - Setting up the computational environment:
    - Python;
    - Numpy;
    - Scipy; and
    - OpenCV, etc.
  - Loading images
  - Playing with pixels
  - Reducing image size
  - Will become available on Canvas

How do I get an A+ in this course?

From ChatGPT

- Understand the Course Objectives
- Stay Consistent with Coursework
- Master the Theoretical Concepts
- Hands-on Practice
- Stay Updated
- Seek Feedback
- Form Study Groups
- Utilize Resources
- Manage Your Time
- Prepare for Exams
- Work on Projects with Passion
- Engage Beyond the Classroom

Lastly, always maintain a positive and curious mindset. Be proactive in your learning and seek opportunities to apply what you've learned. Remember, the ultimate goal is not just the A+ grade but gaining a deep understanding of computational photography and its applications.