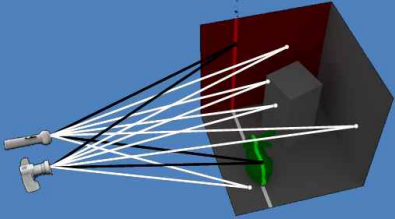


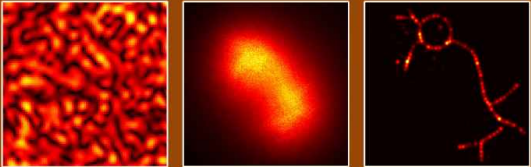
# 1. Introduction

## 3D sensing



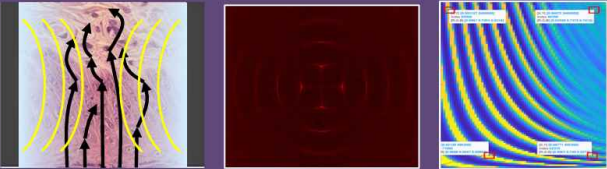
- micrometer 3D sensing using interferometry
- ultrafast 3D sensing using ultrasonic lenses

## speckle imaging




- Monte Carlo rendering of wave optics
- fluorescence microscopy

## acousto-optics



- rendering refractive radiative transfer
- steering light inside tissue

## tissue imaging



- differentiable rendering for tissue tomography
- blood and vein imaging

## 1. 3D 传感

- 使用干涉测量法进行微米级3D传感
- 使用超声波透镜的超快3D传感

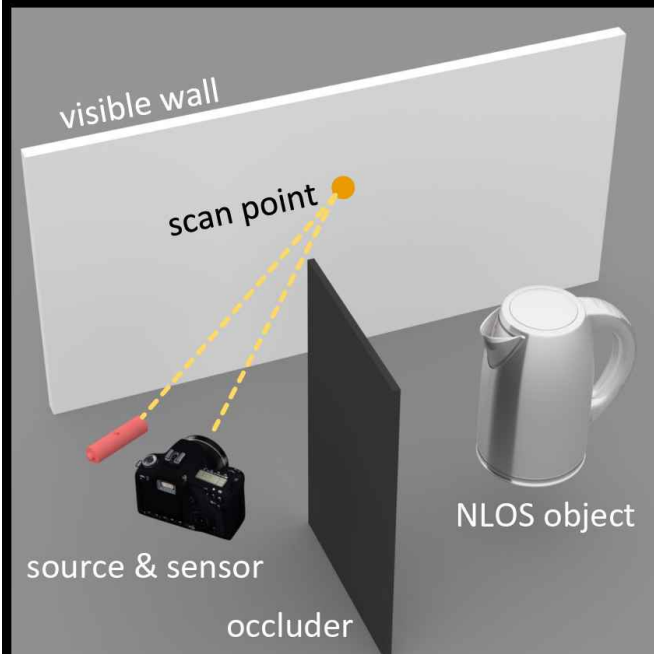
## 2. 散斑成像

## 3. 声光

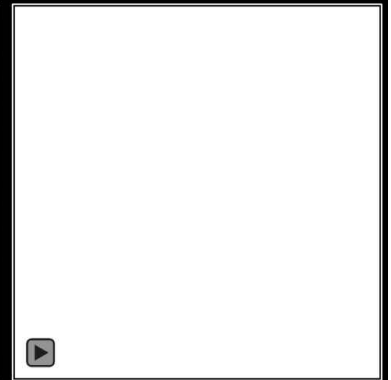
## 4. 组织成像

- 组织断层扫描的可微渲染
- 血液和静脉成像

# Looking around corners



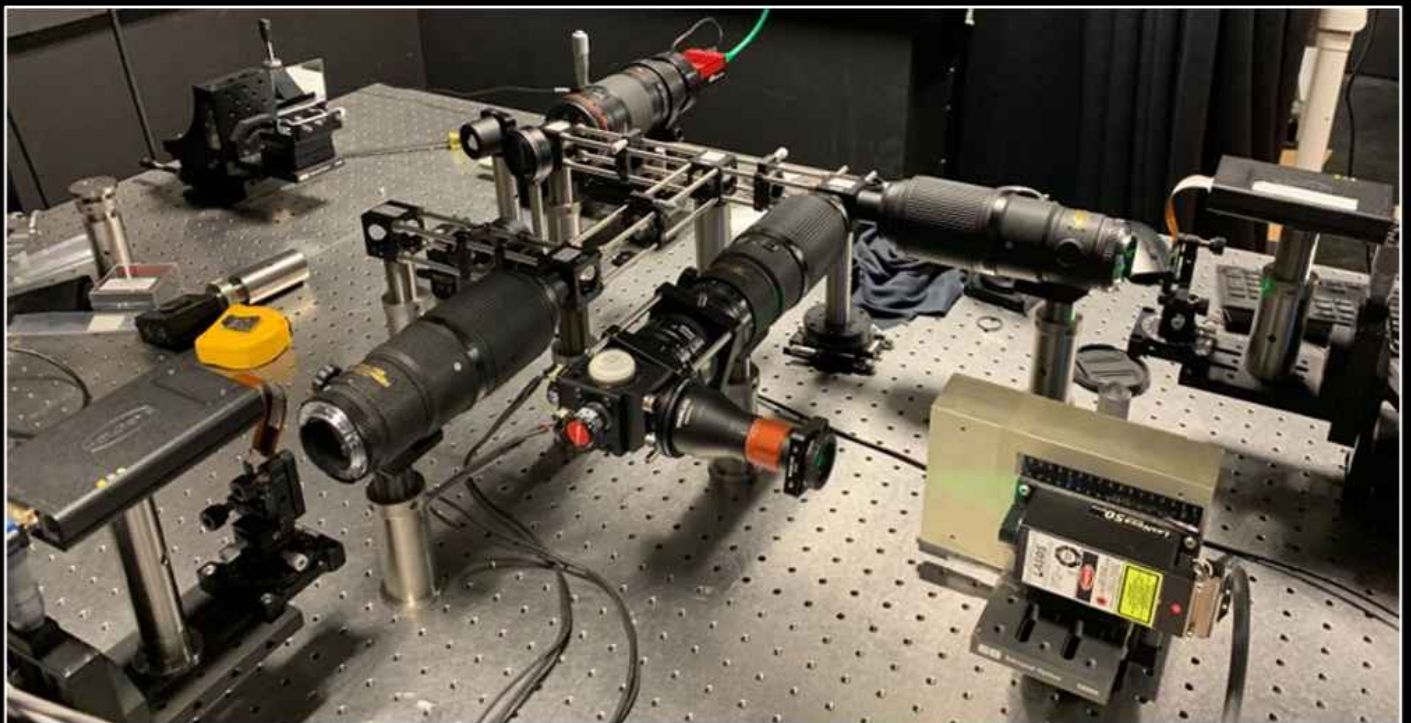
what a regular  
camera sees



what we can  
reconstruct

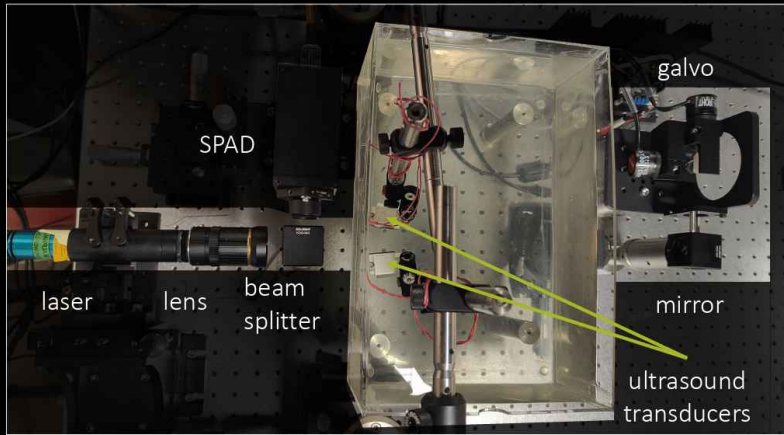
<http://imaging.cs.cmu.edu/>

# Seeing light in flight

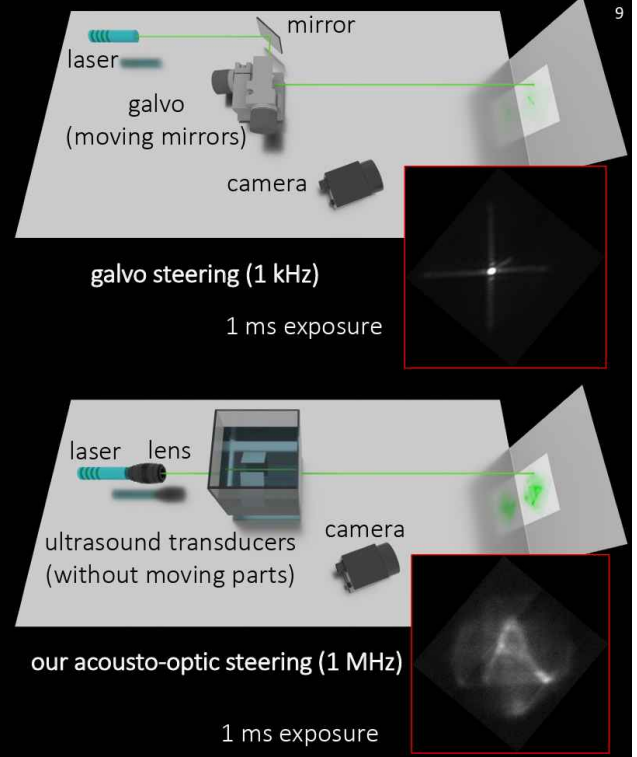


camera for capturing video at  $10^{15}$  frames per  
second

# Ultrafast lidar

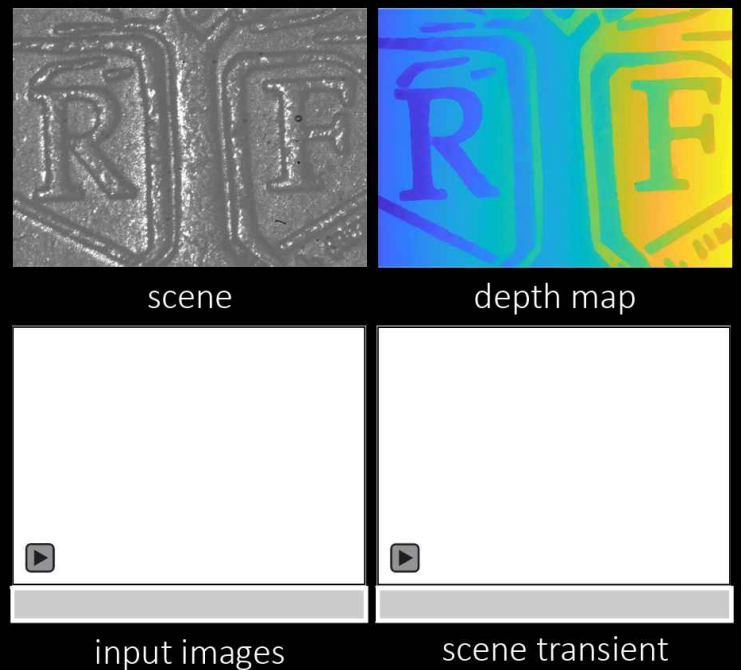
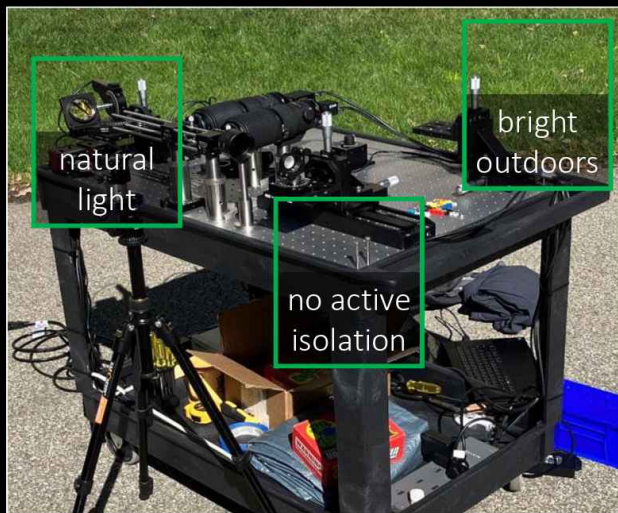


1000 × faster than a commercial Velodyne lidar



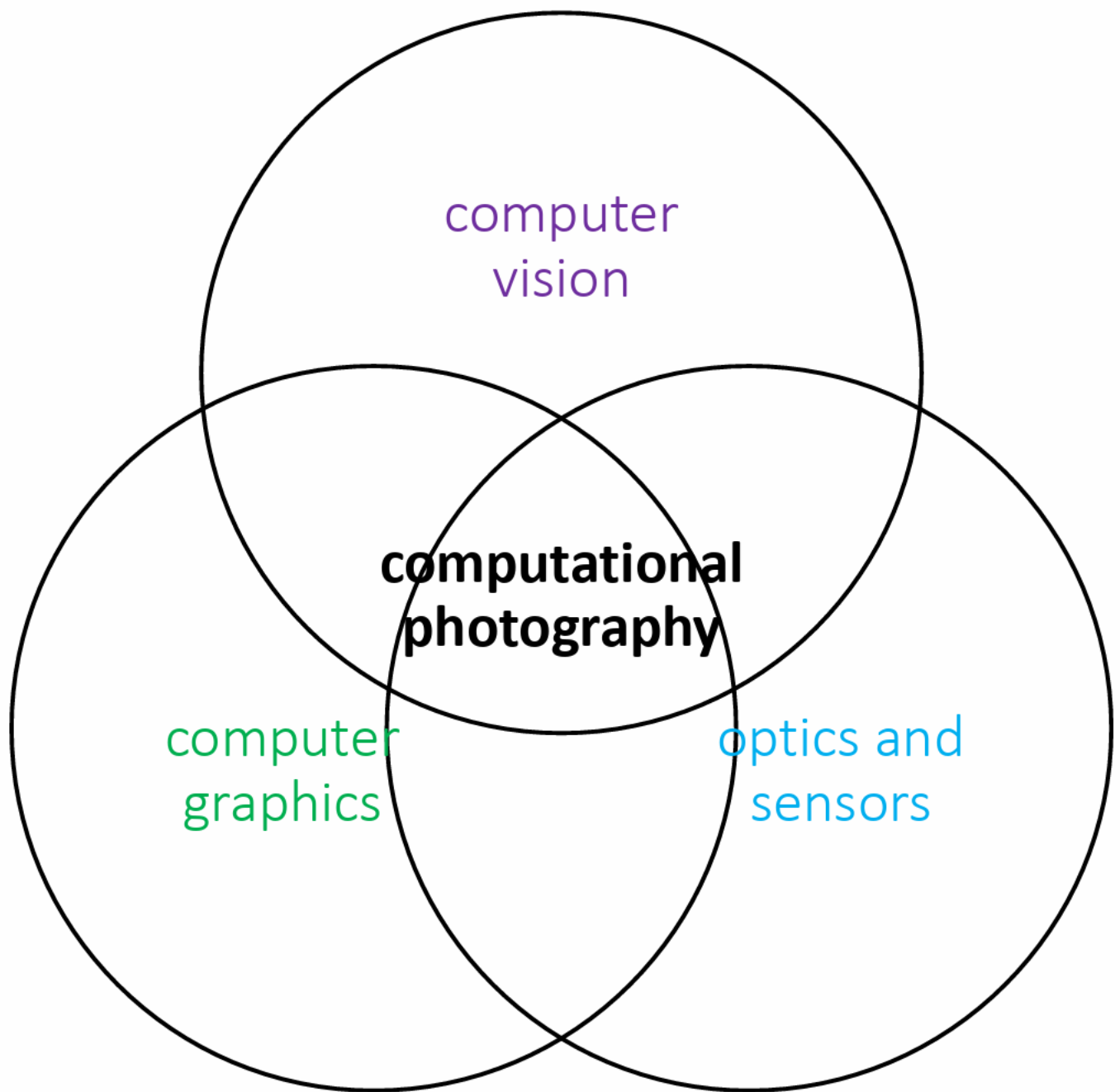
比商用 Velodyne 激光雷达快 1000 倍

## Sunlight micro-3D scanning



### 1. 什么是计算摄影





[Slide credit: Kris Kitani]

计算机视觉、计算机图形学、光学和传感器的交叉

## 1.1 传统（模拟）摄影（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)

## 1.2 数码摄影 (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)

## 1.3 计算摄影 (Computational photography)



optics to focus light on  
an image plane



digital sensor to capture focused  
light (electrical process)



arbitrary computation  
between sensor and image

### 1.3.1 克服数码摄影的局限性

图像增强和摄影外观

## Image enhancement and photographic look



camera output



image after stylistic tonemapping

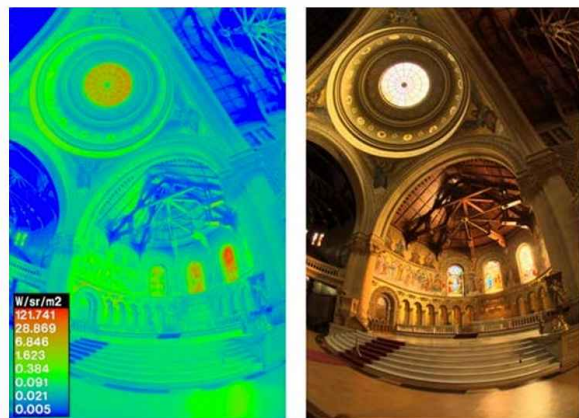
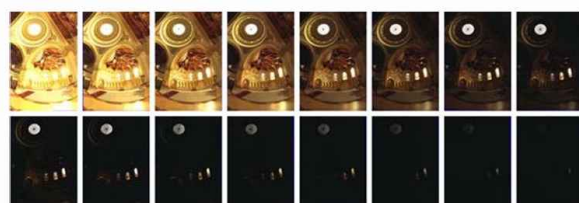
[Bae et al., SIGGRAPH 2006]

## 高动态范围 (HDR) 成像

### High dynamic range (HDR) imaging



One of your  
homeworks!



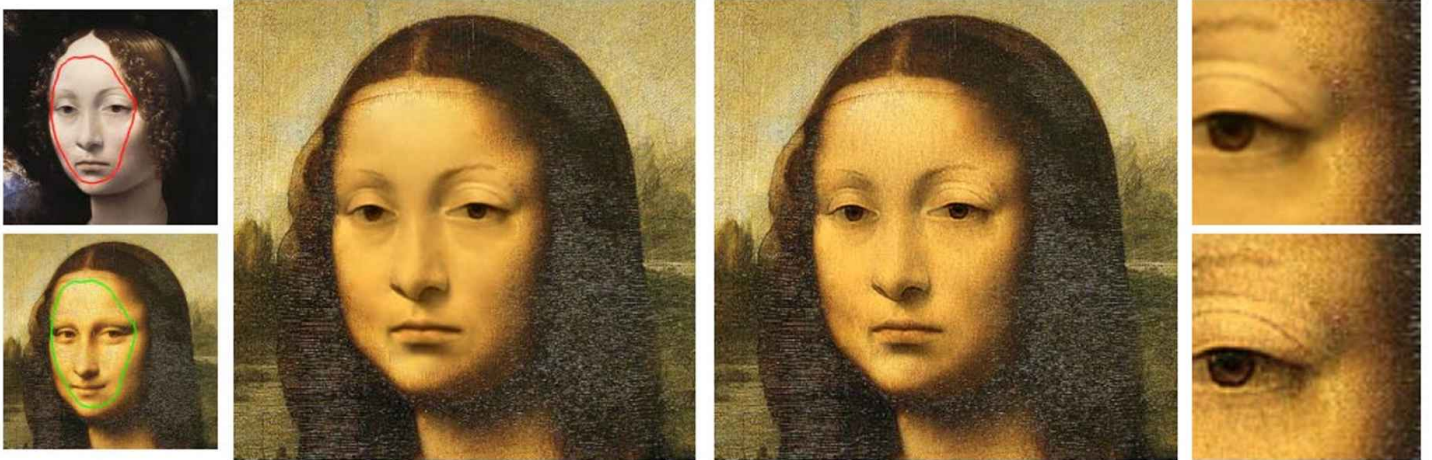
[example from [www.dpreview.com](http://www.dpreview.com)] [Debevec and Malik, SIGGRAPH 1997]

## 1.3.2 创造逼真的新图像

### 图像混合协调



## Image blending and harmonization



One of your  
homeworks!

[Sunkavalli et al., SIGGRAPH 2010]

### 1.3.3 拍照后图像合成

计算变焦

Computational zoom



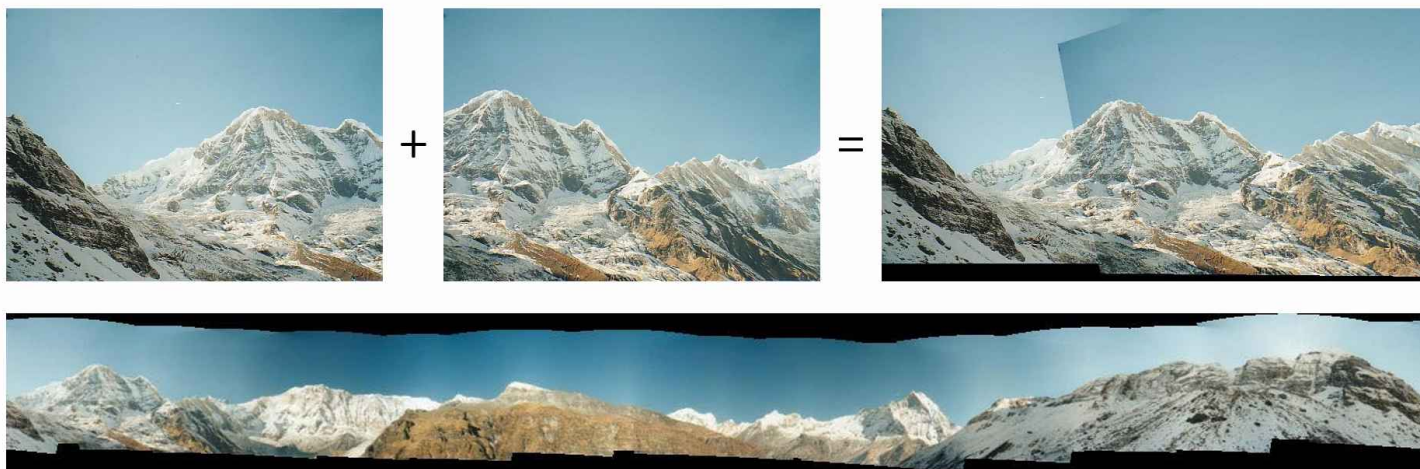
images captured at three zoom settings

post-capture synthesis of new zoom views

[Badki et al., SIGGRAPH 2017]

### 1.3.4 处理图像集合

## Auto-stitching images into panoramas



[Brown and Lowe, IJCV 2007]

### 1.3.5 处理很大的图像集合

#### 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]

有时区分计算摄影和计算成像，可以互换使用



generalized optics  
between scene and sensor



digital sensor to capture focused  
light (electrical process)



arbitrary computation  
between sensor and image

### 1.3.6 (Capture more than 2D images)

用于全光成像的光场相机



## Lightfield cameras for plenoptic imaging



post-capture refocusing

One of your  
homeworks!



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

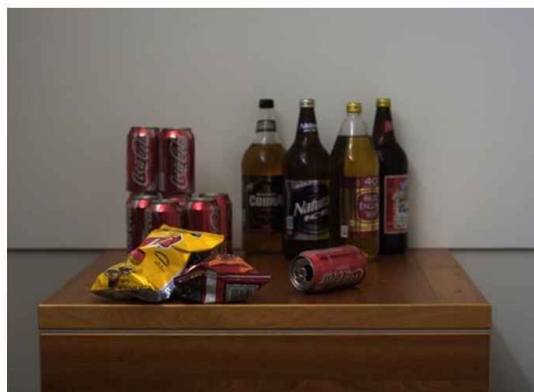
### 1.3.7 从单个 2D 图像测量 3D

用于单图像深度和重新聚焦的编码光圈

Coded aperture for single-image depth and refocusing



conventional vs  
coded lens



input image



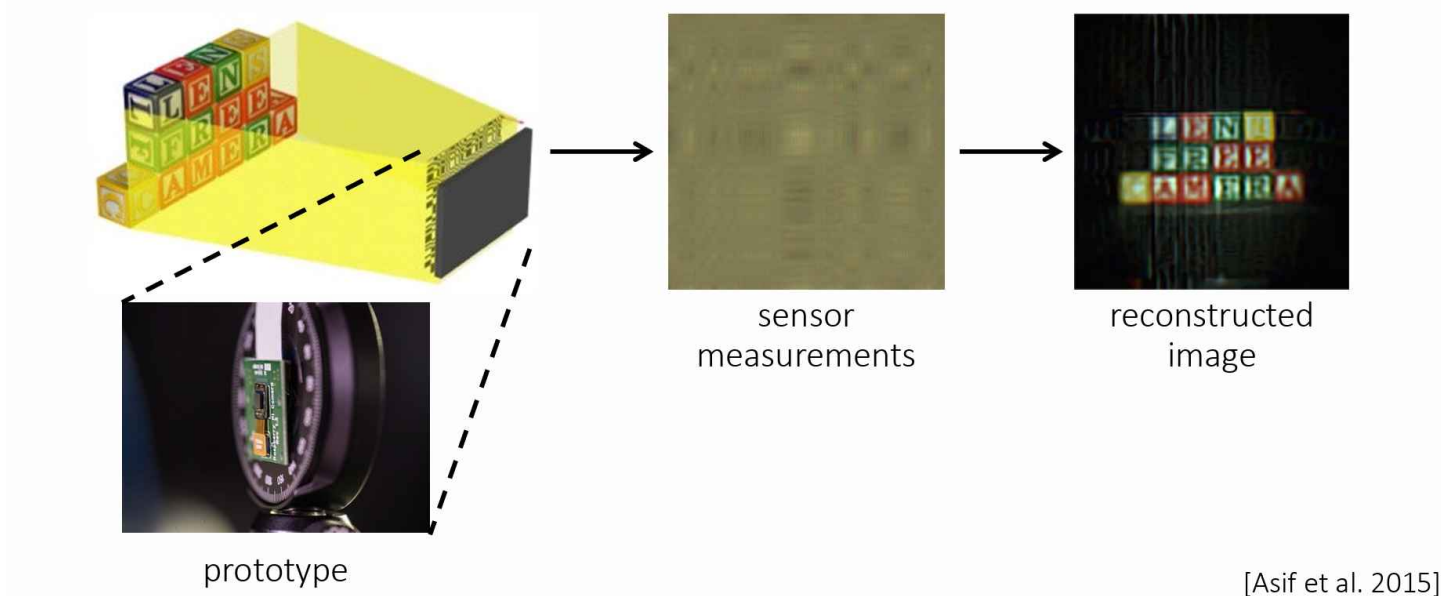
inferred depth

[Levin et al., SIGGRAPH 2007]

### 1.3.8 完全取下镜片

用遮罩代替镜头

## FlatCam: replacing lenses with masks



## 非常规传感和照明



generalized optics  
between scene and sensor



unconventional sensing  
and illumination

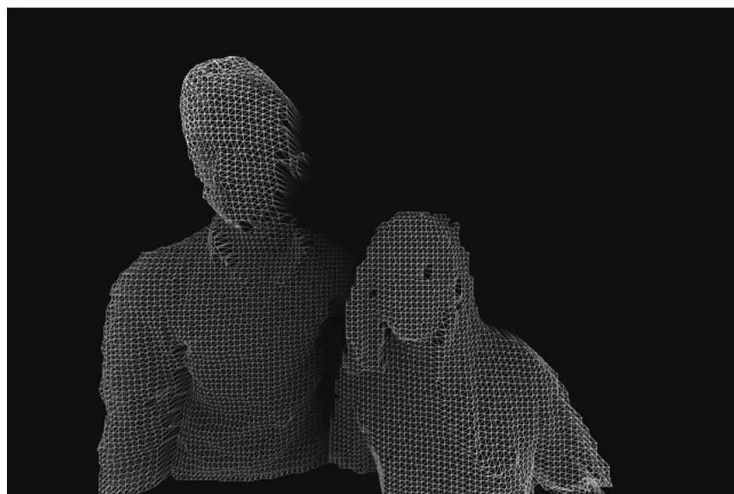


arbitrary computation  
between sensor and image

### 1.3.9 测量深度

用于实时深度传感的飞行时间传感器

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

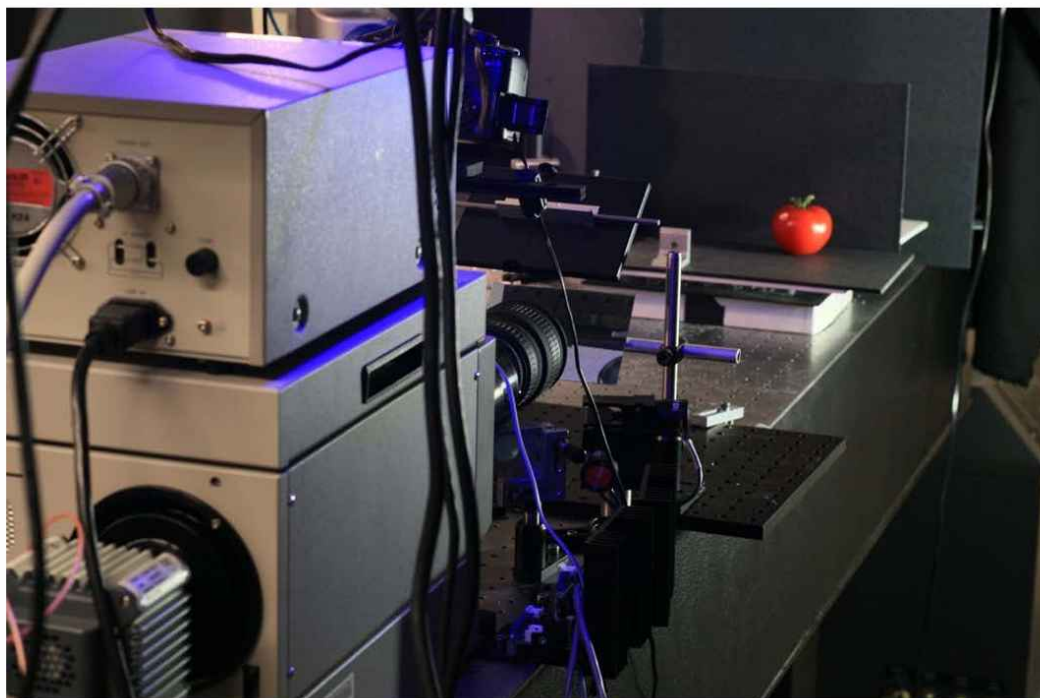


[Microsoft Inc.]

### 1.3.10 测量飞行中的光

用于飞秒摄影的条纹相机

## Streak camera for femtophotography



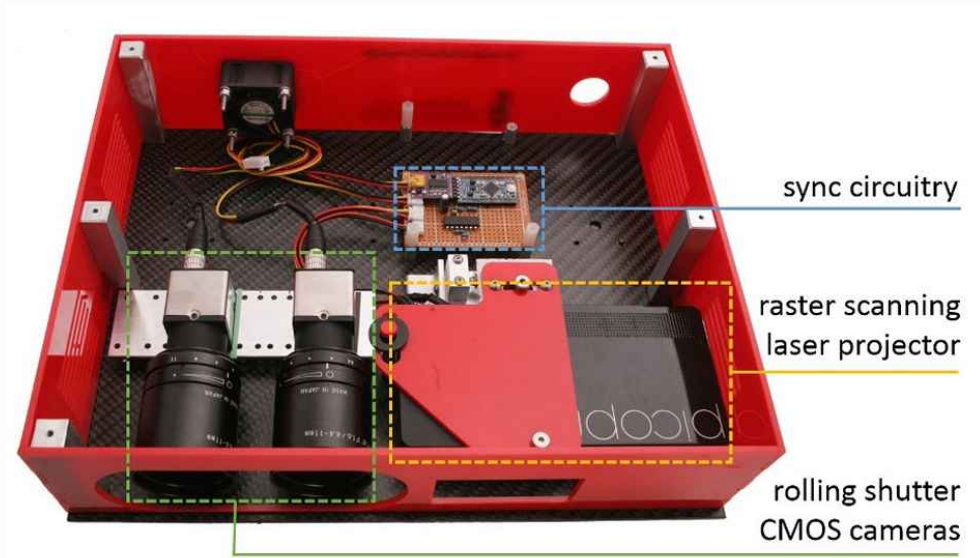
[Velten et al., SIGGRAPH 2013]

### 1.3.11 有选择地测量光子

用于极线成像的结构光



# Structured light for epipolar imaging

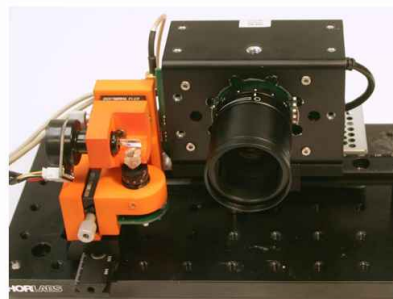


[O’ Toole et al., SIGGRAPH 2015]

## 光学、照明、传感器和计算的联合设计



generalized optics  
between scene and sensor



unconventional sensing  
and illumination

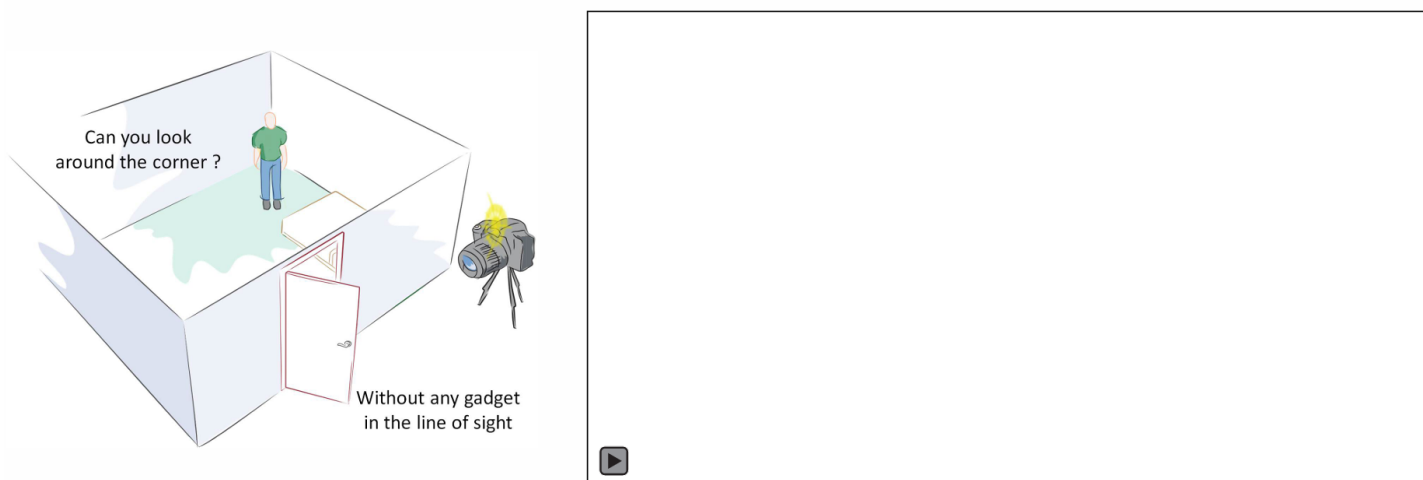


arbitrary computation  
between sensor and image

joint design of optics, illumination, sensors, and computation

### 1.3.12 Putting it all together

## Looking around corners



[MIT Media Lab, DARPA REVEAL]

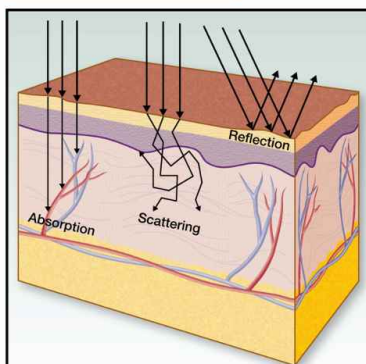
## Looking through tissue

### Opportunity



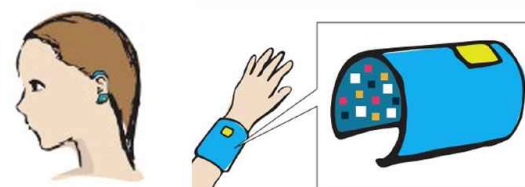
- + Light travels deep inside the body
- + It is non-ionizing (400-1100nm)
- + Cheap to produce and control

### 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]

## 2. 涵盖的主题

### 2.1 数码摄影 (Digital photography)

#### 2.1.1 光学和镜头 (optics and lenses)

#### 2.1.2 颜色 (color)

#### 2.1.3 曝光 (exposure)

#### 2.1.4 光圈 (aperture)

#### 2.1.5 焦点和景深 (focus and depth of field)

#### 2.1.6 图像处理管道 (image processing pipeline)

### 2.2 图像处理和融合 (Image manipulation and fusion)

#### 2.2.1 高动态范围成像 (high-dynamic-range imaging)

#### 2.2.2 双边滤波 (bilateral filtering)

#### 2.2.3 边缘感知滤波 (edge-aware filtering)

#### 2.2.4 梯度域图像处理 (gradient-domain image processing)

#### 2.2.5 闪光/无闪光摄影 (flash/no-flash photography)

#### 2.2.6 高性能图像处理 (high-performance image processing)

### 2.3 相机类型

#### 2.3.1 几何相机模型 (geometric camera models)

#### 2.3.2 光场相机 (lightfield cameras)

#### 2.3.3 编码相机 (coded cameras)

#### 2.3.4 无镜头相机 (lensless cameras)

#### 2.3.5 压缩相机 (compressive cameras)

#### 2.3.6 高光谱相机 (hyperspectral cameras)

### 2.4 主动照明和传感 (Active illumination and sensing)

#### 2.4.1 飞行时间传感器 (time-of-flight sensors)



2.4.2 结构光 (structured light)

2.4.3 计算光传输 (computational light transport)

2.4.4 瞬态成像 (transient imaging)

2.4.5 非视距成像 (non-line-of-sight imaging)

2.4.6 光计算 (optical computing)

## 突击测验

1. 高斯和盒式滤波 (Gaussian and box filtering)

2. 卷积和傅里叶变换 (Convolution and Fourier transform)

3. 锯齿和抗锯齿 (Aliasing and anti-aliasing)

4. 拉普拉斯金字塔 (Laplacian pyramid)

5. 泊松混合 (Poisson blending)

6. 齐次坐标 (Homogeneous coordinates)

7. 同应词 (Homography)

8. 兰萨克 (RANSAC)

9. 对极几何 (Epipolar geometry)

10. XYZ 空间 (XYZ space)

11. 多视图立体 (Multi-view stereo)

12. 辐射度和辐射测量 (Radiance and radiometry)

13. 朗伯反射、漫反射和镜面反射 (Lambertian, diffuse, and specular reflectance)

14. n-dot-l 照明 (n-dot-l lighting)

15. 薄镜头、定焦镜头和变焦镜头 (Thin lens, prime lens, and zoom lens)

16. 去马赛克 (Demosaicing)

17. 折射和衍射 (Refraction and diffraction)

## Final project

Previous years' projects for inspiration: [Fall 2020](#) , [Fall 2021](#) , [Fall 2022](#)

## Homework assignment

Previous years' results for inspiration: [Fall 2022](#)

## 相关链接

Website: <https://imaging.cs.cmu.edu/>

YouTube: <https://www.youtube.com/@cmu-computational-imaging>

International Conference on Computational Photography YouTube channel  
<https://www.youtube.com/@iccp-conference>