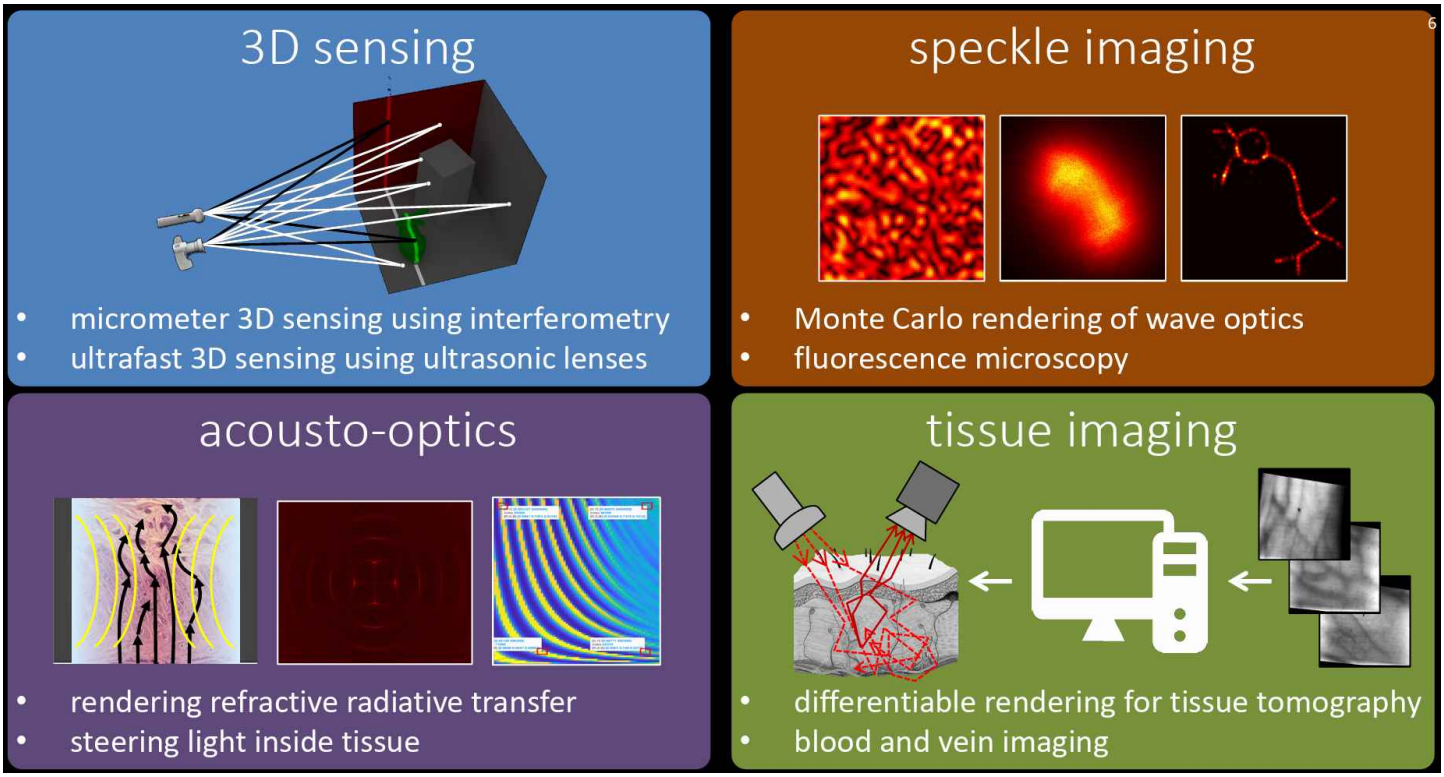
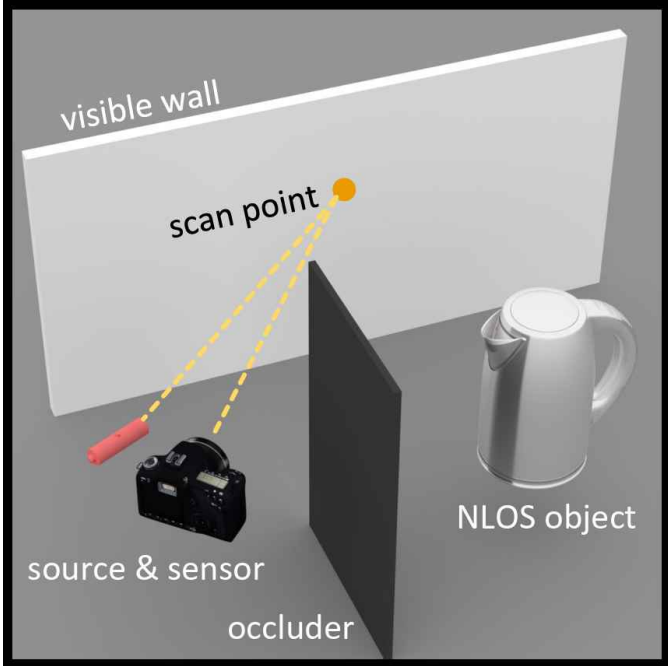
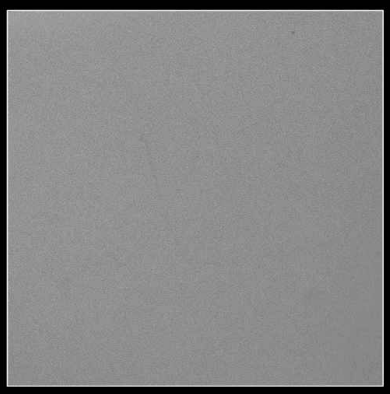
1. Introduction



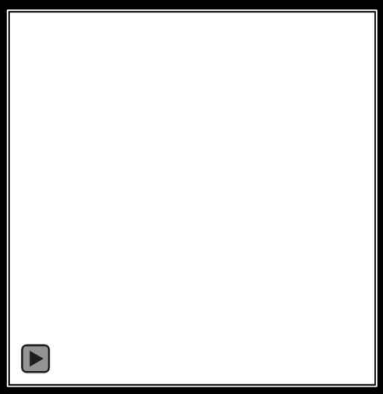
1. 3D 传感
    - 使用干涉测量法进行微米级3D传感
    - 使用超声波透镜的超快3D传感
2. 散斑成像
3. 声光
4. 组织成像
    - 组织断层扫描的可微渲染
    - 血液和静脉成像

Looking around corners





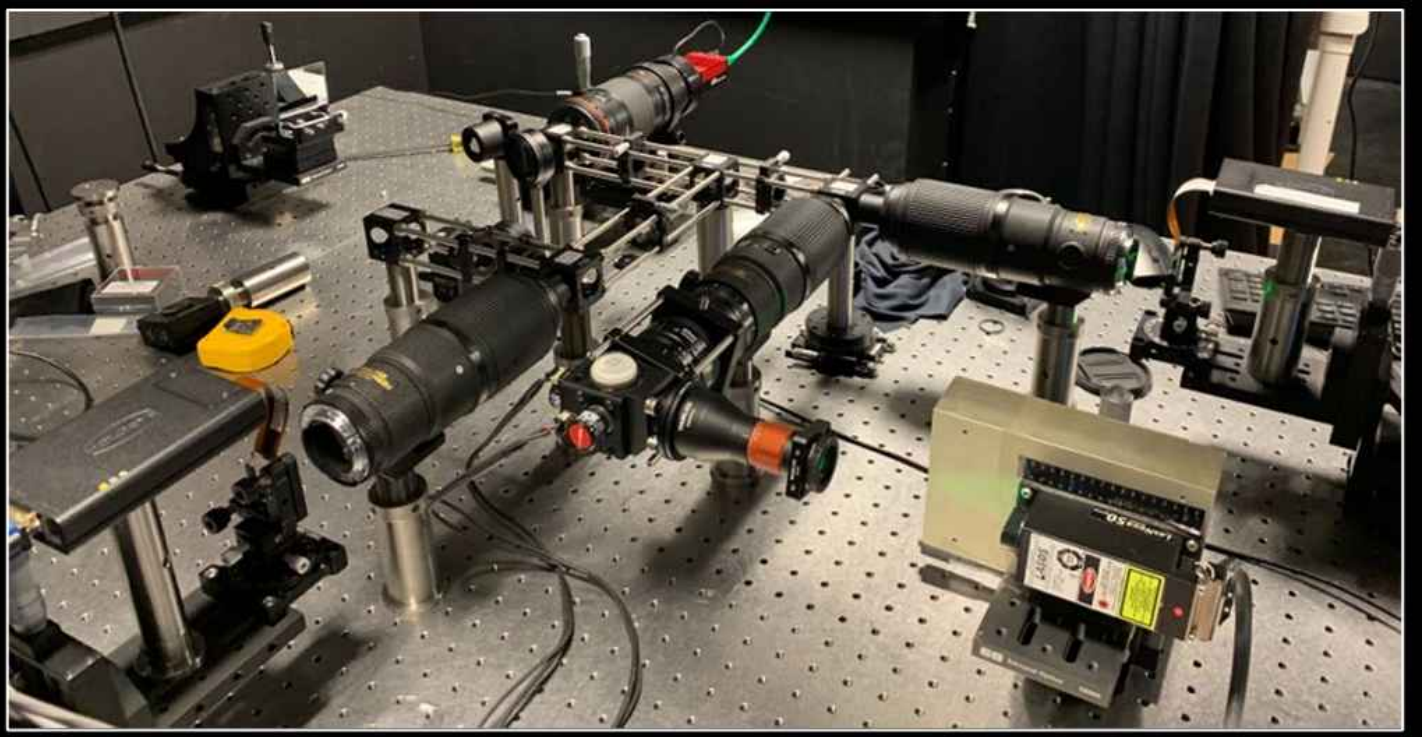
what a regular camera sees



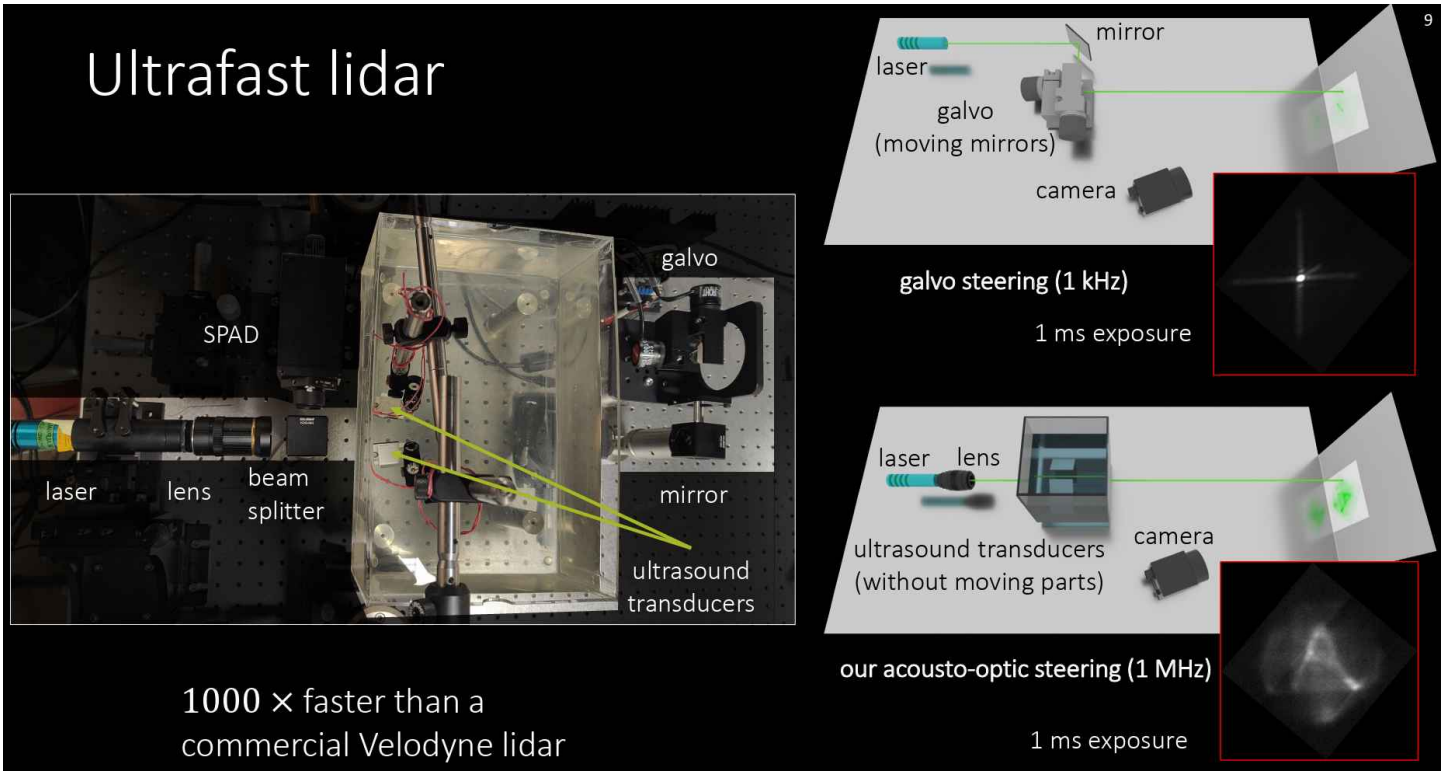
what we can reconstruct

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

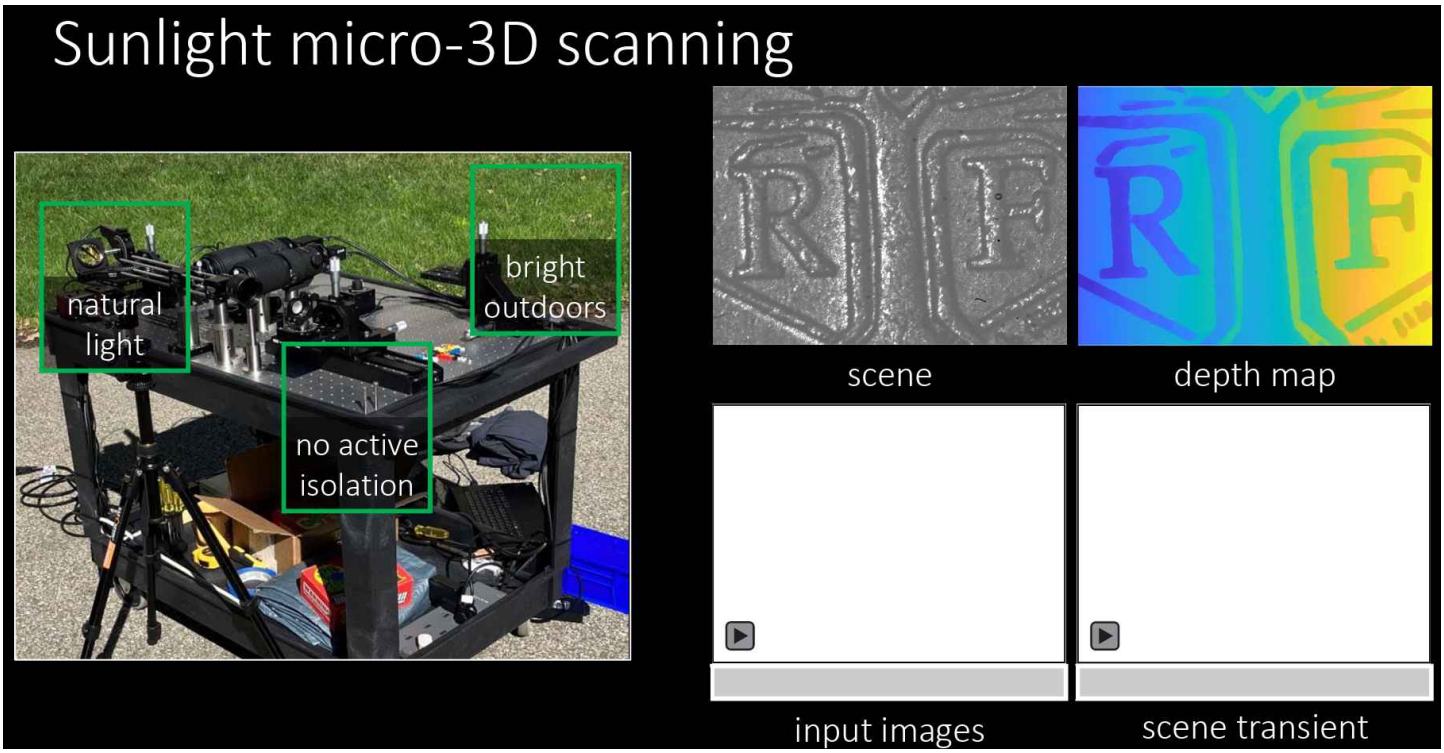
Seeing light in flight



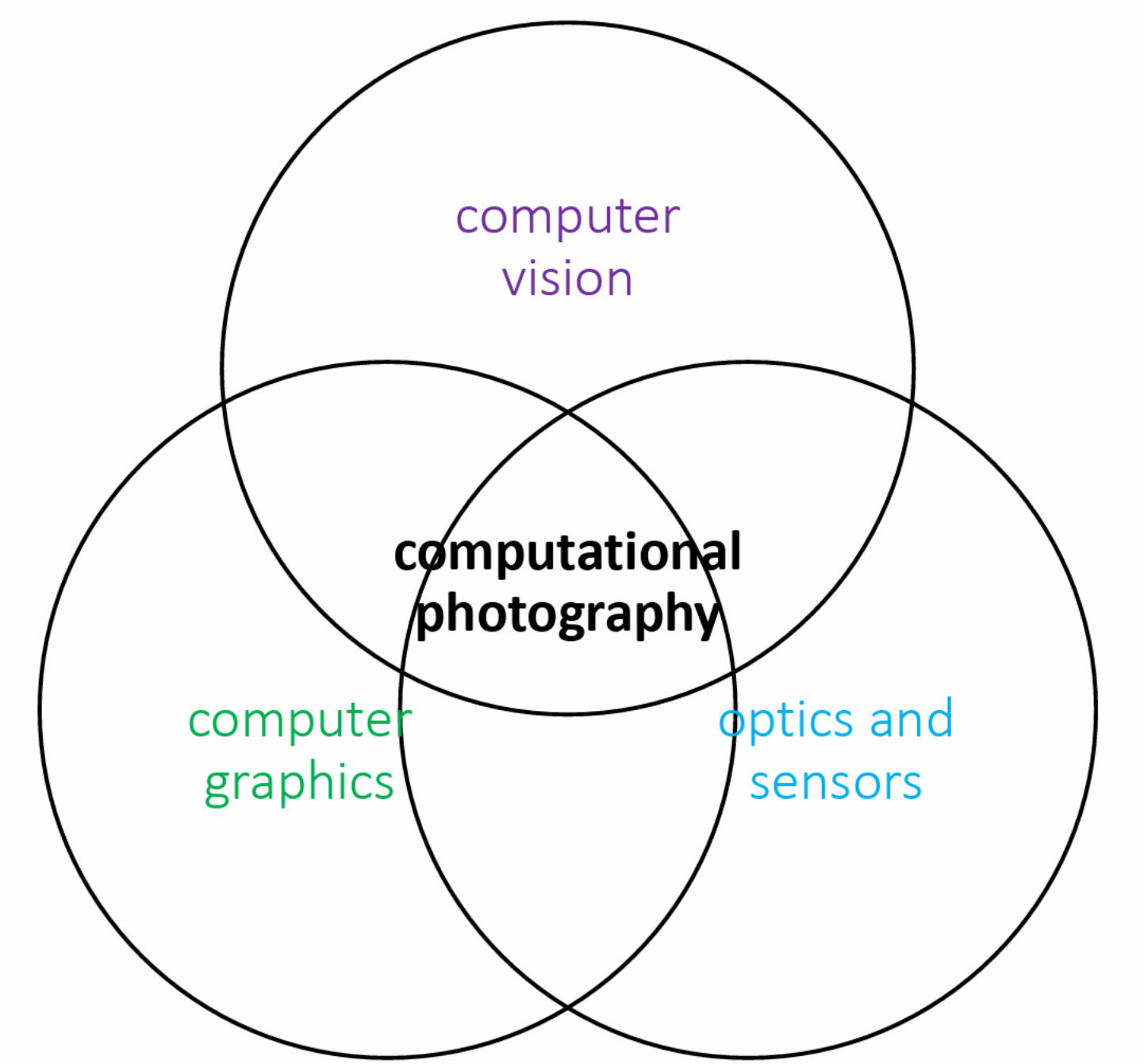
camera for capturing video at 10^{15} frames per second



比商用 Velodyne 激光雷达快 1000 倍



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

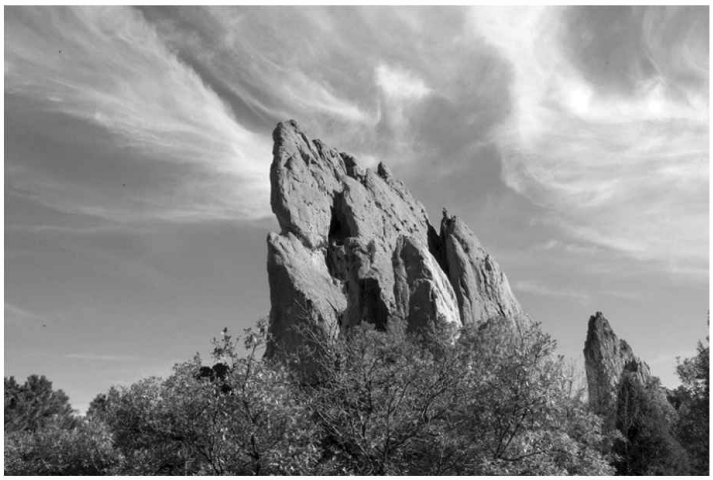
digital sensor to capture focused light (electrical process)

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

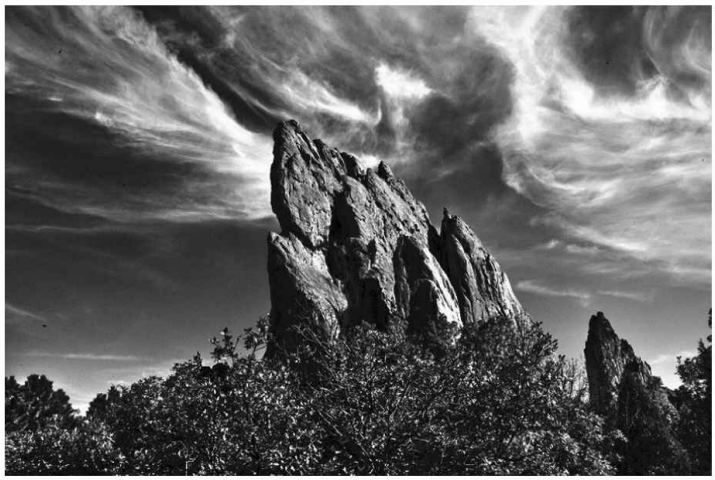
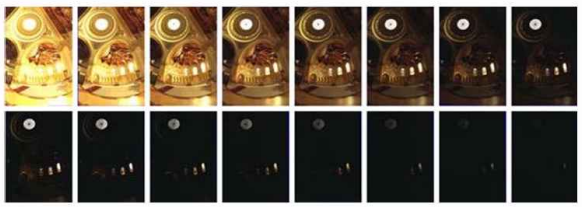


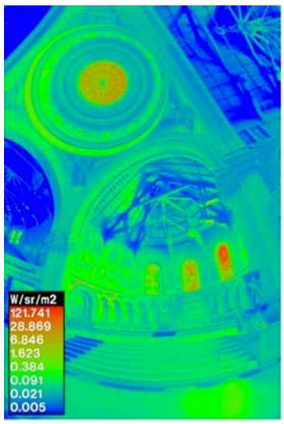
image after stylistic tonemapping

[Bae et al., SIGGRAPH 2006]

高动态范围（HDR）成像

High dynamic range (HDR) imaging





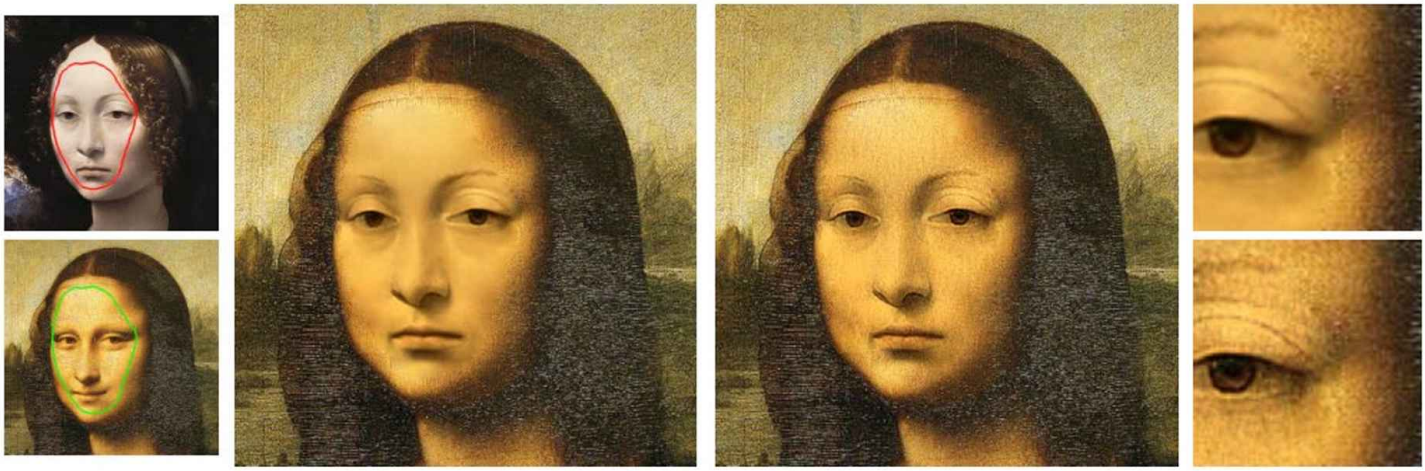
One of your homeworks!

[example from www.dpreview.com] [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

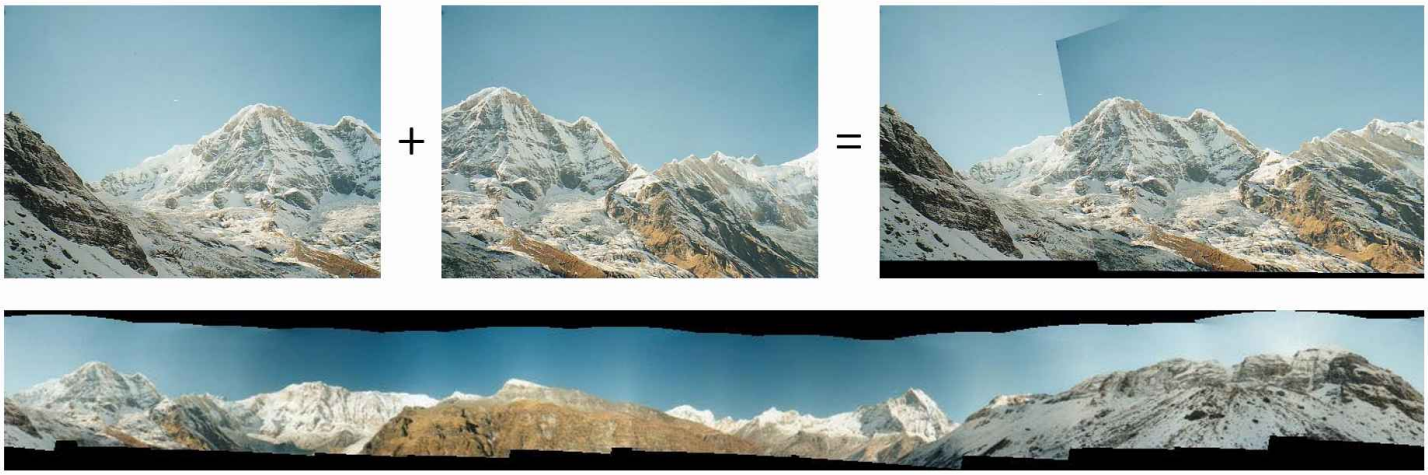
images captured at three zoom settings

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

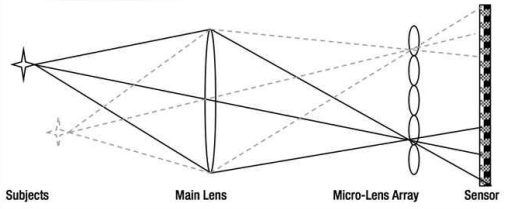
1.3.6 （Capture more than 2D images）

用于全光成像的光场相机

Lightfield cameras for plenoptic imaging

post-capture refocusing

One of your homeworks!



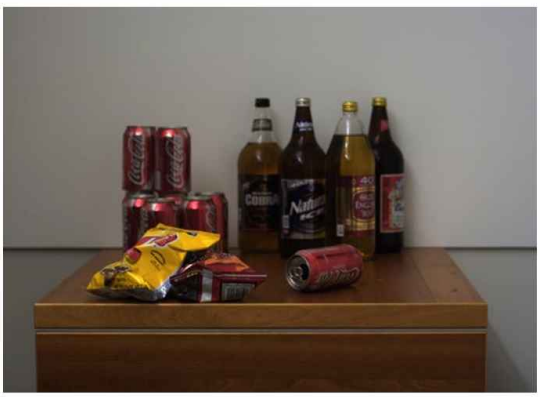
[Ng et al., SIGGRAPH 2005] [Lytro Inc.]

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

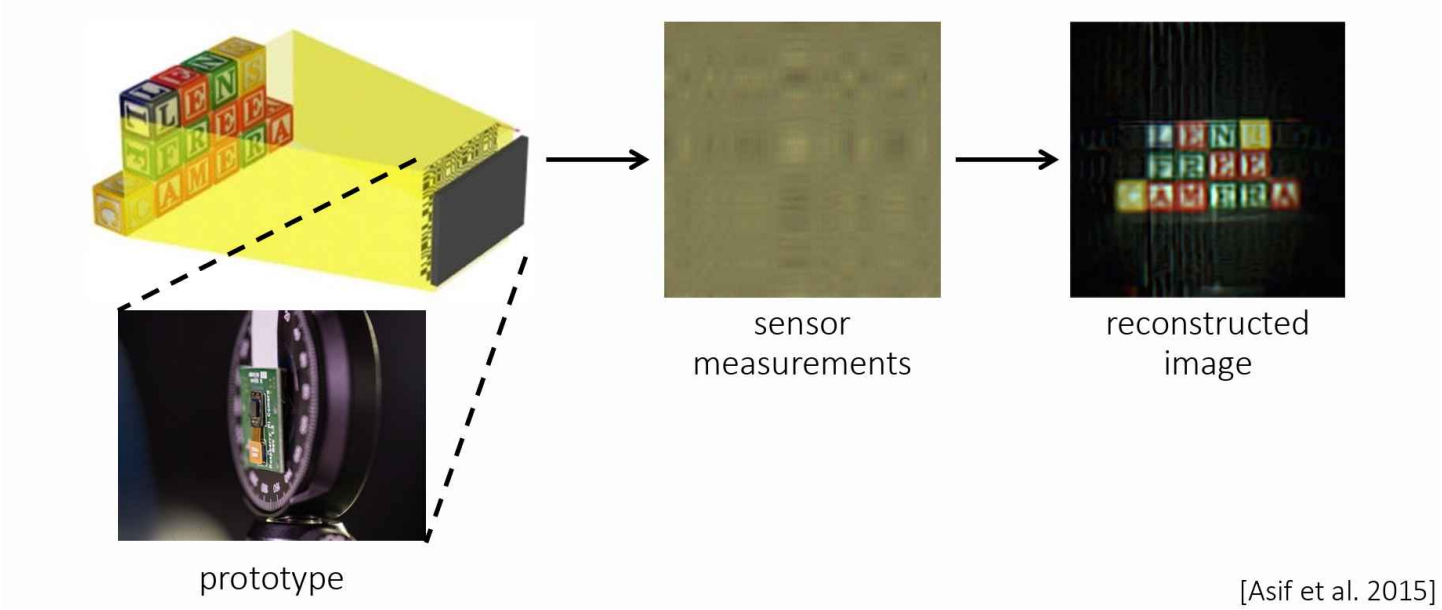
inferred depth

[Levin et al., SIGGRAPH 2007]

1.3.8 完全取下镜片

用遮罩代替镜头

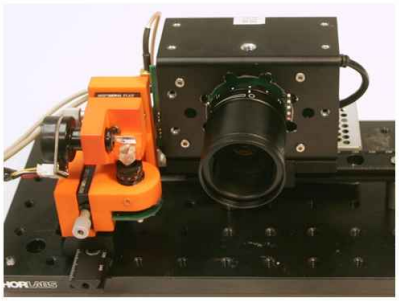
FlatCam: replacing lenses with masks



[Asif et al. 2015]

非常规传感和照明

generalized optics
between scene and sensor



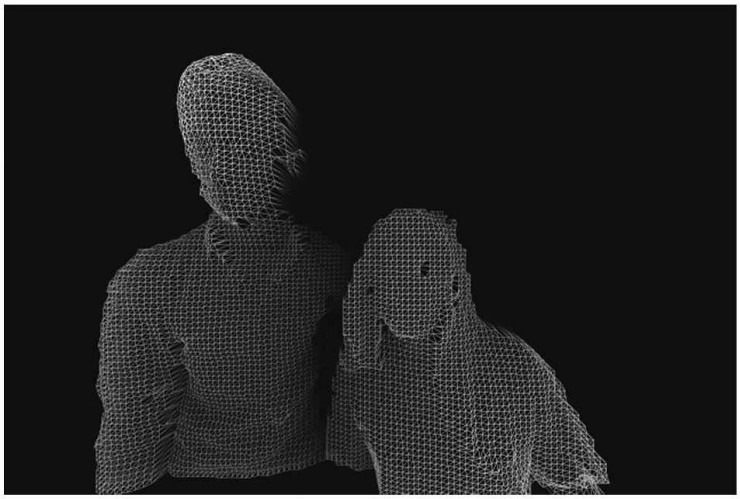
unconventional sensing
and illumination

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

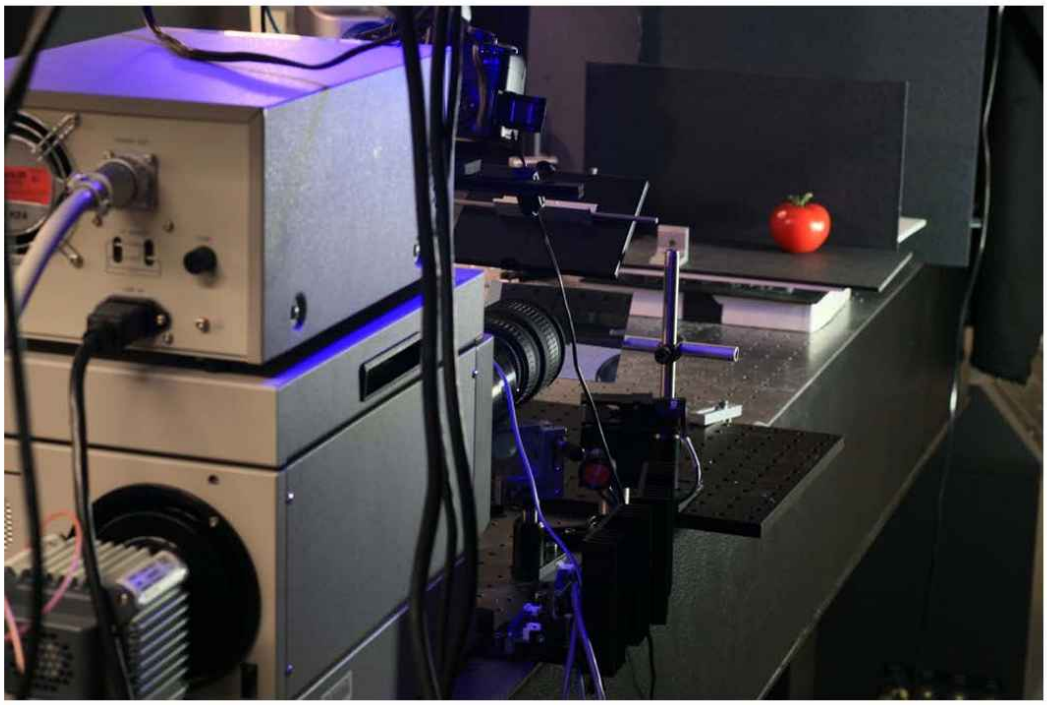


[Microsoft Inc.]

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

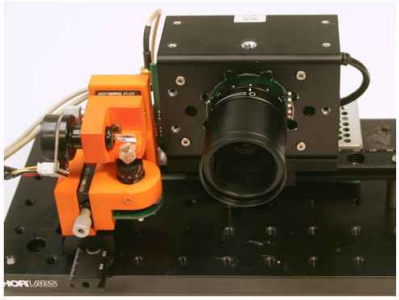
用于极线成像的结构光

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



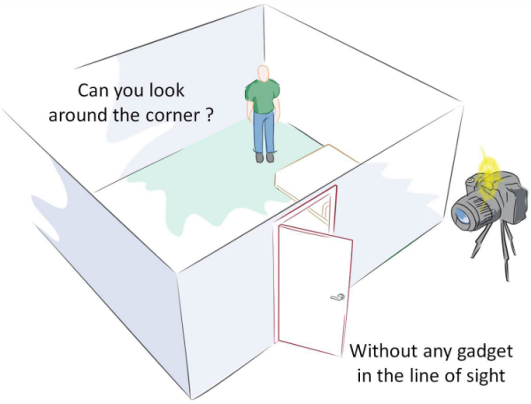
unconventional sensing
and illumination

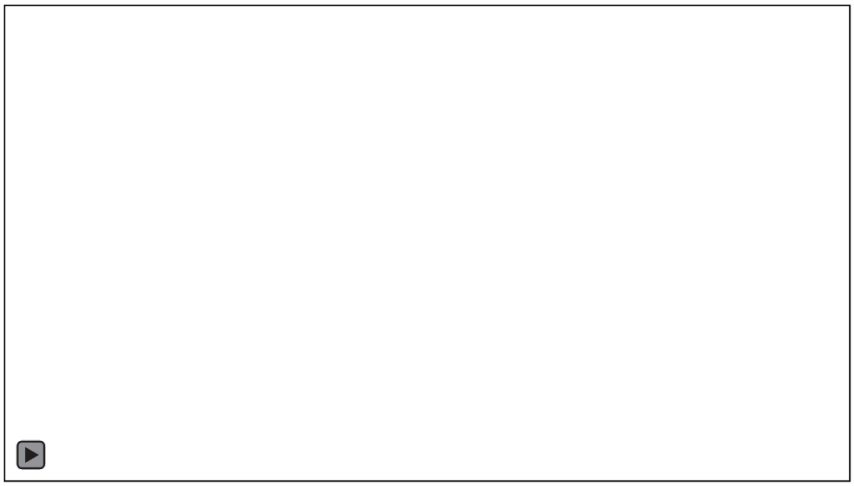
arbitrary computation
between sensor and image

joint design of optics, illumination, sensors, and computation

1.3.12 Putting it all together

Looking around corners





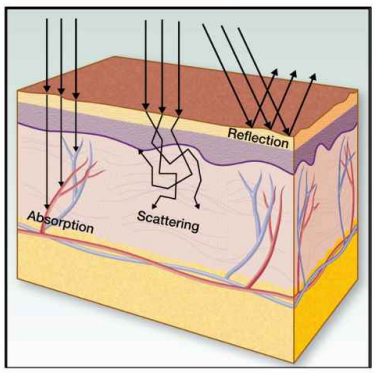
[MIT Media Lab, DARPA REVEAL]

Looking through tissue

Opportunity

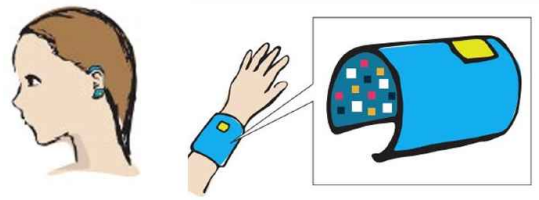
+ Light travels deep inside the body
+ It is non-ionizing (400-1100nm)
+ Cheap to produce and control

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）

2.4.2 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