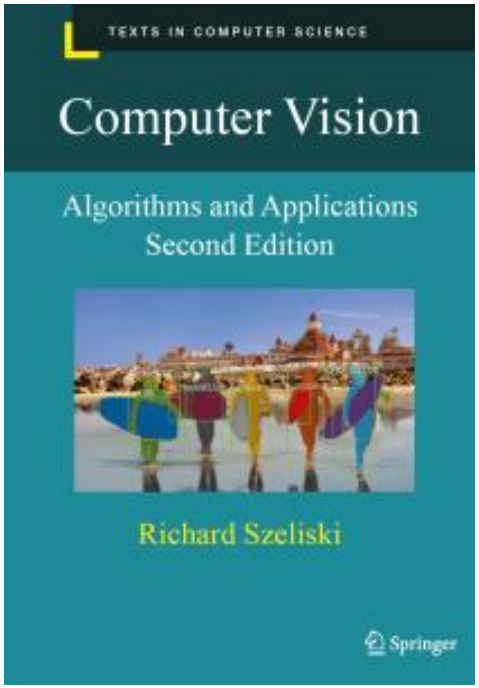
UNIVERSITÉ DE GENÈVE
FACULTY OF SCIENCE
Department of Informatics

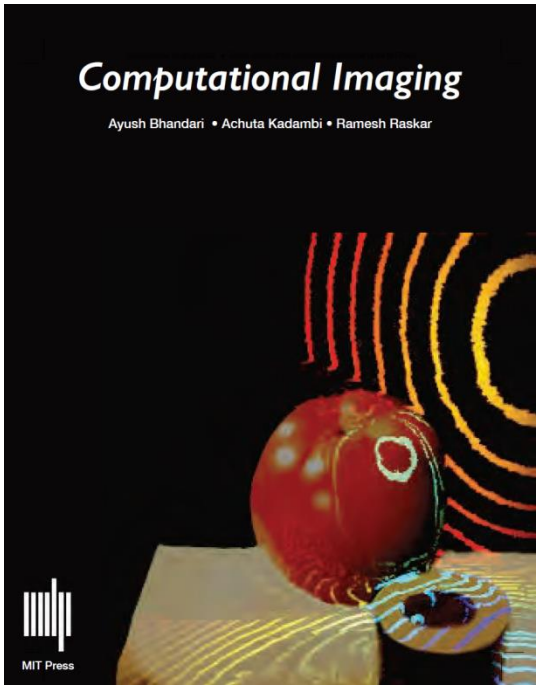
SIP stochastic information processing

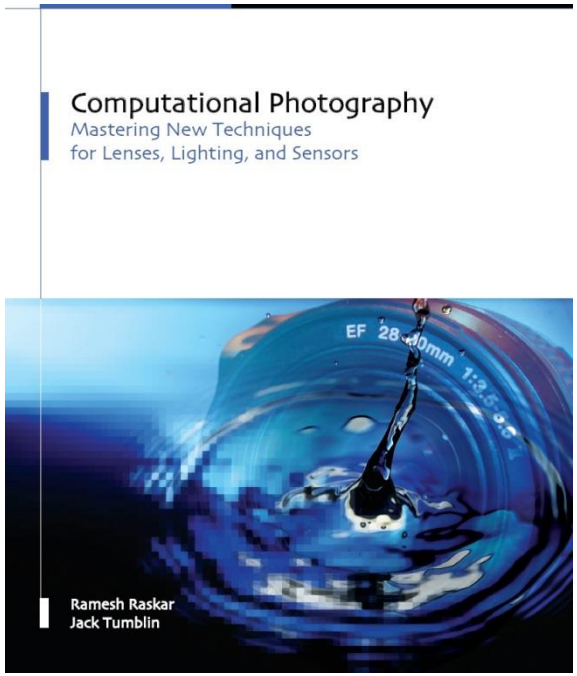
Computational imaging

Taras Holotyak

Recommended books





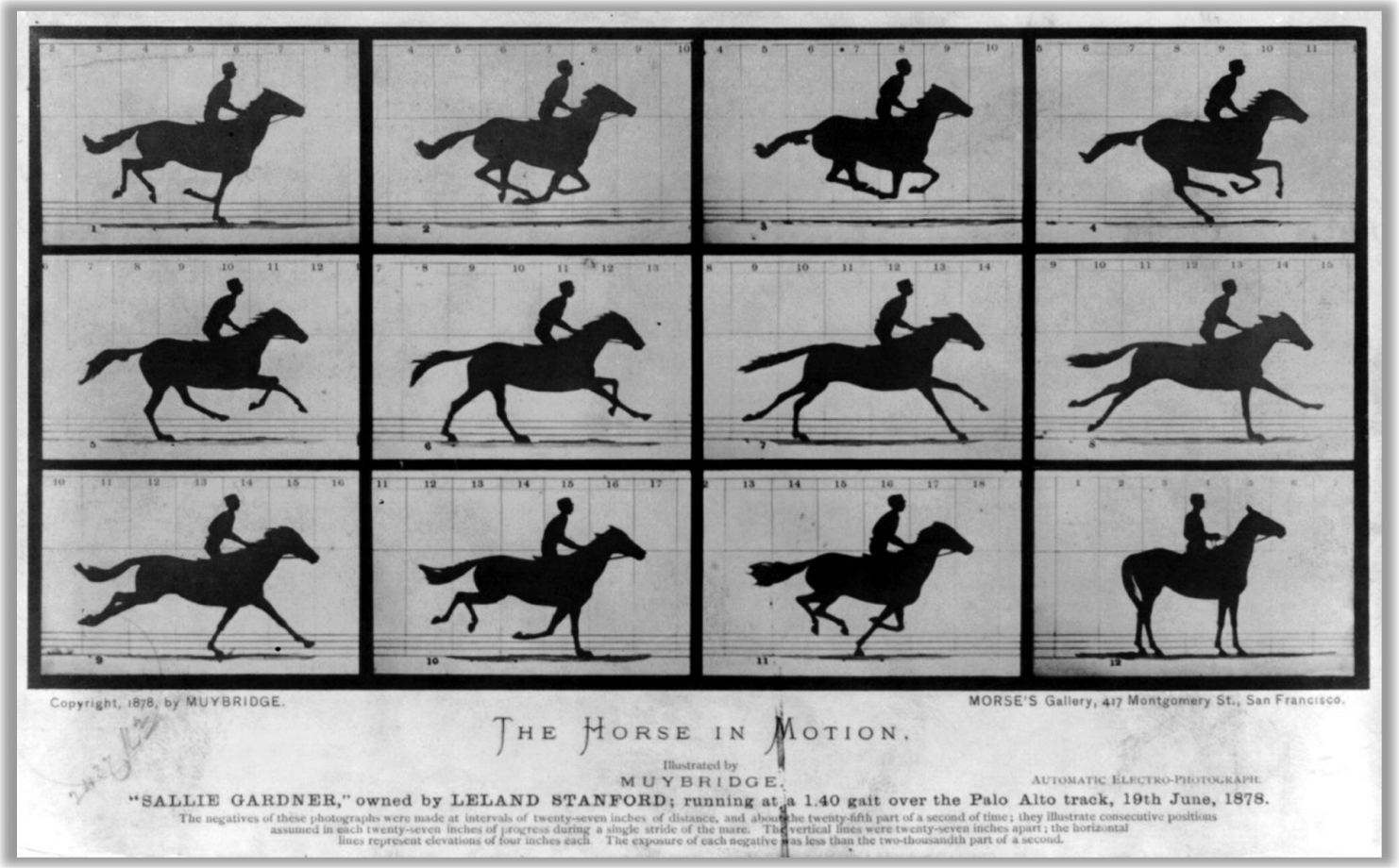


Content

- Introduction to computational imaging
- Motivating examples in computational imaging
- Main topics of computational imaging
- References

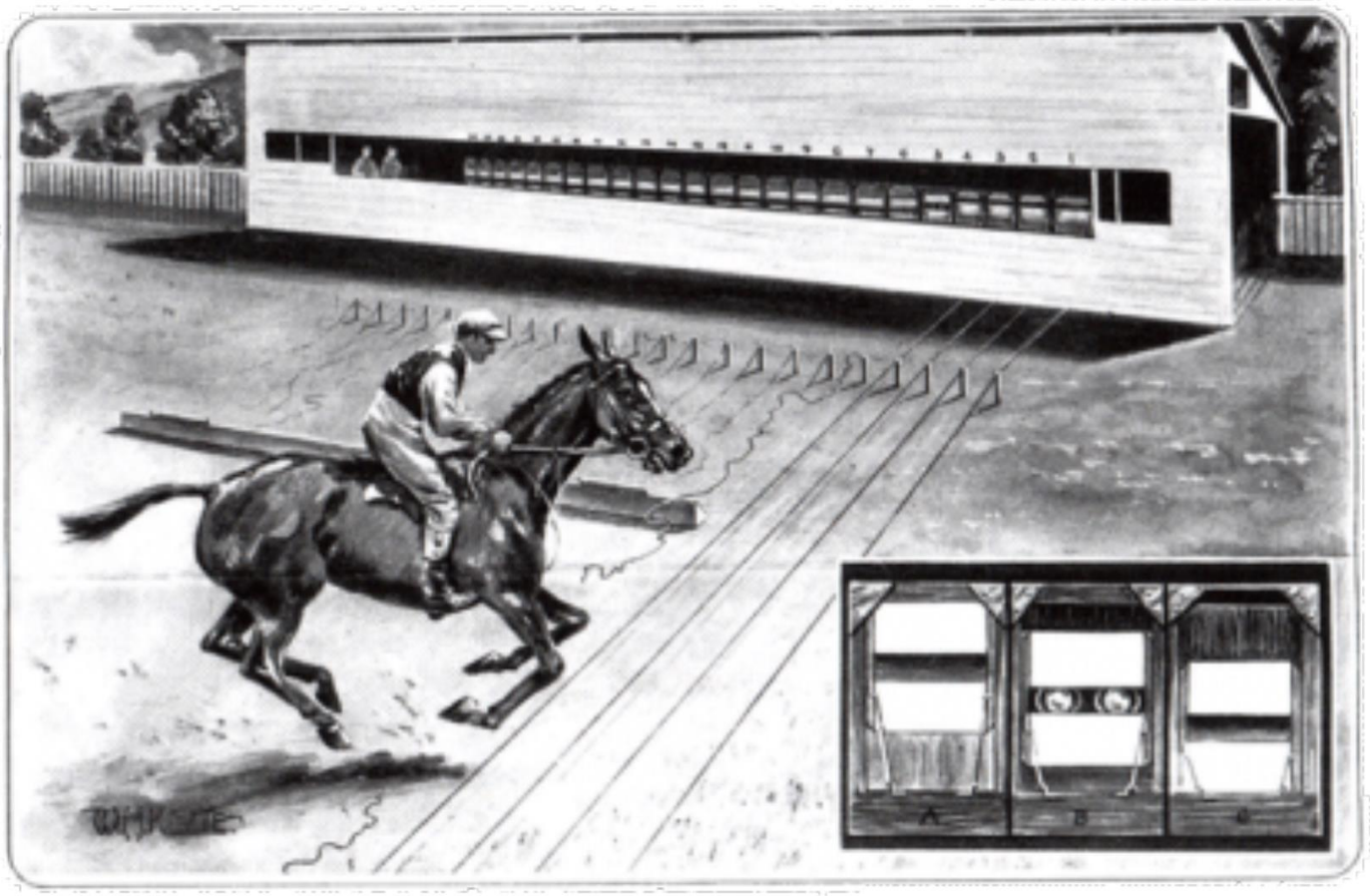
Introduction to computational imaging

Muybridge's multi-camera array (1878)



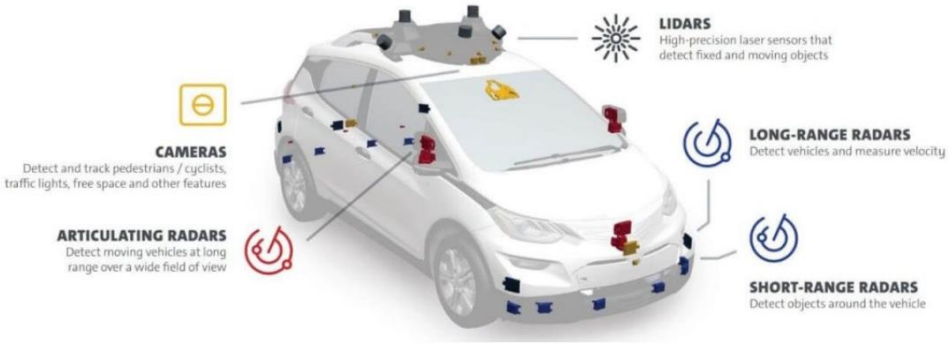
Introduction to computational imaging

Muybridge's multi-camera array (1878)



Introduction to computational imaging

Modern areas of computational imaging



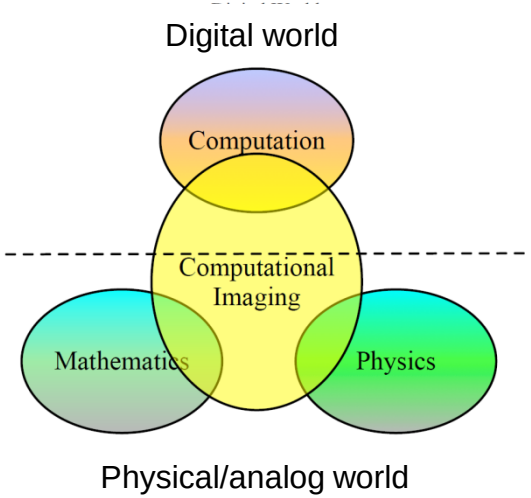
Introduction to computational imaging

Example of biological computational imaging

Introduction to computational imaging

What is computational imaging?

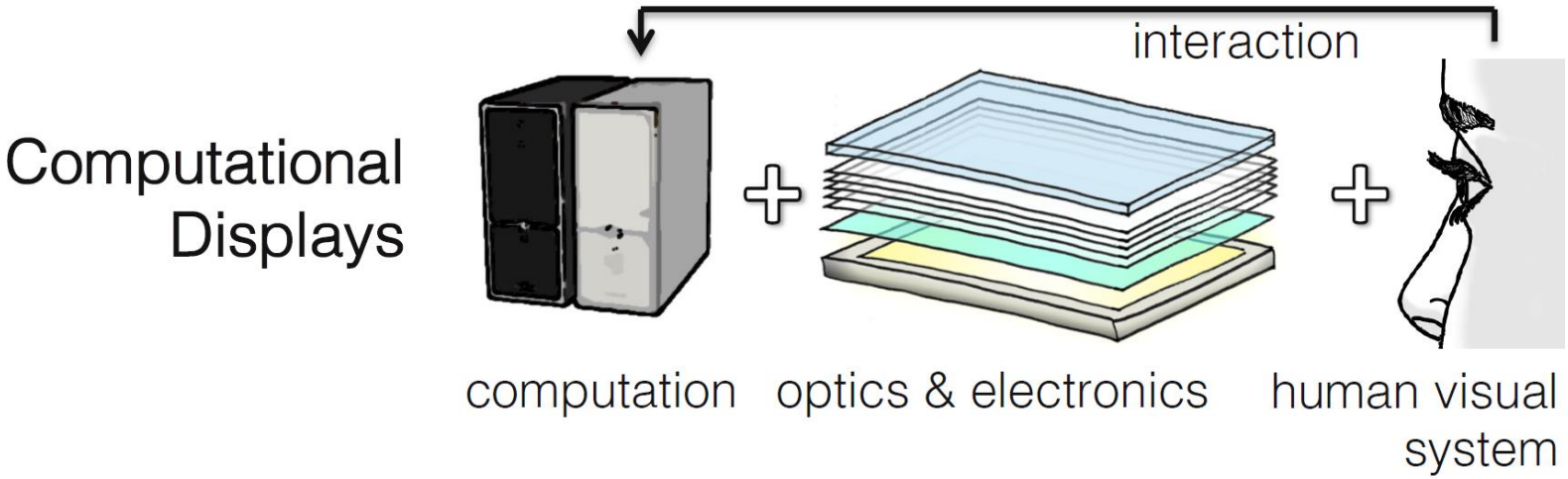
The revolution in sensing, with the emergence of many new imaging techniques, offers the possibility of gaining unprecedented access to the physical world, but this revolution can only bear fruit through the skillful interplay between the physical and computational worlds. This is the domain of computational imaging which advocates that, to develop effective imaging systems, it will be necessary to go beyond the traditional decoupled imaging pipeline where device physics, image processing and the end-user application are considered separately. Instead, we need to rethink imaging as an integrated sensing and inference model.



- Access to the physical/analog and digital worlds
- Consideration of imaging as an integrated sensing and inference model

Introduction to computational imaging

What is computational imaging?

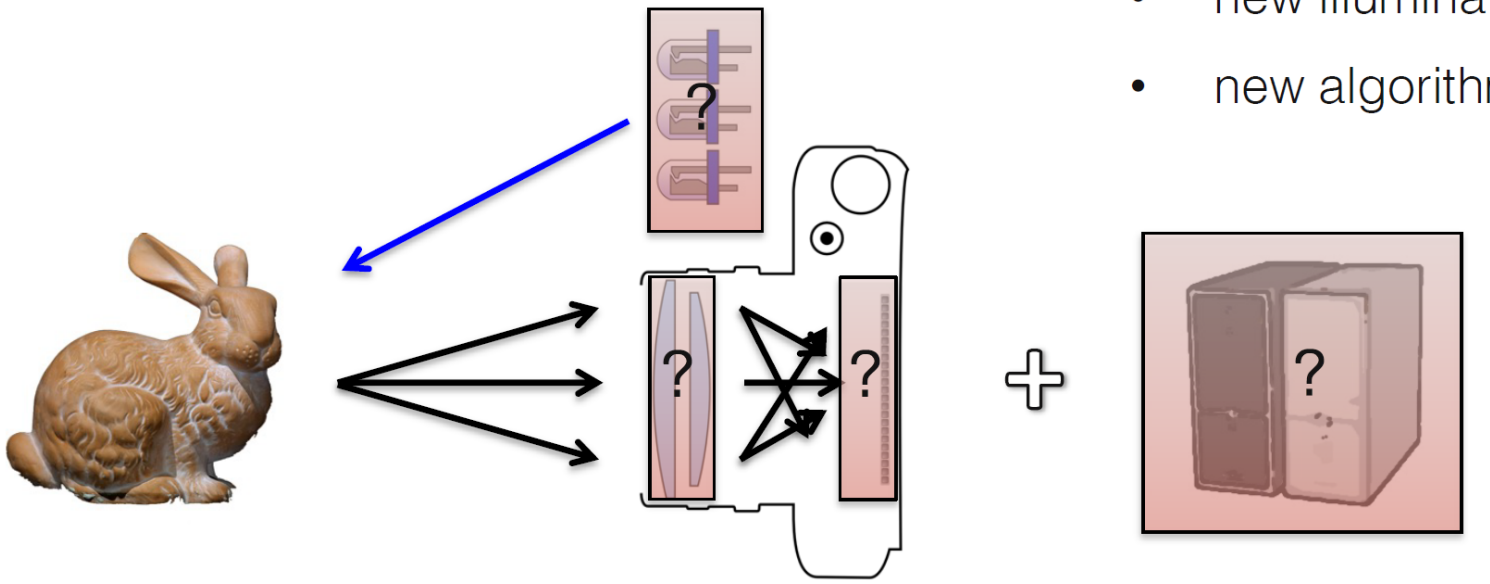


Introduction to computational imaging

What is computational imaging?

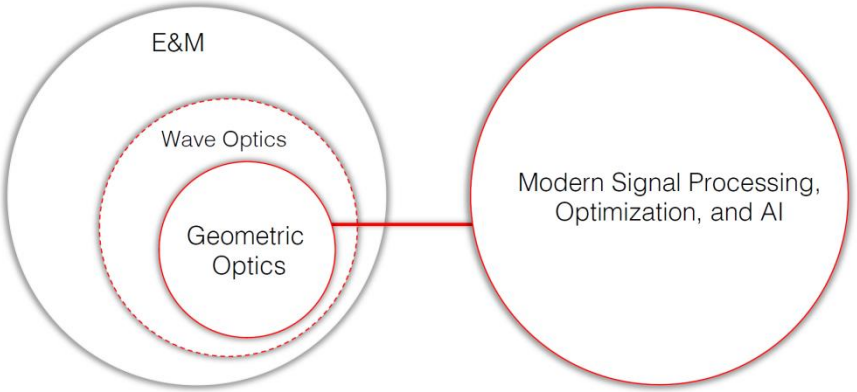
1. optically encode scene information
2. computationally recover information

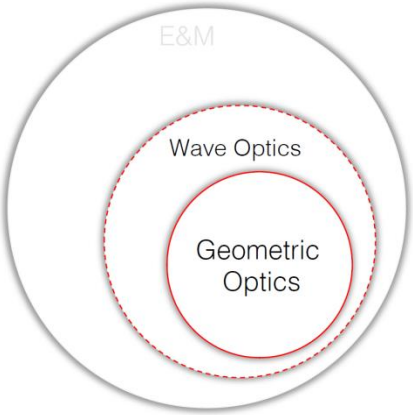
- new optics
- new sensors
- new illumination
- new algorithms



Introduction to computational imaging

What is computational imaging?





- light as rays
- unit: (spectral) radiance
- properties: wavelength, polarization, direction, …
- only brief introduction & outlook for wave optics

Motivating examples in computational imaging

Imaging by mobile devices

Motivating examples in computational imaging

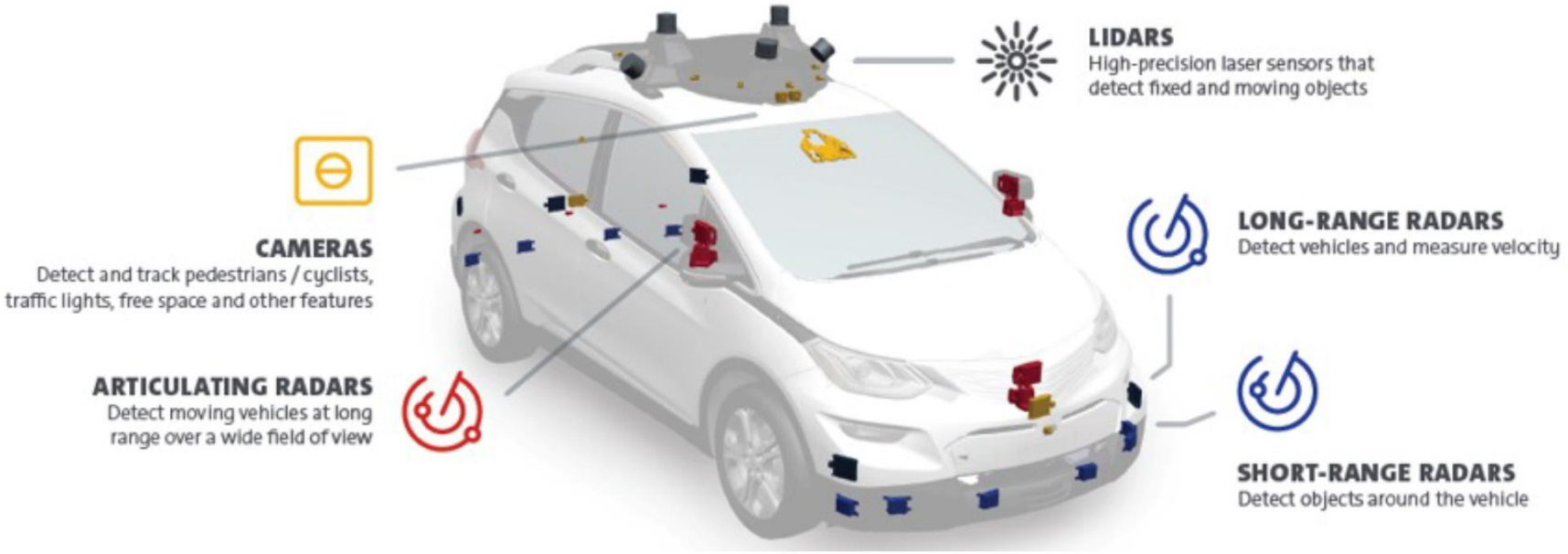
Digital photography

Motivating examples in computational imaging

Multi-sensor / hyperspectral imaging

Motivating examples in computational imaging

Self-driving cars



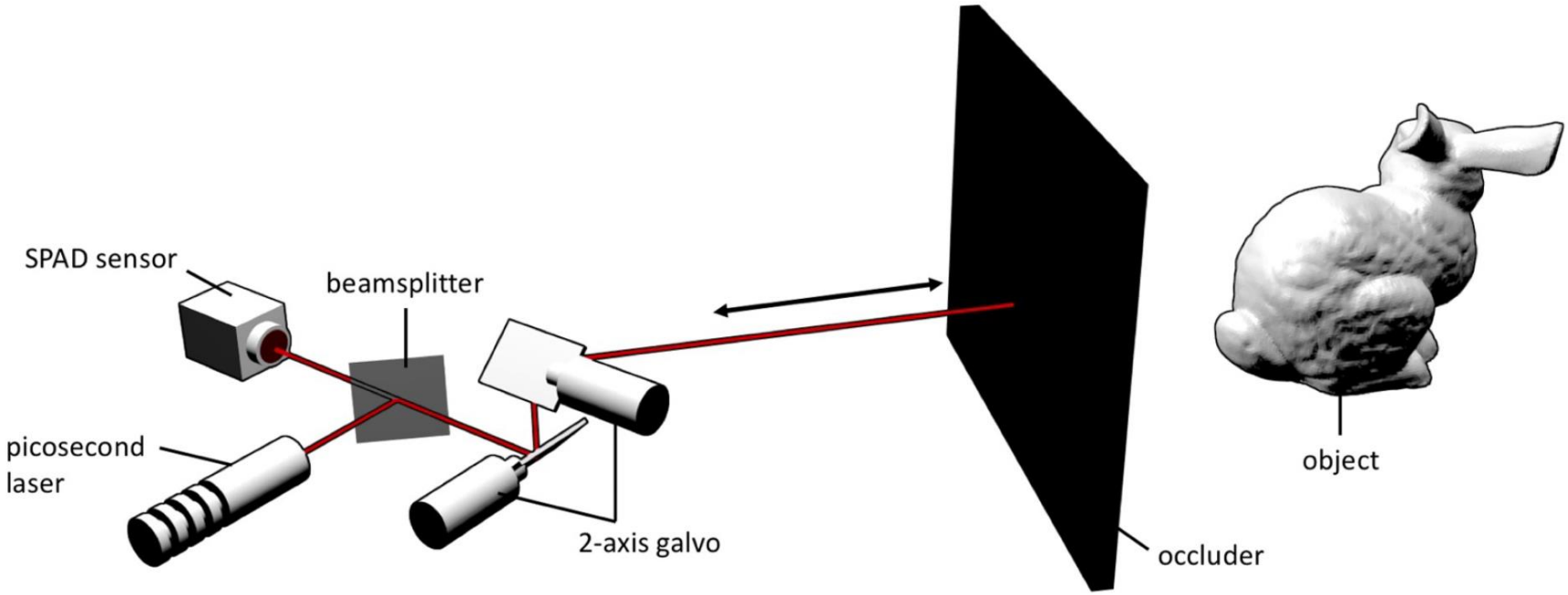
Motivating examples in computational imaging

3D imaging for autonomous vehicles

LIDAR (light detection and ranging)
Velodyne VLS-128

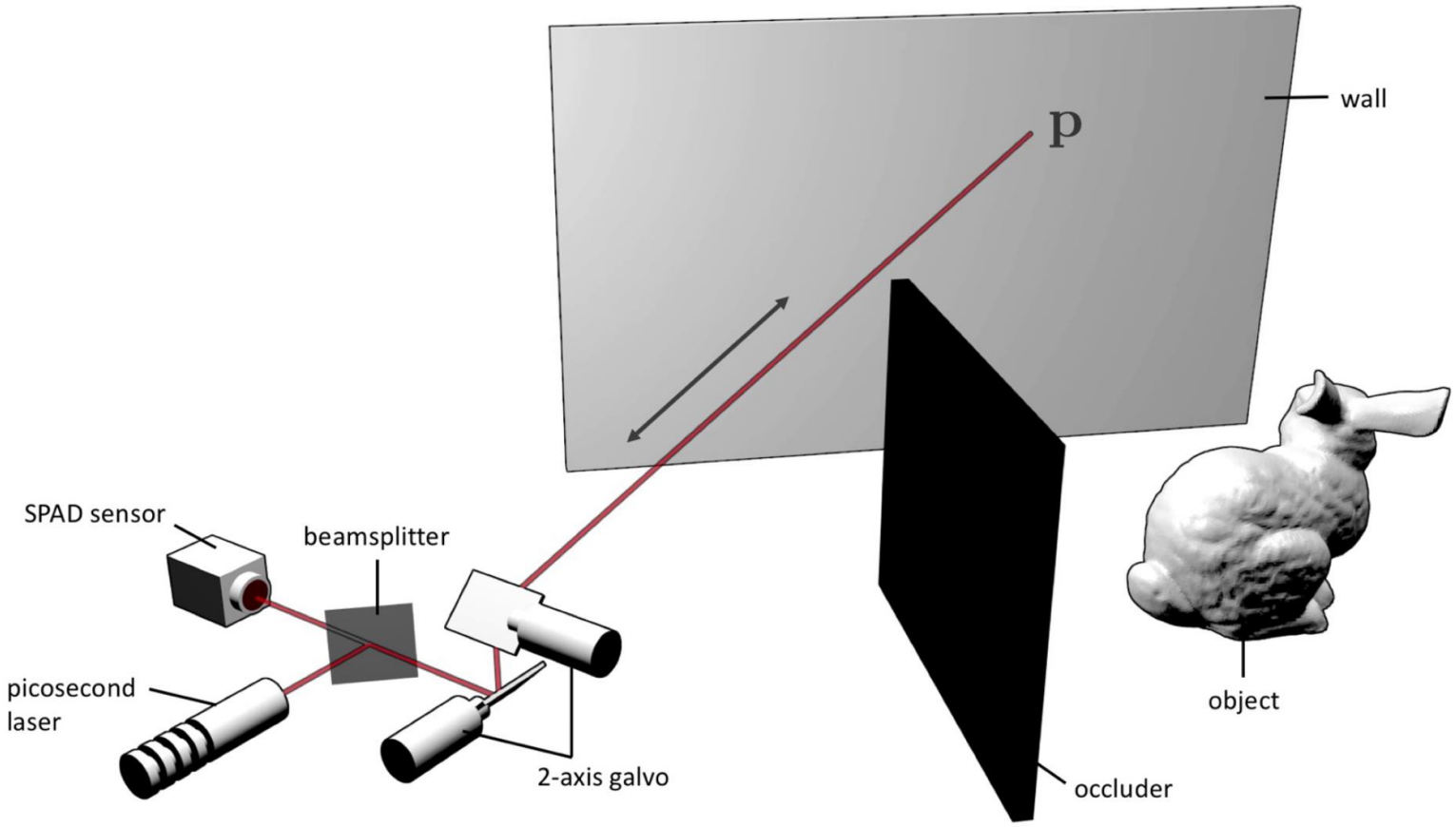
Motivating examples in computational imaging

Non-line-of-sight (NLOS) imaging



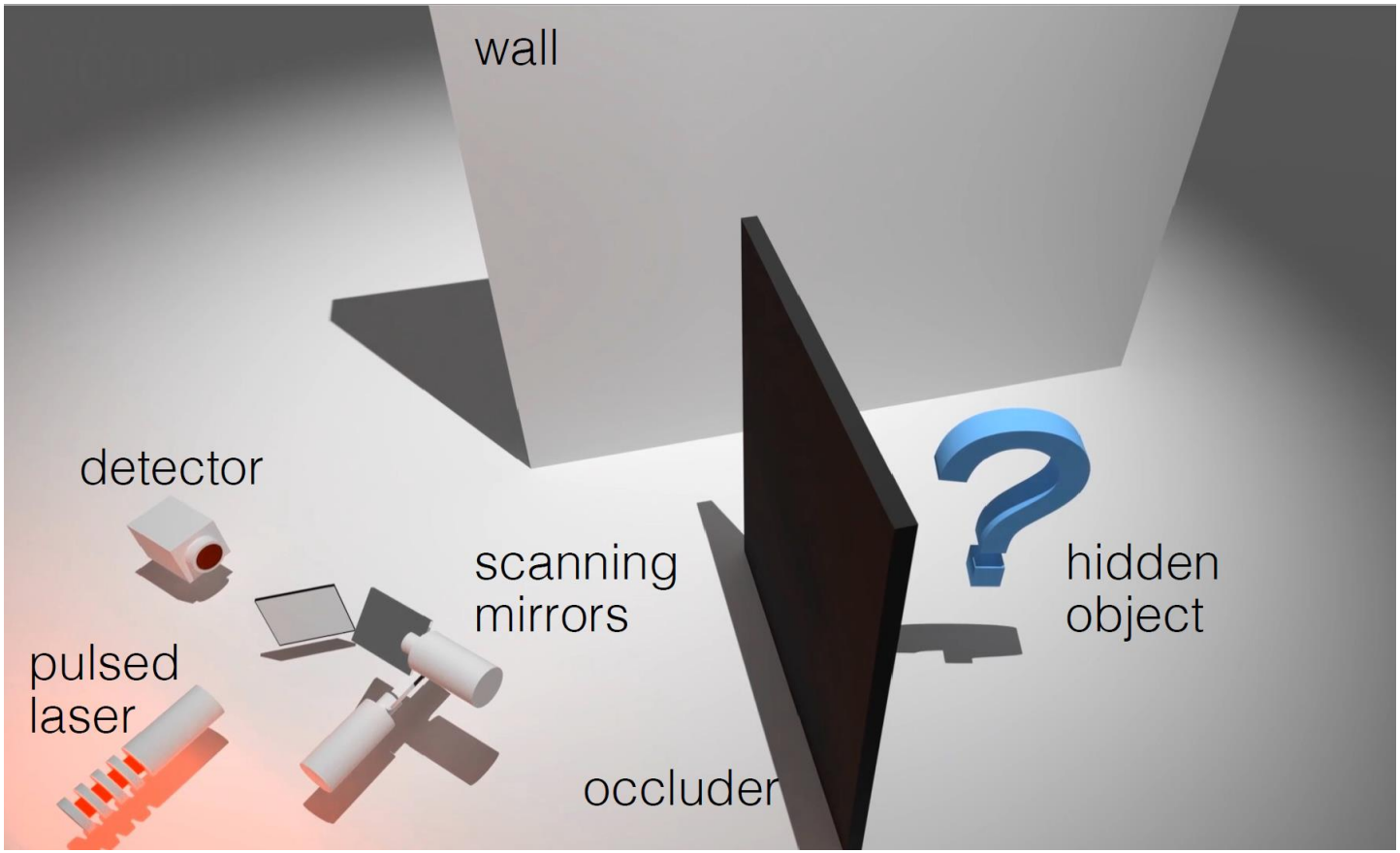
Motivating examples in computational imaging

Non-line-of-sight (NLOS) imaging



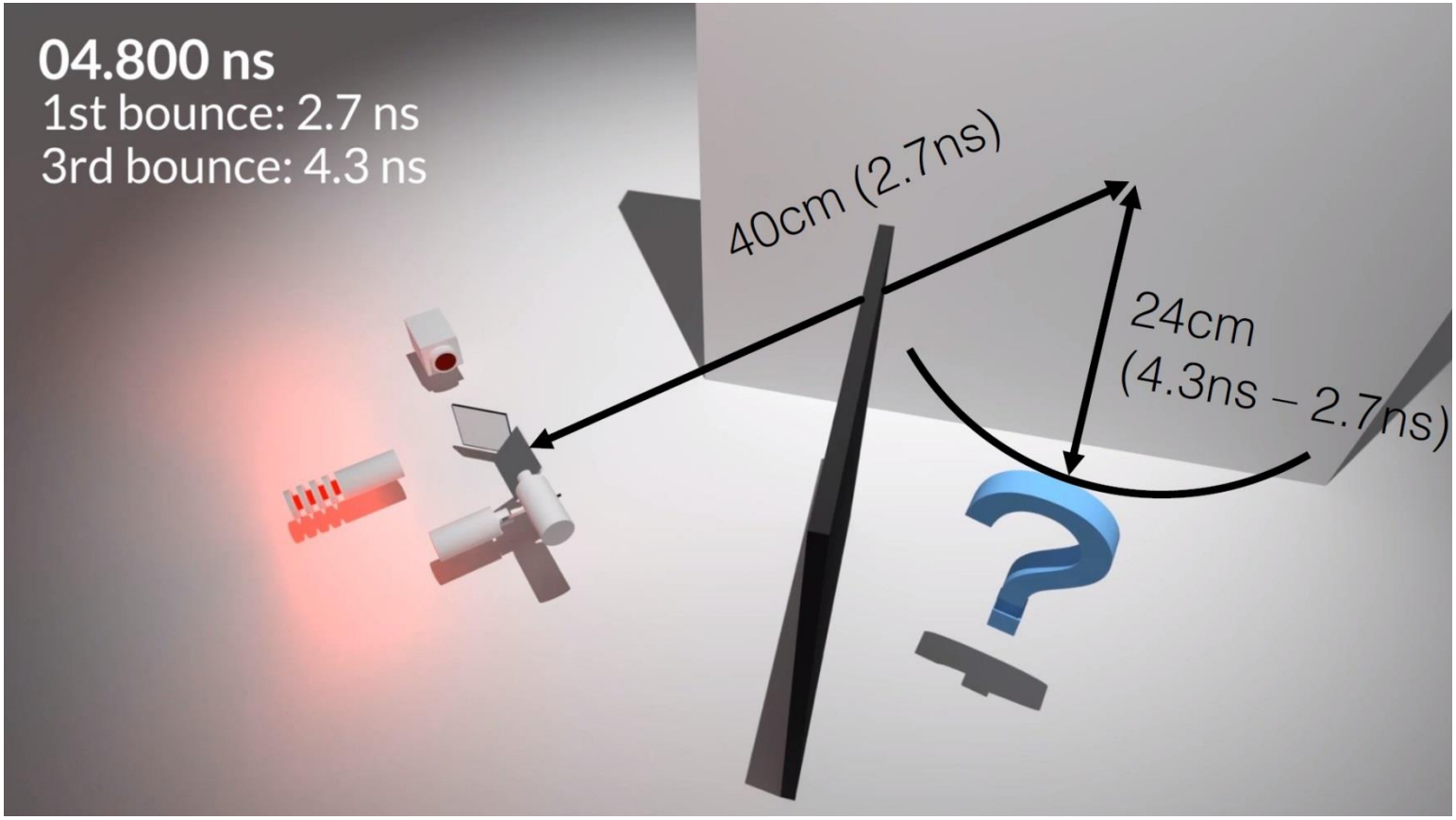
Motivating examples in computational imaging

Non-line-of-sight (NLOS) imaging



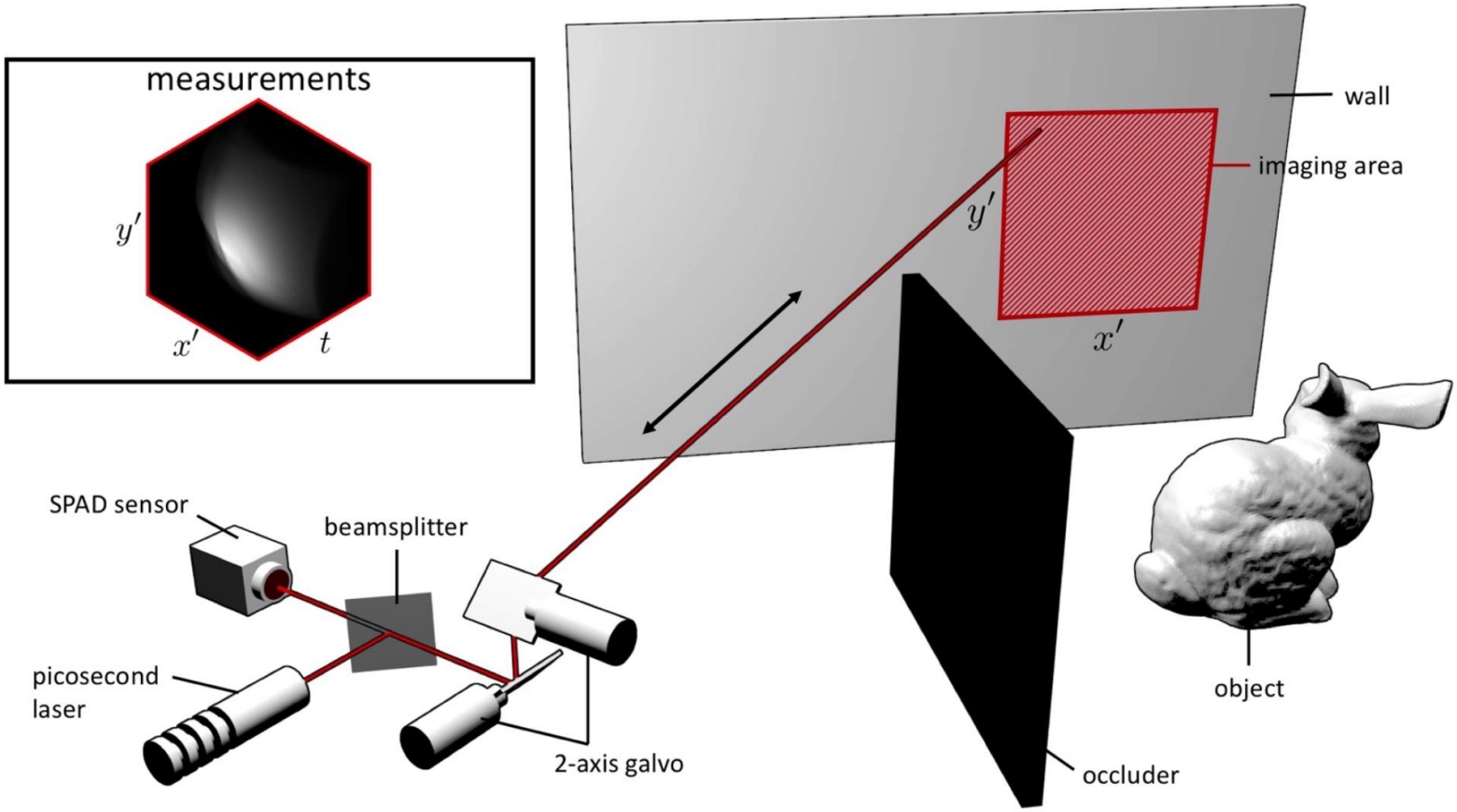
Motivating examples in computational imaging

Non-line-of-sight (NLOS) imaging



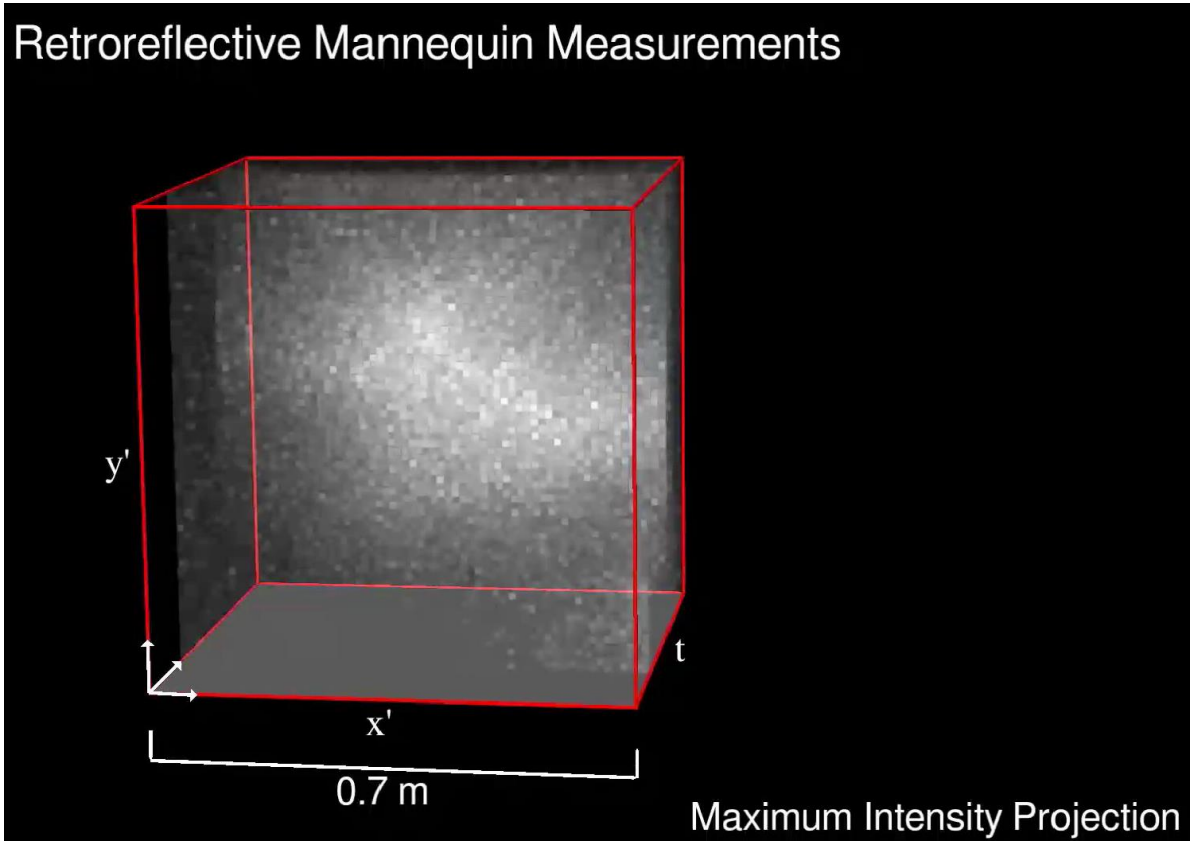
Motivating examples in computational imaging

Non-line-of-sight (NLOS) imaging



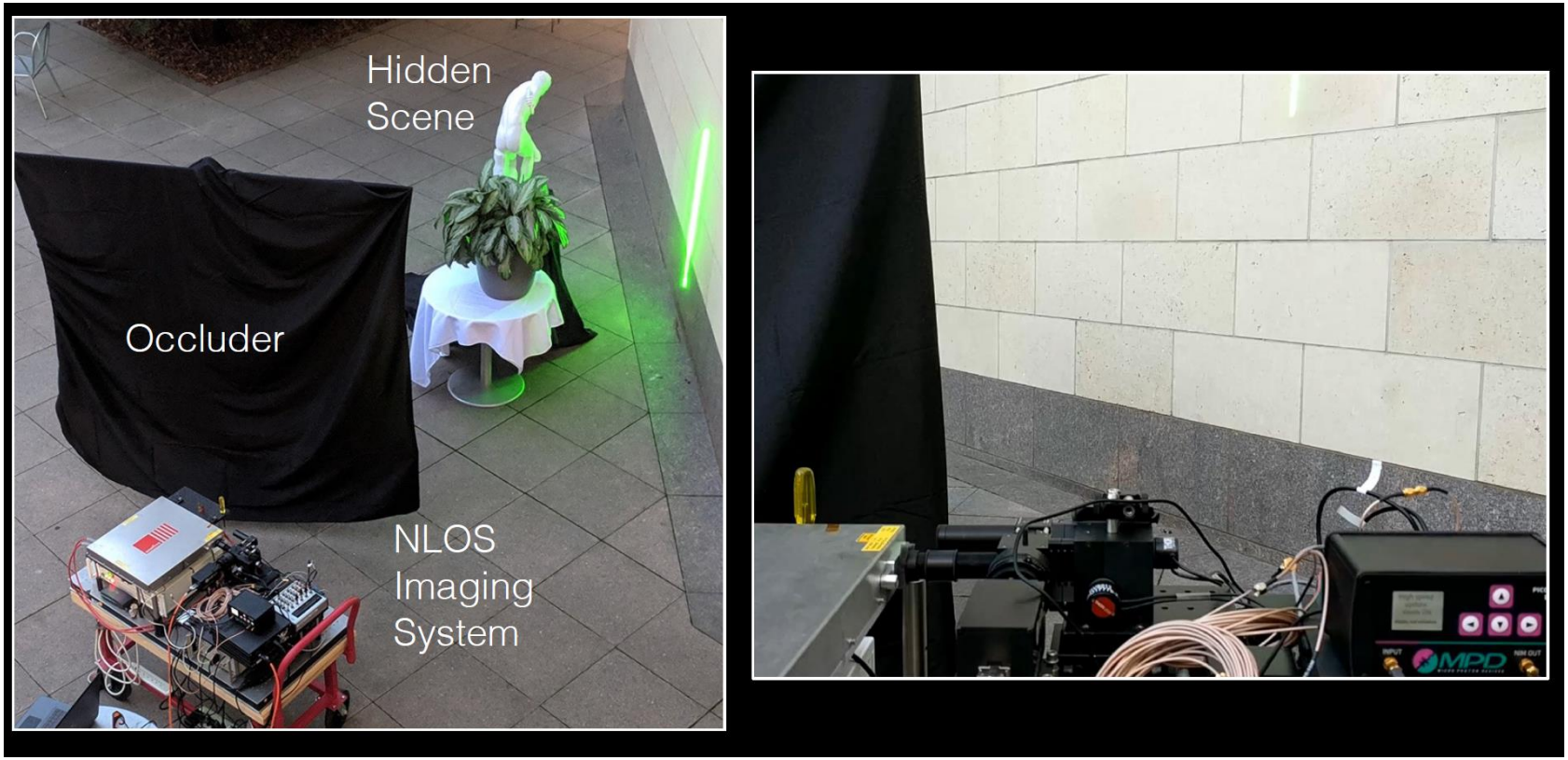
Motivating examples in computational imaging

Non-line-of-sight (NLOS) imaging



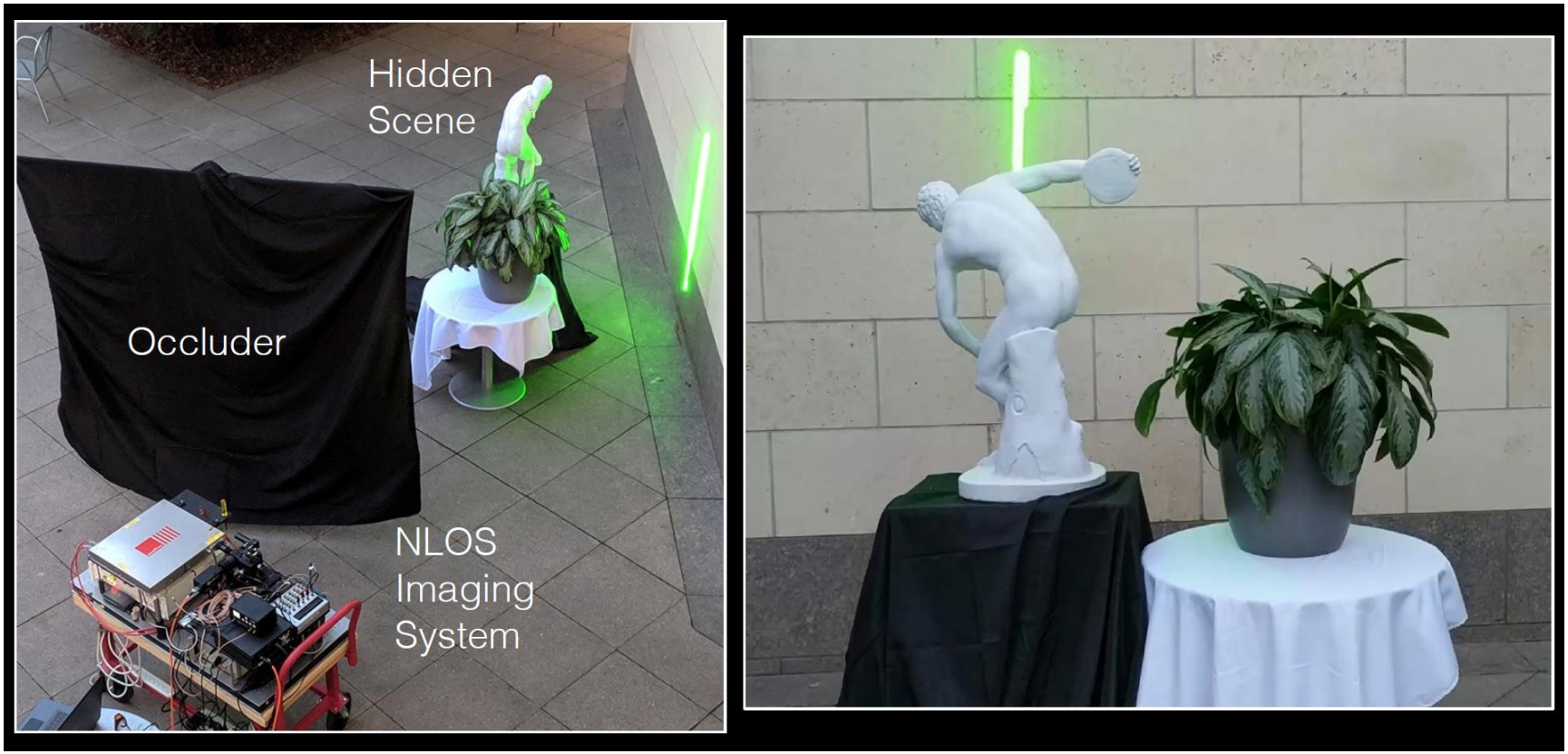
Motivating examples in computational imaging

Non-line-of-sight (NLOS) imaging



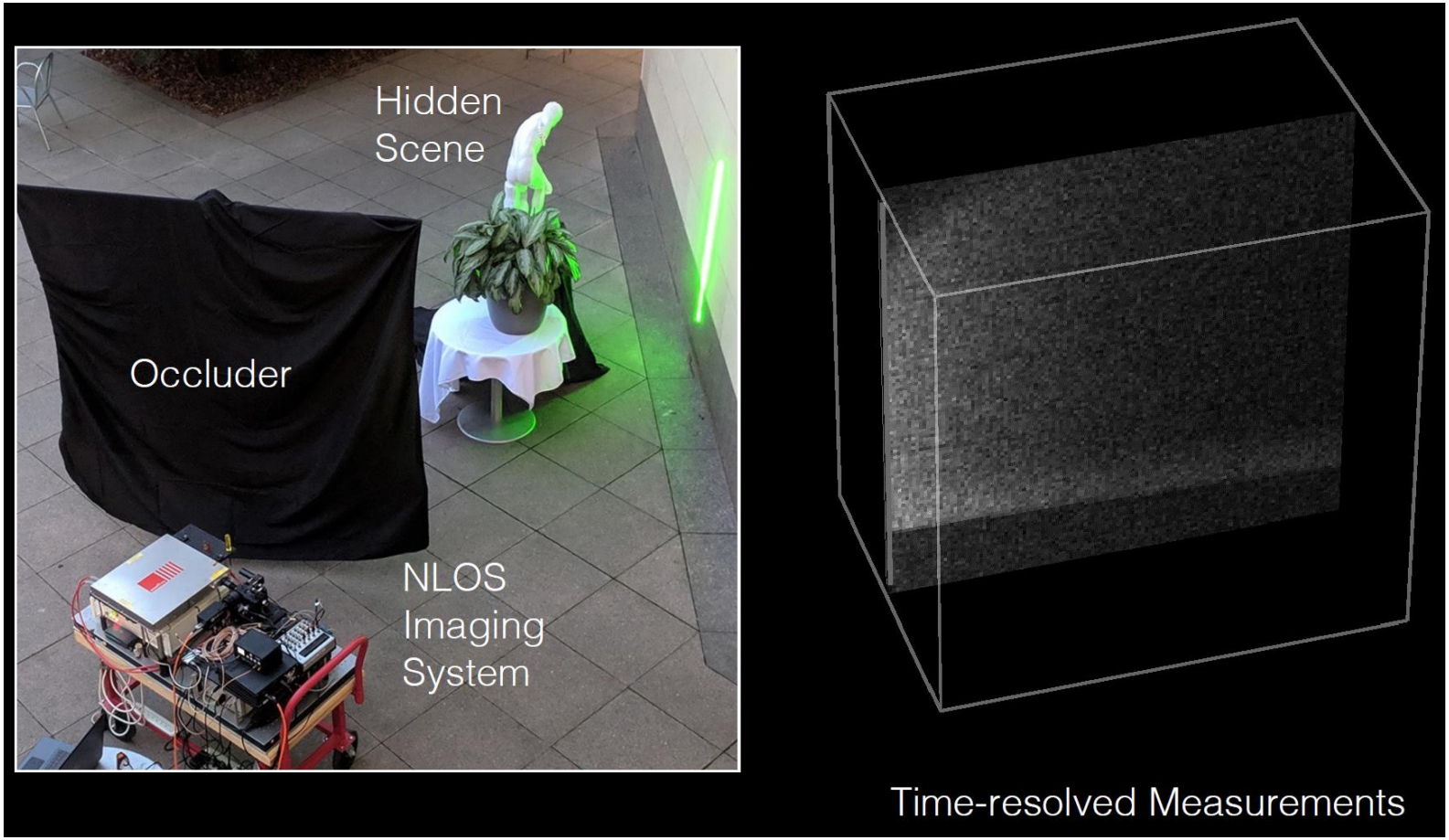
Motivating examples in computational imaging

Non-line-of-sight (NLOS) imaging



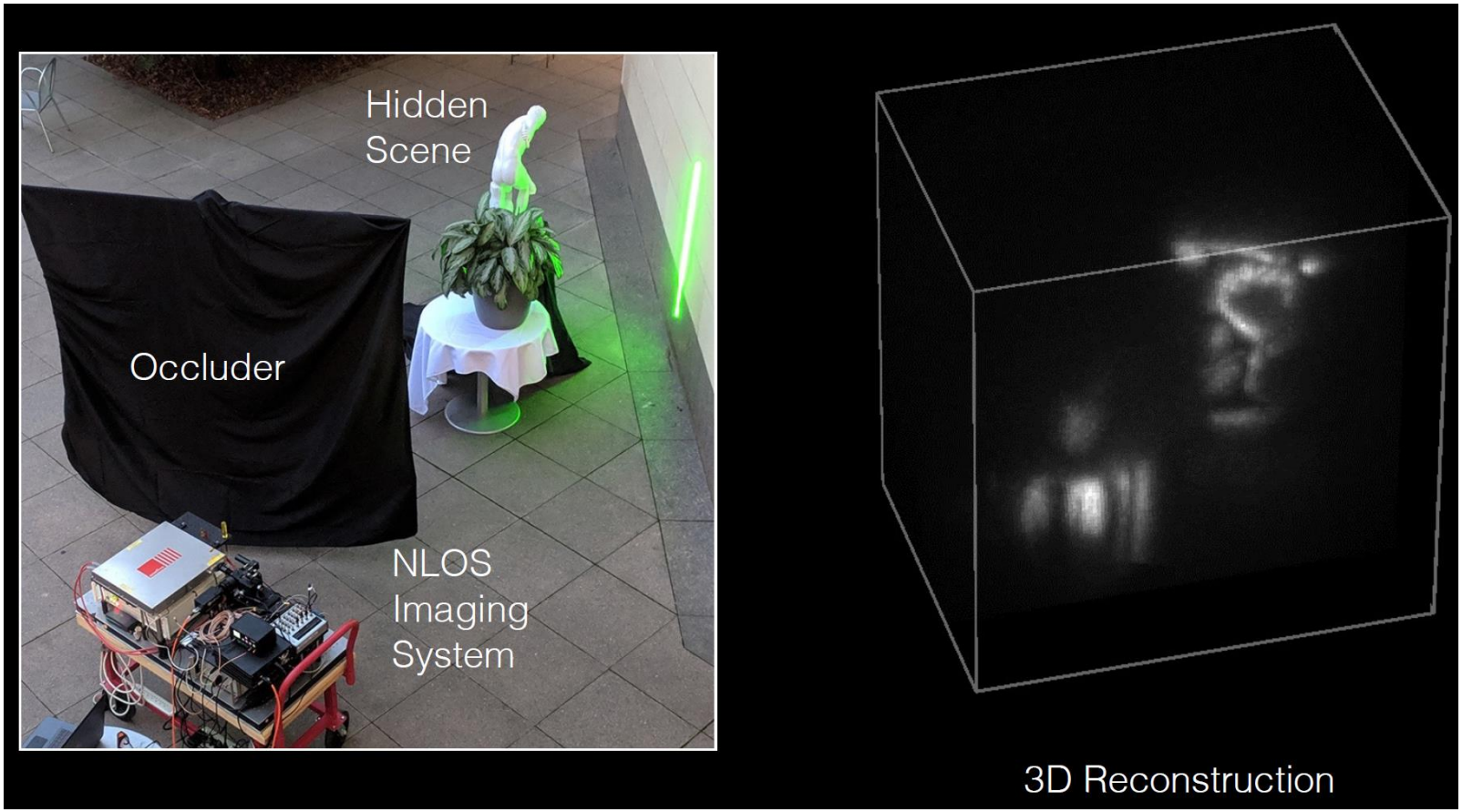
Motivating examples in computational imaging

Non-line-of-sight (NLOS) imaging



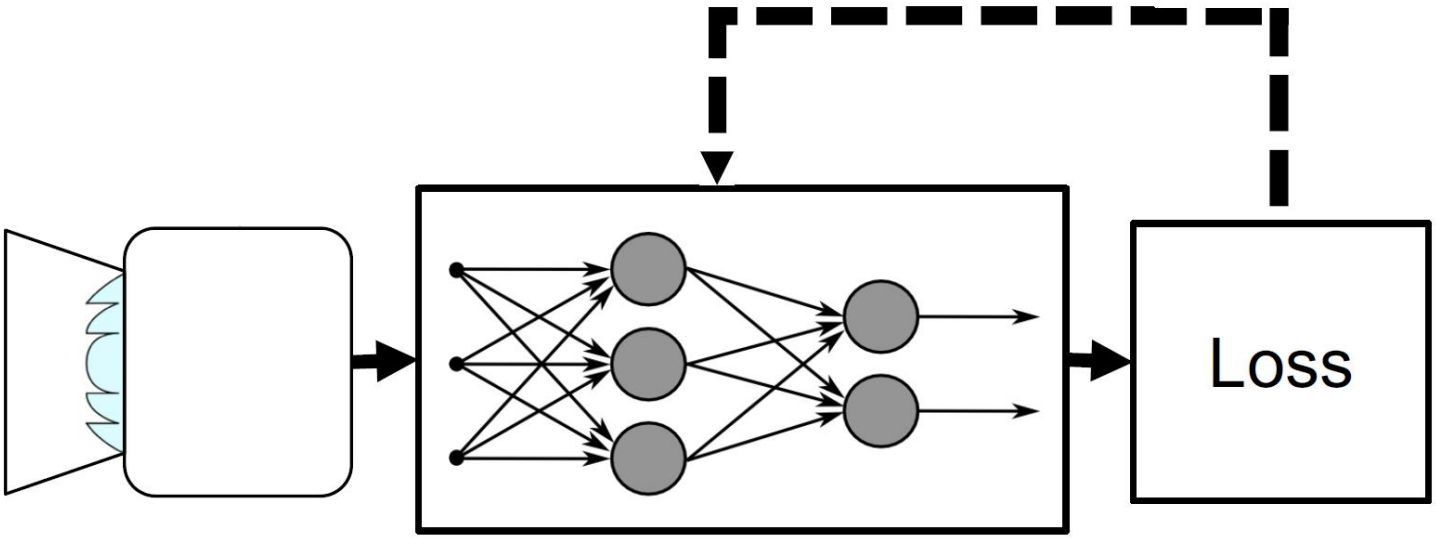
Motivating examples in computational imaging

Non-line-of-sight (NLOS) imaging



Motivating examples in computational imaging

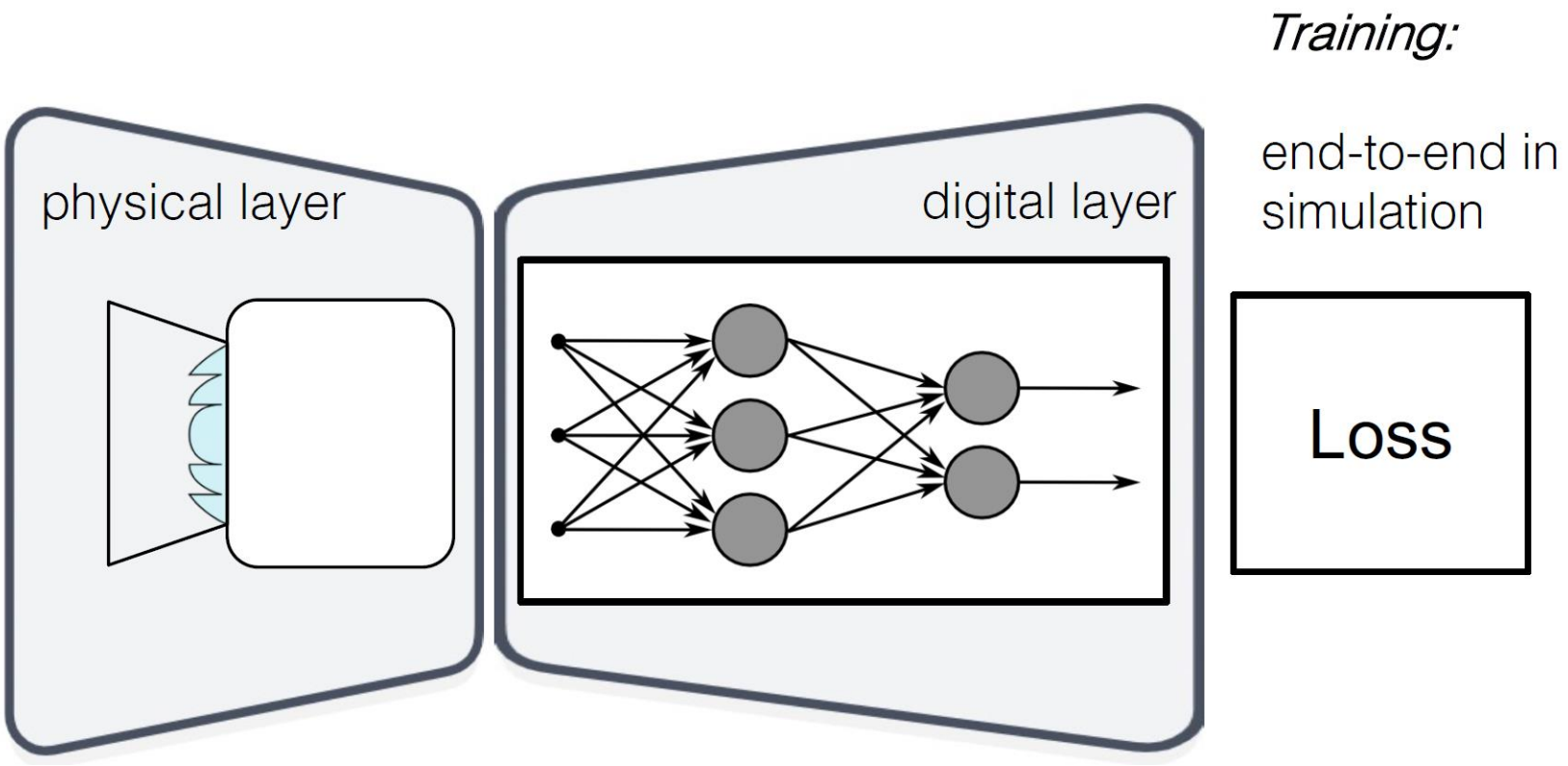
Deep optics



Jointly optimize optics and image processing end-to-end

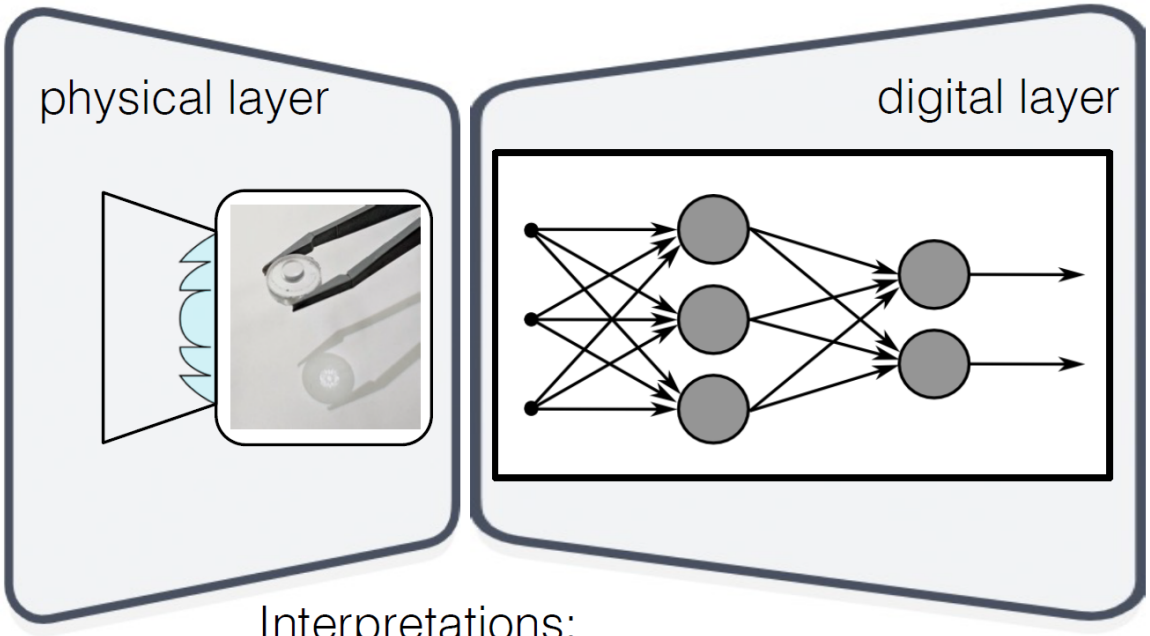
Motivating examples in computational imaging

Deep optics



Motivating examples in computational imaging

Deep optics



Inference:

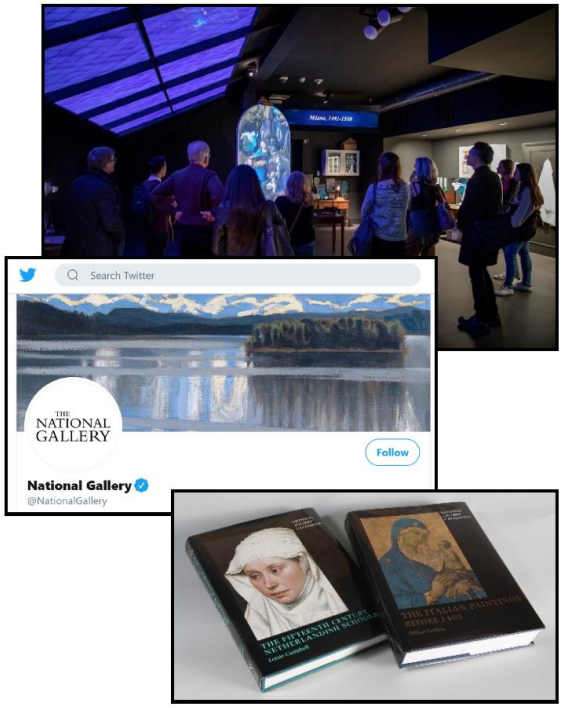
fabricate lens or other physical components, run network

Interpretations:

- Optical encoder, electronic decoder system
- Hybrid optical-electronic neural network

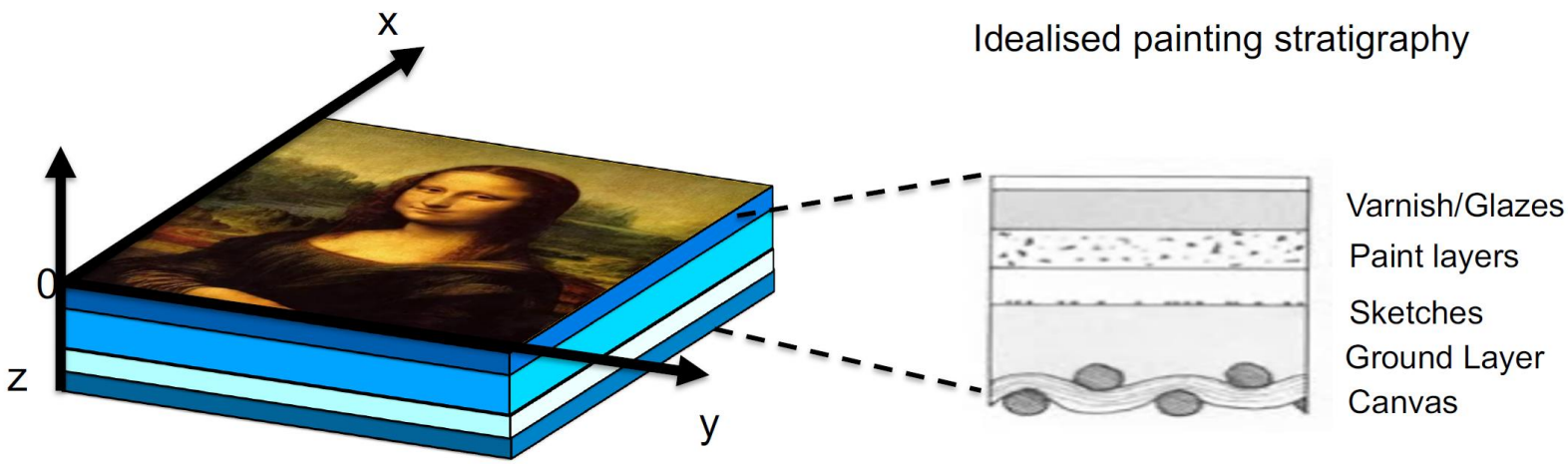
Motivating examples in computational imaging

Examination of old painting

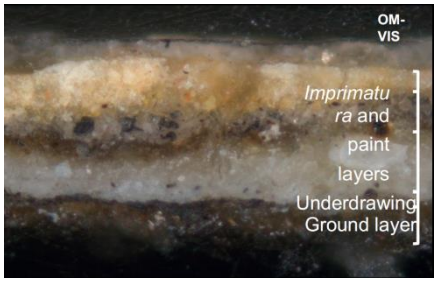


Motivating examples in computational imaging

Examination of old painting (structure of painting)

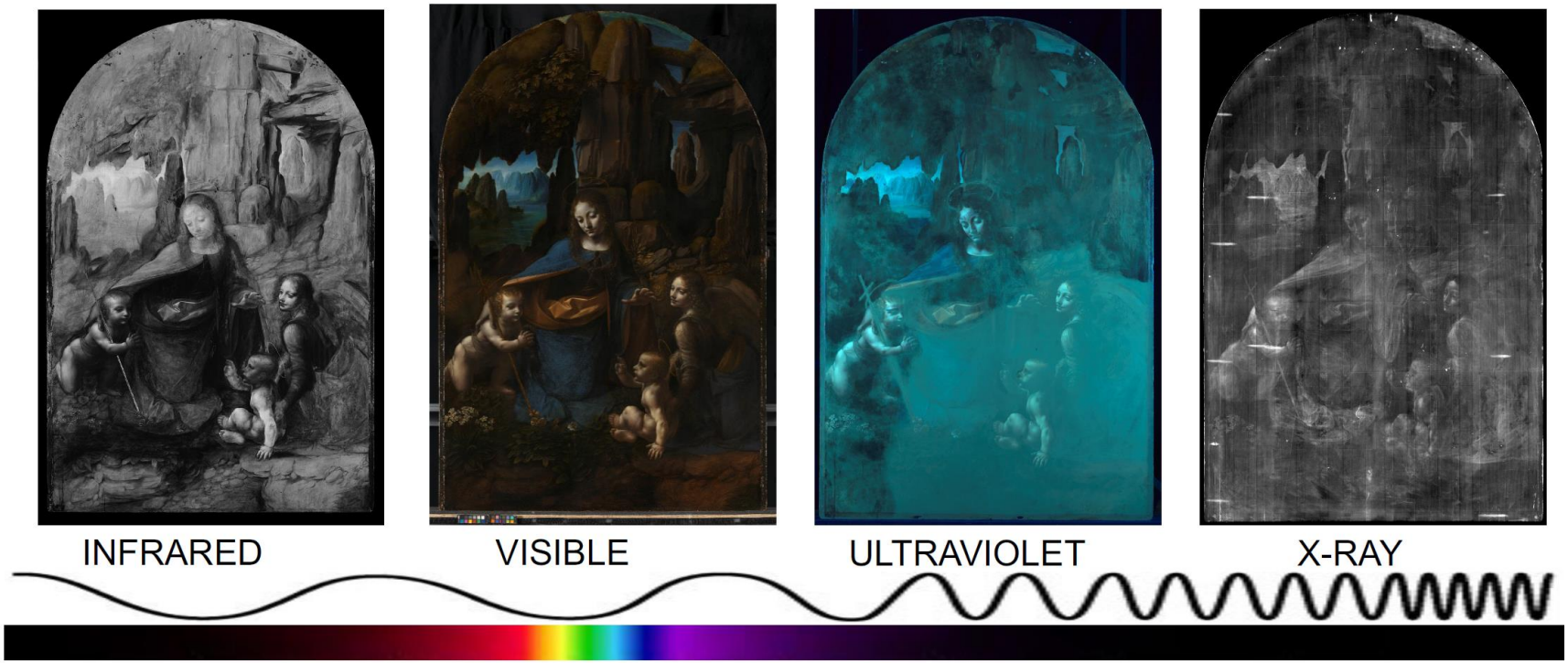


Realistic painting stratigraphy



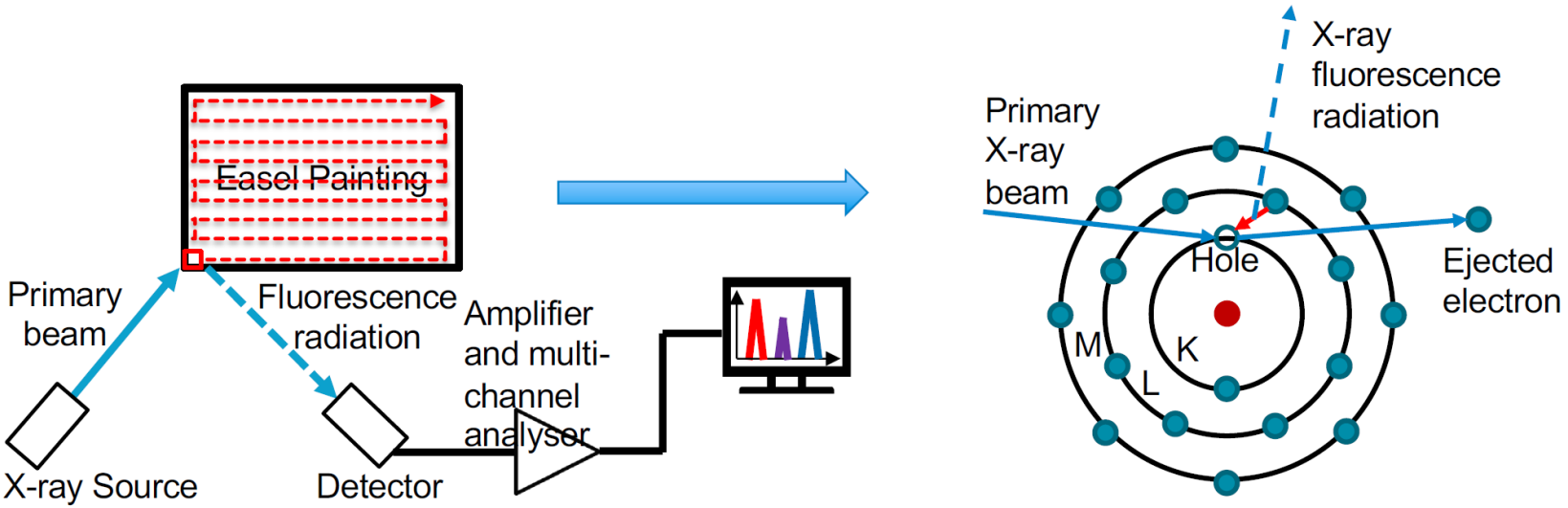
Motivating examples in computational imaging

Examination of old painting (traditional non-invasive imaging)



Motivating examples in computational imaging

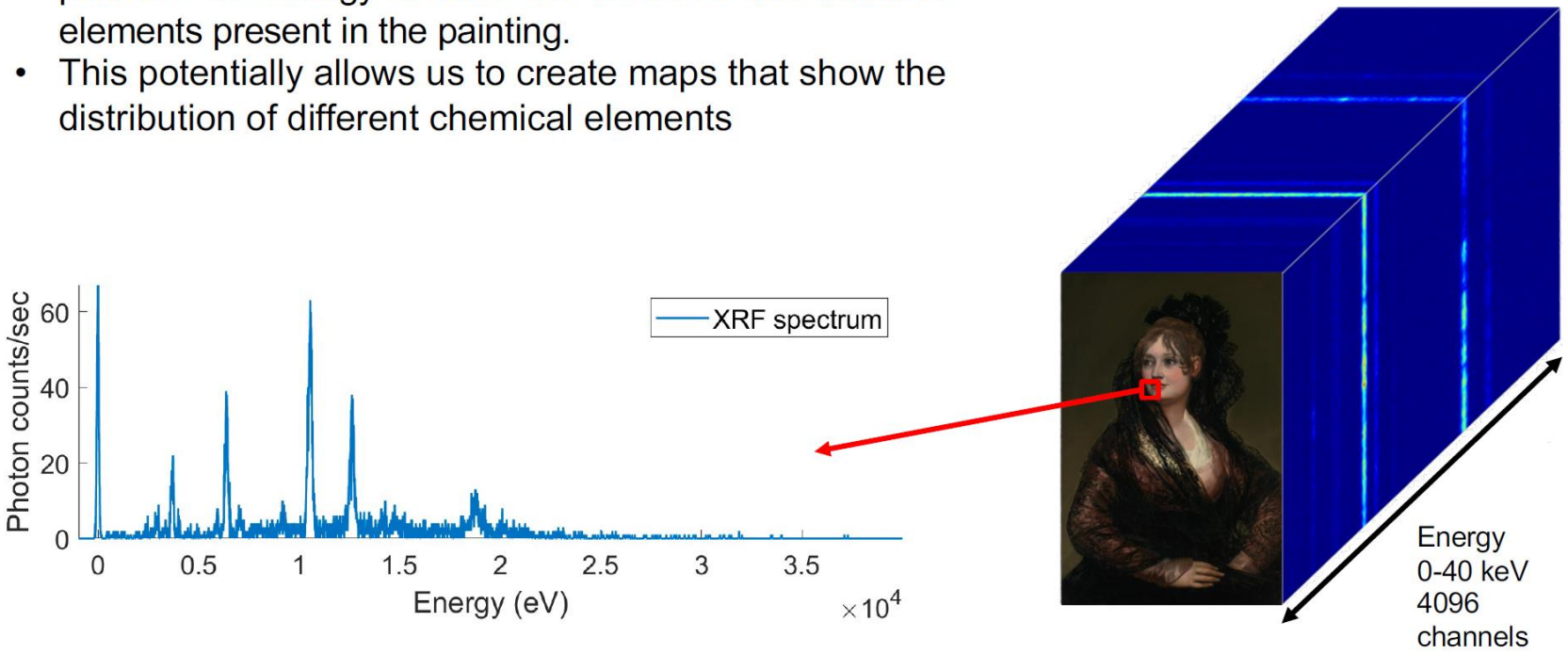
Examination of old painting (macro X-ray fluorescence (MA-XRF))



Motivating examples in computational imaging

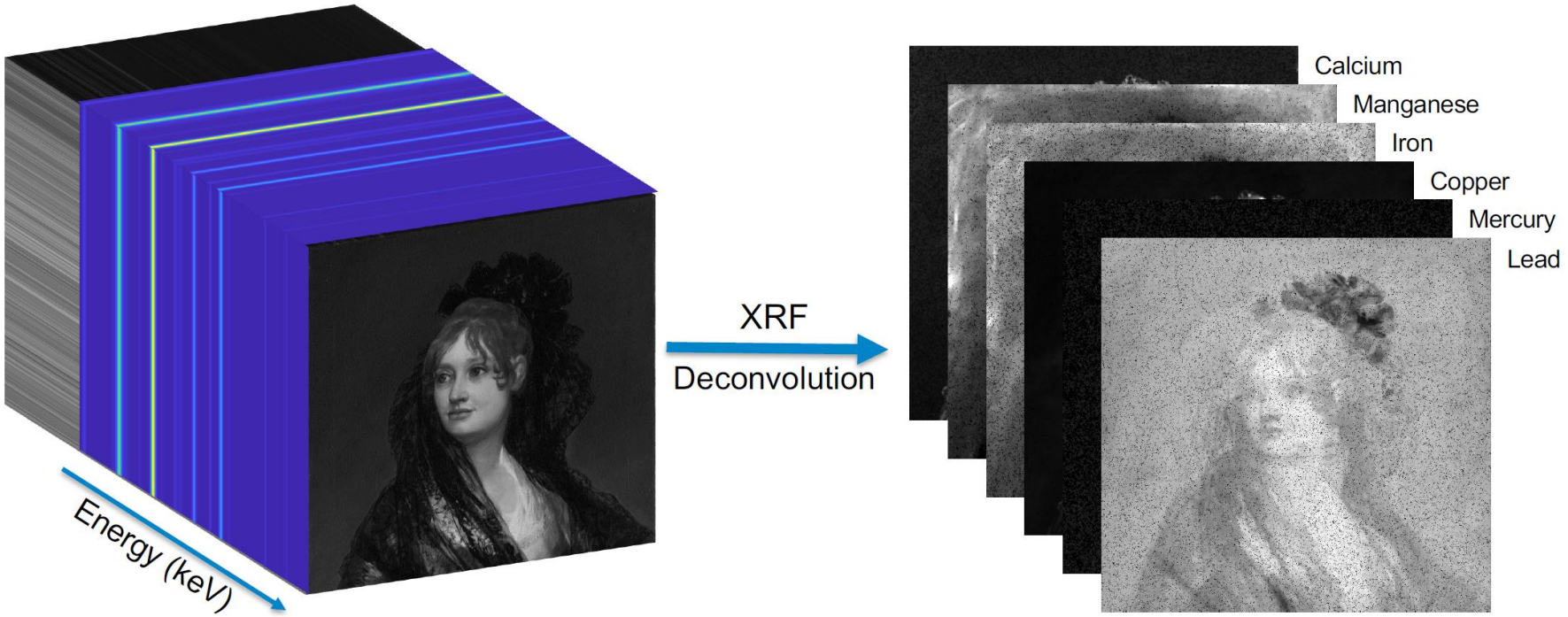
Examination of old painting (MA-XRF datacube and spectrum)

- Macro X-ray provides volumetric data and the locations of the pulses in the energy direction are related to the chemical elements present in the painting.
- This potentially allows us to create maps that show the distribution of different chemical elements



Motivating examples in computational imaging

Examination of old painting (extraction of elemental maps)

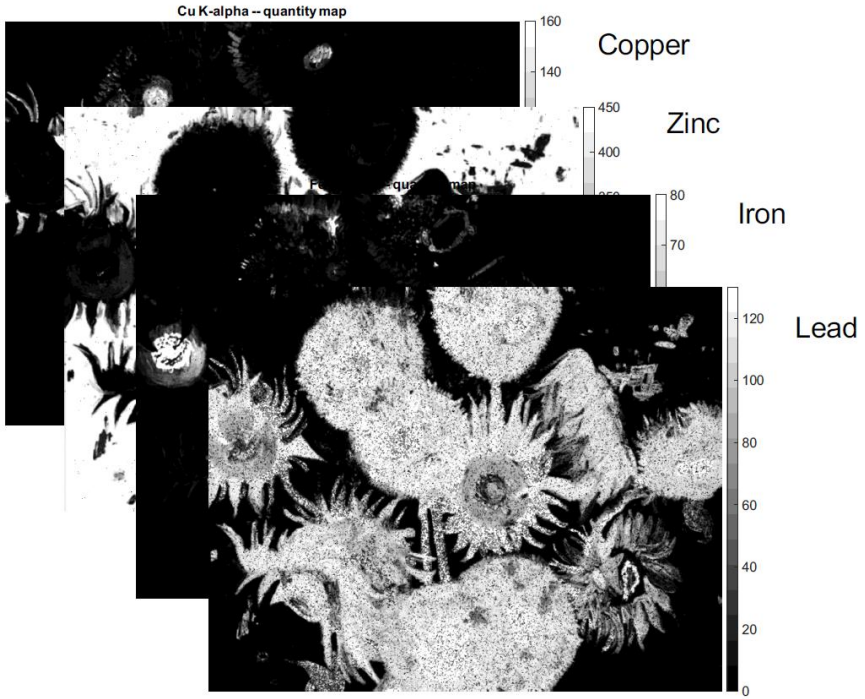


Motivating examples in computational imaging

Examination of old painting (extraction of elemental maps)

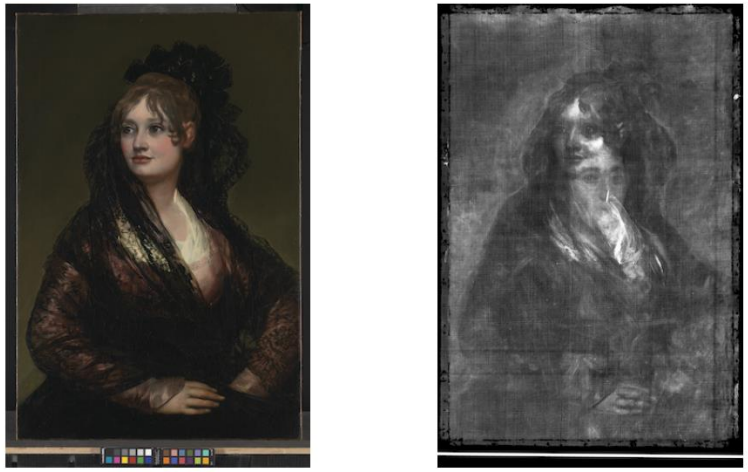
Deconvolution

Algorithm



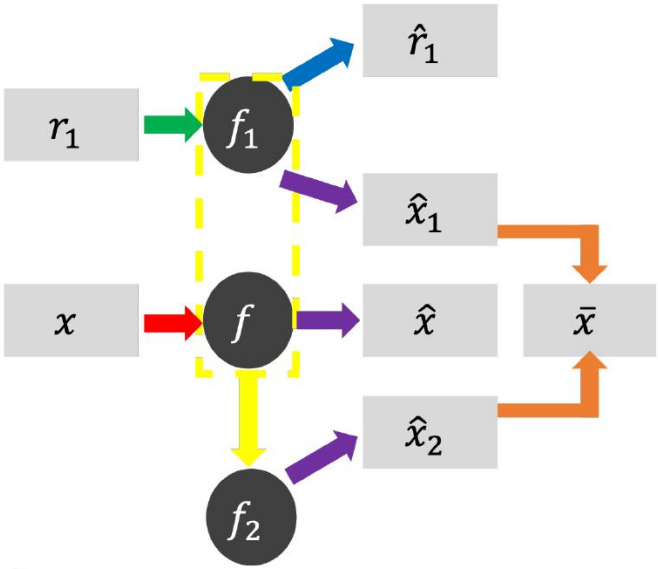
Motivating examples in computational imaging

ML based extraction of painting underneath



(a) (b)

Francisco de Goya, Dona Isabel de Porcel (NG1473), before 1805. Oil on canvas. (a). RGB image. (b). X-ray image.



Motivating examples in computational imaging

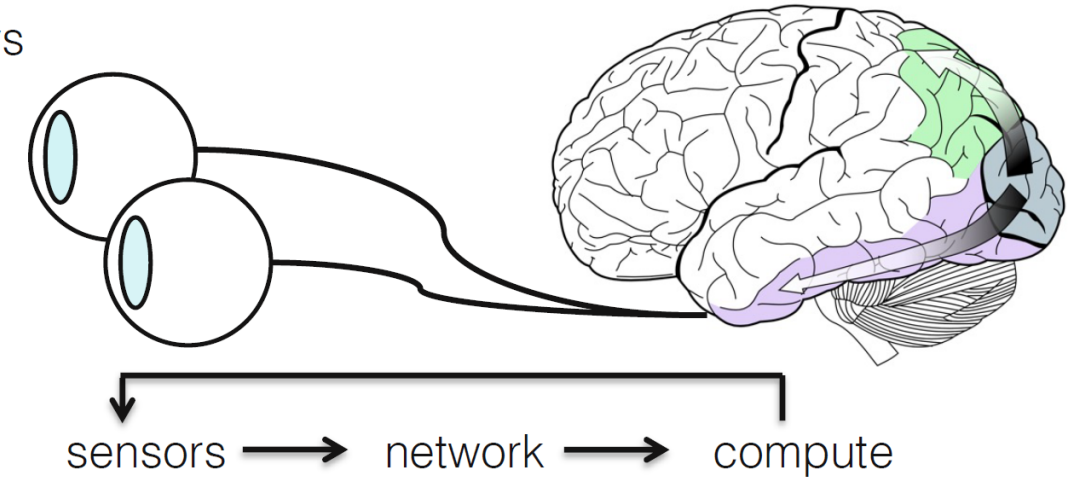
ML based extraction of painting underneath

Separation Results

Main topics of computational imaging

Human visual system

- anatomy of the eye
- acuity, color, 3D vision
- contrast sensitivity
- conflicts in displays
- refractive errors



Main topics of computational imaging

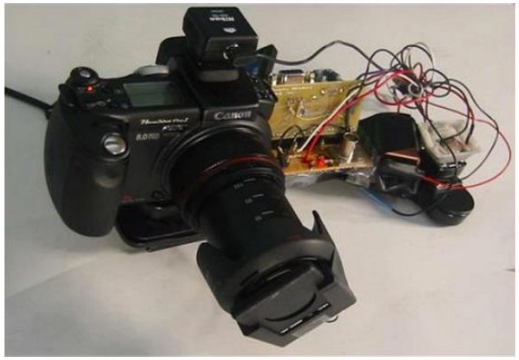
Digital photography

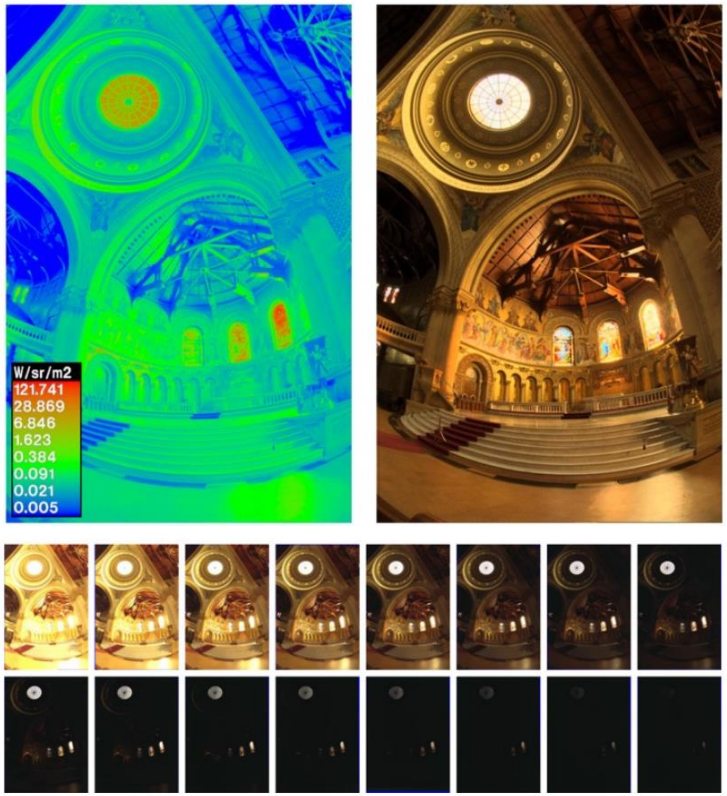
- optics
- aperture
- depth of field
- field of view
- exposure
- noise
- color filter arrays
- imaging processing pipeline

Main topics of computational imaging

Computational photography

- High-dynamic range imaging
- Tone mapping
- Burst photography & night sight
- Coded apertures
- …

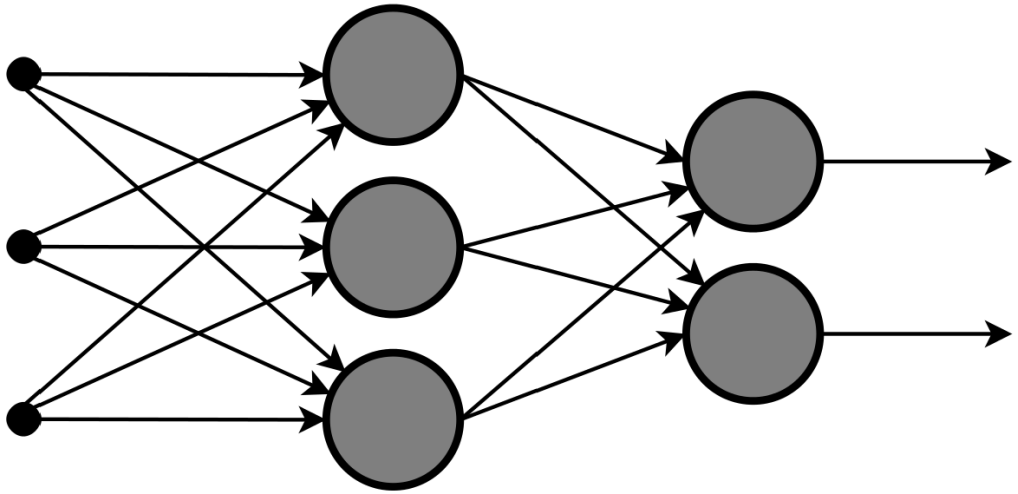




Main topics of computational imaging

Deep learning for computational imaging

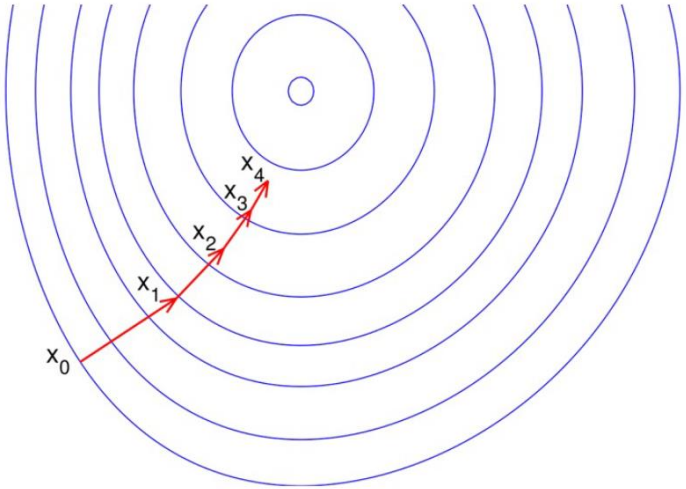
- Convolutional neural networks
- DnCNN
- U-Net
- …



Main topics of computational imaging

Optimization and deep learning

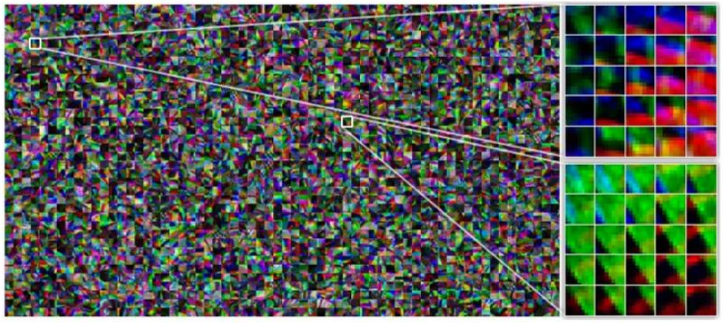
- Proximal gradient methods (HQS, ADMM)
- Iterative optimization with deep priors
- Solving general inverse problems in imaging
- …

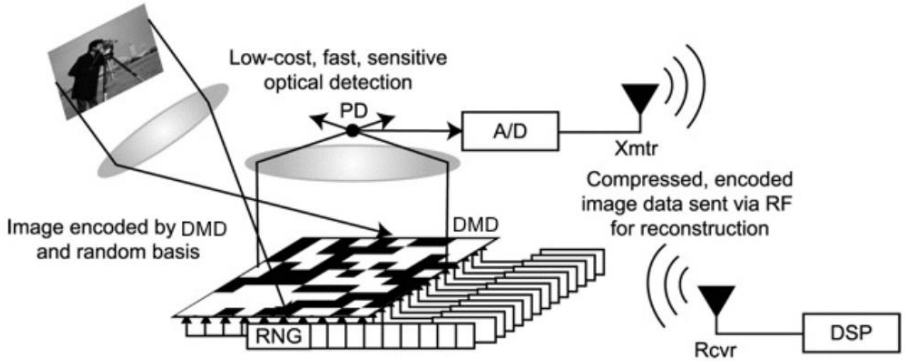


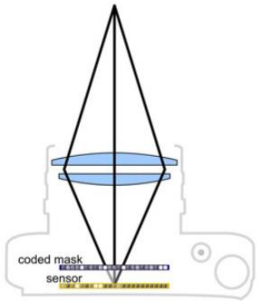
Main topics of computational imaging

Compressive imaging

- single pixel camera
- compressive hyperspectral imaging
- compressive light field imaging
- …



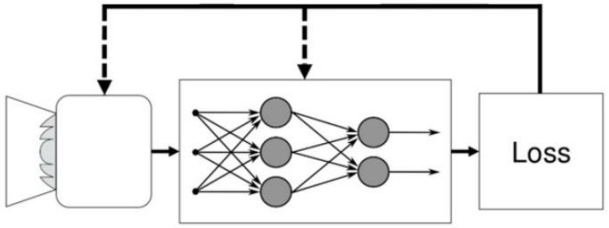


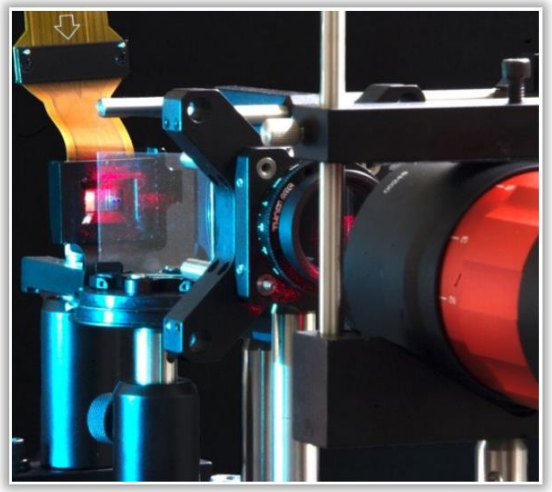


Main topics of computational imaging

Introduction to wave optics and deep optics

- Diffraction & interference
- The diffraction limit
- End-to-end optimization of optics & image processing
- Phase retrieval
- Computer-generated holography





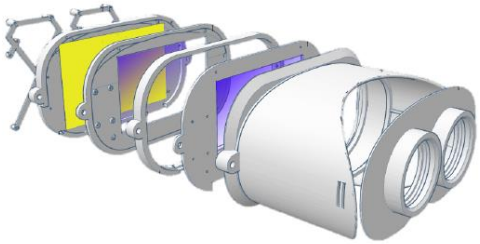
Main topics of computational imaging

Computational displays

Gaze-contingent Focus Displays

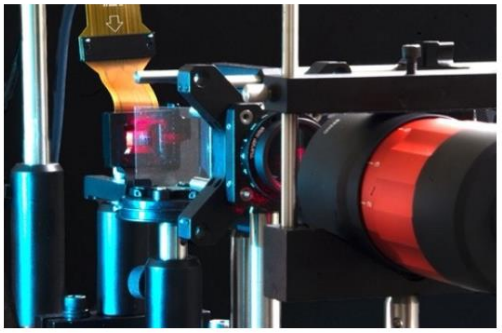
Konrad et al., SIGCHI 2016;
Padmanaban et al., PNAS 2017

Near-eye Light Field Displays



Huang et al., SIGGRAPH 2015;
Wetzstein et al., SIGGRAPH 2011, 2012

Holographic Displays



Padmanaban et al., SIGGRAPH Asia 2019
Peng et al., SIGGRAPH Asia 2020
Choi et al., Optica 2021

References

- Computational Photography (Levoy, Adams, Pulli, Stanford)
- Computational Photography SIGGRAPH Course (Raskar & Tumblin)
- Digital and Computational Photography (Durand & Freeman, MIT)
- Computational Photography (Efros, CMU)
- Computational Photography (Gkioulekas, CMU)
- Computational Imaging (Wetzstein, Stanford)
- Computational Photography (Fergus, NYU)
- Computational Imaging (Dragotti, Imperial College)
- Computer Vision (Seitz & Szeliski, UWashington)
- Introduction to Visual Computing and Visual Modeling (Kutulakos, UToronto)