Computational Optical Imaging - Optique Numerique

Winter 2013

Ivo Ihrke

Organizational Issues

- Course schedule (tentative)

1.	Introduction/Sensors	Tuesday	10.09.2013
2.	Signal Processing Theory	Thursday	12.09.2013
3.	RAW pipeline	Monday	16.09.2013
4.	Passive stereo	Monday	23.09.2013
5.	Active light 3D scanning	Monday	30.09.2013
6.	Volumetric 3D – Tomography	Monday	07.10.2013
7.	Deblurring / Inverse Problems	Monday	14.10.2013
8.	Extended Depth of Field	Monday	21.10.2013
9.	Light Fields	Thursday	24.10.2013
10.	Current topics / exam(?)	Monday	28.10.2013

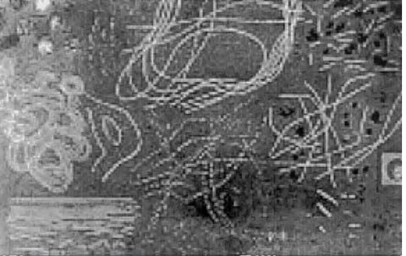
Organizational Issues

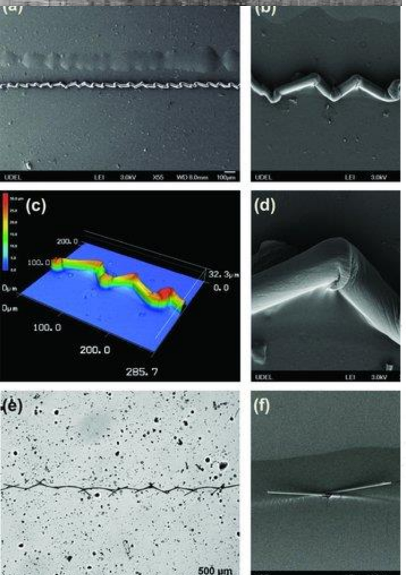
- Written exam – 2 hours
  - Personal notes allowed
  - No computer / mobiles / books
- Active participation encouraged
- Send email to ivo.ihrke@inria.fr to be added to course mailing list

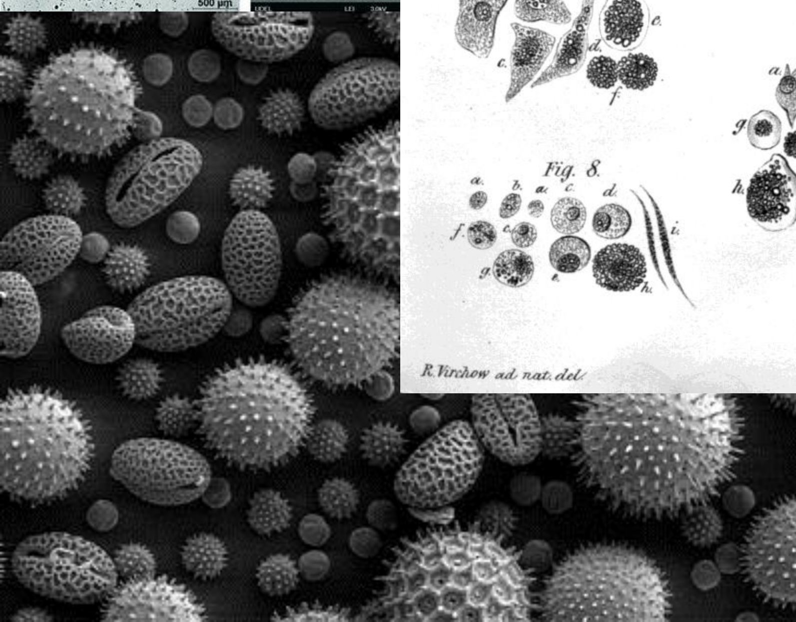
0.
What this course is about …

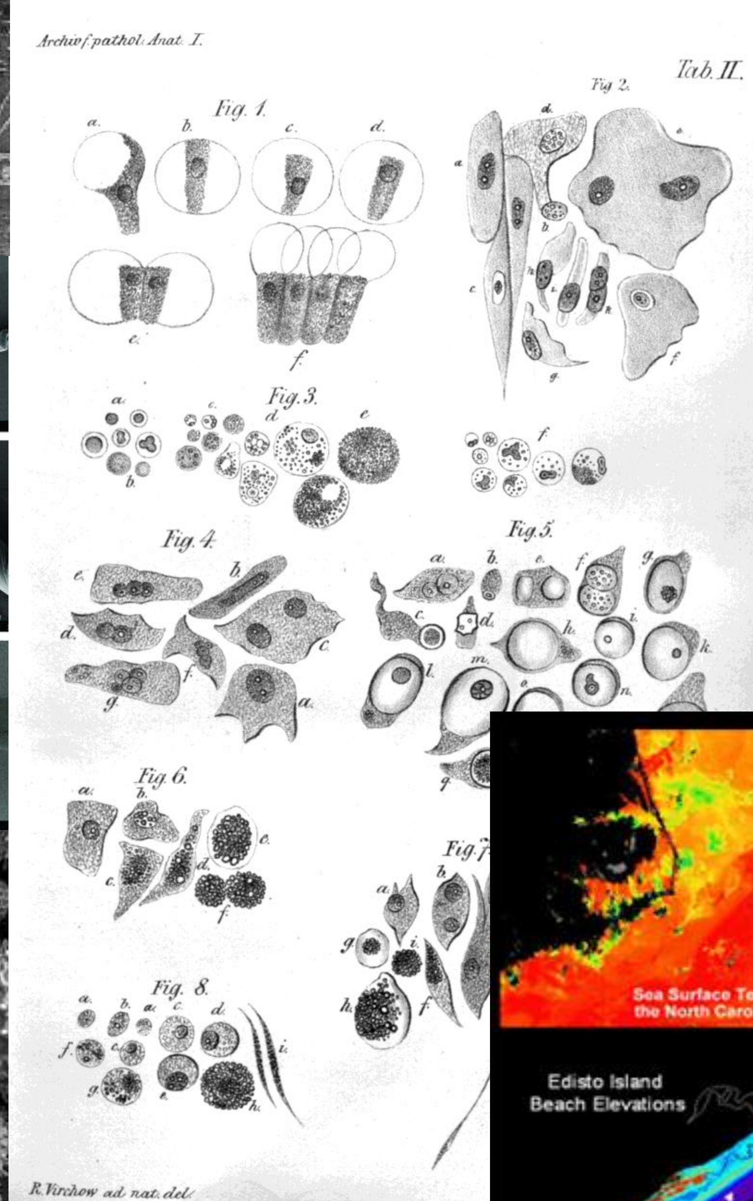
Winter 2013

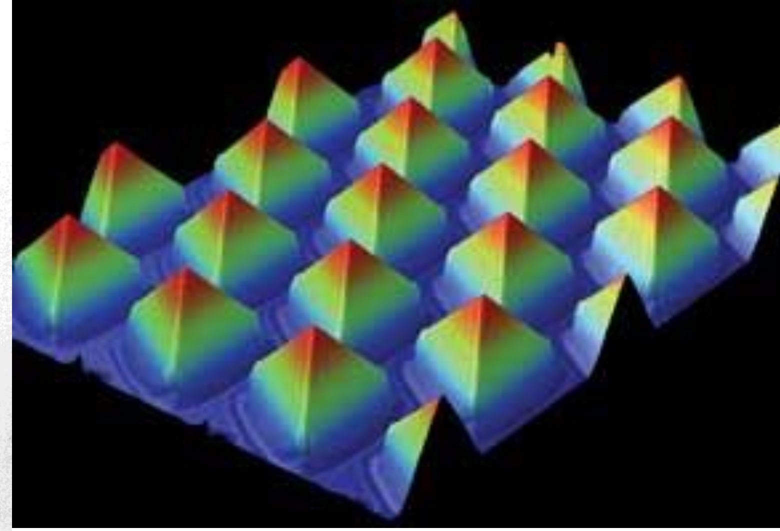
Ivo Ihrke

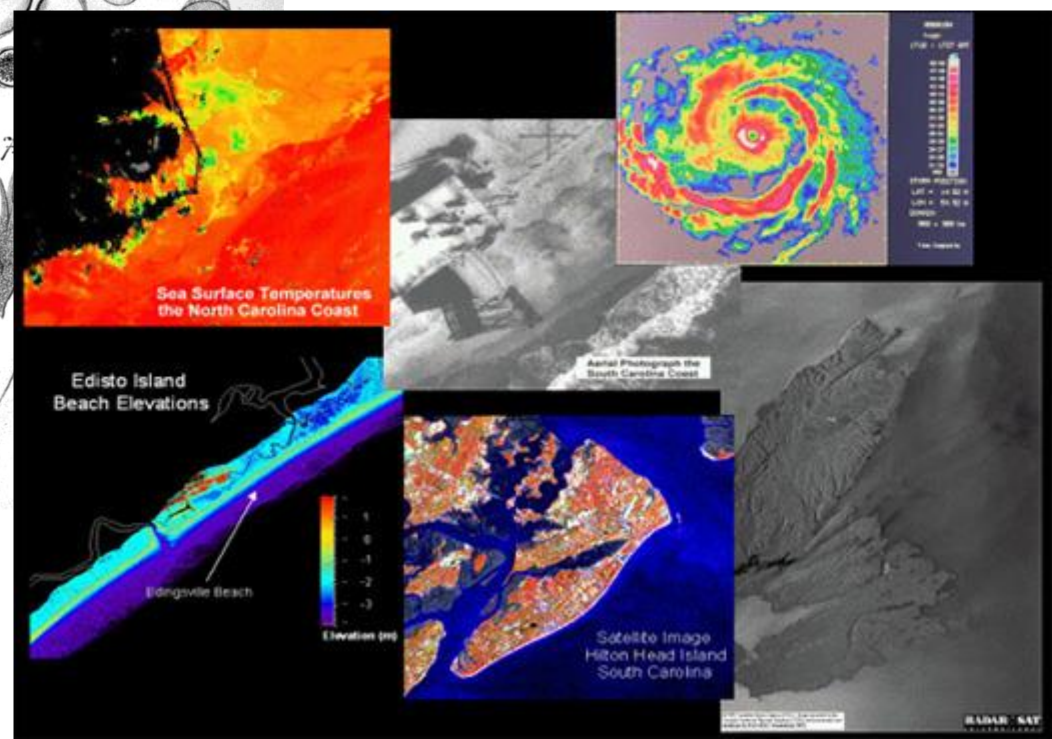



(a)
(b)
(c)
(d)
(e)
(f)
500 µm

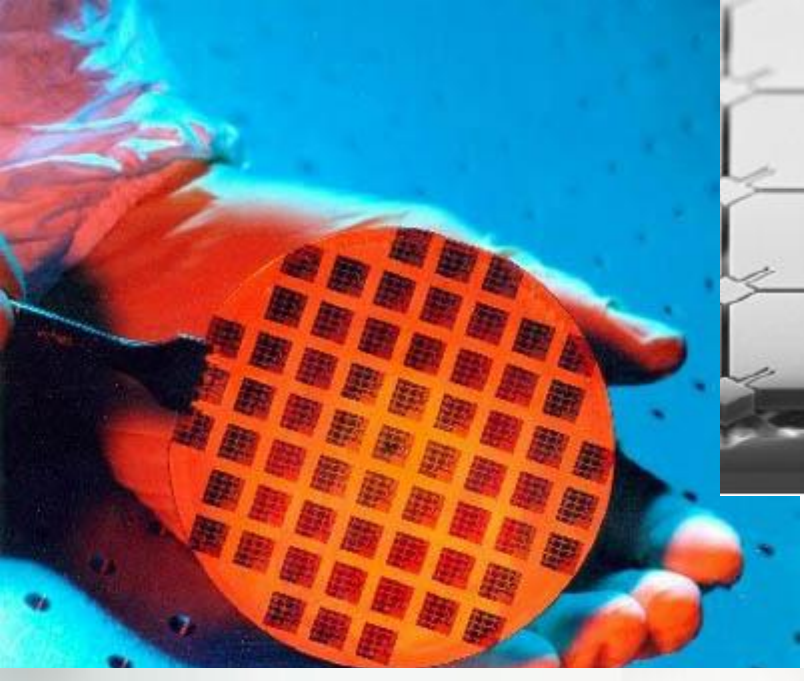


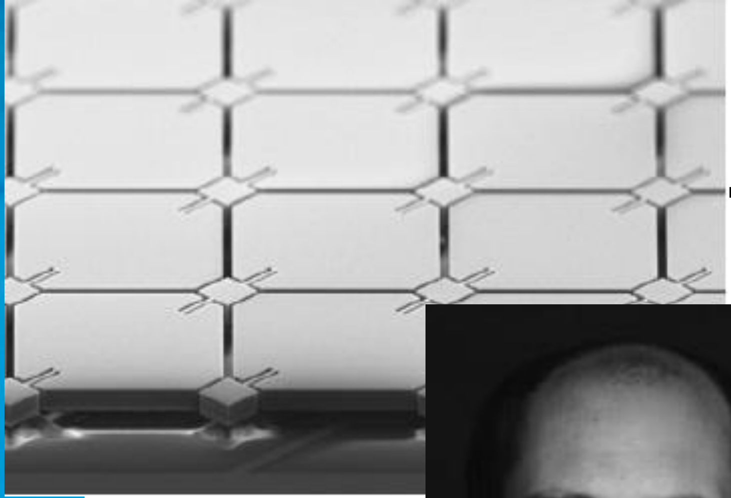

Archiv f. pathol. Anat. I.
Tab. II.
Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
Fig. 5.
Fig. 6.
Fig. 7.
Fig. 8.
R. Virchow ad nat. del.

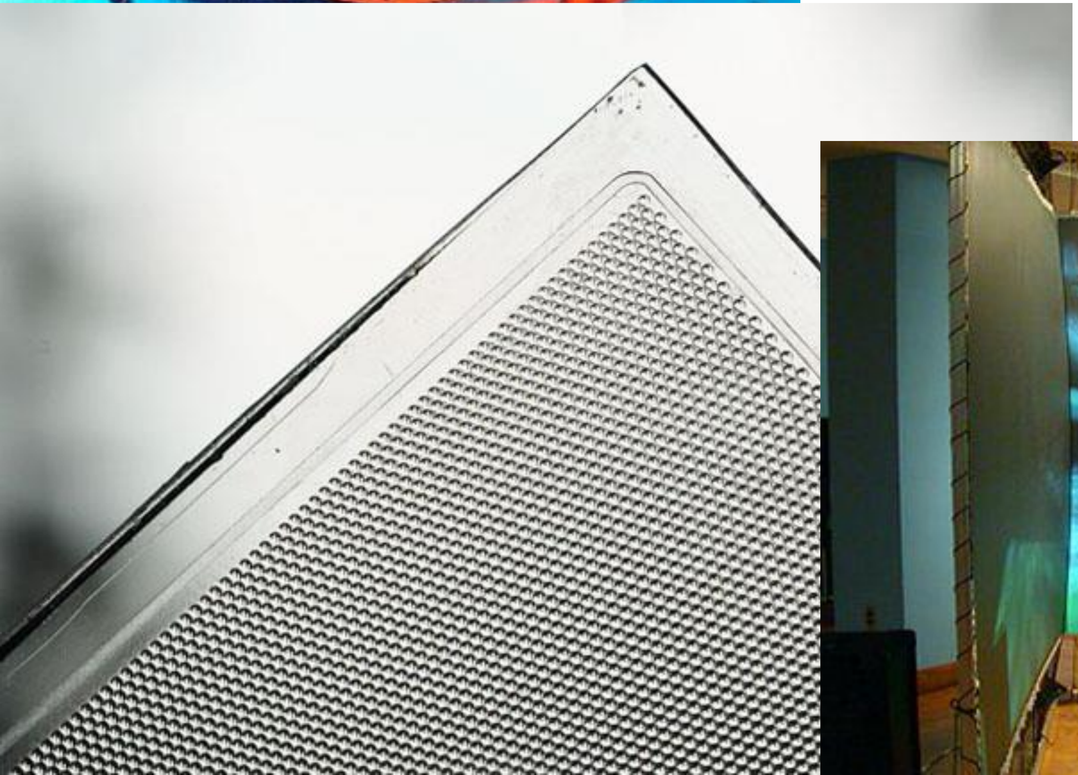


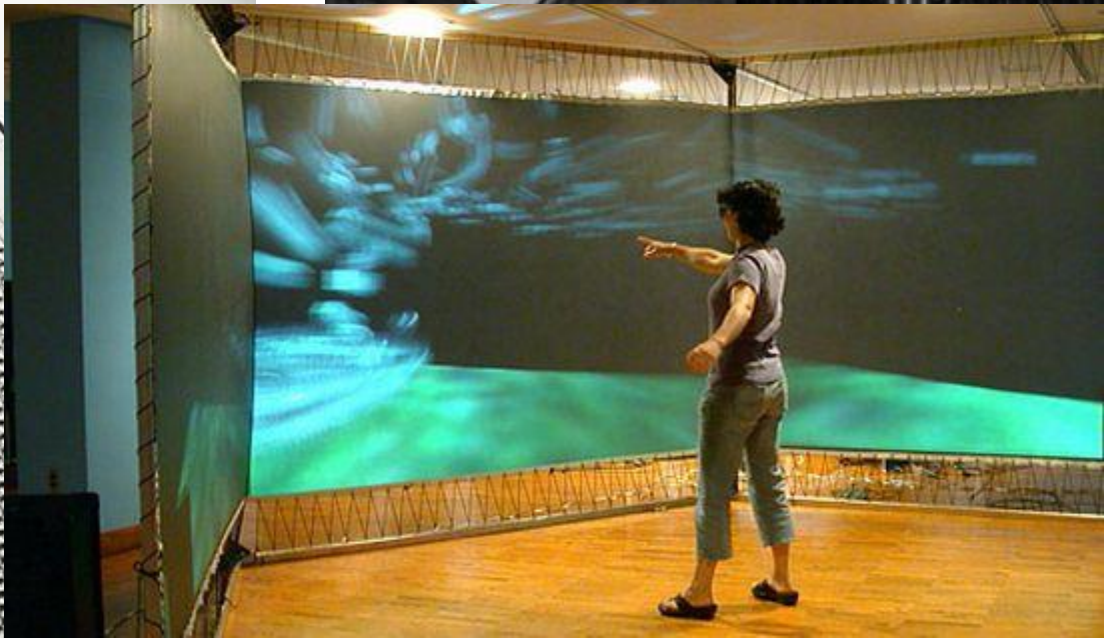

Sea Surface Temperatures
the North Carolina Coast
Aerial Photograph the
South Carolina Coast
Edisto Island
Beach Elevations
Edingsville Beach
Elevation (m)
Satellite Image
Hilton Head Island
South Carolina
RADARSAT

INSTITUT d'OPTIQUE GRADUATE SCHOOL



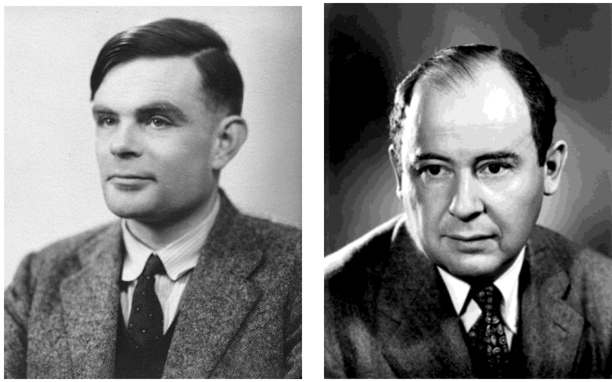






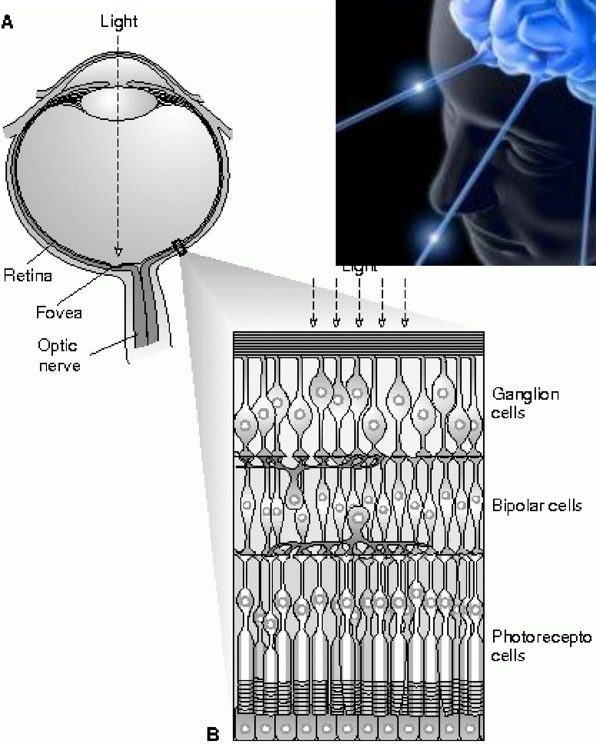
The computational aspect

- Game Changer – Computation

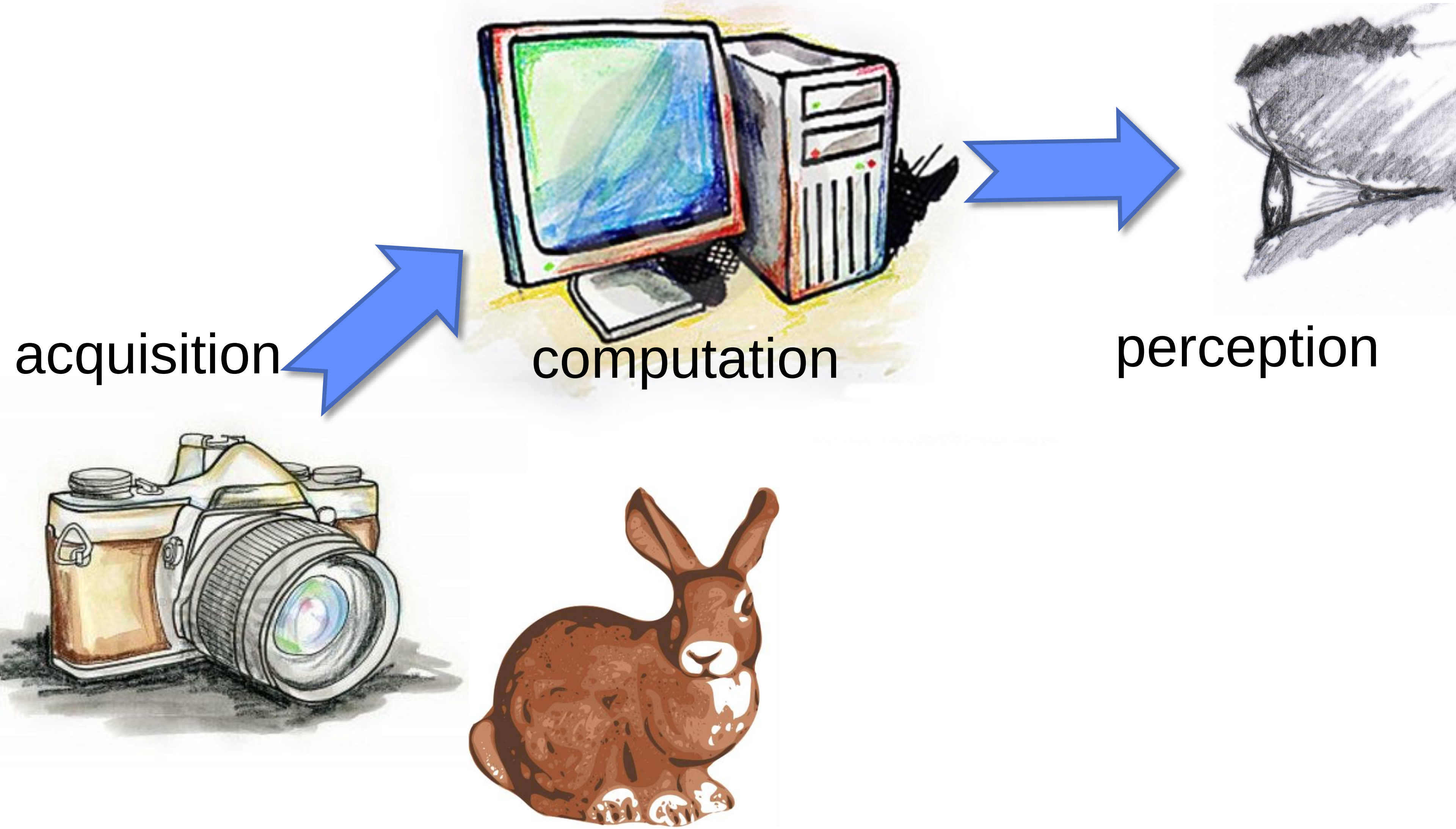


- Within last decade
  - Inexpensive, powerful, small computers
  - → complete digitization of imaging and display pipeline
    - Acquisition, transmission, storage, analysis, display

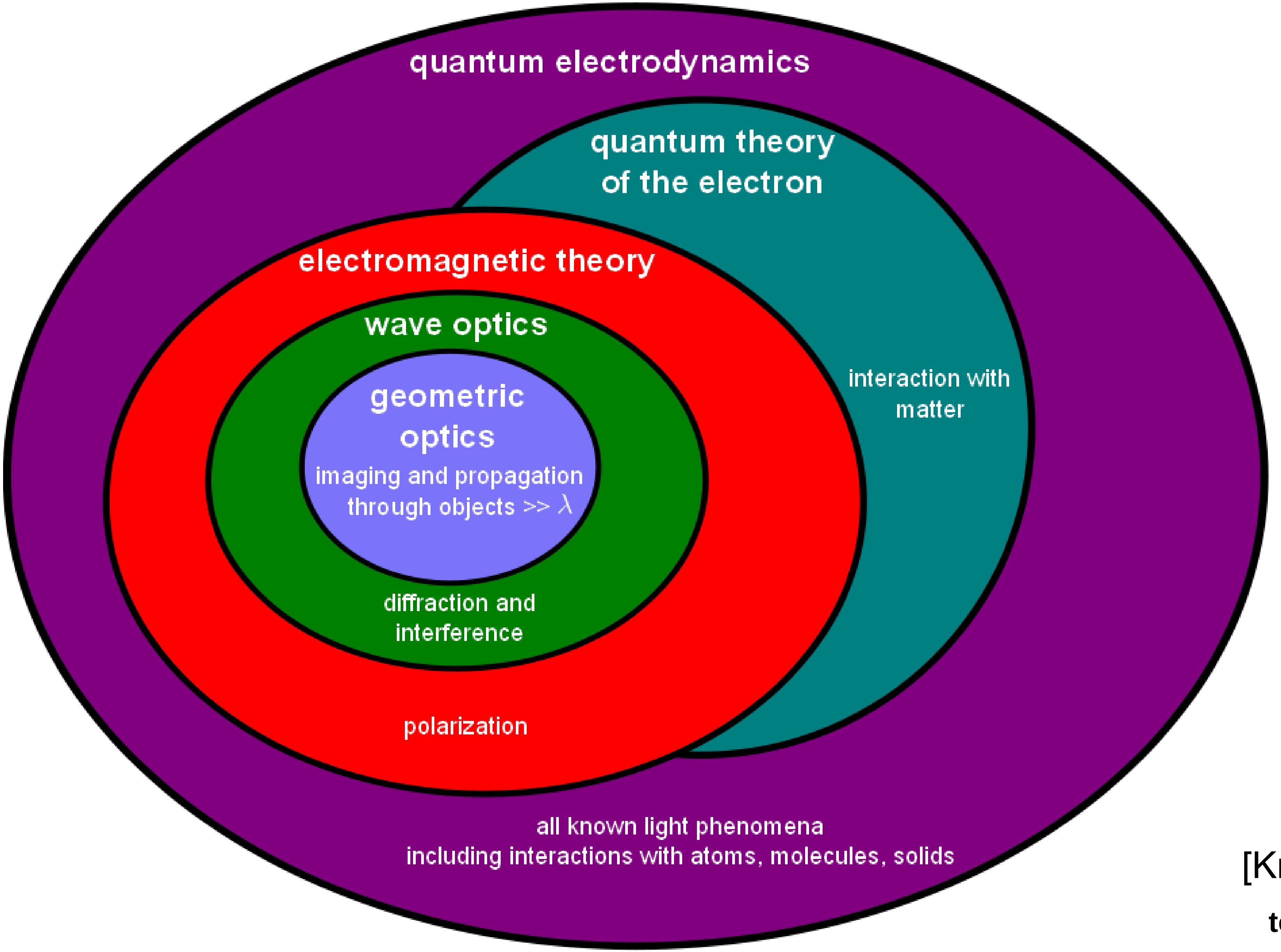
Human -> Silicon Observer



Computational Imaging

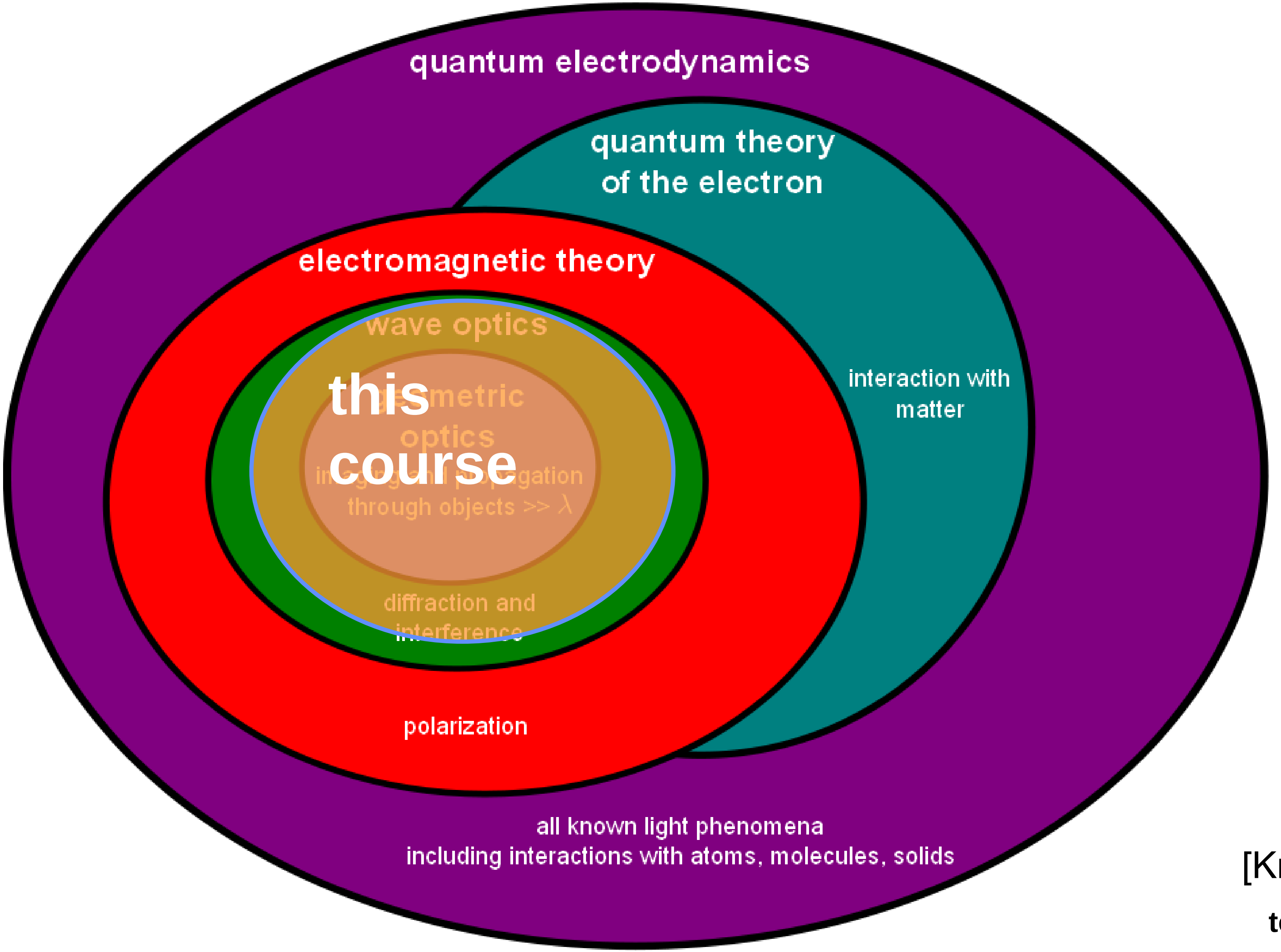


Physical Models of Light



[Krausz'04]

Physical Models of Light



[Krausz'04]

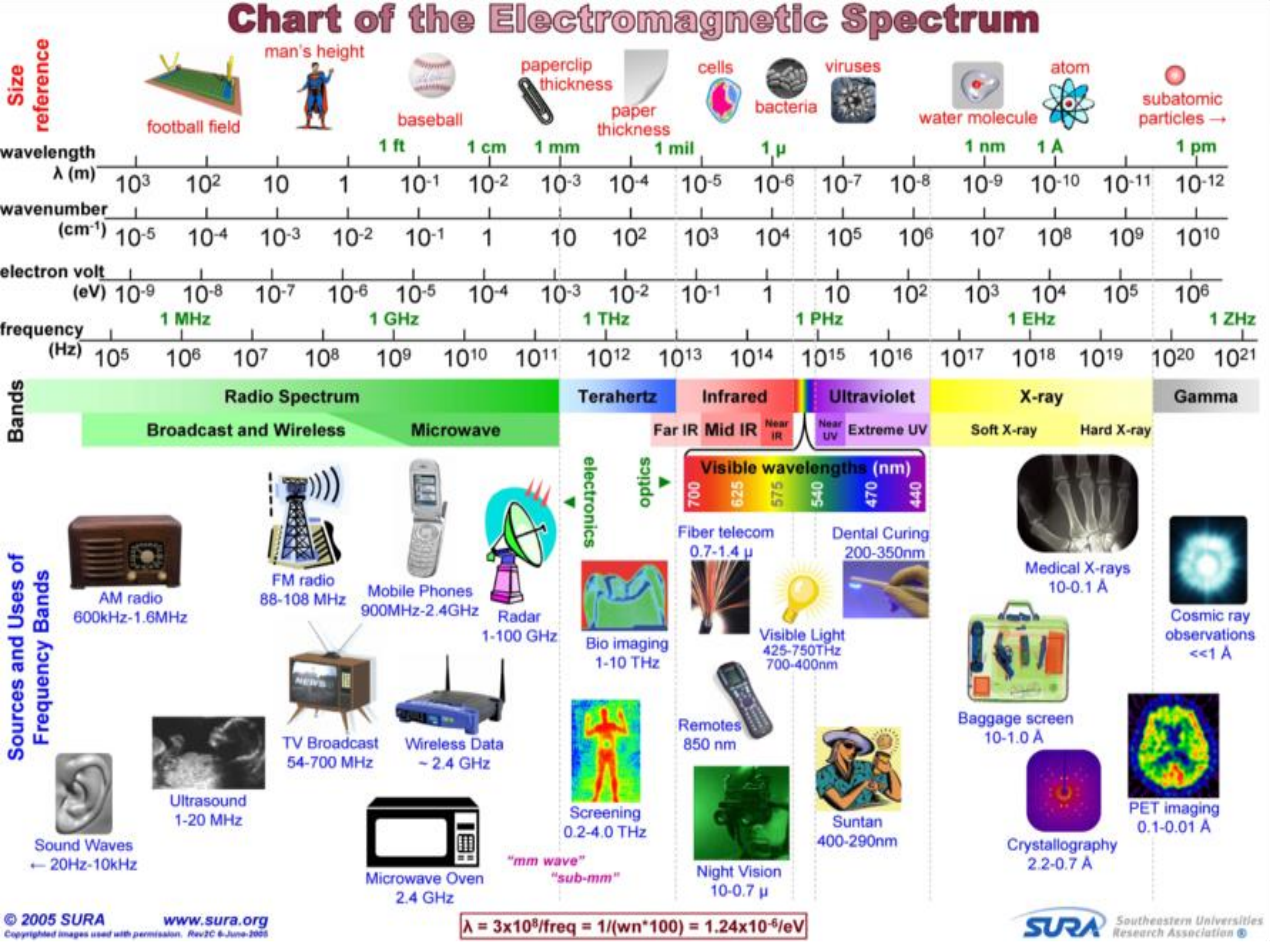


Chart of the Electromagnetic Spectrum
Size reference
football field
man's height
baseball
paperclip thickness
paper thickness
cells
bacteria
viruses
water molecule
atom
subatomic particles →
wavelength λ (m)
1 ft
1 cm
1 mm
1 mil
1 μ
1 nm
1 Å
1 pm
10^3 10^2 10 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}
wavenumber (cm^{-1})
10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10}
electron volt (eV)
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10 10^2 10^3 10^4 10^5 10^6
frequency (Hz)
1 MHz
1 GHz
1 THz
1 PHz
1 EHz
1 ZHz
10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20} 10^{21}
Bands
Radio Spectrum
Terahertz
Infrared
Ultraviolet
X-ray
Gamma
Broadcast and Wireless
Microwave
Far IR
Mid IR
Near IR
Near UV
Extreme UV
Soft X-ray
Hard X-ray
Visible wavelengths (nm)
700 625 575 540 470 440
electronics
optics
Sources and Uses of Frequency Bands
AM radio 600kHz-1.6MHz
FM radio 88-108 MHz
Mobile Phones 900MHz-2.4GHz
Radar 1-100 GHz
Bio imaging 1-10 THz
Fiber telecom 0.7-1.4 μ
Dental Curing 200-350nm
Medical X-rays 10-0.1 Å
Cosmic ray observations <<1 Å
Visible Light 425-750THz 700-400nm
Baggage screen 10-1.0 Å
Sound Waves ← 20Hz-10kHz
Ultrasound 1-20 MHz
TV Broadcast 54-700 MHz
Wireless Data ~ 2.4 GHz
Screening 0.2-4.0 THz
Remotes 850 nm
Suntan 400-290nm
PET imaging 0.1-0.01 Å
Crystallography 2.2-0.7 Å
Microwave Oven 2.4 GHz
"mm wave"
"sub-mm"
Night Vision 10-0.7 μ
© 2005 SURA www.sura.org
Copyrighted images used with permission. Rev2C 6-June-2005
$\lambda = 3 \times 10^8/freq = 1/(wn \cdot 100) = 1.24 \times 10^{-6}/eV$
SURA Southeastern Universities Research Association

Course Contents – Fast Forward

- Digital Imaging
  - 2-dimensional

Course Contents – Fast Forward

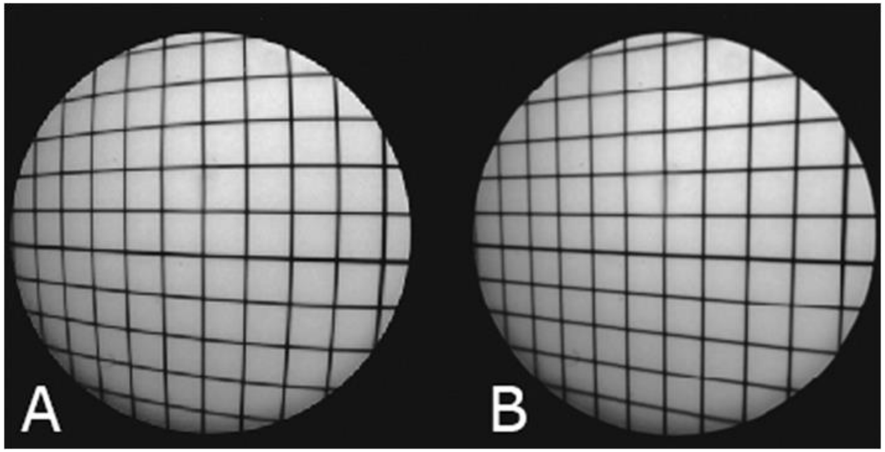
- Digital Imaging
  - 2-dimensional – Computational Preprocessing
    - Handle sensor imperfections
      - Dynamic range, Noise
    - Raw image “development”
      - Color correction, white balancing
    - Digital correction of imaging imperfections
      - Geometric distortions
      - Aberration correction
    - Compression (and why not to use it)

2D Imaging

Demosaicking

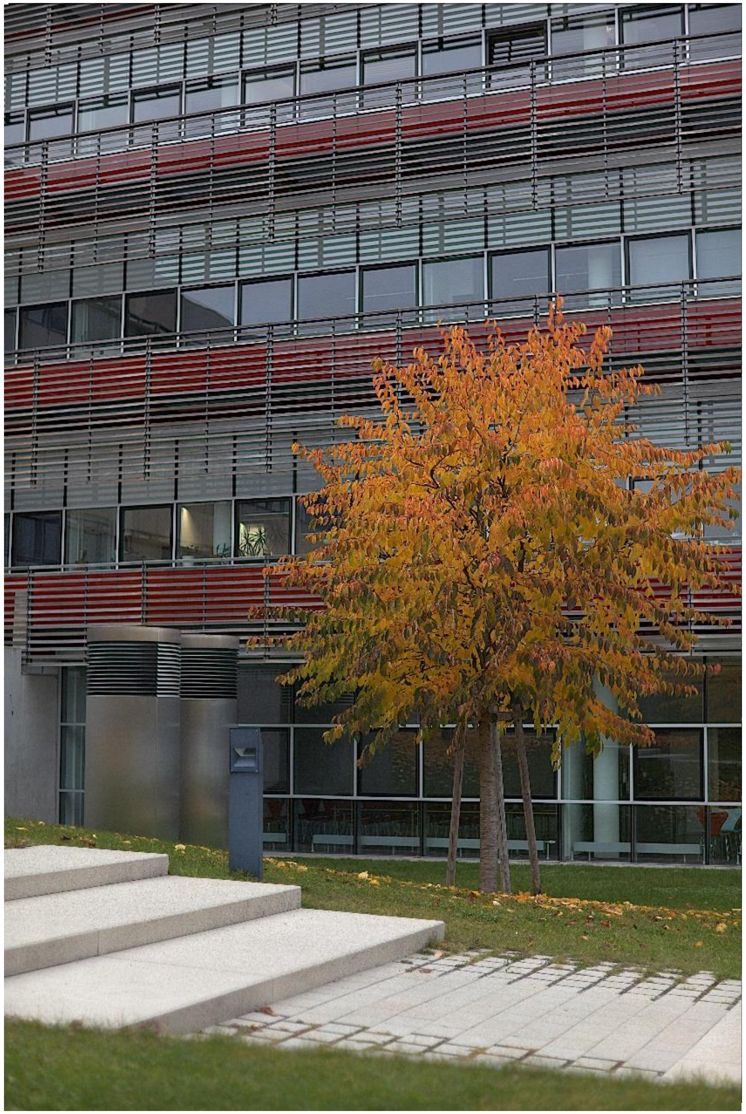
[RAW Explorer]

Undistortion



[van der Jeught'11]

RAW processing



[Schuler et al. 2011]

[Heide et al. 2013]

Course Contents – Fast Forward

- Digital Imaging
  - 2-dimensional – Computational Preprocessing
  - Several 2D images
    - Stereo Reconstruction

Stereo Reconstruction

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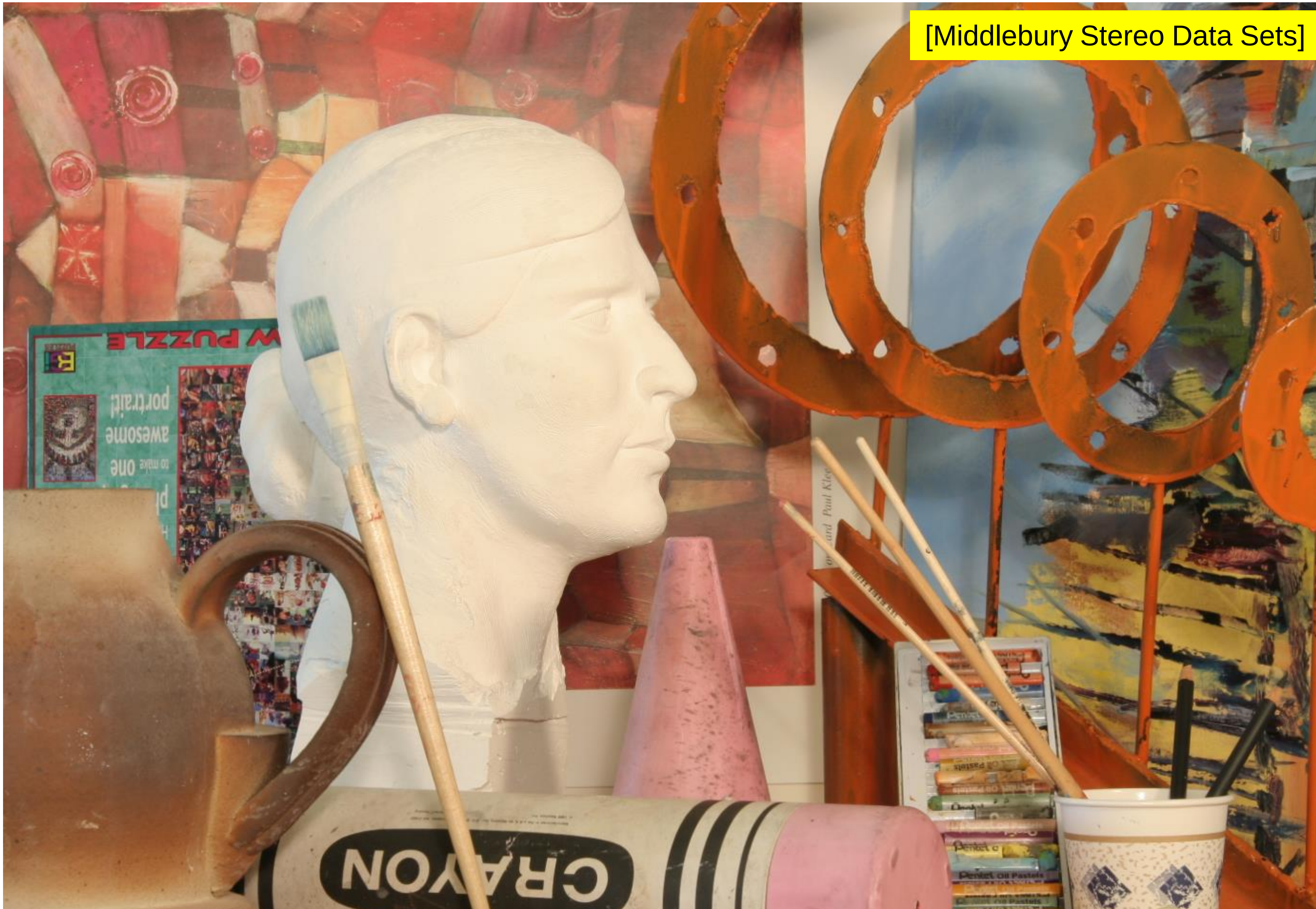
- Disparity estimation
  - Disparity = apparent parallax
    - Inversely related to depth

stereo image (try cross-eye)

disparity map/
depth map

[Tsukuba]

Stereo – Left Image



[Middlebury Stereo Data Sets]

Stereo – Right Image

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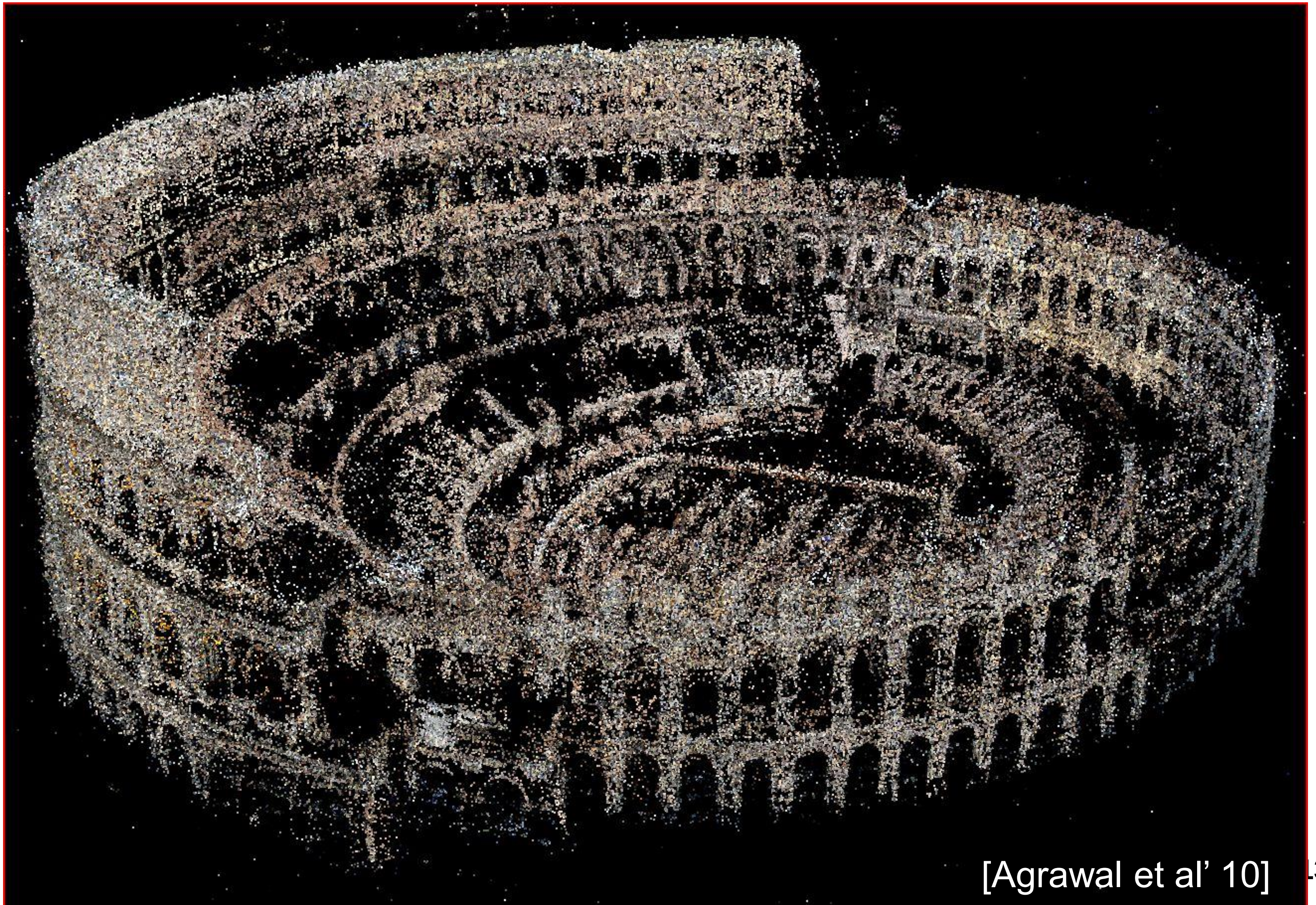
[Middlebury Stereo Data Sets]

Stereo – Disparity Map (bright is close)

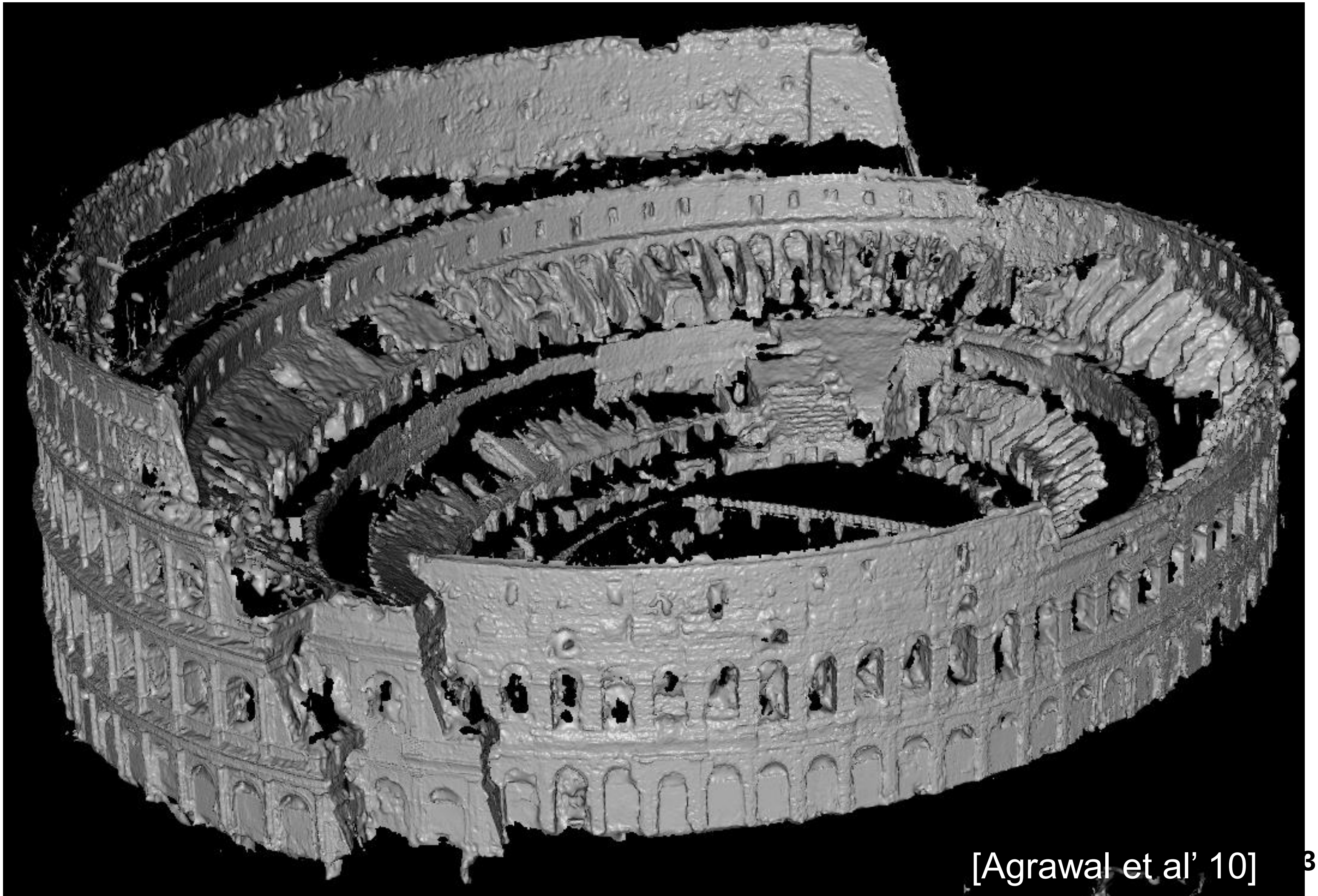
Course Contents – Fast Forward

- Digital Imaging
  - 2-dimensional – Computational Preprocessing
  - Several 2D images
    - Stereo Reconstruction
    - Multi-View Stereo



[Agrawal et al' 10]

[Agrawal et al’ 10]


[Agrawal et al' 10]

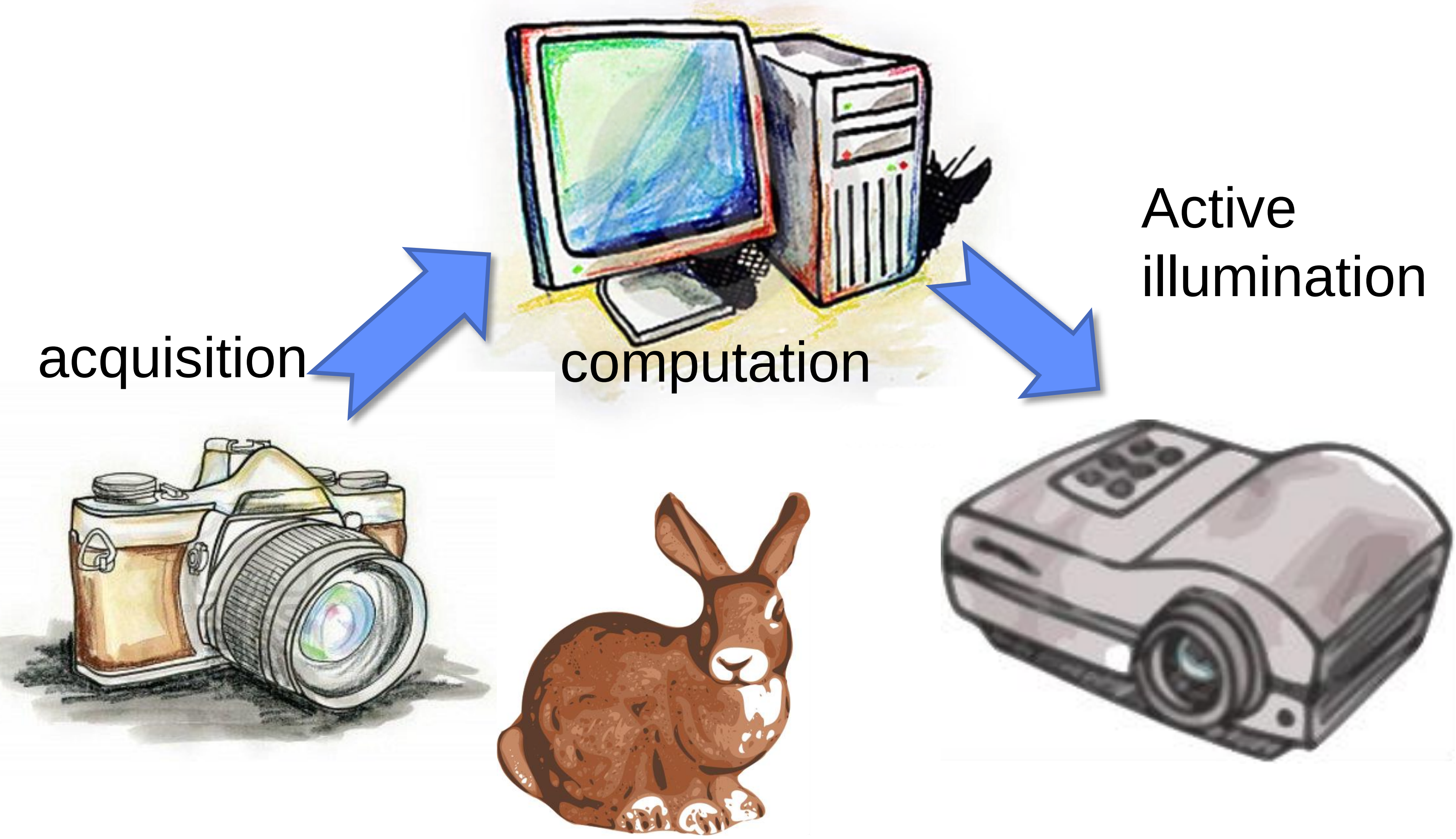
[Agrawal et al’ 10]

[Agrawal et al’ 10]

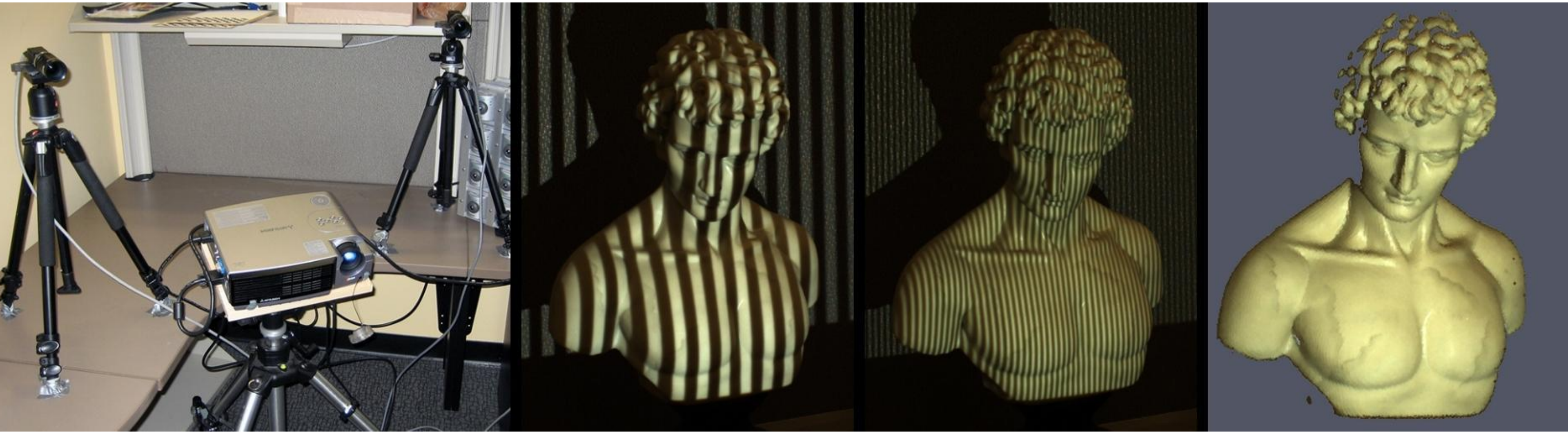
Course Contents – Fast Forward

- Digital Imaging
  - 2-dimensional – Computational Preprocessing
  - Several 2D images
    - Stereo Reconstruction
    - Multi-View Stereo
    - 3D Scanning (active)
      - Laser range scanning
      - Structured light
      - Kinect I

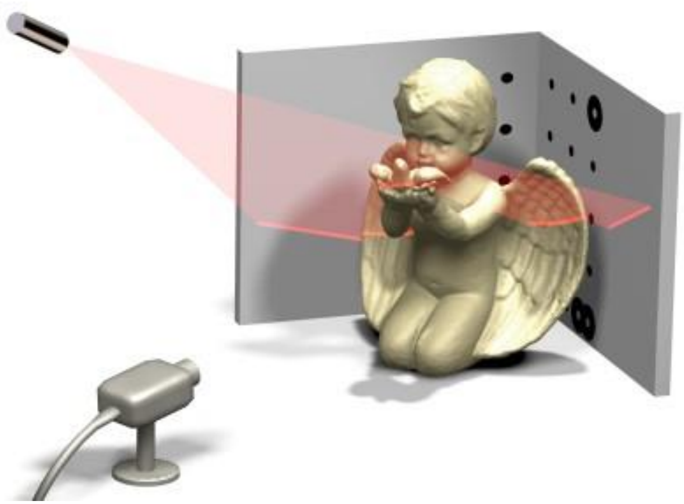
Active Systems - Components



3D Scanning



[Lanman & Taubin'09]



[DAVID Laser Scanner]

[Digital Michelangelo Project, Stanford Univ.]

3D Scanning - Kinect

[Andres Reza]

[Matthew Fisher]

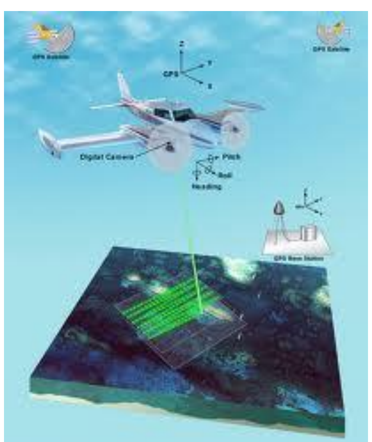
Course Contents – Fast Forward

- Digital Imaging
  - 2-dimensional – Computational Preprocessing
  - Several 2D images
    - Stereo Reconstruction
    - Multi-View Stereo
    - 3D Scanning (active)
    - Time-of-Flight (active)

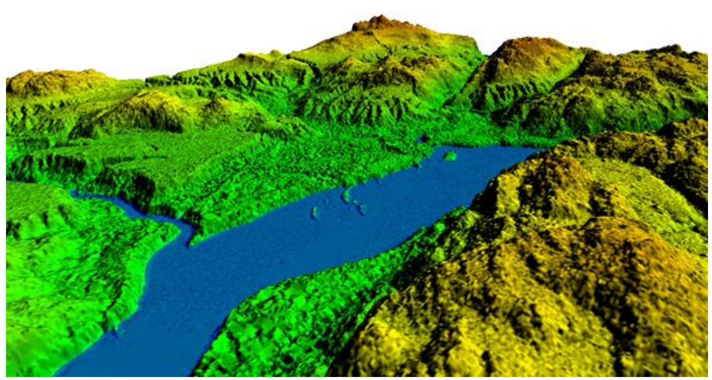
Time-of-Flight Sensing

LIDAR

[SICK AG]

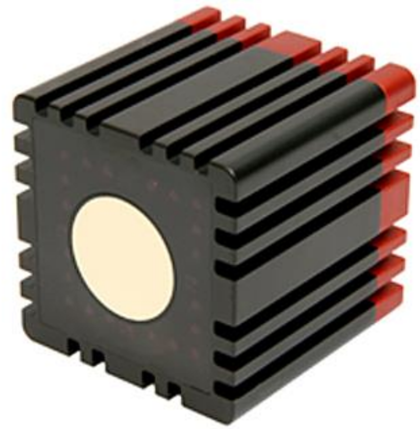


[usgs.gov]



[Groupe Info Consult]

Phase-Based Measurements

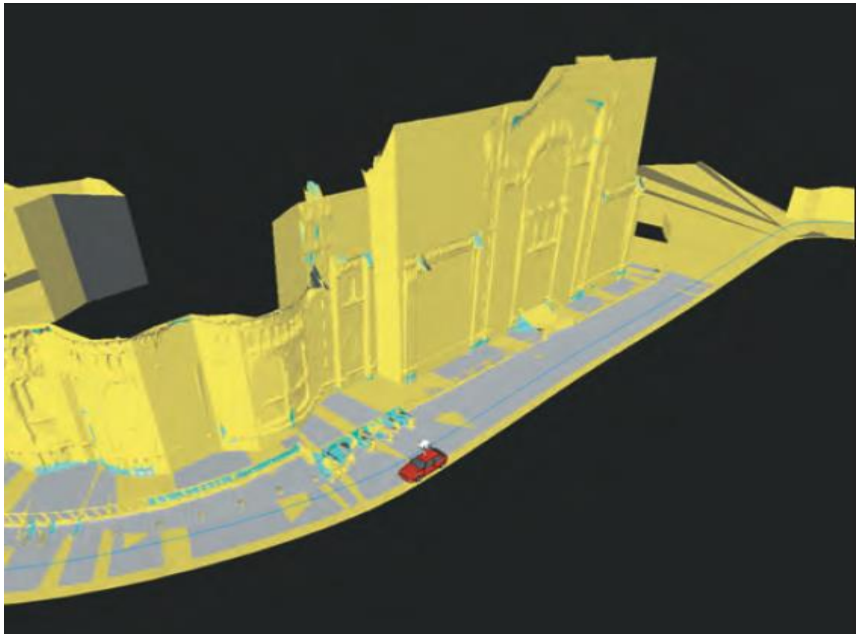


[Mesa Imaging AG]

[PMD Technologies GmbH]

[Microsoft Kinect 2.0]

Application - Google Street View

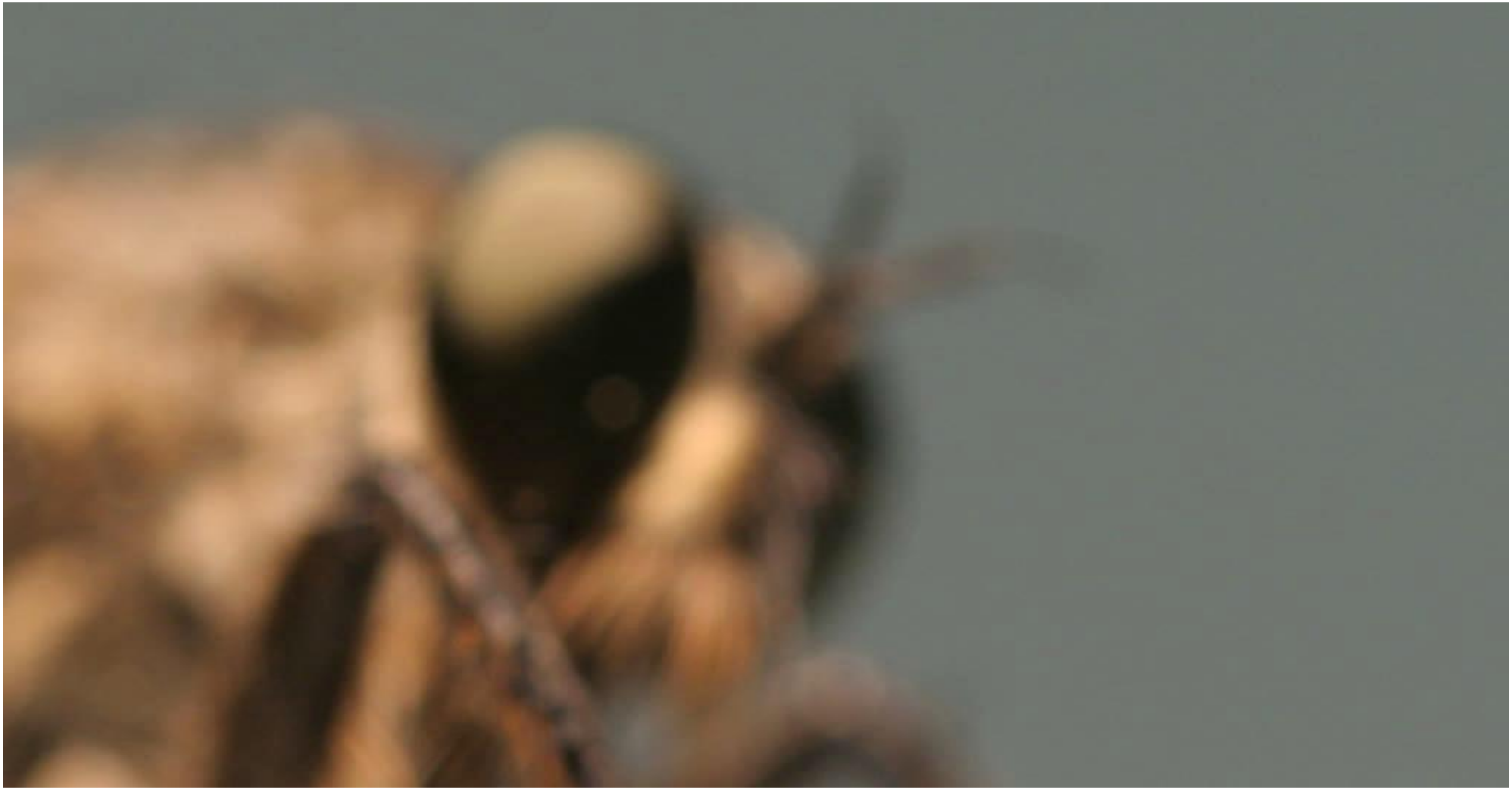


[Anguelov et al.'10]

Course Contents – Fast Forward

- Digital Imaging
  - 2-dimensional – Computational Preprocessing
  - Several 2D images
    - Stereo Reconstruction
    - Multi-View Stereo
    - 3D Scanning (active)
    - Time-of-Flight (active)
    - Focal Stacks

Focal Stacks



Focal Stack

- Extended depth-of-field image

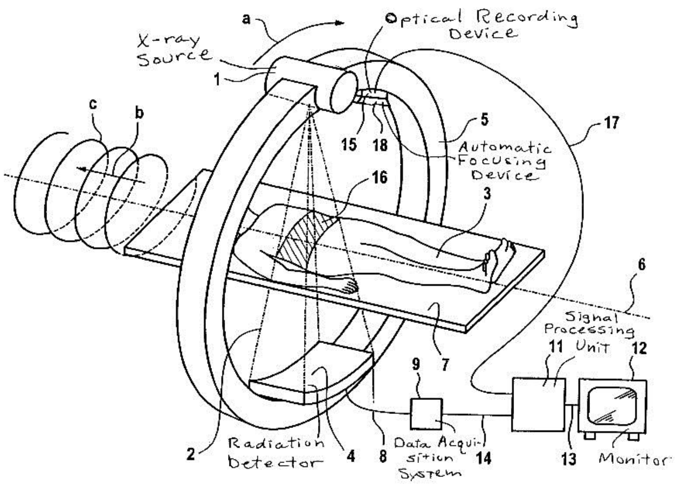
Focal Stack

Extended Depth of Field

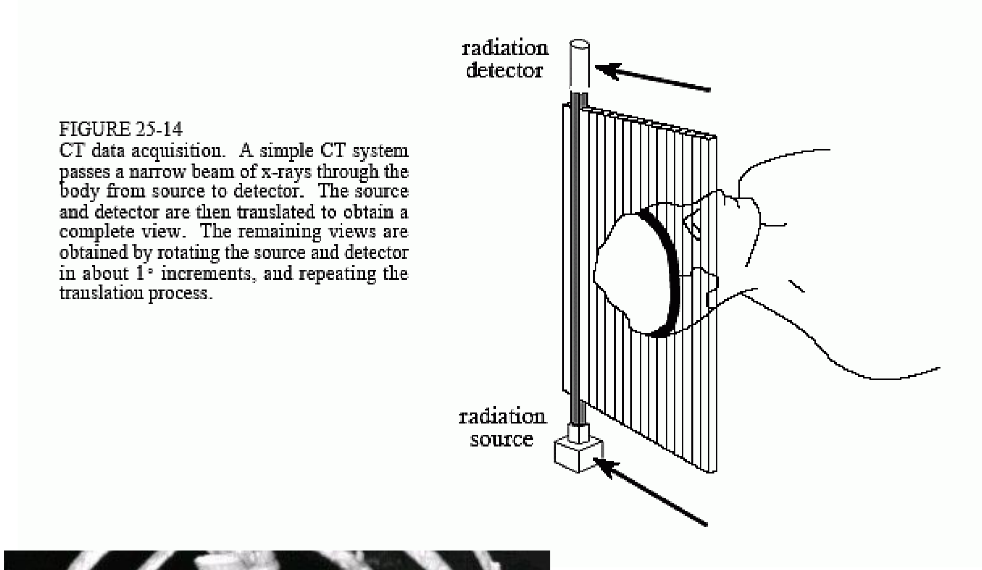
What is this course about ?

- Imaging
  - 2-dimensional – Computational Preprocessing
  - Several 2D images – 3D Surfaces
  - 3-dimensional
    - Tomography
      - Fourier Slice Theorem
      - Filtered Back Projection
      - Algebraic Reconstruction Techniques

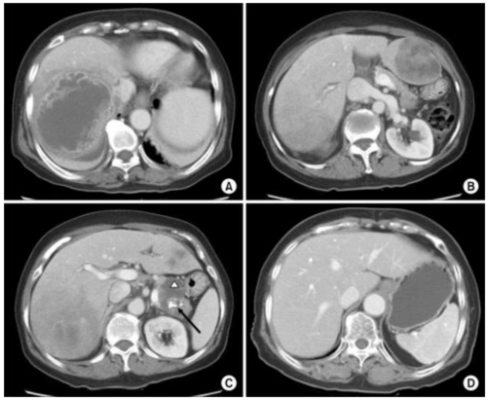
Tomography



[Stierstorfer 2003]



[DSPGuide]

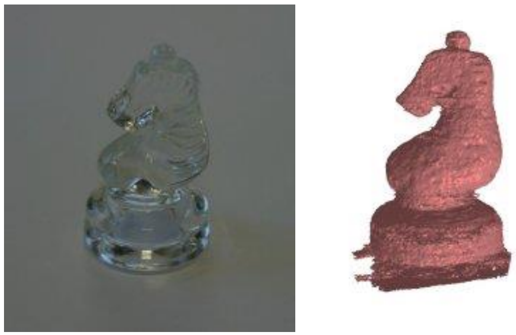


[NIH]

[MadisonRadiologists]

Tomography Applications

Surface Characterization

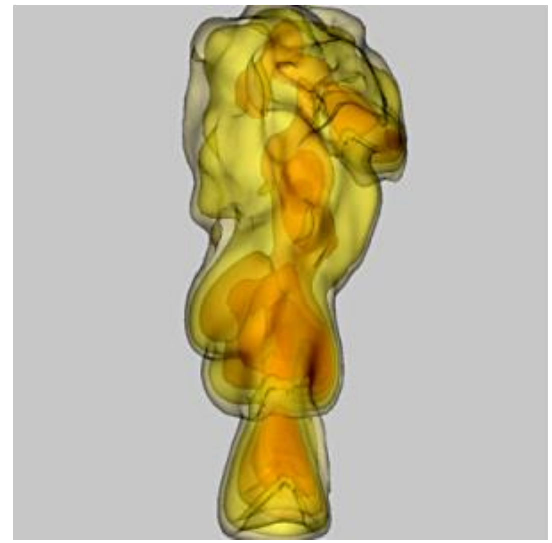


[Trifonov et al.'06]

3D Displays

[Wetzstein et al.'11]

Engineering measurements



[Atcheson et al.'08]

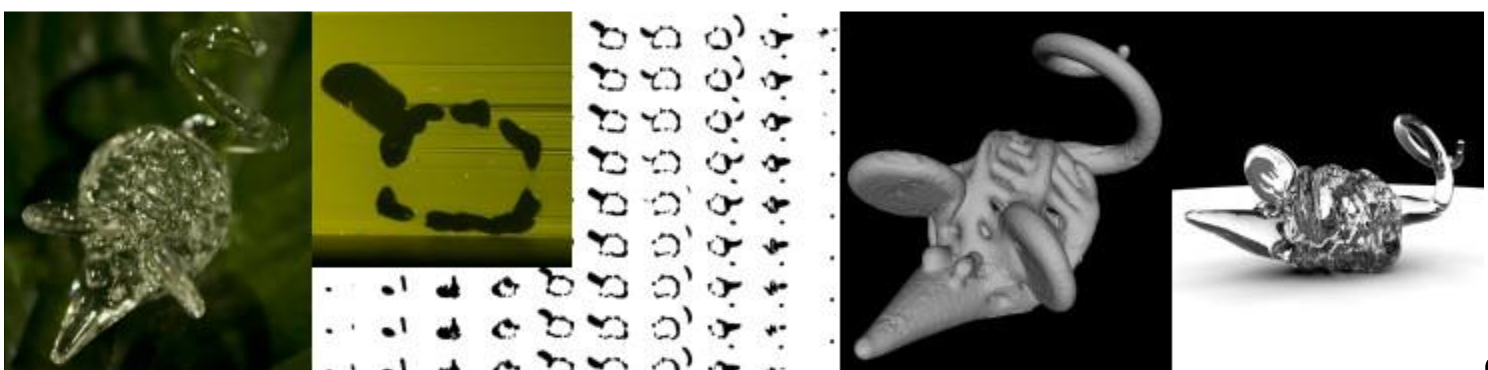
What is this course about ?

- Imaging
  - 2-dimensional – Computational Preprocessing
  - Several 2D images – 3D Surfaces
  - 3-dimensional
    - Tomography
    - Direct Volume Slicing
    - Confocal Microscopy

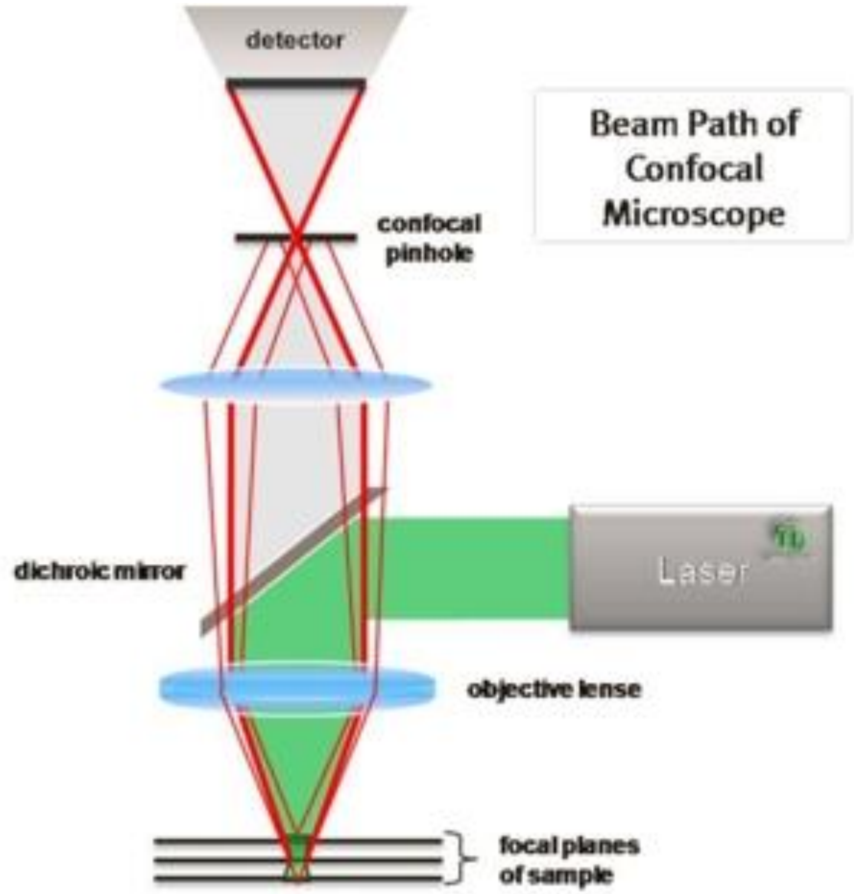
Volume Slicing

Photograph

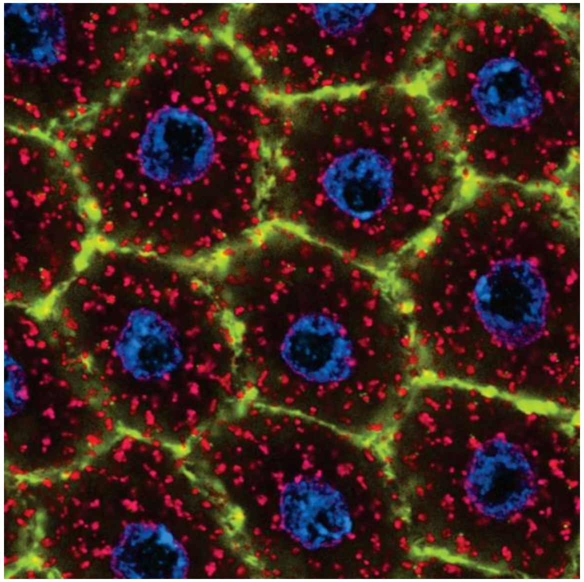
Digital rendering



Confocal Microscopy



[Schürmann,Ramachandra, Uni Münster]

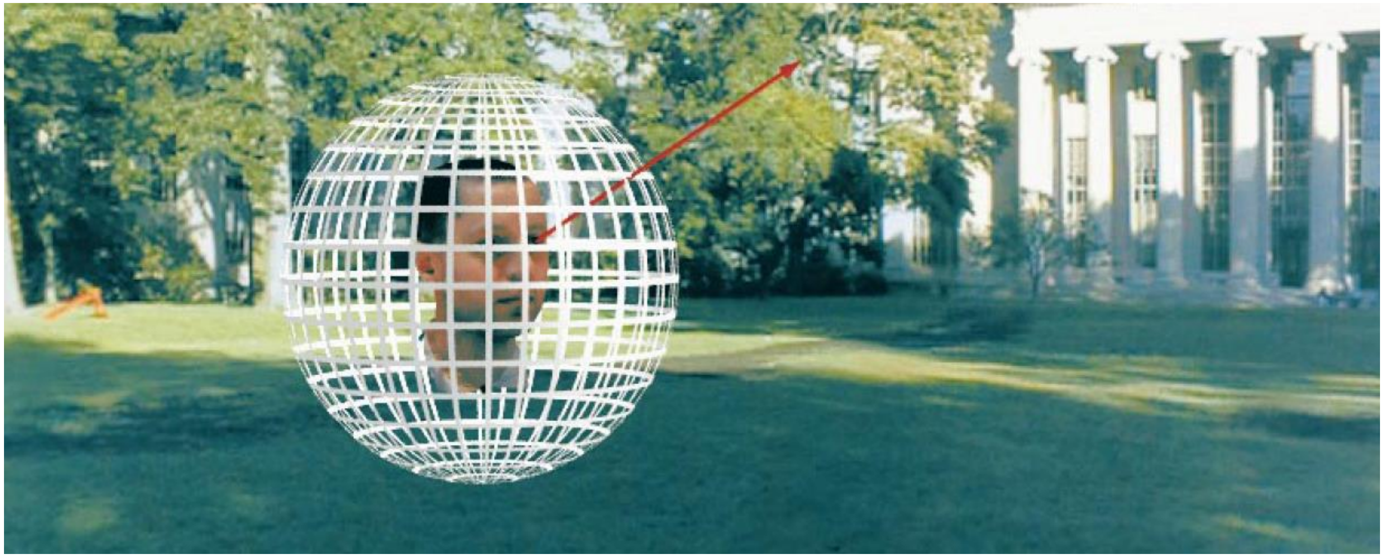


[University of Illinois]

What is this course about ?

- Imaging
  - 2-dimensional – Computational Preprocessing
  - Several 2D images – 3D Surfaces
  - 3-dimensional – 3D Volumes
  - Multi-dimensional
    - Plenoptic function
    - Light fields

The 7D Plenoptic Function



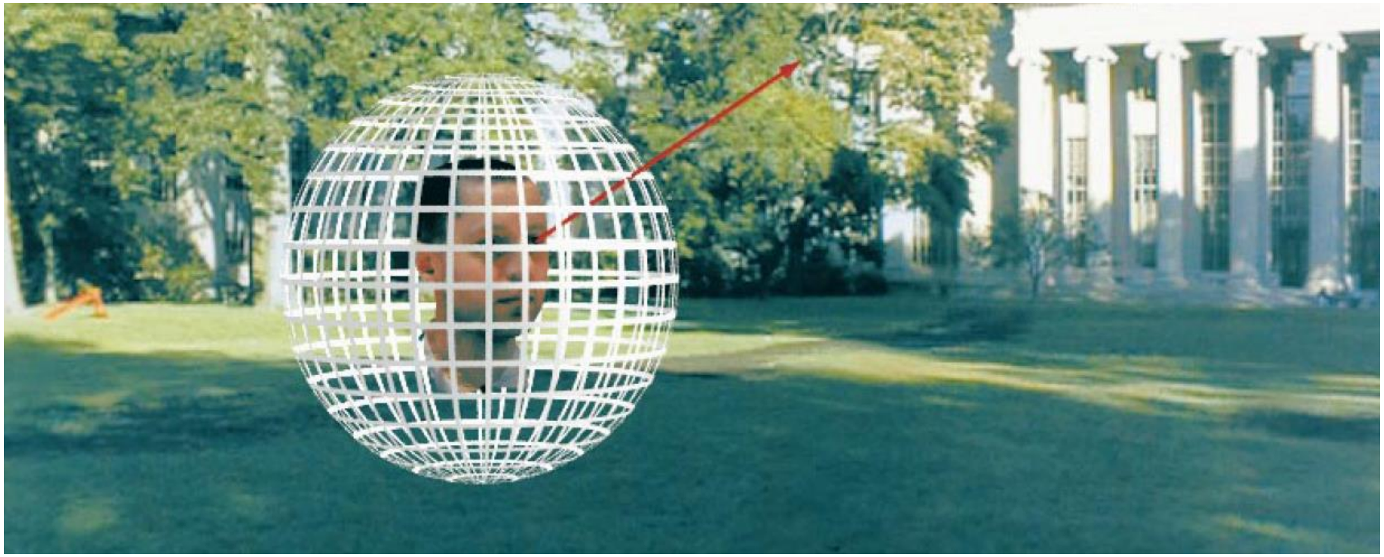
$$I(\theta, \phi, \lambda, t)$$

Q: What is the set of all things that one can ever see?

A: The Plenoptic Function [Adelson and Bergen 1991]

(from *plenus*, complete or full, and *optic*)

The 7D Plenoptic Function



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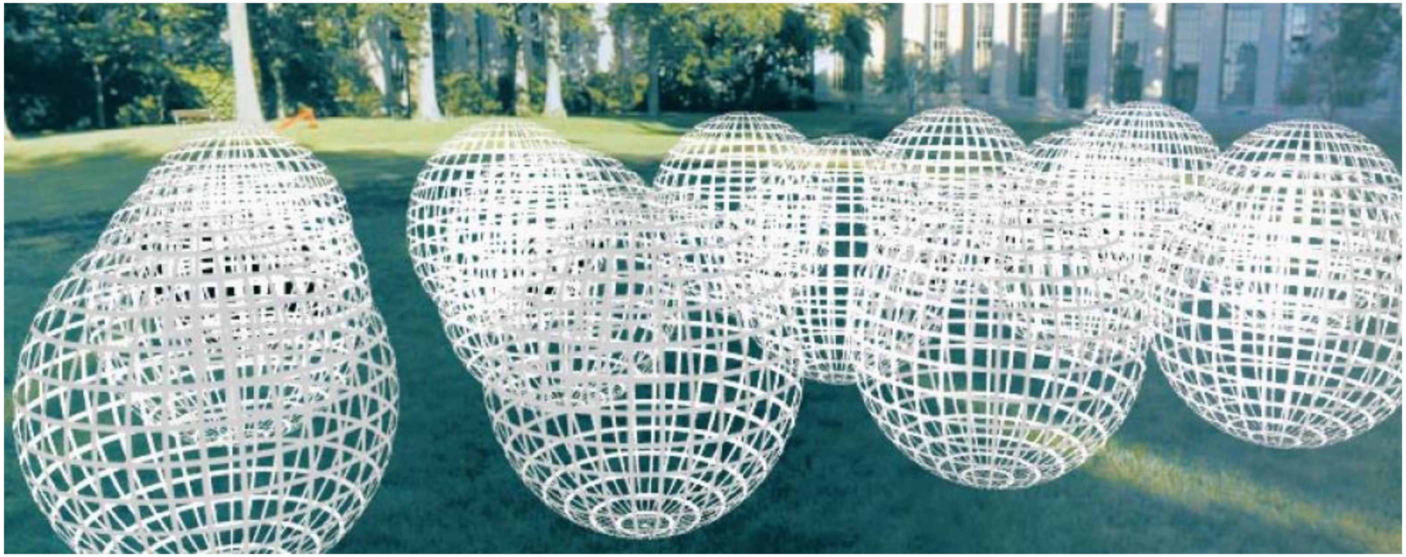
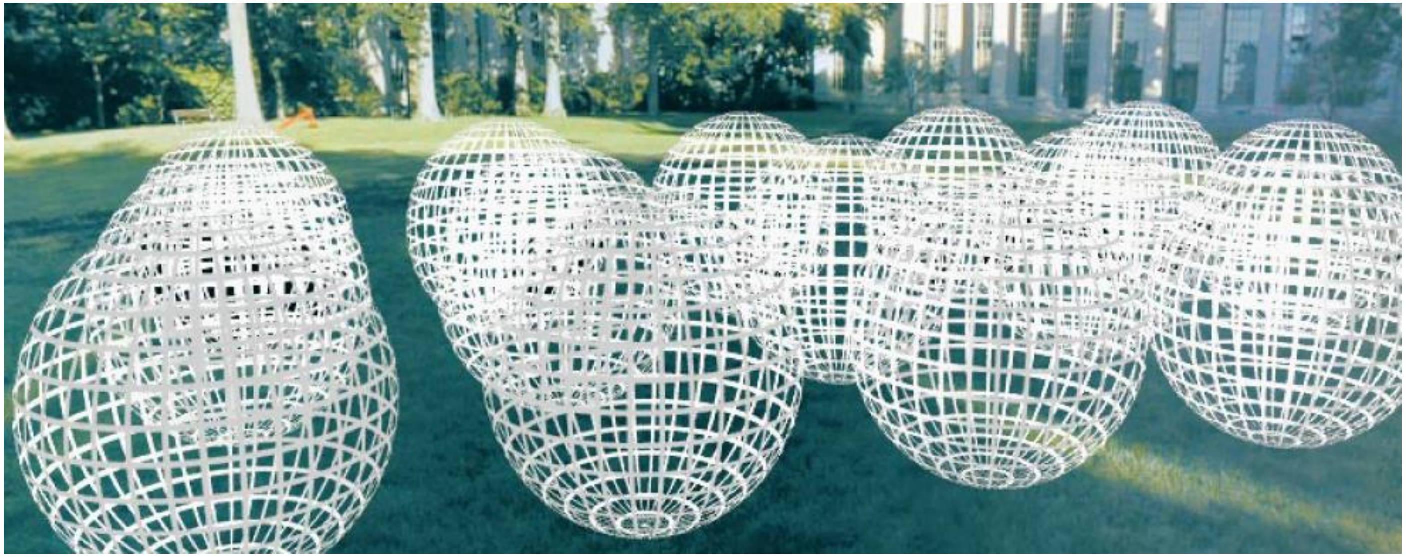


$$I(\theta, \phi, \lambda, t, p_x, p_y, p_z)$$

$P(\theta, \phi, \lambda, t, p_x, p_y, p_z)$ defines the intensity of light:

- as a function of viewpoint
- as a function of time
- as a function of wavelength

The 7D Plenoptic Function



$$l(\theta, \phi, \lambda, t, p_x, p_y, p_z)$$

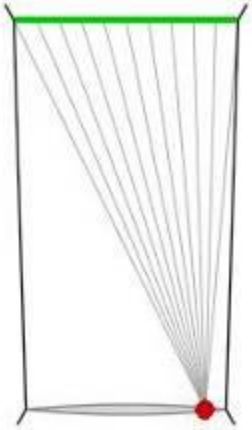
$P(\theta, \phi, \lambda, t, p_x, p_y, p_z)$ defines the intensity of light:

- as a function of viewpoint
- as a function of time
- as a function of wavelength

Example of digital refocusing

[Ng 2005]

Example of moving the observer



[Ng 2005]

START OF THE LECTURE