CE7453: Photogrammetric Computer Vision

Lecture 2

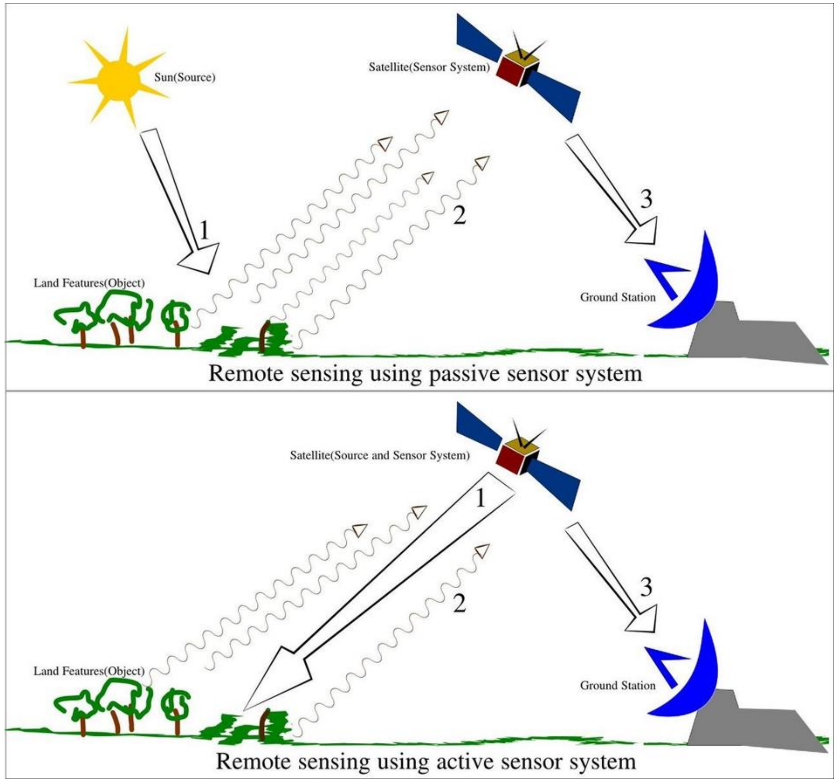
Optical Sensors and Imaging system

Acknowledgements: part of the materials of the all the lecture notes are from Cyrill Stachniss, Ping Tan, Marc Pollefey, Wolfgang Foerstner, Bernhard Wrobel, James Hays, A. Dermanis, Armin Gruen, Alper Yilmaz.

Sensors and Platforms

We primarily deal with images captured by different ***sensors***, carried by different ***platforms***

Passive: Optical camera, geodetic sensors

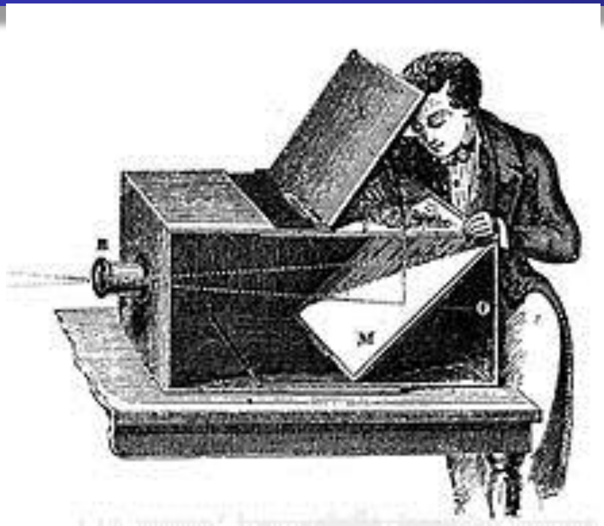


Active: LiDAR, Radar, Altimeter, Sonar system

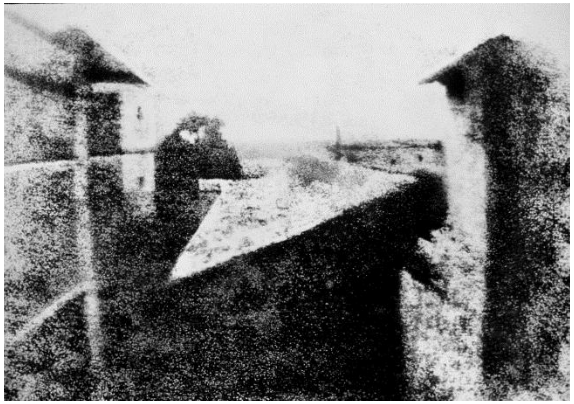
Platforms: Satellite, airplane, UAS, balloon, airship, mobile vehicles.

Image credits: https://en.wikipedia.org/wiki/Remote_sensing

Cameras



An artist using an 18th-century camera obscura to trace an image

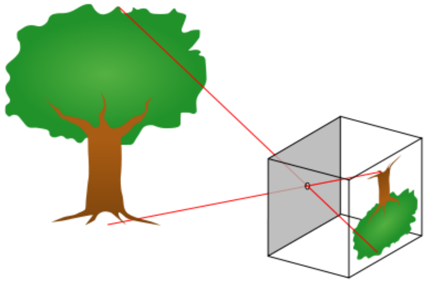


Oldest survival photograph

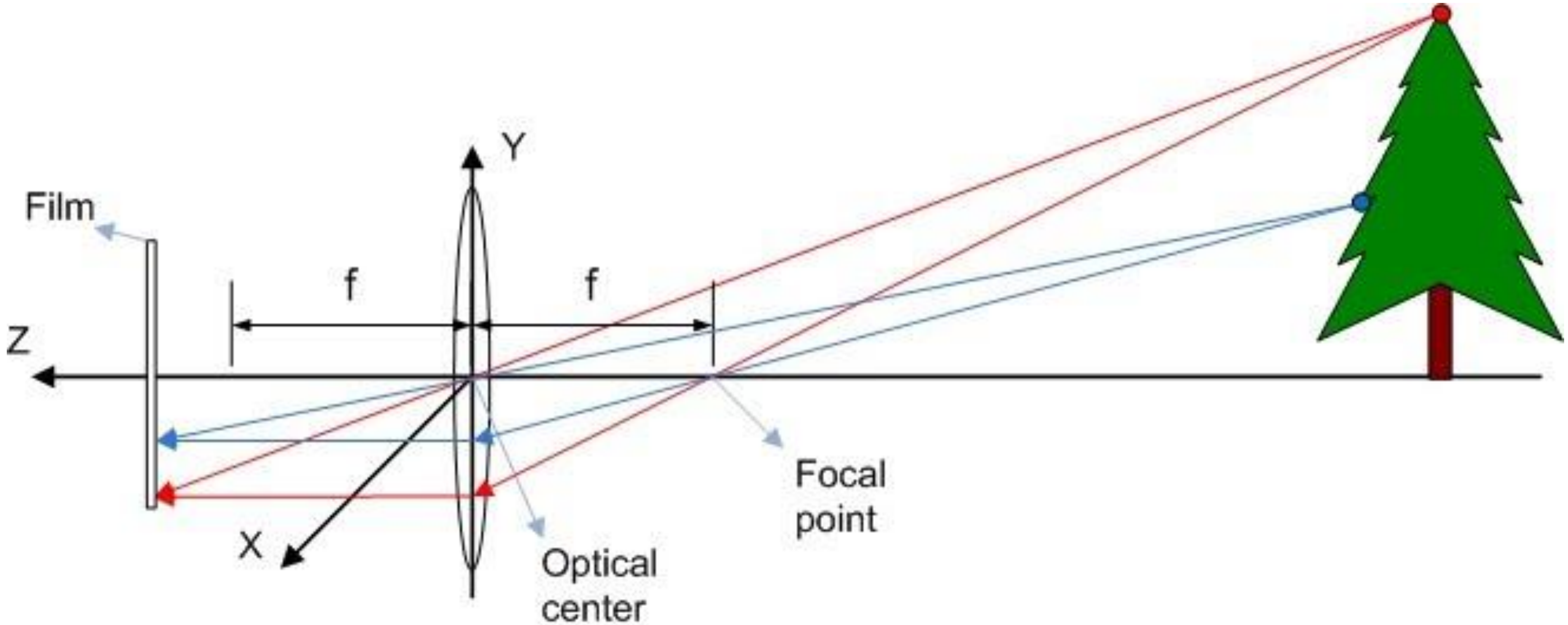
The first commercially available camera: Giroux Daguerreotype

Image courtesy: https://en.wikipedia.org/wiki/History_of_the_camera

Perspective Camera Model



Camera obscura
(Pinhole camera model or perspective model)



Electromagnetic Radiation Spectrum

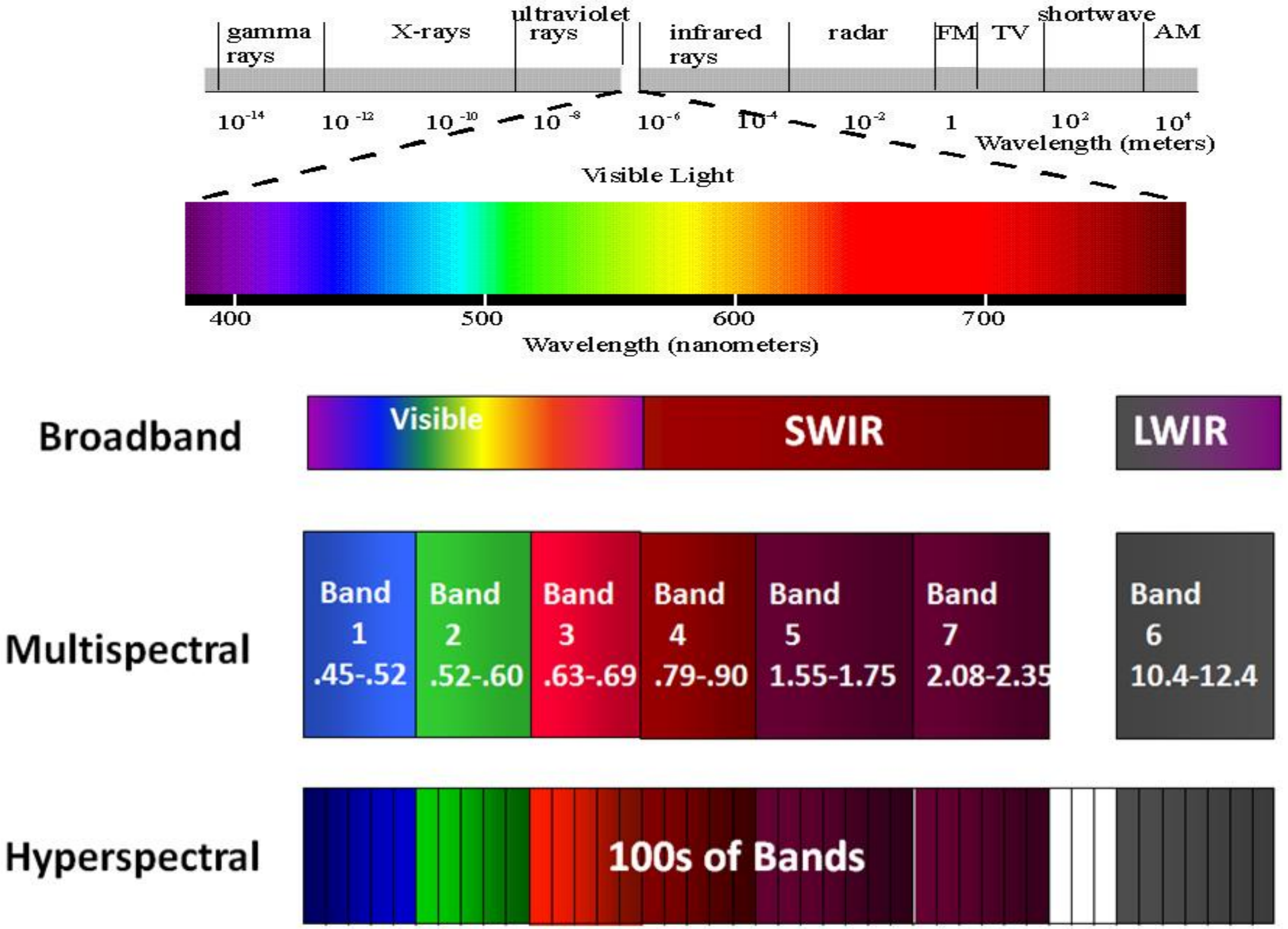
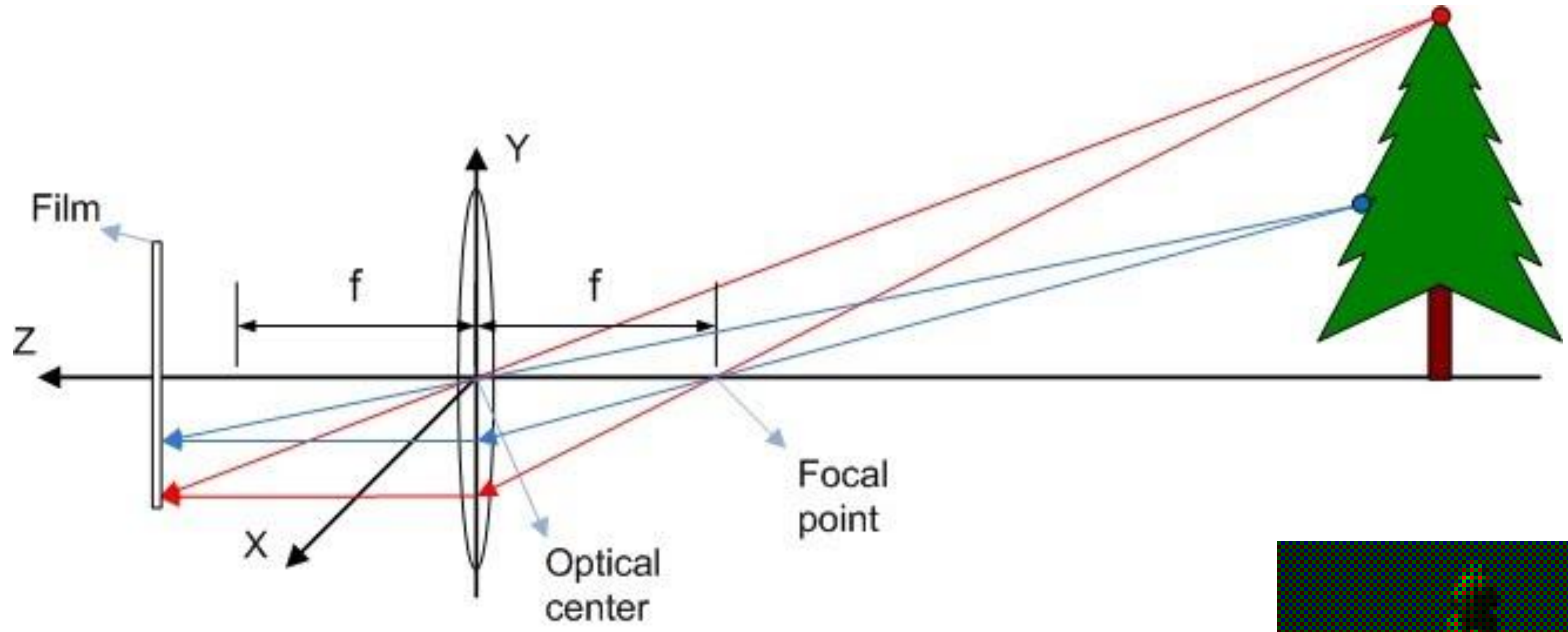
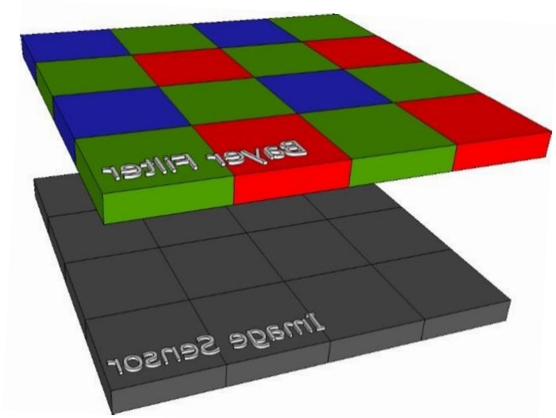
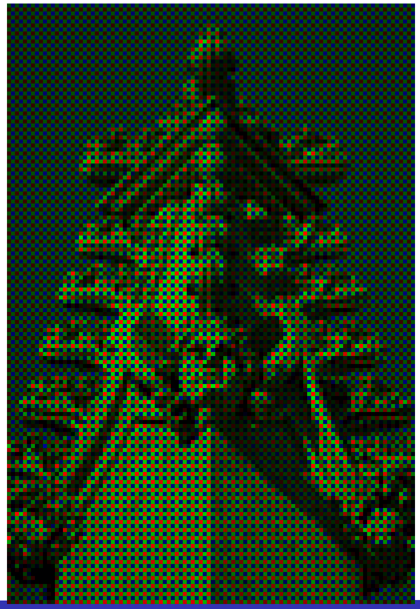


Image courtesy: Wikipedia

Camera



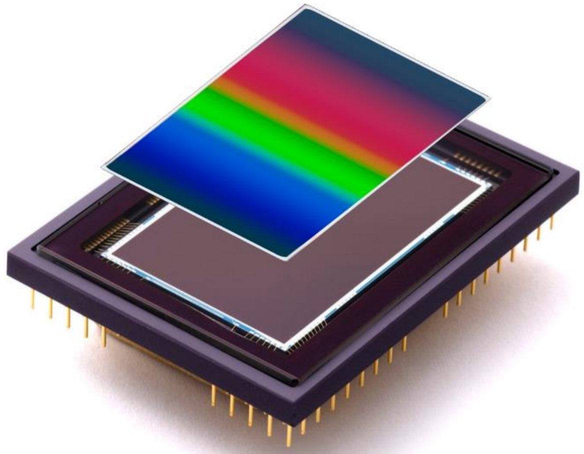




390 nm – 700 nm

Multispectral/Hyperspectral Cameras

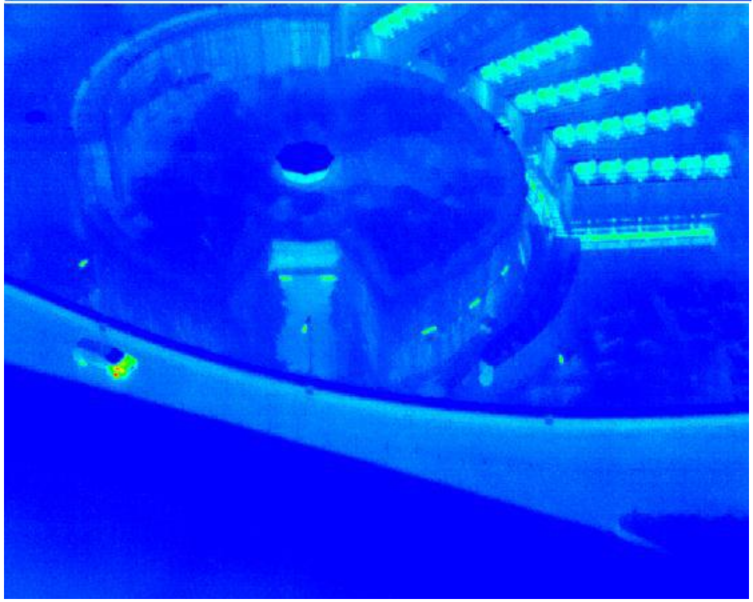
390nm- 2500 nm



Linear Variable Filter based HSI detector

Thermal Infrared Cameras

5000 nm – 40,000 nm



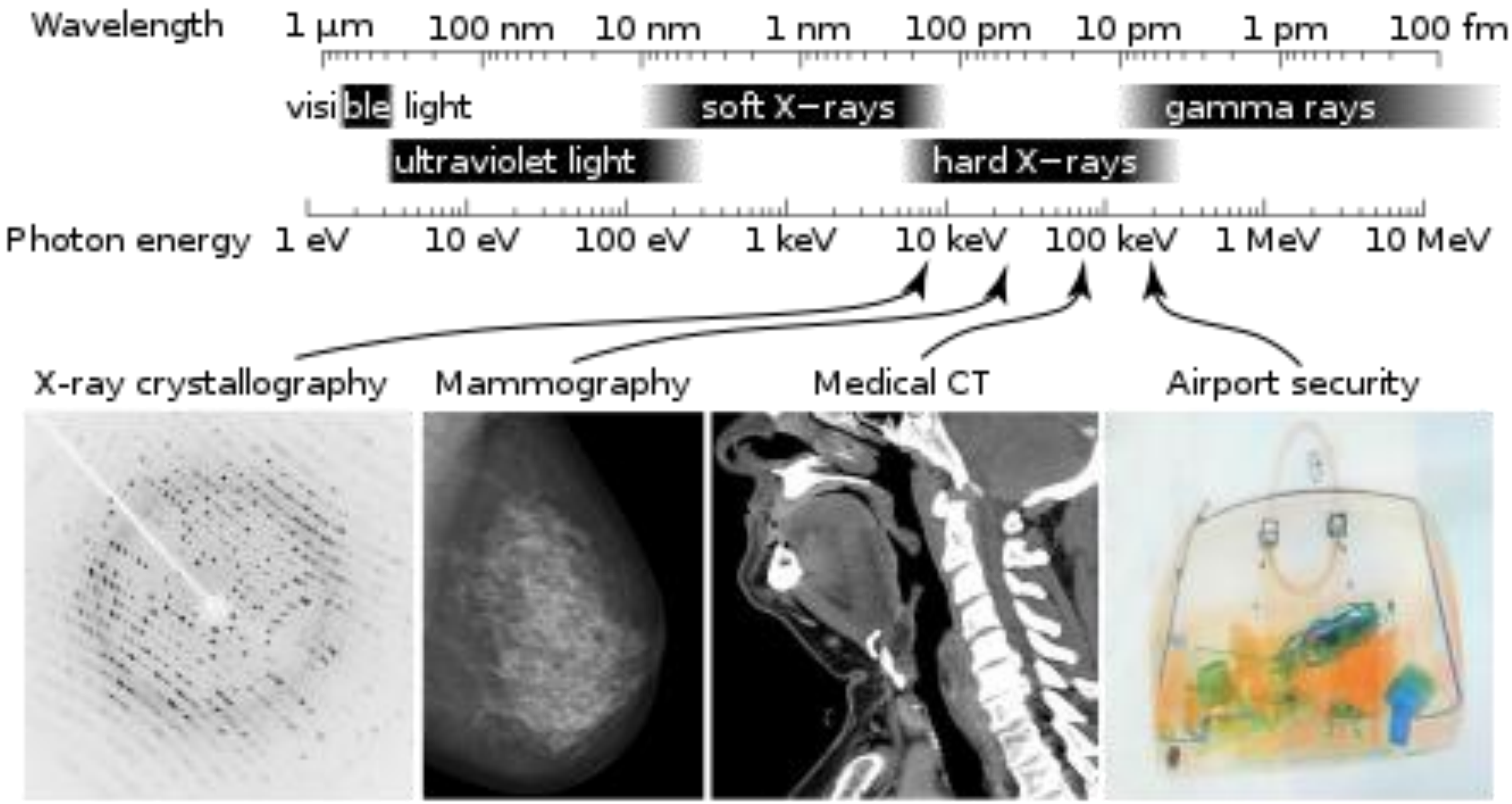
Short-wave Infrared

900-1700 nm

Low responses to water

X-rays

0.01 to 10 nm



Imaeg courtesy: https://en.wikipedia.org/wiki/X-ray

Elements of a (Digital) Camera

lens and camera body

Lens → Aperture → Shutter

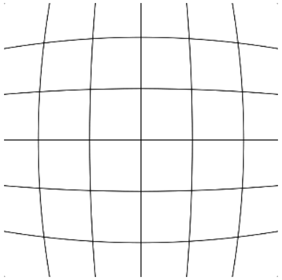
sensor chip

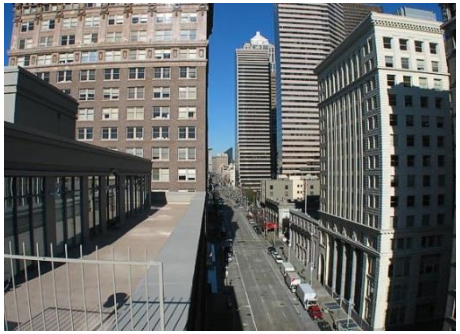
Sensor → A/D converter → Post-processing

Lens

Expecting

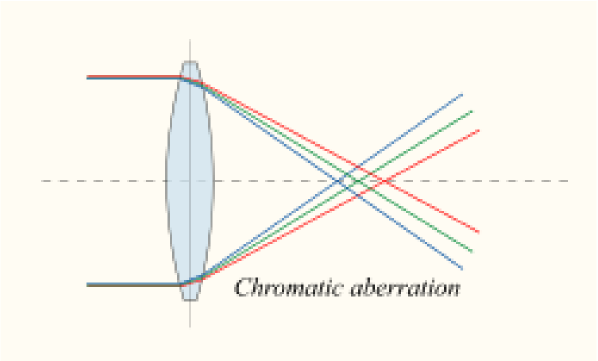
- No distortion



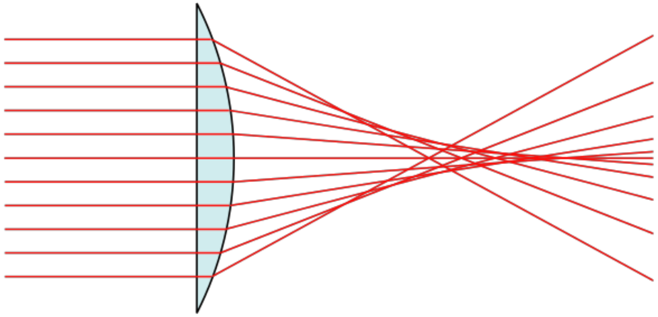


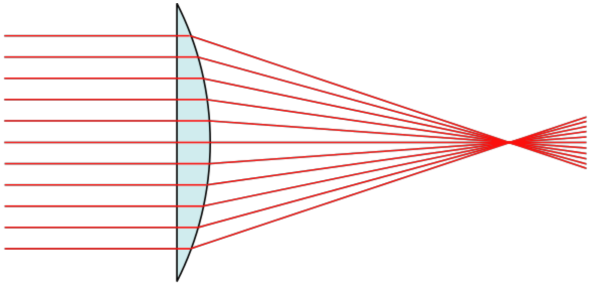
- Sharp, no aberrations

Aberrations

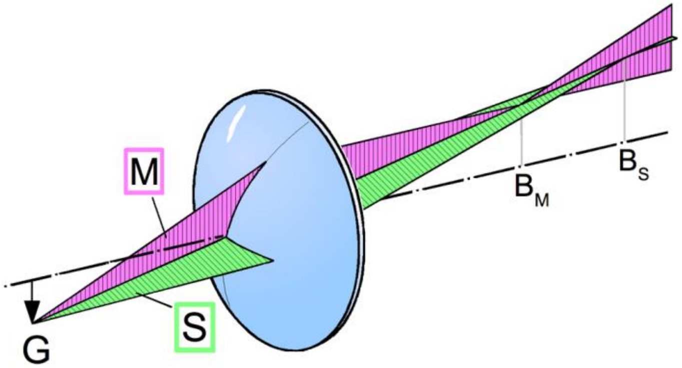


Chromatic Aberration





Spherical Aberration



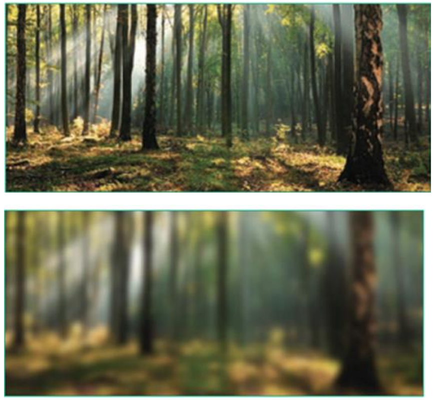


Image courtesy: Wikipedia, Air Optix

Typical Consumer-grade lens

- Telephoto lens, normal lens, wide-angle lens, fisheye lens, …

telephoto

normal

wide-angle

fisheye

Image courtesy: Canon

Lens

Tele lens

Wide-angle

Fisheye

Narrow field of view
Minimal perspective distortion
Parallel lines remain parallel

70-120 deg field of view
Straight lines roughly remain straight
Proportion not correction

130 deg+ field of view
Straight line not straight

Sensor Chip (Digital)

- Portion that receive lights, converts photons to intensity values
- Array of light-sensitive cells

Two main types of sensors

- **CCD**: charge-coupled device
  (lower noise, more expensive, global shutter)
- **CMOS**: complementary metal oxide on silicon
  (higher noise, cheaper, rolling shutter)

Sensor Size

- Larger sensor cells can collect more light per time interval
- Larger chips are more expensive to produce
- Larger chips require larger (and thus more expensive) lenses

Pixelsize = cellsize = sensor-size /#pixels

Sampling Pitch

- Sampling pitch is the physical spacing between (the centers of) adjacent sensor cells

A smaller sampling pitch

- provides a higher pixel resolution
- means a smaller area per pixel so that less photons are accumulated (noisier)

Fill Factor

- The fill factor is the active sensing area size as a fraction of the theoretically available sensing area

A higher fill factors means

- more light capture and less aliasing
- less space to place additional electronics

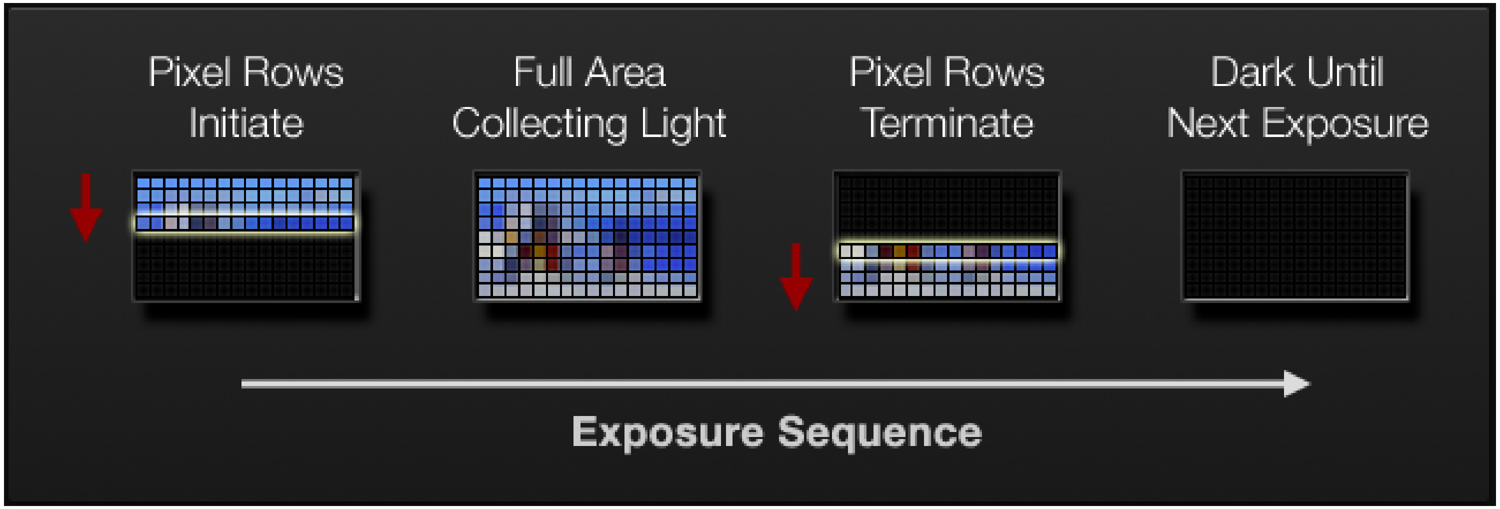
Shutter Speed (Exposure Time)

- Controls the amount of light reaching the sensor
- Longer exposure time = more light = brighter images
- Long exposure time leads to motion blur (for moving cameras)

The oldest camera (Niepce's) takes eight hours of exposure time!

Rolling Shutter (CMOS Sensor)

The shutter rolls (moves) across the exposable image area

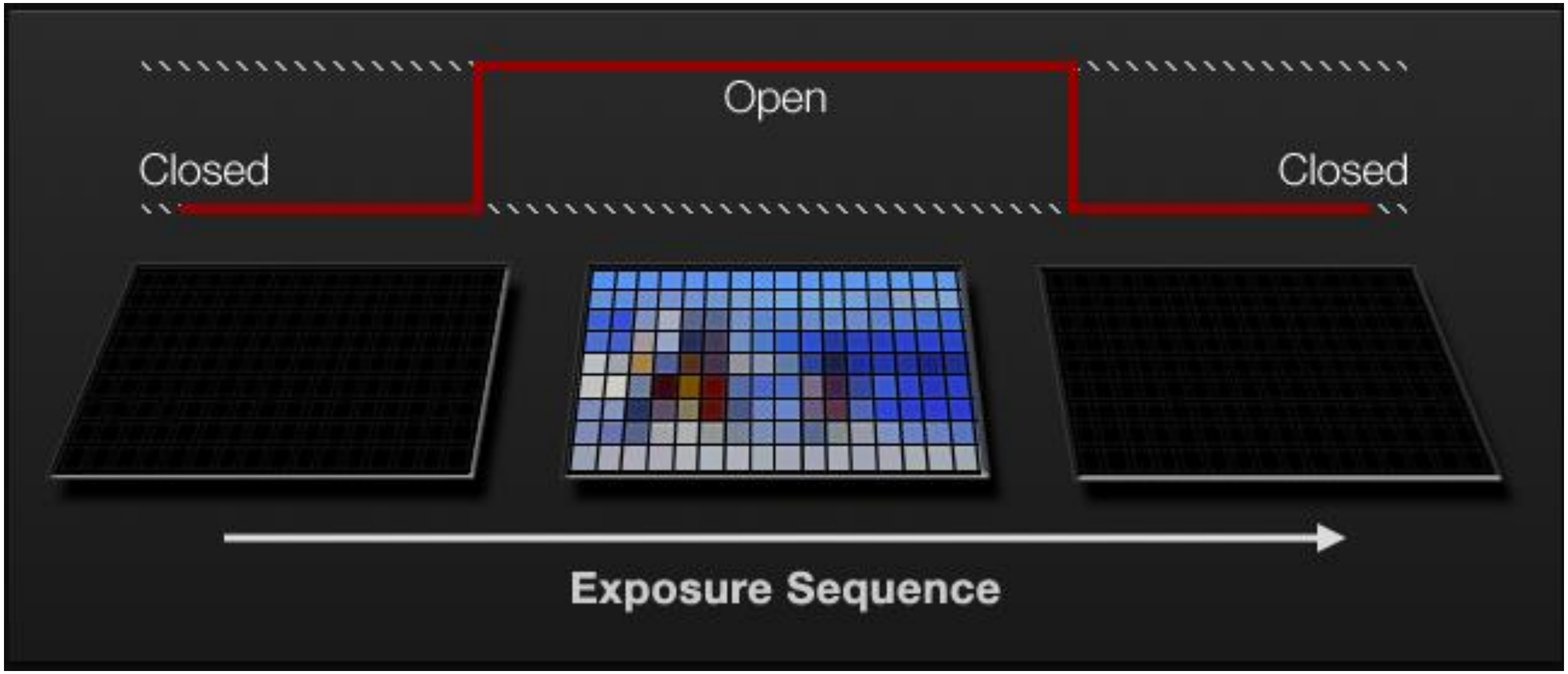


- The pixels at the same line of the image are recorded at the same time
- Produces distortions in case of fast-moving objects or cameras
- Often found in CMOS cameras

Image Courtesy: Red.com, Inc.

Rolling Shutter vs. Global Shutter

Global Shutter (CCD Sensor)



The whole image is recorded at exactly the same time

No rolling shutter distortions

Often found in CCD cameras

Preferable for geometric reconstruction task

Image Courtesy: Red.com, Inc.

From Photons to Intensities

- Photons lead to electrical charge in the sensor elements
- This charge leads to an intensity value
- Ideal case: number of photons   is proportional to the intensity value

$$N \propto I$$

- Special application require different mappings (e.g., logarithmic)

From Photons to Intensities

- Photon flux $b(\lambda)$ is the average number of photons per unit area and time (DE: Photonenfluss)

- Let F be the area of the sensor cell and $b(\lambda)$ its efficiency, we obtain

$$N = F\Delta t \int q(\lambda) b(\lambda)\, d\lambda$$

From Intensities to the Image

- Intensities are often called gray values
- They are elements of the digital image

$$g(i,j) : \mathcal{B} \mapsto \mathcal{G}$$

- with $\mathcal{B} = Z \times Z$ and $\mathcal{G} = N$
- For normal camera, we have

$$\mathcal{B} = [0 \dots I-1, 0 \dots J-1]$$

$$\mathcal{G} = [0 \dots 255]$$ 8-bit

From Intensities to the Image – Cont.

500	485	527	489	493	492	500	498	481	491
513	476	467	492	487	487	497	486	480	491
534	515	478	490	490	491	497	500	508	493
538	554	460	490	489	485	495	496	486	489
532	582	433	498	483	511	480	487	492	506
513	505	474	512	433	492	503	493	491	488
485	455	527	566	586	474	480	490	482	513
464	474	481	458	560	539	521	487	473	521
498	506	497	505	433	536	559	538	491	529
465	494	475	518	496	482	493	537	545	513
508	514	494	500	480	502	484	477	546	566
487	503	489	497	508	497	515	531	495	503
493	499	511	481	511	490	486	529	524	514
511	491	493	498	489	484	544	504	507	572
485	518	481	512	520	521	512	486	537	556
487	508	510	504	500	480	562	520	545	567
484	487	493	473	528	502	516	475	553	617
506	488	511	526	518	546	534	513	571	592
485	487	508	497	487	515	506	542	603	581
514	484	496	505	544	486	538	615	616	580
491	500	481	525	516	509	551	599	562	583
491	494	522	512	516	521	571	591	576	576
508	479	484	557	513	536	576	568	585	602
469	526	531	504	501	521	586	520	598	585
501	482	528	548	545	588	614	579	584	595
511	543	524	499	545	598	603	592	587	594

What is this?

Metric Cameras - RC30

Image courtesy: Leica

Metric Camera – Linear Array

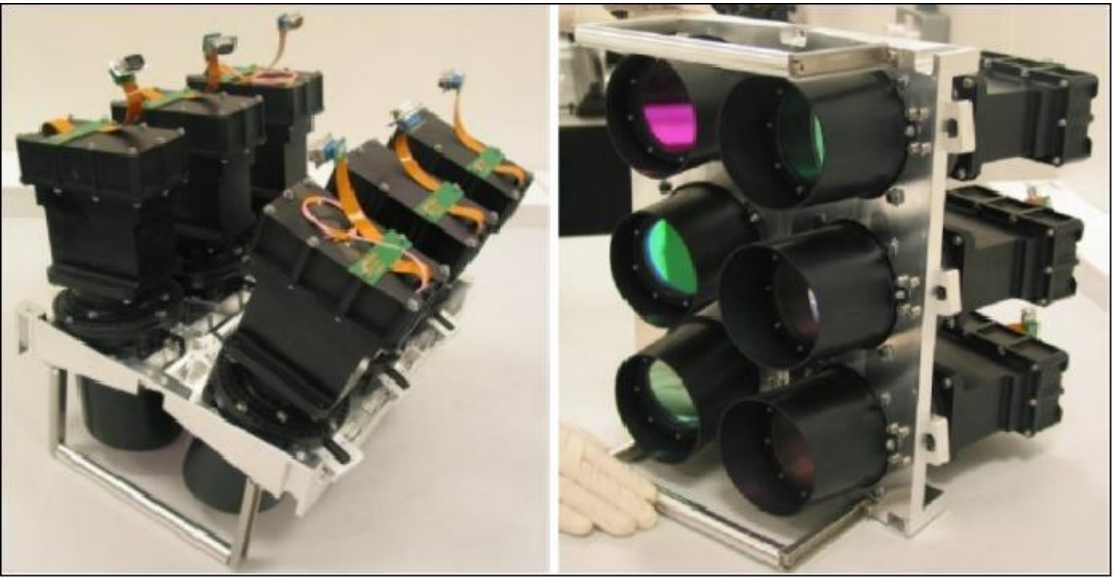
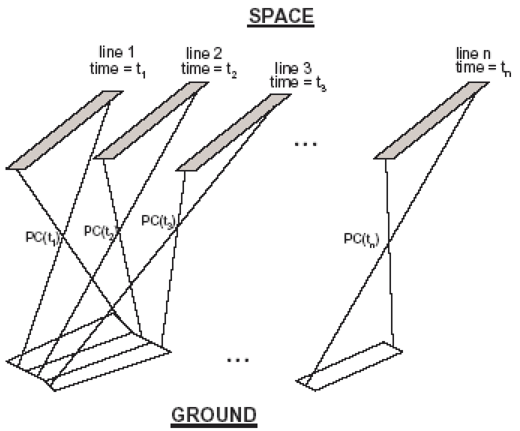


Image courtesy: eoportal

Linear array
Image courtesy: Warsash Scientific



CCD Chip

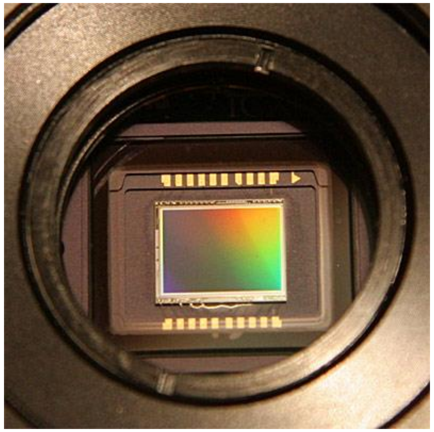
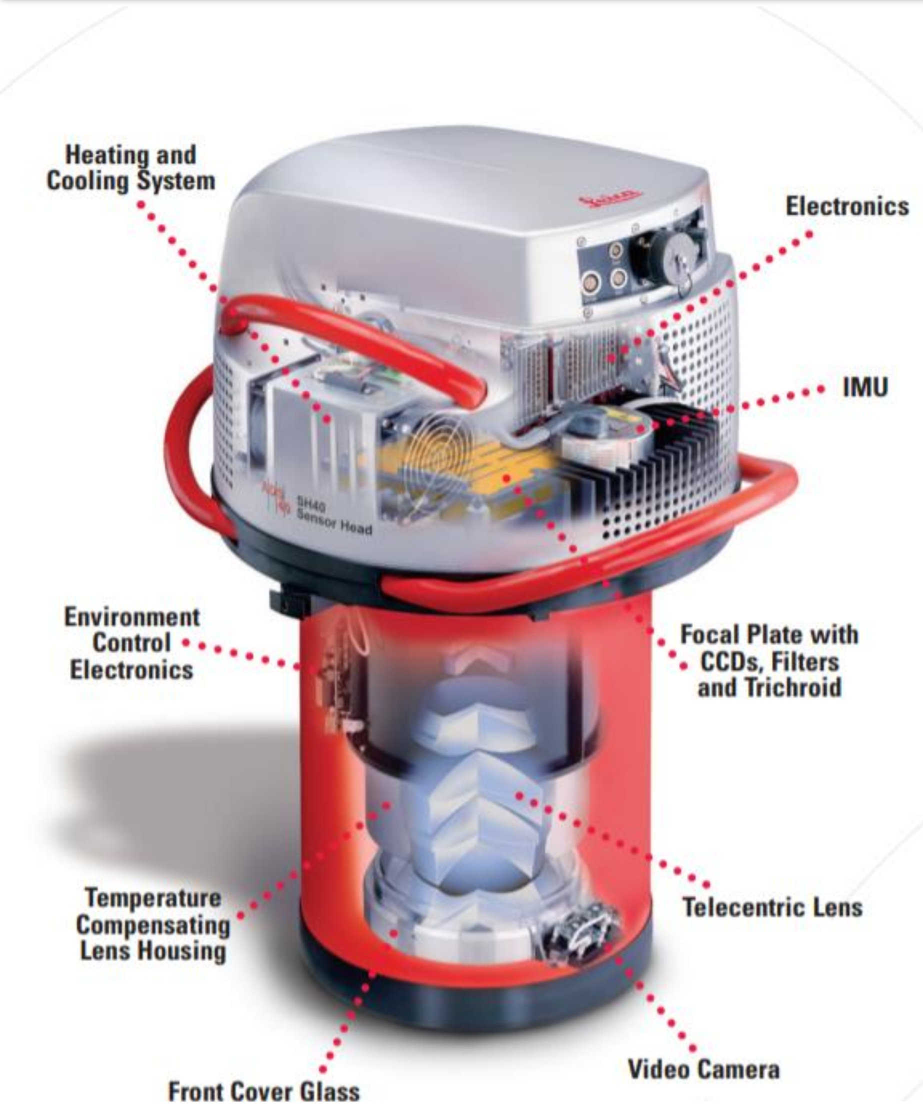
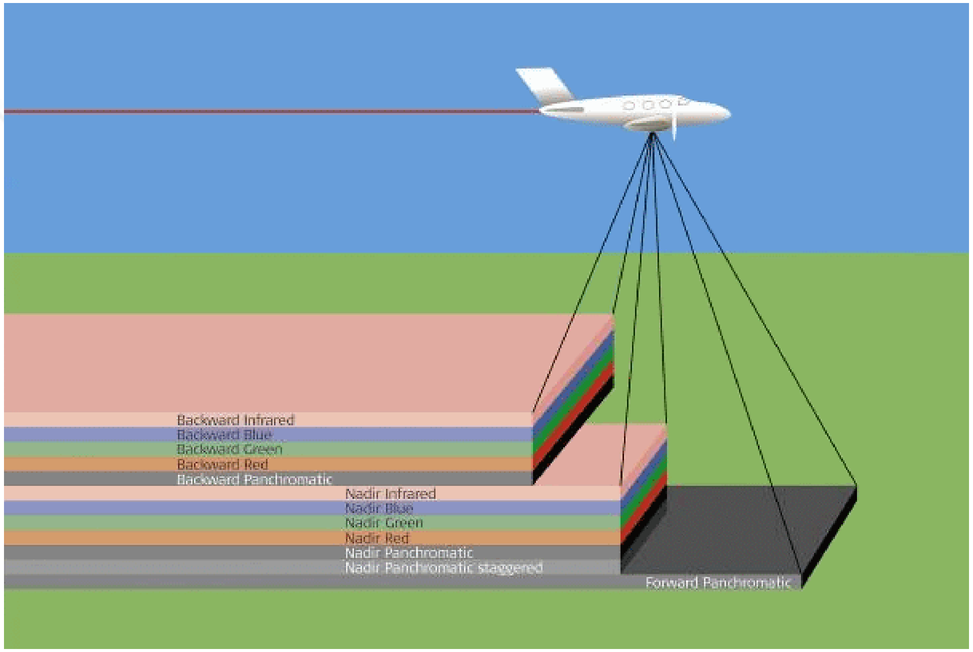
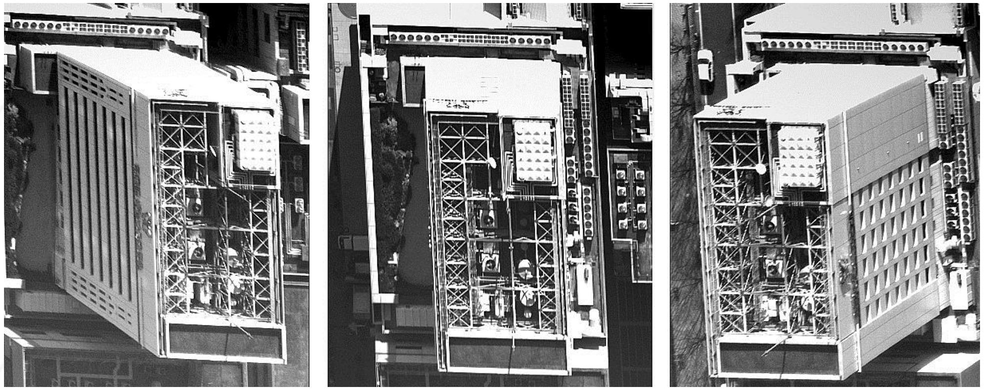


Image courtesy: W. Nuhsbaum Inc.

Metric Camera – ADS40/ADS80







Metric camera – Terrestrial Camera

Image courtesy: Aalto.

Metric vs. Consumer-Grade Camera

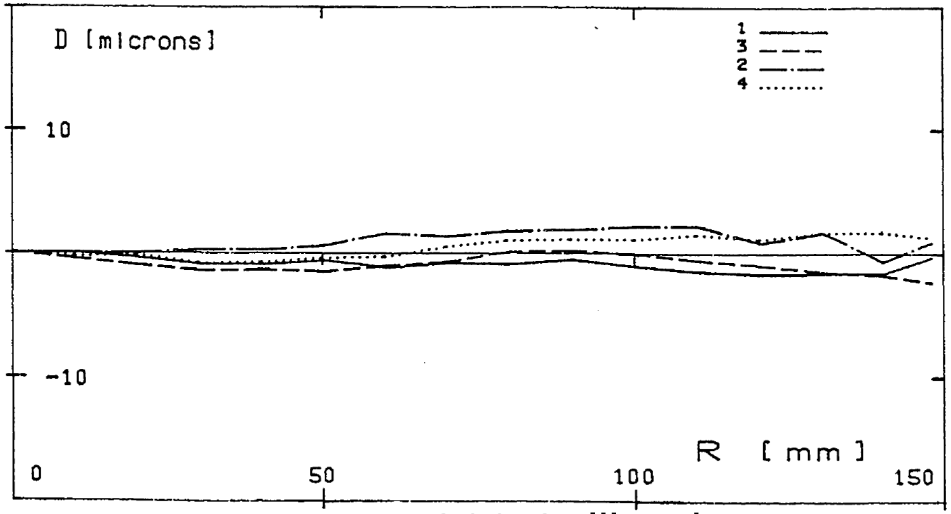


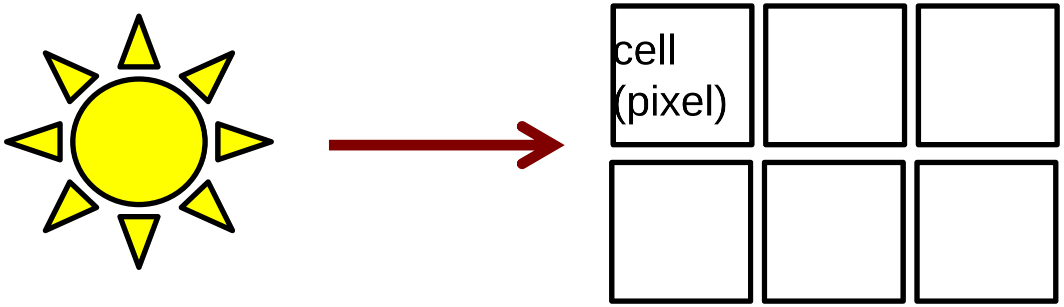
Image courtesy: RC30 Calibration report

Image courtesy: Garda Muhammad

Lighting and Reflectivity

Lighting and Reflectivity

Photons and Intensity



- Quantum optics can model the interaction of light and matter
- Every sensor element of a camera chip turns photons into electric charge
- Intensity is proportional to the number of photons reaching the sensor (pixel)

Images resulted from different light directions

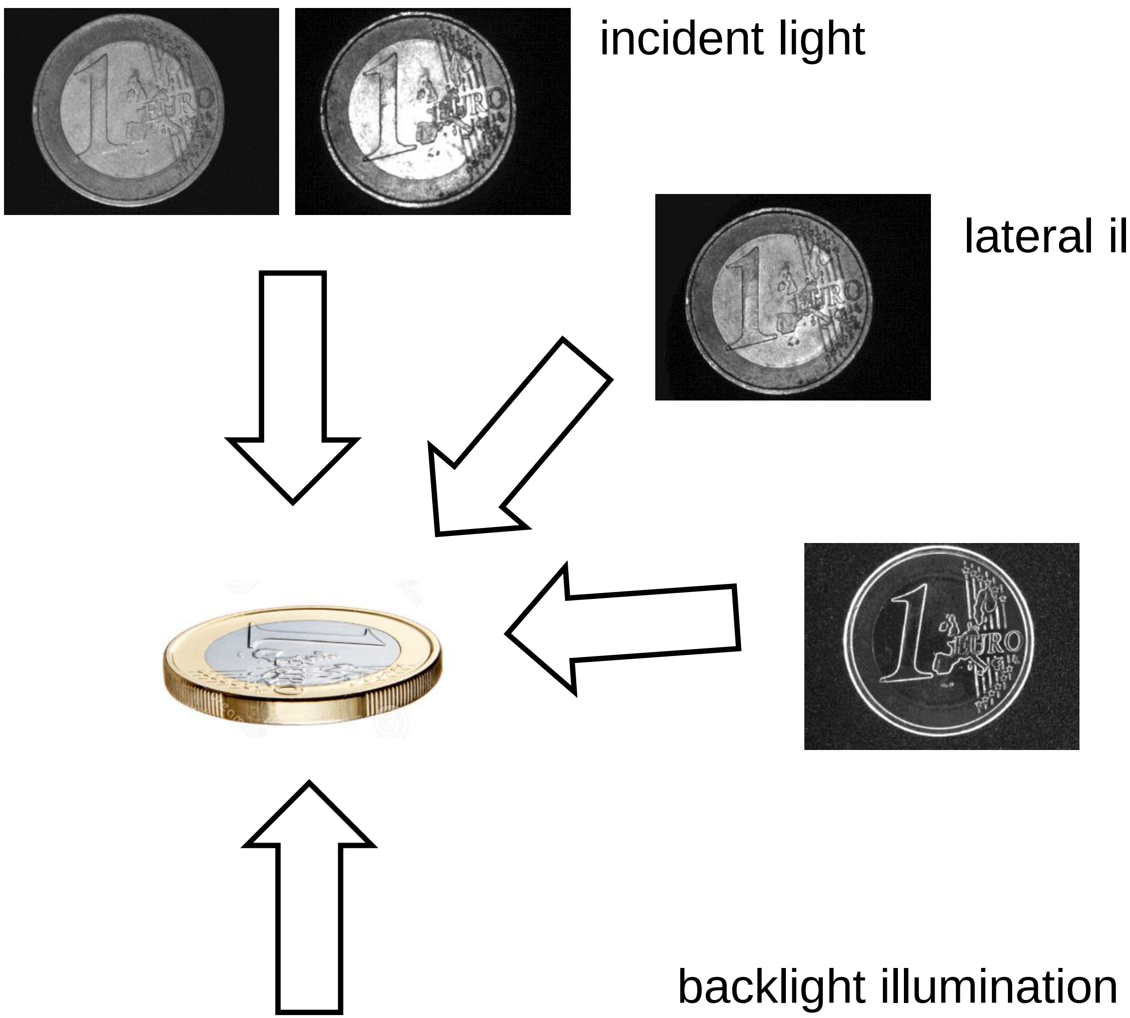
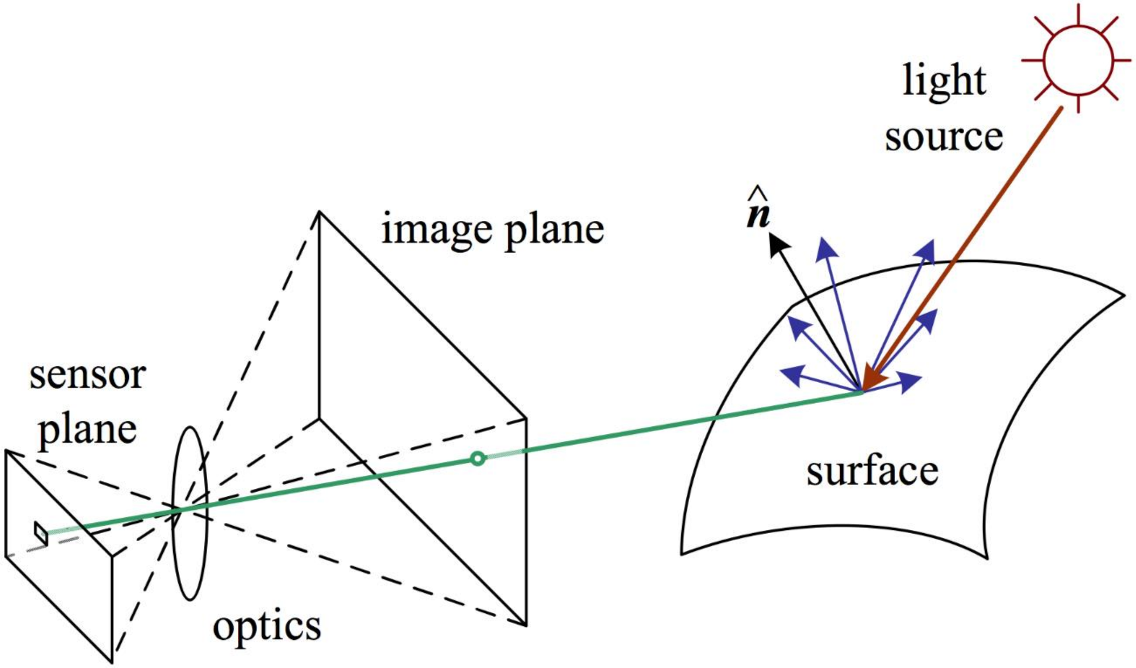


Image courtesy: VisionDoctor

Lighting and Reflectivity

- Lighting is essential
- Light intensity depends on the light source, the reflection properties of the material, and relative locations



Light at surfaces

- Many effects when light strikes a surface – could be:

\- Absorbed, reflected, scattered, and travel along the surface and leave at some other points

Reflectivity

- **General model of light scattering** is the Bidirectional Reflectance Distribution Function (BRDF)

$$\rho(\theta_i, \phi_i, \theta_r, \phi_r, \lambda)$$

geometry wavelength

- Describes how much light of each wavelength arriving at an incident direction is emitted in a reflected direction

BRDF

Describes how much of each wavelength arriving at an incident direction is emitted in a reflected direction

$$\rho(\theta_i, \phi_i, \theta_r, \phi_r, \lambda)$$

$$BRDF = \frac{\sim Outlet\ light}{\sim Inlet\ Light} = \frac{Radiance}{Irradiance}$$

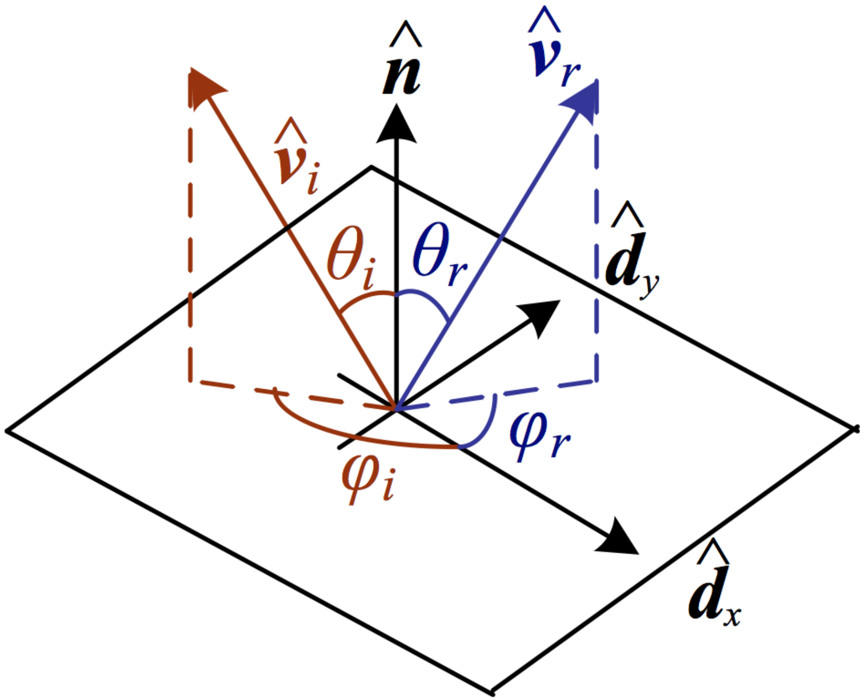
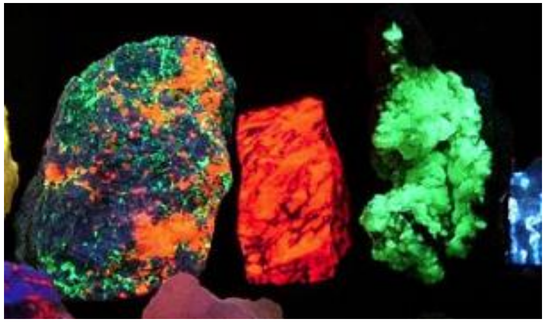


Image courtesy: Szeliski

BRDF – Cont.

Note: This is based on the following assumptions:



- Surfaces do not fluoresce (inlet and outlet wavelength is different)
- Surface do not emit light (i.e. cool surface)

- Light leaving a point ONLY depends on the light arriving at that point. (light does not travel inside the material, i.e. transparent/semi-transparent)

Image Courtesy: Wikipedia

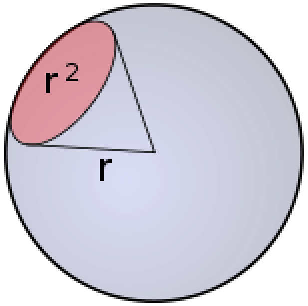
Measure related to the outlet light

- Radiance: Power per unit area reflected perpendicular to the ray and per unit solid angle

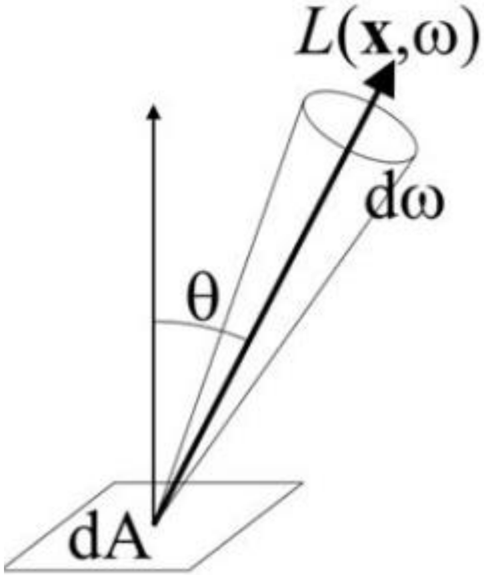
Radiance – *L* [W.m^{-2}.sr^{-1}]

watts per square meter per steradian

$$L(\mathbf{x},\omega) = \frac{d^2\Phi}{\cos\theta \, dA \, d\omega}$$



1 steradian



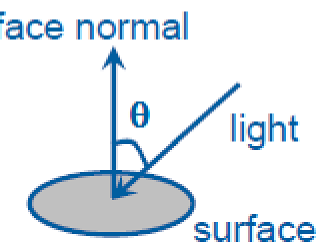
$$d\omega = \sin\theta d\theta d\phi$$

Measure related to the inlet light

- Irradiance: the amount of light/energy arriving at a unit surface patch

$$E(x, \boldsymbol{\omega}) = L(x, \boldsymbol{\omega}) \cos\theta d\,\boldsymbol{\omega} = d^2\Phi / dA$$

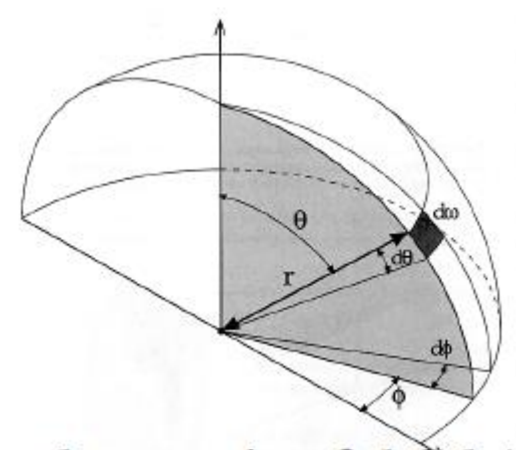
(refer to the previous equation)



- Therefore, the total energy a surface received is the integration over the surface.

$$E_{total} = \int_{\Omega} E(x, \boldsymbol{\omega})\, sin\theta d\theta d\phi$$

$$= \int_{\Omega} L(x, \boldsymbol{\omega})\, cos\theta sin\theta d\theta d\phi$$



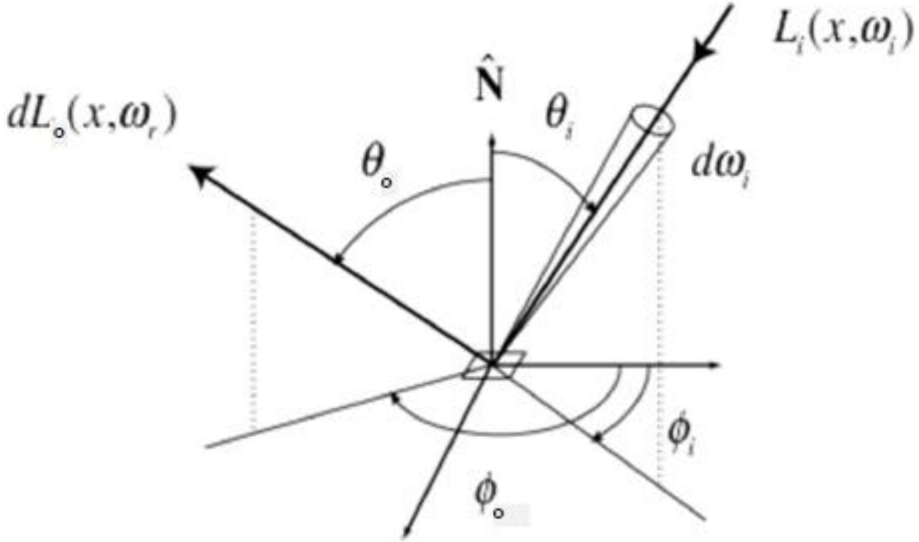
$$d\omega = \sin\theta d\theta d\phi$$

BRDF – Cont.

$$BRDF = \frac{\sim Outlet\ light}{\sim Inlet\ Light} = \frac{Radiance}{Irradiance}$$

We consider wavelength being the same, this is essentially a four-parameter function, being:

$$BRDF = \rho(\theta_i, \phi_i, \theta_r, \phi_r) = \frac{L_o(\theta_o, \phi_o)}{E_i(\theta_i, \phi_i)} = \frac{L_o(\theta_o, \phi_o)}{L_i(\theta_i, \phi_i) cos\theta_i d\boldsymbol{\omega}}$$



Next Class – Shape from Photometry

Questions?