COSC579: Image Formation

Jeremy Bolton, PhD
Assistant Teaching Professor

GEORGETOWN UNIVERSITY

Outline

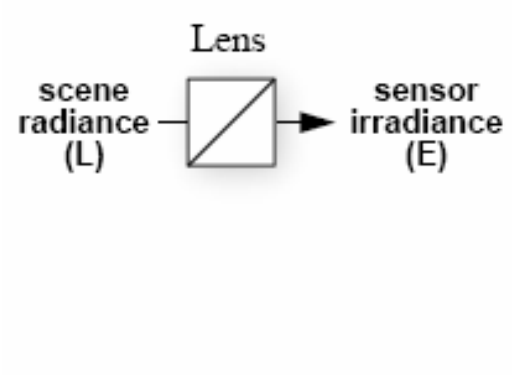
I. The journey: from scene to image
II. Digital Cameras
III. Color vs Grayscale images
IV. Concerns

Camera is not a photometer!

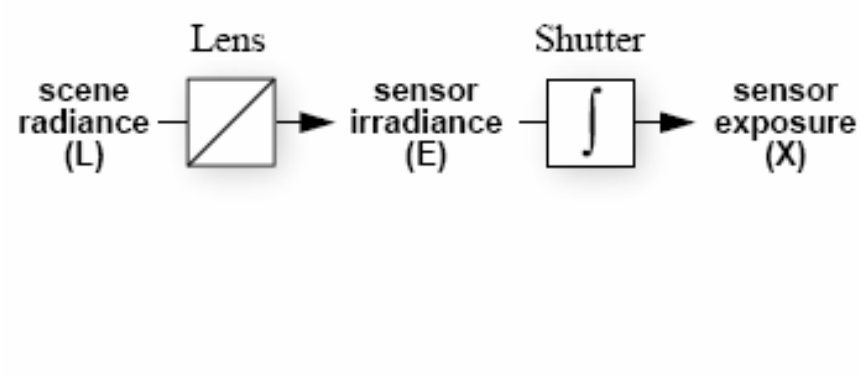
- Limited dynamic range
  - 8 bits captures only 2 orders of magnitude of light intensity
  - We can see ~10 orders of magnitude of light intensity

- Unknown, nonlinear response
  - pixel intensity ≠ amount of light (# photons, or “radiance”)

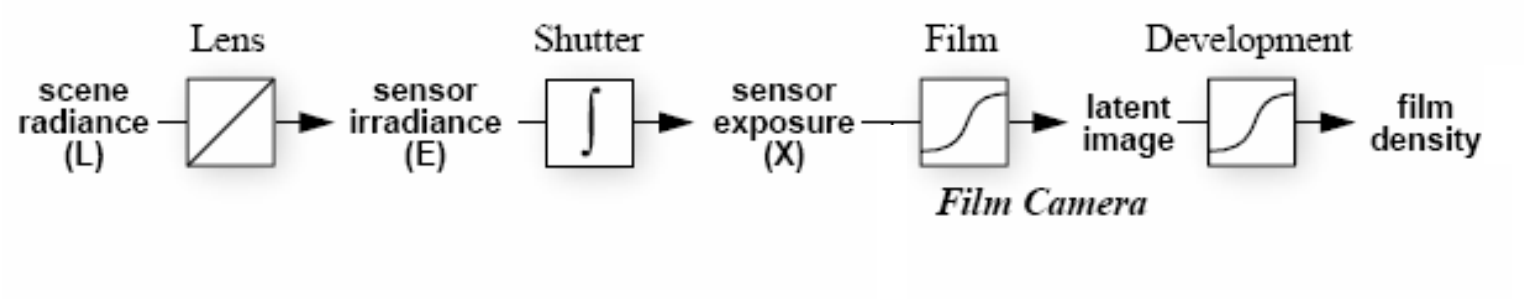
Camera pipeline



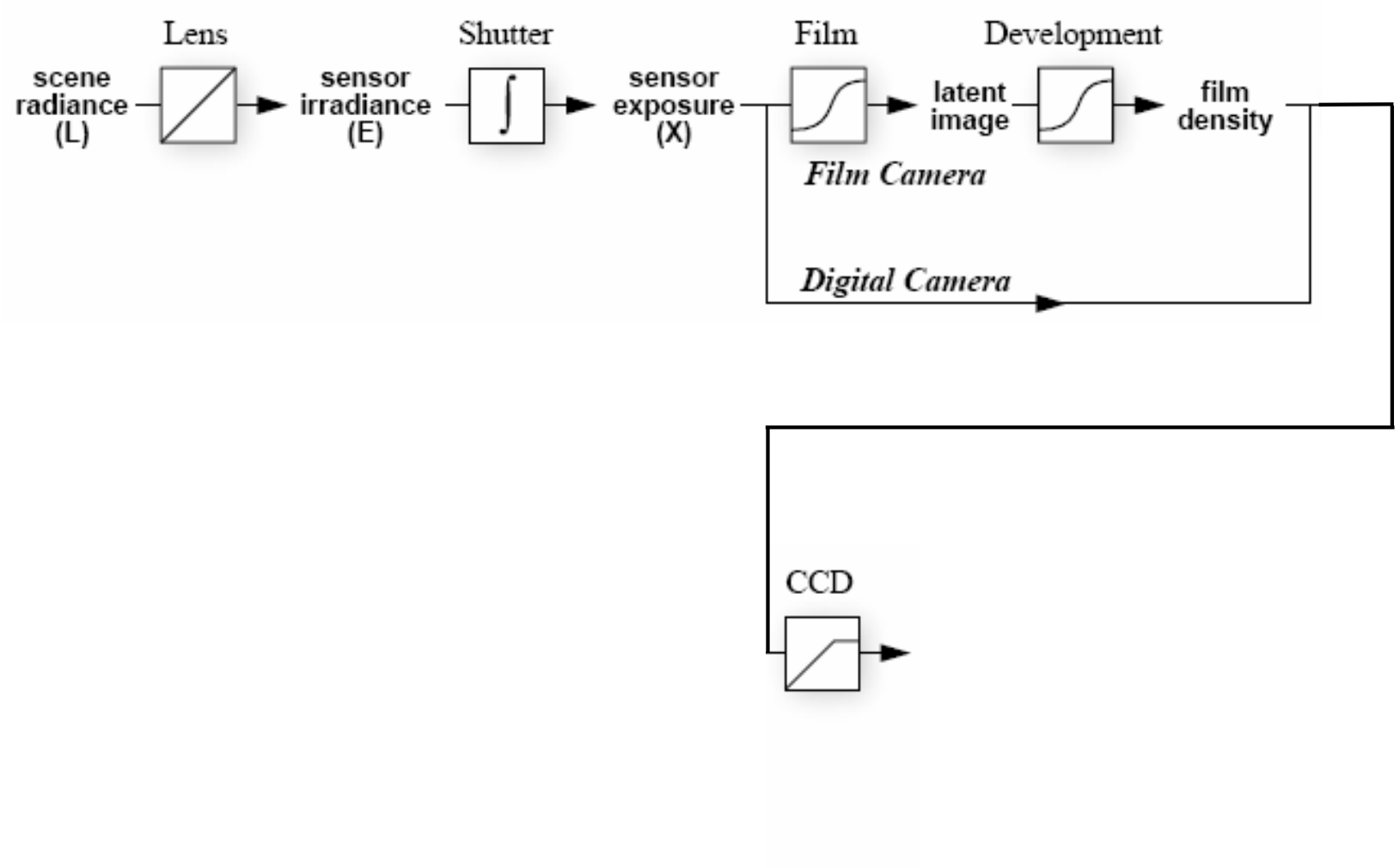
Camera pipeline



Camera pipeline

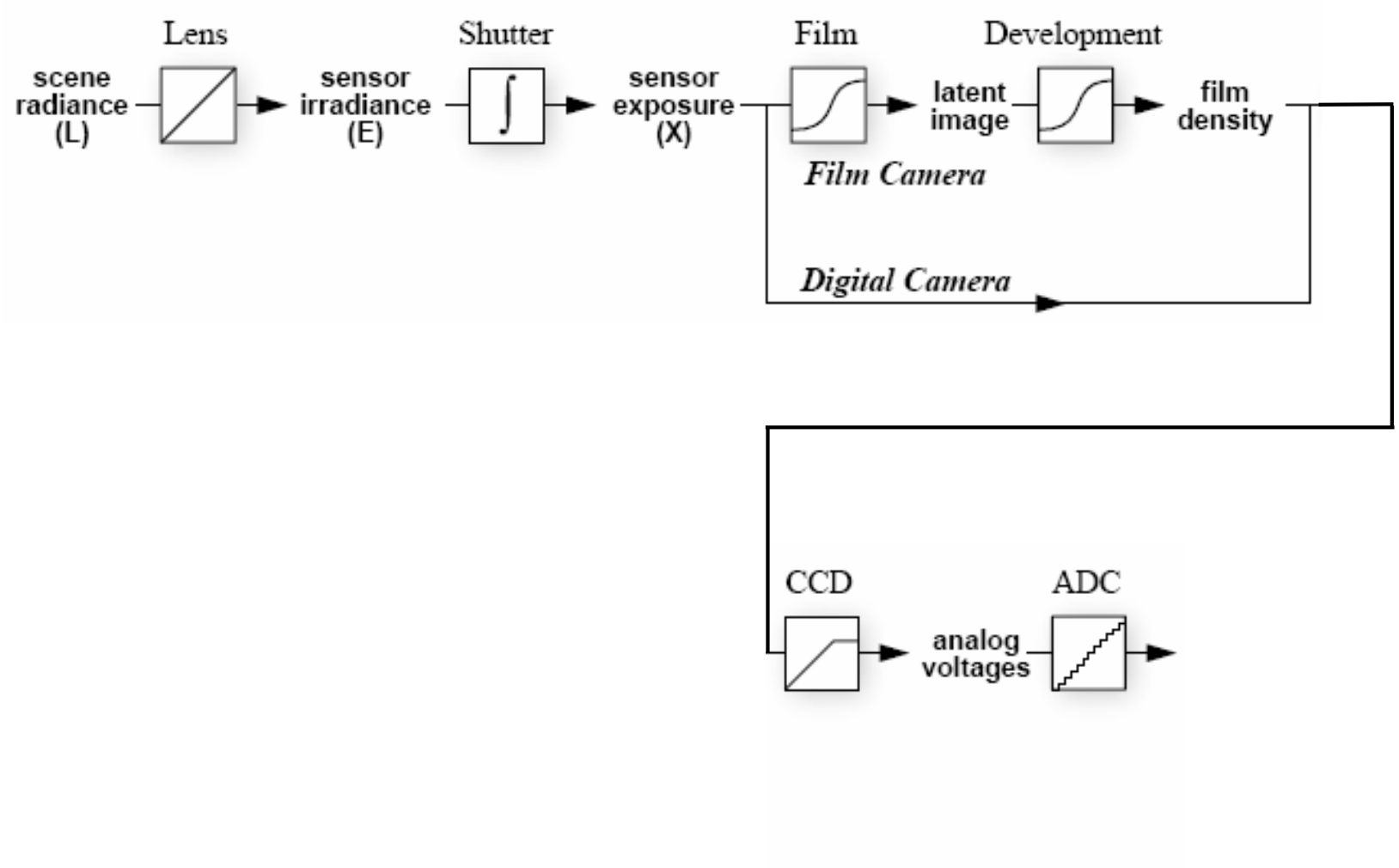


Camera pipeline

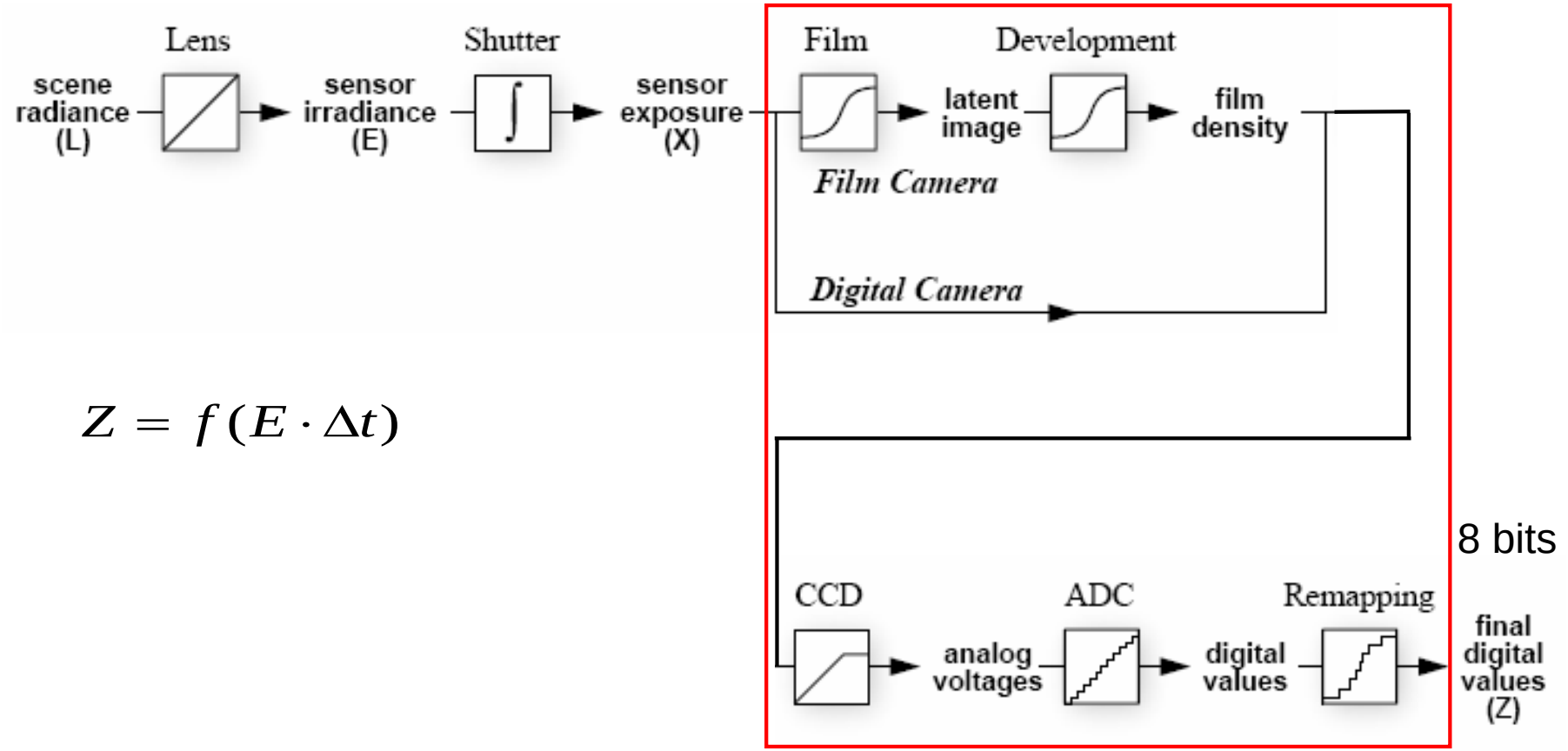


GEORGETOWN UNIVERSITY

Camera pipeline



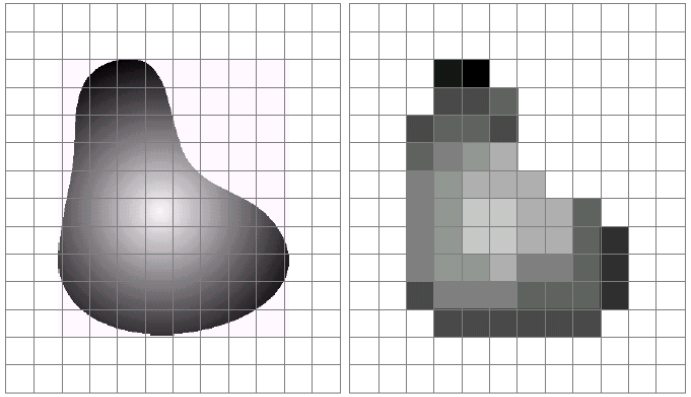
Camera pipeline



$$Z = f(E \cdot \Delta t)$$

GEORGETOWN UNIVERSITY

Digital camera



a b

FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

- A digital camera replaces film with a sensor array
  - Each cell in the array is light-sensitive diode that converts photons to electrons
  - Two common types
    - **Charge Coupled Device** (CCD)
    - **Complementary metal oxide semiconductor** (CMOS)

GEORGETOWN UNIVERSITY

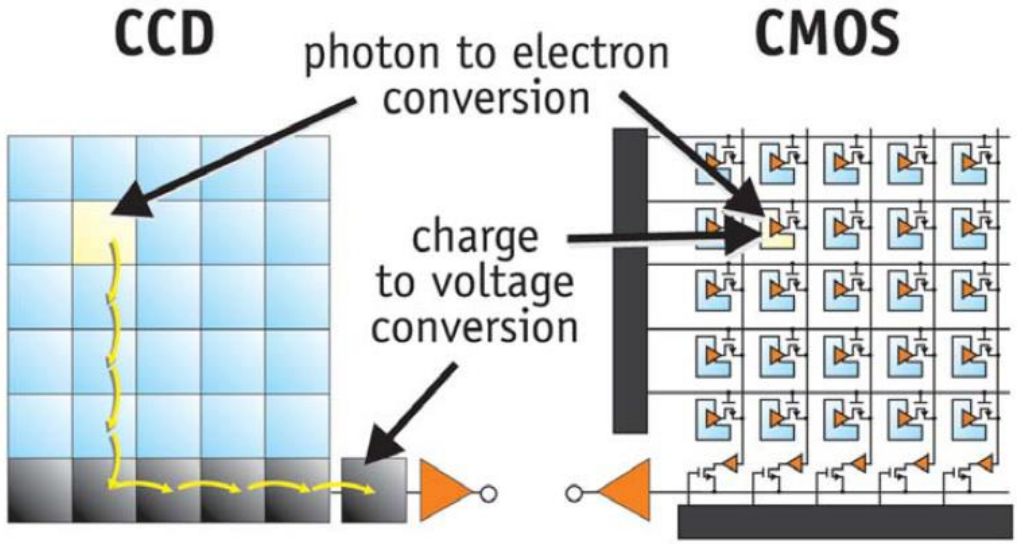
Slide by Steve Seitz

CCD vs. CMOS

- **CCD:** transports the charge across the chip and reads it at one corner of the array. An **analog-to-digital converter (ADC)** then turns each pixel's value into a digital value by measuring the amount of charge at each photosite and converting that measurement to binary form

- **CMOS:** uses several transistors at each pixel to amplify and move the charge using more traditional wires. The CMOS signal is digital, so it needs no ADC.

http://electronics.howstuffworks.com/digital-camera.htm



CCDs move photogenerated charge from pixel to pixel and convert it to voltage at an output node. CMOS imagers convert charge to voltage inside each pixel.

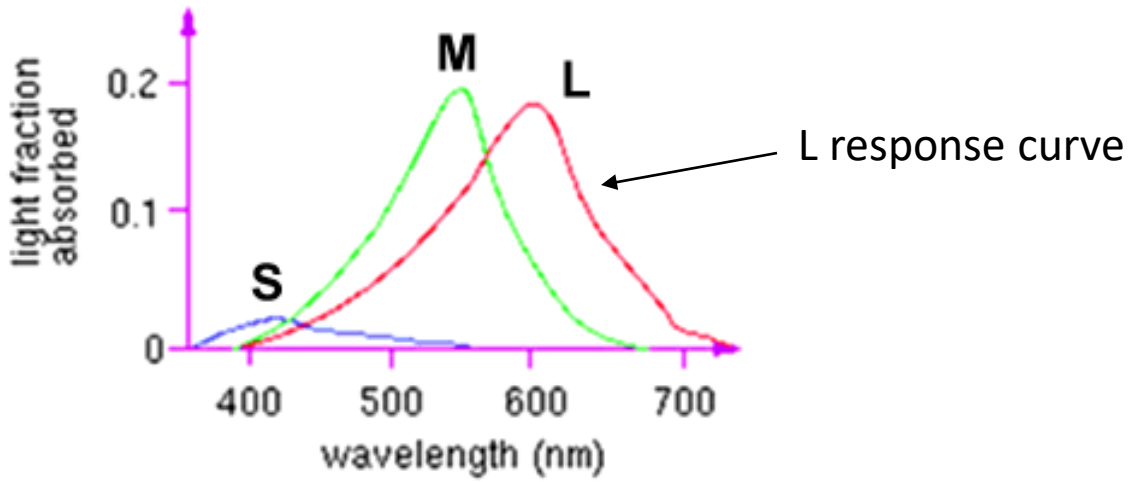
GEORGETOWN UNIVERSITY

Color

- What about color?
- Most digital images are comprised of three color channels – red, green, and, blue – which combine to create most of the colors we can see

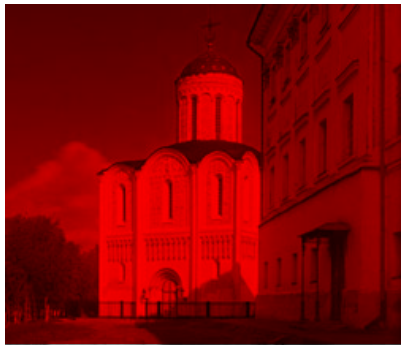
- Why are there three?

Color perception



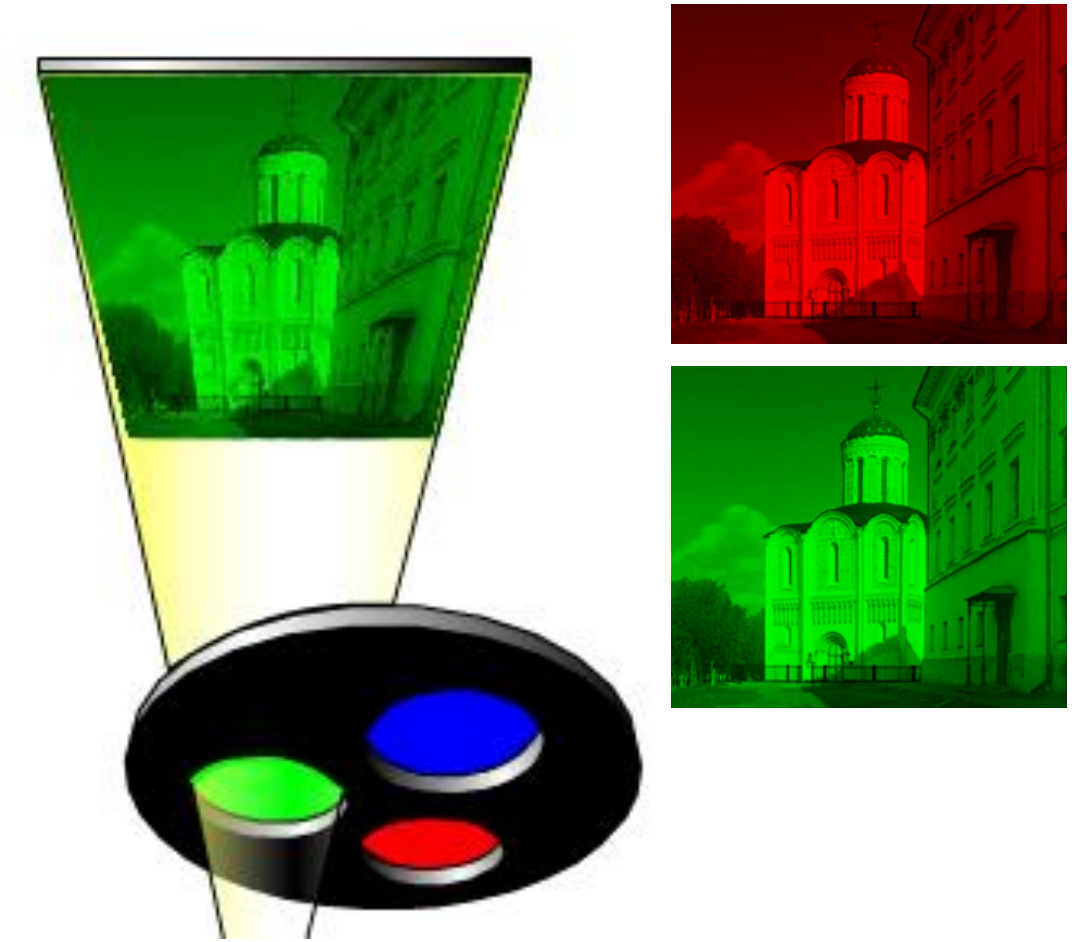
- Three types of cones
  - Each is sensitive in a different region of the spectrum
    - but regions overlap
    - Short (S) corresponds to blue
    - Medium (M) corresponds to green
    - Long (L) corresponds to red
  - Different sensitivities: we are more sensitive to green than red
    - varies from person to person (and with age)
  - Colorblindness—deficiency in at least one type of cone

Field sequential



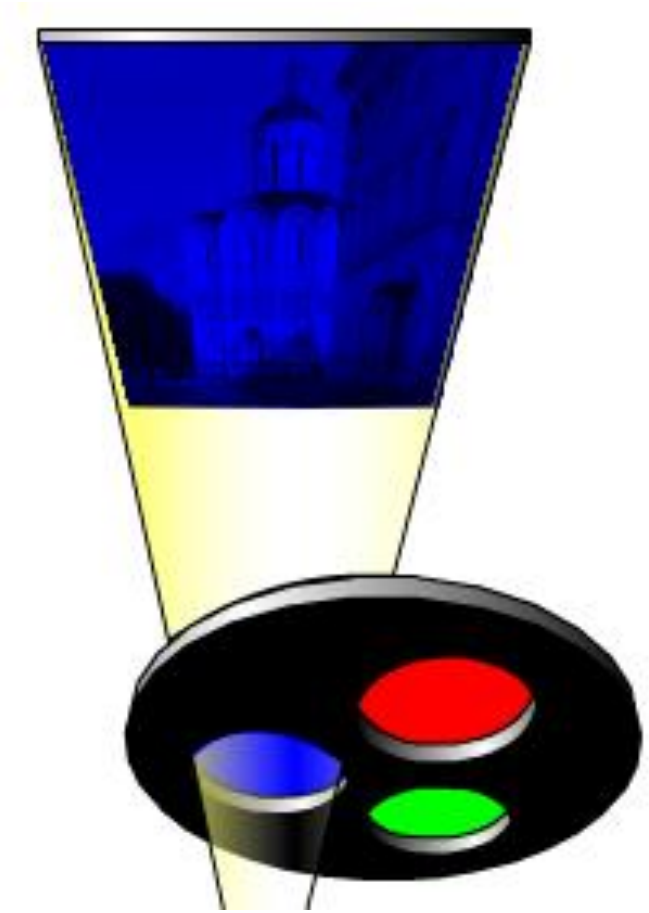
YungYu Chuang's slide

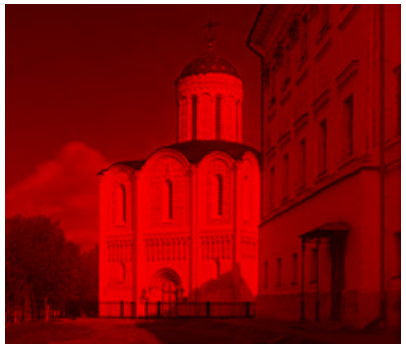
Field sequential

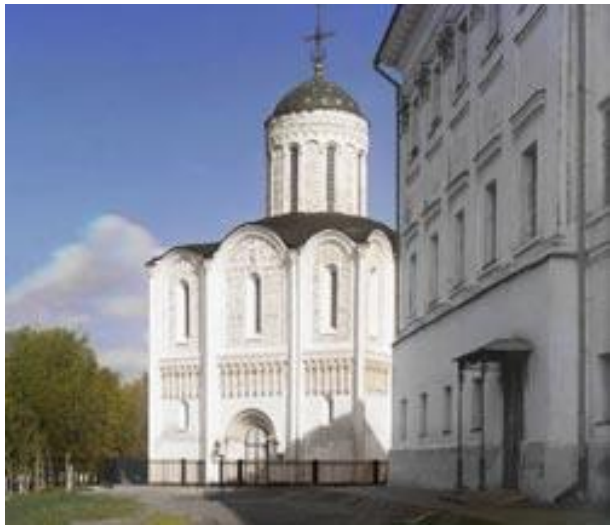


YungYu Chuang's slide

Field sequential

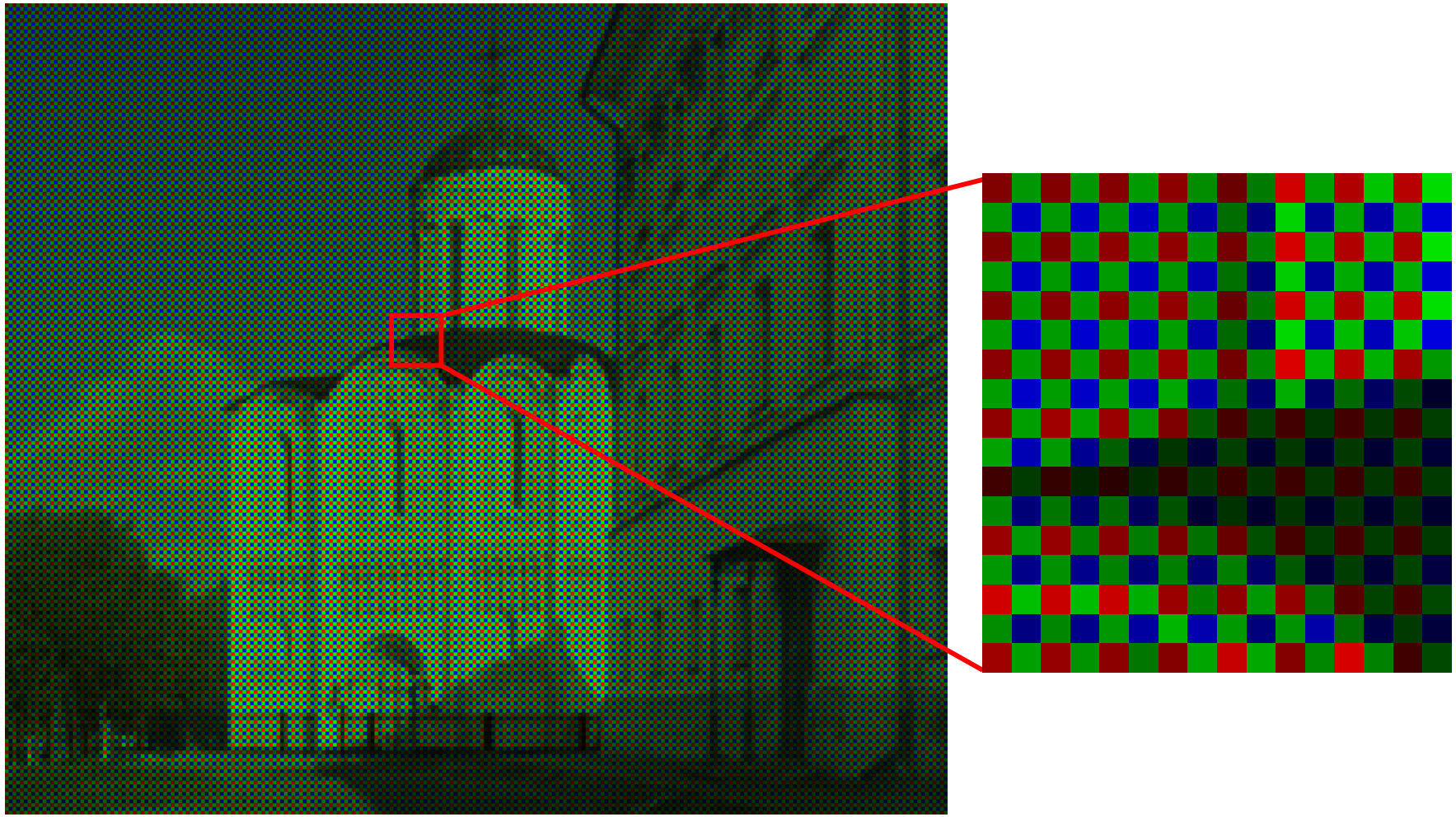






YungYu Chuang's slide

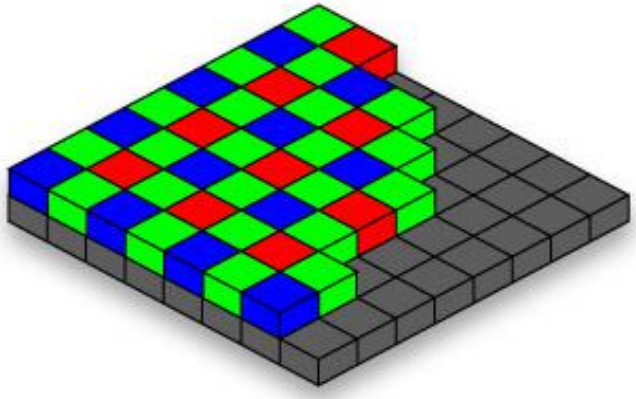
Bayer's pattern



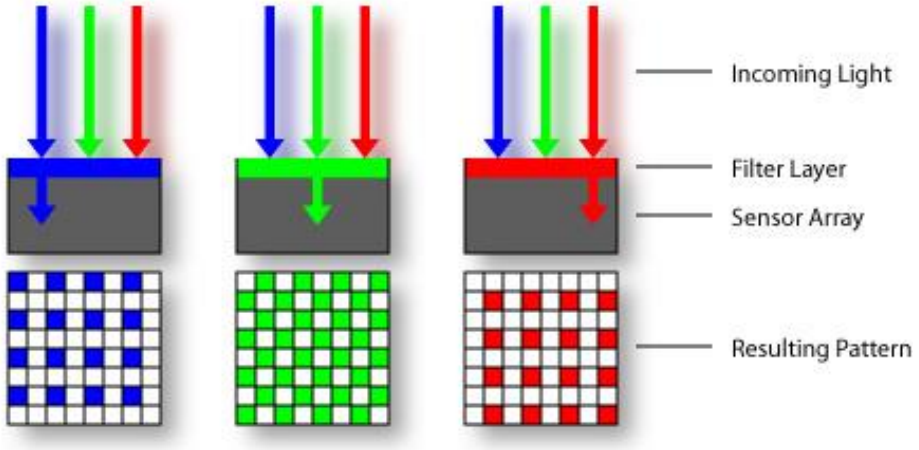
YungYu Chuang's slide

Color sensing in camera: Color filter array

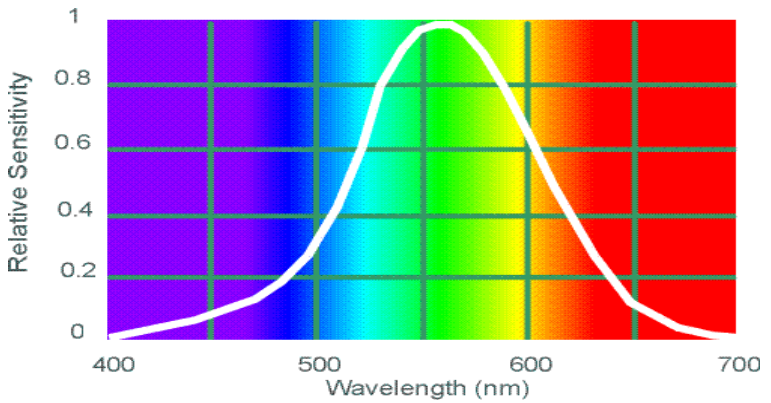
Bayer grid



Estimate missing components from neighboring values (demosaicing)



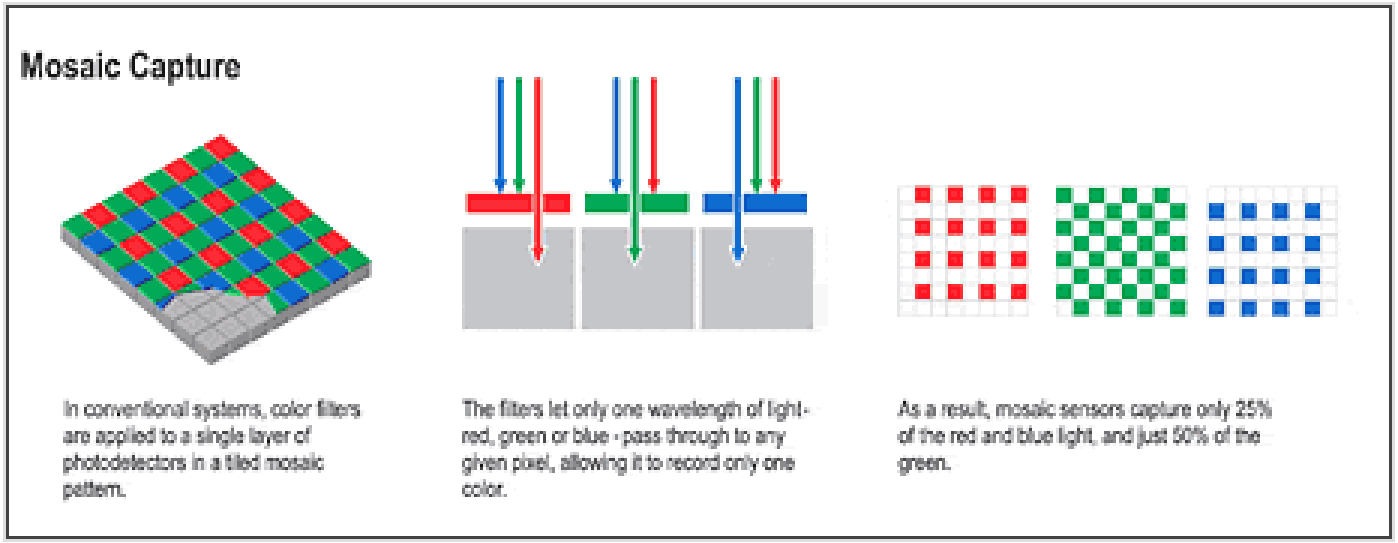
Why more green?

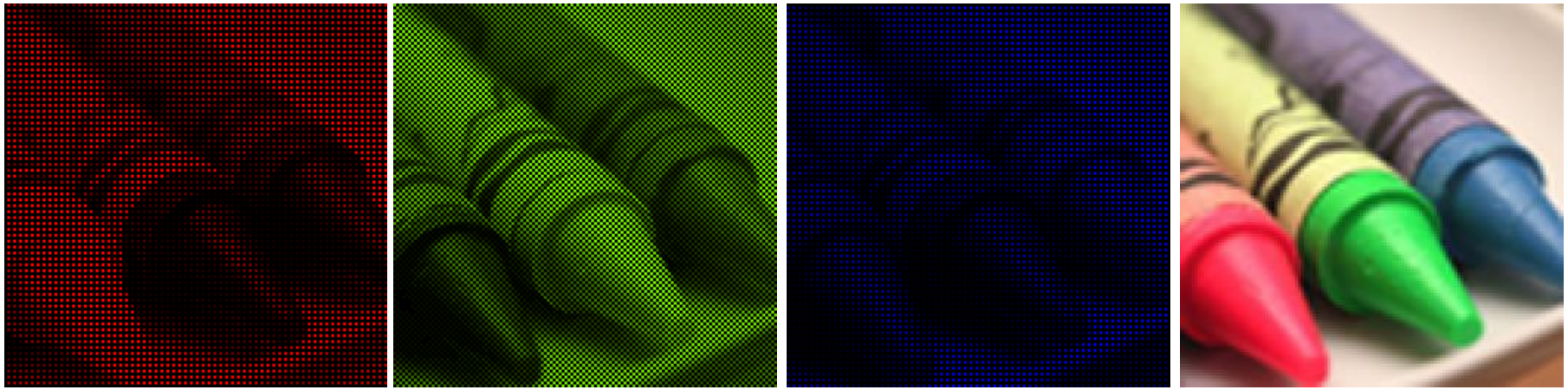


Human Luminance Sensitivity Function

Source: Steve Seitz

Color filter array





red green blue output

YungYu Chuang's slide

GEORGETOWN UNIVERSITY

Color images

- We'll treat color images as a vector-valued function:

$$f(x,y) = \begin{bmatrix} r(x,y) \\ g(x,y) \\ b(x,y) \end{bmatrix}$$

Note: To do this, each pixel is composed of multiple sensors responses from a Bayer grid. This process is called demosaicing.

Each pixels value is a result of a set of neighboring sensors

- Common equation to convert to grayscale

  (0.3 * r + 0.59 * g + 0.11 * b)

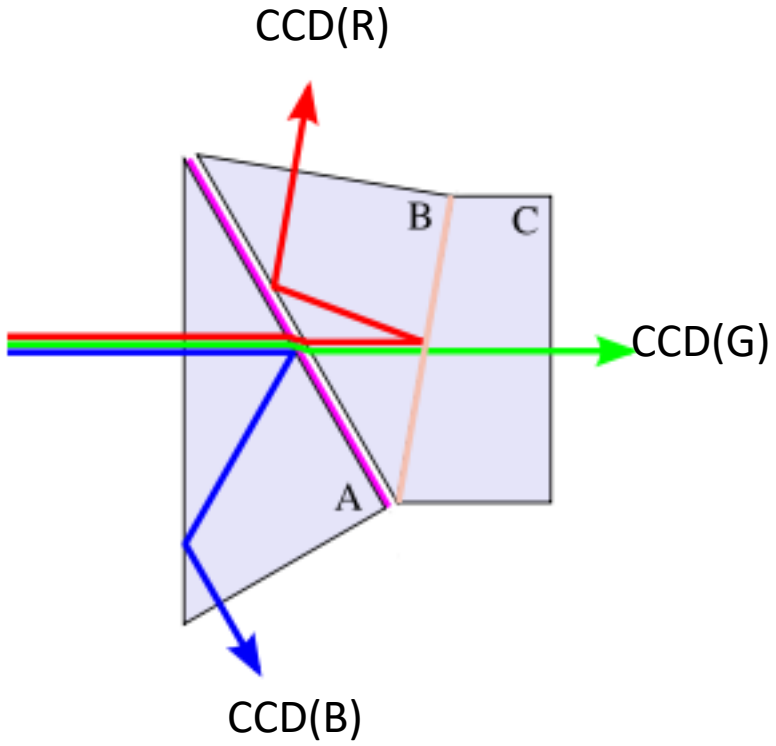
Problem with demosaicing: color moire

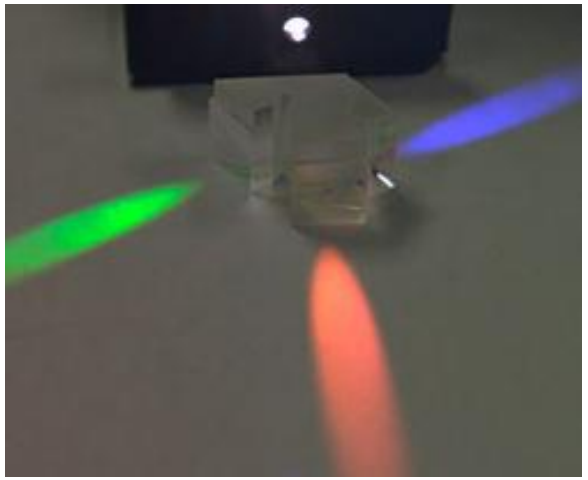
GEORGETOWN UNIVERSITY

Slide by F. Durand

Color sensing: Separate colors using Prism (rather than filter)

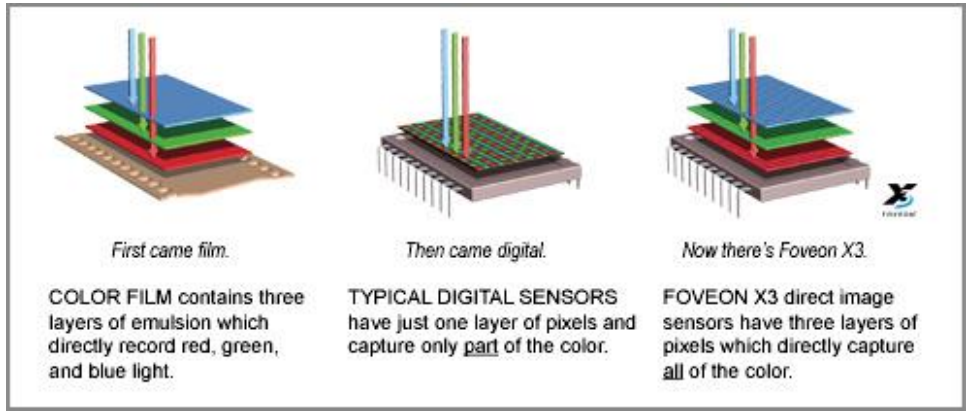
- Requires three chips and precise alignment
- Pro
  - Records rgb measurements for each point in image plane
- Con
  - more expensive



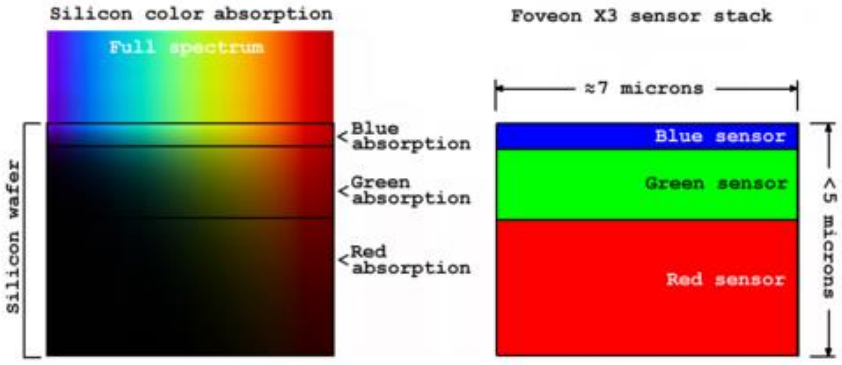


Color sensing in camera: Foveon X3

- CMOS sensor
- Takes advantage of the fact that red, blue and green light penetrate silicon to different depths

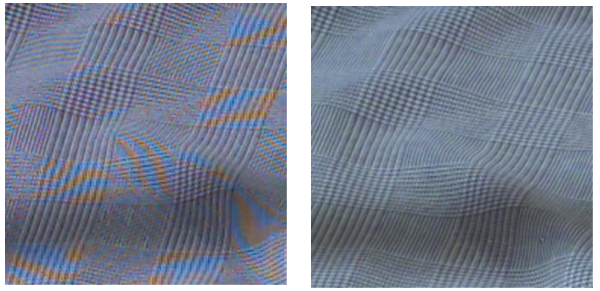


http://www.foveon.com/article.php?a=67



http://en.wikipedia.org/wiki/Foveon_X3_sensor

better image quality



Source: M. Pollefeys

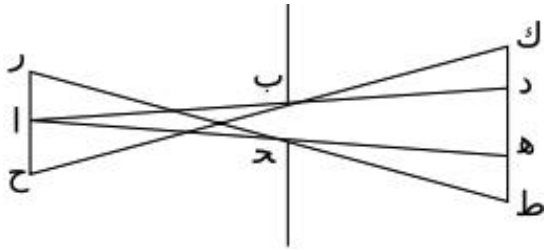
GEORGETOWN UNIVERSITY

Issues with digital cameras

- Noise
  - low light is where you most notice noise
  - light sensitivity (ISO) / noise tradeoff
  - stuck pixels
- Resolution: Are more megapixels better?
  - requires higher quality lens
  - noise issues
- In-camera processing
  - oversharpening can produce halos
- RAW vs. compressed
  - file size vs. quality tradeoff
- Blooming
  - charge overflowing into neighboring pixels
- Color artifacts
  - purple fringing from microlenses, artifacts from Bayer patterns
  - white balance
- More info online:
  - http://electronics.howstuffworks.com/digital-camera.htm
  - http://www.dpreview.com/

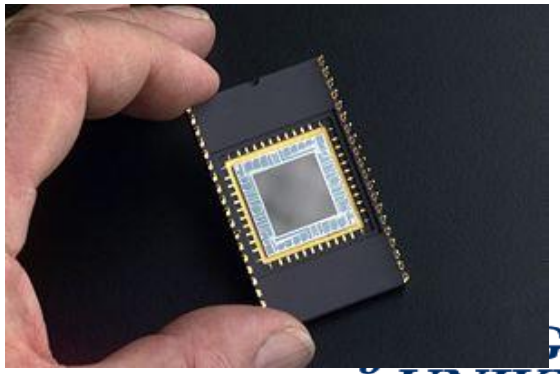
Historical context

- **Pinhole model:** Mozi (470-390 BCE), Aristotle (384-322 BCE)
- **Principles of optics (including lenses):** Alhacen (965-1039 CE)
- **Camera obscura:** Leonardo da Vinci (1452-1519), Johann Zahn (1631-1707)
- **First photo:** Joseph Nicephore Niepce (1822)
- **Daguerréotypes** (1839)
- **Photographic film** (Eastman, 1889)
- **Cinema** (Lumière Brothers, 1895)
- **Color Photography** (Lumière Brothers, 1908)
- **Television** (Baird, Farnsworth, Zworykin, 1920s)
- **First consumer camera with CCD**: Sony Mavica (1981)
- **First fully digital camera:** Kodak DCS100 (1990)



Alhacen's notes

Niepce, "La Table Servie," 1822



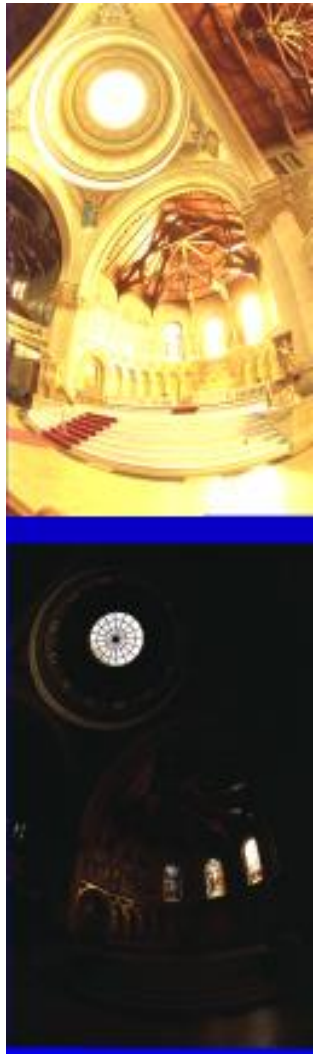
CCD chip

GEORGETOWN UNIVERSITY

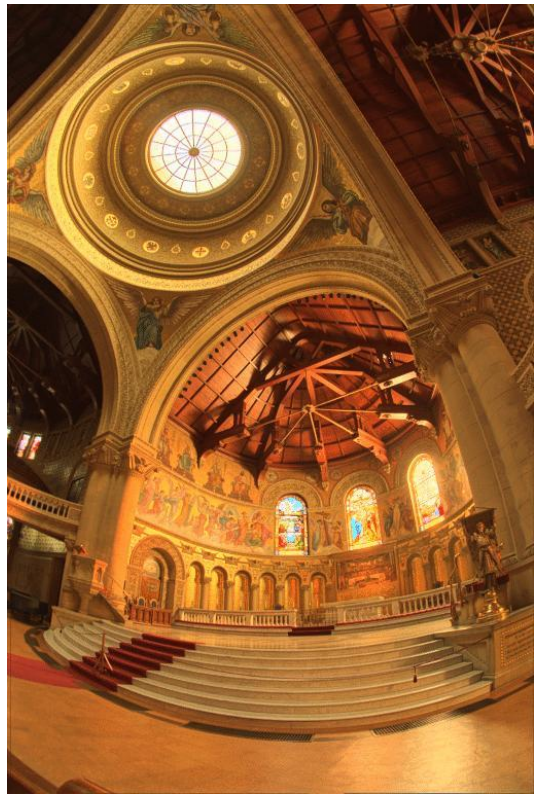
Some Issues (Segue to Image Processing)

- Brightness issues
  - Skewed Histograms
    - Compositing
    - Histogram Normalization (soon … but later!)
- Color Mapping
  - Color transforms
- Others Discussed
  - Noise
  - Distortion

What do we see?

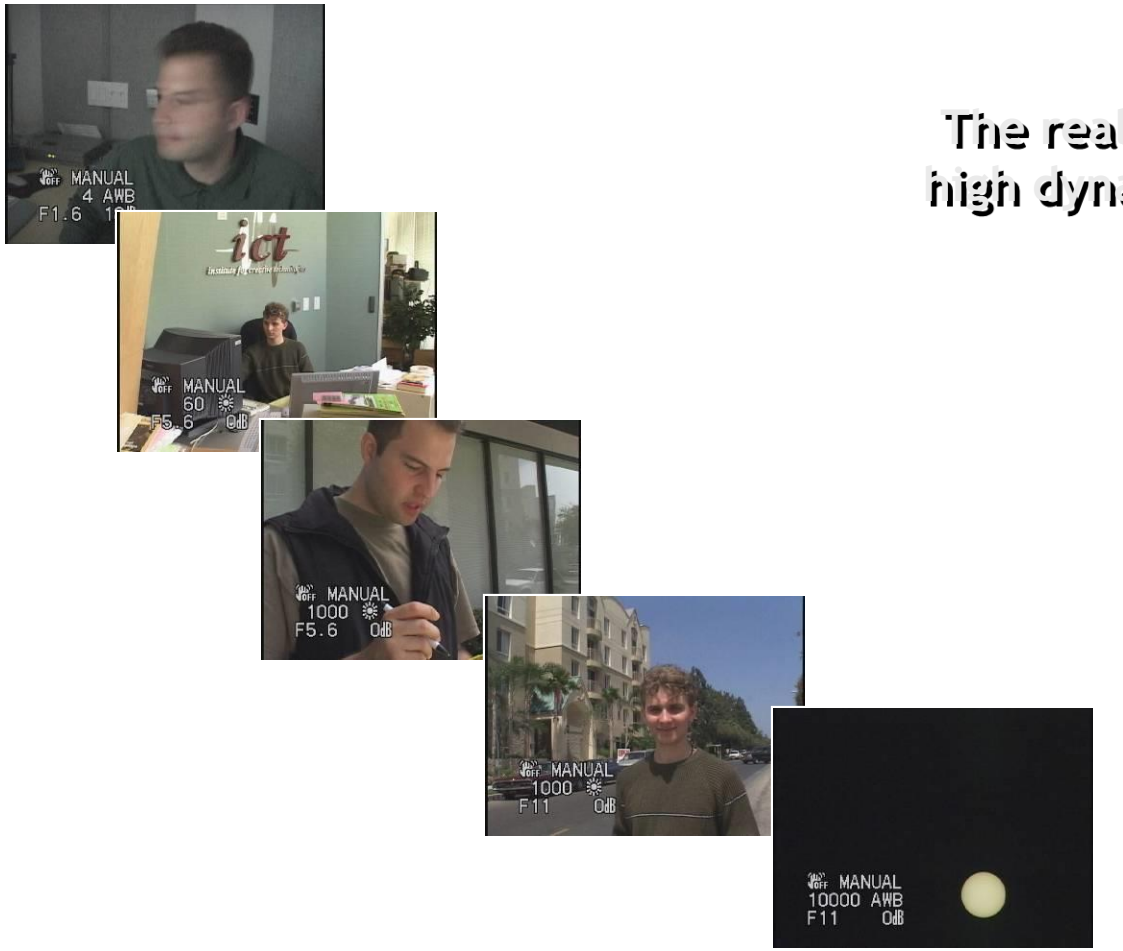


Vs.



GEORGETOWN UNIVERSITY

Problem: Dynamic Range



The real world has high dynamic range.

GEORGETOWN UNIVERSITY

Visual dynamic range

Background	Luminance (candelas per square meter)
Horizon sky	
Moonless overcast night	0.00003
Moonless clear night	0.0003
Moonlit overcast night	0.003
Moonlit clear night	0.03
Deep twilight	0.3
Twilight	3
Very dark day	30
Overcast day	300
Clear day	3,000
Day with sunlit clouds	30,000
Daylight fog	
Dull	300–1,000
Typical	1,000–3,000
Bright	3,000–16,000
Ground	
Overcast day	30–100
Sunny day	300
Snow in full sunlight	16,000

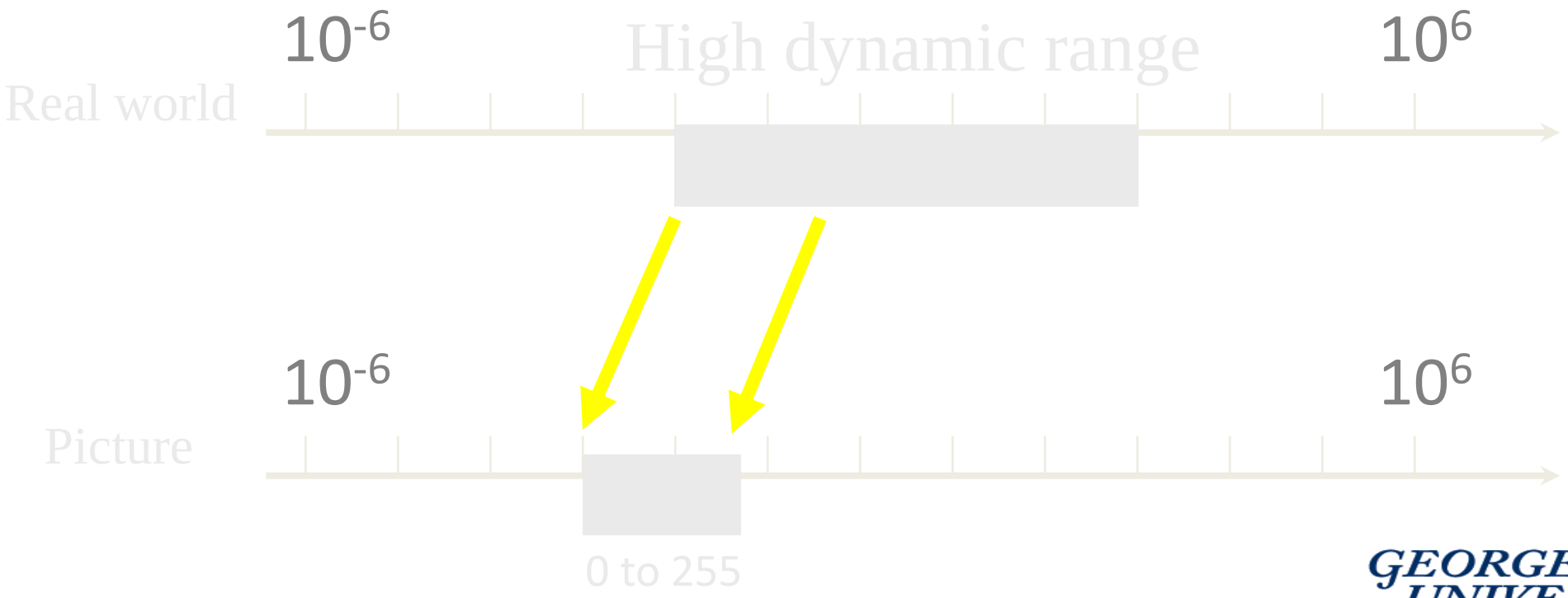
FIGURE 1.13
Luminance of everyday backgrounds. *Source:* Data from Rea, ed., *Lighting Handbook 1984 Reference and Application*, fig. 3-44, p. 3-24.

GEORGETOWN UNIVERSITY

Dynamic range

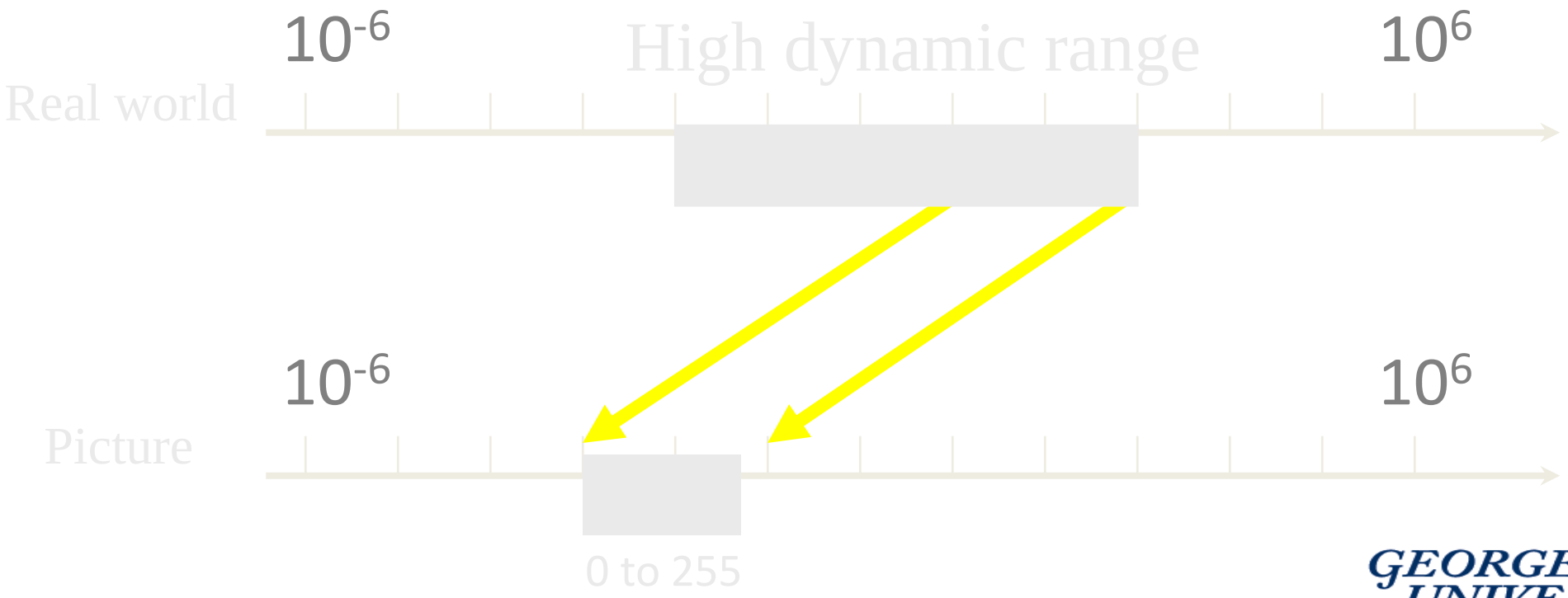
- Our total dynamic range is high (~10^9)
- Our dynamic range *at a given time* is still pretty high (~10^4)
- A camera's dynamic range for a given exposure is relatively low (2^8 = 256 tonal values, range of about ~10^3)

Long Exposure



GEORGETOWN UNIVERSITY

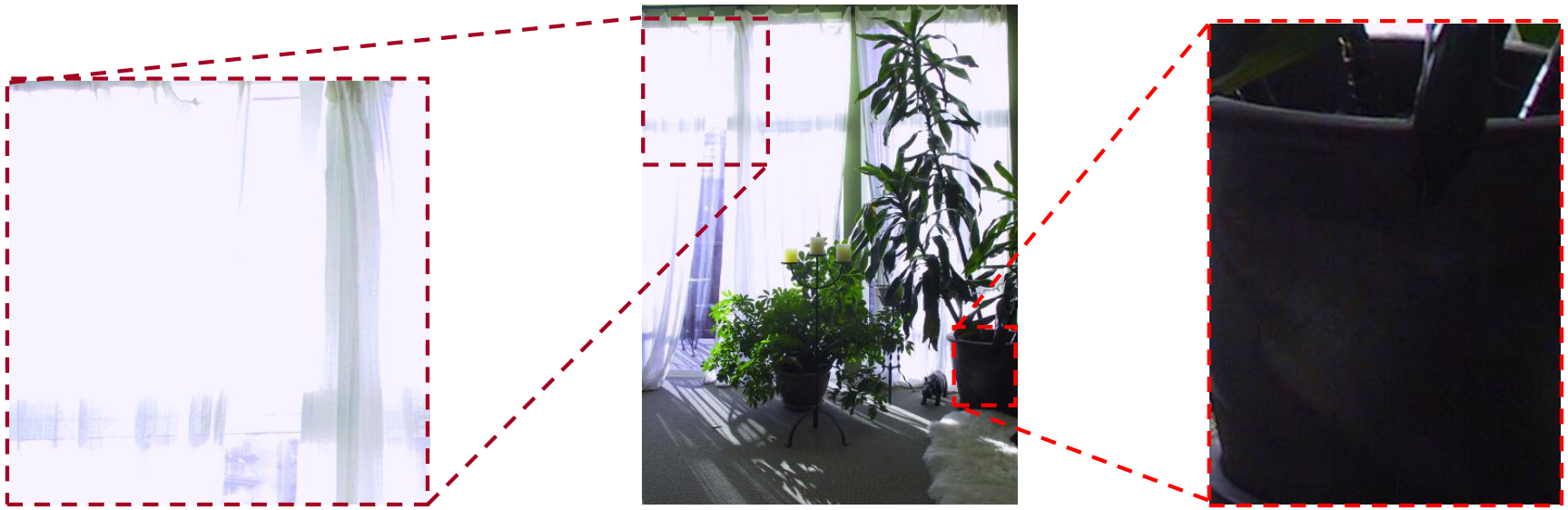
Short Exposure



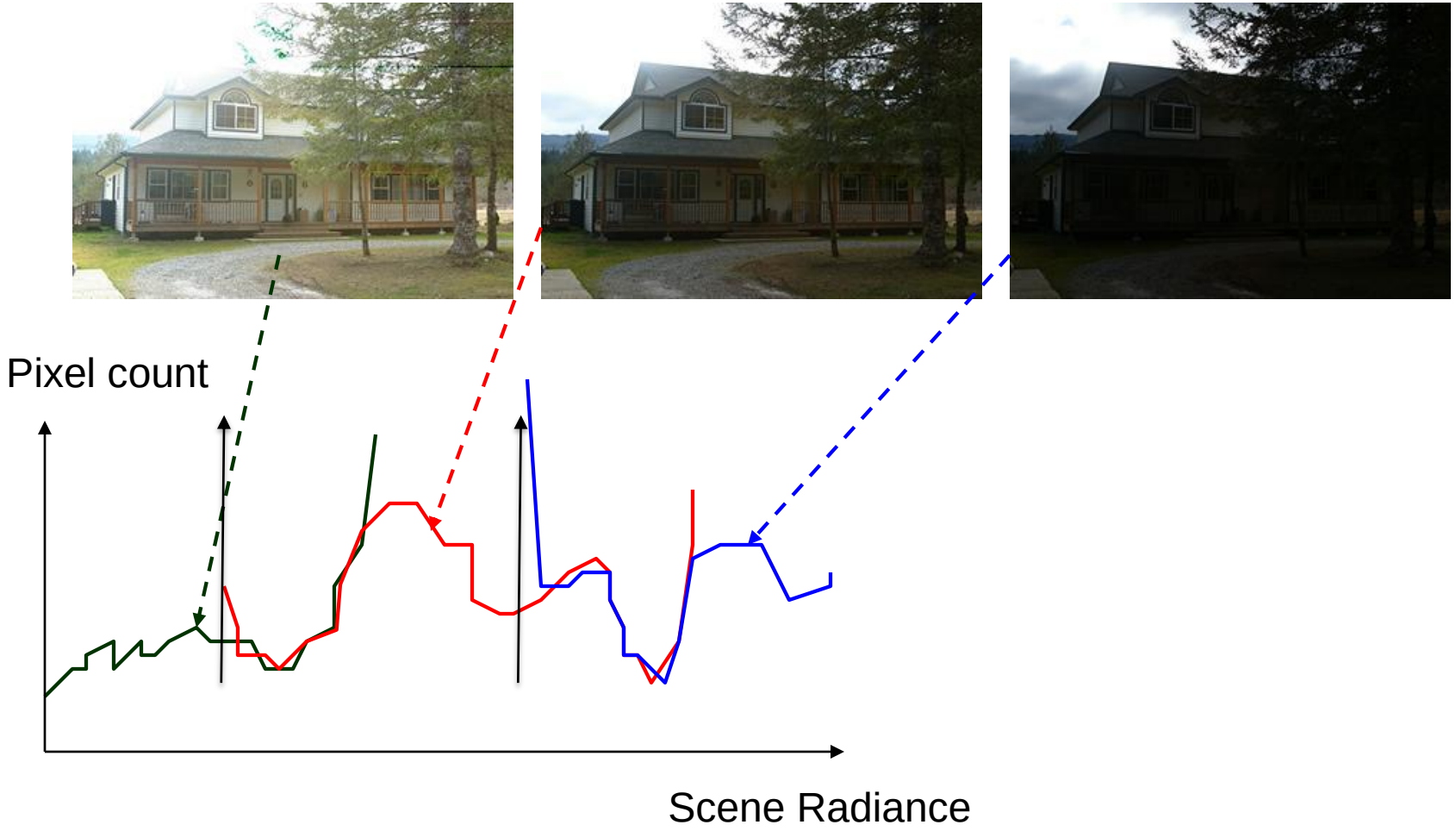
GEORGETOWN UNIVERSITY

Dynamic Range

Typical cameras have limited dynamic range



HDR images — merge multiple inputs

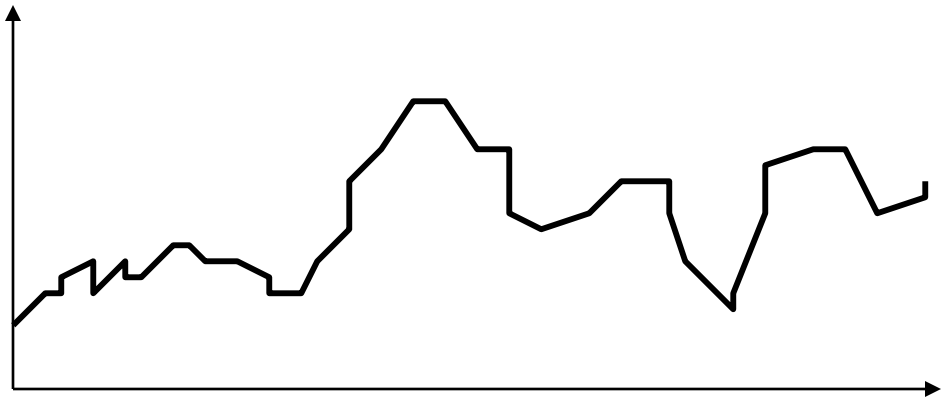


GEORGETOWN UNIVERSITY

HDR images — merged



Pixel count

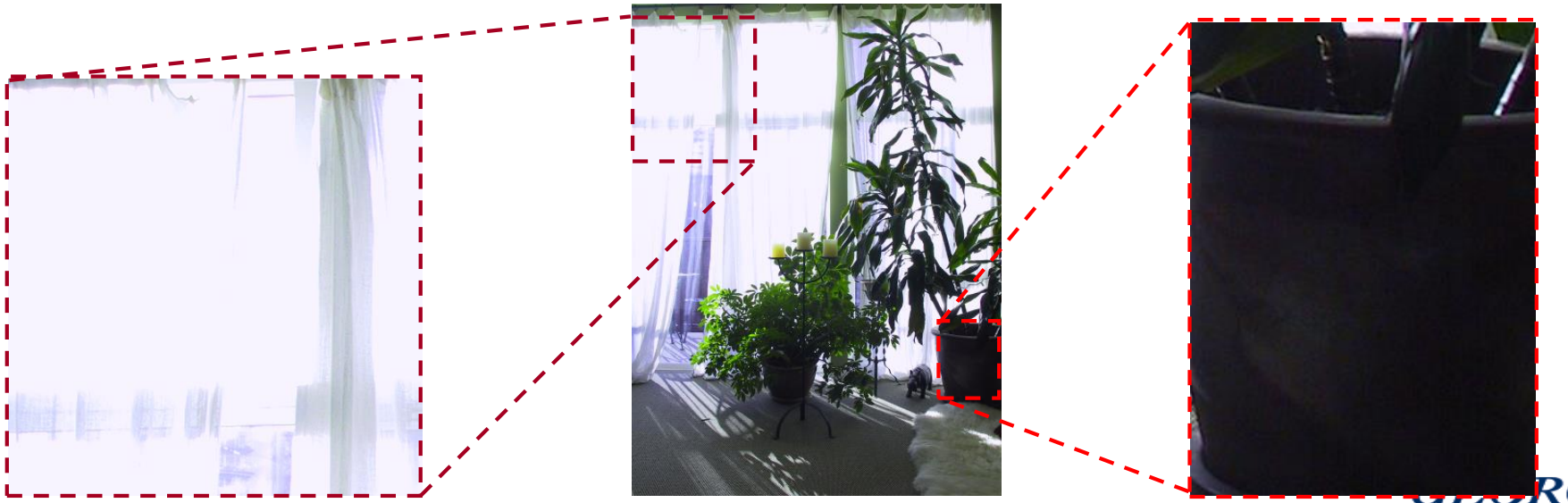


Radiance

GEORGETOWN UNIVERSITY

Dynamic range

- What is the range of light intensity that a camera can capture?
  - Called *dynamic range*
  - Digital cameras have difficulty capturing both high intensities and low intensities in the same image



High dynamic range imaging