SAIR

Spatial AI & Robotics Lab

CSE 473/573-A

L3: COLORING

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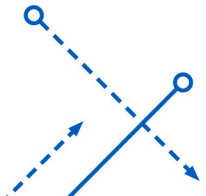
Content

- Optical Sensor
  - Image representation, resolution, sampling & quantization
  - Digital Camera, CCD, CMOS
- Color Space
  - Electromagnetic Spectrum, Bayer pattern
  - RGB, HSV, L*a*b*, YCbCr



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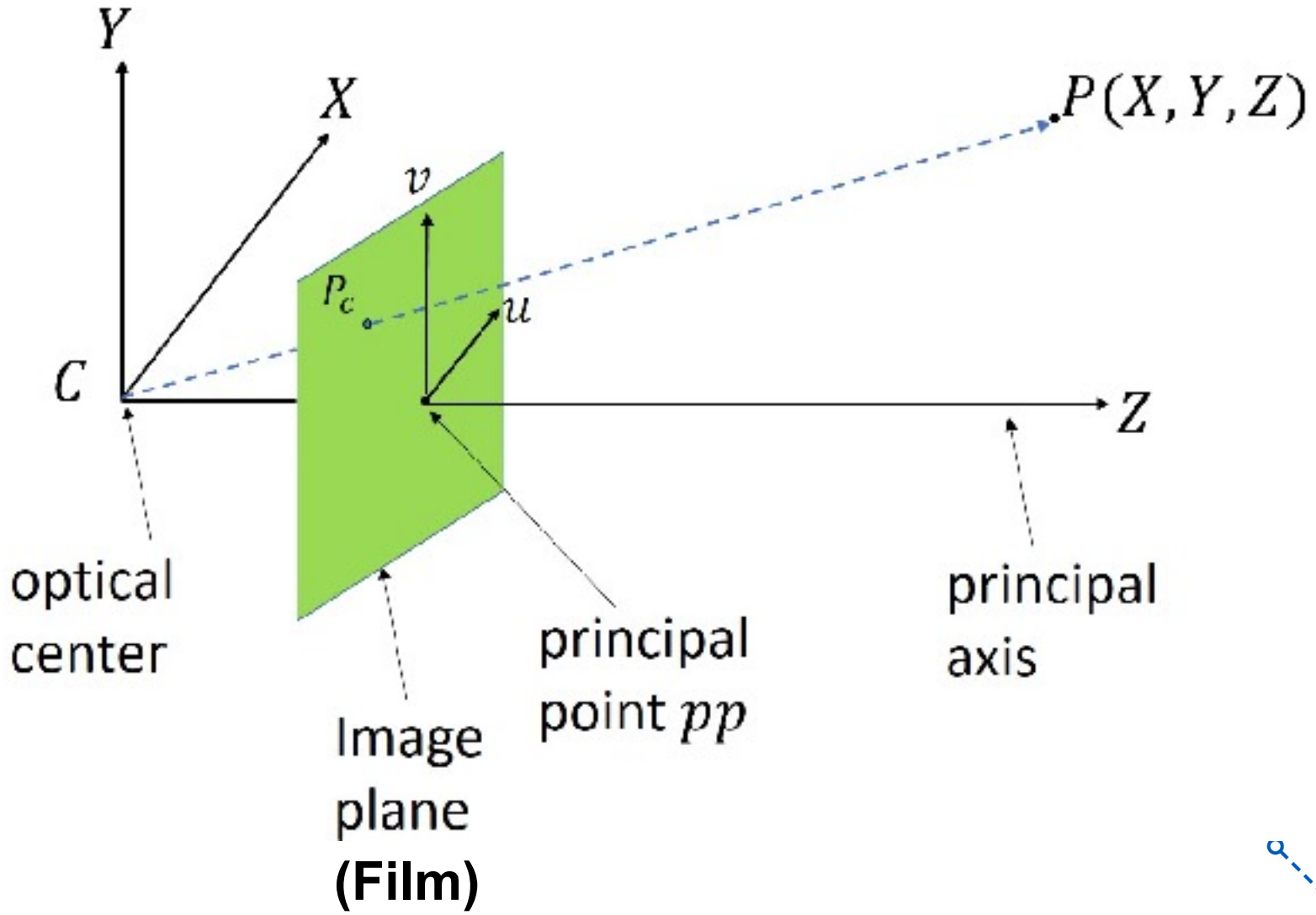
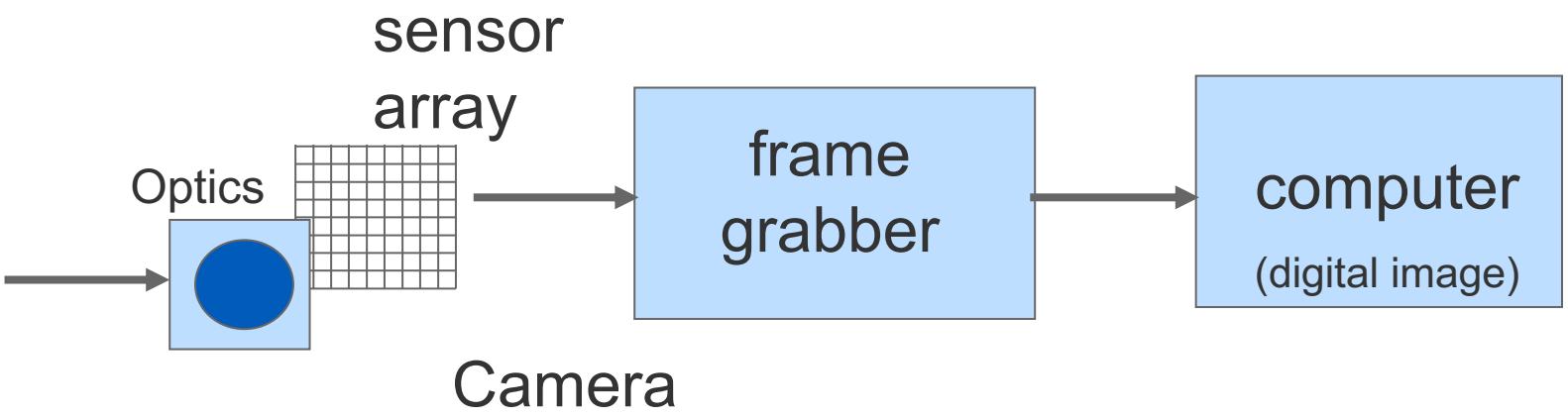
OPTICAL SENSOR

What is the film in a real camera?



Digital cameras

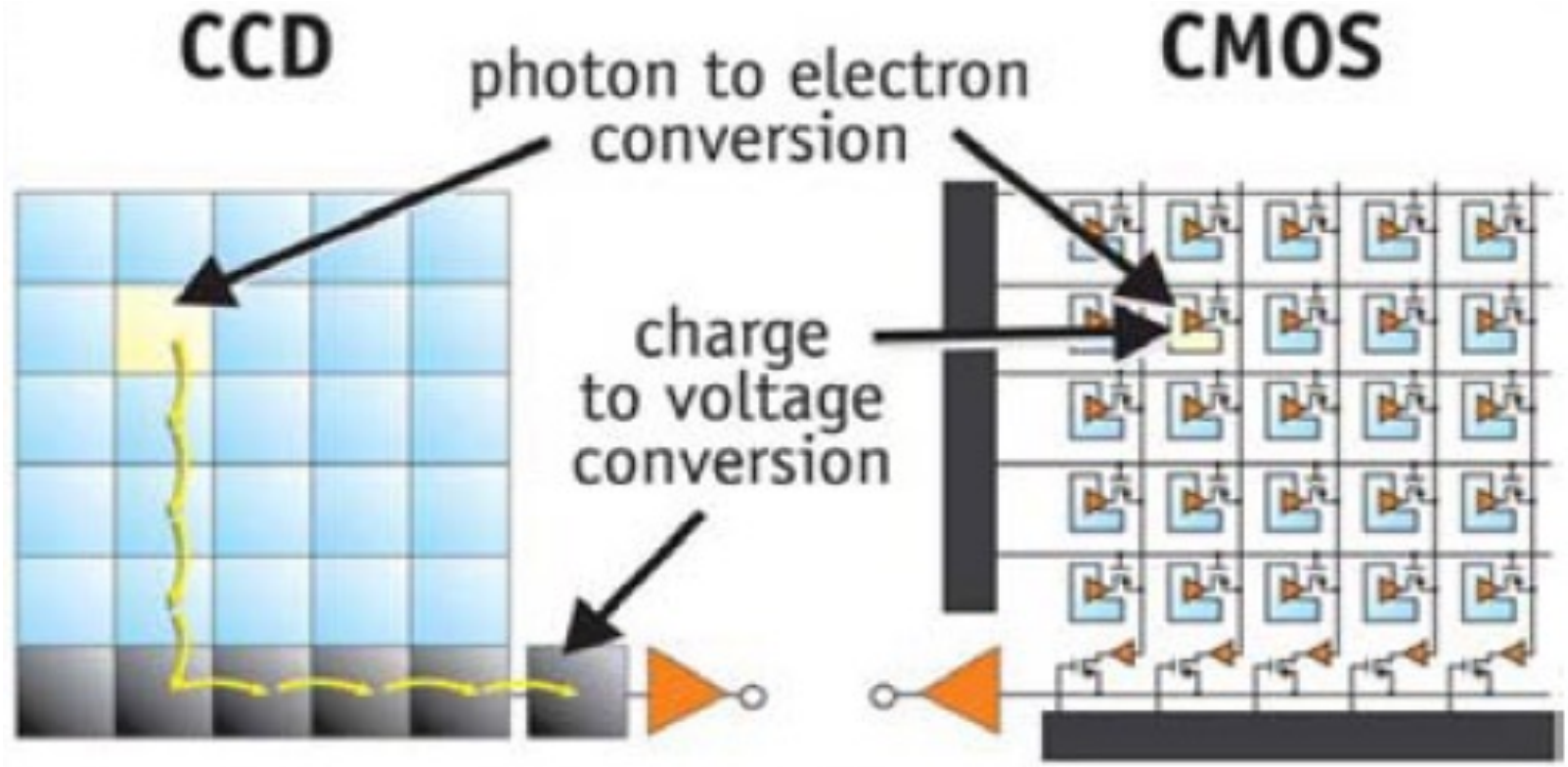
- Film is a sensor (detector) array
- Each position contains a light sensitive diode that converts **photons** (light energy) to **electrons.**



- Basic process:
  - photons hit a detector
  - the detector becomes charged
  - the charge is read out as brightness

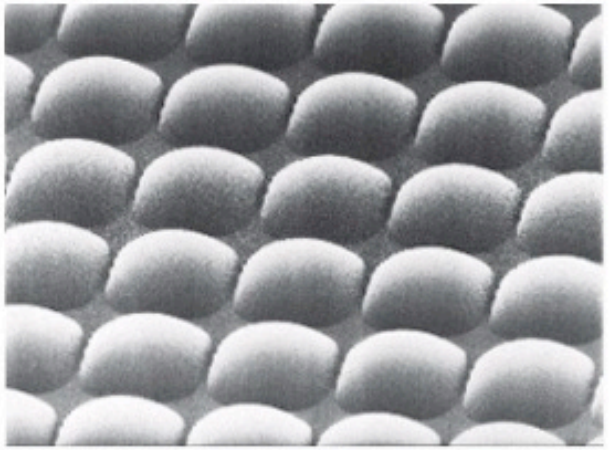
Digital Sensors

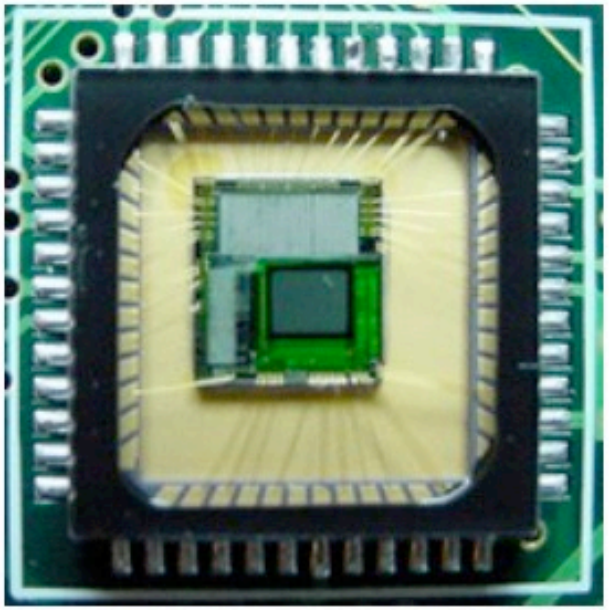
- CCD (charge couple devices): moves photogenerated charge from pixel to pixel and convert it to voltage at an output node.
- CMOS (complementary metal oxide semiconductor): convert charge to voltage inside each pixel.



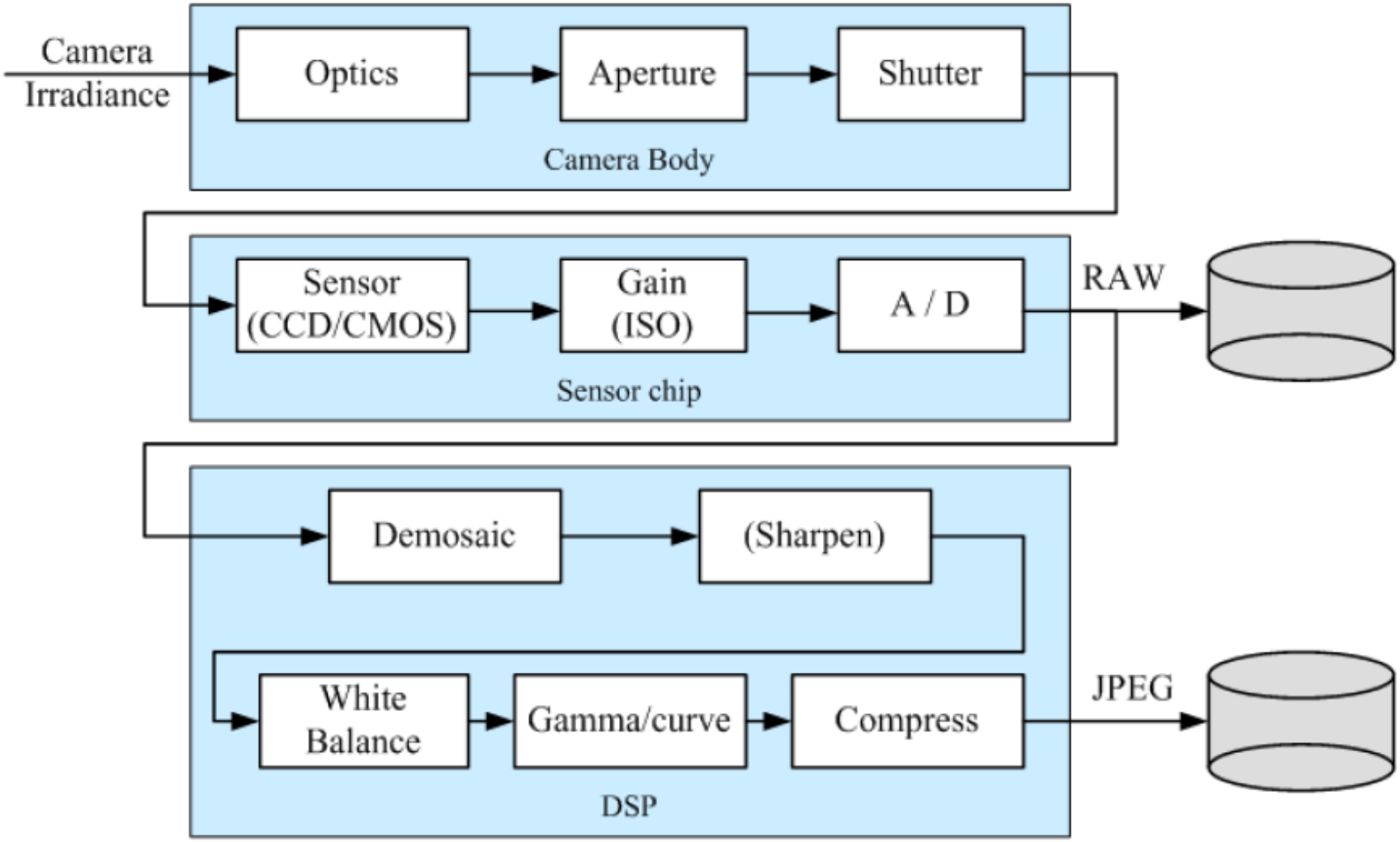
CCD vs CMOS

- Sensor types:
  - CCD (charge-coupled device)
    - most common
    - high sensitivity
    - high power
    - cannot be individually addressed
    - blooming
  - CMOS
    - simple to fabricate (cheap)
    - lower sensitivity, lower power
    - can be individually addressed



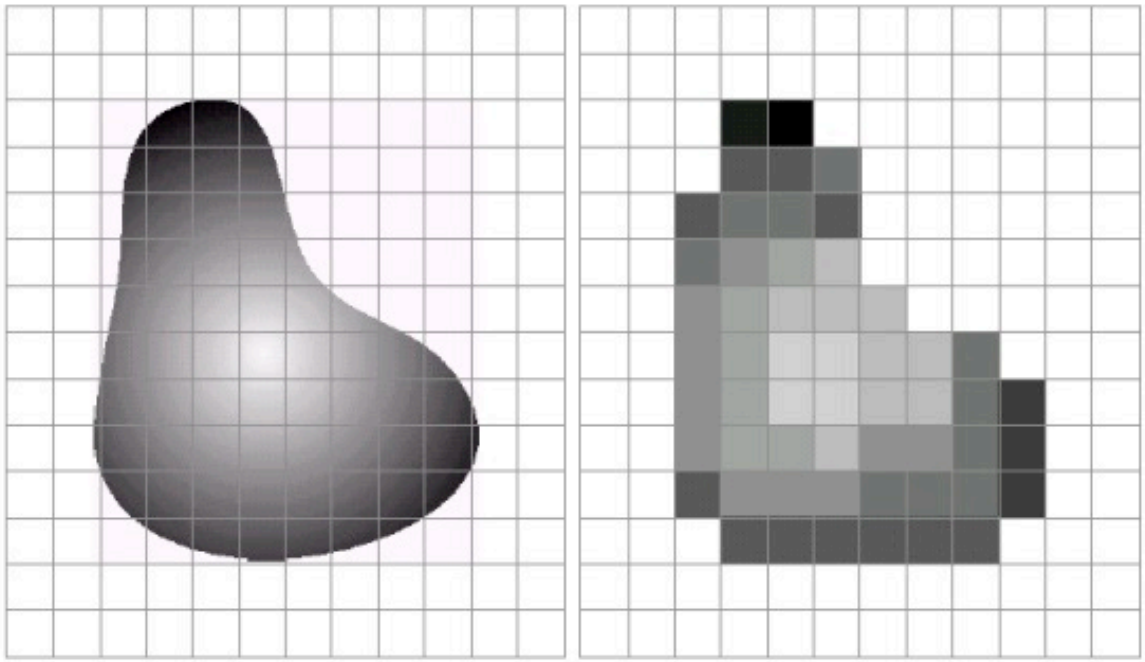


Camera



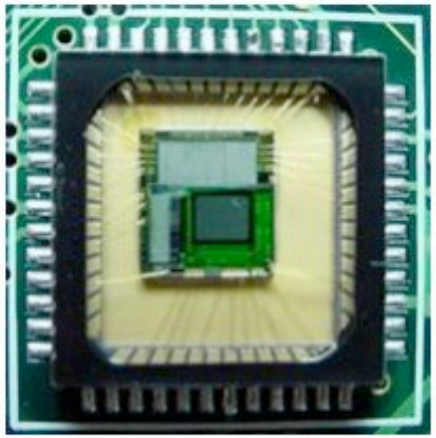
ISO referred to the sensitivity of film

Sampling and Quantization



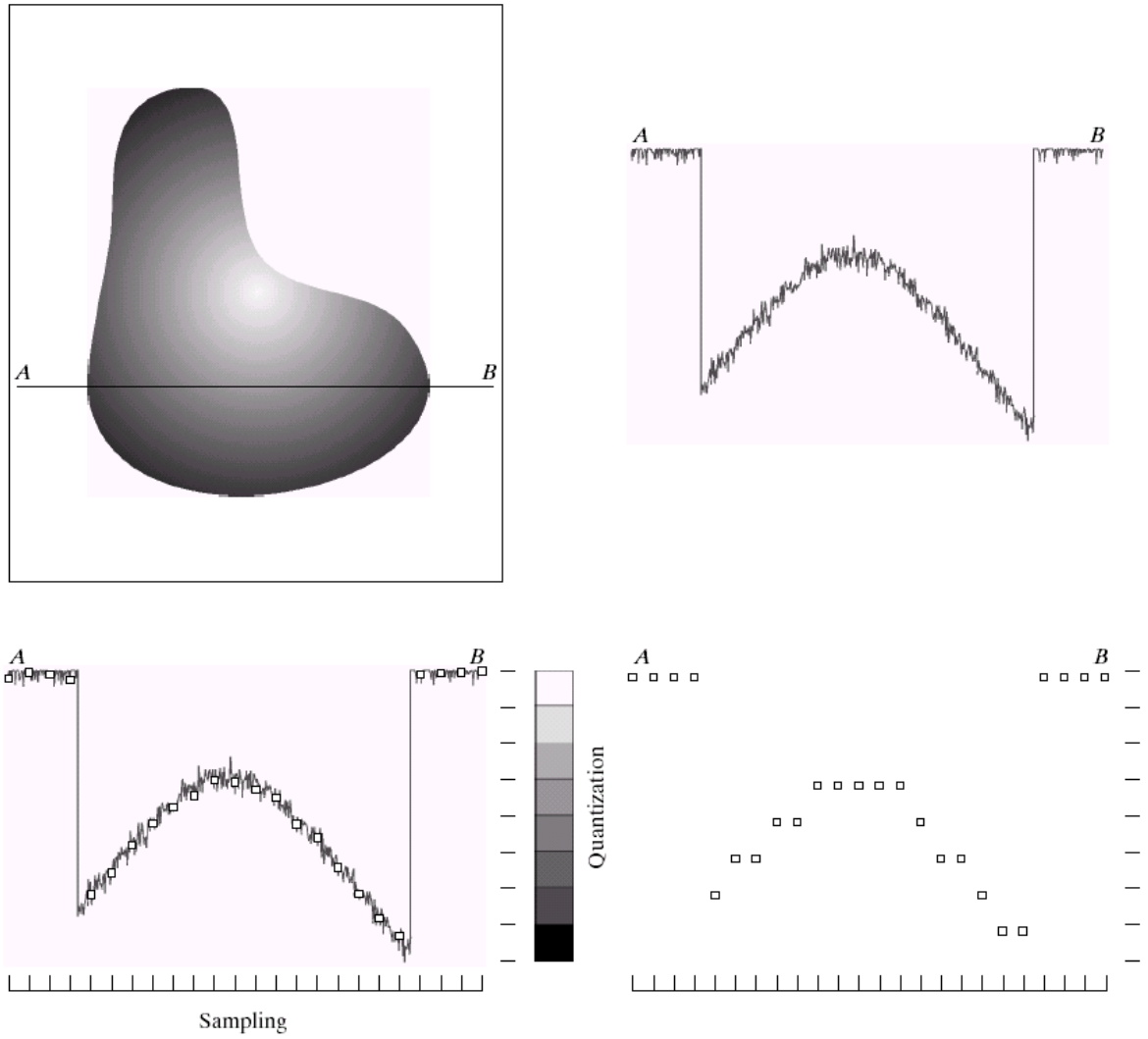
a b

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



CMOS sensor

Sampling and Quantization: 1D Case

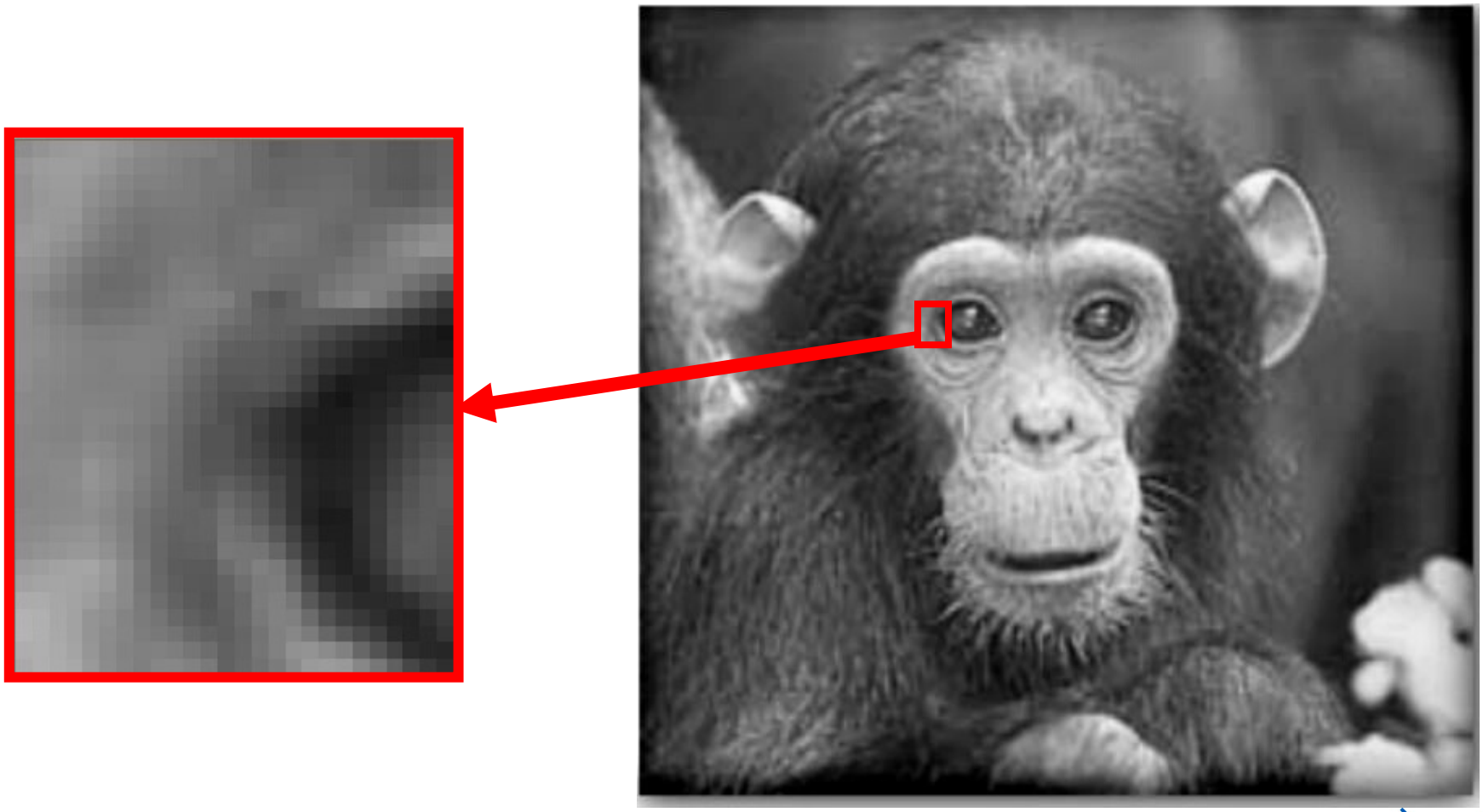


a b
c d

FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

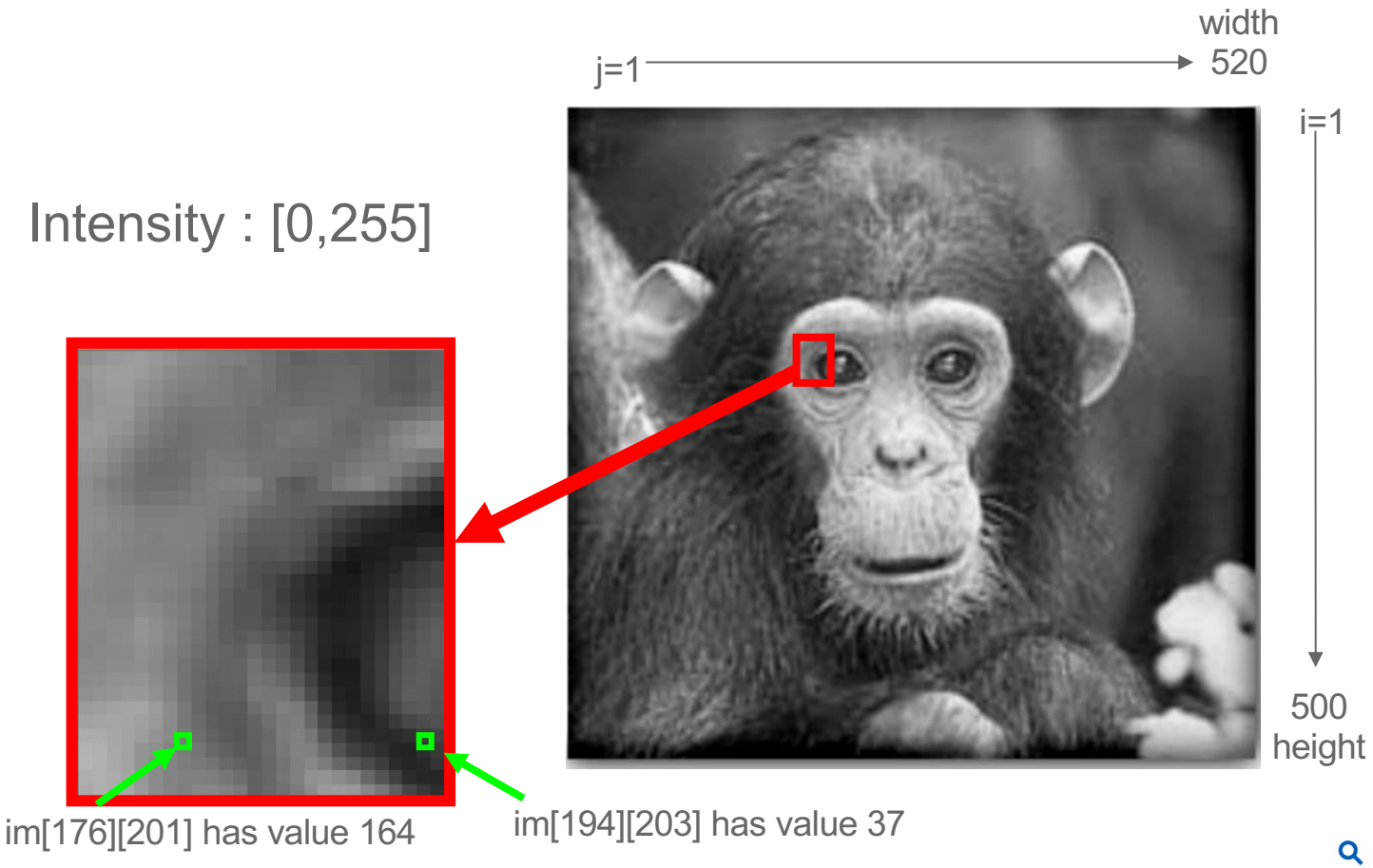
Digital Image

- Think of images as matrices taken from CCD array.



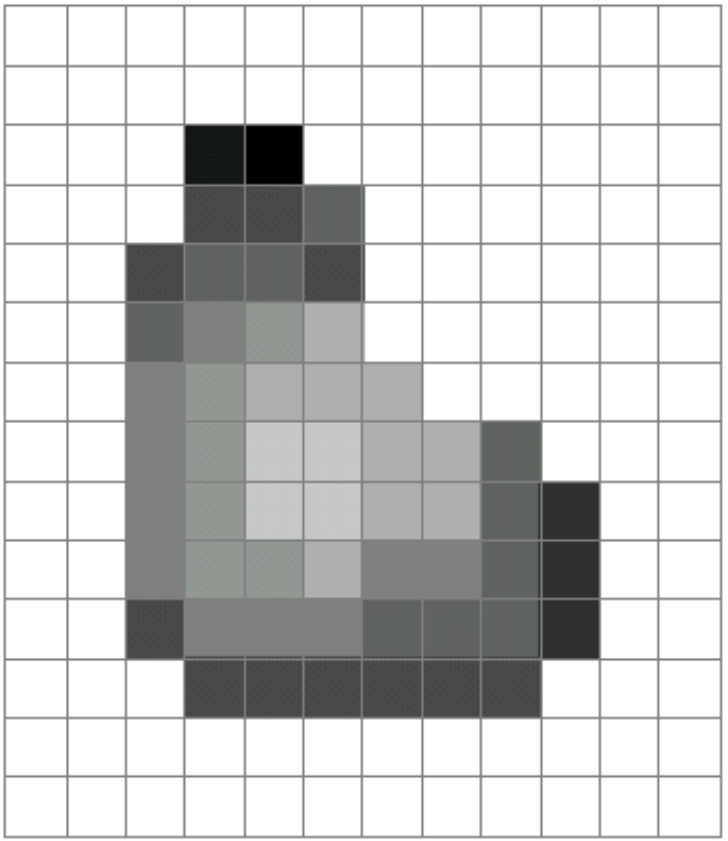
Digital Image

- Think of images as matrices taken from CCD array.



Digital image

- A grid (matrix) of intensity values.
- (common to use one byte per value: 0 = black, 255 = white)



=

255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	20	0	255	255	255	255	255	255	255
255	255	255	75	75	75	255	255	255	255	255	255
255	255	75	95	95	75	255	255	255	255	255	255
255	255	96	127	145	175	255	255	255	255	255	255
255	255	127	145	175	175	175	255	255	255	255	255
255	255	127	145	200	200	175	175	95	255	255	255
255	255	127	145	200	200	175	175	95	47	255	255
255	255	127	145	145	175	127	127	95	47	255	255
255	255	74	127	127	127	95	95	95	47	255	255
255	255	255	74	74	74	74	74	74	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255
255	255	255	255	255	255	255	255	255	255	255	255

Image representation

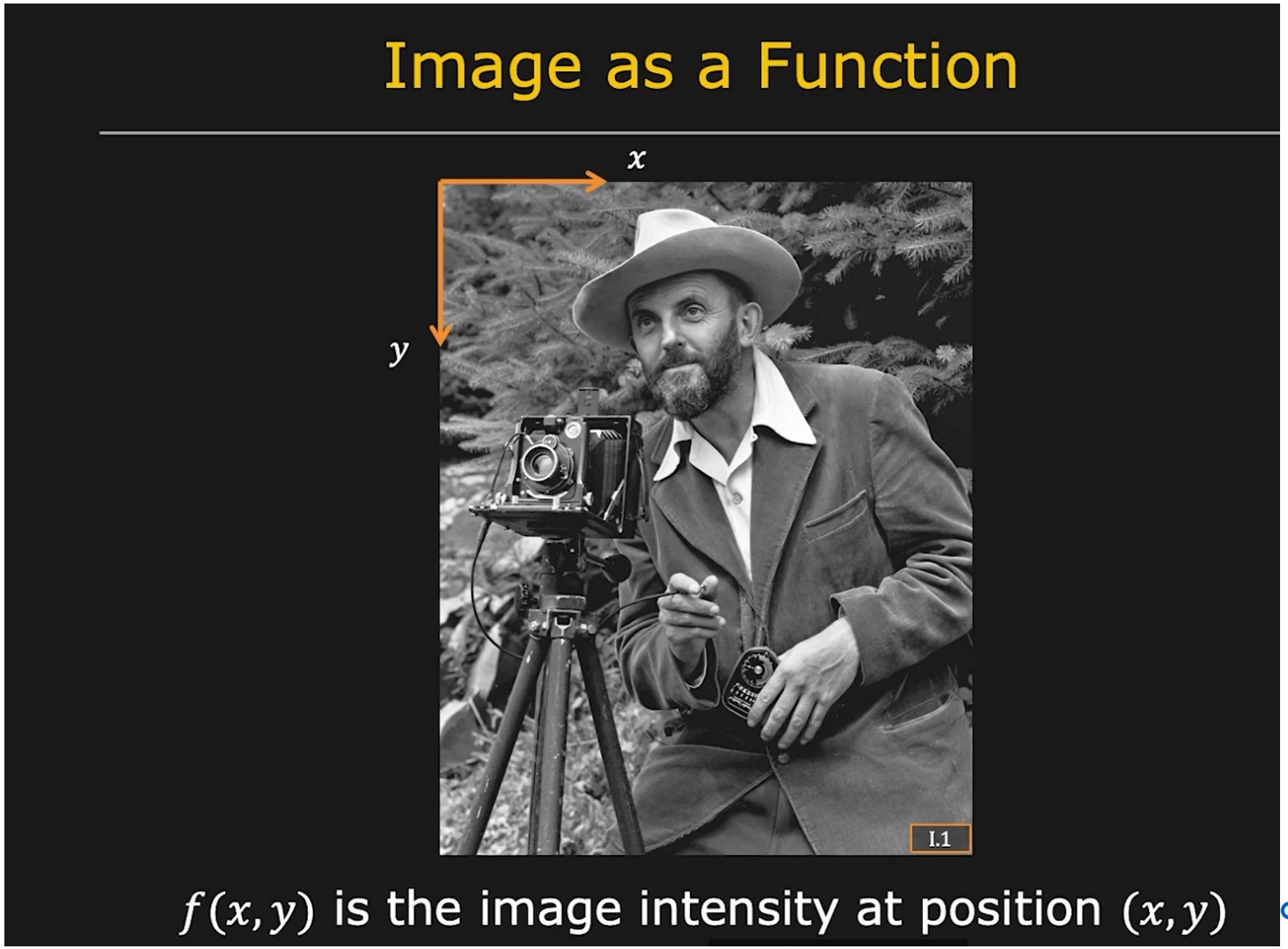
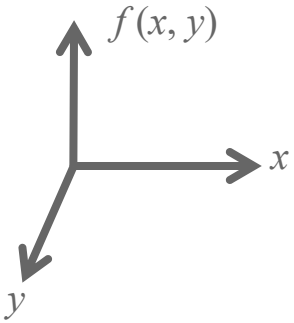


Image representation

- A (grayscale) image as a **function**, f, from $\mathbb{R}^2$ to $\mathbb{R}$:
  - $f(x, y)$ gives the **intensity** at position (x, y).
  - A **digital image** is a discrete (**sampled**, **quantized**) version of this function.



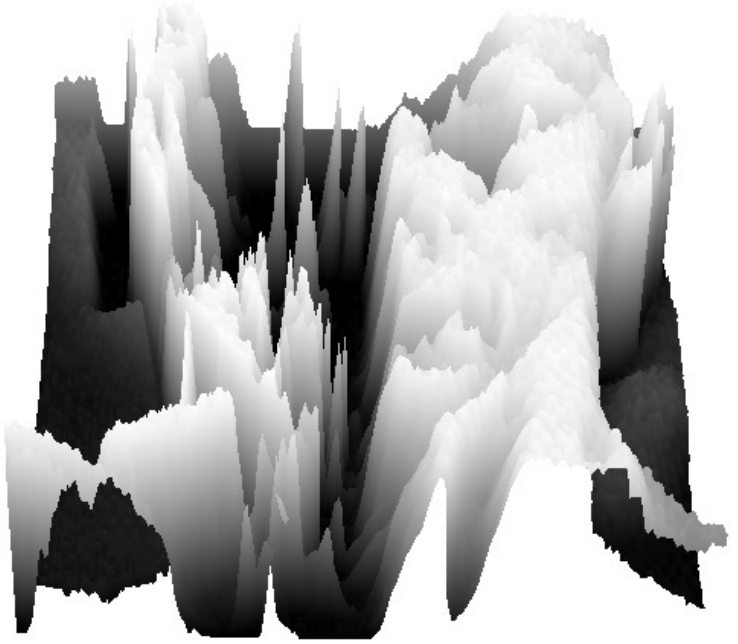


Image Resolution

- Sensor: size of real-world scene element that maps to a single pixel
- Influences what analysis is feasible, affects best representation choice.

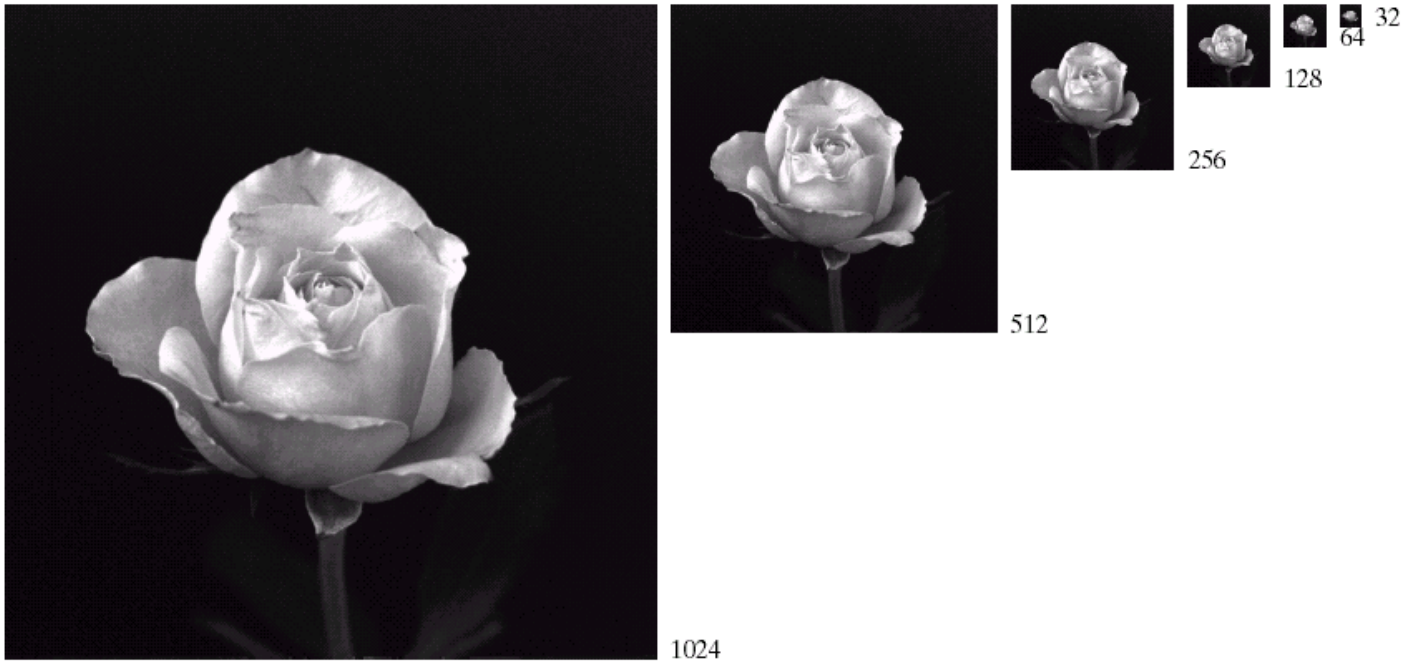


FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

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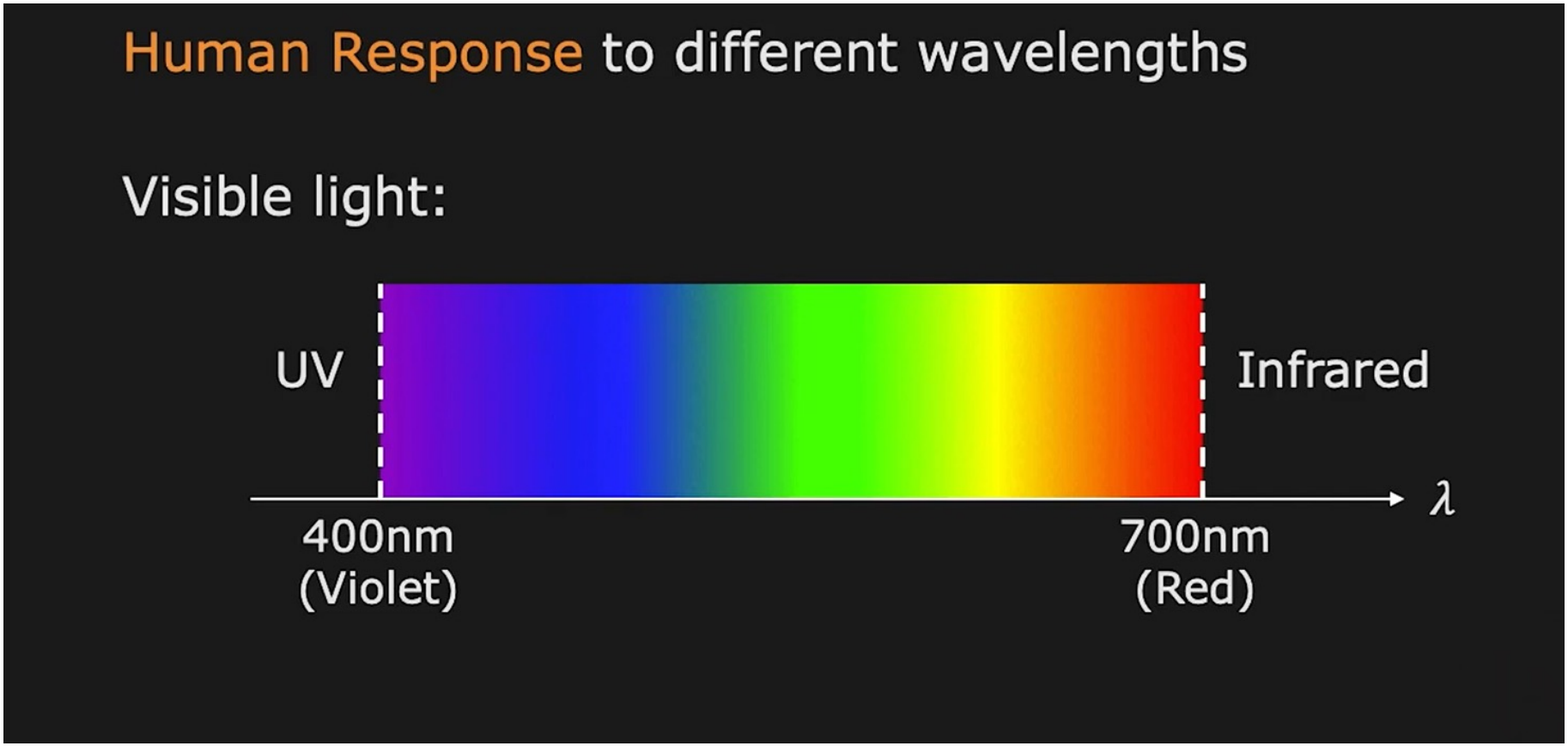
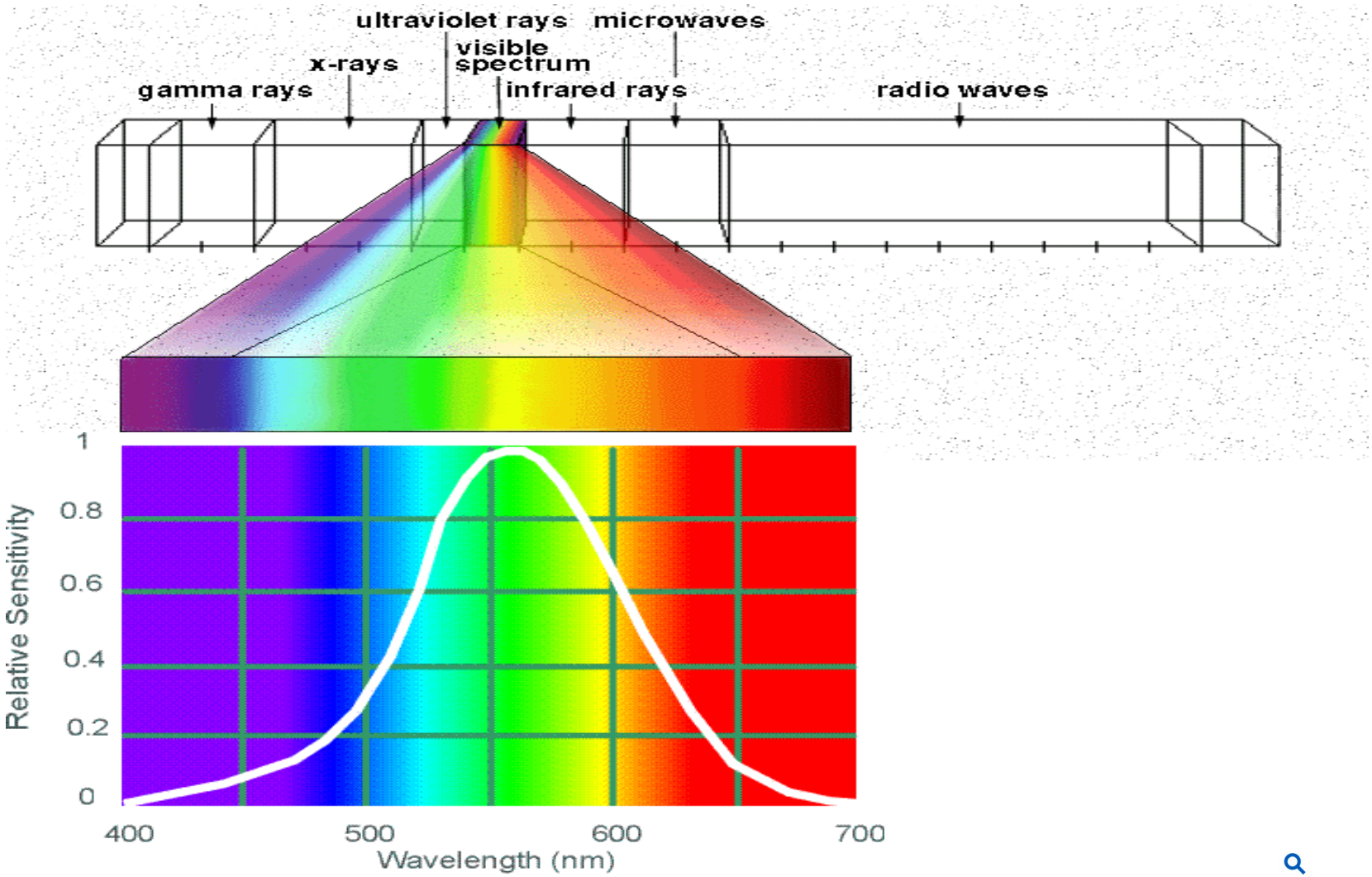
COLOR SPACE

What is Color?



electromagnetic wave

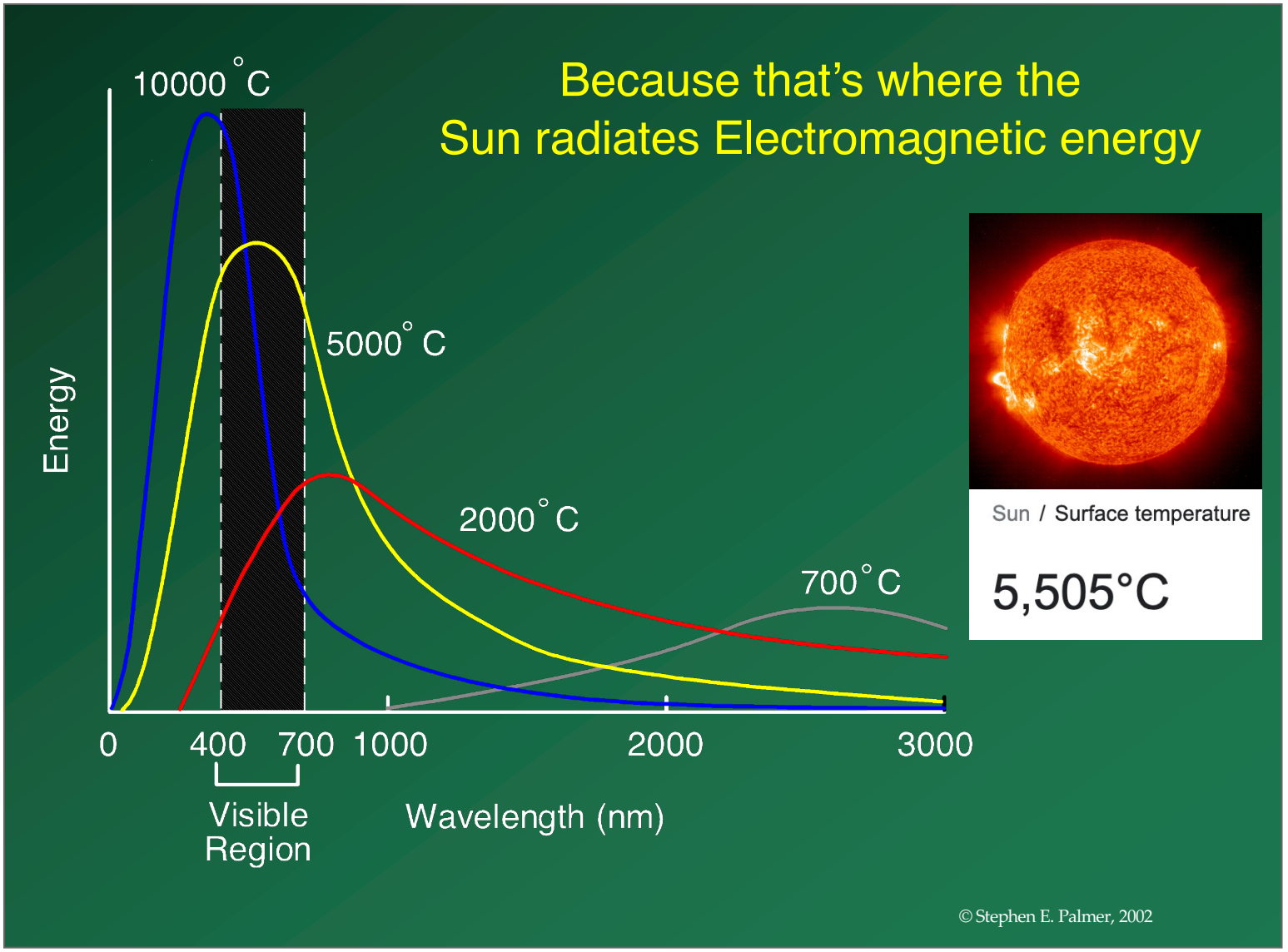
Electromagnetic Spectrum



Human Luminance Sensitivity Function

http://www.yorku.ca/eye/photopik.htm

Why do we see light of these wavelengths



Mixing of color

Young's Experiment on Color Mixture

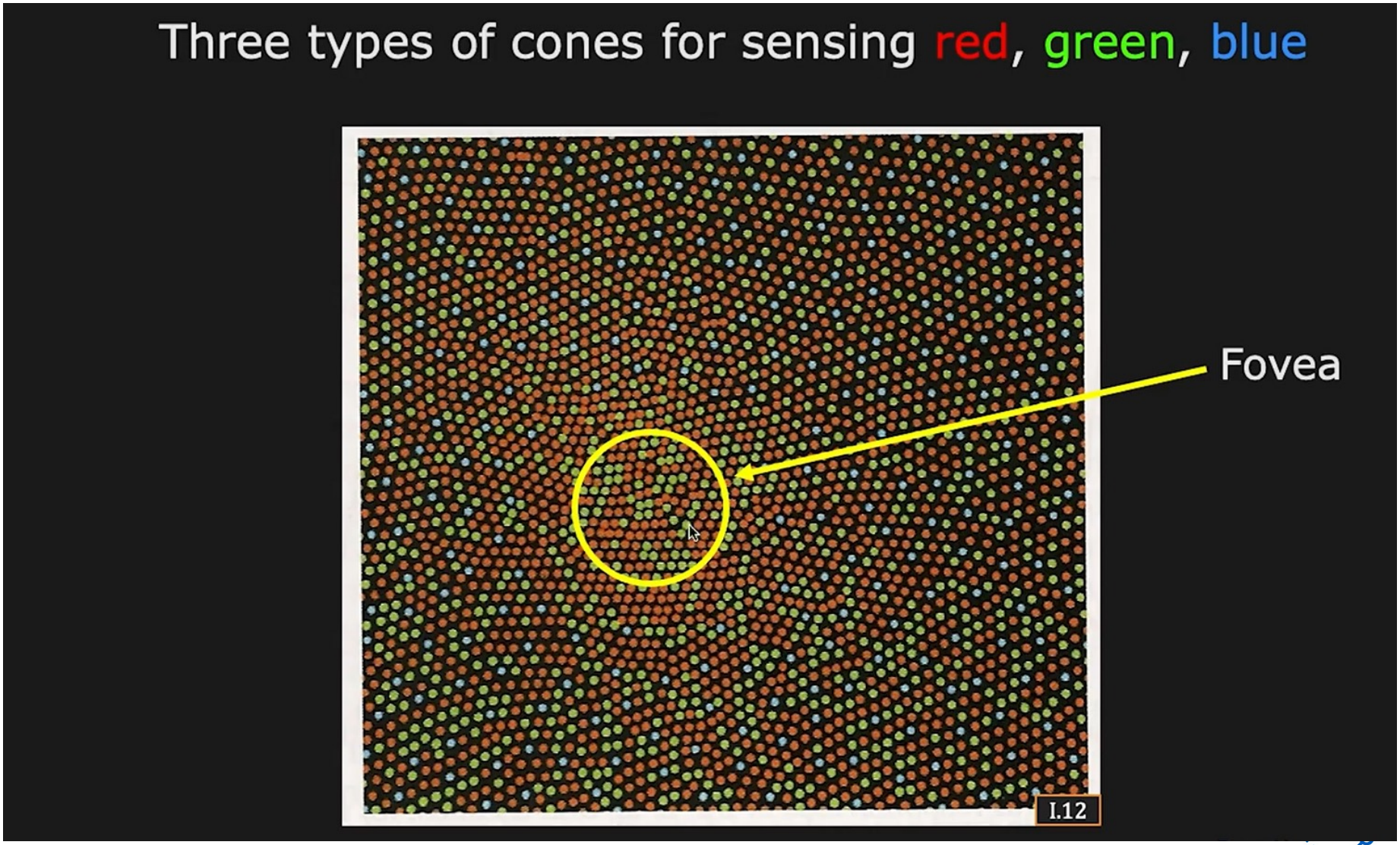
Human Sensation of nearly all colors can be produced using 3 wavelengths!

$$(\lambda_r, \lambda_g, \lambda_b) = (650,530,410)nm$$

Hence, cameras and displays often use 3 filters:

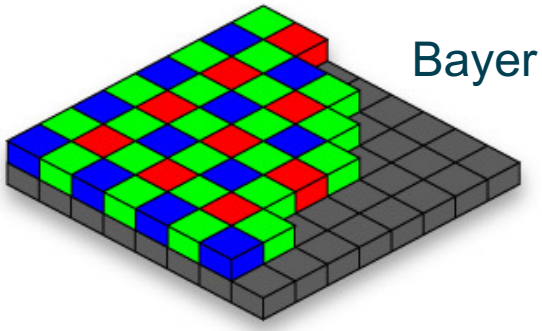
(red, green, blue)

Distribution of Cones in Human Retina

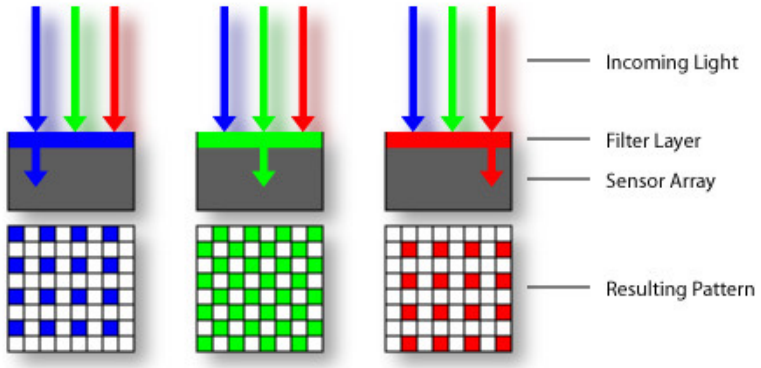


Color sensing in digital cameras

- Estimate missing components from neighboring values (demosaicing)



Bayer grid



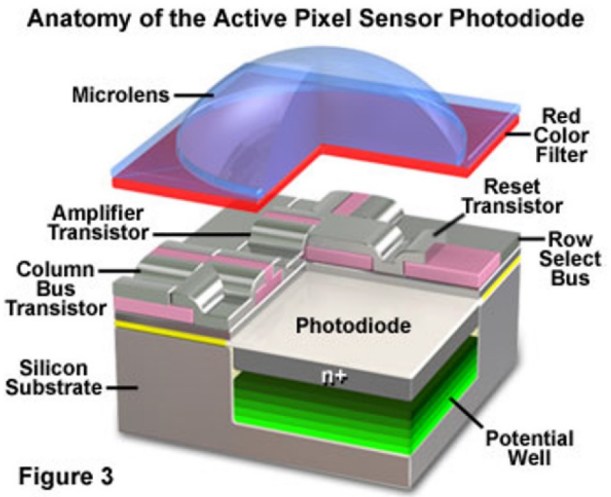
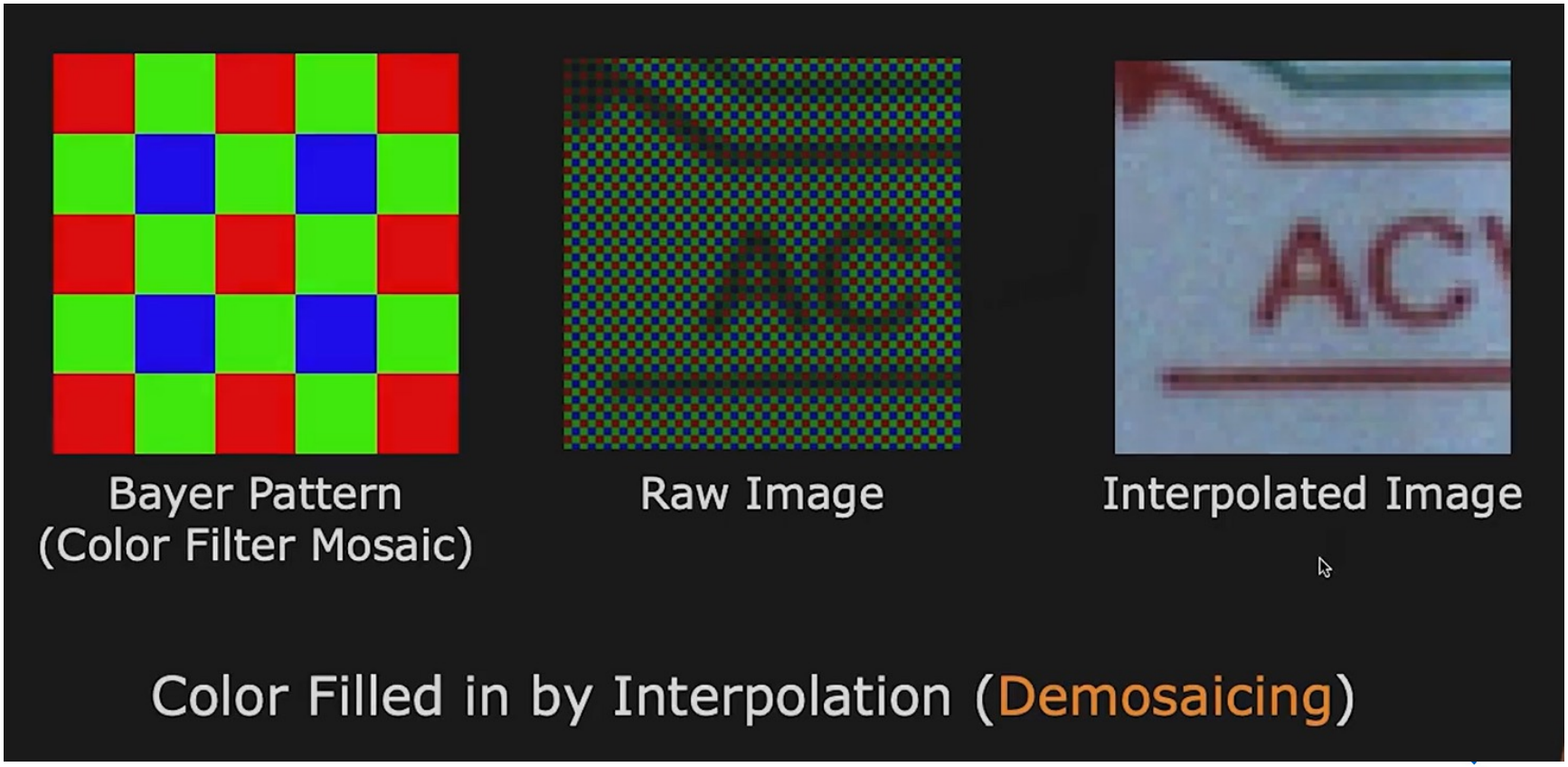
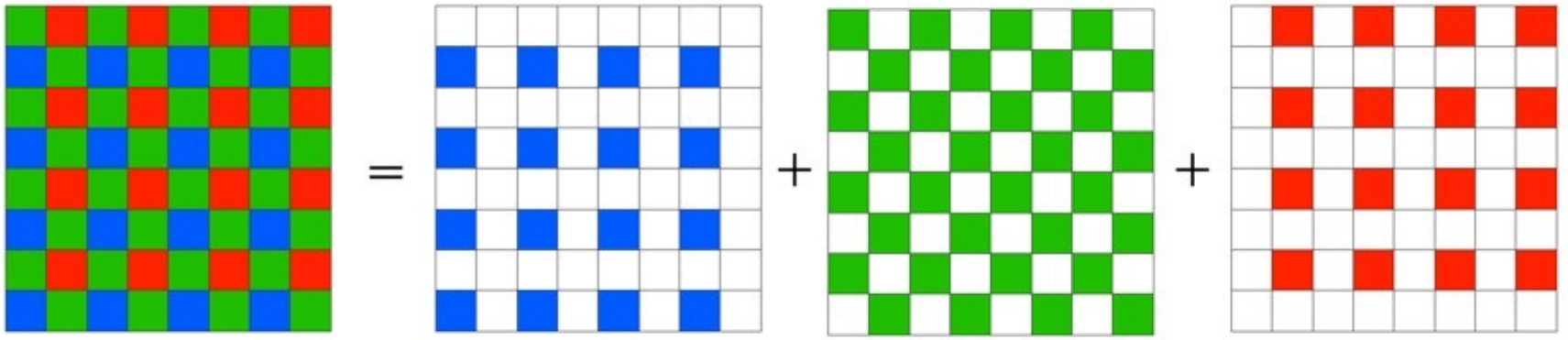


Figure 3

Sensing Color Using Color Mosaic



Bayer pattern



- But why are there more green filters?
- Because human vision is more sensitive to green.
- So, the ratio is 50% green, 25% red, and 25% blue.

https://pixelcraft.photo.blog/2019/12/18/the-bayer-filter/

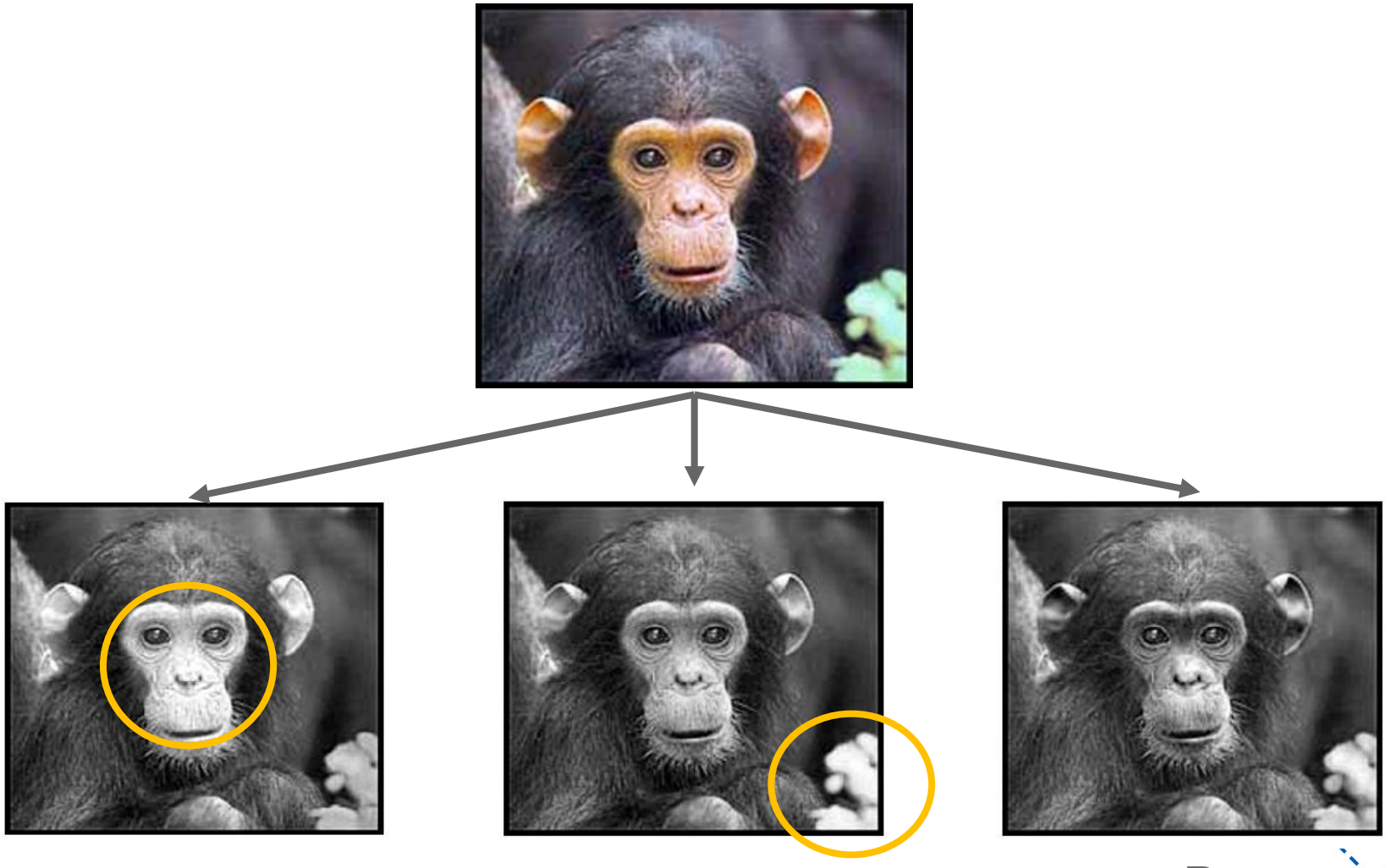
True vs interpolated values of RGB

G	R	G	R
B	G	B	G
G	R	G	R
B	G	B	G

rGb	Rgb	rGb	Rgb
rgB	rGb	rgB	rGb
rGb	Rgb	rGb	Rgb
rgB	rGb	rgB	rGb

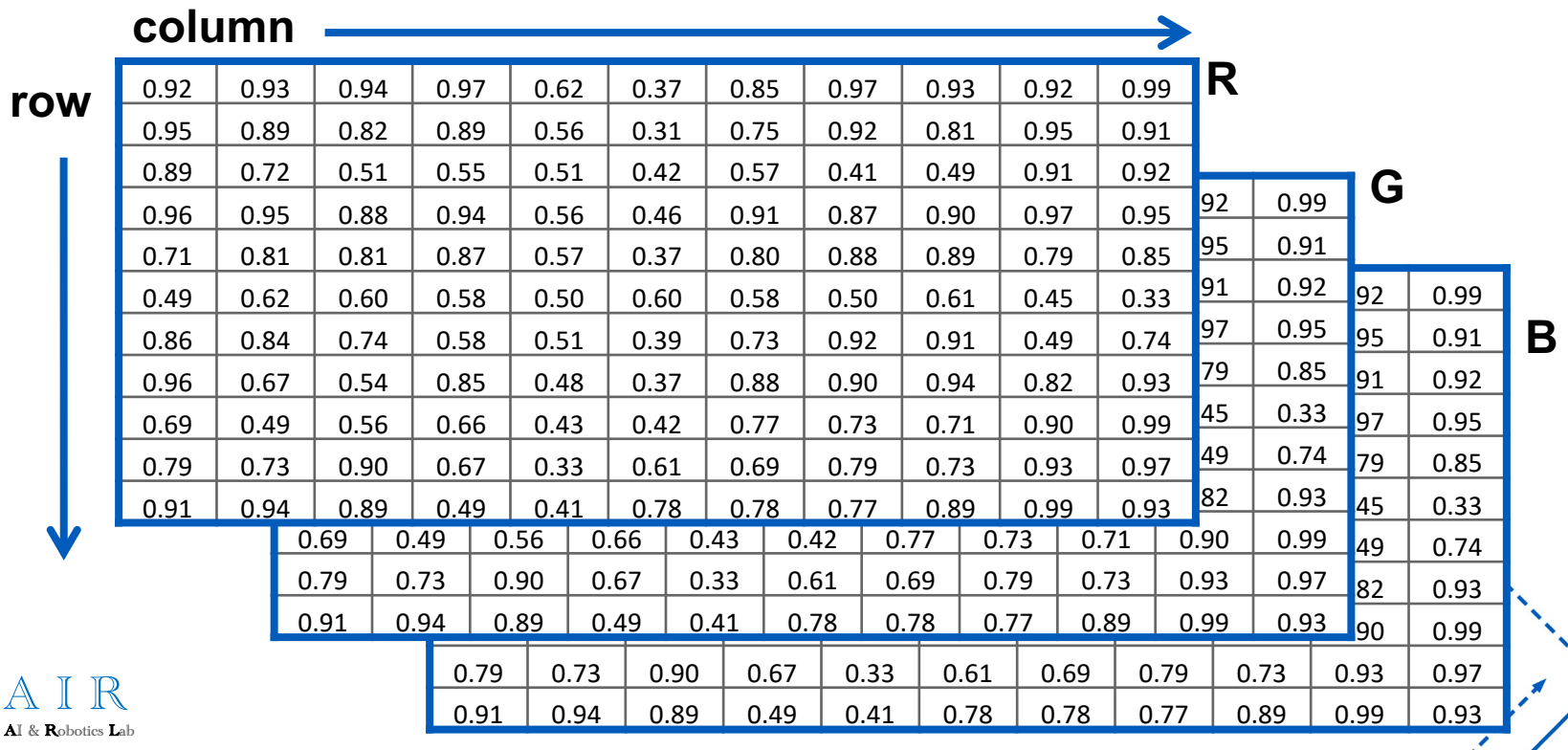
Digital Color images

- RGB color space (3 Channels)



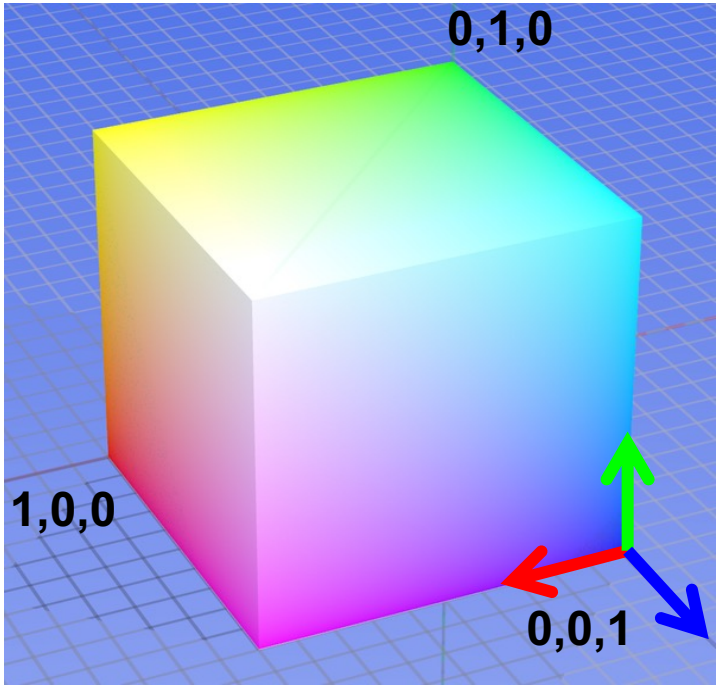
Images in Python (PyTorch)

- Images represented as a matrix (Tensor)
- Suppose we have a $N \times M$ RGB image called "I"
  - I[0,0,0] = top-left pixel value in R-channel
  - I[b, r, c] = c pixels to right, r pixels down, in the b^{th} channel
  - I[B, N-1, M-1] = bottom-right pixel in B-channel

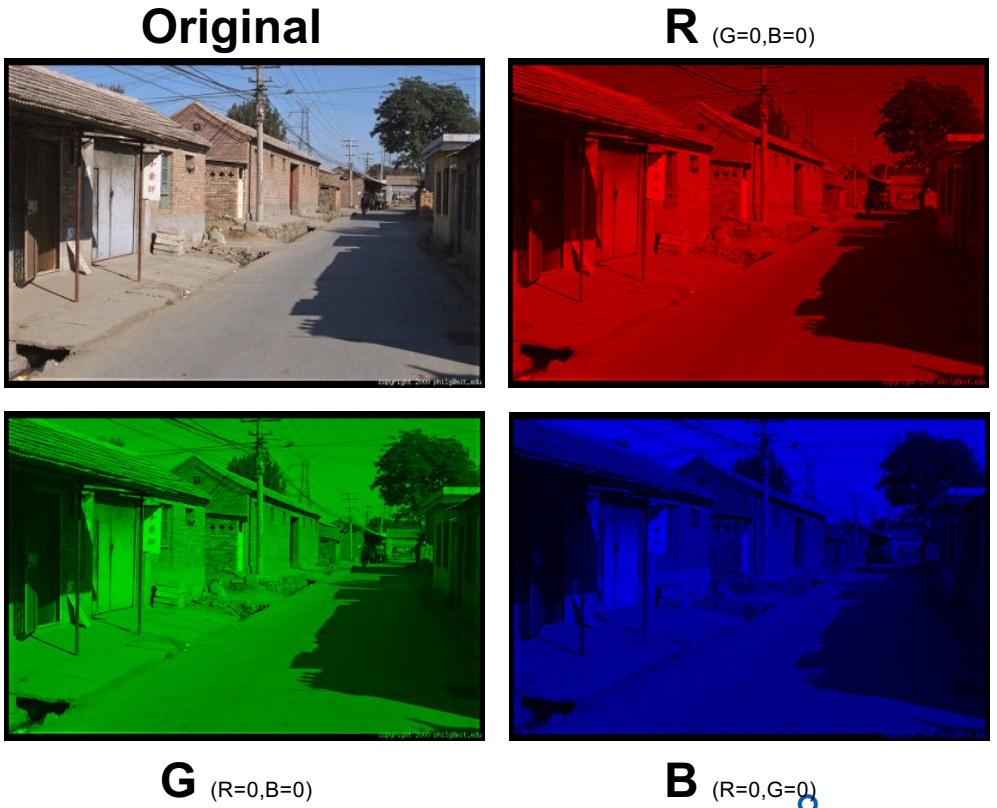


Color spaces: RGB

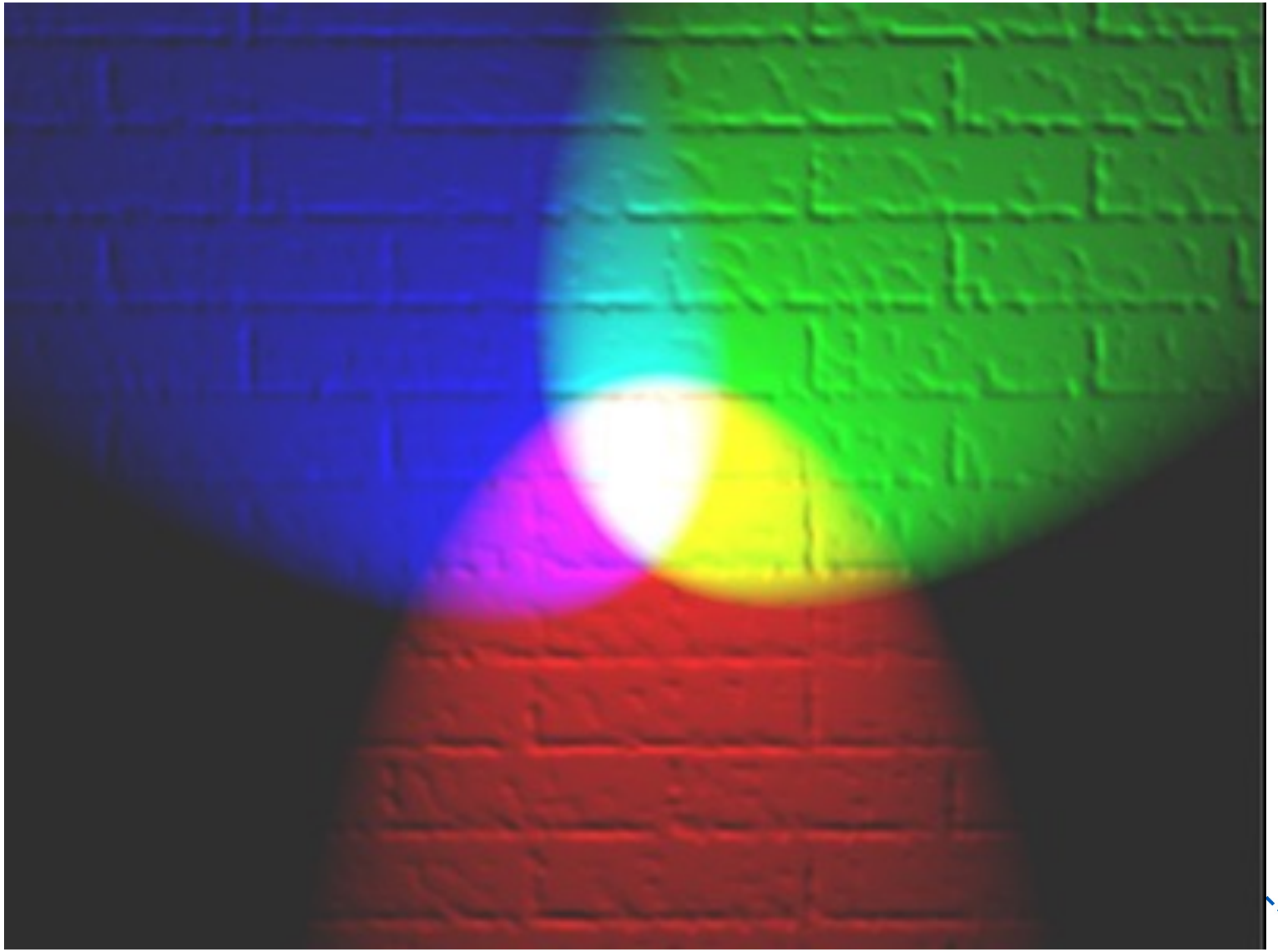
- Drawbacks
  - Strongly correlated channels
  - Non-perceptual



Default color space



Any other color space?

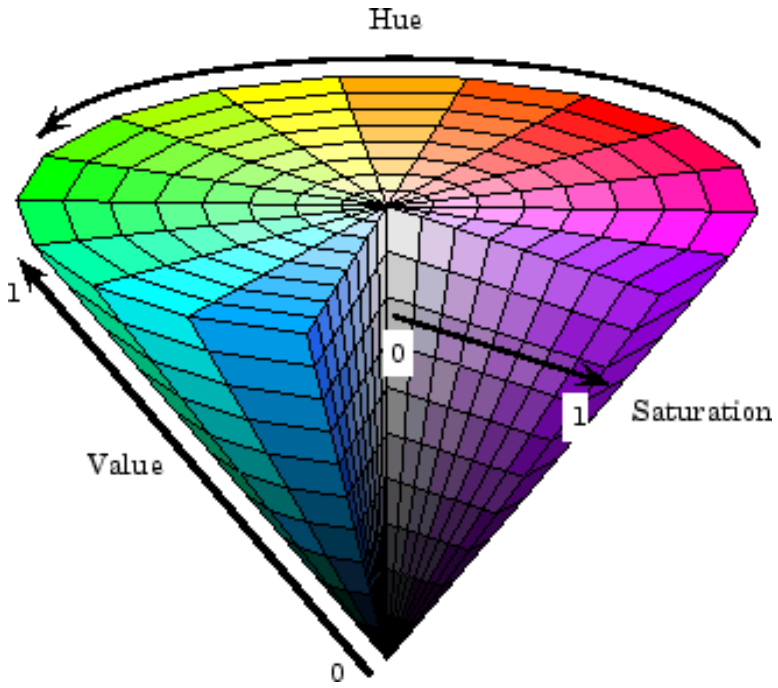


http://en.wikipedia.org/wiki/File:RGB_illumination.jpg

Color spaces: HSV

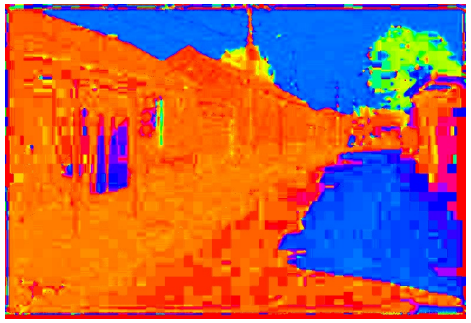
- **Hue, Saturation, Value (Brightness):** how colors appear under light.
- **Saturation** (photography): the intensity of a color, expressed as the degree to which it differs from gray.

Intuitive Color Space



Original

H (S=1,V=1)



S (H=1,V=1)

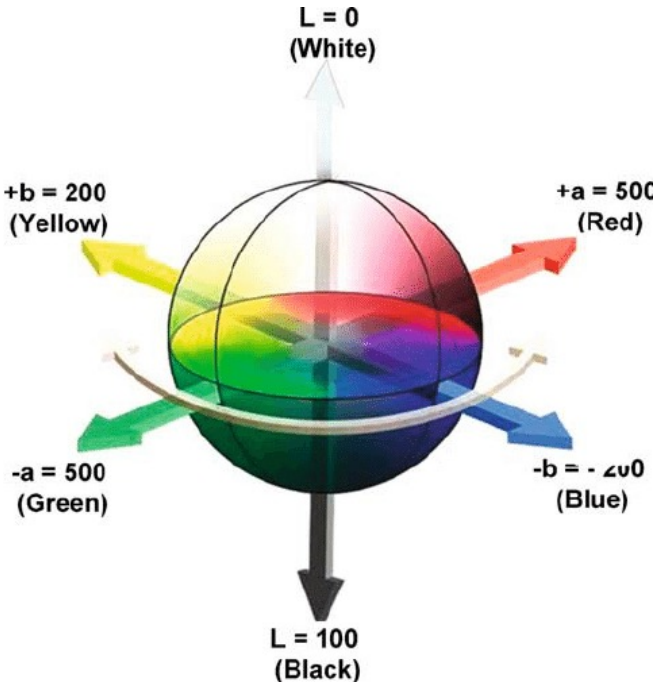
V (H=1,S=0)

Friendly for human intuition

Color spaces: L*a*b*

- **L** is for lightness. It goes from 0 to 100, shows contrast between black and grays.
- **a** is red (+) to green (-).
- **b** is yellow (+) to blue (-).

"Perceptually uniform"* color space



Original

L (a=0,b=0)

a (L=65,b=0)

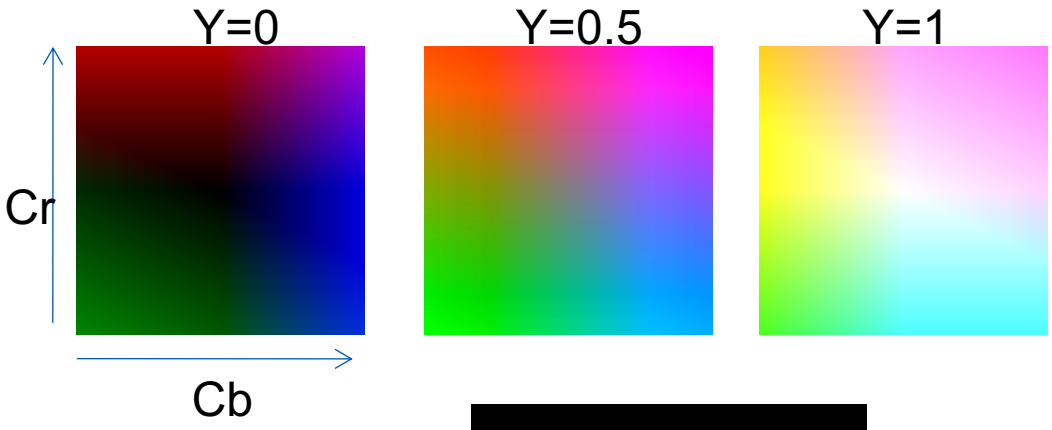
b (L=65,a=0)

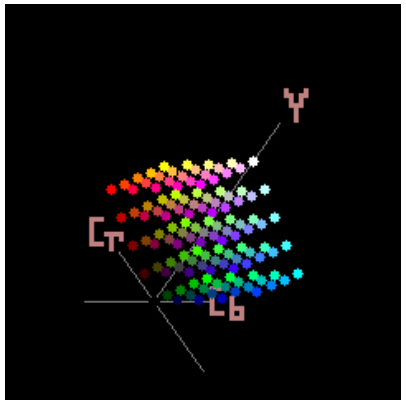
If a change of length in any direction X of the color space is perceived by a human as the same change.

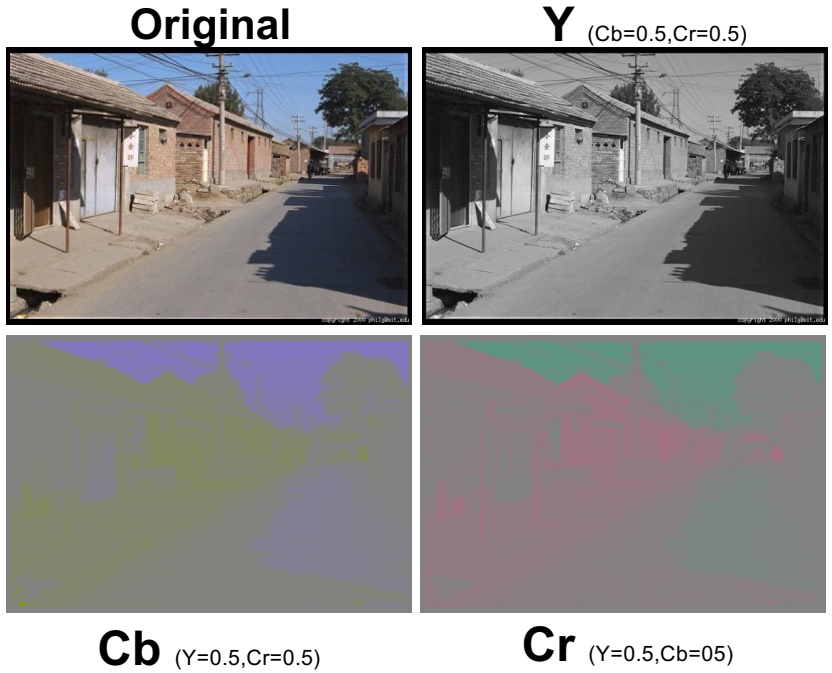
More to read: https://www.printpeppermint.com/what-is-lab-color-space-and-what-should-you-know-about-it/

Color spaces: YCbCr

- **Y** is for luminance.
- **Cb** is difference between **blue** and a **luminance** component
- **Cr** is difference between **red** and a **luminance** component.



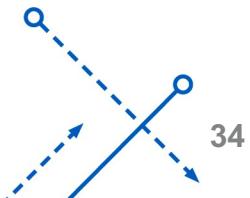




Fast to compute, good for compression, used by TV

Think and Answer

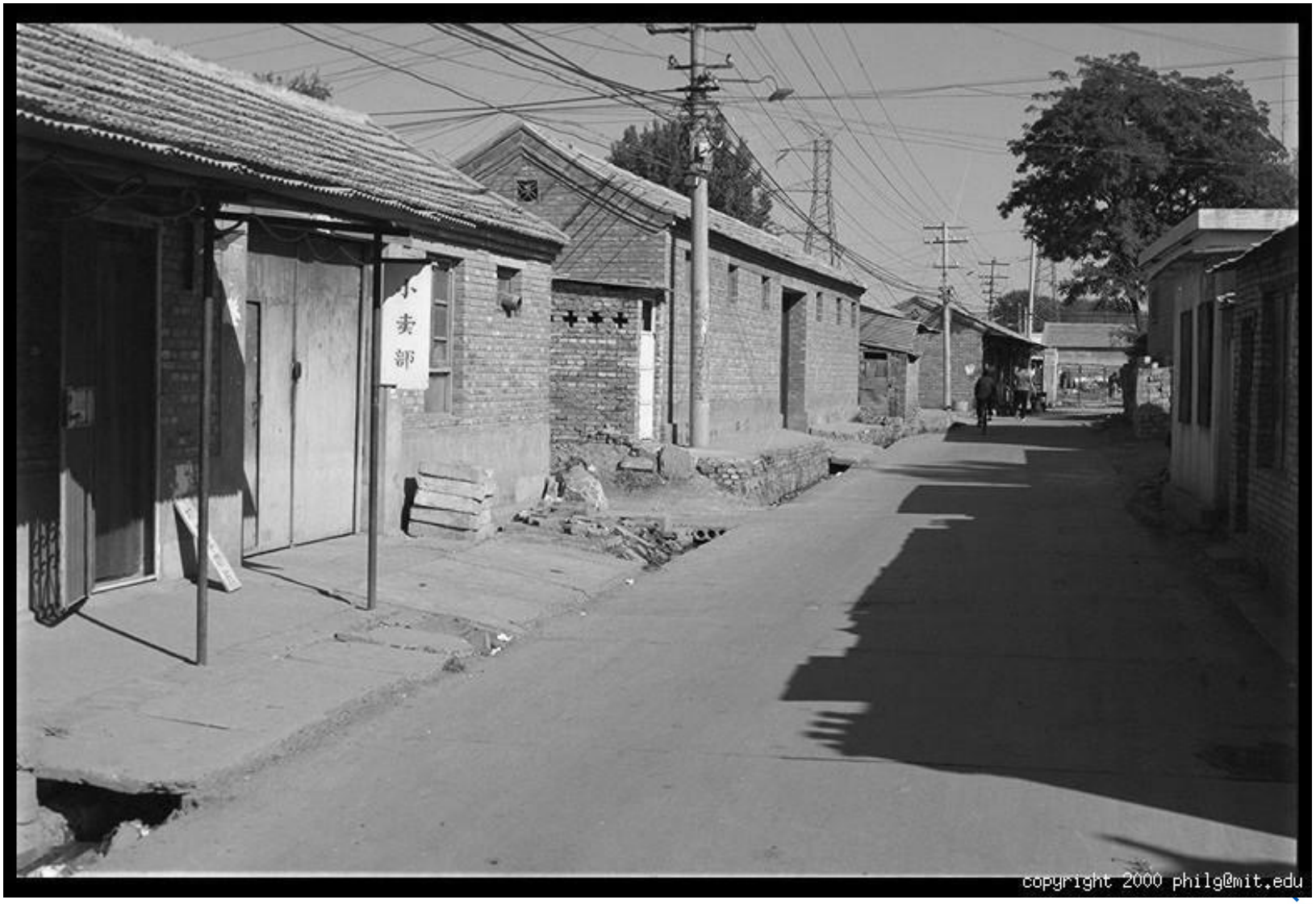
If you had to choose, would you rather go without luminance or chrominance?



Most information in intensity

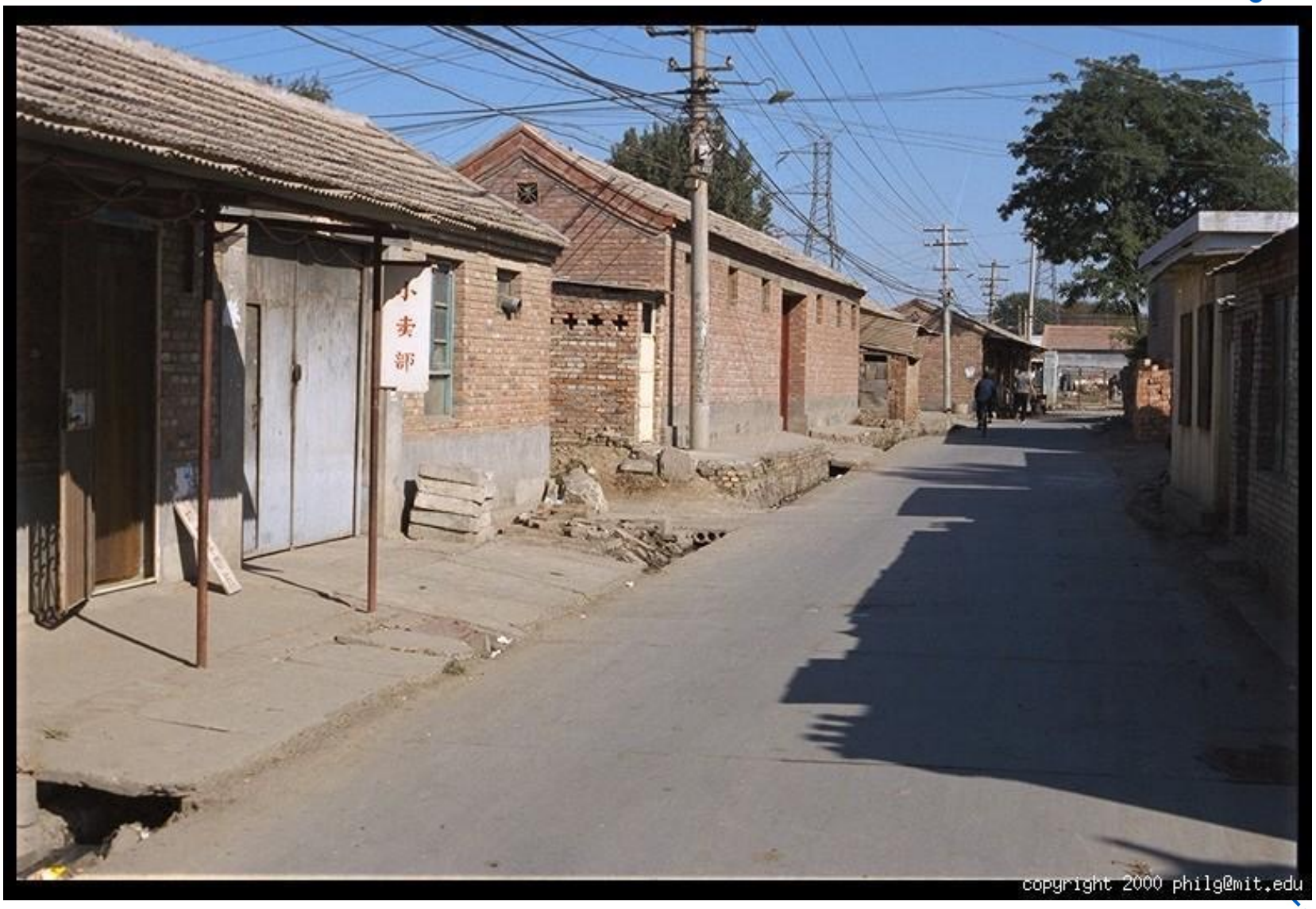
Only color shown – constant intensity

Most information in intensity



Only intensity shown – constant color

Most information in intensity



Original image

Summary for Important Concepts

- Optical Sensor
  - Image representation, resolution, sampling & quantization
- Coloring
  - RGB, HSV